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PUGET SOUND RESEARCH '95

PROCEEDINGS

MEYDENBAUER CENTER
Bellevue, Washington
January 12-14, 1995

Published by the
Puget Sound Water Quality Authority
PO Box 40900
Olympia, WA 98504-0900

VOLUME 2

PSWQA LIBRARY

PUGET SOUND RESEARCH '95 was presented by the Puget Sound Water Quality Authority, with support from the following co-sponsors:

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The mission of the Puget Sound Water Quality Authority includes the dissemination of the results of research on issues pertinent to the health of the Sound and its inhabitants and to the management of its resources. Periodic research conferences have been by far the most significant and successful means of achieving this goal. In 1988, 1991 and 1995, these conferences brought together scientists from agencies, universities and consulting firms, resource managers and other decision-makers, and members of the interested public to review the current findings of the day. The conferences, and the accompanying proceedings, have highlighted the latest trends in basic and applied research, and brought to a wider audience many studies and findings that otherwise might have been confined to relative obscurity in an institution's or department's "grey literature."

Presented by the Puget Sound Water Quality Authority and co-sponsored by state and federal agencies, universities, and private businesses, the third conference on research in Puget Sound, *Puget Sound Research '95*, was held on January 12-14, 1995, at the Meydenbauer Center in Bellevue Washington. It featured speakers from both sides of the border and the latest research on water quality and habitat issues in the Puget Sound/Strait of Georgia region. Over 700 attendees joined speakers in a variety of presentation formats, including plenary and luncheon addresses, concurrent paper sessions, panel discussions of special issues, and student and poster sessions.

Here, in two volumes, are the proceedings of the conference, including panel and plenary sessions transcribed verbatim. You are encouraged to contact the authors/presenters for further information and updates on any of the subjects discussed in these pages.

Conference Manager: Timothy W. Ransom, Ph.D.
Editor: Elizabeth Robichaud
Design and Layout: Zoe Rasmussen
Word Processing: Leslie Helms

This project was funded in part by the U.S. Environmental Protection Agency under grant agreement (X000890-01-2) to the Puget Sound Water Quality Authority and by a grant from the Washington Sea Grant Program, University of Washington, pursuant to National Oceanographic and Atmospheric Administration Award No. NA36RG0071, Project No. M-2. The views expressed herein are those of the authors and do not necessarily reflect the views of EPA, NOAA or any of its subagencies. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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PUGET SOUND RESEARCH '95

SESSION 5A

SEAGRASS HABITAT

Session Chair:

Kurt Fresh
Washington Department of Fish & Wildlife

ENVIRONMENTAL REQUIREMENTS FOR EELGRASSES IN PUGET SOUND

Douglas A. Bulthuis[1]

INTRODUCTION

Eelgrasses are distributed throughout Puget Sound in areas that meet the environmental requirements for their survival, growth and reproduction. This paper reviews the published and reported information on the environmental requirements for eelgrasses, particularly those requirements important in Puget Sound. The environmental requirements and range of conditions that can be tolerated have been gleaned both from records of the conditions in which eelgrasses are found and from experimental studies on eelgrasses. An emphasis is given to studies in Puget Sound, when available, but many studies on this species in other parts of the world and studies on related seagrass species provide important information on the requirements and limits for eelgrasses in Puget Sound.

Two species of eelgrass, native eelgrass (*Zostera marina* L.) and Japanese eelgrass (*Zostera japonica* Aschers. & Graebn.), occur in Puget Sound. Because of the paucity of studies on the environmental requirements of *Z. japonica*, this review concentrates on native eelgrass, *Z. marina*.

Eelgrasses require suitable environmental conditions for all stages of their life cycle: seed germination, vegetative growth, flowering, seed production and overwintering (as seeds or rhizomes). These requirements may differ during distinct stages. For example the salinity range that is optimum for germination is different from the salinity range in which vegetative growth is most vigorous. In this review, the requirements for vegetative growth and survival are emphasized, although requirements for other stages are noted.

This paper considers seven environmental factors for growth of eelgrasses, briefly summarizing the optimum range of conditions, followed by a brief indication of the anthropogenic activities that may alter these conditions. The list of factors is not exhaustive, nor do the anthropogenic activities include all of the ways in which man affects growth and distribution of eelgrasses. Moreover, a review this short cannot include all the relevant studies. A fuller treatment of the ecology of eelgrasses in the Pacific Northwest has been written by Phillips (1984).

ENVIRONMENTAL REQUIREMENTS OF EELGRASS

Substrate

As rooted flowering plants, eelgrasses grow in substrates in which the roots and rhizomes can anchor. Eelgrasses cannot grow on rocky, wave-exposed coasts, although the surf grasses, *Phylospadix* spp., grow by anchoring their roots in and around the rocks. Eelgrasses are found in sediments with a wide range of particle sizes, from pebble (Clark, 1981) to mud (Bulthuis, 1991). The densest, most luxuriant growth of eelgrasses usually occurs in fine sands and mixed sand and mud (Dethier, 1990; Bulthuis, 1991). Such substrates are found in many of the bays and protected sites in Puget Sound.

Anthropogenic activities may alter the substrate by dumping material directly into bays or indirectly via rivers and streams, or by making physical changes to the shoreline or bottom topography. Examples include dredge spoil disposal, armoring of shorelines that cuts off sediment supply, and groins, causeways and docks that modify longshore sediment movement and grain size. There is very little documentation of loss of eelgrasses by activities that change the substrate, either in Puget Sound or elsewhere. Losses of eelgrass habitat probably occur on a small scale in many local areas now but may have occurred on a larger scale in the past in association with major shoreline modifications and activities.

[1] Padilla Bay National Estuarine Research Reserve, Department of Ecology, 1043 Bay View-Edison Road, Mount Vernon, WA 98273

Wave Energy and Currents

The wave energy in which eelgrasses occur is closely related to the substrate, because particle size of the substrate is often controlled by wave energy. Thus, eelgrasses do not occur on wave-exposed rocky coasts. At the other extreme, eelgrasses rarely grow in water that is permanently stagnant, probably because of low oxygen stress (Riggs, unpublished data), although they can survive brief periods of hypoxia. Currents and water movement can enhance photosynthesis and leaf growth of eelgrass by reducing the diffusion boundary layer at the leaf surface (Fonseca and Kenworthy, 1987). Optimum growth of eelgrass occurs in areas of moderate current, whereas very strong currents may mobilize bottom sediments and bury eelgrass (Harlin et al., 1982). Local features such as boulders or constructed groins may alter the wave energy within a bay, making the area on one side or the other unsuitable for growth of eelgrass.

Human activities that cause changes in wave energy include channel and harbor dredging (that may change the configuration of currents and waves) and in-water and shoreline structures which may reflect waves and increase the disturbance of the bottom sediments. In Botany Bay, near Sydney, Australia, dredging of the mouth of the bay resulted in loss of about 47 percent of the areal extent of the seagrass *Posidonia australis* Hook. f. because of increased wave action during storm events (Larkum and West, 1990). In Florida, the wake from recreational boating has caused the loss of seagrasses along channel edges (Kenworthy, personal communication). In Puget Sound, ferries near a ferry dock appear to have caused an increase in bottom currents and loss of eelgrasses (Thom, personal communication). Similar effects may be occurring near marinas and boat docks although there is little documentation of such effects.

Water Depth

Eelgrasses are submerged plants that are able to survive brief periods of exposure to the air. The upper limit of distribution thus is determined by the depth of water in the intertidal and the time of exposure to the air. During exposure to the air, eelgrasses apparently continue to photosynthesize at a rate similar to when they are submersed, but rates of photosynthesis decrease as the leaves dry (Leuschner and Rees, 1993). The native eelgrass, *Zostera marina,* does not survive desiccation as well as Japanese eelgrass, *Z. japonica* (Harrison, 1982a, 1982b). Desiccation of the seeds of eelgrass is lethal (Hootsmans et al., 1987). The upper limit of distribution is determined by the length of time of exposure of the leaves to the air, but this upper limit may be increased by microtopography as well as by the plants themselves. When microtopography holds even a very shallow depth of water on the intertidal flats, the upper limit of distribution is extended higher in the intertidal than occurs on a uniformly sloping beach. The plants themselves retard the flow of water off the intertidal banks, as has been demonstrated for the seagrass *Thalassia testudinum* (Powell and Shaffner, 1991), and thus increase the intertidal depth that can be colonized. These mechanisms alter the upper limit of distribution, but generally eelgrasses are distributed up to MLLW (Harrison, 1982b).

As water depth increases, the vegetative growth of eelgrasses increases (Kentula and McIntire, 1986; Thom, 1990) until decreased light becomes limiting (Duarte, 1991). The lower depth limit of distribution of eelgrasses is usually determined by the light passing through the water and will be discussed in a separate section on light. Water pressure itself, which increases with depth, does not appear to be a major factor for eelgrass, since eelgrass have been reported to be growing in depths as great as 30 m (Dennison, 1987).

Human activities that affect water depth include dredging of eelgrass habitat, making the depth too deep for growth of eelgrass, and filling of eelgrass habitat, making the depth too shallow for growth of eelgrass. Such dredge and fill operations obviously destroy the habitat, usually irreversibly. Dumping of material on intertidal flats may also alter the morphology of the flats, creating pools of water during low tide in which eelgrass is able to survive (Thom, 1993).

Dredging and filling of eelgrass habitat have been a major cause of loss of habitat in many parts of the world and also in Puget Sound, particularly near major ports and cities. Eelgrasses grow in shallow areas of estuaries and bays and thus are often located in areas that are considered suitable for port and marina

development and other industrial uses. Dredging and filling remain major threats to eelgrass habitat in Puget Sound (Fresh, 1994).

Temperature

Eelgrasses are distributed from Alaska to Mexico along the Pacific coast of North America and grow in Hudson Bay, Canada where the annual temperature range is reported to be 0°C-4°C, and in the Gulf of California, Mexico, where the range is from 18°C-32°C (Phillips and Backman, 1983; Bulthuis, 1987). Thus, eelgrasses are genetically able to live and grow in a wide range of temperatures. However, individual plants and ecotypes may have a much more restricted range of temperature tolerance (Phillips et al., 1983b). Rasmussen (1973) suggested that the widespread "wasting disease" of eelgrass in the North Atlantic in the 1930s was due, in part, to slight increases in water temperature in areas affected by the Gulf Stream. Temperature also is important in controlling eelgrass reproductive physiology (Phillips et al., 1983a) and thus may control factors such as the onset of flowering and seed production in eelgrass. In Puget Sound, eelgrasses have been reported growing in waters where temperatures range from 6°C-18°C (Phillips, 1984; Thom and Albright, 1990; Thom, 1990). Thus, within Puget Sound, temperature may be important in controlling the timing of the reproductive cycle and the timing and rate of vegetative growth, but is unlikely to limit distribution of eelgrasses within the Sound.

In spite of the wide latitudinal range of *Zostera marina* and the wide range of temperatures at which the species is able to survive and grow, local populations appear to be vulnerable to even slight increases in temperature (Rasmussen, 1973). Few human activities increase the water temperature enough to affect eelgrass survival. One such activity is the use of sea water for cooling in industrial plants and power generation plants. In Biscayne Bay, Florida, about 35 acres of the seagrass *Thalassia testudinum* were destroyed around the discharge of heated effluent from a power plant (Zieman and Wood, 1975). In Puget Sound, thermal pollution does not appear to be a major threat to eelgrass growth and survival.

Salinity

Eelgrass is a euryhaline species. It is not found in water that is persistently fresh but does grow in stream mouths in which the water is tidally or seasonally fresh (Anderson, 1991). At the other end of the spectrum, it has been reported in water that seasonally has a salinity of 42 ppt (Tutin, 1938). Optimum salinity for growth of eelgrass seems to be about 10-30 ppt (Phillips, 1984). On the other hand, the rate of seed germination is higher at lower salinities. Phillips (1972) reported high rates of seed germination at 5-10 ppt of salinity, but reduced rates above 10 ppt. Thus, in Puget Sound, salinities in most parts of the Sound are within the optimum range for growth of *Zostera marina*, whereas the rate of seed germination is likely to be higher near the mouths of rivers and streams flowing into the sound.

Anthropogenic diversion of freshwater from rivers may cause major changes in salinity in the estuaries at the river mouths. Salinity in San Francisco Bay has increased considerably since European settlement, changing the distribution of many benthic plants (Josselyn and West, 1985). In the Laguna Madre, Texas, salinity changes have caused major shifts in the species composition of seagrasses for decades after the initial hydrologic diversions were constructed (Quammen and Onuf, 1993).

The hydrography of Puget Sound and the rivers flowing into the Sound result in salinity conditions that are highly suitable for growth of eelgrasses. Dams and watershed changes have altered the seasonal timing of salinity in parts of the sound (Ebbesmeyer and Tangborn, 1995), but there is no evidence for deleterious effects on survival of eelgrasses.

Nutrients

Eelgrasses are capable of absorbing nutrients from the water through their leaves or from the sediments through their roots (McRoy and Barsdate, 1970; Short and McRoy, 1984). The nutrients that most often limit growth of eelgrasses are nitrogen or phosphorus (Short, 1987; Short et al., 1990; Bulthuis et al., 1992). Because of the ability of eelgrasses to absorb nutrients from either the water or sediments, and because the concentration of nitrogen and phosphorus is usually higher in the sediments, eelgrasses

generally absorb most of their nitrogen and phosphorus from the sediments. This is particularly true in sediments with a high organic content, where decaying plant material provides a regular source of nitrogen and phosphorus to the sediments. Williams and Ruckelshaus (1993) demonstrated that nitrogen limited growth of eelgrass in Padilla Bay, and that enrichment of the sediments or of the water by nitrogen could increase growth of eelgrasses. Many aspects of the role of nutrients in controlling growth and distribution of eelgrasses remain poorly understood. At the present time, it is not clear that nutrient availability limits distribution of eelgrasses in Puget Sound, although it may control the rate of growth and vigor of many populations.

Numerous human activities increase the amount of nutrients flowing into bays and estuaries, including wastewater discharge, stormwater runoff, industrial discharges, and agricultural runoff. The effects of these increased nutrients on seagrasses, including eelgrasses, vary with the magnitude of the nutrient increases, the hydrodynamics of the receiving water and many other factors. However, in spite of nutrients being required for growth of eelgrass and the demonstration of nitrogen and phosphorus limitation of growth of seagrasses, nutrient additions have caused major losses of seagrasses throughout the world. In Cockburn Sound, Western Australia, more than 8,000 acres of seagrass (97 percent of the original distribution) died back over a 16-year period. Most of this loss was attributed to increased nutrient inputs to the sound (Cambridge and McComb, 1984; Cambridge et al., 1986). In the Chesapeake Bay, the loss of more than half of the eelgrasses and other submerged aquatic plants has been attributed, in part, to increased nutrient inputs (Kemp et al., 1983; Dennison et al., 1993). Nutrient inputs have been reported as a factor contributing to the decline of seagrasses in the Florida Keys (LaPoint and Clark, 1992); Holdfast Bay, South Australia (Sheperd et al., 1989); and the Dutch Wadden Sea (Giesen et al., 1990).

Nutrient inputs cause the loss of eelgrasses and other seagrasses by decreasing the light available for the growth and survival of the plants. The mechanisms for decreased light may be through increased growth of phytoplankton, epiphytes, or macroalgae. Phytoplankton are often nitrogen-limited in the marine environment, and the addition of nutrients can increase phytoplankton biomass in the water. This increased biomass absorbs more of the light passing through the water column and thus decreases the light available to seagrasses. A second mechanism by which nutrient inputs decrease light available for eelgrass growth is through growth of epiphytes. Epiphytic algae grow on the leaves of eelgrass. However, with a high nutrient supply these epiphytes can develop a very high biomass, shading the eelgrass leaf (Bulthuis and Woelkerling, 1983; Williams and Ruckelshaus, 1993), preventing net photosynthesis and eventually causing death (Cambridge et al., 1986). A third mechanism by which nutrient additions reduce light and can kill seagrasses is through growth of macroalgal mats. One of the early symptoms of eutrophication is increased macroalgal growth (Bulthuis and Cowdell, 1982), which can result in large macroalgal mats (Fong et al., 1993; Valiela et al., 1992). These mats may remain stationary or move around with the currents and settle onto eelgrass beds, killing the eelgrass by reducing the light and lowering the oxygen in the water (Valiela et al, 1992; Den Hartog, 1994).

The main basin of Puget Sound shows few signs of eutrophication (Copping, 1990), but the effects of high nutrient inputs have been noted in the south Sound, near wastewater outfalls and where other nutrient sources flow into the Sound. No losses of eelgrasses have been documented in Puget Sound that are attributed to nutrient inputs. However, the effects of nutrient inputs are most likely to occur at the lower limit of distribution of eelgrass, an area that has received very little study other than by Phillips (1972). In addition, the effects of nutrients will be mixed with other factors that reduce light available for eelgrass growth. The location of eelgrass beds, near the coastline, makes them more vulnerable to local effects of nutrient loads, even when the Sound as a whole shows little sign of eutrophication. The lines of evidence that indicate that nutrient inputs are a threat to the health of eelgrasses in Puget Sound in the future include: the examples of nutrient inputs causing the loss of seagrasses in many parts of the world; the current inputs and projected increases in inputs of nutrients to Puget Sound; the location of eelgrass beds along the shorelines near non-point sources of nutrients; and the additive effects of nutrient inputs to other factors that decrease light to eelgrass. In Padilla Bay, circumstantial evidence indicates that macroalgal mats already may have caused the loss of some eelgrass beds (Bulthuis, 1991).

Light

Like all plants, eelgrasses need light for growth and survival; as submerged plants they are vulnerable to reductions in light by the water above them and by substances in the water. Particularly for deeper growing eelgrasses, water clarity in the water above them is important for growth and survival. The lower limit of distribution of eelgrasses in almost all bays, estuaries, and coastlines is determined by light. The importance of light has been demonstrated experimentally (Backman and Barilotti, 1976; Bulthuis, 1983; Dennison, 1987) and in surveys of the lower depth limit of eelgrasses. Duarte (1991) reviewed many surveys of depth distribution of seagrasses and reported eelgrasses down to 30 m depth. Based on these surveys, Duarte suggested that about 11 percent of the surface light is required for survival of most seagrasses. Analysis of the trends in loss of submerged aquatic vegetation in Chesapeake Bay indicated that about 20 percent of surface light is required for survival of eelgrasses (Dennison et al., 1993).

In Puget Sound, Phillips (1972) reported eelgrasses down to -6.6 m. However, in many parts of Puget Sound the depth limit is much shallower than this, presumably because of the reduced light penetration through the water. Near river mouths, the periodic high turbidity associated with high flows and flooding restricts the areas that otherwise could be colonized by eelgrasses. For example, Padilla Bay, which once was part of the Skagit River delta, is now cut off from that source of water (and turbidity). At present Padilla Bay is flooded with relatively clear Puget Sound waters, and the bay contains one of the largest contiguous expanses of eelgrasses along the west coast of North America (Bulthuis, in press), while Skagit Bay has few eelgrasses on the eastern side of the bay where the Skagit River now flows into the Sound (Thom and Hallum, 1990).

Human activities reduce light to seagrasses in two ways: by building structures, such as docks, jetties, and other shoreline and overwater structures; and by reducing water clarity. The effect of structures in the loss of eelgrasses in Puget Sound is seen by the discontinuous distribution of eelgrasses under docks and wharves in places where eelgrasses are growing in adjacent areas (Fresh et al., 1995).

Substances in the water that reduce the amount of light reaching the eelgrass will reduce the area suitable for growth of eelgrass. Many anthropogenic activities increase the substances in the water that reduce water clarity. Some of these, such as construction, agriculture, and stormwater runoff occur up in the watershed; others, such as dredging and disturbance of intertidal flats, occur in the bay. The combination of these activities can increase turbidity of the water and reduce water clarity. The loss of seagrasses through decreased light has been documented throughout the world: in Chesapeake Bay (Orth and Moore, 1983; Kemp et al., 1983; Dennison et al., 1993); in the Dutch Wadden Sea (Giesen et al., 1990); and in Western Port, Australia (Sheperd et al., 1989). The very limited distribution of eelgrasses in San Francisco Bay appears to be a result of low water clarity in the bay (Wyllie-Echeverria, 1990; Zimmerman et al., 1991).

In Puget Sound, the increasing population in the watershed—resulting in increased suspended materials, wastewater, and other substances flowing into Puget Sound—is likely to reduce water clarity and light to eelgrasses. Decreased light and water quality are major factors that are likely to cause loss of eelgrasses in Puget Sound in the future. I do not know of any documented losses of eelgrass due to reduced water clarity in Puget Sound. However, in other parts of the world, the documentation and demonstration of the importance of light and water clarity came only after very large losses of seagrass. In Puget Sound, it is likely that eelgrass has already declined near the lower limit of distribution because of decreased water clarity. Such changes are rarely seen or reported because they occur at the deeper end of the distribution of eelgrasses and not up near the shoreline where changing distribution patterns are more easily seen. The losses also can occur slowly and incrementally. However, their net effect in eliminating eelgrass is just as effective as when habitat is dredged or filled.

SUMMARY

Eelgrasses require suitable environmental conditions in Puget Sound in order to survive and grow. They grow best in sandy or muddy substrate, with moderate to calm wave conditions and currents, a water

depth from MLLW to -22 feet, salinity and temperature conditions as found in Puget Sound, and about 10 percent to 20 percent of surface light.

Human activities that pose the greatest threat to eelgrasses in Puget Sound are direct destruction of eelgrasses through dredging or filling and those activities that lead to reduced light available to eelgrasses through suspended sediments, nutrient inputs, stormwater runoff, wastewater outfalls and agricultural runoff.

ACKNOWLEDGMENTS

Thanks are due to Kurt Fresh for organizing the session on eelgrass and suggesting this review. This work was supported, in part, through a grant to Padilla Bay National Estuarine Research Reserve, Washington Department of Ecology, with funds obtained from National Oceanic and Atmospheric Administration, Office of Ocean and Coastal Resource Management, Sanctuaries and Reserves Division, and appropriated for Section 315 of the Coastal Zone Management Act of 1972, as amended.

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INVENTORY OF EELGRASS (*Zostera* spp.) IN WASHINGTON STATE

Thomas F. Mumford, Jr.[1], Sandy Wyllie-Echeverria[2] and James Norris[3]

INTRODUCTION

Five species of seagrass, differentiated into two genera (*Phyllospadix* spp. and *Zostera* spp.), grow in the coastal margins of the Puget Sound basin and environs (Dethier, 1990; Wyllie-Echeverria and Phillips, 1994). We will focus our discussion on the variety of techniques and platforms implemented to inventory two of these five species: *Zostera marina* L., eelgrass, and *Zostera japonica*. These marine plants are rooted in soft sediments and, as a function of species and light availability (see Bulthuis, this volume; Duarte, 1991, for a review), are distributed across the tide flat from the high intertidal to the high subtidal (den Hartog, 1970; Phillips, 1984; Phillips and Menez, 1988). Not only do they stabilize the sediment and mediate current flow (Wood, Odum et al., 1969; Zieman, 1982), they also provide structure in the water column for epiflora and epifaunal organisms that nourish nearshore fish stocks (Phillips, 1984; Simenstad, 1987; Simenstad, 1994). This above-ground biomass is also an important food source for several water birds and makes a significant contribution to coastal detrital food webs (Einarsen, 1965; Phillips, 1984; Baldwin and Lovvorn, 1994; Simenstad and Wissmar, 1985; Simenstad, 1994).

Changes in the distribution of these plants may have important implications for resource management because: 1) The role of eelgrass as a provider of shelter and substrate for Pacific herring (*Clupea harengus pallasi*), Dungeness crab (*Cancer magister)* and Pacific salmon (*Oncorhynchus* spp.) (Phillips, 1984; Simenstad, 1987; Simenstad, 1994) is well documented, and losses of this habitat have consequences for these fisheries; 2) both species, *Z. marina* and *Z. japonica*, are important in the diets of several water birds (e.g., brant [*Branta bernicla*] and dabbling ducks [e.g., *Anas americana*, *A. platyrhynchos*, *A. acuta* and *A. crecca*]), and detailed seagrass maps are helpful in understanding the migratory patterns and population shifts of these birds (Baldwin and Lovvorn, 1994; Wilson and Atkinson, 1995; Lovvorn, this volume); 3) even though *Zostera japonica* is an introduced plant (Harrison and Bigley, 1982), research shows that this plant is a valuable contributor to nearshore food webs in this region (Thom et al., 1991; Baldwin and Lovvorn, 1994), and detailed maps are necessary to determine the available amount of this resource; 4) although current seagrass management does not consider the spread of *Z. japonica* harmful to the persistence of *Z. marina* or animal dependence on unvegetated mudflats, this assumption has not been adequately tested (Olson and Pawlak, this volume; Pawlak, 1994). Detection of shifts in species composition and areal coverage provided by comprehensive and routine mapping and coupled to experimental research may help resolve this question.

We will briefly describe the types of mapping platforms (data acquisition methods) used to map *Z. marina* and *Z. japonica* along the Pacific Coast. This description will be focused on selecting the platform or combination of platforms necessary to provide the most comprehensive, uniform and detailed inventory for these seagrasses in the Puget Sound basin. We will also make inference to appropriate techniques for other Washington coastal and estuarine habitats and other coastal states in accordance with data acquisition needs and available funds. Finally, we will speculate on the type or types of platforms needed to launch a thorough assessment the three *Phyllospadix* species, should funds and need arise.

[1] Division of Aquatic Resources, Department of Natural Resources, P.O. Box 7027, Olympia, WA 98504-7027

[2] School of Marine Affairs HF-10, University of Washington, Seattle, WA 98195

[3] Marine Resources Consultants, P.O. Box 816, Port Townsend, WA 98368

SEAGRASS INVENTORY: CONCEPTUAL PROCESS

The ultimate goal of seagrass mapping should be to produce expedient and timely information and hard-copy output in line with specific regulatory requirements and mandates. Furthermore, the suitability and efficacy of mapping output must conform to: a) objectives established by the initiator of the survey, and b) geographic scope of the project. For example, particular surveys can range in purpose from general habitat delineation to damage assessment and in size from individual project sites to basin-wide resource inventories. Regardless of survey size or intent, we advocate that seagrass mapping be folded into the larger context of surveys as information systems (Mumford, 1994), an approach that demands the integration of several components in a single conceptual framework (Figure 1). This stepwise process is designed to ensure efficiency of effort and integrity of results, both of which will lead to a systematic chronicle of seagrass resources in this region. In order to detect rates of change (e.g., species composition, areal extent, density and biomass) this level of rigor is required.

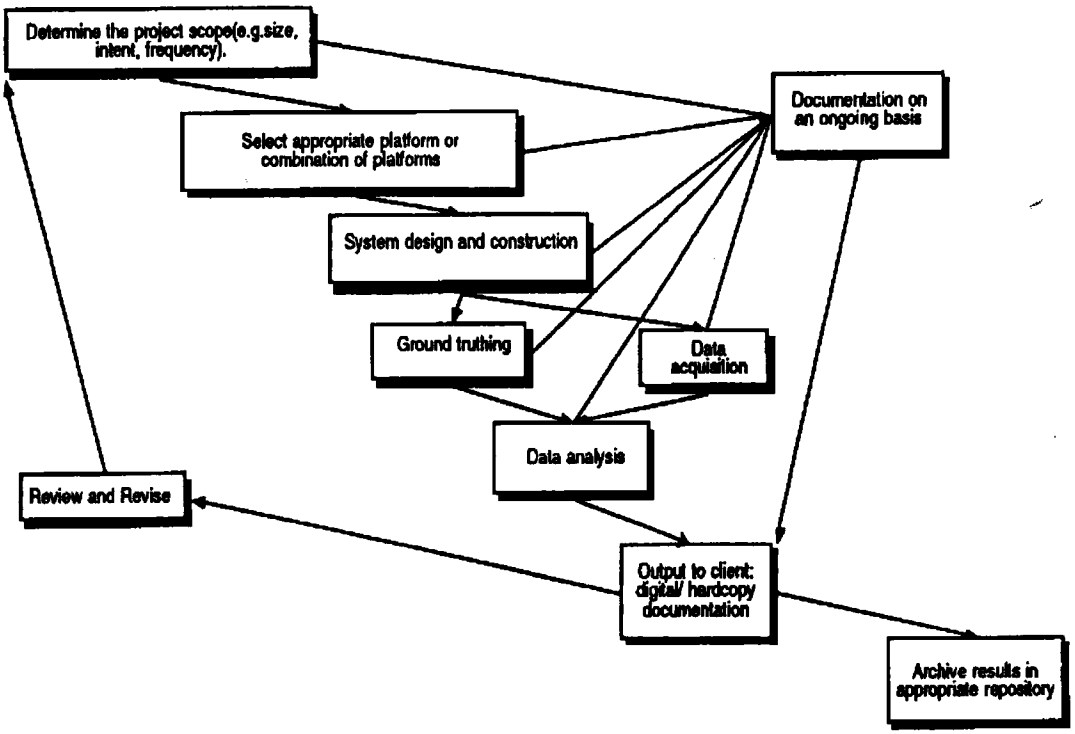

Figure 1. Conceptual framework necessary to achieve maximum success commensurate with project goals and remote sensing capabilities (adapted from Mumford, 1994)

SEAGRASS INVENTORY: MAPPING PLATFORMS

Once the decision to survey seagrass is made, project managers must choose a technique that is in keeping with project goals, seagrass location (intertidal or subtidal) and project budget. In the following review, we briefly describe the various platforms used to describe and delineate seagrass resources. In Table 1, we list these platforms and offer comparison on the basis of several scales of interest and importance to project managers and coastal zone managers. The intent, here, is twofold: 1) to furnish the

initiator of the survey with sufficient information to select an appropriate mapping technique, and 2) to begin regional discussions regarding the standardization of survey techniques.

Seagrass mapping platforms diverge into two broad categories of observation: indirect and direct. Both methods of data collection in this region follow a regionalized Cowardin classification system (e.g., Dethier, 1990). The references imbedded in the technique descriptions describe individual project results in greater detail.

Indirect observation platforms are commonly labeled "remote sensing platforms" and are usually linked to Global Positioning Satellites (GPS) to assist with position accuracy. These methods are those in which an image is collected, analyzed or interpreted, and information is stored either on a paper map or in a digital format (usually in a geographic information system spatial database). The resulting archival image may be reinterpreted by others.

Direct observations may be linked to a GPS, but normally they substitute less sophisticated methods of georeferencing such as the use of shoreline benchmarks and transect markers. In this case, the observer notes seagrass cover (e.g., density and percent cover) and transfers the information onto a map or into a digital spatial database. There is usually no image record.

The use of GPS has revolutionized resource mapping. The ability to gather positional data quickly and relatively cheaply that can easily be used as a geographic information system has made many techniques highly effective that before GPS were not very useful. The impact of GPS cannot be overemphasized.

Table 1.

	Resolution			Population Dynamic Detection			Data Storage (historical record)	
Platform	MMU	Classification	Image enhancement/ manipulation	Coverage (intertidal/ subtidal)	Species Identification	Density/ Biomass	Time Series Available	Comparability
Indirect Observations								
Multispectral digital-satellite	Low	Medium	High	Intertidal	Low	Medium	No	Medium
Multispectral digital-aircraft	Medium	Medium	High	Intertidal	Low	Medium	No	Medium
Aerial photography-color infrared	High	High	High	Intertidal/ sub	Medium	Medium	No	Medium
Aerial photography-natural color	High	High	High	Intertidal	Medium	Medium	No	Medium
Videography-aircraft	Medium	Medium	High	Intertidal	Low	Medium	No	Medium
Videography-underwater	Medium	Medium	High	Subtidal	High	High	No	Medium
Hydroacoustic	High	High	High	Subtidal	Medium	High	No	Medium
Side-scan sonar	High	High	High	Subtidal	Medium	High	No	Medium
Direct Observation								
Diver transects	High	HIgh	Low	Subtidal	High	High	No	Medium
Beach walks	High	High	Low	Intertidal	High	High	No	Low
Aerial surveillance/direct mapping	Low	Medium	Low	Intertidal	Medium	Medium	No	Low

CONCLUSIONS AND RECOMMENDATIONS

In this review we suggest that seagrasses mapping be placed in the larger envelope of coastal resource information systems. This activity demands attention to a particular process—a process designed to balance accurate data acquisition and presentation with project scope and available funding. In order to facilitate this approach, we provide a method by which the various mapping platforms can be compared relative to questions of cost, time, resolution, population dynamic detection and data storage (Table 1). In

addition, we list mapping platforms and particular projects (Table 2-1,2). This information is most useful when plugged directly into the conceptual framework we describe (Figure 1).

Finally, we report four elements that are important in seagrass mapping, not only in the Puget Sound basin but also for the entire Pacific Northwest. These are:

1) In the Puget Sound basin, historical seagrass inventories were both fragmentary and infrequent (Mumford, 1994). However, WDNR began to create a systematic inventory of intertidal habitats including seagrass (Mumford, 1992). This system relies on both aircraft-borne multispectral digital imagery and aerial photography (Mumford, this volume; Bailey, this volume). Although this system represents an advance over previous efforts, the subtidal region is not often included within survey boundaries (Mumford, 1994). This omission is forced by the inability of aerial platforms to capture these data. Based on the research for this review, we suggest that a combination of platforms (e.g., videography, side-scan sonar, hydroacoustic, video) be implemented to provide a comprehensive seagrass map for the Puget Sound basin.

2) In keeping with their regulatory mandates, particular state agencies require seagrass surveys for discrete projects (e.g., site-specific environmental impact statements, leases for aquatic lands [WDNR], and Hydraulic Project Authorities [Washington Department of Fish and Wildlife]). Many of these are for subtidal beds of *Z. marina*. Currently, there is no systematic protocol for the collection of these data or an accessible repository for information storage. We would urge those agencies that currently require or acquire seagrass inventories as part of their regulatory and/or administrative duties to standardized methods and archive results.

3) A residual byproduct of our work has been the compilation of a comprehensive list of West Coast seagrass mapping projects. In fact, the data from which our comparison of mapping platforms (Table 1) is derived come directly from this communication. Contact with project managers has: 1) initiated communication among investigators; and 2) opened discussions about West Coast seagrass mapping protocol, both of which may have positive effects on regional seagrass mapping activities.

4) Mapping projects to describe the distribution and abundance of *Phyllospadix* sp. may be more successful with a combined platform approach. These plants grow on high-energy rocky shores (Phillips and Menez, 1988; Dethier, 1990) and their co-mingling with macroalgae makes species identification difficult. The platforms of aerial photography and underwater videography seem appropriate for baseline efforts.

SUMMARY

In sum, we are convinced that the results of this investigation will prove useful. Tables were designed with the user in mind. If these tools are folded into our conceptual framework, the goal of converting "seagrass maps" into "seagrass information systems" will be met.

ACKNOWLEDGMENTS

SWE would like to acknowledge helpful discussions with Annette Olson, Tom Leschine and Marc Hershman at the University of Washington School of Marine Affairs and Tina Wyllie-Echeverria at NOAA's Pacific Marine Environmental Laboratory. The contents of this document do not necessarily reflect the views and policies of the Washington Department of Natural Resources, nor does mention of tradenames or commercial products constitute endorsements or recommendations for use.

Table 2-1. Data acquisition methods for seagrass inventory—indirect methods

INDIRECT OBSERVATION

Aerial Photography—Color infrared

Color infrared (CIR) photography renders chlorophyll-containing plants bright red, which gives excellent contract to substrate. Water penetration is poor unless the film is deliberately overexposed. Exposure latitude is narrow.

References: Mumford, 1992

Aerial Photography—Natural Color

This is the photography method of choice for the mapping of submerged aquatic vegetation on the east cost (Chesapeake Bay, Boston Harbor) and has been used to map Padilla Bay. Water penetration is good, although contract of the eelgrass with the substrate is sometimes a problem.

References: D. Bulthuis, Washington Department of Ecology, pers. comm., 1990; Ferguson, Wood et al., 1993; Klemas, Thomas et al., 1987; Thomas, Ferguson et al., 1991; Merkel, 1988; Wilson and Atkinson, 1995.

Multispectral digital—Satellite

The use of satellite imagery is limited. Satellite data such as SPOT, Landsat or TM suffer from poor resolution and low probability of collecting predictable data because of the problems of getting a satellite overhead on a clear day at low tide during the summer growing season.

References: Webber et al., 1987.

Multispectral digital—Aircraft

This technique is being used in the Puget Sound Ambient Monitoring program and gives satisfactory results for intertidal and shallow subtidal areas.

References: Mumford, 1992.

Videography—Aircraft

The use of single video cameras using color or multiple cameras in a multispectral mode has been used in several projects. One definite advantage is quick turnaround time, resolution is often poor. A permanent record can be made.

References: Mausel et al., 1992.

Videography—Underwater

Underwater videography provides a cost effective means of sampling subtidal regions that cannot be viewed either directly or by aerial photography. This technique integrates position data with visual images of the seabed from which thematic maps of seabed attributes (e.g., seagrass distribution and density) can be constructed. Underwater videography is most applicable in localized subtidal regions (e.g., less than one mile of shoreline).

References: Norris et al., 1994.

Side—scan sonar

This technique has been explored in Washington and elsewhere several times but due to the expense of equipment and difficulty in interpreting the images without ground truthing, it has not been widely used.

References: Williams and Associates, 1988; Zabloudil et al., 1991; Merkel, 1988).

Hydroacoustic

In certain applications, uncomplicated echosounder equipment can be efficient mapping tools yielding low cost presence/absence maps. In these cases, however, efforts were not linked to a GPS system. Additionally, image interpretation can be difficult when several species are present. Marino and Wyllie-Echeverria (1992) reported a venture to couple echosounder systems to both GPS and environmental sensors (e.g., temperature, salinity, light) but, to date, no sampling has occurred.

References: Spratt 1989; Wyllie-Echeverria and Rutten 1989; Miner, 1993; Zabloudil et al., 1991; Merkel, 1988; Maceina et al., 1984; Perdue, pers. comm.; Marino and Wyllie-Echeverria, 1992.

Table 2-2. Data acquisition methods for seagrass inventory—direct methods

DIRECT OBSERVATION
Diver transect This technique has been used widely for subtidal transects, but is costly, time-consuming and is being rapidly replaced by underwater videography. Lack of permanent records is a problem. References: Goodwin, pers, comm., 1995; Phillips and Fleenor, 1970; Neushul, 1966.
Walk beach—w/GPS/photos Many small sites and some large ones have been mapped using the simple technique of walking the beach and annotating aerial photographs or maps. In the past it was difficult to accurately locate your position, but with the widespread use of GPS, beds can now be walked along the perimeter while constantly recording your position every second, and the resulting file downloaded unto a GIS. References: Mumford, 1992.
Aerial surveillance For a more widespread coverage, annotating maps or aerial photos from an airplane can be done and again has been widely used in many specific site maps and also in the preparation of the Washington Coastal Zone Atlas. References: Ecology, 1980; Wilson and Atkinson, 1995.

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POLICIES AND MANAGEMENT PRACTICES OF WASHINGTON STATE AGENCIES AS THEY PERTAIN TO THE SEAGRASSES *Zostera marina* AND *Zostera japonica*: AN ECOLOGICAL ANALYSIS

Brian T. Pawlak and Annette M. Olson[1]

INTRODUCTION

The success of resource management depends, in part, on the model of the ecosystem implicit in current management practices—the "management model." Management of the native seagrass, *Zostera marina*, in the estuaries of the Pacific Northwest is based largely on its value as habitat for fish and wildlife. The non-indigenous seagrass, *Zostera japonica*, has spread into previously unvegetated areas, however, expanding seagrass coverage and creating new implications for seagrass management. We have examined the management model for seagrass in Washington state in light of the available scientific evidence, with the goal of defining priorities for policy development and ecological research. In particular, we attempt to identify areas where the management model can be improved either by expanding its scope to incorporate additional ecologically important variables, or by developing flexible management strategies that take into account scientific uncertainty. Furthermore, we attempt to define research priorities that will simultaneously contribute to strengthening the management model and increasing scientific understanding of seagrasses (Lubchenco et al., 1991).

METHODS

Our objectives were to identify the management model for seagrasses in Washington state, to evaluate the strength of the supporting scientific evidence, and to define priorities for future policy development and research. The present policies of Washington state agencies were determined through interviews with agency personnel and by a review of agency documents, state laws, and management guidelines (Pawlak, 1994). From these contacts and documents, we inferred the ecological model implicit in present management practices and represented it graphically. From a review of the scientific literature, the ecological functions of *Zostera* spp. were also summarized graphically in an expanded "ecosystem" model that permitted evaluation of the scientific support for the current management model and identification of future management and research options (Olson and Straub, 1994).

ECOLOGY AND DISTRIBUTION OF *Zostera* spp. IN WASHINGTON STATE

In the sheltered intertidal and subtidal regions of Washington's estuaries, two species of seagrass (the native eelgrass, *Zostera marina*, and the non-indigenous *Z. japonica*) occupy more than 165,000 acres and cover approximately 11 percent of the area of Puget Sound, Grays Harbor, and Willapa Bay (Mumford, 1988). Seagrass meadows provide numerous "ecosystem services," including important habitat and feeding pathways for marine fish and wildlife (Phillips, 1984). Furthermore, the seagrass canopy contributes to water quality by reducing the resuspension of organic and inorganic material; the roots and rhizomes of seagrass stabilize the sediment and reduce erosion (Phillips, 1984; Mumford, 1988).

The two *Zostera* species differ in their reproductive ecology and depth distribution. *Zostera marina* is a perennial, reproducing primarily through expansion of vegetative shoots and over-wintering as roots and rhizomes. *Zostera japonica* is short-lived, annually recolonizing the high- to mid-intertidal zone as seedlings produced in spring from dormant seeds (Harrison, 1979). *Z. marina* occurs subtidally and lower in the intertidal zone than the non-indigenous species, *Z. japonica*. The two species co-occur in the mid-intertidal zone (i.e., the extreme of *Z. marina*'s shoreward elevation coincides with *Z. japonica*'s seaward depth limit) (Phillips, 1984).

[1] University of Washington School of Marine Affairs HF-05, Seattle, WA 98195

Z. japonica has rapidly colonized unvegetated intertidal flats (largely sand- and mudflats) in the high- to mid-intertidal zone (Harrison, 1982a, 1987), and it is likely that *Z. japonica* will continue to colonize unvegetated intertidal flats and further expand its range in Washington.

SEAGRASS POLICY AND MANAGEMENT IN WASHINGTON STATE

Present policies of Washington resource agencies for the management of seagrasses are founded on a widespread recognition of (1) the critical ecological role of seagrass in supporting fish and wildlife and maintaining water quality in the state's estuaries, and (2) the potential loss of seagrass habitat to shoreline development (Figure 1; Pawlak, 1994). Seagrass management appears to be founded on a simple model of ecological interactions in eelgrass-dominated (*Z. marina*) systems (Figure 1). Human activities are viewed as affecting eelgrass directly through habitat loss or preservation, or indirectly through factors such as pollution and increased turbidity due to off-site and upland activities. Present management efforts focus on the protection of seagrass habitat, and compensation for its loss and alteration due to dredging and shoreline development. Indirect impacts to seagrass habitat do not receive as much attention as do direct impacts, but indirect effects (e.g., from nearby aquaculture developments or upland development) are becoming a greater concern to resource managers (Bulthuis, 1994; Pawlak, 1994).

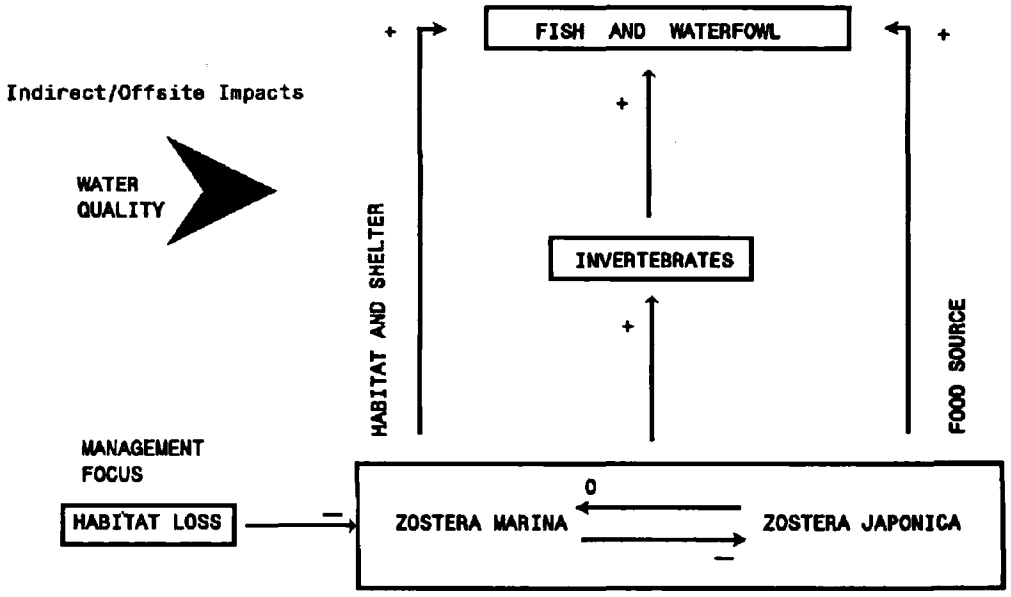

Figure 1. Seagrass management model. Ecological relationships implicit in present seagrass management practices in Washington state (small arrows); and acknowledged indirect effects on seagrass system (large arrowhead).

The model implicit in seagrass management treats the native seagrass, *Z. marina*, and the non-indigenous *Z. japonica* as essentially equivalent (Figure 1), on the assumption that *Z. japonica* provides ecological functions similar to those of *Z. marina*. Inventories of seagrass habitat and most management practices (e.g., mitigation procedures and compensation ratios) do not consistently distinguish between the two species (Pawlak, 1994). These practices implicitly assume (1) that habitat altered by *Z. japonica* has value (as habitat for fish and wildlife) equal to or greater than that of the habitats it replaces (and similar to that of *Z. marina*), and (2) that *Z. japonica* does not pose a direct or indirect threat to native or other habitats or species.

ECOLOGY OF *zostera japonica*

We constructed a simple graphical ecosystem model (Figure 2) that reflects the strength of scientific evidence about ecological linkages within the habitats potentially colonized by *Z. japonica*. The ecosystem model includes additional ecological elements and processes not accounted for in the present management model, focusing on the known and potential ecological effects of *Z. japonica* invasion.

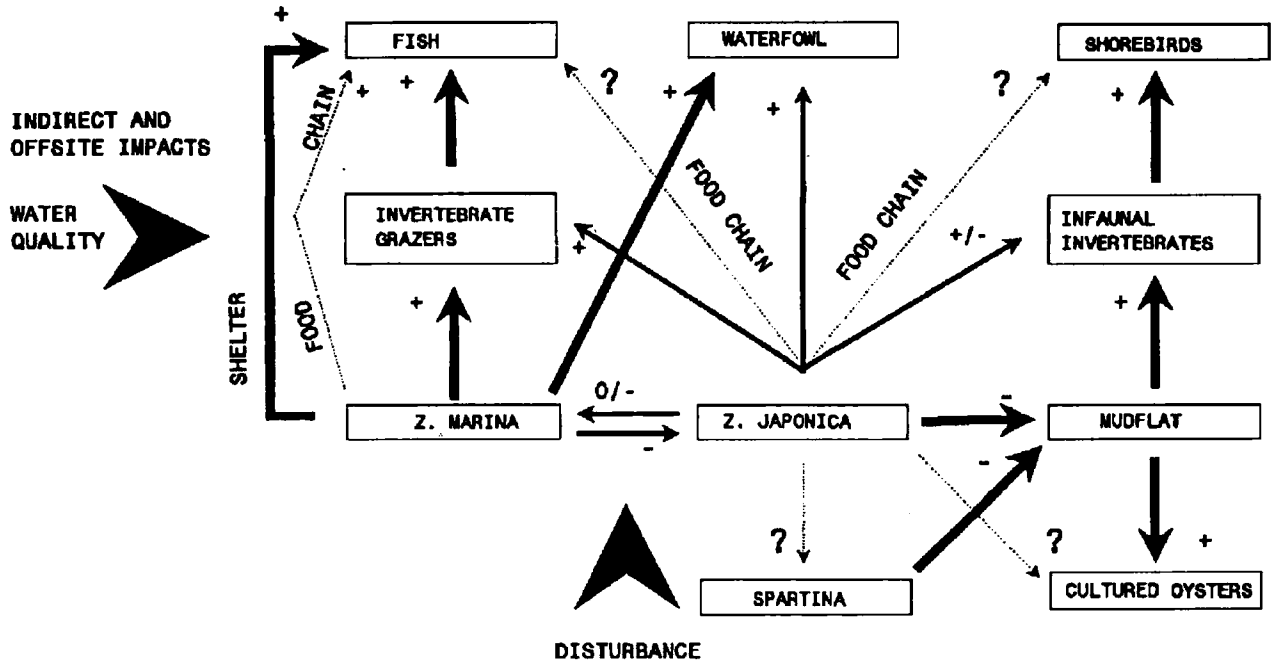

Figure 2. Seagrass "ecosystem" model. Ecological relationships portrayed by arrows that represent strength of scientific evidence: well-documented (wide arrows), inferred from a small number of studies (narrow solid arrows), not directly studied (narrow dotted arrows). Potential indirect effects on seagrass system (large arrowheads).

A small number of studies have documented potential beneficial effects of *Z. japonica* for fish and wildlife. The most direct evidence comes from studies that suggest that the recent expansion of *Z. japonica* has provided a major new food source for migratory waterfowl (Figure 1) (Baldwin and Lovvorn, 1994 and submitted; Thom et al., 1991). *Z. japonica* may also be a significant contributor to the food web through the grazing component of the ecosystem (Thom et al., 1991). However, the potential effect on fish and wildlife of changes in the grazing or infaunal invertebrate communities has rarely been directly studied (Simenstad, 1994). It remains to be directly demonstrated that most fish and wildlife species are able to utilize invertebrate production in *Z. japonica* patches as well as they do in beds of *Z. marina* or on unvegetated flats (see Figure 1, unknown food chain effects on fish, shorebirds).

Evidence regarding potential negative ecological effects of *Z. japonica* on native species also comes from relatively few studies. *Z. japonica*, possibly due to its obstructing root system, has been shown to inhibit some infaunal species (tubeworm and burrowing ghost shrimp) in short-term field experiments (Harrison, 1987) (see Figure 2, negative effect on infauna), but the consequences for the remainder of the community are unknown. Furthermore, anecdotal evidence suggests that *Z. japonica* may inhibit oyster culture (Bulthuis, WDOE, pers. comm.) and may promote the invasion of the state-listed aquatic nuisance species *Spartina alterniflora* (J. Carlton, Williams College, pers. comm.).

Based on a series of studies by Harrison and his colleagues, it would appear unlikely that *Z. japonica* could further expand its depth distribution or out-compete *Z. marina* (Harrison, 1982a, b; Harrison and Bigley, 1982; Nomme and Harrison, 1991a, b; Nomme, 1989). However, *Z. japonica* can survive at depths usually reserved for *Z. marina* (Harrison, 1982b) and may colonize disturbed *Z. marina* habitat. Results of a recent experimental study suggest that *Z. japonica* may slow the recovery of *Z. marina* from natural or anthropogenic disturbances (G. Merrill, University of Washington, research in progress). The success of intertidal transplants of *Z. marina* could also be affected if sites are heavily colonized by *Z. japonica*. Although current evidence suggests that *Z. marina* is not negatively affected by *Z. japonica*, the effect of disturbance on the outcome of interactions between the two species is currently unknown.

The number of studies addressing the ecological effects of *Z. japonica* is very small. Furthermore, some elements and linkages in the system have not been studied (e.g., shore birds, cultured oysters, *Spartina*, disturbance) and some linkages among system components have been inferred only indirectly from studies on invertebrate prey (e.g., beneficial effects on fish, Figure 2). Consequently, the effect of *Z. japonica* on the quality of habitat it invades, as well as its potential for producing negative ecological effects are incompletely understood.

COMPARISON OF MANAGEMENT AND ECOSYSTEM MODELS

By comparing the management model described above to the ecosystem model, we can assess the strength of scientific evidence for assumptions of the management model. We can also identify ecosystem elements and linkages that are absent from, and should be evaluated for incorporation in, the seagrass management model. For example, the management model acknowledges, but does not sufficiently address, indirect effects of off-site or upland activities on seagrass habitat (e.g., water quality, turbidity). Instead, the management model focuses on preventing and compensating for direct habitat destruction. Scientific information is extremely limited on the consequences of large-scale factors such as non-point pollution or altered hydrologic regimes for the persistence, extent, and productivity of seagrass habitat in our region. Without a comprehensive management plan and the necessary tools for its implementation, the management model is likely to continue to focus on direct impacts on habitat, which the current planning and permitting system is equipped to address.

The management model also assumes that the value of habitat converted by *Z. japonica* is equal to or greater than the value to fish and wildlife of the habitats it replaces. Because fish and wildlife species depend on invertebrates as forage, present management policies protect *Z. japonica* and even require mitigation for its destruction, based on the positive role the nonnative seagrass is thought to play in the nearshore food web. However, the ecosystem model emphasizes that, with the exception of waterfowl studies, direct evidence for food chain support provided by *Z. japonica* is extremely limited. Furthermore, uncertainty exists in the extent and mechanisms by which seagrass and unvegetated habitats support fish and wildlife through the food chain, because this has not been directly documented in the Pacific Northwest (Simenstad, 1994). Consequently, the relative value of *Z. japonica*, *Z. marina*, and unvegetated habitats are almost entirely unknown for most fish and wildlife species. Determining the quality of habitat provided by *Z. japonica* is particularly important because its spread is effectively replacing the habitat provided by unvegetated intertidal flats.

Additionally, as illustrated by the ecosystem model, the assumption that *Z. japonica* does not harm native species is also based on very few studies, and some important components of the ecosystem have not yet been studied. In particular, unvegetated intertidal flats, and the effects of *Z. japonica* on the fish and wildlife dependent on this habitat, are not explicitly considered in the management model, and little research has been conducted to determine the ecological effects of converting unvegetated flats to seagrass habitat. Because *Z. japonica* invasion is not likely to be controlled, the important management question is how to predict the consequences for populations of shorebirds or juvenile fish that would normally utilize unvegetated intertidal flats. The possible interactions of *Z. japonica* with oyster culture and with the aquatic nuisance species *Spartina alterniflora* also suggest that the sand and mudflat community deserves additional management consideration. Finally, although available evidence suggests that *Z. japonica* is not

a threat to *Z. marina*, interactions with natural or anthropogenic disturbance have not been fully explored. Thus, considerable uncertainty exists regarding the assumptions implicit in the management model that *Z. japonica* and *Z. marina* are functionally equivalent, and that *Z. japonica* poses no threat to native habitats or species.

RECOMMENDATIONS FOR SEAGRASS MANAGEMENT AND RESEARCH

Our analysis suggests that a clearly documented and formalized seagrass policy is needed that details management practices and is uniformly accepted by Washington state resource agencies. A watershed approach is one option that should be considered if the management model were to be expanded to incorporate indirect effects on the seagrass system. A watershed approach would facilitate monitoring of cumulative impacts and effects of upland (or off-site) activities on seagrass habitat. Finally, the possibility that *Z. japonica* and *Z. marina* may have different functional values should be anticipated in defining mitigation requirements (Baldwin and Lovvorn, 1994), and developing inventories of seagrass resources (Mumford, pers. comm.).

In general, research priorities should focus on simultaneously providing the data needed to evaluate and strengthen the management model and increasing basic understanding of the ecosystem (Lubchenco et al., 1991; Olson and Straub, 1994). Based on our analysis, we have identified several priorities for research that would support our management recommendations to increase the spatial scale at which seagrass management occurs (in order to incorporate water quality issues), to reflect potential functional differences among habitats in management strategies, and to further assess the potential ecological benefits and costs of *Z. japonica* invasion. A modest research agenda should address uncertainties regarding off-site and upland influences on seagrass, seagrass habitat quality, potential negative effects of *Z. japonica* invasion, and should inventory seagrass habitats.

SUMMARY

In Washington state, resource managers acknowledge both the ecologically important role that seagrass plays in providing habitat for fish and wildlife and the threat that exists from direct anthropogenic impacts to seagrass habitat (e.g., shoreline development and dredging). Nevertheless, state management plans have not evolved beyond an informal policy of no-net-loss of habitat. Current seagrass management is based on a model of ecological interactions in seagrass systems, based primarily on research conducted on *Z. marina*, and extended to management decisions regarding the invasive, non-indigenous seagrass *Z. japonica*. Although available research does not implicate *Z. japonica* as a threat to the ecosystem, the relative quality of *Z. marina*, *Z. japonica*, and unvegetated flats is not addressed in present mitigation procedures. Further research is needed to assess the effects that the spread of *Z. japonica* may have on the coastal environment.

ACKNOWLEDGMENTS

The authors would like to thank Dr. Thomas M. Leschine and Sandy Wyllie-Echeverria, University of Washington, School of Marine Affairs, for providing guidance in developing the project and for comments on early drafts of the manuscript. Thanks also are due to Dr. Douglas A. Bulthuis, Padilla Bay National Estuarine Research Reserve, for assisting in project development and reviewing an early draft of the manuscript. Financial support for this project was provided by Padilla Bay National Estuarine Research Reserve, Shorelands and Coastal Zone Management Program, Washington Department of Ecology; and the University of Washington, School of Marine Affairs.

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IMPLICATIONS FOR RESTORATION: LIGHT, TEMPERATURE AND ENRICHED CO_2 EFFECTS ON EELGRASS (*Zostera marina* L.)

Ronald M. Thom[1]

INTRODUCTION

Eelgrass forms meadows throughout the shallow subtidal zone in Puget Sound, the Strait of Juan de Fuca and Washington's coastal estuaries. It is generally known that these meadows are extremely important as rearing and feeding grounds, as well as locations for reproduction for a large variety of fisheries resources (e.g., Thom, 1987). Development of shorelines directly affects eelgrass, and ways to avoid or minimize these impacts has been the subject of wide concern. Although planting eelgrass can be accomplished with relatively high degree of success, establishing eelgrass meadows as mitigation for impacts through transplantation has been fraught with problems (Thom, 1990a). The pressure to develop shorelines will continue into the foreseeable future. How to mitigate impacts of development on eelgrass is one of the greatest and most urgent challenges facing scientists and resource managers in this state.

In an earlier review of eelgrass transplanting projects (Thom, 1990a), I found that most projects failed primarily because of inappropriate physical conditions at the transplant site. Experimentation and studies conducted since that review are beginning to yield the type of data that can be used to better determine the appropriateness of the potential transplant sites. The purpose of this paper is to present some new data that help define physical and chemical conditions required for growth by the plant.

In addition, I describe the Grays Harbor Shell project, one of several transplant projects that was begun after the 1990 review, which illustrates a moderate degree of success. In 1992, the U.S. Army Corps of Engineers-Seattle District placed oyster shell on tidal flats to mitigate for Dungeness crab mortalities caused by dredging in Grays Harbor, Washington, in 1990. Experiments conducted on 1-acre shell plots in 1990 indicated that the shell served as a viable nursery habitat for young crab. Shell placement in 1990 damaged isolated patches of eelgrass. To help assess the potential for the recovery of eelgrass in plots that may have been significantly affected, eelgrass transplanting experiments were initiated in May 1990. Eelgrass was transplanted into 16 ponded areas that were created by the uneven placement of the shell. Transplanting was carried out in spring 1990, and sampling of the survival of the transplants was conducted in August of 1990, 1991, 1992 and 1993.

EXPERIMENTAL STUDIES

Since 1990, a variety of studies have been conducted at Battelle's Marine Sciences Laboratory (MSL) on the effects of variations in temperature, light and CO_2 on net apparent photosynthesis (NAP), respiration (R) and growth rate of eelgrass. Although detailed papers are in preparation on these studies (Thom, in review), I will briefly summarize what has been found. Physiological measures (i.e., photosynthesis, respiration) were conducted using oxygen flux measurements for leaf sections. Growth rates were measured *in situ* at the meadow adjacent to MSL, and in 130L mesocosms. The physiological methods and growth rate measurement generally follow the procedures outlined in Thom (1990b). All treatments were replicated, and most experiments were conducted at least twice.

Short-Term Irradiance Experiments

The basic relationship between photosynthetic rate and photosynthetically active radiation (PAR) was established using several hundred incubations. Experiments showed three important aspects of this relationship for plants collected near MSL: (1) photosynthesis was essentially saturated at about 350 μM m^{-2} s^{-1} PAR; (2) winter plants produced a much steeper initial slope than summer plants, and had a much

[1] Battelle Marine Sciences Laboratory, 1529 West Sequim Bay Road, Sequim, WA 98382

greater maximum rate than summer plants (spring plants had an intermediate initial slope and maximum rate); and (3) photo-inhibition was indicated in winter plants. Observations of the morphology of plants indicated that winter plants were shorter and tended to have thicker leaves (not quantified) as compared to summer plants. These results suggest that winter plants use light much more efficiently than summer plants.

Longer-term *In-situ* Growth Studies

Growth rate of plants located at the mouth of Sequim Bay showed a strong relationship with *in-situ* integrated PAR (Figure 1). This relationship is probably more indicative of the physiological requirements of the plants in the field as compared to relationships established using short-term photosynthesis experiments. What is not known for the Puget Sound populations is the annual PAR requirement needed to sustain eelgrass populations. Although we currently can calculate this requirement based upon existing short-term data, there is a significant level of uncertainty in extrapolating the existing empirical data to annual minimal PAR requirements.

Temperature Experiments

Short-term incubations showed that temperature affected NAP and R rates (Thom, in preparation). Peak NAP occurred at about 12°C. In contrast, R increased linearly with increasing temperature. The ratio of NAP to R provides an indication of the response of the plant to changes in temperature. Values above 1 indicate that the plant is generally doing well in that NAP exceeds R. In contrast, values less than 1 indicate that the plant is not supplying adequate energy needs. The experiments showed that the ratio peaks at a very narrow range of approximately 7-10°C. This suggests that plants that experience temperatures consistently outside this range may be stressed. This type of information can be used to explain why eelgrass does not exist in some areas, and may be used to help determine appropriate sites for transplantation.

Carbon Dioxide

Water enriched with CO_2 was used for short-term incubations of leaf sections and for longer-term growth experiments with whole plants (Thom, in review). In general, experiments with eelgrass showed variable results but indicated that CO_2 was at times limiting NAP and growth rate, that doubling of CO_2 would result in an increase in NAP, and that greater enrichments were effective in increasing NAP up to a point. Growth rate did show a general increase with enrichments in one experiment but not the second.

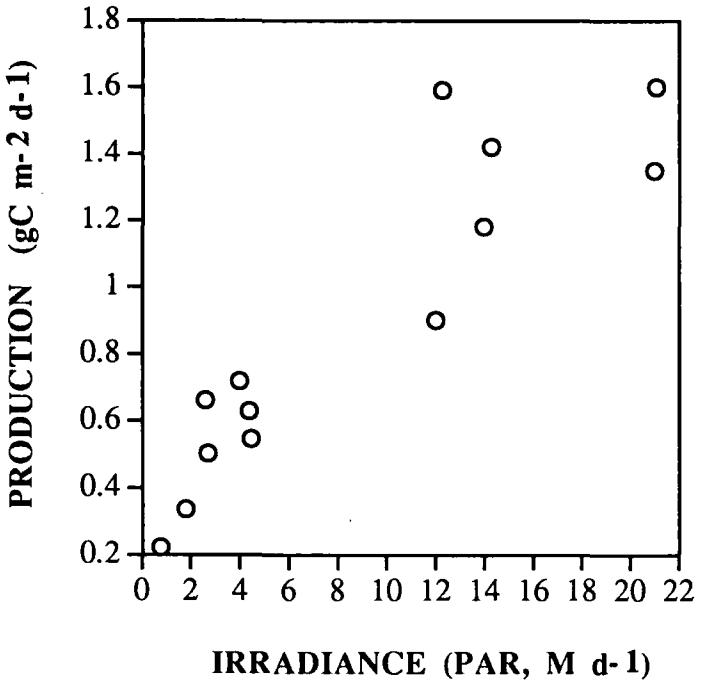

Figure 1. In-situ *integrated irradiance vs. growth rate of eelgrass at Battelle's dock at the mouth of Sequim Bay*

GRAYS HARBOR TRANSPLANT PROJECT

The number of shoots in all but plot 2 at Campbell Slough (CSS2) steadily increased over the 52 months since transplantation (Figure 2). It is not possible

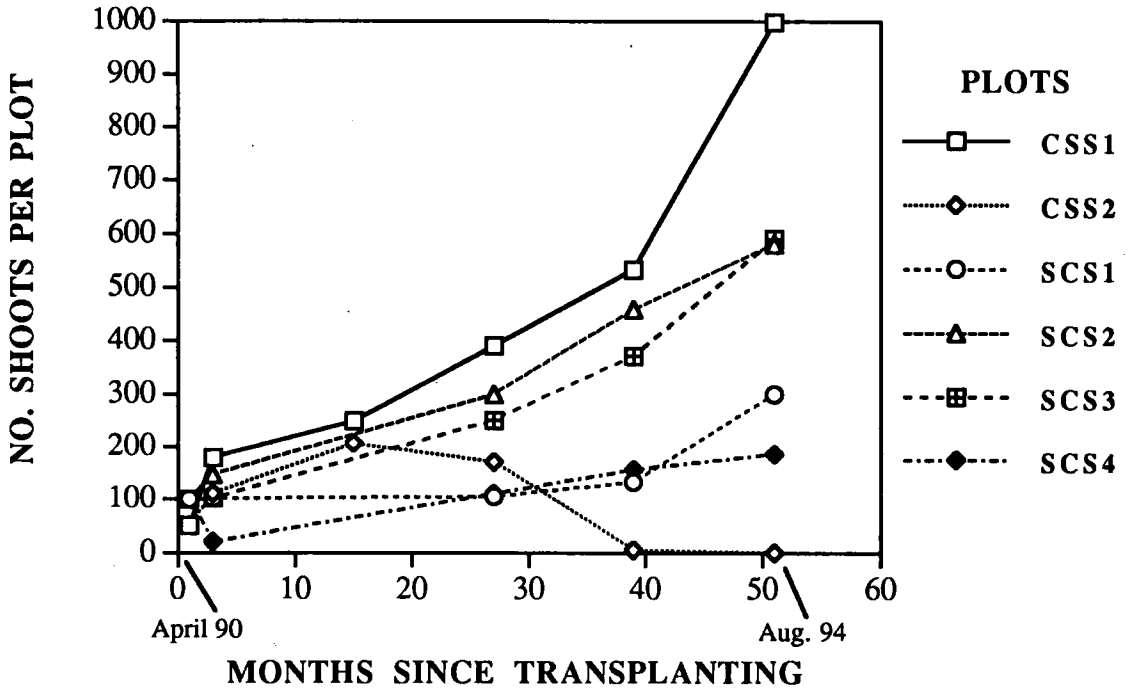

Figure 2. Change in number of shoots in each transplant plot in Grays Harbor over time. CSS1 = Campbell Slough Plot 1; CSS2 = Campbell Slough Plot 2; SCS1 = South Channel Shell Plot 1; SCS2 = South Channel Shell Plot 2; SCS3 = South Channel Shell Plot 3; SCS4 = South Channel Shell Plot 4.

to determine whether the plants in the plots are from the original transplants, new colonizers, or both. If plot CSS2 is excluded, the number of shoots per plot has increased an average of 7.3-fold since 1990. Although plot CSS2 did show an increase between 1990 and 1992, heavy sedimentation apparently caused shoot losses since 1992. The rate of increase in number of shoots per plot is represented by linear regressions in Table 1. These regressions provide an indication of the relative habitat suitability of each site for eelgrass colonization. Plot CSS1 showed an average increase of about 16 shoots month^{-1}, whereas other plots increased at rates of nine shoots or less per month.

Table 1. Linear regression of number of shoots per plot (Y) as a function of number of months since transplanting (X) in Grays Harbor. The form of the equation is $Y = mX + b$. r = correlation coefficient. See Figure 2 for plot codes.

Plot	m	b	r
CSS1	16.057	35.71	0.95
CSS2	-2.008	136.02	0.45
SCS1	3.001	74.78	0.77
SCS2	9.184	94.76	0.99
SCS3	9.065	63.23	0.97
SCS4	2.513	53.58	0.87

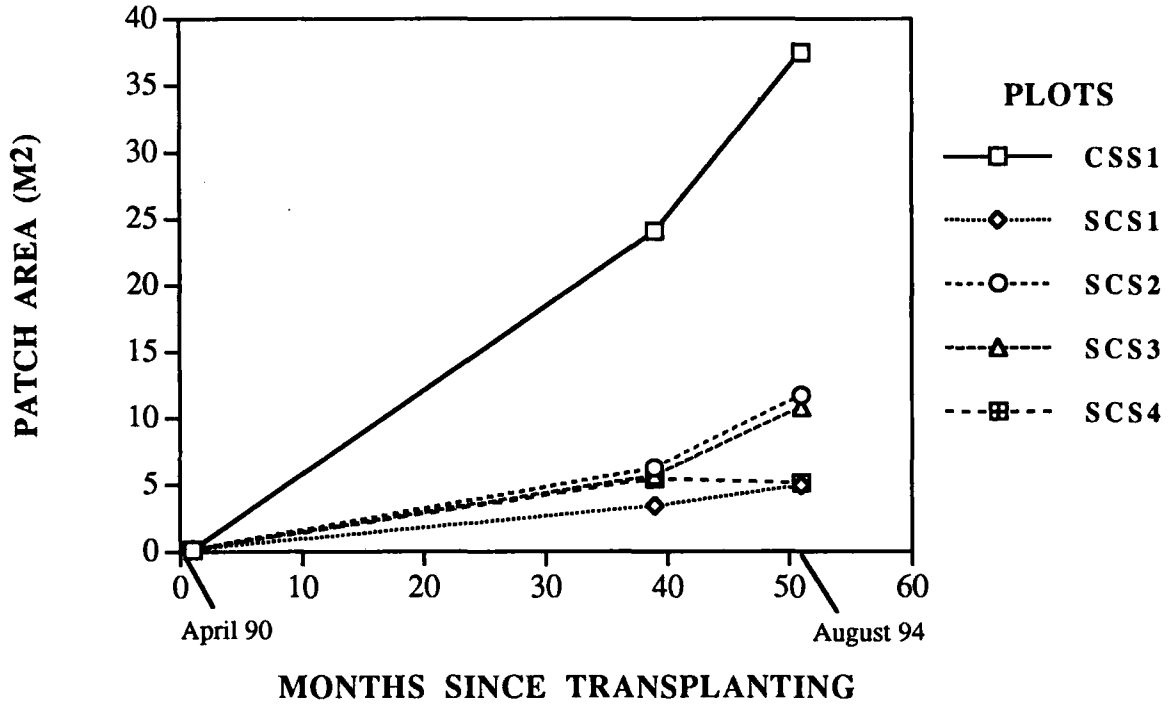

Figure 3. Change in area of eelgrass in each transplant plot in Grays Harbor over time. See Figure 2 for plot codes.

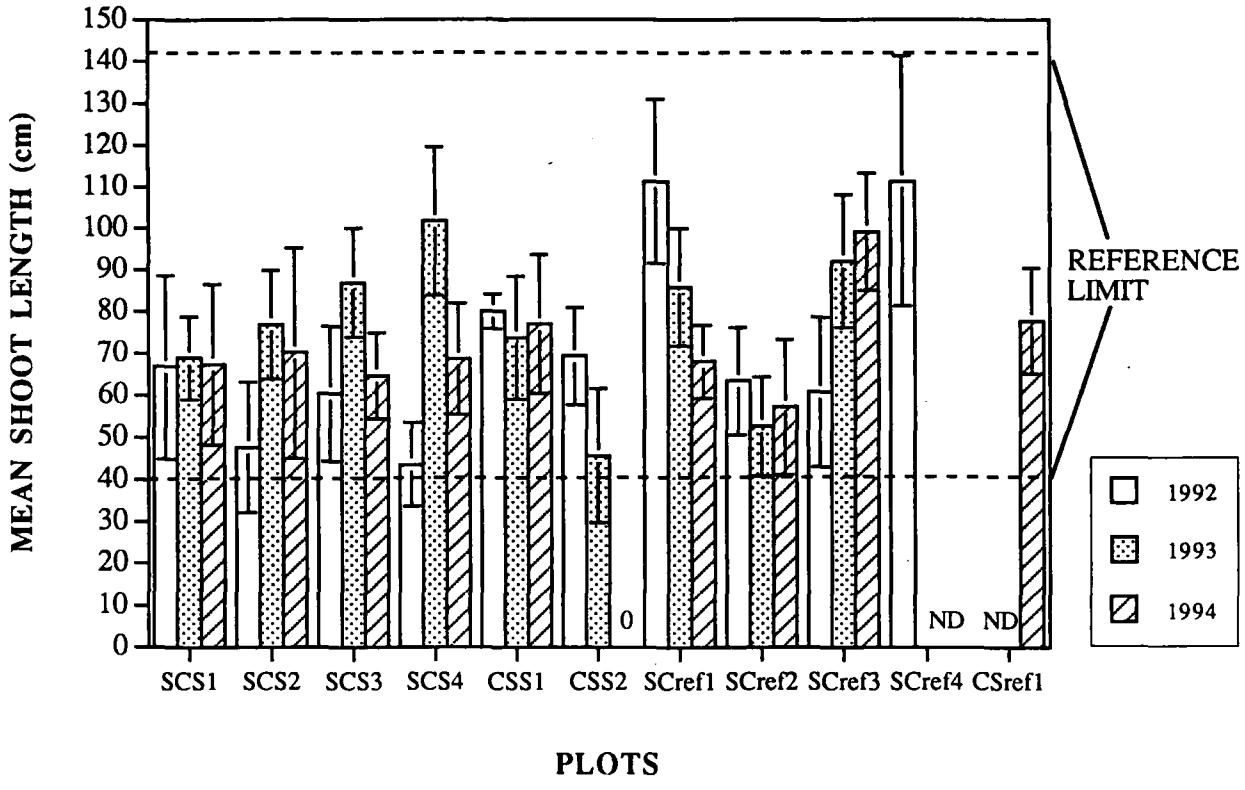

Figure 4. Mean shoot lengths at the transplant plots and reference plots in July and August 1992, 1993 and 1994. See Figure 2 for plot codes.

Patch expansion is shown in Figure 3. Although there are less data on this parameter, all patches except CSS2 showed steady increases in the area occupied by the patch. Linear regressions indicate a rate of spread of 0.09 - 0.72 m^2 $month^{-1}$ (mean = 0.27) for each patch.

Three reference plots (SCref1, SCref2, SCref3) located in ponds adjacent to the South Channel shell plots and one reference plot (CSref1) near the Campbell Slough plots were sampled for eelgrass shoot lengths, pond depth and shoot density (i.e., number of shoot in random 0.1m^2 quadrat samples) to provide data for comparison with the transplanted plots. The reference plots contained what appeared to be the densest stands of eelgrass in the immediate vicinity. Mean shoot density in 1994 in the transplanted plots ranged from 33-68 m^{-2}, which was very similar to the range of densities at the reference plots (Figure 4). In 1994, mean shoot lengths ranged from about 45 to 102 cm in all plots sampled. Shoot lengths in transplant plots did not differ substantially from the range of shoot lengths found in reference plots.

CONCLUSIONS

Light, temperature and CO_2 all have a significant influence on eelgrass photosynthesis and growth in Puget Sound. Although we cannot accurately calculate the minimum PAR required to support net annual growth in Puget Sound, the data from the experiments are a first step in developing this capability. Puget Sound shorelines are more or less highly influenced by turbidity from cliff erosion and river-borne sediments, as well as phytoplankton blooms. These factors reduce light energy at the bottom and will limit the depth to which eelgrass can grow. The frequency, intensity and duration of turbidity will dictate the relative impact on the depth distribution of eelgrass (e.g., Kirk, 1994). Although a model that relies on secchi depth measurements for assessing the impact of turbidity on eelgrass has been developed for Chesapeake Bay (Dennison et al., 1993), tide dynamics and the magnitude of Puget Sound make this model unreliable in this region.

Temperature effects on photosynthesis and respiration are important in assessing sites for potential transplantation. Although temperatures well above and below the optimal range are known to occur within the extensive eelgrass meadow at Padilla Bay (Thom, 1990b), the experiments show that optimal temperature conditions for eelgrass are relatively narrow. Sites, such as protected back bays, that vary significantly from this range over extended periods of time may be unsuitable for transplanting. The results of these experiments also have relevance to large climatic variations (e.g., El Niños) that may affect temperature and result in damage to meadows that occur in areas that are at suboptimal conditions under normal climatic conditions.

Increasing CO_2 in the surface waters of the coastal ocean would predictably result in increased eelgrass NAP and potentially increased growth rate (Thom, in review). Eelgrass showed highly variable responses to the treatments, which may be due to factors such as the availability of carbon in source water, storage and translocation of gases, products of photosynthesis and anatomical structure (e.g., Sondergaard and Wetzel, 1980; Kraemer and Alberte, 1993). At present, I have no evidence to support any conclusions regarding the relative effect of these factors. Factors such as temperature and nutrient limitation, which I also did not evaluate in the present study, could interact to alter the production response (Zimmerman et al., 1987; Williams and Ruckleshaus, 1993). Although there are very limited data on the effects of enriched CO_2 on the photosynthetic rates of eelgrass, Kirk (1994) showed that inorganic carbon-limitation can be a major factor controlling nearshore production by benthic plants. I suggest that carbon becomes limited in water over large, dense, meadows (e.g., Padilla Bay), especially during periods of low slack tides in spring-summer, when irradiance and temperature are highest.

Five of the six transplanted plots in Grays Harbor are viable eelgrass patches very similar in density and size to naturally colonized patches. These transplanted areas continue to show an increase in shoot abundance, which indicates that the plots are areas of active eelgrass recruitment. Whether this high rate of increase is related to development of sediments, maturing of the rhizome system, or creation of a habitat conducive to settlement of eelgrass seeds is difficult to determine without further study. The rates of increase in shoot abundance, shoot length, and perhaps plant migration appear to be strong indicators of the physical suitability of a site for eelgrass transplants. The regressions represent our first attempt to model

shoot abundance and patch-area increases based on a relatively long-term data set. Theory suggests that the rate of increase should slow at some point when abundances reach background (reference site) levels. Although the plots are at natural levels of plant density, shoot abundance continues to increase. The area of eelgrass patches also continues to expand. There has been the general observation that transplanted eelgrass plots always shrink in area (Fonseca et al., 1988; Thom, 1990a). Our findings indicate that this is not the case at our sites. Continued sampling of these plots will provide us with an indication of whether trajectories in shoot abundance and patch area are maintained or decrease with time.

ACKNOWLEDGMENTS

I gratefully acknowledge the support of the U.S. Corps of Engineers-Seattle District for the eelgrass transplant studies in Grays Harbor. Help and advice for the research was provided by R. Phillips, D. Shreffler, J. Lipfert, S. Hinds, V. Gaedecki, X. Duarte, and T. Conners. D. Shreffler provided excellent review comment on the manuscript.

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EELGRASS AS A NATURAL RESOURCE: IMPLICATIONS FOR FORMAL POLICY

S. Wyllie-Echeverria[1], R.C. Phillips[2], E.S. Hunn[3], N. J. Turner[4] and M.L. Miller[1]

He hin ntcma'inim hanso into'oscl hant zo commo'ii.[5]
Me mos he hin ntcma'inim hanso into'opol hant zo commo'ii.

[You weren't mixed with me,
you're just so drab there where you are.
You, also, you weren't mixed with me,
you're just so black there where you are.]

There are five species of seagrasses growing within the confines of the Puget Sound basin (Dethier, 1990; Wyllie-Echeverria and Phillips, 1994). In this paper we will focus on only one, *Zostera marina*, eelgrass. Although we realize the limitations of this approach, it is necessary for comparative analysis over time. There is simply much more data available on eelgrass, and it has a long history of both direct use and scientific investigation in this region. Of the other five, *Zostera japonica* was introduced more recently (Harrison and Bigley, 1982; see Olson and Pawlak, this volume, for more discussion) and insufficient data, for our analysis, are available for the three endemic surfgrasses (*Phyllospadix torreyi, P. scouleri* and *P. serrulatus*) (Phillips and Menez, 1988).

Unofficial procedures to protect and conserve eelgrass in Washington state (Fresh, 1994; Pawlak, 1994) are derived from ecosystem studies, ongoing since the mid-1960s, that link these plants to the sustenance of regionally important fisheries (see Phillips, 1984; and Simenstad, 1994, for a review). Missing in this region, however, is a formalized seagrass policy. Although some argue that such a move may be unnecessary (Hershman and Lind, 1994), others contend that the current situation may contribute to a perceived disparity in agency responses to particular projects and link this perception to: 1) differing regulatory authority, 2) individual project demands, and 3) general "no net loss" criteria (Fresh, 1994). The residual effect of this perceived disparity may, in turn, mobilize development interests and overturn current regulatory practices threatening eelgrass "resources."

Natural resources are commonly defined as the material by which a government entity achieves economic and political development. Historically, these resources are seen to encompass "extractive" or "aesthetic" benefits to humankind (Miller et al., 1987). More recently, "critical habitats" are seen in this context (e.g., Committee on the Role of Technology in Marine Habitat Protection and Enhancement, 1994). Our intent is to explore the theme of eelgrass as both an extractive resource and a critical habitat and discuss what this might mean for the development of a more comprehensive seagrass policy in Washington state. In the spirit of brevity, we will examine: 1) traditional use of eelgrass by two aboriginal groups in the Puget Sound basin; and 2) the increasing use of the term "resources" to describe seagrass ecosystems.

TRADITIONAL USE

A continuing search to catalogue traditional seagrass use on the west coast of North America has revealed coastwide usage of several species, and depending on location and season, these plants were a pivotal component of a people's resource base (Wyllie-Echeverria and Hunn, in prep). Individual species

[1] School of Marine Affairs HF-05, University of Washington, Seattle, Washington 98195

[2] Battelle-Pacific Northwest Laboratories, Richland, Washington 99352

[3] Department of Anthropology DH-10, University of Washington, Seattle, Washington 98195

[4] Environmental Studies Program, University of Victoria, Victoria, B.C. V8W 2Y2 Canada

[5] This chant was recited by Seri women from Sonora, Mexico, as they mixed and ground thrashed eelgrass seeds with cardo'n (*Pachycereus*) seeds into an "eelgrass gruel" (Felger and Moser, 1985).

were recognized, and specific plant parts were named and used by at least seven coastal groups. For the purposes of this discussion we report the following findings.

In eloquent style Suttles (1951) describes the country and culture of the Straits Salish (specifically the Salish-speaking Klallam, Songish, Saanich, Semiahmoo, Lummi, and Samish) in northern Puget Sound basin. His description includes items that were gathered and hunted, the methods and mechanisms by which items were procured and, in some cases, the major site of harvest (Suttles, 1951). Eelgrass was a common feature in accounts of activities below the tideline. In fact, in the general narrative of marine collection zones, only eelgrass and kelp are highlighted as valuable habitats for fish and waterfowl. Although this account stresses the strong connection between the Pacific herring roe (*Clupea harengus pallasi*) fishery and eelgrass, reference is also made to the harvest of crab and waterfowl at eelgrass sites (pages 47 and 73, Suttles, 1951). In contrast to peoples to the north (e.g., Hesquiat and Kwakwaka'wakw; Kuhnlein and Turner, 1991) and south (e.g., Makah and Quileute, Gunther, 1945; Gill, 1982), no mention of direct consumption is made for Puget Sound peoples. Instead the focus is on the eelgrass ecosystem as a sustaining environment (Suttles, 1951).

The Hesquiat, living on the central west coast of Vancouver Island, harvested two varieties of eelgrass (Turner and Efrat, 1982). From habitat location, these can be distinguished as *Zostera marina* var. *latifolia* and *Zostera marina* var. *typica* (Setchell, 1927; Backman, 1991). The *latifolia* variety is wide-leafed (6-20 mm) and grows in the subtidal, while *typica* has narrower leaves (1.5-4 mm) and is found primarily in the intertidal (Backman, 1991). The Hesquiat, however, distinguished the two varieties by the color, thickness and taste of the eelgrass rhizome in addition to leaf width (Turner and Efrat, 1982). The intertidal variety was also listed as a food for black brant, Canada geese and mallard ducks (Turner and Efrat, 1982), which is in keeping with current observations of the feeding habits of these species (Ward, 1983; Baldwin and Lovvorn, 1994).

The fact that the Straits Salish and Hesquiat had expert knowledge of the eelgrass resources, albeit for different reasons, is instructional. The practice of gathering, either the eelgrass rhizome or the animal life that was sheltered or fed by the same, was not trivial. These people, like other North American aboriginal people, gathered plants and hunted animals to sustain their numbers on yearly and seasonal schedules (Williams and Hunn, 1982; Hunn, 1990). Knowledge of plant and animal location as well as optimum harvesting period was essential to the maintenance of healthy diets (Hunn, 1990; Kuhnlein and Turner, 1991). Furthermore, as in the case of the Straits Salish, the presence of the eelgrass was recognized as an indicator that other desired food items were present. As a consequence, resource management in the sense of resource location and abundance was necessary. Knowledge of eelgrass presence at particular sites remains unbroken for many generations. This knowledge is now referred to as Traditional Environmental Knowledge (TEK) (Johnson, 1992).

ECOSYSTEM MANAGEMENT AND RESOURCE MANAGEMENT

Although eelgrass has been recognized as a critical habitat in U.S. waters since the impact on plants by the "wasting disease" epidemic in the 1930s, (see Milne and Milne, 1951; Burkholder and Doheny, 1968, for a review), the term "resource" was not applied. The precise beginning of this term is vague. However, in the Proceedings of the International Seagrass Workshop (Leiden, The Netherlands, 22-26 October 1973) authors link the term "living resources" to seagrass ecosystems and recommend a research agenda for the Seagrass Ecosystems Study funded by the National Science Foundation (McRoy et al., 1973). This study was a cooperative effort in which scientists from several countries collaborated in interdisciplinary research programs to understand the "contribution of seagrass ecosystems to the ecology of coastal oceans" (McRoy et al., 1973). Implicit, but not directly stated in these proceedings, was the recognition that these studies would lead to conservation and protection of seagrasses by federal, state (or provincial) and local government vested with this regulatory responsibility.

Three separate but linked phenomena were necessary in order for these studies (and others to follow) to have impact in the regulatory environment and initiate a policy of protection and conservation. These nested criteria include: 1) the recognition that this suite of plants comprised a discrete ecosystem; 2) the

realization that links between this ecosystem and the sustenance of commercially and recreationally important species needed to be established; and 3) the recognition that the sustenance of these commercial and recreational species was of enough value to require protection and conservation. Once value was recognized, changes in administrative law were necessary.

The administrative process (e.g., regulations and restrictions imposed by local, state and federal agencies) is not only a fundamental feature of environmental law (Plater et al., 1992), but also an important characteristic of prudent resource management. This process can be informed and should be directed by ecological studies (Lubchenco et al., 1991; Olson and Straub, 1994). In other coastal states, ecological investigations have guided the development of formalized seagrass policies (e.g., Batiuk et al., 1992; Morris and Tomasko, 1993). What follows is a brief review of two examples of the convergence of administrative law and ecological science to produce formal seagrass policy.

Declines of submerged aquatic vegetation (SAV) and resulting impacts to waterfowl in the Chesapeake Bay were brought into sharp focus in the early 1970s (Orth and Moore, 1983, 1984). These declines, which began in the 1960s, were linked to degradation of water quality, a condition forced by coastal and watershed development and poor land-use practices associated with agriculture (Orth and Moore, 1983, 1984; Dennison et al., 1993). The seagrasses (*Zostera marina* and *Ruppia maritima*) are folded into the larger ecological unit of SAV (submerged aquatic vegetation). This region now has a complete and comprehensive policy titled "Chesapeake Bay Submerged Aquatic Vegetation Policy" (1989), which through an Implementation Plan (1990) began to: 1) emphasize the need to identify environmental conditions necessary for the persistence of SAV and 2) develop system-wide restoration goals (Batuik et al., 1992). Although 1991 SAV distribution in Chesapeake Bay and its tributaries represents a reduction of 90 percent from historical estimates (Dennison et al., 1993), there was an increase when compared to 1990 (Orth et al., 1992). Additionally, 1991 SAV distribution has increased approximately 21 percent since 1987 (Orth et al., 1987, 1992), and studies indicate that more strict environmental regulation for managing land drainage and coastal development is an important factor in this increase (Dennison et al., 1993).

In compliance with the 1989 passage of the Surface Water Improvement and Management (SWIM) program and coincident with the formation of the Indian River Lagoon National Estuary Program at Indian River Lagoon Florida (IRLNEP) in 1991, resource managers developed the Submerged Aquatic Vegetation Initiative (SAVI) in 1992 (Busby, 1993). The goal of this initiative is to "increase the amount and quality of seagrass (dominant species: *Halodule wrightii* and *Syringodium filiforme*) and associated resources in the Indian River Lagoon" (Morris and Tomasko, 1993). Justification for the establishment of SAVI was linked to: 1) the concession that prevailing federal and state administrative law was not adequate to protect the seagrass ecosystem and 2) the awareness that particular growth-limiting factors, identified by scientific inquiry (e.g., Kenworthy, 1992; Higman, 1993) were responsible for declines. The initiative adopted a model focused on the relationship between water quality and seagrass distribution (Kenworthy, 1992). Although this model is region-specific (Busby and Virnstein, 1993) and emphasizes reduced light environment as the primary limiting factor (see Bulthuis, Thom and Fresh, this volume, for complementary discussion relative to the Puget Sound basin), SAVI represents a positive step in the integration of ecological science and resource management within the context of administrative law for the conservation and protection of Indian River Lagoon seagrasses.

CONCLUSIONS AND RECOMMENDATIONS

Knowledge of the distribution and abundance of eelgrass (and other seagrasses) over time is a fundamental component of resource management. This was true for the Straits Salish and Hesquiat, and was a primary agent in the development of formal seagrass policy in both the Chesapeake Bay and Indian River Lagoon. On this score, knowledge not only for the Puget Sound basin (Mumford, 1994) but also for most of the West Coast of North America (Wyllie-Echeverria and Thom, 1994) is incomplete. We advocate that Washington state initiate a program to document the current distribution and abundance for all seagrass species as part of a formalized seagrass policy. In addition, efforts should be made to uncover historic distribution patterns. Although Thom and Hallum (1990) do provide records for eelgrass, no other

seagrass species are referenced, and data and information from Traditional Environmental Knowledge are not mentioned.

Data linking seagrass species and ecotype, as well as particular geographic location, to consumer preference should also be a priority. Ongoing and recent work suggests that intertidal eelgrass and *Zostera japonica* are the preferred food for a number of water birds on the Pacific Flyway (Wilson and Atkingson, 1995; Ward, 1983; Baldwin and Lovvorn, 1994). In the Puget Sound basin, recent data documents that a "gray-bellied" form of Pacific brant (*Branta bernicla nigricans*) may not migrate as far south as the darker-bellied variety (Shields, 1990). This goose winters in Padilla Bay, in the Puget Sound basin, instead of Baja California, Mexico (Pacific Fly Management Plan, 1992). Although brant will eat floating eelgrass leaves (and occasionally other marine plants), they tend to feed primarily on rooted intertidal vegetation (Ward, 1983). Consequently, the conservation and preservation of intertidal seagrass may be critical for those geese wintering in Padilla Bay.

Furthermore, current conservation and preservation measures adopted by Washington Department of Fish and Wildlife (Fresh, 1994) are predicated on the knowledge that Pacific herring (*Clupea harengus pallasi*) revisit spawning sites (e.g., Clemens and Wilby, 1961; Hourston, 1980). This has led to a very conservative policy with respect to the development of particular locations. Again, Traditional Environmental Knowledge may be helpful. For instance, Suttles (1951), on the basis of extensive interviews, provides maps depicting the location of various preferred coastal gathering sites, including herring spawn locations. This information could be supplemented and expanded through contact with tribal elders within the Puget Sound basin and, coupled to WDFW research, could provide a partial picture of Pacific herring spawn site preference over time.

Numerous studies over most of this century have delineated the vital role seagrasses play in the coastal environment not only as shelter, substrate and food but also as an erosion buffer. In sum, when you have seagrasses, important fisheries and waterfowl are sustained; when you have none, these same fish and birds are threatened. We suggest that, although the perception of seagrasses as a resource is a step in an acceptable direction, the protection and conservation of this resource may call for formal seagrass policy—a policy that demands systematic, rigorous and frequent inventories (see Mumford et al., this volume, for more discussion).

Finally, and aside from extractive and critical habitat value, seagrasses have aesthetic value, which contributes to the enjoyment by many visitors of estuarine and ocean coasts. Windrows of gnarled mats entwined with algae, shell and ocean debris, the gentle sway of leaves in tidal currents, or the swirled mats left on beach or mudflat with a retreating tide provide those who swim or stroll with the stuff and substance of creative thought. In fact, this beauty and function has enhanced poetic and artistic product through time and culture (e.g., Darwin, 1791; Felger and Moser, 1985; Standing et al., 1975; Whitt, 1988). To these, seagrasses undoubtedly have value apart from that imposed by utilitarian philosophy (cf. Miller and Kirk, 1992). This topic, however, is beyond the scope of this paper.

ACKNOWLEDGMENTS

The authors acknowledge the contributions of aboriginal peoples of the Pacific Northwest Coast to our understanding of seagrasses, and in particular, the late Alice Paul of Hesquiat, for providing details of seagrass use by the Nuu-Chah-Nulth (Hesquiat) people of Vancouver Island. Additionally we thank Robert J. Orth (Virginia Institute of Marine Science), Mike Durako (Florida Department of Environmental Protection), Lori Miller (St. Johns River Water Management District, Palatka, Florida), Doug Bulthuis (Padilla Bay Natural Estuarine Research Reserve), and Keith Merkel (Merkel and Assoc., San Diego, Calif.) for helpful suggestions on the seagrass policy section. SWE acknowledges the support of the Hardman Foundation to catalog traditional seagrass use and the helpful suggestions of Marc Hershman and Dave Fluharty at the School of Marine Affairs, University of Washington.

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OVERWATER STRUCTURES AND IMPACTS ON EELGRASS (*Zostera marina*) IN PUGET SOUND, WASHINGTON

Kurt L. Fresh[1], Brian Williams[2], and Dan Penttila[2]

ABSTRACT

Eelgrass (*Zostera marina*), one of the most important aquatic habitats in Puget Sound, grows in intertidal and shallow subtidal areas, where it is particularly vulnerable to various types of shoreline development. In this study, we evaluated whether there was a decline in the density of eelgrass underneath and immediately adjacent to small overwater structures (so-called "single-family residence" piers, floats, and docks) built over eelgrass beds. We focused on small overwater structures because while the "footprint" of an individual structure is small, the large number of such structures that have been built suggests the potential for significant cumulative effects. A second objective of this study was to assess whether the use of gratings in the construction of overwater structures mitigated impacts on the eelgrass.

Under six of seven structures examined to assess their impacts on eelgrass, we found a significant reduction in the density of eelgrass. At several sites, there was also a loss of eelgrass immediately adjacent to the dock. There were differences between sites in the magnitude of impacts that likely depended upon such factors as width of the structure, orientation, and height over the water, as well as local environmental conditions. We believe the major source of impact is shading of the eelgrass, although the structures may have other effects as well (e.g., alterations in current patterns, use-related impacts). Thus far, we have tested gratings that enhance light penetration at five sites. Preliminary results suggest that the gratings tested thus far at least reduce impacts of overwater structures on eelgrass and that their effectiveness varies between locations.

INTRODUCTION

Eelgrass (*Zostera marina*) is the most abundant seagrass species in coastal waters along the West Coast of North America. In Puget Sound, the plant grows in intertidal and shallow subtidal areas in discrete patches, in narrow bands, or in extensive meadows. Eelgrass habitats are critical components of estuarine ecosystems (Orth et al., 1984; Phillips, 1984; Bell and Pollard, 1989). In Puget Sound, eelgrass is one of the major spawn deposition substrates used by Pacific herring (*Clupea harengus pallasi*). Eelgrass provides critical habitat for a variety of small crustaceans that are consumed by economically important fish and invertebrate species including Dungeness crab (*Cancer magister*) and Pacific salmon (*Oncorhynchus* spp) (Simenstad et al., 1988). It is also eaten by migratory waterfowl such as black brant (*Branta bernicla*), American widgeon (*Anas americana*), northern pintail (*A. crecca*), and mallards (*A. platyrhynchos*) (Yocum and Keller, 1961; Baldwin and Lovvorn, 1994).

In some areas of Puget Sound, substantial losses of eelgrass have occurred (Thom and Hallum, 1990). One source of eelgrass loss is the development of Puget Sound shorelines, such as the construction of small (so-called "single-family residence") overwater piers, floats and docks. Many such structures are built over eelgrass beds, and, while individual structures are small, the large number of structures built in some areas, such as the San Juan Islands and Hood Canal, suggests the potential for significant cumulative effects. For instance, 94 docks and floats have been built in the last five years in the San Juan Islands.

Little quantitative information is available on the nature and extent of the impact of overwater structures on eelgrass. One type of impact that could occur is a reduction in the light reaching areas directly under and adjacent to the structures. Light is known to be an important environmental factor for

[1] Washington Department of Fish and Wildlife, Fish Management Program, 600 Capital Way, MS 43149, Olympia, WA 98504-3149

[2] Washington Department of Fish and Wildlife; Mt. Vernon Field Office, Mt. Vernon, WA

eelgrass (Backman and Barilotti, 1976; Zimmerman et al., 1991) and can affect eelgrass density, depth distribution, and growth (Bulthuis, 1983; Dennison and Alberte, 1985; Dennison, 1987). A certain amount of light is needed for eelgrass to flourish, and when light levels drop below a minimum, the eelgrass will die. Burkholder and Doheny (1968, cited by Backman and Barilotti, 1976) reported that at a light transmittance of 20 percent or less, eelgrass plants eventually died. In a literature review, Duarte (1991) concluded that seagrass could grow at depths receiving an average of 11 percent of the surface irradiance. Reductions in light intensity, such as that resulting from increases in turbidity, have caused major losses of eelgrass in some areas, such as Chesapeake Bay (Orth and Moore, 1983).

While the average light environment is important, episodes of extreme light attenuation can cause a significant and rapid change in eelgrass distribution and density (Zimmerman et al., 1991). Backman and Barilotti (1976) found, for example, that eelgrass densities declined within 18 days under experimentally shaded areas. Thus, impacts on eelgrass under and adjacent to structures are possible even if small reductions in irradiance occur.

The Washington Department of Fish and Wildlife (WDFW) began studies in 1989 to determine whether there was a loss of eelgrass (as reflected by a change in density) under and immediately adjacent to overwater structures. We did not quantitatively measure responses in other floral or faunal components associated with the eelgrass. When results of this work indicated that overwater structures negatively impacted eelgrass and that impacts were most likely shade-related, we began a program in 1991 to test whether building floats and docks with gratings could mitigate impacts on eelgrass. Preliminary results of this ongoing work are presented in this paper as well.

MATERIALS AND METHODS

Effects of Overwater Structures on Eelgrass Density

Impacts of overwater structures on eelgrass were assessed by measuring the density of eelgrass under and adjacent to selected structures in Puget Sound (Figure 1). Sites were selected that met the following criteria: 1) eelgrass surrounding the structure was relatively homogenous, 2) bottom topography was relatively uniform (i.e., there were no abrupt changes in bottom contours), and 3) the bottom was relatively unaffected by the presence of the structure. Three sites were studied in 1989 and four in 1990 (Figure 1, Table 1). One of these sites, MP1 (see Table 1 for site codes) was much larger than all other structures, but because it met the site-selection criteria, it was included in this study.

Eelgrass density was measured at each site along two or more depth strata oriented parallel to shore and perpendicular to the structure. Eleven sampling sectors were established along each depth stratum. The middle sector was located directly under the structure, and five sectors ex-

Figure 1. Map of Puget Sound showing the location of the sites used in this study. Numbers on the map refer to the following sites codes (see Table 1 also): 1- RH1 to RH5; 2- FH1; 3- OI1 and OI2; 4- BB1; 5- MP1; and 6- HC1 and HC2.

tended from the structure in opposite directions along the depth strata. The width of each sector was approximately equal to the structure's width. Eelgrass was counted in either $0.25m^2$ or $0.10m^2$ quadrants, and three measurements were made at each combination of depth and distance from the structure. All eelgrass density values have been converted to shoots/m^2.

Effectiveness of Alternative Construction Methods

Selected individuals applying for an HPA (Hydraulic Project Approval) to build a pier, dock or float in a non-herring spawning area were asked to build the structure using a type of grating. Gratings were used to increase light penetration under the structure and were fabricated using a variety of materials (e.g., fiberglass and steel). The amount of grating installed varied among sites depending on structural considerations. Applicants were asked to measure density of eelgrass under and adjacent to the structure prior to construction and for three years post-construction. To date, baseline measurements and at least one year of post-project monitoring have been completed at five sites (Table 1).

Table 1. Characteristics of the overwater structures used in this study. Most of the data presented applies to the portion of the structure over eelgrass. At sites with two sets of measurements, there are two portions of the same structure built over eelgrass. (NA= Not applicable)

Site	Location	Type,Shape[1]	Orient.	Approx. Length (m)	Approx. Width (m)	Mitigation
Impact Evaluation Study Sites						
HC1	South Hood Canal	Pier, L	N-S	13	9.0	NA
HC2	South Hood Canal	Float, L	N-S	24	2.0	NA
MP1	Near Padilla Bay	Pier, L	N-S	396	14.0	NA
RH1	Roche Harbor	Float, T	N-S	38	12.1	NA
RH2	Roche Harbor	Float, I	NW-SE	26	3.0	NA
RH3	Roche Harbor	Pier, I	N-S	18	2.4	NA
RH4	Near Roche Harbor	Float, L	N-S	30	~5.0	NA
Mitigation Study Sites						
FH1	Friday Harbor	Float, L	N-S	14	2.4	Grating
			E-W	13	2.4	Grating
RH5	San Juan Island	Float, I	N-S	24	3.0	Grating
OI1	Orcas Island	Float, I	N-S	15	2.4	Grating
OI2	Orcas Island	Float, T	NW-SE	14	2.4	Grating
BB1	Bellingham Bay	Float, I	E-W	6	2.4	Grating

[1] Shape refers to the general configuration of the structure. For example, a T shape is a straight section that extends from the shoreline with a segment on the end over deep water that is parallel to shore.

Baseline and post-project monitoring at each site were done by a diver/consultant approved by WDFW. The same set of protocols was used at all sites, although some minor adjustments were made to accommodate site-specific conditions. Briefly, protocols generated measurements of eelgrass density in $0.25m^2$ plots along transects that were: 1) directly under the structure, 2) within one structure width to either side, and 3) at an undisturbed reference area that was distant from the structure. Counts were also made at a distance of two structure widths at one site. At least four randomly selected stations were counted along each transect, and three or four counts were made at each station. By contrasting changes in densities in the undisturbed areas with those in the potentially impacted locations, effectiveness of the grating could be assessed. Because of the ongoing nature of the study, we did not subject data to statistical analyses.

RESULTS

Effects of Overwater Structures

At three of seven sites evaluated, eelgrass was not found growing under the structure (Table 2). At three other sites (RH2, RH3, and RH4; see Table 1 for site codes), some eelgrass was found growing under the structure, but densities were greatly reduced compared to areas more distant from the structure (Table 2). At RH3, for example, although there was eelgrass in both depth strata under the structure, mean densities were 9 percent to 13 percent of what was measured more than one structure width away. At MP1, RH1, and RH2, eelgrass density declined immediately adjacent to the structure. The largest difference occurred at MP1, where densities of eelgrass in areas more than one structure width away from the dock were 2.0 to 7.5 times greater than densities in areas one structure width away (Table 2).

Table 2. Mean eelgrass densities (shoots/m^2) and standard deviations (SD) under overwater structures (centerline), within one structure width, and greater than one structure width from the structure. All depths are estimated relative to MLLW and are given in meters. (NM = not measured)

Site/Depth	Width	Under structure		Within 1 structure width		> 1 structure width	
		Mean	SD	Mean	SD	Mean	SD
HC1 - 1.2m	9m	0	0	348.3	41.2	320.8	112.6
- 1.8m	9m	0	0	135.0	69.8	127.5	128.7
HC2 - NM	2m	373.3	47.3	330.0	74.3	317.9	109.1
- NM	2m	313.3	60.3	368.3	65.5	492.9	99.3
MP1 - 1.0m	14m	0	0	5.3	6.8	18.0	11.4
- 1.2m	14m	0	0	25.7	14.7	50.6	14.4
- 1.2m	14m	0	0	10.7	13.1	33.8	11.7
- 1.2m	14m	0	0	12.7	10.9	24.8	11.9
- 1.5m	14m	0	0	2.0	2.5	14.9	9.1
RH1 - 1.1m	2.4m	0	0	7.4	9.6	38.8	25.2
- 1.9m	2.4m	0	0	16.0	24.9	43.7	22.7
RH2 - 3.6m	2.4m	0	0	20.7	23.2	35.2	18.5
- 3.7m	2.4m	6.7	8.8	23.3	20.1	46.0	21.5
RH3 - 2.9m	3.0m	4.0	4.0	44.0	14.3	43.3	19.9
- 3.2m	3.0m	4.0	4.0	18.7	15.5	30.0	23.2
RH4 - 1.6m	6.1m	28.0	21.2	64.0	8.8	56.5	24.4
- 1.7m	6.1m	0	0	76.7	14.8	59.6	17.6

At one site (HC2), there was no measurable effect on eelgrass density (Table 2). We believe this occurred because the structure, in this case a float, was on chains and could move up and down and side-to-side as the tide changed. This appears to have mitigated the structure's effects on eelgrass growing below it.

Effectiveness of Alternative Construction Methods

Under four of the five structures evaluated (FH1, OI2, BB1, and RH5), eelgrass densities declined following construction (Table 3). In undisturbed reference areas associated with two of these sites (FH1 and OI2), eelgrass densities also declined, but decreases measured in reference areas were less than those under the structures. At the other two sites (BB1 and RH5), eelgrass densities in undisturbed areas increased (Table 3). The largest decrease in eelgrass density occurred at BB1, where mean density in the reference area increased 38 percent but declined 83 percent under the structure. At the fifth site (OI1),

eelgrass densities under the structure and in the reference area increased (Table 3). However, the increase in mean density under OI1 was 132 percent compared to a 431 percent increase in the reference area.

At four sites (FH1, OI1, OI2, BB1), there was evidence of a decline in the density of eelgrass growing within one structure width of the float or dock (Table 3). For instance, at OI2, mean density of eelgrass within one structure width declined 23 percent compared to a 6 percent decline in the reference area; under the structure, the decline was 25 percent. At the one site where eelgrass densities were measured more than one structure width away, we could detect no impact on density of eelgrass at this distance (Table 3).

Table 3. Mean eelgrass densities (shoots/m^2) under overwater structures, one structure width from edge of structure, and > 1 structure width. All depths have been pooled. For FH1, data for both sections of the float are presented. (Base= Pre-project densities, PP= Post Project)

Site	Undisturbed		Under structure		1 structure width		>1 struct. width	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
FH1								
Float (E-W)								
Base.	23.6	12.4	9.8	8.6	8.9	9.3	-	-
2 yr PP	18.4	12.9	3.2	5.7	4.1	4.6	-	-
Float (N-S)								
Base.	-	-	9.8	11.7	14.0	9.8	-	-
2 Yr PP	-	-	5.3	6.7	9.8	8.7	-	-
RH5								
Base	8.5	5.8	8.7	6.0	7.5	5.3	7.2	5.3
3 Yr PP	10.9	4.9	3.8	5.4	8.1	5.2	9.9	5.2
OI1								
Base	17.6	10.0	25.0	3.8	20.0	10.5	-	-
1 Yr PP	93.6	6.7	58.0	22.0	60.5	14.1	-	-
OI2								
Base	9.9	7.9	21.8	10.0	23.8	19.5	-	-
1 Yr PP	9.3	6.7	16.4	11.0	18.4	15.8	-	-
BB1								
Base	218.0	76.2	210.3	62.7	211.7	61.5	-	-
1 Yr PP	301.3	140.2	36.3	45.8	213.7	104.7	-	-

DISCUSSION

Results of this study suggest that many structures built over eelgrass beds in Puget Sound negatively impact local eelgrass densities. While impacts on eelgrass associated with most individual structures are not large because of the structures' small size, cumulative losses are more significant. In some areas with large numbers of docks, we speculate that significant amounts of eelgrass have been lost.

We found that the extent of the impact varied among sites, suggesting that site-specific factors have an important influence on eelgrass impacts. At sites where the impact was most severe, eelgrass was eliminated under the structure, and some loss occurred in adjacent areas. Conversely, at several sites some eelgrass was able to persist under the structure. Structure length, height over the bottom, design, and orientation, as well as local environmental conditions (e.g., current patterns) all may play a role in the nature and extent of impact.

Although we did not specifically assess how overwater structures impacted eelgrass, results of this study support the hypothesis that shading is the major reason for the loss. Light is one of the key environmental factors affecting eelgrass distribution and density (Backman and Barilotti, 1976; Bulthuis, 1983; Dennison, 1987). In this study, shade-related impacts were indicated by the significant reductions in

eelgrass density that occurred under six of seven docks and floats we examined. In addition, when grating was used, we found that some eelgrass would grow under the structures. Thus, increasing the amount of light reaching under the dock enabled some eelgrass to grow. In the future, we hope to measure light intensity under structures to better understand how specific features of piers, docks, and floats affect the amount of light reaching under the structures and how this influences eelgrass density.

Other than reducing the amount of light reaching eelgrass, overwater structures may have other types of impacts as well. For example, the presence of pilings appeared to alter sediment distribution and local topography in some areas, creating depressions along piling lines that precluded eelgrass growth. Substrates in the immediate vicinity of pilings may also be modified by calcareous debris from barnacles and mollusks inhabiting hard surfaces of the structure. Some loss of eelgrass may be related to use of the structures. Typically, there is boat usage associated with most overwater structures. Vessels moored along the float or dock create a larger shading footprint and increase eelgrass impacts beyond that associated with the structure itself. Vessels do not have to be moored for very long, perhaps only a number of days, to affect eelgrass (Backman and Barilotti, 1976).

Based upon data collected so far, the gratings we used appear to at least reduce impacts on eelgrass (as opposed to eliminating impacts). At all sites, some eelgrass continued to grow under the structures. However, when compared to undisturbed areas, mean densities were less than what would be expected if there was no impact. We caution that this evaluation of the effectiveness of alternative dock construction methods is part of an ongoing study. Final conclusions about how well these methods mitigate impacts on eelgrass should wait until all work has been completed and statistically analyzed. This is particularly important since there was considerable variability associated with the density data, which may have an important influence on outcomes of statistical analyses.

The effectiveness of gratings varied from site to site. For instance, at the three sites with one year of post-project data, the decline in eelgrass density was much greater at BB1 than the other two sites. This indicates that site-specific factors influence effectiveness of the grating. Clearly, one important factor is the type and amount of grating used; these variables directly influence how much light reaches under the structure. We hope to measure irradiance under structures with gratings so that we can evaluate relationships between eelgrass loss, the amount of light reaching the eelgrass, and method of construction.

Other site-specific differences that may influence the effectiveness of gratings include local environmental conditions and structure design (e.g., dock orientation). For example, the site with the most dramatic change in eelgrass density under the structure was BB1. One factor that may be responsible for the reduced effectiveness of the grating at this site is that the grating trapped eelgrass underneath the structure, thereby reducing light penetration. In the future as our data base expands, we will be better able to assess how site-specific factors influence the effectiveness of mitigation methods.

ACKNOWLEDGMENTS

The assistance of many divers in collecting the data presented in this paper is gratefully acknowledged. In particular, we thank, R. Buckley, D. Doty, C. Landry, B. Bookheim, and J. West for their help. We greatly appreciate the cooperation of the property owners whose structures form the basis of this research.

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PUGET SOUND RESEARCH '95

SESSION 5B

TRANSBOUNDARY ISSUES

Session Chair:

John Armstrong
U.S. Environmental Protection Agency, Region 10

PANEL: TRANSBOUNDARY ISSUES

CHAIR

John Armstrong, U.S. Environmental Protection Agency, Region 10

PANELISTS

Andrea Copping, Washington Sea Grant Program, University of Washington, and Chair of the British Columbia/Washington Marine Science Panel
John H. Glynn, Water Quality Section Supervisor, Washington Department of Ecology
Bob Ferguson, British Columbia Ministry of Environment, Lands & Parks, Environmental Protection
Barry Wenger, Washington Department of Ecology, Nooksack Initiative, Bellingham
Lindsay Jones, Habitat Biologist, British Columbia Ministry of Environment, Lands & Parks
Michael Hawkes, Professor, Department of Botany, University of British Columbia

John Armstrong, U.S. Environmental Protection Agency, Region 10:

We hope you'll find this is a session you're really glad you attended. We're going to do more than talk just about transboundary issues, though. We're going to talk about the status of our general environmental interactions between British Columbia and Washington in the last two and a half years. We'll hear a summary of an independent report on the current conditions and trends in the marine waters shared by Washington and British Columbia. We'll also hear briefly from five panelists, who will address several important areas that will be referred to by our next speaker, as well as some of the other critical environmental issues between Washington and British Columbia.

I thought I'd start with a map to show you just what area we're talking about (see Figure 1). We're talking about Washington and British Columbia's inland marine waters, and for some of you, this might seem kind of basic. But then again, maybe it's important to show a map like this. Almost every other map I've seen so far at this conference ends at the border. I would love to see us talk more in the future about the bigger waters, the shared waters of Washington and British Columbia, rather than only Puget Sound or only the Strait of Georgia.

It's interesting to note that for various reports I'll talk about later, you can tell who published or printed the reports by whether Puget Sound or the Strait of Georgia comes first in the title. These waters, of course, are all connected. Many of us don't think about that. We just work in Puget Sound, or in the Strait of Georgia. But the waters definitely are connected. The resources are traveling back and forth across those political boundaries. Water-quality problems may also be moving back and forth across those boundaries. The Puget Sound Water Quality Management Plan, even though it's quite good, doesn't talk at all about cross-border issues.

I want to start with an overview of what's happened in the last two and a half years. In May of 1992, Governor Gardner of Washington and Premier Harcourt, from British Columbia, signed the B.C.-Washington Environmental Cooperation Agreement. The agreement was inspired by our environmental concerns, by the movement of our waters and resources across our borders, by a desire of both British Columbia and Washington to share information and work together addressing environmental issues, and by a need for government to get involved in some of these complex problems. This cooperative agreement established the B.C.-Washington Environmental Initiative.

The purpose of the B.C.-Washington Environmental Initiative was to promote and coordinate efforts by the state and the province to ensure the protection, preservation, and enhancement of our shared waters. To carry out this environmental initiative, an environmental cooperation council was formed. This council meets about twice a year, alternating between Washington and British Columbia. The meetings are open to the public, although they're not well publicized. The council is establishing subcommittees and task forces,

and it produces an annual report on what the council has done in the past year. Examples of the issues addressed by council task forces are the Nooksack River flooding issue, Abbotsford-Sumas drinking water aquifer and air quality issues.

But the one we're going to talk about today is the Puget Sound/Georgia Basin International Task Force. This task force is made up of representatives of the B.C. Ministry of the Environment, Lands & Parks, Environment Canada, and the Department of Fisheries & Oceans in Canada; and in the U.S., the departments of Ecology, Natural Resources, and Fish & Wildlife, the E.P.A., and the Water Quality Authority. We've recently hired a liaison to work with this task force, Holly Schneider-Ross of the Puget Sound Water Quality Authority. And we're hoping that British Columbia can hire a liaison soon to help this international task force as well.

The Puget Sound and Georgia Basin task force had to decide exactly what issues we should work on between Washington and British Columbia, so the task force and the Environmental Cooperation Council named a marine science panel. If you were here yesterday morning, you saw that the Marine Science Panel, three scientists from Washington and three from British Columbia, received a recognition award from EPA and many of the other agencies involved with the task force. We appreciate their work on these transboundary environmental issues. There were also a lot of scientists who supported their work, but who weren't recognized. It's been a large effort to date, working between British Columbia and Washington.

This Marine Science Panel convened a symposium in Vancouver in January 1994. At that symposium panel members asked scientists from the United States and Canada to collaborate on papers summarizing the issues, concerns, and biological resources on both sides of the border. From that symposium came the Marine Science Panel Report, which gave recommendations to our task force and, ultimately, to the Environmental Cooperation Council, of things that should be addressed to improve and

Figure 1.

maintain environmental conditions between Washington and British Columbia.

So our task force has taken this report from the science panel and come up with what we call a draft action plan. I won't go into details on that draft action plan, but we're in the process of forming work group to address 12 recommendations from this marine science panel—recommendations on things like how to deal with exotic species in our waters, how to work differently with permitted discharges, how to work on reducing habitat loss, and so on. Each of these topics will have a work group that will develop a detailed work plan and describe how these topics should be addressed. From those work plans, we will see actions initiated. Some of those actions will require money that may or may not be available right now, but some of those actions won't require money. After the actions are initiated, we hope to monitor the situation over time to determine whether those were the right actions and whether we have done enough, and to revise those actions if need be.

There have been some recent reports completed on transboundary issues. The first one is the *Review of the Marine Environment and Biota of the Strait of Georgia, Puget Sound, and the Strait of Juan de Fuca.* This came out of the symposium of January 1994. It's a great report. It's in limited supply though; to get one, go to a library or contact the Puget Sound Water Quality Authority or B.C. Environment. The next report is the *Shared Marine Waters of British Columbia and Washington*; this is what I called the Marine Science Panel Report. From the above symposium—a two-day effort in which the panel questioned various scientists as they presented their papers—the Marine Science Panel came up with a 120-page report describing what they felt the environmental issues and conditions of most concern were, and essentially asking the council to move ahead to do something about them.

The next report, *Shared Waters, A Vulnerable Inland Sea,* is a report we produced more for the public. It's a summary of the Marine Science Panel Report, around 25 pages long.

The next report of interest is *Marine Monitoring Programs in the Border Areas.* Our task force felt one of the first things we needed to do was find out what kind of information is being gathered right now in the border areas, so we put together a report that summarizes those monitoring programs. The last report on this list is *Laboratories and Field Stations in the Shared Marine Waters of Washington and British Columbia.* This was a survey we did of all the marine laboratories and field stations in Washington and British Columbia, and I'll be talking about this at another session.

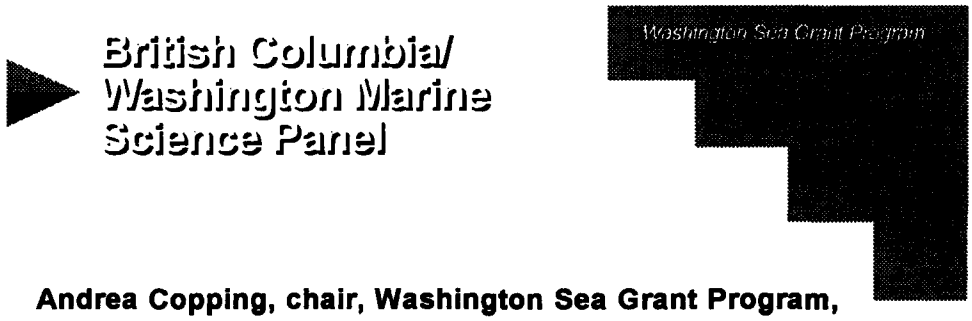
In order to learn more about needed and ongoing monitoring in the inland marine waters, the B.C.-Washington Task Force set out to identify all the monitoring programs dealing with marine organisms or water quality in the border areas, and to get some basic information on those programs. The programs that we ended up including in this report—about 75 programs—addressed the following topics: marine water quality; sediment chemistry; chemical contaminants in fish and wildlife; shellfish poisoning and demoic acid in shellfish; fecal coliform bacteria in clams; near-shore habitat monitoring; bird abundance; marine mammal abundance, sitings and strandings; pulp mill-related ambient monitoring; and salmon aquaculture-related monitoring.

As I said, there were about 75 programs within 30 kilometers of the border, and we included all of these in this report. We provided a contact for each program—name, address, phone—the kind of information they were collecting, the year they began, the frequency of their monitoring, and a map of any sampling stations or areas. So it's a good starting point. If you want to know about a certain resource or water-quality monitoring program in the border areas, this report will tell you who is gathering that type of information and where.

As I mentioned, the Washington-B.C. Environmental Cooperation Agreement led to an Environmental Cooperation Council, which led to the formation of a Marine Science Panel to help us determine the main issues we should be addressing in our shared waters. The next talk will be by Andrea Copping, the chair of that Marine Science Panel. She will go over the results of the Marine Science Panel Report.

Andrea Copping, Washington Sea Grant Program, University of Washington, and Chair of the British Columbia/Washington Marine Science Panel:

Thanks, John. What I'm going to do now is briefly describe the findings of the six-member B.C.-Washington Marine Science Panel. You've seen this map before, and you'll see it several times more—it's the only one we have currently on slide. These are the shared waters. John has described the process by which we got here, and I don't want to go into much detail on that. I'm here representing the six-member Marine Science Panel; my colleagues are listed in Figure 2. We were appointed by the state and province to report about the status of marine resources, to document harm to marine organisms from human activities, and to project the condition of these waters and resources 20 years into the future, as we saw them.



Andrea Copping, chair, Washington Sea Grant Program, University of Washington, Seattle, Wash.

Richard Beamish, Pacific Biological Station, DFO, Nanaimo, B.C.

Curtis Ebbesmeyer, Evans-Hamilton, Inc., Seattle, Wash.

Chris Garrett, Department of Physics, University of Victoria, Victoria, B.C.

Bruce McCain, Northwest Fisheries Science Center, NOAA, Seattle, Wash.

Tom Pederson, Department of Oceanography, UBC, Vancouver, B.C.

Figure 2.

We have built on the work of hundreds of our colleagues. As John Armstrong mentioned, the January symposium in Vancouver took place a year ago today, which I think must be symbolic or something. In addition to that, we had a number of scientists, managers, and non-profit organizations come and give us oral and written briefs, providing more information. We've had the opportunity to consult with many of our colleagues and get into the scientific literature. So although we are the authors of this report, we really can't take much credit for it, other than for the musings.

In order to look at these very large waters and resources, considering the amount of information available, we took what we called a risk-based approach; that is, we felt the ecosystem components that are most at risk ought to get the most management protection. Within that risk-based approach, we thought the most important factor to look at was recovery time: How long does it take a piece of the ecosystem to bounce back to its original condition after a human or other assault is removed? If it takes a very long time to recover, it deserves our greatest protection efforts.

These are the shared marine waters of Washington and British Columbia. I don't want to say too much about them; you know the Strait of Juan de Fuca, the Strait of Georgia, and Puget Sound. We're looking at the waters in these areas. We really haven't dealt with things off the coast at all. This area acts as one large estuary, with fresh water flowing seaward at the surface, marine water coming in at depth—and that's responsible for much of the great productivity. Everyone knows how rich the fish, shellfish, bird and marine mammal populations are, and I think it's no surprise that there's a lot of human impact in the area.

I'd like to give you a quick idea of some of the ways we looked at the problems. For the Strait of Georgia from pre-European settlement times, from a total of 4.4 million acres of near-shore wetland

habitat about 18 percent has been lost. For Puget Sound, the drop is much greater at 58 percent. The total for Puget Sound and the Strait of Georgia is somewhere in between. This is very representative of what we see between Washington and British Columbia, where the losses and the degradation are much greater in Puget Sound than in British Columbia, though British Columbia is coming right along.

I think it's no surprise to anyone that fish populations are in danger in these areas. Everyone knows about the salmon collapses—including about half the runs in Puget Sound. Some of the Strait of Georgia runs—since we wrote this report—have become a concern, with missing salmon. The marine fish in Puget Sound are in somewhat sorry shape. Several of the populations are at quite low levels—hake, or Pacific whiting, for instance. Figure 3 shows that in Washington waters, shown on the map by the solid line, population levels for these species have dropped precipitously, despite the removal of fishing pressure several years ago. As for B.C. stocks—Strait of Georgia catch of hake is continuing to rise, which is a good sign. Lingcod is another story, as you can see in Figure 4; the populations in both British Columbia and Washington have done very poorly and have in effect collapsed, despite the removal of virtually all the recreational fishing pressure.

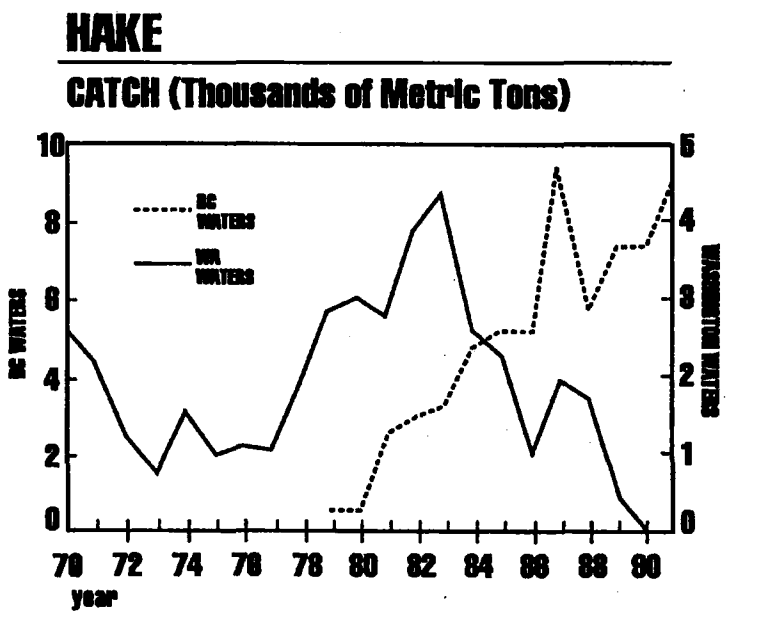


Figure 3.

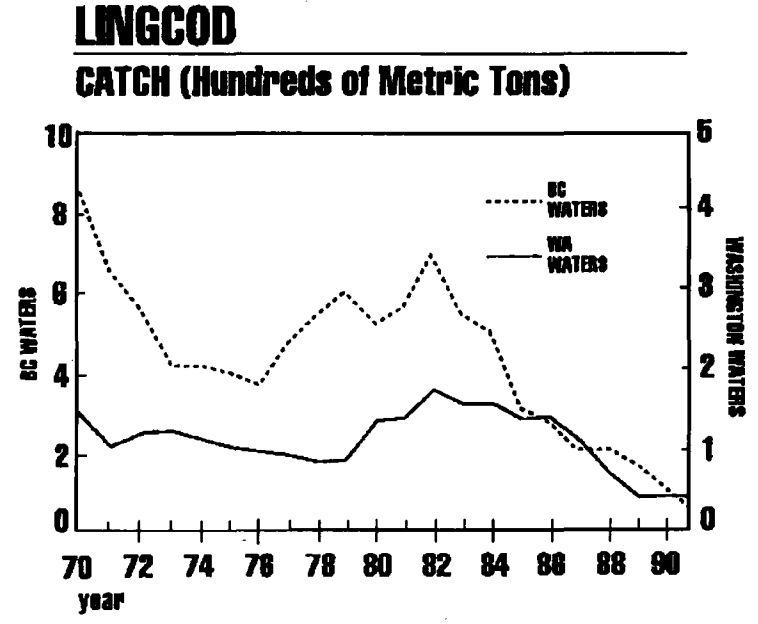


Figure 4.

What the Marine Science Panel did with this tremendous amount of information was divide it into three major ecosystem components or threats: habitat, living resources, and threats to human health. We also looked at three points in time. We asked, what is the status of habitat, living resources and threats to human health? Where do we think we will be in 20 years if we continue with our present land-use, waste disposal, and environmental management practices? Now, we didn't like the answer to that question very well, so we also asked a third question: Where *could* we be in 20 years if we applied all our technological abilities to improving these conditions?

Our results for those three components at those three points in time are as follows: Let's start with aquatic habitats in the present day. We consider vegetated shores in British Columbia to be in good shape, while those in Washington are in very poor shape. Unvegetated shores were rated acceptable, which is a

little less than good, I think. Rivers, we felt, were in better shape in British Columbia than in Washington. The subtidal areas are generally in pretty good shape in both areas, simply because human activities are farther removed from the subtidal areas, and simply don't affect them as greatly.

As for sediments in urban bays—in British Columbia, they are poor, generally speaking, in the few really urbanized bays there are: Vancouver, Victoria, and Esquimault. In Washington, they're in even worse shape—partly, I think, because we have bigger urbanized bays. The water column is generally in very good shape in both areas, mainly because human activities have a fairly limited ability to affect the water column, and of course we do have major programs in place—sewage treatment and so on.

Let's look at where we believe the habitat will be. This is a projection, not a prediction, of where we could be in 20 years time, in what we called our business-as-usual scenario—that's continuing the practices we have today. We felt in British Columbia, vegetated shores would go downhill very rapidly. The anomaly here is Washington shores will only be slightly worse, simply because much of our vegetated shore's already gone—there's not a lot more left to lose. Unvegetated shores and rivers we feel are all going to go downhill significantly. We think the intertidal areas and the water column will remain unchanged and stay in pretty good shape, even with our present practices.

The other anomaly here is, we believe sediments in urban bays will be unchanged in 20 years, even though we are in fact reducing the per capita toxic input to sediments in urban bays now—so things are actually improving at the moment. Unfortunately, the tremendous increase in human population is likely to undo that trend within this 20-year time frame, so we'll end up about where we started.

In what we like to think as our optimum future scenario for aquatic habitats, we feel that if we were to bring all our technological knowledge to bear now, never mind the political reality of whether we can do this in 1995 starting today, we felt that the best we could hope for in most of these habitats would be for them to remain unchanged. We have very little hope of improving the condition they're in now. When we get down to the subtidal areas, we think we can do a little better, just by significantly cleaning up the water column some more. Where sediments are concerned, we think we could do a little better if we managed to keep the contaminants away even more. The water column would remain unchanged.

Moving from the habitats to the living resources, and what we considered to be their present condition: Most salmon in British Columbia we considered acceptable or good, whereas they're very poor in Puget Sound waters. Probably if we had to make a change now (as opposed to when we finalized our report in 1994), we might even want to downgrade this one a little bit, depending on which fisheries biologist you talk to in Canada. Marine fish: Generally in British Columbia they're good, with the exception of the lingcod population, and now there's some indication that some of the rockfish are not doing well, either. They're in poor shape in Puget Sound, as I pointed out to you.

Bottomfish are generally good in British Columbia with one exception: We do see some diseased fish in Vancouver Harbor. They're in considerably poorer shape in Washington. The commercially and recreationally harvested invertebrates are generally in good shape because of the management programs we have in place. There are a few exceptions, such as certain non-game marine invertebrates. There are concerns about these non-traditional fisheries that seem to be gearing up very fast and taking a great deal of the resource off the beaches.

Birds and marine mammals: Some are doing well; some are doing poorly. In other talks at this conference you've heard a good deal about which birds and mammals are doing poorly or well.

Where will the living resources be in 20 years? Generally speaking, we think they're all going to go downhill. The bottomfish in urban bays are the anomaly; they will remain at about the same level, for much the same reason that the sediments in urban bays will stay the same: decreasing per capita contaminant output, increasing number of people.

Where *could* the living resources be in 20 years? We think they could all do better. Obviously, some toxic control is needed. But more important is protecting and rebuilding habitat. We also need to get a lot more serious about our regulations on the harvest of living resources.

Moving to human health. This was not a major focus of our process, though we clearly had to look at it. The bottom line on human health is, the programs we have in place in British Columbia and Washing-

ton generally succeed in protecting human health where seafood-related hazards are concerned. Direct contaminant pathogen exposure—from swimming in it, playing on the beaches and so on—just doesn't happen enough here for it to be a major risk to the population. Safety from toxic algae—PSP, domoic acid, etc.—we treated as separate from seafood safety, simply because toxic algal blooms are not very much under human control, as far as we can tell. In the toxic algae session yesterday, we heard a great deal about that.

Where will we be in 20 years under the "business as usual" scenario? We think that all the safety issues will be slightly worse, simply because of increased population in the basin. There will just be more people putting in more contaminants, and also more people exposed to them.

Where *could* we be? We do think that the safety from direct contaminant and pathogen exposure can stay about the same. It doesn't have to be a major issue in this area; there just isn't enough contact recreation in these waters. Safety from contaminated seafood we can probably improve a little bit with even more stringent programs. The only one we think will continue to get worse is safety from toxic algae, because, as I said, we haven't been able to show that this is generated or facilitated by humans, so we're not sure there's much we can do about that, one way or the other.

That is a summary of our assessment of where things are in the shared waters. From that, we developed some priority issues for the shared waters. In this column, we've listed recovery time, as I mentioned earlier: How long does it take the ecosystem to snap back after an assault or an activity is stopped? We also list the overall priority of environmental issues in the shared waters. In addition to recovery time, we looked at several other criteria. These included: How big a part of the ecosystem does this affect? What is the cost of mitigation or recovery from these kinds of human activities and problems? Is the problem preventable?

I don't think Table 1, our priority issues, will be a surprise after what I've shown you. We considered *habitat loss* to be the highest-priority marine issue in the shared waters. Habitat loss, once you dredge and fill a near-shore area, is virtually an irreversible process. We are learning things about habitat restoration and mitigation, but basically, once you pave it, it's gone. As for fish and shellfish populations: Even though many of them, we think, can recover—and our medium time frame is 10 to 30 years—some will never recover when they're down below a certain level. So we rated this our next highest priority.

Exotic species, or non-indigenous or non-native species. Here's what we thought was the sleeper issue. Some of you are familiar with *Spartina*, the invading cordgrass in Willapa Bay and parts of Puget Sound. We also have an oyster drill that's been an annoyance to oyster growers for years. It's a Japanese import that is very tough on the oysters. We have a few other exotic species that have gained a real foothold here, but we have warning signs from a lot of other places that we're in for a lot worse. There's the zebra mussel in the Great Lakes for instance. We have a European green crab marching its way up from the California coast. This may be the issue that turns ecosystems on their heads in the next few years. We think it's a very real threat.

Fresh water diversions. You heard a little about this from Usha Varanasi yesterday. Most of these are basically long-term or irreversible changes—the dams on the Columbia, various other diversions we've seen. Washington around Puget Sound has diverted most of the water it's likely to; British Columbia is still working on some big projects that could have many large effects. The point here is that it affects not only stream habitat, but also estuarian habitat and can, in fact, affect the actual estuarian flushing mechanism. In San Francisco Bay, so much fresh water has been taken out that the flushing mechanism is only a shadow of its former self.

Toxics and living resources, toxics and sediments. Most of these recover fairly quickly—"short" being three years or so, "medium" being up to about 10 years. Toxics are still a source of concern, however, as non-point source contaminants. We've got many of the point sources under control. But non-point sources, particularly things like hydrocarbons, are continuing to increase in the shared waters.

Table 1.

Washington Sea Grant Program

Priority Issues

Issue	Recovery Time	Overall Priority
Habitat loss	Irreversible	Very high
Fish & shellfish populations	Medium	High
Exotic species	Long/irreversible	High
Freshwater diversions	Long/irreversible	High
Toxics in living resources	Short/medium	Medium
Toxics in sediments	Medium	Medium
Oil spills	Medium	Medium
Toxic algae	Irreversible	Medium
Fecal contamination	Short	Medium
Water column contamination	Short	Low

Toxic algae. Even though we think there is a potential for great problems from it, we didn't give it very high priority, partly because there's very little we seem to be able to do about it. Many episodes are of short duration, but it seems if you get an area seeded with a toxic algae-producer, it may stay for good. This problem tends to be irreversible.

Fecal contamination and water column contamination. We considered these not to be huge ecosystem problems, largely because of the management programs we have in place. All these priorities assume we continue our present management programs—that we don't suddenly decide not to treat our sewage.

Finally, from these priorities, we developed a set of recommendations. When this panel came together, we were committed to writing a short, pithy 40-page report with three recommendations. Well, sadly enough, when we were finished, we had a 120-page report, and there were 12 recommendations. But these things happen.

The first seven recommendations we considered our action recommendations. They are in the order of highest priority to lowest, and again, they flow from the priorities I just mentioned (Figure 5).

The first is simply to *minimize estuarian habitat loss.* We simply have to stop taking away the near-shore wetlands if we want to try to preserve many of these ecosystems, especially in our more urban and developed areas.

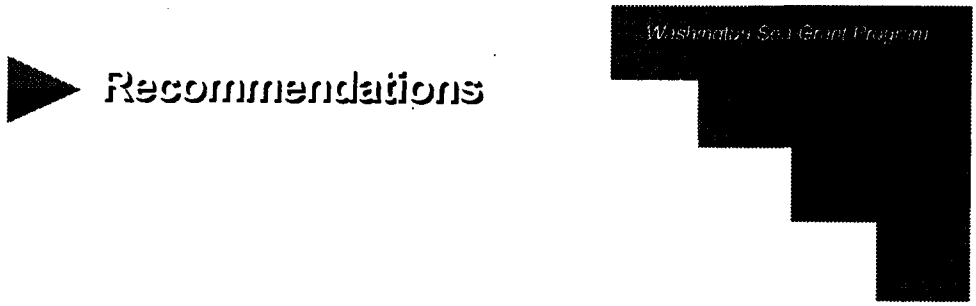


Figure 5.

The second recommendation is related, and that is the *establishment of marine protected areas*—parks, sanctuaries, preserves, whatever you want to call them. It's been shown clearly in several parts of the world that when you have fish and wildlife stocks with serious problems, if you can set aside nursery ground and refuges, those populations have a better chance of recovery than if you simply take off fishing pressure. We're recommending that marine preserves be established on both sides of the border as well as straddling the border.

The third recommendation is fairly obvious: *Protect marine plants and animals.* We don't have a particularly good record here, or elsewhere in the world, of looking seriously at our fisheries and other resources purely for the sake of the resource. We ask what we can take out of them, rather than how we can achieve a truly sustainable resource.

Minimize large fresh water diversions. Again, these projects tend to be few and far between, but they can be devastating to the estuarian system, to productivity, to the animals, to the plants, etc.

Minimize the introduction of exotic species. As I said before, this may be one of the major issues we face in the future. Unfortunately, it's one that's hard to do much about. There are some steps, such as restricting ballast-water dumping from other parts of the world, that can have a major impact in controlling the carriers of certain organisms.

We also believe that a serious public education campaign is important. People need to understand that they can't bring things in, and why. If you've been to Hawaii, you've probably been through one of their agricultural inspections. I don't know whether the inspections catch many agricultural hazards, but they certainly raise consciousness.

Control toxic waste. Clearly, we have to go on working on our point sources, but our non-point sources are a major source of some of the contaminants coming into the Sound, particularly things like hydrocarbons. Clearly, this is related to land use and automobile use. We are recommending, among other things, that people who deal with water and air get very serious about fuel conservation campaigns.

Finally, *preventing large oil spills.* As I said before, preventing these spills is extremely important. We've got to keep oil in the tankers, off the beaches, and not try to clean it up after it's spilled. We've essentially endorsed the work of the States/B.C. Task Force on Oil-Spill Prevention on cost-effective measures for preventing large oil spills.

Our other five recommendations relate to management, and they can be summed up fairly quickly (see Figure 6). We feel it's very important that there be joint *strategic planning* between British Columbia and Washington; this is one watershed, one ecosystem. We also feel it's important that monitoring, research and management activities be done jointly on both sides of the border. It's crazy to be reinventing the

wheel by running separate monitoring programs or doing separate research studies on each side of the border. We need to approach this together.

The second management recommendation is *comprehensive program review*. You can also read that as environmental audit. As an independent group, we felt very strongly that it's important that we take a much harder look at how we spend our management dollars. The example of salmon is what prompted us here: Look at the millions that have gone into management of salmon hatcheries, and yet we still don't have healthy salmon resources. We need to look harder at what we've done, learn lessons from what we've done well, and turn away from the things we've done badly.

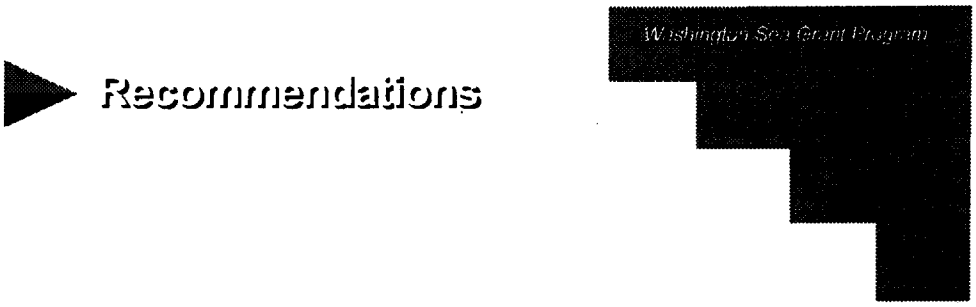


Figure 6.

The last two recommendations deal with better communication. Scientists and managers must communicate more on the same side of the border, as well as across the border. I think meetings like this are a very important step because there is a tremendous mixture of managers, scientists, students, and so on here. I think that's excellent. We need to encourage this more.

The final recommendation has to do with *freedom of scientific discussion*. It has been noted on both sides of the border that scientists working for government agencies do not always have the freedom to discuss their scientific findings, which may be either embarrassing or contrary to agency policy. In order to do really good science, we have to be free of these restraints.

I just want to stress that this is one ecosystem. The dotted line on the map is strictly a human invention. We know that things communicate freely across the border—the fish, the birds, the larvae, the oil spills—and we need to look seriously at dealing with them in that context.

Armstrong: Thank you very much, Andrea—an energetic presentation, as usual. You can see from Andrea's discussion of her panel report that this B.C.-Washington, or Puget Sound-Georgia Basin Task Force, has its work cut out for it in how to bring about action—relatively quick action—in all these areas. I would like to mention, since one of our main goals is sharing information, that if you want copies of any of these reports, you should contact the Puget Sound Water Quality Authority, or B.C. Environment.

Next in this session we're going to talk about a couple of the issues that Andrea mentioned. From her 12 recommendations, we chose three: permitted discharges, estuarian habitat loss, and marine parks and sanctuaries. We've asked someone from British Columbia and Washington to address us briefly on each of those issues, to tell us what programs are in place now and how they see changes coming in the future and to tell us about the level of communication that exists now across the border. Each panelist will approach this a little differently, but we've asked each panelist to speak for six or seven minutes. Then I hope we

can all take advantage of this panel to ask any questions that come to mind. Our first panelist is John Glynn from the Department of Ecology Water Quality Section.

John H. Glynn, Water Quality Section Supervisor, Washington Department of Ecology:

I appreciate the opportunity to speak at this forum. It's been observed many times how important it is for Washington and British Columbia folks to get together and talk about common issues. On the all-too-infrequent occasions when we've been able to work with our B.C. colleagues, I've found it enormously helpful, on both a professional and a personal level. I hope this forum will provide us with an occasion to reestablish our cross-border contacts and expand on them. I think a lot can be gained in doing so.

John asked me to address three questions on the nature of the permit program in the state of Washington. The first one is, how has the awarding of discharge permits evolved in Washington state over the last 20 years or so? It has indeed evolved—the state of Washington first began issuing waste discharge permits in 1955. These were state discharge waste permits, and they were issued only to industries and commercial operations—municipalities were not covered. I think it's fair to say that those permits were fairly superficial and not terribly sophisticated, but at least it was a start in the process.

There's no question that the regulation of point sources in Washington and elsewhere in the country really got its real start in 1972, with a major overhaul of the federal Water Pollution Control Act—now called the Clean Water Act. The act established a number of things, not the least of which was uniform standards throughout the country, and the requiring of waste discharge permits for all discharges to surface water. These waste discharge permits are called "national pollutant discharge elimination system permits." The feds of course had to call these NPDS permits—a truly awkward acronym, but you'll hear it frequently. The issuance of these permits started in the state of Washington in 1973, and we have been issuing them since that time.

Essentially, what the act says is that no one has the right to pollute waters of the United States or the state, and anyone wishing to do so must obtain a permit. Second, it says permits must limit pollutants to be discharged, and violators are subject to fines. It says all permittees must use the best control technology available and must provide any additional levels of treatment necessary to maintain water quality standards and beneficial uses.

The early history of the NPDS program in the state of Washington was an emphasis on technology-based standards; that is, we required municipalities to upgrade to secondary treatment; we required industries to upgrade their treatment levels, based on uniform standards that applied throughout the country. There was some addressing of the impacts of those discharges on water quality, but frankly, during the 1970s the major portion of the effort was to get people up to speed and install minimum levels of treatment. In the 1980s, there was a much greater emphasis in toxicants. Some of you may recall a lawsuit filed by the NRDC against the EPA and the federal government, which established a list of priority pollutants that we all had to address when we permitted discharges.

There was also an increased emphasis on stormwater discharges. Although these had been addressed in the initial act in 1972, they had been largely ignored—largely, I say, because many of us didn't know how to deal with the problem. Many lawsuits insisted that the EPA and the states address it and deal with it head-on. Although we have done so to some extent, we are still not adequately dealing with stormwater issues—it's a very difficult and complex area. In the 1980s, we placed greater emphasis on pre-treatment. This was a process that recognized that many of the toxicants entering municipal sewage treatment plants and discharging into Puget Sound originate from certain industrial sources. It was recognized that the best way to deal with these was to go to those sources and implement pollution control there.

Another issue was combined sewer overflows. Many of the older towns have combined sewers, that is, sewers that contain not only sanitary sewage and industrial waste, but also stormwater. And during storms they overflow, causing pollution problems and sediment contamination. So the state of Washington and the EPA are addressing combined sewer overflows much more intensely than they did before.

Finally, under the aegis of the Puget Sound Water Quality Authority, we started looking much more seriously at sediment quality, and that is a continuing effort.

The most recent developments in administration of NPDS permits involve requiring people to do effluent toxicity testing of their discharges. Through this requirement we're addressing water quality-based ethyl limitations much more seriously, examining human health effects and the quality of municipal sludge. An initiative the state of Washington started several years ago, which is now being incorporated in many other parts of the country, is what is loosely referred to as the watershed approach. This approach calls for looking not at individual point sources as isolated entities, but at all of the point non-point sources in an entire watershed. This allows us to look at cumulative effects. The watershed approach is an extremely powerful tool, and one that I believe will revolutionize the way we regulate point and non-point sources in the future.

Finally, related to the watershed approach are what we refer to as total daily maximum loads, abbreviated as TMDLs. This is an elaboration of the watershed approach, which asks us to look at the cumulative impacts of all sources—point sources and non-point sources—on a receiving water and to determine whether those cumulative effects will violate water quality standards or adversely affect beneficial uses. If so, we may assign TMDLs, allocating to each of those sources a certain amount they may discharge and no more. It's a controversial issue. It's difficult to do because you have to allocate the pie to various sources, and you get into some rather difficult discussions with jurisdictions, municipalities, industries, and agricultural and urban interests. But it's necessary, if we expect to maintain water quality.

Another question that John asked me to deal with is, what are the roles of federal, state and local governments in awarding discharge permits? Roughly, in the state of Washington, the federal government sets the general goals and standards through federal laws and regulations. They delegate to the state of Washington the authority to issue waste discharge permits and the authority to establish water quality standards, subject to the review of the EPA. Finally, to the locals in some jurisdictions mainly we can delegate the administration of pre-treatment programs. We have done so in a number of larger jurisdictions in the Puget Sound area.

John asked me to discuss very briefly what is involved in the evaluation of a proposed waste discharge to a specific body of water, and what scientific information is routinely collected as part of that evaluation. The issuance of waste discharge permits is becoming increasingly complex. The first thing we get involved in is comprehensive and facility planning. We ask the proposed discharger to look at the kind of discharge being proposed, and where the receiving water is, where it will go in, and what effects it will have on the water quality. We also ask them to consider the implications of their discharge on watershed basin and local jurisdiction planning.

We look at the receiving water—its hydrology, the depth current, re-aeration rates, and certain critical minimum flows. We look at the water quality standards and the beneficial uses of those streams, as well as the historical ambient water quality data. We look at the characteristics of the proposed discharge: not just the flow, but the physical, chemical, and bacteriological quality. Increasingly, because of the interest in toxicants, we are asking those responsible for the more complex and larger discharges to analyze the priority pollutant characteristics of their discharge. This entails an analysis of more than 120 chemical constituents, as well as some constituents relating to human health that are not part of that initial priority pollutant list.

We look at other point source and non-point sources in that watershed. We ask for mixing-zone modeling, and perform it ourselves, to determine the existing or ambient conditions and the characteristics of the waste discharge—and what effect those will have on water quality. And finally, we examine the implications of TMDLs, or total maximum daily loads; that is, if we have done a TMDL on a stream, we can tell new dischargers what they are allowed to discharge.

Two further questions John asked me to address were: Upon issuance, what are the monitoring requirements? And are these results reviewed and used? They are indeed; we are required to ask all permittees to monitor for compliance with their effluent limits, and in addition we may ask them to monitor for effluent data and also for process control monitoring. We use this data in a number of ways. We accumulate it and use it when we do inspections of facilities to make sure they're in compliance with their

waste discharge permits. We also have a laboratory accreditation program, which requires all permitted dischargers to demonstrate that their analytical and sampling techniques are adequate and accurate.

What else do we do with this data? We evaluate it monthly as the data comes in, to make sure the dischargers are in compliance with their permits. Furthermore, we are increasingly using a new computer database system that allows us to evaluate the effluent quality on a cumulative basis for permit compliance, for inspection purposes, for the permit renewal, for watershed analysis, and for determining total maximum daily loads. So it's important information, and we're using it now much more than we did in the past.

John's final question: What changes do I expect in the next five to 10 years? Permit dischargers frequently ask us this because obviously they have a financial interest in the answer. They need to know if they have to invest additional money in facilities or monitoring. Yet it's very difficult to answer because the regulatory atmosphere is in a great deal of flux, and I need hardly tell you that's the result of the recent elections in this country. It may become even more in flux. But given that uncertainty, let me try to make a few guesses.

I think there's going to be greater emphasis on human health effects and greater emphasis on sludge quality, primarily from municipal facilities. I think there will be continued refinements in the protocols for sampling and analysis of toxicants and for performing bio-assays. And by refinements I mean not necessarily just reducing the criteria, but in some instances also raising the values. We've observed this recently.

Finally, and equally important, we're going to be revising the state water quality standards, which will affect the quality of water that we require permit holders to discharge. We're considering use-based standards and will probably be implementing those in the next several years.

So, in a quick review, that is the picture of point source waste discharge permits in the state of Washington.

Armstrong: Thank you very much John. I know that was a lot to cover. Maybe one of the questions we get later will lead to more discussion of monitoring, which interests me a lot. But moving on, I'd like to introduce our first British Columbia speaker, and I'd also like to thank the British Columbia folks for coming. Those of you who work for government realize one thing that restricts the flow of information across the border is the difficulty we have traveling across it. On a weekend, we can jump in our car and go, but it's as if you're traveling to Japan when you tell your boss in the U.S. that you want to go to Canada—and vice versa.

Our next speaker is Bob Ferguson, who's with the B.C. Ministry of Environment, Lands & Parks. Bob is responsible for coordinating the development of waste-water discharge criteria and regulations, and also for the development of an electronic information system containing all environmental protection and management documents, such as statutes, technical criteria, codes of practice, and so on.

Bob Ferguson, British Columbia Ministry of Environment, Lands & Parks, Environmental Protection:

Thank you, John. Having heard the previous speaker, I think I can shorten my talk quite a bit. Andrea observed in her presentation that the dotted line that's shown on the map of the Strait of Georgia and Puget Sound is just an imaginary line, and that's quite true. I think in many respects, it's also imaginary to draw a hard line between the two jurisdictions in their approaches to waste-water control.

But there are, of course, some differences. One of the main distinctions is that in Canada, the provinces have the first responsibility for controlling waste discharges. Here in the United States it's the federal government. This is not to say that Environment Canada and the federal government do not get involved; they do have some very strong requirements and legislation themselves. By and large, though, each province has the leading role in authorizing and controlling waste discharges within its jurisdiction. Some of the provinces have chosen to delegate this responsibility upward to the federal government. This happens more often in eastern Canada than it does out west.

The province is the principle agency to authorize waste discharges within British Columbia, except for operations on federal lands and on First-Nation lands. I think to some extent the situation is similar here in

Washington state. The principle legislation in British Columbia for controlling waste is the Waste Management Act. Under that act there is a public notification regulation, which identifies the procedures that must be followed in authorizing waste discharges.

The permits we issue are similar to those in Washington state. These are long-term documents. They don't normally have expiration dates on them, but they're usually reviewed on a fairly regular basis, both to examine the requirements of the permits and to deal with amendments to the permits that may be brought up by waste dischargers. These involve formal applications, which go through a process of publishing, posting, and referrals to a variety of agencies, including the federal government. Environmental groups get involved as well. There's a 30-day response period.

Public meetings and hearings are held to review positions of concern among the parties. The regional waste managers who make the final decisions have to notify the concerned agencies and individuals of their decisions. There is an appeal process regarding these decisions. Appeals are taken to the director of waste management, whose decision is subject to further appeal to the Environmental Appeals Board. The Appeals Board exists to hear these kinds of things, as well as appeals on other authorizations that are granted under the Ministry of Environment in British Columbia, such as for water allocations, fisheries decisions, wildlife decisions, and so on.

Under the Waste Management Act, we deal with not only liquid but also solid and gaseous wastes. We also handle what we call special wastes, the equivalent of what you call hazardous wastes. In many respects, the processes are very similar. We also develop criteria documents for solid, liquid and gaseous waste discharges and for the receiving environment, and we go through a process similar to that in the U.S., involving literature studies, research on impacts, working back from environmental impacts to what controls there ought to be on waste discharges to protect the environment, and so forth. We'll also consult with many stakeholders in developing those criteria documents.

We charge fees for our various waste discharge permits. This practice is becoming popular around the world, but I believe we were one of the first agencies in the world to establish fees for waste discharges. These fees are based, essentially, on the quantity and quality of the waste discharge, so there's an incentive for the waste discharger to keep his discharge to a minimum.

We also issue short-term approvals for smaller discharges that are expected to exist only for a limited period of time. Fifteen months is the maximum amount of time covered by a short-term approval. Usually in those cases, there's very little time to develop the approval, interface with stakeholders and so forth. The regional waste manager usually will process the application, make a decision, and publish the decision. That decision is then subject to appeal, in accordance with the provisions already mentioned.

We have another means of authorizing waste discharges, apart from permits and approvals. This is what we call a waste management plan. This approach is intended only for municipalities or regional governments, and it's only to deal with sewage and refuse disposal. The process calls for the municipality or regional district to pull together a variety of interested parties to develop the plan. The plan can address a broader range of things than permits normally do: It can deal with collection of waste, areas to be sewered, financial aspects, treatment levels, monitoring, methods, reporting, growth potentials, and so forth. We find that this sort of plan gives municipalities better control of land development in their areas. They're not quite so subject to pressure from developers and so forth, because they've got a plan laid down that marks out areas for development, sewering, refuse collection, and so forth, over a long period of time. The process also helps control the infrastructure costs associated with this kind of development.

If our minister of Environment is satisfied that adequate consultation has taken place in the process of developing the waste management plan, he can approve that plan, thus bypassing the money by-law vote that would normally require the assent of owner-electors. Municipalities can simply establish the by-law, get the money, and proceed with the work. Waste management plans are normally followed by detailed operational plans issued by our regional waste managers. These plans address the details of how the plan is actually carried out—the degree of treatment, monitoring and reporting requirements. It can also address closure plans and so on—all the details that normally would not appear in the overall waste management plan.

Of course, the regional waste manager's decision on operational plans is open to appeal under the legislation. The minister's original decision to approve the waste management plan, however, is not subject to appeal.

We also develop regulations to deal with specific waste discharges. We are trying to issue more of these to deal with small discharges that are of a uniform nature. Examples of discharges we are addressing in this way are discharges of site stormwater from the bulk storage of fuel, and emissions from fiber glassing operations, gravel crushing and washing operations, asphalt plants, and so forth—operations that create fairly minor types of discharges that are fairly uniform in their makeup.

We're trying to develop these regulations to help us administer our program. We just do not have enough legs to get around to permitting all these operations. Yet legally, all these operations require permits under our act. We simply can't issue that many permits. There are too many of them. We're hoping that over the next five years, we'll put a lot more of these regulations in place that will reduce the number of permits we issue. The regulations would also reduce our routine workload since we wouldn't have to deal with so many incidental permits. Instead we could devote our attention to operations that have far greater environmental impact.

As far as cross-border consultations go, my colleague from Washington state identified what is going on. I don't really have any more to add to that, other than to say that there simply isn't enough of it. We all know that. The situation can certainly be improved by the sorts of things that Andrea's task force identified. This is something that we really have to concentrate on. There are measurable benefits in doing that, not only on the technical side, but also on the administrative side. We just can't afford not to pursue better communication.

Armstrong: Thank you, Bob. As you point out, we are discharging to the same bigger waters, but the systems we use for controlling those discharges are somewhat different. It would ultimately pay off to discuss things a little more across the border. Another area of concern pointed out by the Marine Science Panel was the loss of our wetlands and estuaries, one of the big problems we hear about every day. We have two folks to address that now. First, from Washington, Barry Wenger, who is with Ecology's Nooksack Initiative Office in Bellingham. Barry is a land-use and shoreline management expert for Ecology, and also a GIS expert for them. He's also worked on marine sanctuaries. I'd like to ask Barry briefly to address wetland loss and estuaries.

Barry Wenger, Washington Department of Ecology, Nooksack Initiative, Bellingham:

Thank you, John. And just to clarify, I'm not a GIS expert, but I'm the GIS lead for the Nooksack team in Bellingham. I rely on the GIS experts to do the technical work so we can do the planning work.

I'm sitting in for Tom Mark, with whom I've worked for years at the Shorelines Program, and it turns out I cleverly concealed my notes for this talk, somewhere in my office, so I'm going a bit extemporaneous here.

Wetlands—estuarian wetlands in particular—have been the subject of a lot of debate in the last 20 years. When you start regulating, you have to understand what you're regulating. But 20 years ago, we weren't aware of the value of eelgrass and of wetlands in general. We're all aware of the explosion of data and studies and education in this area in the last 10 years. Yet it was about 20 years ago that most of the environmental laws in this state were passed—the Shoreline Management Act, the State Environmental Policy Act, and a number of other interrelated environmental laws.

As a result, at the beginning, our regulations were fuzzy. They didn't apply good standards, and they outlined some fairly broad policy to protect the environment—whatever that was. The implication was we could figure out later what the critical parts of that environment were. Fortunately the plans that were written 20 years ago—especially in small cities and towns—have evolved, some a lot slower than others. The regulatory web we have here in Washington state consists of, essentially, some very coarse nets. One net is the federal level, and the Army Corps of Engineers in particular, which deals with wetlands. This works fairly well with large projects. But it's a very coarse net, and a lot of things fall through it.

The next level is the state level, where the main tools are the state Shoreline Management Act and the hydraulic code, under which Fish and Game issues hydraulic project approvals. Both these tools have limitations. They're both of a finer mesh than the federal net, though there are seams and holes here and there. But when joined with the Army Corps and the federal regulations, they tighten up the wetland protection net somewhat.

At the local level in this state, the Planning Enabling Act has existed since the 1950s, with comprehensive plans at the city and county level. The teeth of those plans are in zoning ordinances and, more recently, critical area ordinances. Those tend to be lacking in clarity and accuracy, and they are full of loopholes. So they may cover one thing fairly well, and another not at all.

Add all those up, and you have a tool that for the most part has worked amazingly well, given the amount of resources put into it. But at the same time, it's failed in an awful lot of ways. The concerns Andrea talked about, the wetlands we've lost—all those things have fallen through that regulatory net. A lot of them are little bits, but all those little bits have a powerful cumulative impact. We're seeing the effect of that on our fisheries, our wildlife, and our water quality.

Another aspect of our recent failures is the fact that our regulations are only a tool, and the tool is only as good as the practitioner. Sometimes you get what I call regulatory slippage. That is, on paper your plan looks good. But out in the field there are all these problems. There are problems because people don't know how to use that tool. A lot of people have, in the past, not understood the laws very well or known what their abilities are within those laws. There's also a lack of budget and political will to address these issues. This happens especially at the local level, where elected officials are accountable to their constituents in a very direct way and need to get their direct support. Under these circumstances, it's tempting to bend the rules, especially if the rules are fuzzy.

That's one thing I like about the Shoreline Management Act—it's a real balance of state and local concerns. We tend to keep each other honest. State officials are not subject to the local pressures, from development or other interests. The state officials are not elected by those interests. So they provide a kind of balance, if things get off-track at the local level. Likewise, local government can always bring the state interest down to what happens on the ground at the local level and balance those interests. I believe that has worked fairly well in the last 20 years.

The third problem with our approach has been a lack of coordination and communication among these different levels of government. Sometimes a project comes along, and everyone thinks someone else is taking care of it. Essentially it falls through the cracks. It's like a seam in a number of these nets we were talking about. And that's happened on many occasions.

But given all that, if you look at the collective regulatory net, things are a lot better than they would have been if that net hadn't been there. I can think of many proposals that were just ghastly when they came into the planning office, and they never saw the light of day because they hit that net and got caught. Apartments built out over the beaches, parking lots going into eelgrass beds—things you can't imagine someone could dream of doing. They're out there.

So it's been a good tool. It could be improved in a lot of ways, and that's the trend I see happening now. To put in a plug for the watershed approach: We've only been up in the Nooksack Basin for about six months, kind of tooling up, finding our way through the political process with the local interest groups, etc., I think it's very promising, because we've been able to get a number of our own agency's programs working a lot closer together. The other advantage of the watershed approach is it prompts you to bring in both regulatory and non-regulatory approaches, and you really need both of those to have a sound, comprehensive approach.

Many of the things I've heard about education at this conference are right on target. It's also important to remember that the regulations are only effective if they're enforced, yet there's a dire lack of enforcement at every level. There's just not enough money, and it's extremely time consuming. You just have to pick the big ones and let a lot of the little ones go—more of that regulatory slippage.

With a community-based approach, you have a lot more eyes and ears out there. People take pride in their own community if they understand the values of those resources. The people take responsibility to

protect their resources and to educate their neighbors and their kids. That's the only way I see out of this mess that we've gotten ourselves into over the years. The problems and the solutions have to relate to people's daily lives. The panel that spoke on watershed community approaches a little while ago was right on target. If people don't feel they're getting something for their tax dollars that affects them directly, they're going to ignore the whole thing. The only way we're going to turn this around is by having people understand the problem and participate in the solution.

Armstrong: Thank you very much, Barry. We asked Lindsay Jones from B.C. Ministry of Environment, Lands & Parks, to give us a brief talk about the approach in British Columbia and perhaps some comparisons based on Barry's talk. Lindsay's a habitat biologist who right now is responsible for biodiversity planning and forest ecosystems within Cleaquot Sound. Before that he worked on B.C. coastal wetland assessment and conservation programs, including securement plans. And maybe Lindsay will tell us what securement plans are.

Lindsay Jones, Habitat Biologist, British Columbia Ministry of Environment, Lands & Parks:

Thanks John. What I would like to do very quickly is give you some background on the coastal wetlands of British Columbia, with just a broad brush; talk a bit about the jurisdictional differences that I see; and then maybe get into some specifics on coastal wetland mitigation and loss.

B.C.'s coastline is more than 18,000 miles, or 27,000 km, long, so it's a significant coastline. However, less than 3 percent of that consists of coastal wetlands or low-gradient shorelines. This limited area, of course, is where all the action takes place, from the point of view of wildlife or biodiversity. We're fortunate to have this diversity in British Columbia, and it's highlighted by a number of high-profile species like Roosevelt elk on Vancouver Island; grizzly bears, fortunately for me not on Vancouver Island but on the mainland coast; and killer whales, which particularly congregate in certain estuaries on northern Vancouver Island. And of course, salmon is the big fisheries resource in coastal British Columbia, highlighted by the Fraser River Estuary and the Skeena River Estuary in the north.

However, this steep, mountainous shoreline has concentrated development on the flatlands adjacent to the estuaries and on the estuaries of British Columbia. And European development, as near as I can tell, paralleled that of the Puget Sound area, with original settlement diking, agricultural diking, flood protection diking, pre-empting the marsh area, followed by more intensive development for industry, port facilities, roads, and other structures from there on. Most of this initial wetland loss occurred around the turn of the century.

There are, however, major jurisdictional differences between Washington and British Columbia. The main one is that more than 94 percent of the land of British Columbia is what we call Crown land, or land owned by the B.C. government. This is true within our tidal lands as well, where most of the land below the mean sea level, or the mean high-tide to the low-tide line, belongs to the provincial crown. Near-shore areas and inland seas, such as the area we're talking about today, the actual bed of the ocean, has been determined to be provincial Crown land, as are all the resources associated with that. Federal jurisdiction in intertidal areas is mainly confined to fisheries, shipping, navigation, harbor defense, and international relations among various countries.

Some intertidal marsh areas were granted into private ownership beginning about 1860. After about 1880, however, only the lands above the mean tide level were allowed to pass into private ownership. This, I think, has allowed government a great deal of control over intertidal land since that time. Unfortunately, most of the private intertidal lands that exist are located in the Georgia Strait area and the lower mainland. Local governments play a large role, as well. If you look at any town along the Georgia Basin, or basically any municipality along the coast, you'll find an estuary within those municipal boundaries. While the municipalities don't control land below that mean sea level, they have a great effect on the uplands through the zoning controls and the power to zone these upland areas for uses that may or may not be appropriate to the intertidal areas.

So, in summary, most of the intertidal and near-shore coastal areas are owned by the province. The use of these areas is affected and regulated by at least 15 provincial agencies and 16 federal agencies.

Now a word or two about wetland loss and mitigation. When you strip all these agencies away—and this government jurisdiction—probably the most effective coastal wetland habitat protection tool comes from the Federal Fisheries Act, which specifically prohibits the harmful alteration of fish habitat, regardless of land ownership or tenure. This has evolved into a policy of no net loss of the productive capacity of wetlands. This has been a focus throughout the 1980s. Most of the development and practical application of this policy has focused on the Fraser Estuary near Vancouver. Ratios have been developed when a fish habitat is unavoidably impacted. Replacement habitat is required at a ratio of 1:1 or greater, depending on the type of habitat. Proponents are required to study and fund these compensation projects, as we call them. Monitoring and follow-up are undertaken by the proponent or a government agency.

As far as the future goes, I don't see an increase in our regulatory ability, and I'm particularly concerned about the federal government. Now that we're all playing hockey again, the feds are kind of deep in their own end, and I'm concerned that they're just going to clear the puck up the ice and head out to the bench, given the financial shape the country is apparently in.

Provincially, I think there's some interest in examining growth management legislation as a tool to deal with development on the uplands, particularly on eastern Vancouver Island and the Fraser Valley. I think we still have to see what happens with the aboriginal people in our country, which we call the First Nations. The provincial governments and the federal government have made a commitment to negotiate treaties with these people, and I think the First Nations are going to play an increasingly large role in what happens with wetlands and other natural resources in the province.

When it comes to preventing habitat loss, I think the most effective measure to date is one that was taken in the Fraser Estuary. It's based on an inventory of habitats and a simple zoning of the habitats in red, yellow and green. In this scheme, the critical habitats are represented by red, and they just can't be affected. I think people have learned from compensation or mitigation projects that you can't replace these critical habitats. So I hope we're going to evolve to a point where we identify our critical habitats, and we just say no. Society will have to deal with the private property rights, or whatever is affected, but we can't afford to continue as we have been doing.

But I think the brightest spot is really something that Barry emphasized. I believe it's in the area of the non-regulatory partnerships that have been set up—a number of them in British Columbia. These really offer some hope for the future by dealing directly with land owners and government agencies to improve the long-term security of important lands for wildlife. I may be a bit out of turn, but I think if some of the government agencies were to write a few judicious checks to community and local interest groups, a lot more could be accomplished than is currently being done directly by the agencies themselves.

Armstrong: Thank you very much, Lindsay. The next areas we're going to talk about before we start the panel discussion are marine sanctuaries and preserves. As we lose habitats and some of our fish and wildlife populations go down, more and more we hear people calling for sanctuaries and reserves as a way of taking care of the problem. But how much can sanctuaries and reserves really do? The first speaker to address this issue is from British Columbia. He is Michael Hawkes from the Department of Botany at the University of British Columbia. He has extensive experience in seaweeds of the British Columbia coast, but he's here today to discuss his more recent work focusing on marine protected areas as key components of marine conservation strategies. Some of his recent experience has been in New Zealand, where sanctuaries and reserves appear to be a model for the rest of the world.

Michael Hawkes, Professor, Department of Botany, University of British Columbia:

Thanks very much, John. As John mentioned, seaweeds are my area of research expertise, the primary producers in the system, and that's how I got involved in marine protected areas about eight years ago. Somebody asked me to generate a list of endangered seaweeds. I came up with a short list of candidates. But then I asked myself, what will I do with this short list? Who cares if Whidbeyella, a red seaweed, has

been collected six times, whether there are only four known populations in the Strait of Georgia? And who cares what we are going to do about it? That led me to more of an ecosystem approach, covering all of marine biodiversity—not just the economic species, but also a lot of those things we will never have an adequate data set for and certainly will not be going after individually to set aside protected areas for.

Today I'm wearing my humpback whale tie. This is to remind me to ask you, how many of you have seen humpback whales in the Strait of Georgia? I see three hands going up. How many times have you seen them out there? Once or twice? O.K. Good.

If you went back to the 1850s, at a time when four of my great-great-grandparents actually settled Victoria, before that boundary line even existed, there was a flourishing population of humpbacks in the Strait of Georgia. Through various harvesting efforts, that population was eliminated by 1907. There's been the occasional sighting since then, but the humpback whale population has not reestablished itself.

Andrea mentioned the importance of the long-term time frame. I like to think in long terms, both into the past and into the future. Some of the statistics we've heard about endangered or threatened fisheries make me wonder what's going to be out there for my great-great-grandchildren. I hope some of the things that come out of today's meeting will improve the situation.

In May last year, I went to a week-long conference in Halifax on marine protected areas (MPAs). The main reason for this conference was the crash of the Atlantic cod fishery, as well as other fisheries. Marine protected areas were being looked at as a fisheries management tool. There was a week of presentations by various folks, particularly from Australia, New Zealand, and Florida. Good evidence was presented that MPAs were potentially effective fisheries management tools—not a complete solution to the problem, but part of a conservation strategy.

Of the 12 recommendations Andrea went over with you, the top three all deal with marine protected areas in some way, and she commented on that. What is a marine protected area? There is a World Conservation Union definition. It reads, "any area of intertidal or subtidal terrain, together with its overlying waters and associated flora, fauna, and historical and cultural features, which has been reserved by legislation to manage and protect all or part of the enclosed environment." That's a fairly vague definition. What about some specific examples?

Worldwide, there's a whole range of marine protected areas. At one end of the range you'll find very small pieces of the ocean that are completely protected from all harvesting of organisms. An example is the Leigh Marine Reserve in New Zealand, where I had the opportunity to work for three years. It's 4 square kilometers in extent. At the other end of the range would be the Great Barrier Reef Marine Park, which is the largest marine protected area in the world, covering some 345,000 square kilometers. It works on a zoning system. There are core areas, which have high levels of protection, surrounded by buffer areas and other areas where various activities are allowed. It's patterned after the U.N. Biosphere Reserve model, if any of you are familiar with that.

Why establish marine protected areas? Well, I think some of the comments Andrea made are quite relevant, and I don't want to go into any more detail there. These areas are where you can protect breeding stock or part of the habitat.

I was asked to address four questions about marine protected areas. The first one was, what does it mean to establish a marine protected area? Will the area have the power to protect habitats and organisms, or will additional regulations be required? As Lindsay has pointed out, there is a jurisdictional nightmare out there. Many levels of government, lots of agencies, lots of legislation. Suffice it to say, there isn't legislation that was conceived specifically for the designation of MPA's. There's nothing like the Great Barrier Reef Park Authority and their single act.

However, just because there is no single agency that can effectively designate marine protected areas, doesn't mean agencies can't work together. Certainly these jurisdictional problems have been solved in other areas such as aquaculture.

The second question was, what marine protected areas do we have in the Strait of Georgia and the Strait of Juan de Fuca, at the federal, provincial, and regional level? At the federal level, Parks Canada establishes national marine conservation areas, as they're now called. At the present time, there are no

national marine conservation areas in the straits. Although Parks Canada does have an ongoing interest in part of the southern Strait, nothing has been designated to date. There are no federal MPAs in the area.

I did a quick tally of the existing provincial reserves and parks in the area. There are five ecological reserves in the area with a marine component, and there are 23 Class-A Provincial Parks that have a marine component. These represent about 51 square kilometers, or about 0.7 percent of the area of the Strait of Georgia and the Canadian portion of the Strait of Juan de Fuca. When you look at the level of protection in those existing areas, you see none of them protects all of the organisms within their boundaries. Why is this?

This has to do again with jurisdiction, federal vs. provincial. Any regulations restricting the use of marine resources that are in the water column (i.e., marine mammals and fish) fall to the Department of Fisheries and Oceans, and a separate closure would have to be made for those. Some of these existing areas have varying degrees of DFO closures within them. The most protected of the lot is Race Rocks Ecological Reserve, which is just southwest of Victoria. It's closed to all harvesting except recreational harvesting of salmon and halibut.

At the local level, we have one example in Vancouver Harbor—that's Whytecliff Park in West Vancouver. It's a very tiny area, about half a kilometer. In the summer of 1993, DFO put a complete closure on all harvesting of marine organisms in the area. It was a joint effort of local community groups, some non-government organizations, like the Marine Life Sanctuaries Society of British Columbia, the Vancouver Aquarium, and a number of other organizations, to try to raise public awareness of marine conservation in general and MPAs in particular. The effort amounted to a public educational tool to try to get Whytecliff established as the first fully protected marine protected area in British Columbia. My understanding is it was also the first in Canada, and it remains the only one in the country.

The third question I was asked to address was, for what purposes have marine protected areas been established in these waters? In the case of provincial marine parks, the purpose has been recreational, especially recreational boating. That has been changing in the last few years to emphasize conservation of marine biodiversity. The ecological reserves have been established for ecosystem conservation, as well as species protection, and research and education are a component of ecological reserves establishment, as well.

The last question I was asked to address was, are scientific data collected as part of these MPA programs? The answer to that is, in general, no, unless somebody has happened to pick a particular marine protected area as the site for a study on a specific marine organism. There are a few examples, but in general there's no monitoring of those areas that I'm aware of. There may be people in the audience who can correct me on that.

Last, I'd like to mention some current Marine Protected Areas initiatives in British Columbia. There's a tendency to give up hope because of these jurisdictional complexities that have been mentioned, but I don't believe we should give up hope. If there's a will, we can find a way to do it. Just take a look at what's going on the East Coast. I came back from the meeting in Halifax feeling very positive about the situation in British Columbia because we have options open to us. We haven't closed off those options yet.

British Columbia has a protected area strategy that commits the province to designating and managing both a terrestrial and marine system of protected areas consisting of 12 percent of the province by the year 2000. The terrestrial component has been moving ahead very well through a detailed process of identifying ecosystems, identifying fine-filter elements in the ecosystem, and making sure we have a representative system.

For the marine environment, work has also begun. There's a Provincial-Federal Marine Protected Areas working group. There's also a project between B.C. Parks and Environment Canada to develop an ecological classification scheme for the marine waters out as far as the 200-mile limit. This is an essential first step for making sure we have a representative system of Marine Protected Areas. There are a number of other initiatives both in non-government organizations and within government. There may be folks in the audience who can comment on this. I'll leave further discussion for the question session.

Armstrong: Barry Wenger has worked in the past with the Marine Sanctuaries Program in Washington. In just one or two minutes, Barry, is there a big program in Washington for establishing marine sanctuaries, and do we have a lot of them out there?

Wenger: There is not. But when you come right down to it, what does it mean to establish a marine protected area? I think it would mean that we finally came to our collective senses. Because we definitely need a strong marine sanctuaries program, as far as I'm concerned.

The structure of all the various agencies—federal, state and local—is badly fragmented. Most of the agencies are focused on the land issues or on critical marine issues such as contaminated sediments in the urban bays, which tend to be in the lower Puget Sound area. The area we're speaking of, essentially, is the Fraser River Estuary as it comes into the United States through the San Juan Islands and connects with the Strait of Juan de Fuca. It is a world-class estuary, which is surrounded by increasingly urbanized area.

When you go out in the Strait, you just can't find that imaginary line we talked about earlier. You look around and you can see Victoria, Vancouver, Bellingham, down I-5, down to Seattle, then over toward the Olympic Peninsula and Port Angeles. It's especially dramatic to fly over the area at night, because you can see the lights, and everything shows up a lot clearer. The area is surrounded, and the population is going to be doubling in very short order. All those people are recreational users; they all use their boats to come down to the San Juans. It's well documented that the resources have been hard hit and that bird populations on a lot of the smaller rocks are suffering.

Yet all we have to protect that area is little bits and pieces of the various programs. There's the U.S. Fish and Wildlife refuge island out there. The State Parks has some underwater park areas. There are protected areas under the Department of Natural Resources. They in fact have a mechanism to set aside some small preserves, but to my knowledge it hasn't been implemented anywhere. There are some county underwater parks.

The University of Washington Friday Harbor Lab has a few research reserves on Shaw Island and Point Caution outside Friday Harbor. There are some things being done by port authorities in various parts of the Sound, mostly through mitigation measures, to establish small reserves. And there are non-profit organizations, such as The Nature Conservancy, that own a number of little islands up in the San Juans and the intertidal and subtidal areas. And of course, there are some land trusts.

But all those are fairly uncoordinated and don't communicate very well with each other. That's what I find to be the biggest problem, and it's one that could be solved by having a regional forum in the form of a marine protected area program. The one that's currently being studied is the National Marine Sanctuary Program, and the study area is essentially the entire Georgia Strait through the San Juans and out through the Strait of Juan de Fuca. It's called the Northwest Straits Marine Sanctuary Proposal. Of course, the problem is, there are seven counties and numerous cities involved. All of them prefer to concentrate on the land area, but then don't want to give up any jurisdiction in the water. So there are a lot of turf battles, and no one wants the federal government to tell them what to do.

Getting down to basics, I believe the word *sanctuary* is a major problem in itself. By calling it sanctuary, we tell everyone in the San Juans they're going to have to leave all the water alone, e.g., They can't go fishing or boating anymore. Rather, we should call it a marine management area or marine protected area. I think marine management area suggests the proper use of the area, which is that it can be used for recreation, etc. You may establish preserves or nursery stock areas for rockfish, etc.; and use education and research, combined with some existing regulatory handle, which we have, which we don't use—especially in that area; to have the effect of a comprehensive program to protect the marine resources.

Armstrong: As you can see, we've got some real technical issues. We've got some programs that are just getting under way but that seem to make a lot of sense. Now we invite you to ask questions, either of Andrea about the panel report, or of any of these panel members about programs they have and how they might differ between the countries.

Q: What are the bright spots in the Northwest Straits Marine Sanctuary Program, especially as it relates to Island County?

Wenger: It's really difficult for local government to talk to state government, because of the inequality in their legal positions. It's difficult for state government to talk to the federal government, for the same reasons. So on issues such as those that were addressed in the Olympic Coast Marine Sanctuary traditionally there's not been very good communication.

The bright spot about the National Marine Sanctuary Program is that the federal program brings to the table federal agencies to sit next to state agencies, tribal agencies, and local government. Local government then actually has, as well as state government, much more equitable access in discussing issues that may affect their marine waters. There's a great potential there. What's more, because it's a National Marine Sanctuary, it can relate to the Canadian government more on an equal basis than when you have a state government trying to deal with the federal government of Canada.

Another bright spot I see is that there's a little bit of federal funding there that can act as seed money for a program that would, to my mind, have to be regionally driven. In other words, the interests—the local government, counties, the ports, the tribes, state agencies—would all be able to sit at a table and steer the direction of that sanctuary, backed up by some federal funding and essentially federal authority.

Q: Many of our salmon populations seem to be in serious decline. Why isn't that brought up? Why isn't there a moratorium, a long-term moratorium, on killing the fish so that they can get back to that again?

Copping: Maybe I can address that in my semi-ignorance, but among the issues we looked at in the Marine Science Panel process, clearly our fisheries are being affected for a number of reasons. Some of those reasons are human-caused, and some of them arise from the natural environment. Typically, cycles in the open ocean that affect productivity or the carrying capacity of fish out in the open ocean, have changed cyclically over time repeatedly in the past, and no doubt they will continue to do so. For some of the fish, we're at a low level of productivity in ocean conditions right now. We can't do anything about that. The salmon runs and the other fish runs, have survived this cycling in the past, and they will again.

The places where we can do something about declining populations are where we are adding insults—through habitat degradation and loss and through fishing, particularly where you're stopping stocks from getting back in sufficient numbers to reproduce. There are things we have some control over; the open ocean conditions are not part of them. Whether the fish are caught in the open ocean or at terminal fisheries, there has to be a balance to try to keep a sustainable population. But if those fish do not have habitat to go back to—if they are, in fact, as we heard yesterday, being affected by contaminants as juveniles—that is like compromising the immune system of a whole population. They then go out to a poorer than usual ocean, and they don't have the same reserves to make it back and support a healthy population. Let me add the caveat here that I'm not a fisheries biologist.

Q: I'm in the forestry industry, and the scenario I see is we have a spotted owl, and it's supposedly on the Endangered Species List. If we were to go out and hunt the spotted owl, we would reduce its population. In the case of salmon you would think that they would say, you really can't go out and hunt that salmon. Seems logical.

Wenger: I think all the different catch factors are part of the equation, and all have to be looked at. But as far as the private property vs. public resource issue, in the marine fisheries, all the subtidal bottom land is a public resource. It's not owned by private individuals. So as far as rockfish, baitfish, herring, stuff like that, we're dealing with public resource there. When you get to the larger rivers, larger streams, those are also a public resource, not privately owned—you don't own that water body going by your house there. When you get to the edge of those, which is where a lot of the habitat is, then we're getting into kind of an interesting interplay between a public resource and a private property issue. Twenty years ago, when the people of this state put forth the initiative for the Shorelands Management Act, they said back then: These are critical areas for long-term productivity; we need to protect this public edge here and put into

effect the standards, rules and regulations. That is always a careful balancing act, between a private property right and a public resource or a public interest. I think there must be careful review along that edge. I think as we learn more and more about these systems, we're going to have to address that issue of equitable compensation, or, if there's restriction or limitation of private property rights, how to make that balance out. Some of that could be through acquisition or easements that are bought by the government. But a balance must be sought.

Q: I have a question for Mr. Hawkes. You mentioned the protected area strategy that's started to be implemented in British Columbia. How far along are they in the classification system, and is there some kind of international forum developing between British Columbia and Washington?

Hawkes: I'll start with the first one—that's easier. The marine mapping for the protected areas strategy is progressing quite well. I was at a meeting in Victoria about a month ago where some preliminary results were presented. They have some data in a GIS system, they have some preliminary maps, and they are just trying to fine-tune what criteria they were going to use for the system. So they're well under way with that, and we hope to have something within the next six months.

As far as your second question goes, I don't see any reason why you couldn't start a task force for marine protected areas like the one that was created for the Marine Science Panel or for any of these other issues. I'm a naive biologist, though, so I'll pretend I don't know anything about the politics.

Q: The discharges, as we all know, can be very serious if they're not monitored. How can we in the United States leave monitoring up to the dischargers, with the volume that they're discharging under their permit? And in British Columbia, how can the B.C. government continue to pour raw effluent into the Strait, and—with what I've read and understood over the last few years—claim that it's not affecting the water at all? And has the science committee under Andrea looked at that problem?

Glynn: I'll repeat the part of the question that I believe applies to me, which is, how do we regulate wastewater discharges when we rely upon the dischargers to do the monitoring, measuring of flow, and so on. It's a very troublesome question, which was raised at the very beginning of the regulatory process and passage of the law. As a practical matter, we don't have enough people to go out there and regulate and individually monitor, sample, and analyze what the dischargers put out. We do have to rely on self-monitoring. But there are some safeguards. When you ask a discharger to monitor and report his results to us, he is required to certify that what he's submitting to us is true and accurate, and not a misrepresentation. If he does submit an intentional misrepresentation, he's subject to fines or jail time. And that has happened in the past.

More important, however, is reviewing the monitoring reports that come in to us. We ask dischargers to submit a lot of data, and there are ways of checking whether their reports are internally consistent. We do that routinely. Second, as I mentioned we have a laboratory accreditation program, which requires each of the permittees either to have their laboratories accredited to ensure that they meet the proper standards, or to use a contract laboratory that does. Coincidentally, I just went through a batch of those results this morning.

Maybe the most effective way of checking on the accuracy and precision of self-monitoring is inspections. An experienced and savvy inspector, when he or she goes out and looks at the discharger, can look at the quality of the discharge, and see if it jives with the reports the permittee has been submitting to us. The inspector can also perform sampling and analysis to find out whether the discharge is consistent with the reports the permittee has been submitting to us. All of these efforts are an important part of verifying the accuracy of self-monitoring. In addition, we do our own sampling occasionally, but a very small percentage of the time, simply because of cost. Is this a failsafe system that assures everybody reports to us accurately? No, it isn't. But I think it's a pretty good system, and we do catch people if they are not reporting accurately.

Armstrong: Bob, would you address the second part of the question on Victoria discharge?

Ferguson: Well, I should say right off the top, our policy in British Columbia is to treat sewage discharges. It's not a question of whether the sewage will be treated; it's a matter of when is it going to be done. Right now, work is being done to identify sites for the treatment facilities. I understand the federal government is expected to provide funding assistance, so treatment will be put into place. It's just a question of time.

Armstrong: I assume Andrea might want to comment for the panel?

Copping: Perhaps not—but sure. I would have been awfully disappointed if Victoria hadn't come up, of course. This was an issue when the Marine Science Panel was first formed: Should we be looking at Victoria? Should we not be looking at Victoria? And the answer is, Victoria is a piece of the puzzle. However, I have to say that we did not look at a great deal of very detailed data for Victoria. In some cases, for the toxics data, it's not readily available, if at all. But what we did look at was nutrients coming out of Victoria, and biological oxygen demands from the breakdown of the organics from the pipe. Based on the location of the Victoria discharges—the ones into the Straits that are not treated at this point—the physical oceanography, the current movement, and so on, the amount of loading that goes in, we could not see any discernible effect of nutrients or biological oxygen demand loading into that body of water. We did not look, specifically, at pathogen reports, because we did not readily find them. So we can't say there might not be some esoteric pathogen that could miraculously survive in seawater and have an impact. Contact recreation—again, not much of an issue. Shellfish beds in that area, and for a good distance around, are closed to harvesting—that being the major concern, the filtering of pathogens. Toxic contaminants coming out of Victoria—what we could discern, without looking at much data, is there are very low toxic concentrations in that effluent, mainly because there's not a great deal of heavy industry putting out organics and metals there. From our perspective, the biggest problems with the Victoria raw sewage is probably a perceptual or aesthetic one. But we did not look sufficiently at the data to be able to say there is no risk.

Armstrong: I hope you agree that with the Environmental Cooperation Agreement that was signed two years ago, this Environmental Cooperation Council and our Puget Sound-Georgia Basin Task Force, there's a lot of work under way. Development of the work plans to address these 12 issues, including the three we've just heard about, will start in the next month or so. I hope by the next conference we have like this, we'll be an awful lot further along. Thank you for your interest.

* * *

PUGET SOUND RESEARCH '95

SESSION 5C

STUDENT SESSION

Session Chair:

Sheri Tonn

Puget Sound Water Quality Authority

OTOLITH INCREMENT ANALYSIS AND THE POTENTIAL FOR EXPLAINING RECRUITMENT VARIABILITY IN PACIFIC HAKE *(Merluccius productus)* FROM DABOB, PUGET SOUND, WASHINGTON

Dewayne Fox[1]

ABSTRACT

In recent years, there has been an increase in the amount of research devoted to understanding the mechanisms controlling recruitment, the process by which young fish are added to adult or fished stocks. Since the early 1970s the use of otolith increment analysis has added a much-needed tool in our search for the underlying mechanisms controlling recruitment. Daily increment deposition rates have been validated for many marine fishes. This daily periodicity has allowed researchers to calculate birth dates of individual fish with greater accuracy and precision than previously possible with other techniques. In addition, timing of first increment formation is important when generating birth date distributions of fish. Laboratory experiments were conducted to determine increment periodicity and timing of first increment formation in Pacific hake *(Merluccius productus)*. Preliminary results suggest that increment formation is daily at 12° C and that timing of the first increment formation occurs four to five days post hatch at 12° C.

The Pacific hake is common throughout Puget Sound and the western coast of North America. Currently, the coastal stocks of Pacific hake support large fisheries, while the major Puget Sound stocks are so low that there is no commercial harvest. Overfishing and recruitment failure have been some of the reasons proposed for this decrease in the local Puget Sound stocks. In an attempt to understand the processes affecting recruitment success of Pacific hake, samples of juvenile hake were collected during the early summers of 1990 and 1991. Birth date distributions generated from these fish will be compared to spawning cycles to show period of differential survival during early life history stages. This data can then be used to increase our understanding of the factors controlling recruitment and population dynamics of Pacific hake within Puget Sound.

[1] University of Washington, Fisheries Research Institute, School of Fisheries, WH-10, Seattle, WA 98195

MOLECULAR PROBES FOR DETECTION OF NON-CULTURABLE MARINE PATHOGENS

Jennifer Dyer[1]

ABSTRACT

In some Washington state beaches populations of the Pacific razor clam, *Siliqua patula*, crashed in 1983 and again in 1985. An obligate intranuclear bacterial pathogen called "NIX" was discovered in clams, and thought to be the cause of mortality. Initial studies of NIX suggested this agent was a bacterium. Because the microorganism is not culturable, preliminary identification of NIX was based primarily on electron micrographs. Recently, a partial rRNA sequence analysis of NIX confirmed that it is a bacterium. NIX is a member of a large and diverse group called gamma proteobacteria. The closest relative to NIX, according to our database, is *Pseudomonas aeruginosa*.

Molecular probes based on rRNA sequences have been developed. We have designed two oligonucleotide sequences (65D and 841D), which serve as primers in polymerase chain reactions (PCR) to selectively amplify NIX rDNA sequences. The PCR product is verified by an additional oligonucleotide probe (463D) which hybridizes specifically to the 463-486 region of the NIX rDNA. Thus we have a PCR screening procedure which potentially could detect the presence of as few as 10-15 copies of NIX genomic DNA.

Probe 463D was used for *in situ* hybridization tests. Slides of clam tissues prepared from paraffin blocks were tested. It seems that only nuclei of NIX-infected cells were positive. This investigation is still in progress. Applying molecular tools for screening miocrobial species of interest has potentially very broad applications in fisheries disease management and in environmental studies. The NIX research reported here is a model for other potential applications of molecular probes and nucleic acid sequence analysis.

[1] Pacific Lutheran University, Department of Biology, Tacoma, WA 98447

HEAVY METAL DISTRIBUTION IN THE INTERTIDAL SEDIMENTS OF McALLISTER CREEK, THURSTON COUNTY, WASHINGTON

Kurt Johnson and Seth Stroup[1]

INTRODUCTION

Because of their toxic potential, considerable research has focused on the concentration of heavy metals in the environment and the physical processes that contribute to their mobility. In our research we intended to delineate the variability of heavy metals in the sediments of one of the most productive waterways of the Puget Sound area, McAllister Creek. In doing so we hoped to provide insight into the factors that might contribute to this variability.

Site Description

McAllister Creek issues from a spring 5 miles south of the Nisqually Delta in Washington state. The headwaters of the creek are lined by an alder forest with a surface soil of reddish-brown muck. Farther down its course, McAllister Creek cuts through land mainly vegetated by sedges and rushes where the surface soil is mottled silt loam. In the tideland, the creek winds through an estuarine delta typified by salt-tolerant grasses with a surface soil of olive-gray fine sandy loam, formed from alluvium (Pringle, 1990). Along much of its length, McAllister Creek is affected by tidal movements.

METHODS

Sediment samples were collected approximately every 100 meters along the length of McAllister Creek. They were taken from the bank of the creek at a depth of 8-15 centimeters below the water line. In addition, a sediment corer was used periodically to extract samples from depths greater than 15 centimeters to determine variation with depth. A total of 74 samples were gathered with plastic tools and stored in plastic bags until analysis.

The metals were extracted from the sediments by using a nitric acid digestion procedure (Appendix A). The samples were then analyzed using Inductively Coupled Plasma Atomic Emission Spectroscopy (ICPAES). The wavelength scanned for each metal is given in Table I. A 10 ppm Pb, Cu, Zn, Ni, and As standard was used for calibration.

Table 1. Selected wavelengths for ICPAES analysis

Element	As	Cd	Cu	Ni	Pb	Zn
Wavelength (nm)	189	214.4	327.3	231.6	220.3	213.8

DATA

Error

Because of the scope of our research we were concerned mainly with relative concentrations. For this reason, it was assumed that much of the error present from sample to sample remained constant. Making this assumption allowed us to run single analyses of many sample sites, as opposed to running multiple analyses on far fewer locations. However, there were two main sources of quantifiable error that should be addressed. The first occurred during the metal extraction procedure. To estimate the variance incurred as a result of the nitric acid digestion method, we digested and analyzed one sample three times. The resultant standard deviations, shown in Table II, were used to gauge the precision of the procedure.

[1] The Evergreen State College, Olympia, WA 98505

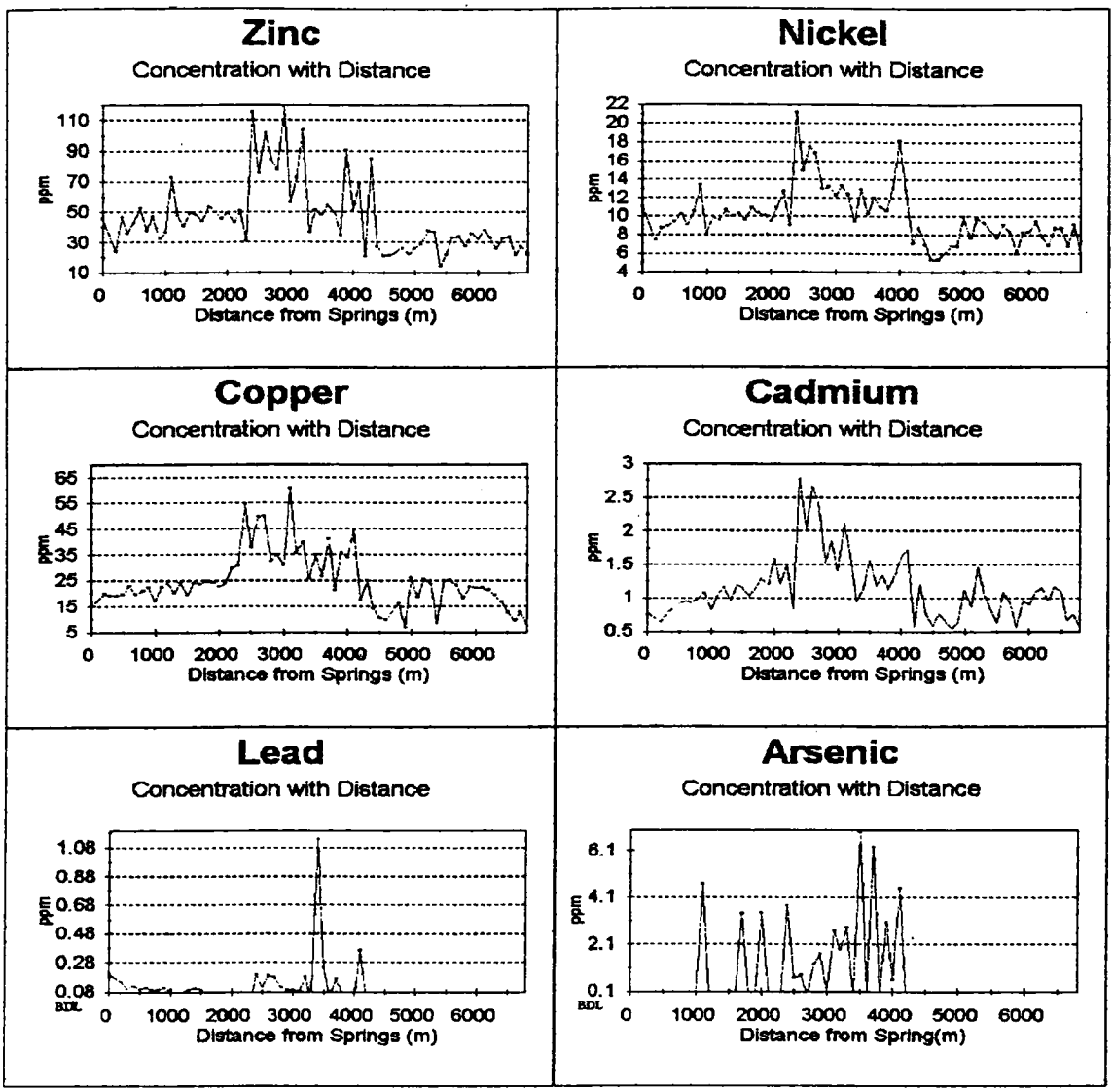


Figure 1. Zn, Ni, Cd, Cu, Pb, and As in the sediments of McAllister Creek

The data shown by Table II indicates that the nitric acid digestion used produces a relatively high standard deviation. For example, if an extraction yielded a 100 ppm concentration of Zn, the standard deviation would be roughly +/- 10 ppm. Although a standard deviation of this magnitude is usually unacceptable, the total variance in metal concentration over the length of the creek is a magnitude larger than these standard deviations. Therefore, since we are concerned mainly with the trends in concentration, the error introduced by the digestion method has only a minimal effect on the results. A second area where error was introduced was the ICPAES analysis. This error is rendered insignificant when compared to the method error because it occurred mainly in the ppb range.

Although the objective of this study was to evaluate not the absolute concentrations of the metals, but rather the change in relative concentration, Table III indicates that the absolute concentrations measured in McAllister Creek were within the range estimated as background by previous research (Furgusson, 1990; Moore and Ramamoorthy, 1984). This implies that the sediment analysis produced reasonable results.

Table 2. Error in digestion method

	As	Cd	Cu	Ni	Pb	Zn
Trial A (ppm)	BDL	0.83	17	8.4	BDL	37
Trial B (ppm)	BDL	0.97	19	8.7	BDL	43
Trial C (ppm)	BDL	0.76	16	7.0	BDL	35
SD	NA	0.09	1.2	0.74	NA	3.4
SD's % of mean	NA	10%	7.0%	9.2%	NA	8.8%

Table 3. Concentration at McAllister Creek

Element	at McAllister Creek	Estimated Background in the United States
As	<0.7-6.9ppm	~8ppm (Furgusson, 1990)
Cu	7-61ppm	3-76ppm (Moore and Ramamoorthy, 1984)
Cd	.6-2.7ppm	0.1-1ppm (Furgusson, 1990)
Ni	1-21ppm	0.6-58ppm (Moore and Ramamoorthy, 1984)
Pb	0.1-1.1ppm	<10-70ppm (Furgusson, 1990)
Zn	14-119ppm	13-155ppm (Furgusson, 1990)

DISCUSSION

As Figure 1 illustrates, the metals showed remarkable trends in concentration over the length of the creek. These trends were not as apparent in the distribution of arsenic and lead; the concentration of these metals were consistently below detection limits. However, every metal, including arsenic and lead, was found to reach a peak concentration between 2,200 and 3,400 meters from the source of the creek.

Figure 2a shows the correlation between the distributions of Zn, Cu, Cd, and Ni. These metals occurred in relatively steady concentrations from the springs to a distance of 2,200 meters. At 2,200 meters from McAllister springs the metals sharply increase in concentration and maintain peak levels for the next 1,100 meters. Then, at 3,400 meters, there is a general decrease in the metal concentration to the initial background level, or slightly below. To show the trends more clearly, the data was smoothed using a moving average with a period of 4. The result is shown in Figure 2b.

In order to offer an explanation for this trend in metal distribution we located a comparable assay. Muller and Forstner (1975) reported metal distributions similar to those shown in this report. Specifically, they assessed the distribution of Pb and Cd in the Elbe River and estuary. Muller and Forstner concluded that where fresh water and salt water mix at a 1:1 ratio, the underlying sediments obtain maximum metal concentrations for the Elbe River and estuary. Muller and Forstner suggested that when fresh water and salt water mix, flocculation of clay particles occurs, precipitates drop out, and new ion-complexes are formed. The overall result can be a region where heavy metals are concentrated in the sediment.

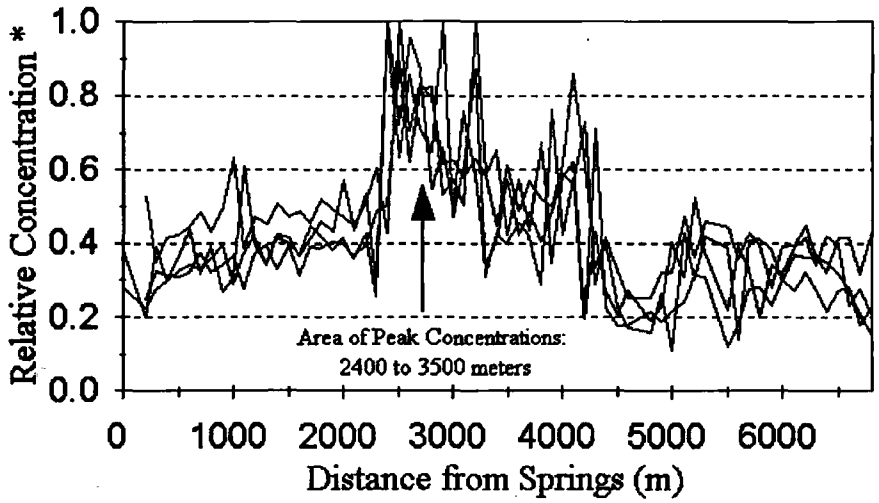


Figure 2a. Comparison of relative concentrations of Zn, Cu, Ni, Cd

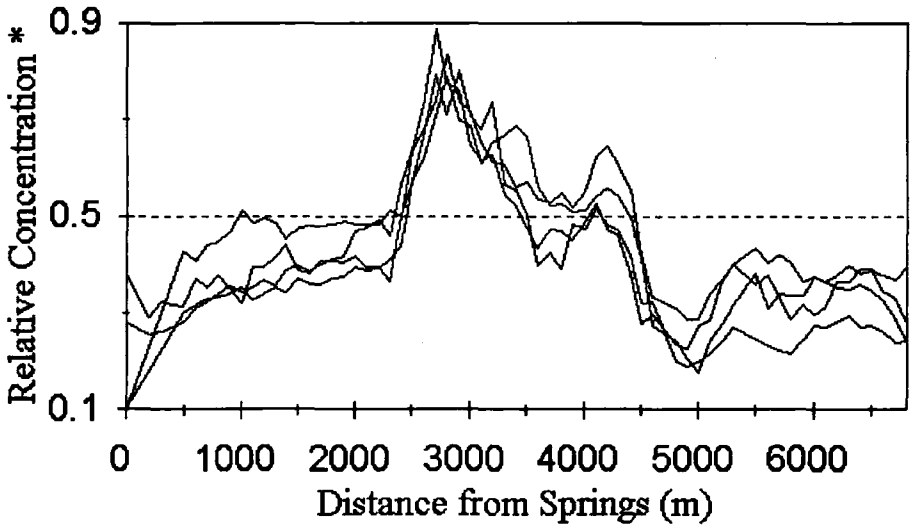


Figure 2b. Comparison of Relative Concentrations, moving averages of Zn, Cu, Ni, Cd

This model seems to be a plausible explanation for the pattern of metal distribution found at McAllister Creek for two reasons. First, the water of the Puget Sound does travel at least half way up McAllister Creek during high tide. This conclusion is based on the observation of the vegetation on the bottom of the creek being bent upstream, while the top layer of water was moving steadily downstream. During high tide the incoming saline water probably terminates in a long, dense salt-wedge at the bottom of the creek. Second, the creek is mostly spring-fed and is chemically very different from the water of the Puget Sound. When these two sources mix, a new equilibrium must be reached. This process may enrich the underlying clays with heavy metals.

Additional work would be required to define the specific chemical processes which contribute to the metal enrichment; this was beyond the scope of this study. Further attention must also be paid to the sediments. The distribution of the heavy metals is undoubtedly affected by the sediment types listed in the introduction. These sediments were extremely variable in their clay fraction, clay mineral content, shrink/swell potential, and organic content.

CONCLUSION

1) This study determined that the concentrations of zinc, copper, nickel, and cadmium showed similar trends along the length of McAllister Creek.

2) The data suggests that the distribution of heavy metals in the sediments of McAllister Creek is influenced by the interaction of fresh water and sea water.

3) The research implies that estuaries of the Puget Sound may act as filters that concentrate heavy metals in estuarine sediments. This warrants further study.

ACKNOWLEDGMENTS

The Nisqually Wildlife Refuge and the City of Olympia for providing access to McAllister Creek; The Evergreen State College for providing instrumentation and funding; Jason Parker for aiding in lab preparation; and Professor Ken Tabbut for his invaluable guidance.

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APPENDIX A: METAL EXTRACTION PROCEDURE

1) All glassware was cleaned with 4X diluted 12M HCl solution for at least 24 hours before the extraction period.

2) Samples were dried at 190° for 15 to 20 hours.

3) Samples were weighed out to 5 grams and transferred to 50 ml beakers.

4) 20 ml of 5.4 M HNO3 solution was added to each sample.

5) The samples were then refluxed, with evaporation dishes for covers, on Corning PC-353 heating units for 120 minutes. A value between 2 and 3 on the heat dial was used because it sufficiently digested the sediments while preventing the solution from boiling over.

6) The samples were then filtered using a vacuum filtering system (including a spill stop hose and flask). The system was fitted with a ceramic filter and Watman #40 filter paper. After filtering, the samples were diluted to 50 ml with ultra-pure deionized water. The samples were then poured into flasks and stored for 1 to 2 days before analysis.

A COMPARISON OF THREE DIFFERENT METHODS FOR EXTRACTING HEAVY METALS FROM MARINE SEDIMENT TO ASSESS BIOAVAILABILITY

M.G. Bills and Vizma Schulmeisters[1]

INTRODUCTION

Sediments are one of the most concentrated sinks of heavy metals in aquatic environments. Within sediments metals may be found on or in several different types of binding sites or substrates. This partitioning is influenced by the physical and chemical characteristics of the sediments. Partitioning among different physicochemical forms plays an important role in determining the biological availability of sediment-bound metals, and in determining metal exchange between sediments and water (Luoma and Bryan, 1978). Research has shown that total digestion of sediments does not reflect quantities available to the water column or to biota (Weiman, 1992; Luoma and Bryan, 1981). A differential extraction study will provide insight into the stability of sediment-bound metals and more accurately assess their bioavailability (Luoma and Bryan, 1982).

Necessary to the understanding of heavy metal analysis is knowledge of the stasis of sediments. Both metal speciation and biological availability or toxicity are functions of the tendency of the metal to react, as quantified by the free metal ion activity under pseudo-equilibrium conditions (Chakrabarti, 1993). A metal can be present in sediment on one or more of several locations. These locations include: (a) the lattice of crystalline minerals (metals not available to biota); (b) the inter-layer positions of clay (phyllosilicate) minerals (available only when clays break down); (c) heavy metals adsorbed on mineral surfaces and cation exchange sites (generally considered biologically available); (d) metals associated with hydrous ion and manganese oxides and ferric hydroxides, which can exist as surface coatings or discrete particles (considered available after acidification in the digestive tract of biota or while in solution); (e) metals complexed with organic matter (considered available, unless the organic complex is encased within the clay lattice); and (f) metals dissolved in the sediment interstitial water (are also available) (Engler, 1977).

The most significant associations between heavy metals concentrated in marine sediments and concentrations in burrowing organisms occur with associated Fe and Mn oxides at the solid-solution interface (Luoma and Bryan, 1978, 1981, 1982). E.A. Jenne (1968) established that Fe and Mn oxides exist as nodules, concretions, cement between particles, or simply as a coating on particles. Tessier (1979) established that these oxides are excellent scavengers for heavy metals and are thermodynamically unstable under anoxic conditions (i.e., low Eh). Therefore, mobility and bioavailability of heavy metals can be more fully assessed by a differential extraction scheme specific to metals adsorbed on surface coatings associated with Fe and Mn oxides, than by chemically dissolving the whole structure.

Methods for differential extraction of bioavailable metals associated with Fe and Mn oxides come from the combined works of Tessier (1979), Solomons and Forstner (1980), Luoma and Bryan (1978), and Batley (1987). According to Tessier (1979) the most successful methods for leaching Fe and Mn oxides involve the action of reagents that reduce these metals to their ferrous and manganous forms, the most commonly used being hydroxylamine hydrochloride. Tessier evaluated the optimum time for leaching of Fe-Mn oxides by hydroxylamine HCL and found it to be 6-24 hours. In an assay of six metals, four of which appear in this study (Cd, Cu, Pb, and Zn), Tessier showed that the metals associated with Fe-Mn oxides represent a large fraction of total metals present: ~ 22% of Cd, ~ 44% of Cu, ~ 42% of Pb and ~ 24% of Cu. This substantiates his claim that Fe-Mn oxides are excellent scavengers for heavy metals, and furthermore, that extraction with hydroxylamine HCl gives elemental concentration in this fraction. Hydroxylamine hydrochloride will dissolve all the carbonates, oxides and hydroxides present. It will also dissolve complex metals bound to cation exchange sites.

[1] Chemistry and Natural Sciences, Lab II, The Evergreen State College, Olympia, WA 948501

In contrast, EDTA was selected based on a comparative study of the distribution and bioavailability of heavy metals by G.E. Batley (1987). EDTA is not dependent upon reduction but rather acts as a chelator of Fe and Mn at pH 8 (Batley, 1987). According to Batley's results the amount of Fe extracted by EDTA and hydroxylamine hydrochloride was not significantly different (9.9 mg g^{-1} for hydroxylamine and 10.7 mg g^{-1} for EDTA). Additionally, EDTA will potentially complex group II metals, Mn (II), carbonates, and Mn(II) hydroxides. It is unclear whether EDTA complexes all metals bound in Fe-Mn oxides, but it has an extensive history of associations with the bioavailability of heavy metals (Agemian and Chau, 1976; Batley, 1987; Luoma and Bryan, 1981).

Our intent with this work was to study differential extraction of heavy metals (Cd, Cr, Cu, Pb, and Zn). This research was part of a larger study comparing differentially extracted heavy metals from marine sediments with spatially representative biota (polychaetes and bivalves), and with corresponding interstitial water. Based on this work we elected to attempt to complex heavy metals associated with Fe and Mn oxides by a differential extraction procedure using hydroxylamine hydrochloride and EDTA. For the purpose of comparison we also included a method for the total digestion of the lattice of crystalline minerals, and the inter-layer positions of (phyllosilicate) mineral clay sediments by nitric acid/hydrogen peroxide. This digestion served as a point of comparison between biologically available metals and the amount of total metals present.

The ASARCO (American Smelting and Refining Company) site in Commencement Bay (Tacoma, Wash.) has been assessed by the Washington Department of Ecology, and is known to be contaminated with heavy metals. This heavy metal contamination is the result of the dumping of slag from the ASARCO operation directly into Puget Sound. The Cu ores, having come largely from the Philippines, had a high incidence of heavy metals. In contrast, a local beach at Priest Point Park has little or no history of dumping. All extractions were performed on sediment samples from these two locations, one contaminated (ASARCO site) and one control, Priest Point Park. Priest Point Park is a public beach on the east side of Budd Inlet (Olympia, Wash.). There is some history of heavy metal contamination from industry in that area; however, other studies have shown that concentrations are below detectivity.

SITE DESCRIPTION

We obtained samples from two sites in northwest Washington. The sites were selected based on the following factors: a) Their heavy metal profiles fit the focus of this work; and b) they both have similar sediment grain characteristics.

Priest Point Park at 47° 04.1' W, 122° 54.5' N, located in northeast Olympia, Thurston County, Wash., is a public park on the east side of Budd Inlet. The west side of the park is bordered by an estuarine beach, with Ellis Creek flowing out to create Ellis Cove, which divides the park into north and south sections. East Bay Drive divides the park east and west providing easy access to the park by road. There is no history of industrial pollution in the immediate vicinity, and in preliminary sampling we found the organisms and general sediment characteristics adequate for comparison to the other sites. We sampled about 100 meters south of the stream outfall, and about 100 meters out from the high tide water line.

For our second site we chose the Les Davis beach at 47° 17.7'N, 122° 29.9' W, located 100 meters southwest of the ASARCO plant boundary. This beach sits between the ASARCO plant and the Les Davis fishing pier. We gathered samples in 1 m deep water approximately 50 feet from the low tide line and midway between the small cliff on the southwest and the rock outcropping to the southeast.

MATERIALS AND METHODS

Sampling Procedure

Because we worked with the intent of making direct correlations between total heavy metal concentration, organisms, interstitial water, and two differential extraction procedures, it was necessary to maintain integrity of all factors during sampling. To avoid trace metal contamination all glassware, plastic ware, filtering apparatus, and plastic utensils were coated with 3M HCl and allowed to stand for at least one

hour. This process was followed with at least three thorough rinsings with copious amounts of ultra-pure water.

We sample in sub-tidal areas using organism availability as a governing factor. By choosing to sample at the ASARCO site we accepted that benthic communities would be somewhat limited. We chose a tide of -0.1 ft. on 13 April 1994, and sampled in water as deep as possible using sieves for organisms and a sediment collector made of PVC tubing. This consisted of a 1 meter section of pipe capped with a screw-type fitting on one end and an easily removable cap on the other. The sediment was collected from the area surrounding the organisms. During core retraction some water from the sediment-water interface (non-interstitial water) was unavoidably introduced into the sampler. This water from the surrounding water column was immediately decanted. Because of the short exposure time it is assumed that the contamination from the non-interstitial water was minimal. In cases where the entire sample was flushed the sample was discarded. In all cases excess water was poured off.

Sediment Sample Handling

Samples were taken by driving the corer into the sediment. Upon withdrawal samples were placed directly into gallon size ziplock-type polypropylene bags. The samples were refrigerated upon return to the laboratory. Five samples were taken from each location. Interstitial water was removed by centrifugation at 12,000 rpms.

Grain Size Analysis

Grain size analysis was performed before this experiment (see *Sediment Grain Size Analysis of Two Puget Sound Beaches,* Monica Murray (unpublished)). The analysis showed that the two sites had roughly the same fractional composition (grain size 0.05 mm to 0.1 mm).

EDTA Extraction (Ethylenediaminetetracidic Acid)

The procedure was similar to the work of R.M. Engler (1977) for extraction of metals at cation exchange sites. However, we adjusted the concentration of the EDTA extracting solution to allow for large amounts of Ca and Mg as the carbonates in marine sediments. We extracted with a pH 8, 0.25M EDTA solution. The EDTA solution was made from the disodium salt (Baker Analyzed Reagent), and the pH was adjusted by adding solid KOH (Baker Analyzed Reagent).

To 50-gram sediment parcels we added 50mL of the EDTA extracting solution using a graduated cylinder. The flasks were covered with DuraFilm (Diversified Biotech) and placed on a wrist-action shaker table for 23 hours. A sample consisting only of the extracting solution (blank) and an external standard were treated to the same procedures as samples containing sediment. The external standard was 10 µg/mL in Cd, Cr, Cu, As, Pb, and Zn in the extracting solution prepared from 1000 µg/mL primary standards.

Hydroxylamine Hydrochloride Extraction

Hydroxylamine HCl extraction was similar to R.M. Engler (1977) as an equitable extractant of heavy metals in the easily reducible phase. We extracted 50-gram parcels of sediment with 50 mL of extracting solution, which was 1M hydroxylamine hydrochloride (Baker Analyzed Reagent) and 0.6 M in HNO_3 (Baker Analyzed Reagent), and extracted for 23 hours. The pH of each sample was adjusted over the duration of the extraction in an attempt to compensate for *in situ* factors such as the presence of carbonates in estuarine sediments. As the carbonate and hydroxide precipitate dissolved, the pH increased above 2. To compensate for these changes, we monitored pH every hour and made adjustments with 18M Nitric acid. This process continues until pH stabilized at 2. Samples were extracted for 23 hours on stir-plates with polyethylene stir-bars.

A sample consisting only of the hydroxylamine hydrochloride extracting solution (blank) and an external standard were treated to the same procedures as samples containing sediment. The external standard was 10 µg/mL in Cd, Cr, Cu, As, Pb, and Zn in the extracting solution prepared from 1000 µg/mL primary standards.

Nitric Acid/Peroxide Digestion

Twenty-five-gram samples were digested at 85°C on Corning hot-plates with 25 mL of 18M Nitric acid (Baker Analyzed Reagent) and 10 mL ultra-pure water. After 2 hours we added 15 mL of 30 percent Hydrogen Peroxide (Baker Analyzed Reagent) and continued the digestion for an additional hour to remove organic matter.

Preparation for Analysis

After extraction all samples were filtered using Gelman glass fibre filters (nominal pore size 1 μm) and a *Millipore* filter stage.

Analysis by ICP-AES

Filtered samples were analyzed by ICP using a Thermo Jarrell Ash AtomScan 16.

Statistical Analyses

Statistical analyses were done using QuattroPro 4.0 for Windows and SPSS/PC+ in the DOS environment.

RESULTS

Table 1 shows the means and standard deviations for our total digestion results and shows that there is a significant difference at each site with regard to total metals present ($p = .001$). Nitric acid extracted a significantly greater amount of metals than EDTA or hydroxylamine HCl, $p = 0.02$. When both EDTA and hydroxylamine HCl extracted an element, hydroxylamine hydrochloride extracted a significantly greater amount than EDTA. Furthermore, generally greater amounts were extracted at higher sites. Table 1 demonstrates that: a) the total concentrations of Cd, Cr, Zn were roughly 50 percent higher in sediments at Les Davis than in those at Priest Point Park; b) Cu concentrations were about 15 times higher; and c) Pb (near detectivity in Priest Point Park sediments) is approximately 100 times higher in Les Davis sediments.

Table 1. Mean and standard deviation for metal concentrations extracted by a total digestion using nitric acid and 30% hydrogen peroxide and heat for 1 hour. All means were significantly different by location, $p < 0.05$, $N = 5$.

Comparisons of Total Metals Present by Site				
	SITE			
	Les Davis Park		Priest Point Park	
ELEMENT	Mean (ppm)	St Dev (ppm)	Mean (ppm)	St Dev (ppm)
Cadmium	1.294	0.346	0.865	0.022
Chromium	138.212	5.575	87.747	3.266
Copper	123.751	26.585	7.823	0.248
Lead	0.615	0.097	0.005	0.003
Zinc	49.471	4.769	29.312	0.372

Table 2 shows concentration extracted by nitric acid/peroxide, hydroxylamine hydrochloride, and EDTA. We compared the amount of metal extracted by hydroxylamine HCl and EDTA to the total digestion concentration. Table 2 also demonstrates that hydroxylamine HCl and EDTA removed less of the metals than the digestion, and also demonstrate a higher bioavailable fraction at the high site.

Cadmium

At Les Davis a significantly greater quantity of Cd was extracted by hydroxylamine HCl (60%) than by EDTA (20%), $p < 0.0001$. Additionally, at Priest Point Park, Hydroxylamine Hydrochloride (30%) extracted a significantly higher quantity of Cd than EDTA (6%), $p < 0.0001$.

Chromium

There was no significant difference in the amount of Cr extracted by EDTA between the two sites. For both sites hydroxylamine HCl (30%) extracted significantly more Cr than EDTA (10%), $p = 0.001$.

*Table 2. Mean and standard deviation for each extraction method. We t-tested the total extraction of each metal against each of the extraction methods, and found that all were significantly different (n = 8-10), p<0.05. * denotes samples of 25 grams wet weight. ** denotes samples of 50 grams wet weight. Bd = <0.0046 below detectivity. HH = hydroxylamine HCl.*

RELATIVE EXTRACTION FOR BOTH SITES							
		Method of Extraction					
Site	Element	Total Extraction (ppm*)	St Dev (ppm*)	H-H - pH 2 (ppm**)	St Dev (ppm**)	EDTA (ppm**)	St Dev (ppm**)
Les Davis Park	Cadmium	1.294	0.346	0.758	0.087	0.287	0.076
(high site)	Chromium	138.212	5.575	44.143	5.362	0.961	0.115
	Copper	123.751	26.585	86.323	15.785	33.351	16.147
	Lead	0.615	0.097	0.577	0.068	0.314	0.044
	Zinc	49.471	4.769	83.625	39.901	18.251	4.447
Priest Point Park	Cadmium	0.865	0.022	0.261	0.026	0.054	0.013
	Chromium	87.747	3.266	10.355	2.945	1.107	0.172
	Copper	7.823	0.248	bd		2.534	0.463
	Lead	0.005	0.002	bd		0.013	0.001
	Zinc	29.312	0.372	8.657	0.986	1.505	0.328

Copper

Hydroxylamine HCl was able to extract Cu (70%) only from the Les Davis site. Levels of Cu at Priest Point Park were below detectivity by ICP-AES. For Les Davis hydroxylamine HCl (70%) extracted a significantly greater quantity of Cu than EDTA (50%), $p < 0.0001$.

Lead

We extracted a significantly greater amount of Pb with EDTA from Les Davis than from Priest Point Park, $p = .0009$.

There was no significant difference between the two extractions at Priest Point Park, $p = 0.27$. At Les Davis hydroxylamine HCl (70%) extracted a significantly greater amount of Pb than EDTA (50%), $p = .01$.

Zinc

Hydroxylamine HCl extracted a significantly greater amount of Zn from Les Davis than from Priest Point Park, $p < 0.00001$. There was a significant difference between both sites by hydroxylamine hydrochloride extraction, $p < 0.00001$.

DISCUSSION

As part of a larger study we extracted heavy metals from marine sediments that were considered biologically available. We tested three extraction methods (nitric acid/peroxide, hydroxylamine HCl, and EDTA) on a contaminated site and a control/clean site. The concentration of heavy metals obtained from a total sediment digestion (nitric acid/peroxide) has been shown not to reflect concentrations in organisms (Weimann, 1992). For this reason we selected two extraction procedures that would mimic bioavailability by complexation of heavy metals bound to: a) cation exchange sites; b) carbonates; and c) Fe-Mn oxides. As Table 1 demonstrates, there is a significant difference between the total concentrations of heavy metals present at each location (Les Davis Beach and Priest Point Park), $p = 0.05$. In addition, we established that the total extraction yielded a significantly greater amount of heavy metals than hydroxylamine HCl ($p = 0.001$), and that hydroxylamine HCl yielded a significantly greater amount than EDTA ($p = 0.01$), indicating a significant concentration that is not bioavailable (See Table 2).

This conflicts with the results given by G.E. Batley (1987), which showed EDTA to be the stronger extractant. It was later discovered that Batley did his work in river water. This, we believe, changed the nature of the hydroxylamine HCl extraction. This concern was in part addressed by Bermond (1993), who offered that the non-selective extraction of hydroxylamine HCl is more a function of the protonation of the extraction solution by nitric acid (pH 2 extraction), than a function of its ability to bind heavy metals to the hydroxylamine ion. This is supported by Luoma (1981), who suggested that hydroxylamine HCl was extremely sensitive to the presence of any $CaCo_3$ in sediments (due to the poor buffering capacity of nitric acid). Carbonate precipitation at the fresh water-salt water interface, combined with the very low buffering capacity of nitric acid, make our extraction largely a pH 2 extraction rather than one solely dependent on hydroxylamine HCl.

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ENHANCEMENT OF GROWTH IN NATURAL ASSEMBLAGES OF MARINE PHYTOPLANKTON FOLLOWING ADDITION OF NITRATES AND PHOSPHATES: EVIDENCE FOR THE LIMITING EFFECTS OF INORGANIC NUTRIENTS ON PRIMARY PRODUCTIVITY IN BUDD INLET

Alberto J. Napuli[1]

INTRODUCTION

Budd Inlet is an eutrophic estuary in the South Puget Sound, which is heavily affected by urban and industrial development. It is exposed to major sources of organic and inorganic materials which may have a significant impact on the productivity and trophic dynamics of its ecosystem. The Lacey, Olympia, and Tumwater, Thurston County secondary sewage treatment plant (LOTT) discharges a yearly average of 789,951 lbs of total nitrogen and 156,103 lbs of total phosphates (Department of Public Works, 1991). The outflow of the Deschutes River, which drains agricultural lands and metropolitan areas, also contributes significant amounts of nutrients to the system.

The discharge of large quantities of nutrients is one of the greatest anthropogenic environmental threats to estuaries. Increases in the concentration of limiting nutrients can cause large algal blooms, which may have several deleterious effects on the ecology of an estuary. One of these deleterious effects occurs when a few species of phytoplankton are able to exploit the nutrient excess more rapidly than others, leading to the competitive exclusion of many species normally present (Hobbie and Copeland, 1977). Phytoplankton blooms also create large quantities of sinking dead algae, which are decomposed by bacteria. The resulting increase in bacterial respiration can lead to oxygen concentrations low enough to kill fish and benthic populations (Hobbie and Copeland, 1977). Finally, blooms can also lead to decreased light penetration, inhibiting the photosynthetic activity of bottom plants (Hobbie and Copeland, 1977).

The addition of nutrients to estuaries is of particular importance when primary production is limited by these nutrients. Primary production in many estuaries has been shown to be limited by either phosphorus or nitrogen. D'Elia et al. (1986) stated that fresh waters are generally assumed to be P-limited and marine waters are generally assumed to be N-limited. However, in estuaries it is hard to determine the limiting nutrient (D'Elia, 1986). D'Elia et al. (1984) found that primary production in the Patuxent River estuary, a tributary of Chesapeake Bay, was limited by N in the low-flow summer season and by P in the high-flow winter season. Rudek et al. (1991) also found that in the spring, additions of N and P in the lower Neuse River estuary, South Carolina, caused a greater increase in phytoplankton growth than additions of N alone.

The objective of this study was to determine whether primary production in Budd Inlet was limited by combined nitrates and phosphates during mid-spring. Natural assemblages of phytoplankton were collected from Olympia Shoal. The net primary production of these assemblages was determined before and after the addition of nitrates and phosphates. Results show that the addition of combined nitrates and phosphates significantly enhanced the productivity of phytoplankton in Budd Inlet.

MATERIALS AND METHODS

Study Site and Sampling Procedures

Natural assemblages of phytoplankton for experimental tests were obtained at the day marker for the Olympia Shoal in Budd Inlet (Figure 1), on May 5 and May 14, 1993. All samples were collected during daylight, at slack tide, from a small boat. Phytoplankton assemblages were collected at surface using pre-cleaned 20 L polyethylene bottles. Bottles and caps were rinsed with sample water three times before filling. The samples were filtered on board using 173-micron filters to remove large zooplankton from the

[1] The Evergreen State College, Olympia, WA 98505

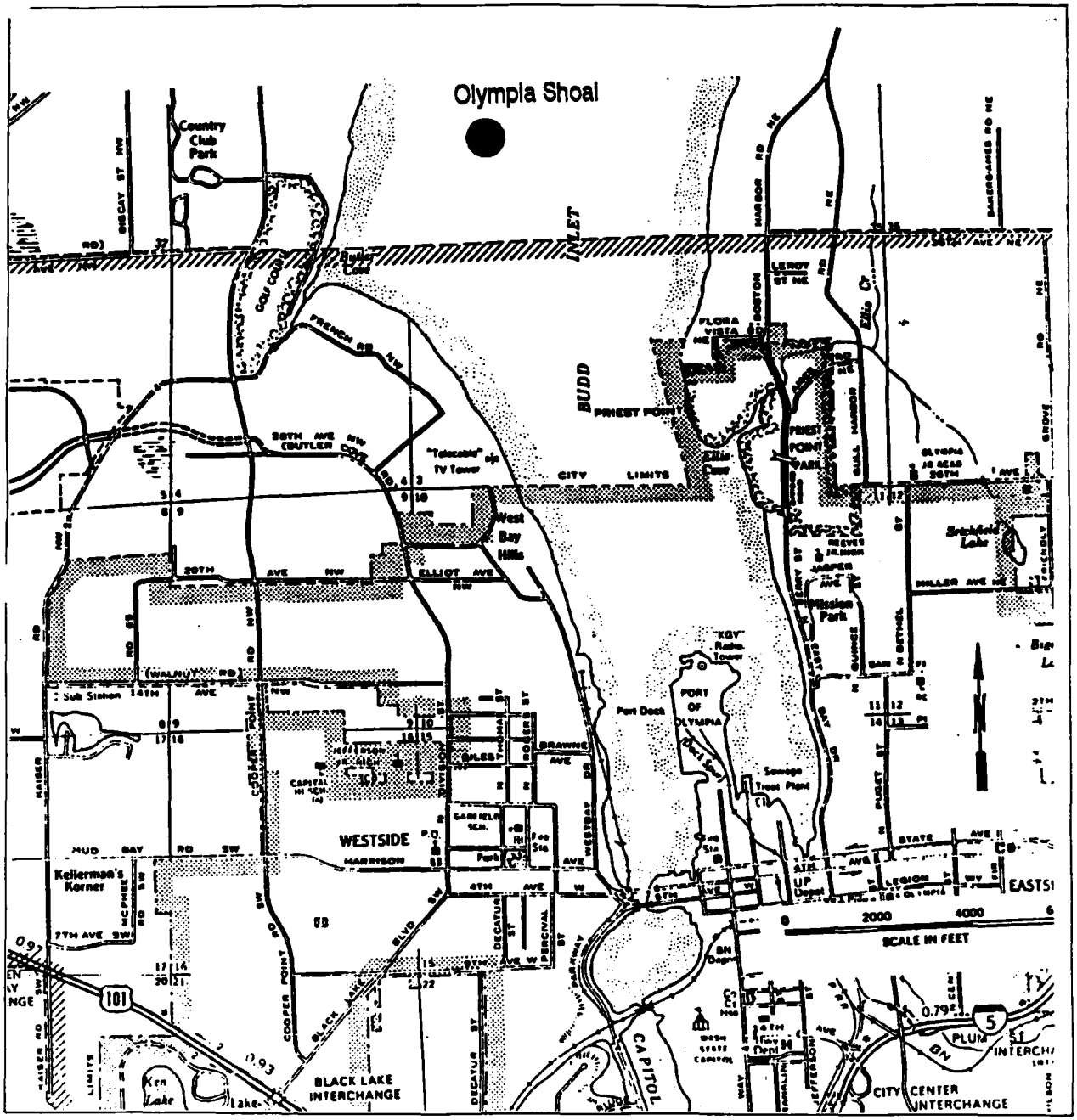

Figure 1. Natural assemblages of phytoplankton and water samples were collected at the day marker of the Olympia Shoal, Budd Inlet, Wash.

phytoplankton assemblages and kept at low temperature and in the dark. Water samples for nutrient and chlorophyll analysis were obtained at surface and subsurface with 2.5 L Van-Dorn bottles secured to a nylon line. The samples were collected in pre-cleaned 2 L polyethylene bottles rinsed with sample water three times before filling and stored on ice and in the dark. In the laboratory, water samples were filtered with a 0.45 μm glass filter under a gentle vacuum. The filter and filtrate were stored frozen for later

chlorophyll and nutrient analysis. During field sampling, salinity was determined by refractive index (Reichert refractometer) or conductivity (YSY salinity to temperature meter).

Measurement of Primary Productivity

The stoichiometry of the general photosynthetic reaction (1) has been extensively studied and is well understood.

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2 \quad 1)$$

Theoretically, the rate of production of organic compounds can be determined by measuring the rate of appearance or disappearance of some component of the general photosynthetic reaction (Nybakken, pg 65, 1988). In this experiment, primary production was measured by the light-dark bottle method. This method measures phytoplankton oxygen production in a given volume of water and unit of time, which in turn can be used to determine carbon uptake.

The conversion factors (2) used to convert the rates of oxygen production to rates of carbon dioxide assimilation vary depending upon the organic compounds produced (carbohydrate, lipid, or protein) (Nybakken, pg 66, 1988). In this experiment, we used an average conversion factor of 1.2, as suggested by Nybakken (1988).

$$Net\,C_{uptake}\,mg/L/day = \frac{(DO_{final} - DO_{initial})\,mg/L}{1.2} \quad 2)$$

The rate of phytoplankton oxygen production was determined by the Winkler method, described in Standard Methods (APHA et al., 1975). Samples from the 20 L polyethylene bottles containing natural assemblages of phytoplankton were collected in 300 ml BOD (biological oxygen demand) bottles. One set of four replicate samples was immediately fixed with 1 ml of MnCl2 (2.1 M) and 1 ml of NaOH-NaI (12.5-0.9 M) solution and mixed by inversion. After the precipitate settled, 1 ml of H2SO4 (18M) was added and the samples analyzed for DO. Another set of four replicate samples were incubated for 24 h, at 15°C, and constant irradiance (2000 lux). Following incubation, samples were fixed as described above. DO was determined with titrant sodium thiosulfate (0.025M), added with Guiltman microburetes. Replicate 25 ml subsamples from each of the fixed samples were titrated until almost clear. Then, starch was added to form a purple iodine-starch complex. The first disappearance of this complex signaled the stoichiometric end of the titration. Replicated measurements for each fixed sample were no more than 0.015 ml of sodium thiosulfate apart.

The DO in each sample was calculated stoichiometrically from its relation to thiosulfate:

$$mg\,O_2/L = C_{Thio} * V_{Thio} * \frac{1}{V_{sample}} * \frac{8\,mg\,O_2}{1\,mmol\,S_2O_3^{2-}} \quad 3)$$

where C_{thio} is the concentration of thiosulfate in mmol/ml (0.025 M), V_{thio} is the volume of thiosulfate used in each titration in ml, and V_{samp} is the volume of sample titrated in L (0.025 L).

The net oxygen production (mg/L/day) was calculated as the difference in DO before and after the 24 h incubation period. Net oxygen production was used to measure total carbon uptake.

Nutrient enrichment experiments

The possible limitation of phytoplankton growth by the availability of N and P in Budd Inlet was investigated by measuring differences between the production of natural assemblages of phytoplankton enriched with potassium nitrate (0.60 mg/L) and sodium orthophosphate (0.05 mg/L) and the primary

production of a control group of unamended samples. The concentrations of added nutrients were chosen to at least double the expected ambient concentrations. The nutrient enrichments were added to the 20 L samples collected in polyethelene bottles. Subsamples were immediately delivered into BOD bottles, and the net primary production for both the enriched and control groups was determined by the light-dark bottle method, as described above.

Nutrient and chlorophyll analysis

The concentrations of dissolved N03, NO2, and O-P04 in water samples were determined by colorimetric methods described in Standard Methods (APHA et al., 1975).

NO2-NO3

The combined concentrations of NO3 and NO2 in water samples were determined by reducing NO3 to NO2 and measuring the total concentration of dissolved NO2 in the samples. To reduce NO3 to NO2, samples were buffered with 0.1 M NH4Cl (final concentration) and pumped through an amalgamated Cd column at a flow rate of 10 ml/min. For each sample three 10 ml replicate subsamples were collected in clean test tubes. Each subsample was immediately mixed with 2 ml of sulfanilamide to form a diazo compound in about 2 minutes. This compound was then coupled with 0.2 ml of N_(1-naphthyl)-ethylene-diamine dihydrochloride solution to form a purple azo dye. The absorbance of the colored solutions was measured at 542 nm with a Hewlett Packard 8452A diode array spectrophotometer. A set of standard samples with known concentrations of NO3 diluted in ASW (artificial sea water) were used to determine the X-coefficient and Y-constant of the linear equation that defines the relationship between absorbance and NO2-NO3 concentration (R2 > 0.97).

O-PO4

The concentration of phosphates in the water samples was also determined colorimetrically. Each of three 125 ml replicate samples was mixed with 10 ml of coloring reagent. The coloring reagent was composed of 125 ml of H2SO4 (2.3 M), 50 ml of ascorbic acid (0.3 M), 50 ml of ammonium molybdate (0.15 M), and 25 ml of antimonyl potassium tartrate solution (0.004 M). The absorbance of the colored solutions was measured at 885 nm with a Bausch and Lomb Spectronic 88 spectrophotometer. A set of standard samples with known concentrations of H2PO4 diluted in ASW were used to determine the X-coefficient and Y-constant of the linear equation that defines the relationship between absorbance and H2PO4 concentration (R2 > 0.97).

Chlorophyll *a*

The glass filters containing planktonic concentrate were dissolved in 90% acetone for 24 hours in the cold and dark. The samples were centrifuged, and the supernatant analyzed with a Hewlett Packard 8452A diode array spectrophotometer at 750, 664, 646, and 630 nm. Chlorophyll *a* was calculated in mg/m3 using standard conversion factors

$$C_a mg/m^3 = \frac{(11.85 * A_{664}) - (1.54 * A_{646}) - 0.08] * A_{630} * V_{acetone}}{V_{sample}} \quad 4)$$

where A_i = (absorbance$_i$ - absorbance$_{750}$), $V_{acetone}$ is in ml and V_{sample} is in L.

Statistical analysis

A one-tail t-test statistic was used to detect any differences between $\mu_{enriched}$ and $\mu_{control}$, where $\mu_{enriched}$ is the mean production of phytoplankton assemblages enriched with combined N and P and $\mu_{control}$ is the mean production of the unamended controls. This statistic tested the null hypothesis

$$H_o:(\mu_{enriched} - \mu_{control})=0$$

against the alternative hypothesis

$$H_a:(\mu_{enriched} - \mu_{control})>0$$

The small sample test statistic was calculated using a two-sample Z statistic formula where σ^2 was substituted by the pooled sample estimator Sp^2:

$$t=\frac{(X_{enriched}-X_{control})-D_o}{\sqrt{S_p^2(\frac{1}{n_{enriched}}+\frac{1}{n_{control}})}}$$

where

$$S_p^2=\frac{(n_{enriched}-1)S_{enriched}^2+(n_{control}-1)S_{enriched}^2}{(n_{enriched}-1)+(n_{control}-1)}$$

The hypothesized difference in mean production was $D_o=0$. The rejection region was one-tail based on a t-distribution with $(n_{treatment} + n_{control}-2)= 6$ df. For $\alpha=0.5$ the rejection region for the test was $t>t_\alpha$ where the value for $t_{0.05}$ is 1.943. Thus, t values greater than 1.943 provide sufficient evidence to indicate that the mean phytoplankton production differed between the treatment and control groups.

The same t-statistic was also used to construct the 95 percent confidence interval for the difference between the two population means.

$$(X_{enriched}-X_{control})\pm t_{\frac{\alpha}{2}}\sqrt{S_p^2(\frac{1}{n_{enriched}}+\frac{1}{n_{control}})}$$

P is the observed significant level for the test or the probability of observing a value of the test statistic that is at least as contradictory to $H_o:\mu_{enriched} = \mu_{control}$ as the value observed if in fact H_o is true. In this experiment, P was computed with Quattro Pro spreadsheet statistical software. P values ≤ 0.05 support the conclusion that differences exist between the production of the control and test groups.

RESULTS

Nutrient enrichment experiments

The mean primary production in Budd Inlet was 0.512 mg C/L/day on May 5 and 0.472 mg C/L/day on May 14 (Table 1). The addition of combined NO3 and O-PO4 to natural assemblages of phytoplankton collected during the same dates caused them to nearly double their carbon production (Table 1). A small inference t-test was used to determine the significance of the differences observed between the mean primary production of phytoplankton before and after the addition of combined NO3 and O-PO4 (Table 2). The results of the test showed that the addition of combined NO3 and O-PO4 to natural assemblages of phytoplankton significantly enhanced their primary production ($\alpha = 0.05$). This experiment ultimately implied that phytoplankton growth in Budd Inlet was limited by the availability of NO2 and/or O-PO4 ($P \leq 0.020$).

Temporal distribution of nutrients and chlorophyll *a*

The ambient concentrations of NO2-NO3 measured in this survey ranged from 0.45 mg/L to 0.15 mg/L respectively and were within the range reported by Ecology (1991) (0.45 mg/L to 0.05 mg/L) during surveys conducted from October to September, 1991 (Figure 2). Typically, NO2-NO3 values are maximum (> 0.30 mg/L) during the winter and minimum (< 0.05 mg/L) during the summer (Figure 2), as extrapolated from data measured by Ecology (1991). Minimum NO2-NO3 values are also generally associated with periods of maximum chlorophyll *a* concentrations (Figure 2). In this survey, minimum (0.15 mg/L) NO2-NO3 values measured during May were greater than the minimum (0.05 mg/L) values observed during previous years (Ecology, 1991). Furthermore, the measured concentrations of chlorophyll were typical of winter (< 0.24 mg/m3). These data suggest that this experiment was conducted before the phytoplankton spring bloom, and that minimum NO2-NO3 values measured during this survey were caused primarily by decreased rainfall.

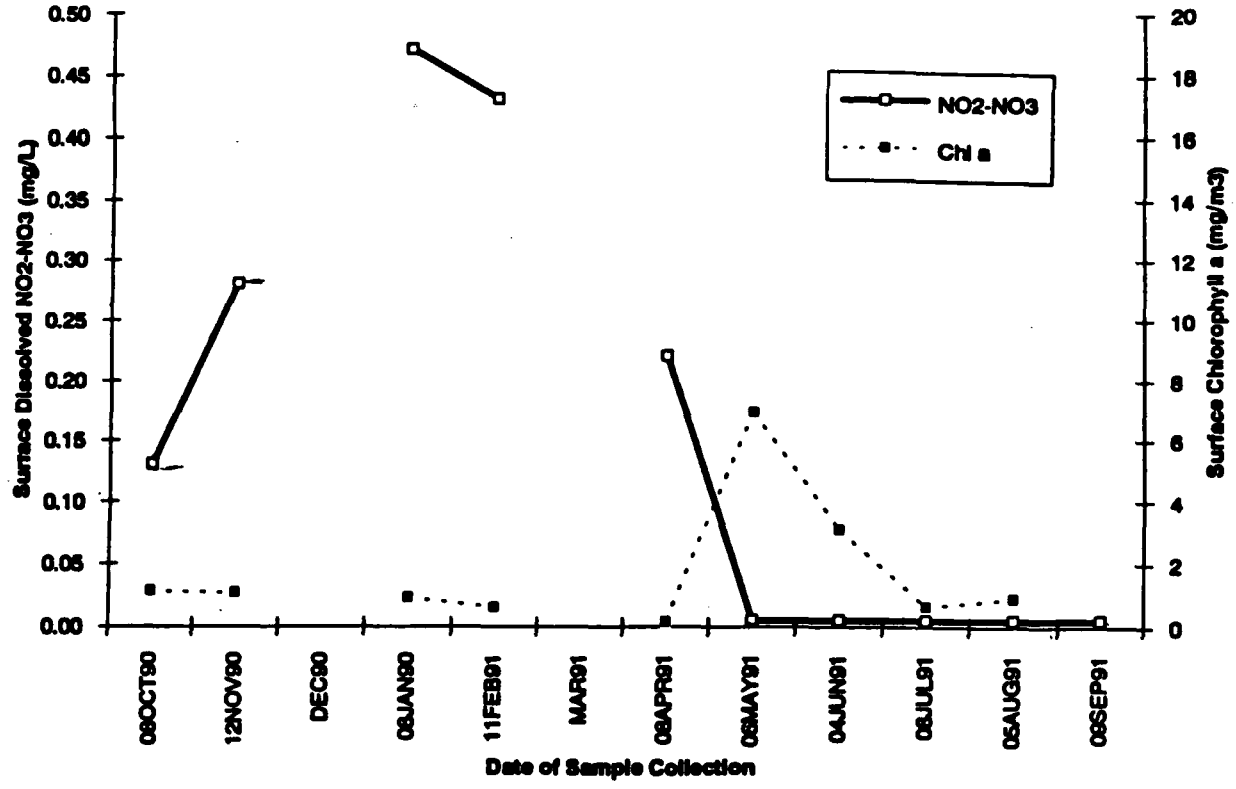

Figure 2. Budd Inlet surface dissolved NO2-NO3 and chlorophyll a from October 8 to September 9, 1991. Plot and data provided by the Washington Department of Ecology (Ecology, 1991).

Table 1. Net primary production for natural assemblages of phytoplankton enriched with N and P (treatment group) and unamended controls (control group), where "n" is the number of replicate samples used to determine each of the means

Date	May 5, 1993		May 14, 1993	
Group	Control	Treatment	Control	Treatment
n	4	4	4	4
Mean*	0.512	0.868	0.472	0.815
Standard Deviation	0.117	0.102	0.164	0.189

*mg C/L/Day

Table 2. One-tail t-test results about the differences between the net mean primary production for natural assemblages of phytoplankton enriched with N and P (treatment group) and unamended controls (control group) during May 5 and May 14, based on a t-distribution with 6 df for $\alpha = 0.5$, where P is the observed significant level for the test

	t	P	Mean Difference*	95% CI*
May 5, 1993	4.59	0.002	0.356	(0.166,0.545)
May 14, 1993	2.6	0.02	0.343	(0.020, 0.665)

*mg C/L/Day

The ambient surface concentrations of O-PO4 (Figure 3) also decreased from a maximum value of 0.1 mg/L on April 14 to a minimum value of 0.05 mg/L on May 5. Typically, O-PO4 (Figure 4) concentrations in Budd Inlet are high during the winter (> 0.08 mg/L) and low during the summer (< 0.07 mg/L). Thus, this survey revealed a significant decrease in the concentrations of O-PO4 from April 21 to May 5.

DISCUSSION

Although the outcome of this experiment provides evidence for nutrient limitation, we do not intend to suggest that the minimum chlorophyll *a* values measured during this experiment were caused by nutrient limitation alone. The natural assemblages of phytoplankton used for the experimental tests were cultured under conditions of unlimited light. Thus, it is possible that phytoplankton growth in Budd Inlet was also limited by light during the sampling period.

Ultimately, the results of this experiment provided enough evidence to support that phytoplankton growth in Budd Inlet was limited by NO3 and/or O-PO4 when light was plentiful ($P \leq 0.020$). These data suggest that primary production in Budd Inlet may be limited by light during the winter and by nutrients during the summer.

This was an unexpected result considering the large quantities of NO3 and O-PO4 discharged into Budd Inlet. However, the primary production of many estuaries exposed to large quantities of nutrients has also been shown to be limited by phosphorus and/or nitrogen. For example, D'Elia et al. (1984) found that primary production in the Patuxent River estuary, a tributary of Chesapeake Bay, was limited by N in the low-flow summer season and by P in the high-flow winter season.

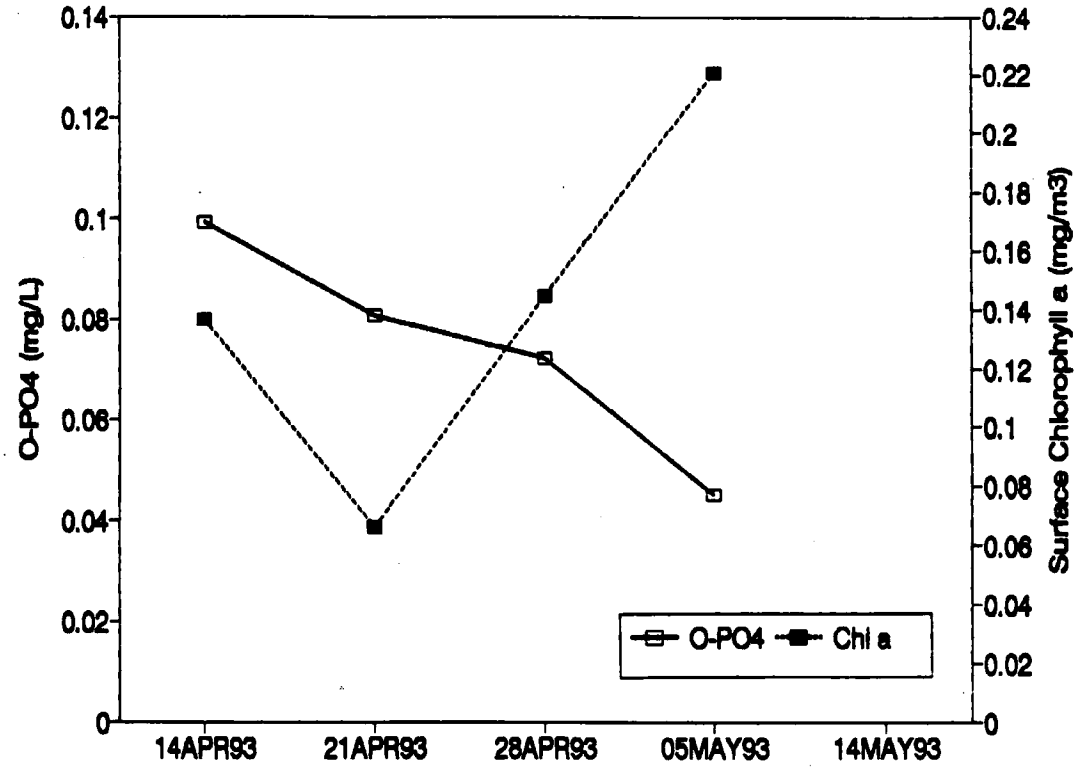

Figure 3. Surface dissolved O-PO4 and chlorophyll a concentrations at Olympia Shoal, Budd Inlet, from April 14 to May 5, 1993

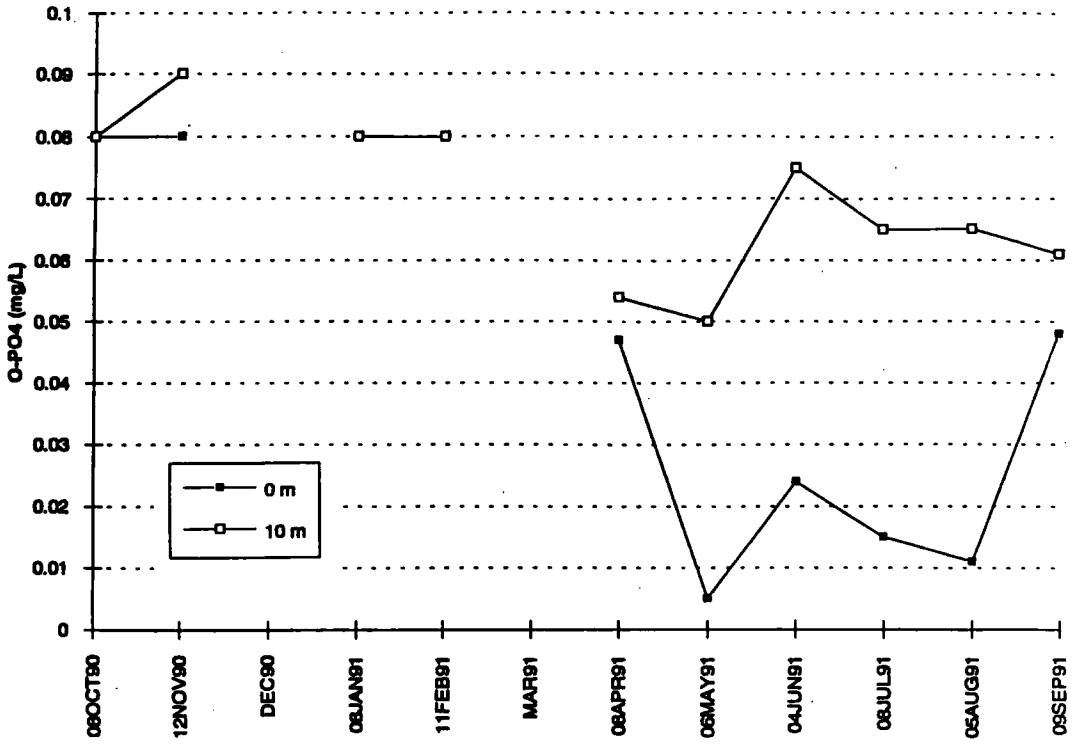

Figure 4. Budd Inlet dissolved O-PO4 concentrations at surface and depth from October 8 to September 9, 1991. Plot and data provided by the Washington Department of Ecology (Ecology, 1991).

In this experiment, we demonstrated that the additions of combined nitrogen and phosphates enhanced phytoplankton primary production without distinguishing which of the two nutrients was limiting. Therefore, further research is necessary to determine the particular characteristics of nutrient limitation in Budd Inlet.

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WATER QUALITY, SUSTAINABLE AGRICULTURE AND WILDLIFE HABITAT ENHANCEMENT

Lorna Ellestad[1]

ABSTRACT

Agriculture has been implicated as a source of nitrate pollution in surface and groundwater. Studies suggest that different cultivation practices can influence the concentration of nitrogen available for nitrate leaching. Cover crops can improve water quality by removing nitrates from the soil, and can improve soil quality by reducing erosion, thereby increasing water infiltration and nutrient retention, and by adding organic matter.

For the past two years, the Ducks Unlimited "Barley for Birds" project has been implemented in the Skagit Valley, in cooperation with the U.S. Fish and Wildlife Service, the Puget Sound Water Quality Authority, the Washington Department of Fish and Wildlife, and local farmers. The planting of fall cover crops of barley in 1993 reduced the levels of nitrogen in surface and subsurface soils by an average of 130 lbs per acre, while providing more than 450 tons of grain for overwintering waterfowl.

The purpose of my research is to identify factors that relate to the accumulation and transportation of nitrates in the soil column. Soil samples were taken in tiers to delineate vertical movements, and at different times to establish sequential changes in ion type and concentration. The fields were further analyzed for biomass and yield, soil type, organic matter, and weed suppression.

On-farm research using real field conditions and farming methods is the best way to persuade farmers to adjust fertilizer applications for better nutrient management. Providing farmers with a practical way to monitor available nitrogen and creating an awareness that both money and resources are being lost can help accomplish a significant reduction in nitrate pollution.

Farmers have found that the "Barley for Birds" project has been a positive way of building partnerships within the community and with regulatory agencies. One field day was attended by more than 30 people, representing 15 agencies and groups. We have been successful in presenting a favorable environmental image at a time when the public has focussed attention on water quality problems associated with agriculture.

[1] Western Washington University, Huxley College of Environmental Science, Bellingham, WA

THE GEODUCK CLAM *(Panope generosa)*: THE POTENTIAL BENEFITS OF A CO-MANAGED FISHERY

Harry W. Branch[1]

INTRODUCTION

The geoduck is a unique and long-lived animal. Successful harvest management policy has been difficult to establish because of the animal's naturally low level of recruitment.

Management policy has also been difficult to enforce. Geoducks are harvested from subtidal grounds by divers. During its most lucrative years, the fishery was dominated by vertically integrated, harvest-to-market enclaves, capable of concealing assets. Poaching is known to have been widespread.

Like the geoduck, the Caribbean spiny lobster is harvested from specific subtidal geographic areas. Both fisheries are difficult to monitor. The spiny lobster represents one of the world's most lucrative fisheries. There are 14 countries for whom the fishery is a major resource. Each country has developed its own management system.

Some of the methods employed by the spiny lobster fishery might be applicable to the geoduck fishery, particularly those involving long-term appropriation of geographic areas. Appropriating the public trust can result in an unfair business advantage, as occurred during the 19th century with U.S. rail, oil, mining and timber concerns. However, long-term appropriations have been arranged with cooperatives that have distributed the resources of fisheries among all involved according to effort. What possibilities might such a co-management system offer to the geoduck fishery?

METHODOLOGY

The Washington state geoduck fishery is a tightly regulated state bureaucracy. The Caribbean spiny lobster fisheries of Belize and Mexico operate under systems of co-management. The geoduck and spiny lobster fisheries address similar issues in different ways. How capable is each system of enhancing its fishery by countering ecologically limiting factors? How effectively do they promote resource sustainability and social and economic stability? What specific difficulties has the geoduck fishery faced? And how have spiny lobster fisheries dealt with similar difficulties?

RESULTS

The Geoduck Clam

The geoduck is the world's largest burrowing clam, measuring up to a meter in length and weighing up to 10 pounds. Geoducks may live to 160 years of age. A geoduck burrows deep in subtidal or intertidal sand or mud and extends its neck to the surface where only the "show" is visible, sometimes nothing more than two holes in the sand, one siphoning water and nutrients in and the other siphoning them out (Goodwin, 1976).

Geoduck reproduction begins when millions of gametes are released directly into the water. Gametes are mature male and female germ cells. Male and female geoducks both release their gametes in the presence of those of the opposite sex. The gametes fuse to form trocophores, free-swimming larvae that feed and drift on the tides for four to six weeks (Barnes, 1980; Goodwin et al., 1979; State of Washington MP/EIS, 1985 [MP/EIS, 1985]).

For each day the geoduck remains adrift, it is exposed to additional threats of predation and a greater possibility of being carried on currents to where it cannot survive. In populations of some attached animals such as oysters and barnacles (*Balanus balanoides*), chemical attractants seem to draw larvae of their own species (Sumich, 1976). This process can increase the survival rate of larvae that are swimming free

[1] The Evergreen State College, Olympia, WA 98505

looking for a particular kind of stratum on which to settle (Barnes, 1980). The presence of adults may encourage settlement and/or survival of young geoducks (Goodwin and Pease, 1989; MP/EIS, 1985; Goodwin, 1978 and 1984).

Natural mortality among adult geoducks is low. Adults have no known predators. Some mortality has been observed that appears to be the result of accumulated material such as detritus algae lying on the benthos surface. Such material could obstruct the geoduck's ability to siphon water and nutrients (Goodwin and Pease, 1987).

Geoduck Harvest Management

Geoduck management is shared between the Washington Department of Natural Resources (DNR) and the Washington Department of Fish and Wildlife (WDFW, previously the Washington Department of Fisheries, WDF) (RCW 75.24.100). Both agencies are responsible for monitoring and enforcement activities. WDFW is responsible for protecting the resource and maintaining "economic well-being and stability" (RCW 75.08.212). DNR leases harvest beds to the highest bidder for fees that have steadily climbed since 1970.

Geoducks are harvested by divers using a hand-held water jet, a pipe about 18 inches long with a 5/8-inch tip and a shut-off valve. A long hose connected to a work boat above supplies water pressure at 40 lbs. to 60 lbs. per square inch. Divers breathe through a second hose called a hooka, which supplies air. When the nozzle is placed next to the "show" of a geoduck, the substrate around the geoduck is immediately liquified. The geoduck is dislodged and placed in a mesh sack that the diver carries. When the sack is full, it is sent to the boat and another sack begun (Goodwin, 1977).

Geoduck harvesting is dangerous work. A diver may work for four hours on the bottom at 60 or more feet and spend up to an hour ascending. Despite long decompression times, the bends are not uncommon. An average diver can harvest 1,000 lbs. per day. An expert can harvest four geoducks per minute, for a total of 2,000 lbs. in a day (Bowhay, 1986; O'Carroll, 1994).

In some locations, juveniles are clumped around adults (Goodwin and Pease, 1989). These juveniles are displaced and exposed during harvest and are not expected to survive because they are unable to dig back into the substrate. Divers can replant dislodged juveniles, though the survival rate of re-planted juveniles is unknown (O'Carroll, 1994).

A geoduck hatchery was begun by WDF in 1983. Attempts to propagate and plant geoducks were showing promise, so in 1990, 7 million young geoducks were planted. Within a year, less that 1 percent had survived. DNR discontinued funding to the hatchery in 1991. Research continues at the WDFW on a small scale, aimed at improving survivability by using biodegradable devices that shield young from predators and planting both geoduck and shield by machine (Olympian, 11/6/88, 12/31/88; conversation with WDF personnel, 1/15/92).

To ensure seed stock, divers are prohibited from diving closer than 200 yards from shore, or in water shallower than -18 ft., or in waters deeper than -60 ft. The theory is that "Extensive geoduck beds remain inshore and offshore of harvested tracts ensuring continued geoduck abundance in the area" (MP/EIS, 1985). In reality, it is difficult to observe diver activities on the bottom. The divers' air bubbles are visible from the surface, but these bubbles can drift considerably on the current before they appear. Divers have verbal communication with the boat above and can readily move if enforcement officers approach by boat. As a result, the areas adjoining harvest tracts on the shallow and deep side have been largely harvested (Bowhay, 1986). DNR knew of illegal geoduck harvesting for many years, though the magnitude of the problem may have been underestimated (Olympian, 11/13/88). Harvesters have poached large areas intended to provide a supporting biomass for the resource (Bowhay, 1986).

Between 1970 and 1987, the reported Puget Sound geoduck harvest netted about 63,760,000 lbs. The harvest was very lucrative for some commercial harvesters. As much as an equal number of pounds may have been poached (Campbell, 1989). The harvest was also lucrative for the state. In 1987, harvest fees paid to DNR totaled $930,000 (Olympian, 11/6/88). The geoduck harvest was projected to generate more than $5 million in state revenues between 1989 and 1991. The harvest level dropped 80 percent in 1991

partly because harvesting was banned by counties in much of the North Sound and partly because of the poor shape of the South Sound beds.

Before 1985, the largest, most commercially valuable geoducks appear to have lived in South Puget Sound (MP/EIS, 1985). As of 1991, many of these beds had been commercially "fished out" (Washington DNR, 1991). In 1991, WDF recommended phasing out and closing the South Sound geoduck fishery for an unspecified period of time (Goodwin and Burge, 1991).

The Spiny Lobster

Caribbean spiny lobsters begin life as minute planktonic larvae, drifting on oceanic currents for about a year. Larvae returning from the ocean undergo a profound metamorphosis and settle in several stages to a benthic existence, becoming adults after five years. Adult lobsters inhabit rocky ledges and coral outcrops (Phillips and Sastry, 1980).

As the lobster matures, it moves through a juvenile phase occupying inshore grassy beds. During this phase, the lobster is vulnerable to predation from octopus, turtles, dolphins and various fishes (Eggleston et al., 1989; Smith and Herrnkind, 1992; Herrnkind et al., 1994). Cuba has constructed a system of "pesqueros," simple structures that provide protective cover for juvenile lobsters. Lobsters that remain in pesqueros as adults are harvested by free diving using a gaff and net (Chubb and Brown, 1991). Lobsters are harvested throughout the Caribbean with an assortment of nets and traps. Cuba's annual harvest often equals that of the balance of the combined Caribbean harvest (FAO, 1984 and 1991).

Harvest Management

Pesqueros appear to greatly increase the harvest, and yet they have found limited acceptance in open-market systems. There is little incentive for an individual to build and maintain structures one year that may be in a competitor's hands the following year.

A co-managed system allows the practical division of fishing grounds into appropriated zones (turfs), which are held year after year, thereby justifying enhancement by such means as pesqueros (McGoodwin, 1990). Appropriating the public trust can result in an unfair business advantage to some individuals. However, long-term appropriations have been arranged with cooperatives that have distributed the resources among all involved, according to effort.

Cooperatives have played a vital role in the development and assessment of the spiny lobster fishery in Belize (Bert and Hochberg, 1992). Co-ops provide handling facilities, credit and fishing supplies. They pay cash at the dock and a share of the co-op's profits at the end of each season. High prices, mostly obtained by auctioning to the highest bidder, bring economic success to most harvesters. Reported annual incomes from lobster fishing run as high as $63,000 U.S. The most minimal effort in a good year will bring $20,000 U.S. Some island communities, such as Caye Caulker, Belize, have become the wealthiest in Central America, because of innovative management of the lobster fishery (Sutherland, 1986).

In Mexico, the Cozumel and Vigia Chico co-ops divide their zones among members who construct casitas, the Mexican equivalent of the Cuban pesqueros. As of 1989, the Vigia Chico co-op had 107 members using more than 10,000 casitas.

In 1980 there were six cooperatives operating in the Quintana Roo district of Mexico, each with clearly defined boundaries. Established co-ops north of the successful Cozumel and Vigia Chico co-ops tried unsuccessfully to resist the incursion of additional co-ops and the resulting division of existing campos. Newcomers initially formed cooperatives to take finfish, and then, through legal maneuvering, to take lobsters. Virtual open access has led to near-abandonment of the system of casitas in northern Quintana Roo. Failure of the co-managed system in this case resulted from failure of the legal system to protect basic property rights (Miller, 1989).

CONCLUSIONS

If adult geoducks encourage juveniles to settle, it makes sense to leave some adults—that is, to harvest selectively, perhaps taking every other clam. It is unreasonable to expect a private operator to harvest only every other clam under the current management scheme. Harvest damage to tracts is difficult to assess (Goodwin, 1978). Such conditions for harvest would be impossible to monitor and enforce.

Harvesters, working their own holdings through a cooperative, would harvest by thinning rather than clear-cutting, or by any other method that would best guarantee future productivity. They could groom geoduck beds of material threatening geoduck survival. Divers could re-plant juveniles dislodged in the harvesting process. Harvesters could lead the way in research, development and implementation of the growing and planting of post-larval geoducks.

Harvesters have been brought into this level of management in the coastal fishery of Japan (Ruddle, 1989) and in the clawed lobster fishery of New England (Hancock, 1980). It is a system that allows individuals to perform enhancement activities while their representative co-ops develop markets. Cooperatives function well as vertically integrated, harvest-to-market businesses because revenues are transferred directly to the harvester.

DISCUSSION

There are problems with the Washington state geoduck fishery. It is expensive and difficult to administer. Millions of pounds of geoducks have been poached. A well-run poaching operation is virtually impossible to detect (Campbell, 1989). There have been problems associated with the long-standing domination of the business by enclave monopolies (Campbell, 1989; Olympian 11/13/89).

Under a system of co-management, much of the cost of protecting the resource is passed on to the co-ops, or eliminated altogether. Those in the business, monitoring both harvesting and marketing activities, have a better chance of discovering a poaching operation than the government ever could.

Co-management between government and cooperatives is a method that has proven itself effective in managing fisheries that harvest specific subtidal areas. Harvesters having rights to the future of such a resource will harvest with the resource's future in mind.

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RCW 75.08.212—The role of the WDF
RCW 75.08.020—The role of the WDF
RCW 79.96.080—The role of the DNR
RCW 79.96.085—The role of the DNR

PUGET SOUND

RESEARCH '95

SESSION 6A

TRUTH OR CONSEQUENCES: TRIBAL EXPERIENCE IN WATERSHED ANALYSIS

Session Chair:

Jeff Dickison

Squaxin Island Tribe

PANEL: TRUTH OR CONSEQUENCES: TRIBAL EXPERIENCE IN WATERSHED ANALYSIS

CHAIR

Jeff Dickison, Squaxin Island Tribe

PANELISTS

Tim Beechie, Skagit System Cooperative
George Pess, Timber, Fish and Wildlife Stream Ecologist, Tulalip Tribe
Mike McHenry, Lower Elwha S'Klallam Tribe
Ed Salminen, Forest Hydrologist, Nisqually Indian Tribe
Dave Schuett-Hames, Squaxin Island Tribe

Jeff Dickison, Squaxin Island Tribe:

We're here for a panel presentation on watershed analysis. We have five tribes represented today. Let me introduce the panel. Dave Schuett-Hames got his B.S. from Evergreen State College and is working on his master's in Environmental Studies at Evergreen State. He now works for the Squaxin Island Tribe; before that he worked for the Lummi Tribe in the Nooksack Basin.

George Pess received his undergraduate degree from Bowdoin College in Maine and received his Master of Forest Science degree in Forest Hydrology and Geomorphology from Yale University. He currently works for the Tulalip Tribes in Marysville.

Ed Salminen works for the Nisqually Tribe on the Nisqually Basin. He's a forest hydrologist, and received his B.S. in Forest Management from the University of Massachusetts and a master's in Forest Hydrology from Oregon State.

Tim Beechie works for the Skagit System Cooperative on the Skagit River. He's working part-time on his Ph.D. in Forest Hydrology at the University of Washington. He received his B.S. in Geology and his master's in Fisheries, both from the University of Washington.

Mike McHenry received his B.S. from Humboldt State, and his master's from New Mexico State. Mike works for the Lower Elwha S'Klallam Tribe up on the Strait.

We have some geographic dispersion here—straits, north Puget Sound, south Puget Sound—and undoubtedly we'll have some varying perspectives among the tribes on the relationships of their programs with watershed analysis.

The purpose of this panel is to discuss that tribal involvement in watershed analysis, and in so doing to profile what tribes are contributing to our baseline knowledge on the Puget Sound environment. Tribes typically are dedicated to the collection of on-the-ground data and information. You will find that while they publish few papers, tribes are often the most knowledgeable parties on a given watershed. In the case to be presented today, you will see that the tribes represented here (and I can assure you that the same is true of many others) have spent extensive time collecting and interpreting data—what some may call applied research. Much of this data is useful input into the watershed analysis process. Often the goal of data collection is to influence management decisions where an adaptive management process is in place. You heard the references earlier at Dr. Hilborn's address to the success of the adaptive management process.

So, watershed analysis—let me take a moment to establish the context. The relevant section of the Washington Administrative Code (WAC) is 222-22, which addresses the state of Washington's watershed analysis procedure. To quote: "The purpose of this rule is to address the cumulative effects of forest practices on the public resources of fish, water, and capital improvements of the state or its political subdivisions. The long-term objective of this rule is to protect and restore these resources." The operative phrase there is "cumulative effects," which is defined as "the changes to the environment caused by the interaction of natural ecosystem processes, with the effects of two or more forest practices."

Under that rule, we have the State Forest Practice Act to address the administration of forest practices. I'll first give you a little history on that (and there's much more history than I will cover briefly). The Timber, Fish and Wildlife (TFW) Agreement in 1987 spoke, but rather meagerly, to cumulative effects. It said things like, goals and objectives should be set. It said that monitoring should determine whether goals are being met. It said an adaptive management process should be implemented. There were a lot of *should*'s there—and they didn't happen right away.

In 1989, watersheds became a part of that discussion, but there was still no substantive mechanism for addressing "cumulative effects" under the rule. Some would say that it might not have happened yet, save for a judge's ruling. It seems judges' rulings often surround us in these days of natural resource management. There was a case at Lake Rossiger, which some of you may be familiar with, in which a judge said that the Forest Practice Act didn't meet the standards established for the review of cumulative effects under SEPA.

By 1992, the Forest Practice Board finally adopted a cumulative effects rule—and that is watershed analysis. It changed the standard best-management approach to a science-based assessment process. This resource assessment method requires specialists to gather information and interpret watershed processes and resource conditions. They are to identify resource sensitivities that require additional and specific management standards under the Forest Practice rules. So they're still the sidebars of the Forest Practice rules. The method here reflects the fact that stream resources are shaped and affected by hill slope and riparian processes—with their respective inputs of wood, water, energy and sediment.

Evaluation conducted under watershed analysis must include an assessment of delivery to a specified public resource (that would be like a delivery of sediment, of wood)— and the vulnerability of the resources to that impact (for instance, the status of a fish run). Watershed analysis is a defined process in the state administrative code, where the team of experts examines information on resource condition and risk. As a result, prescriptions are established for land-use activities associated with forest practices.

Does this system work? Is data useful for the process? Is applied research directed at management systems a useful opportunity? Well, let's hear these presentations, and then we'll get into further discussion on some of those questions.

We'll start off by listening to Tim Beechie from Skagit Cooperative.

Tim Beechie, Skagit System Cooperative:

I'll start with a short discussion of how we view the watershed analysis process as one of the tools that we use at the Cooperative. I'd like to touch briefly on a comparison between the state process and the federal process because there seem to be some significant differences. And then I'll spend a little more time describing the overall research program of the Skagit System Cooperative. I think it's important in view of what we see as a common misconception that watershed analysis is the only management tool out there. We use lots of other tools, too. I think it's important to present the context into which watershed analysis fits in the tribal program.

A few years ago during the Sustained Forestry Roundtable, there were lots of discussions about cumulative effects and watershed analysis. At that time the Cooperative decided that the concept of watershed analysis was very important and that we would spend a significant amount of time working on the development of that approach. After the Sustained Forestry Roundtable broke up, the process of discussing watershed analysis continued and eventually became its own rule. During that time, we spent probably several man-months a year working on the process, trying to develop it into the tool we needed for fisheries management.

In the state process, we tried to make it as rigorous as we could within certain time constraints. From our standpoint as fisheries habitat managers, we feel we've been successful. At this point, there are obvious problems in applying the watershed analysis. We fully expected to run into problems, because it's a new process. Some of them are technical, but I think in the Northwest region we run into more

procedural problems associated with processing the analysis once it's completed than we have with the analysis itself.

There's a major distinction between the state and the federal process, judging by our experience in the Mt. Baker-Snoqualmie National Forest. (I don't know whether other national forests are handling the federal process differently.) But the state process is based on the assumption that we will go out there and get the information we need to make an assessment. The federal process, on the other hand, is limited mainly to existing information. In our view, this makes substantial progress in land management very difficult from a forest perspective. We haven't made any decisions yet about how we're going to deal with the federal process, but at this point it looks as if there's apt to be significant confusion when somebody says a watershed analysis was done, because the two versions of the analysis—federal and state—are *not* comparable.

At the Skagit System Cooperative, most of our research over the past five years has been directed at essentially one major issue, along with one related sub-issue. The major issue is management-driven, and it's not based on an ecosystem policy or anything like that. The tribes hire people like us to try to make sure that the basin can produce the fish that they would like to be able to harvest. So in that sense, we're very much a management agency. What we have focused on for the past several years is the Coho salmon stock in the Skagit River Basin, because it's one of the limiting stocks in north Pacific fisheries. "Limiting stock" means that its run size is viewed as one of those that needs to be protected, and it is often protected by restricting other open-ocean fisheries that catch these Coho as bycatch.

So the implications of this stock reach much further than just to the Cooperative, and we've been able to gather funding from the Pacific Salmon Commission and other organizations to look into the question, what *is* the productive capacity for salmon in the Skagit Basin? And, is there anything that we can do to enhance that?

Related to that, what we have embarked on now is what we call our restoration program, and that's really an outgrowth of the earlier PSC study. (When the program started, before the word "restoration" was very big, it was called an "enhancement investigation.") The question we wanted to answer was, were there opportunities to enhance coho stocks or coho production from the Skagit? What we found was yes, there were opportunities, and the opportunities were defined based on our current productive capacity now. We compared that current capacity to our probably capacity before the advent of significant land use and development of the lower floodplain. We found there was a large difference, and that there were in fact lots of restoration opportunities out there. We also found that traditional restoration methods had been largely unsuccessful in accomplishing any of the things necessary to restore productive capacity.

We now have a system that structures our research, and watershed analysis is just one part of that. Our restoration approach is based on two things: goals and priorities. We use these goals and priorities essentially as the policy statements that drive our management action. Our goal is to restore the natural processes and watershed functions that sustained the stocks before human intervention. We have chosen that goal because it's important to deal with all species out there. We fully believe in the ecosystem concept, but it becomes cumbersome if you apply it on a species-by-species or a species-richness basis, or using some other biological aggregate measure. What we've chosen to do instead is look at the processes that drive the habitat conditions, and try to get those back in place.

In contrast to that approach, we have chosen to focus on a single species in prioritizing our restoration activities. We look at the coho salmon to rank the effectiveness of our various restoration actions. One of the tools we use is watershed analysis—but it doesn't give us everything we need to know for our restoration program. It's a management tool that gets us what we need to know to regulate forest practices on a site-specific basis. It provides us only part of what we need to do in restoration. So the rest of our program is geared around getting the various other components that we need to build our restoration information base, so that we can actually proceed with effective restoration.

Dickison: George Pess is going to be next. George has the distinction among our panelists of having worked on the Tolt River watershed analysis, the first one done under the new rule.

George Pess, Timber, Fish and Wildlife Stream Ecologist, Tulalip Tribe:

I'm just going to give you the answer to the four questions I'm going to pose to outline our fish habitat management program at Tulalip. Tim already gave you that answer, and it is: Watershed analysis is a component of our fish habitat management program. The reason it's a component is that we have four questions that drive what we do.

The first question is, which watersheds in the usual and custom area of the Tulalip Tribes—and that includes the Stillaguamish and the Snohomish River basins, both north of here—produce most of our salmon?

The second question is, what are the current habitat conditions of these basins? For those two questions, watershed analysis is a very effective tool in helping us answer the current habitat conditions.

But the other two questions that guide our management program are these: What watersheds historically produce salmon? And what will the future condition of the habitat be? To answer these questions, we use other tools in addition to watershed analysis..

But let me go into the first two questions first. Where does our salmon come from now, and what are the current conditions in these watersheds? We use watershed analysis as a tool to help guide that. We have looked at both river basins, and we've examined where most of our fish have come from over the last 10 years. To give you an example of how different the two river basins can be with respect to production, in the Stillaguamish River Basin over the last 10 years, more than half the coho appearing in our stream surveys come from one watershed. In the Snohomish, more than 80 percent of the production comes from seven or eight watersheds. So each river basin functions differently and has different habitat conditions. That gives us a context for where we want to see watershed analysis performed.

We've been involved in seven watershed analyses to date. Some of these have been formal processes with people like the Department of Natural Resources and Weyerhaeuser. Three others we've done on our own, as the Tulalip Tribes; these were watershed assessments. So we've come up with some basic observations, and I'm not going to into any details about our findings. But what we're trying to do is look at physical processes such as changes in sediment supply and loadings of large woody debris, and see how those affect fish habitat and fish production.

One of the things to have come out of the watershed analyses so far is that large woody debris is a critical component of certain types of fish habitat and different channel types, and that if we're going to see long-term increases in fish production from different watersheds, we're going to need to increase loadings of large woody debris.

The problem is, with the state of our riparian zones, it's going to take between 110 and 150 years to do that. That's where restoration and accelerating that process as much as possible would be helpful. The other thing that we've concluded is that, at least in the Stillaguamish and Snohomish river basins, wetlands are critical to coho and steelhead production. In 90 percent of the watersheds that do produce fish at near-capacity levels, we found that wetlands are the critical component that are still functioning in those watersheds. Examples are Squire Creek in the Stillaguamish and Griffin Creek in the Snoqualmie River Basin, which is part of the Snohomish.

These are just some of the tidbits of information that are coming out of these watershed assessments and analyses. These are important because they allow us as co-managers to take the next step and write prescriptions for those areas that protect—like Tim said—the processes and the function of these variables.

As I said earlier, the first two questions I posed to you are ones we're trying to answer with watershed assessment and analysis. For the other two questions about what was and what will be, we're using other tools. One of the tools is a habitat loss assessment, similar to what the Skagit System Cooperative has done. We're trying to undertake that as an interlocal agreement with the Snohomish County and the Stillaguamish Tribe to see where the habitat has been lost in the Stillaguamish River and see what kinds of long-term management strategies we can devise to protect the areas that are working, and then recover some of the other areas that have been lost.

Another component of the what-was-and-what-will-be question is restoration efforts, obviously. In my opinion, the trick to natural resource management is that there's never one answer. You always have to put things into their spacial and temporal context. As Tim was saying, you don't want to go off half-cocked with restoration efforts. I think a good illustration, of that is the Tolt Habitat Restoration Group of which we are co-chairs. In that process, we took the information from the watershed analysis, and we said, now that we have prescriptions in this basin, what are we going to do next in terms of recovery? One of our first priorities was to solve the problem of fish blockages resulting from culverts. This problem may seem minor, but it can in fact cut off a lot of habitat. It's not as sexy as putting wood in the channel, but if you calculate the number of miles of river that is currently off limits to salmonids because of culverts, I believe it's more than 3,000 miles in the entire state.

To address the problem of culverts, we got some money from the Jobs for the Environment program, under the auspices of the Tolt Habitat Restoration Group. Then we got some displaced timber workers and taught them how to do culvert surveys. So far, these workers have surveyed more than 900 culverts in the Tolt River and in the Skykomish. The next step for this year will be fixing some of those culverts to open up habitat that has been fragmented by the blockages. A similar culvert survey will be made in select watersheds in the Stillaguamish Basin. For that, we got funding under the Fish Commission in conjunction with the Stillaguamish Tribe.

The final component of our approach to the what-was-and-what-will-be questions is independent research. I think the tribes go unsung in terms of how much research they actually do and what they contribute to applied science as a whole in this area. If you look down the panel here, a number of these guys have published papers in leading journals, and I think that's an important step toward gaining credibility for the tribes' research efforts.

I'd like to mention two research projects we've been involved in. One has been with Dave Montgomery of the University of Washington. In this project we examined the role of large woody debris in different channel types. We found that under certain conditions, in certain channel types, where you don't have wood, you don't have pools; as a result, you don't have rearing habitat. This kind of information can be applied to protection of areas and recovery of areas as well, so you can target where you want to do things like in-channel wood placement.

Another research project we've undertaken in cooperation with the University—and Tim Beechie is also working on this—is the examination of the spatial and temporal dynamics of spawning chinook salmon in the North Fork Stillaguamish. What we found is that the peak spawning densities of chinook salmon have been migrating downstream in conjunction with changing sediment supply. This shows you the dynamic nature of these fish. And if you're going to make any protection or restoration efforts, you have to take into account their dynamic natures—they are not static creatures.

That basically sums up what we've doing. If anybody has any questions about the research, talk to me later on and I can tell you. Again, the most important thing to keep in mind is that watershed analysis is a component of our larger management efforts—and it's an important component in terms of the current habitat conditions and protection of those areas that need protection.

Dickison: The next speaker is Mike McHenry.

Mike McHenry, Lower Elwha S'Klallam Tribe:

Thank you. I have an example that I'm going to use of some data we collected out on the Olympic Peninsula and how it can apply to watershed analysis, restoration, and status of our stocks in general.

This is a rather short-term study, by ecological standards, but for the kind of information we work with, it's rather long-term. We're looking at changes in woody debris in Olympic Peninsula streams. We stumbled across an old master's thesis that was done by Glen Grady in 1982. Glen did an amazing amount of work, and to show you what one graduate student can do, it has taken the collective resources of these agencies to resurvey some of his efforts. These are the cooperators, I want to give a special thank you to

Eric Schott of the Northwest Indian Fisheries Commission, who was instrumental in coordinating this monster.

We haven't heard much about riparian zones in this conference. We've heard a lot about eelgrass and clams, but I think most of us in fisheries habitat and wildlife know how important these zones are. They're basically the transition between the terrestrial environment and the aquatic ecosystem. With regard to fisheries, they're absolutely critical. We've got to remember this is a high-energy environment we're living in, and basically the fish out here evolved in that environment, essentially under an old-growth canopy. We've made wholesale changes to that ecosystem, as you'll see.

Some research has correlated coho density in winter with woody debris density or volume and has shown a pretty strong linear relationship. There is a relationship in summer, but it's not as great. Woody debris does a lot of things in streams. It makes pools. It traps gravels in high-gradient environments that fish will use. It tends to dissipate energy. We see a lot of deleterious effects from scouring out there—and I think you might hear some of that from one of our other speakers.

The study area that Glen set up comprised 28 streams on the Olympic Peninsula, under various ownerships—federal, state, and private. They're all fish-bearing streams; they're all third- and fourth-order streams, low gradient. When Glen set this up, he divided the 28 sites into four different treatments: old growth; recently logged; and two others being various stages of recovery after logging. He collected a lot of information. We repeated these surveys in the summer of 1993, and had crews out all over the peninsula. One of the biggest problems was finding the sites, because, as you know, it's a jungle out there. And things like stakes and flagging tend to disappear rather quickly. But we did track them all down.

These were 100-meter sites, and we re-inventoried the wood in the sites. Basically, we measured diameter, then determined species, state of decay, length and position in channel. Maps were produced, both by Glen and by our crews.

Quickly, what we found was a rather dramatic decrease in the volume after logging. Now, Glen's sites, at the time of his study, were unlogged, but they've all since been logged. We have no more controls left on this study, unfortunately. You can see, all for except one site, we had at least a 50 percent loss in woody debris volume.

The relationship is pretty much linear on the old-growth sites. We also looked at the decay at these sites of the remaining wood within the sites. This stuff is still out there, but it's got a limited life span, in my opinion. This wasn't a big surprise, considering how our watersheds have been managed.

The trend on the young second-growth sites was similar. We saw a rather dramatic loss, similar to what we had seen in the old-growth sites. By the time you hit middle-aged sites—these are between 25 and 50 years old—the trend seems to have stabilized a bit. But we're essentially managing for volumes of wood that are a quarter of what we started with. We were up in here, on the old-growth sites.

On the mature second-growth sites, at first glance it seems you're starting to see a change. Volumes at some of the sites are actually increasing, and you're seeing some pretty hefty volumes of wood. But on closer inspection of the maps, once we got them in, we saw that most of these increases were due to formations of large woody debris jams. These basically reflect the instability of the systems out there.

This is pretty typical of the condition of our stands today, with regard to riparian zones and most of our streams. This is a tributary to the Pysht River. You can see that there's very little wood in the channel. It's dominated by riffles. It's not a very friendly environment for fish rearing. What input of debris we have coming in is primarily alder. The timber companies have actually done a pretty good job of protecting riparian zones in the last few years. However, we've inherited this situation where we've converted from a largely mixed conifer, old-growth condition to an alder-shrub stand. One of the problems with this is that the inputs of wood, obviously, are alder, and alder tends to break down rather quickly in a stream. Conifers, by contrast, can last hundreds of years.

This reinforces what we're saying: This is a survey we did on the Pysht River, and it shows that out of approximately 15,000 meters of channel we surveyed, more than 12,000 of them were dominated by red alder. Alder tends to break down quickly because of its favorable carbon-to-nitrogen ratio. A conifer will

have a carbon-nitrogen ratio of somewhere around 1,000:1. For alders, it's around 23:1, which is highly conducive to microbial action.

This is an alder that fell in over a creek. It had been here about a year at the time the slide was taken, and you can already see that there's microbial action on in the form of fungi. Another problem with the size and quality of wood we're getting is that we've de-stabilized our stream networks. This is a picture of Deep Creek, an independent tributary to the Strait of Juan de Fuca, and it's a time-series: This was 1971, this is 1990, and this is 1992. You can see that as a result of landsliding, debris flows, and things like that, the stream network is actually enlarged over time. It doesn't look like a whole lot on this map, but when you get on the ground it amounts to a channel widening of about three to four times its original width.

In addition, a lot of our channels are completely overwhelmed with sediment. This is an extreme example, but I think it shows you what happens to a lot of the woody debris in these stream-widened situations where there is an oversupply of sediment. The wood tends to get pushed out to the margins, where it provides no benefit to the stream.

This is the model of what we thought was happening out there after an old-growth site was logged. Everyone knew the total debris went down; Glen showed that in fact the old-growth debris plummeted. But we thought after 50 to 60 years, we'd start to see some pick-up of the second-growth debris. After the re-survey we did a little bit of plotting, and while we haven't completed all our statistical analysis yet, it looks pretty close to a flat line. We're concerned that the recovery may actually be hundreds of years off—and certainly, left to its own natural processes, it would be.

As far as watershed analysis goes, the Hoko Basin is one that I've worked on. More than 95 percent of the basin is in trouble.

So what are we doing about it? In watershed analysis, you boil down all this information, and then you sit down at a table with a bunch of timber company representatives and state agencies and try to figure out what you're going to do.

This is a graph that a lot of people have seen. It came out of the FEMAT work done on President Clinton's forest plan. On this side you have the effectiveness of the treatment, and on this side you have the distance in a tree-height potential, and a number of different variables. The one that I want to focus on is the recruitment of coarse woody debris. We're talking about, in a prescription phase, maximum RMZs of about 75 feet. If you go across here you can still see that despite the dire situation, we're managing for about 40 percent of potential.

Getting back to our condition, this has forced, I think, a lot of tribes to reconsider the restoration route. Lower Elwha is looking at both engineered solutions and cooperative solutions with timber companies to try to turn the situation around. So the news isn't all bad. However, it's going to take a lot of money and a lot of effort to reverse the trends.

On the Olympic Peninsula and throughout the state, everyone knows our salmon are in bad shape. This summarizes the status of coho. In the Strait, the region I work in, we're in *really* bad shape. In fact, we've never actually made our spawning escapement for coho. We've got to change that.

Things look a little better on the coast. However, I think that may have been the result of a lack of information at the time this was made. This year we've had a record low return of coho on the Hoh, as well.

Not wanting to sound too negative, we'll end on a happy note of chum spawning away, and happy tribal members. But we're definitely not there yet.

Dickison: Next we have Ed Salminen to talk about the Nisqually River.

Ed Salminen, Forest Hydrologist, Nisqually Indian Tribe:

I want to talk just briefly about a cooperative agreement that the Nisqually Tribe has been involved with since 1990. A lot of the project work we're doing came about through this cooperative agreement.

One of the provisions of the original Timber, Fish and Wildlife Agreement was the idea of setting up local resource management plans that were cooperative efforts among the tribes, forest landowners, and state agencies to build consensus on addressing resource management issues—fisheries issues primarily—in a cooperative fashion. The first resource management plan done in the state was in the Nisqually Basin, the Nisqually Resource Management Plan (NRMP). It was developed in 1990, as I said, by the major forest landowners, the tribe, and state agencies involved in the basin.

We found that the NRMP has been a pretty useful tool in that it provides us a forum for bringing issues before the forest landowners. They've generally been fairly receptive to things we've brought forward. We found in recent times, in going after grant money, it's been helpful to have a cooperative infrastructure already established that we can point to.

When I started my position two years ago, the first version of the watershed analysis manual had just come out. I looked at the data that was available on current conditions of streams and wetlands in the Nisqually Basin, and found that we had very little information. I realized that before we went into a watershed analysis, we needed to have a good foundation of data to support that effort. We have two major projects focused on gathering that data.

I was lucky enough that my predecessors had applied for and received a couple of grants to do some specific work in the basin. One was a grant funded through the Centennial Clean Water Fund to do a wetlands inventory in the area covered by this cooperative plan—which is about 90,000 acres in size. Over the beginning of this past year, we contracted to have this inventory done. It should be finished for the entire area by the end of next year, and we plan to do watershed analysis in one of the sub-basins that's included in the resource management plan area. That information should be available by the time we start an analysis this year.

In this wetlands inventory, what we're doing is first delineating wetland boundaries. This requires a lot of field work. We're trying to get the contractor involved to get out and sample about 80 percent of the wetlands. They are trying to characterize the function and values of the wetlands. They are also trying to determine which disturbances have occurred in these wetlands to date and what the current state of recovery is. They will also outline some restoration ideas for each wetland, so that we'll have that material to present to the landowners as well.

The original manual, and in fact the manual that we're currently using for watershed analysis, doesn't include a wetlands component. However, I think that having this information for the sub-basins that we're concerned with will be real helpful at the time we start an analysis to identify which wetlands are high priorities for special protection. In addition, this information will provide a sense of what the overall trends in wetlands are in the basin.

The second project we're working on is a water quality/stream habitat assessment project in two sub-basins. Each one is a watershed analysis unit. We're looking at several parameters in these studies—water column measurements (nutrients, dissolved oxygen, suspended solids, that type of thing). We're also doing an extensive stream temperature monitoring project, using recording thermographs at about 20 different segments of stream within these two basins, trying to find out where our temperature problems are, and tie that to riparian condition.

We've done a lot of work with fine sediment and spawning gravel analysis. We're looking at macroinvertebrates, and that will be useful to tie to the water quality measurements we have and the stream habitat information. Also we're doing quite a bit of channel assessment work, looking at large organic debris and fish habitat, and trying to tie those things to riparian condition as well.

I'm happy that the work we've done has progressed to the point that it has before watershed analysis was initiated. I have been kind of nervous the last couple of years, thinking that the landowners might start one up before we actually had some data that we could enter into the process with. But I think that we'll be in pretty good shape when we start one.

Dickison: The next presentation will be by Dave Schuett-Hames from Squaxin Island Tribe.

Dave Schuett-Hames, Squaxin Island Tribe:

The Squaxin Island Tribe has made a substantial effort to gather information on habitat conditions and use this information to obtain protection for the salmon runs of southern Puget Sound. We've taken that initiative because we found there was little information was available on habitat conditions from other sources. We found that the lack of information was contributing to poor watershed management. Often, the people managing the land, or the regulating agency, seemed to be unaware of salmon populations, their habitat requirements, and effective land use practices around them.

This lack of information often seemed to contribute to an assumption that everything was O.K., even though there was ongoing degradation of salmon habitats from human activities. So by filling the role of providing information on salmon and their habitat, the tribe intends to increase awareness of the plight of the salmon and promote more informed and effective watershed management. Our habitat protection strategy combines efforts to gather more and better information with active participation in many planning processes. Habitat information, for us, has proved to be an effective tool for influencing these processes and improving the protection of salmon habitat.

We see watershed analysis as a valuable opportunity for us to tackle the tough cumulative effects problem. This is an issue that's been very frustrating for us. It is conceptually very complex, so it's been very difficult to get land managers or regulatory agencies to address cumulative effects in a meaningful way. Watershed analysis provides a promising approach to deal with cumulative effects because it's based on identifying the cause and effect linkages between land use activities and the processes that create and maintain salmon habitat.

We were offered the opportunity to do the fish habitat module for the Kennedy Creek watershed analysis, which is under way right now. That watershed analysis has been sponsored by Simpson Timber Company and the state Department of Natural Resources. We took a data-intensive approach to the module. We collected extensive habitat information from many stream segments, and we used the TFW ambient monitoring survey methods. We found it was very beneficial to have first-hand data when we went into the analysis process. When questions arose at many points in the resource assessment or the synthesis process, often having first-hand observations on habitat conditions affected the outcome of the analysis.

I'd like to share briefly some of what we learned through the analysis, even though we're still in the process. First of all, we realized that the current habitat conditions reflect the physiographic setting, the past disturbance history, and the subsequent recovery processes that are going on in these watersheds.

In general, we found that spawning gravel is typically abundant, except in the wetlands and channelized reaches. Many streams have moderate to high fine-sediment levels, and scour to egg pocket depth is a concern in some of the reaches.

The canopy shade is often inadequate to avoid exceeding state water quality standards for summer stream temperatures, and many of the stream reaches are low on functional large woody debris, especially the large key pieces of the long-lasting conifer. They're replaced by the smaller deciduous pieces. There's often low recruitment of large woody debris from the young, alder-dominated riparian stands or areas where the riparian forests are absent.

Some reaches are low on pool habitat, often due to the lack of large woody debris or due to abundant supply of bedload.

Finally, some of our reaches have lost their wetland and off-channel refuge habitats due to local drainage or channelization projects.

The current habitat conditions have been shaped primarily by four disturbance factors. First, we've had clearing of the riparian forest for timber harvest, agriculture, and development. Second, we've had an increase in the sediment supply due to channel disturbance, especially from the early logging techniques of the 1930s through the 1950s, which often involved yarding[?] through and down the stream channel system. Third, we have increased peak flows due to the conversion of forest land to freeways, agriculture,

and development. And fourth, we've had some straightening of stream channels and drainage of wetland systems.

So this watershed, in some respects, seems to be in a recovery mode, and we're hoping as we go into the prescription process of watershed analysis that we can minimize future disturbance from forest practice, especially to the riparian zones and to the sediment regime. Over time, recovery of the riparian forest should increase large woody-debris loading, due to increased recruitment of conifers from the second growth stands as they mature. In Kennedy Creek, the riparian forests are getting into mature second-growth state. The rate of sediment input to Kennedy Creek from current logging practices appears to be relatively low. However, sediment from the 1930s to 1950s era is still working its way through the system. It's estimated to take more than 50 years for this material to go all the way down through the stream channel. However, as this recovery occurs, there should be a decrease in fine sediment levels and an increase in pool habitats.

Urbanization appears to be the most serious long-term threat facing fish habitat in the watersheds. Conversion of forest land to residential development often results in clearing of the riparian forest, and site preparation and poorly designed and maintained road systems are ongoing sources of sediment input. Also, the increased run-off from forest land as it's converted to freeways, agricultural uses, and urban development is going to cause increasingly higher peak flows.

That's some of what we learned through the analysis, and I just wanted to conclude with some observations about the process. First of all, some strong points about watershed analysis. I think one strong point is that it uses the approach based on the cause and effect linkages between the land use, the geomorphic processes, and the habitat. This really provides a basis for improving our understanding of how each watershed functions, so we can build on that and improve our general understanding over time.

Second, watershed analysis is a data-driven management system; it actually uses information. It can be done with limited field data; however, this seriously weakens the product and makes it less likely to identify problems accurately or provide adequate protection. So I think we need to take advantage of the fact that the process can use data.

Third, from the tribal perspective, it's an opportunity for the tribes to participate in cooperative management. From what I've seen of the tribes, they like to participate in decisions that have an influence on their resources and their future, so that's a very positive point. The attitude of the group you work with is very important, however. In the Kennedy watershed analysis, we had a relatively inexperienced group, but the people were open-minded and cooperative. And the watershed was not in a crisis stage. Consequently, we were able to learn together in kind of a team-building type of atmosphere, and I think that provides a basis for positive cooperative management of the watershed in the future.

I'd like to mention some limitations of watershed analysis. First, watershed analysis is targeted at forest practices; however, in this analysis we identified several significant effects on salmon habitat from agricultural and residential development, which were outside the purview of the watershed analysis process. From the tribal perspective, we would really prefer to have one comprehensive procedure that looks at all of these pieces, as long as we're going to the trouble and expense of doing the analysis.

Second, the prescription teams may not have adequate information or expertise to develop reliable site-specific prescriptions. We're attempting to do management on a very site-specific basis, but do we really have the research to know exactly how many trees that we need to leave in a riparian zone, or how many trees to leave in a groundwater recharged zone for a deep-seated landslide? I don't know. So I think the prescription process is going to have to be kind of a learn-by-doing, trial-and-error process for a while.

And third, preventing future impacts will not necessarily achieve our fish habitat goals. Watershed analysis does affect future practices, but much damage has already occurred in these watersheds from past practices. So recovery and restoration are critical elements of the habitat management plan that are not going to be adequately addressed by watershed analysis.

So, what's next? I think that watershed analysis is far from perfect right now, so I think that we'll see continued evolution and refinement of the process as our experience with it grows. However, no matter how well refined the process becomes, it's unrealistic to think that it will answer all our questions about

the watershed. The tribes will continue to be faced with uncertainty about how well the process is going to work. In this context, I think follow-up monitoring is imperative to determine whether the fish habitat goals of the analysis are being met. If we can do the monitoring, that will allow us to evaluate and improve the watershed analysis over time.

Question and Answer Period

Dickison: It's time to move into some questions. I wanted to make another observation that the Northwest Native American tribes have a long cultural history of transmitting information from generation to generation. They typically did that as an oral history. have adapted fairly well, I think, to the late-20th-century standard of writing everything down and circulating it. They've managed their fishery resources for generations upon generations; it wasn't something that they conducted haphazardly. And they still manage them now. They have undertaken to hire biologists, as you see here—in our case, a number of white males—who do not necessarily reflect the tribal population but who thrive in an atmosphere that is more weighted toward proof and re-proof and toward working through these management issues in an academic environment.

I want you to understand that the burden of understanding these issues and responding to them-the adaptive management question that's been raised earlier in the conference—is something the tribes always participated in. It's not something new that we have created by taking a more academic approach to things.

Having said that, one of the questions that was raised earlier by Dr. Ray Hilborn was the question of monitoring, and Dave mentioned it here as well. If you're going to have a truly adaptive management system, where you try out alternatives and respond to the results, you've got to do something about monitoring the result. Watershed analysis, as it's currently practiced, does not require monitoring. So it might be hard to claim that this is an adaptive management process. I want to pose this question to the panel: Recognizing that monitoring is not required (though it certainly does exist in some circumstances), what do you think is the best way to assure that monitoring occurs? The approach we have now is kind of hit or miss; we do things, certainly industry does things; occasionally, there's other public funding for such projects. But what's the best strategy for us as resource managers to assure that monitoring is done? Anybody want to step up to that question first?

Beechie: I think, first, let's recognize that all of us here are technical members of the tribal organizations, and I think this question extends well into the policy realm. I don't believe we have the authority to speak on policy. But in the Skagit Basin, based on the way we've seen things develop with the timber companies we work with, I wouldn't immediately jump to the conclusion that we need to require monitoring in the watershed analysis. Over the past five or six years, starting even before watershed analysis began, we've developed a pretty good working relationship with all of the companies that operate there. And we have been able to come up with funding, or at least bootstrap methods for doing the monitoring we've needed. I think the one thing that's important to do in each of these analyses is to make sure we're clear about what we expect from watershed analysis: We expect to come out of it with a hypothesis. We have already done the adaptive management in the sense that we have run the first experiment. When we do the analysis, we're looking back at that first round of land use practices to see what happened. Now we adapt to that. This time around, we have adapted from the first round, and we're trying to make a guess as to what will make it better the next time around. Again, it's important that we make clear what results we expect from the watershed analysis and then what parameters we need to monitor. It can be a large and costly effort, but I don't think it necessarily has to be.

Schuett-Hames: I think those are good suggestions. Sometimes it's amazing to me to think of how many experiments we've applied to the landscape over the last 100 years. We've created many changes, and very rarely have we tried to understand or document what's happened when we did things. And I think we're suffering from that carelessness today. This is part of the problem we have when we're on a

prescription team trying to figure out how to manage forest practices in a particular way. There just isn't a lot of information out there on how the systems have responded to various site-specific practices—or at least anywhere near as much information as there could have been if people had made a conscious effort in the past to follow up on land treatments and determine whether they were effective. That's one of the ways that we need to persuade people to do monitoring follow-up to watershed analysis. You have to take a bit longer to look at the cost, and realize that if we can go out and apply some prescriptions now and do follow-up monitoring, evaluate how they work and what the effects were, that's going to create more certainty for us, more confidence in our management, and it's also going to give us the information we need to apply these management prescriptions in the future, know their limitations, and know the context in which they're effective.

Q: I was wondering if any of you have any examples of your adaptive management techniques, either in specific assessment techniques that you supported in your watershed testing, or the specific prescriptions that came out of this. Is there any change that you can remember that would be representative of adaptive management?

Beechie: I'll start with one comment. There has been some formal adaptive management in the sense that the watershed analysis manual has gone through several revisions already, and those were primarily driven by experiences in the first watershed analyses. A lot of heated debate went into the development of the manual, and discussions of which way to do it and how to get to the right answer. We could only come up with one method, in the end, so we used that. And then I took the one that I'm most familiar with—the fish module, the habitat module—and we went through a long series of meetings and developed an early version of that assessment procedure that had very few diagnostic indices in it, because those are the ones that we had the most confidence in, based on the literature. After having gone through that, we found that really it didn't present us with a very good picture of what was going on with the habitat, and we chose at that point to change the procedure and add more diagnostics that we had less confidence in, under the understanding that we would try to use as many of them as possible to arrive at a better picture of what was going on with the habitat. I think that's just one example.

Dickison: Several of these guys have been involved in rewrites of the watershed analysis manual, which is essentially the book of procedures—how this is carried out. And what version are we up to now? 3.2?

Pess: Does your question relate to the prescriptions, or the assessment, or both?

Q: Either one.

Pess: With regard to the prescription, does your question relate to how do you come up with two slightly different prescriptions for different basins? Is that kind of getting to the heart of it?

Q: That's getting to it, yes. For instance, have you come up with one prescription, seen the result of that prescription, and then changed it the next time around?

Pess: The answer is no, because watershed analysis hasn't been around long enough. It's a space-for-time substitution at this point. What's happening is that you have several different watershed analyses going on, and they're coming up with different, let's say, riparian prescriptions. I've seen range from 100-foot no-cut to partial cuts within the riparian zone. So the stage is being set to see what that actually means in the long run. And just to repeat what Tim said about the assessment, if you read the watershed analysis manual you'll see a caveat at the end of each module saying, this is not the end-all. This is something that is ongoing, and it will be evolving, dynamic, and adaptive. The module I was involved in was the channel module, and if you compare the first one to this one, there's a big difference. There might

be a really big difference in the next one coming down the pike—who knows? From the applied science perspective, we are trying to bring in information from people who are actually doing it. So, it's the first time that I've seen something that has certain accountability and responsibility with it—because it's a cooperative effort. You know, if you're going to put your name on an assessment and you're going to get credit for what it accomplishes, then you're also going to have to take the heat for what it doesn't. But with where prescriptions are concerned, we haven't had enough time to really see what that actually means on the ground yet.

Q: When you sit down...[with the timber companies to discuss your findings] ...what's happening at that table?

McHenry: We have an active exchange of information. I think each party tends to put its own spin on the information, so have a lot of spin-doctoring going on. There is also some disagreement over what the information actually means. Then you've got unique areas in each watershed, so it comes down to trying to tailor those, frankly, to what's acceptable. You know, there's an economic consideration from the timber companies, too. From their standpoint, that's very important.

Beechie: I'll add to that. The part of the watershed analysis process I've been involved in is the prescription phase. Once we finish the analysis, which involves just the technical team, we go into the prescription phase, which involves land managers, and in our case included all of the assessment people as well. At that point, what we do is take the understanding that we have of the watershed with all of that data, and then using the expertise of the forest land managers, try to understand how we can manage that, and set up the prescriptions for each of the hazard areas or each of the areas of concern that we've identified in the watershed. So each of those are enumerated with a clear description of what the problem is, and what triggers that problem, from a land management context. That's what the prescription team works off of. Given the problem and what it is that causes it and what the effect is, then the foresters contribute their expertise, which is: how can we accomplish this? In our case, given that we had already developed a working relationship with them, it was a relatively easy process to go through. It only took 3 or 4 days, which I think is relatively short, compared to some of the other ones.

Pess: I'll just add one thing to that. It does vary quite a bit with regard to what you're talking about on the landscape. For example, if you're talking about landslides and mass wasting events, it seems like sometimes you could come up with a pretty straightforward prescription. There's a learning curve involved for both parties, where you're banging against myth and legend, sometimes. For some problems you can come up with prescriptions pretty easily, and then in other cases your knowledge isn't as good, and it becomes more ambiguous. In either case, you're learning something, whether you're a landowner or a tribal or fish habitat manager. I know I've learned a lot more about how forests are managed in my two years of working with prescription than I did in graduate school. And I think the same can be said for the forest managers, as well. They're beginning to see that some of these management myths that have been promoted over the years just don't hold up against the data.

Q: Is there a difference between watershed analysis and watershed assessment? If so, what is it?

Pess: Watershed analysis is an official process that's under state regulation. As Jeff described the WAC to you, it's initiated by a landowner, who owns a certain percentage of a watershed. Then it goes through the official process, and prescriptions are made, and then it goes through SEPA. Watershed assessment is basically using some of the tools that are in the watershed analysis manual to assess how a watershed functions, and what kind of impacts you're seeing there. But that has no legal binder to it, like a SEPA process or anything. It's just basically going in and assessing the physical processes and how a watershed functions. That's why I tried to point out the differences—at Tulalip we've been involved with the fish

and watershed analyses that have been initiated by Weyerhaeuser and the DNR. But we've also done our own watershed analysis, and we call it watershed assessment, because it has legal implications if we call it watershed analysis. And we have more flexibility because we don't have to do all the modules. We can concentrate on a couple of things. But the trade-off is that there are no prescriptions that follow that watershed assessment. So it's basically a report that we do.

Beechie: You will also see the same language in the Forest Service documentation that's come out, that there are both watershed analyses and watershed assessments, from their perspective. I don't fully understand their procedure at this point, but I believe that the watershed assessments are interim processes, and I think most of those should be over by now. They are now into the pilot watershed analyses, and I don't believe they're allowed to use the assessment procedure anymore, which was a briefer version and not tied to the watershed analysis guidelines that they were given.

Dickison: There are a number of questions up here having to do with the notion that watershed analysis should take many factors into account and not just timber harvest. The tribes have been very interested in working with timber companies because they generally view timber companies as a large landowner in the basin—a landowner who is probably going to be there for a long time. And we've got a long history of working together. But can watershed analysis be applied beyond this narrow relationship with the timber industry?

We have another question here, in this case about the Skagit System: How are the tribes dealing with Island County's expressed need for off-island water? There's a question about wood debris in streams as a cause of problems for rural small-landowners—bank erosion and flooding. There's animosity among small hobby farmers because of all the back-to-nature fishery regulations—When are you going to recognize and handle this problem? And here's another question: If watershed analysis is working well dealing with timber companies, how should the tribes address impacts from agriculture and urban development?

So let me group all those questions together this way: Do we, as tribal biologists, think that watershed analysis has an application downstream from a forested watershed, getting into the more intense land uses—agriculture, and urban development? I think you heard some of the guys up here saying that, for the tribes, watershed analysis is a piece of the management system, and we are doing other things in these areas. Do we hope or expect to be able to bring watershed analysis to these other land uses? Can we perfect it in forest practices, and move it downstream?

Q: It seems like most of the techniques used to assess forested watersheds could be directly applicable to agricultural land or other non-forested areas. There just isn't the regulatory framework to do it. That seems to be the stumbling block, in my opinion.

Dickison: That's a good point. With the Forest Practice Act, we had rules in place that we were adding pieces to so that we could fill in the section of the puzzle. The next big downstream land use is agriculture. What exact regulations are there? I'm not sure. Agriculture is largely unregulated land use, and it's hard to fit a piece like this into that regulatory scheme.

Q: I was just going to mention that in the Kennedy watershed analysis, using the assessment modules, the team actually identified a number of instances where non-forestry activities were causing impacts to the salmon habitat. In that watershed we actually wrote causal mechanism reports for those activities that described the cause and effect linkages, in the same way that we did for the forest activities. We haven't done anything with that yet, but there is a provision in the process for watershed analysis where the DNR would send that information to the appropriate jurisdictions for their information. But that demonstrated to me that there is potential to use these assessment techniques to identify important impacts from other activities. From a tribal point of view, what we're really interested in is the protection and restoration of the fish runs, and it's been very frustrating to deal with the very piecemeal approach to watershed

management and habitat management that's out there with all the different agencies and jurisdictions. I think there would be some real benefit from looking at these watersheds in a more holistic fashion, and at least doing the assessments holistically, while understanding that dealing with the problems would have to take into account the different jurisdictions.

Dickison: That might be nice in theory, but typically, when we're dealing with the watersheds that most of us are involved in, we tend to be involved with a fairly small number of timber-related landowners. When we move into the agricultural and urban areas, we get vastly increasing numbers of interested parties. Does watershed analysis have a role to play in these circumstances where there are huge numbers of interested individuals?

Pess: In theory, when you're writing a prescription for watershed analysis, you're writing it for the processes that are at work in that watershed. It's supposed to blind to landowners. In theory, it's supposed to apply throughout the landscape. But again, that's from a technical standpoint, and I don't know how that would work in the real world.

Q: I understand that the depth of information you're getting from watershed analysis may allow you to predict and know the level of water allocation you need for your fisheries. That way other demands for, say, municipal water systems, or for agriculture, would be part of your prescription for the surplus. Are your watershed analyses designed so that you know how much you're getting?

McHenry: You've brought up an excellent point. The state of Washington currently has no coherent policy for allocating water. And the tribes are very concerned about this problem. Maybe Jeff might want to comment, but we closely monitor the allocation issues, and we have a number of basins that are over-allocated.

Q: Do you know how much you need?

McHenry: Yes and no. Watershed analysis does not cover minimum stream flows at this point.

Dickison: There are other programs in place for collecting data on stream flows. I think, though, that a somewhat broader issue is, as we work with these systems, can we identify the needs? These are the kinds of questions George was asking and that the Tulalip program asks. What is the historical and future potential? Can we evaluate the conditions of these systems and project what the potentials are going to be and the needs associated with them? Through a combination of programs that work in tribal country, I think that we can. Watershed analysis, itself, does not do that. I think Dave wants to respond in part to that question. I would just say that regarding water, I think the tribes are generally strong believers in western water law: first in time, first in right—and we have all the senior rights.

Schuett-Hames: I'd like to go back to the question we skipped about the small landowners. In the basin I was working in, there were many small landowners there because the area contained some residential areas. We had some involvement from the small landowners in the process, and I think that was a positive factor, both for the analysis and for the landowners. For one thing, they had a lot of first-hand experience and knowledge, as well as historical information that was very useful to us in doing the analysis. So they were an asset to the analysis team. The analysis was a positive experience for them, too, because it gave these landowners the opportunity to sit in on the prescription team. Watershed analysis looks at very site-specific management of the land, so they were able to come in and talk about one particular stream that was bringing gravel down and clogging up a particular culvert. Getting down to that level of management, I think, is very beneficial for the small landowner. So I think there's potential in this process for the small

landowners, and I think they also have something to contribute to the other people who are involved in the process.

Q: [regarding federal lands]

Beechie: As of yet, we haven't seen any federal watershed analyses in the Skagit Basin, so I'm not sure exactly to what degree they have any clear statement of what the management is going to be in a particular place. In a state process, it's very clear, and it's legally binding. Once you've completed prescriptions, those *are* the forest practices rules for that place. You could easily pick out in a state watershed analysis. But in the Forest Service ones, I'm not familiar enough.

Q: How about giving us some idea of where the greatest opportunities for improvement in watershed analysis lie?

Dickison: In responding to that, let me wrap up with another question from the audience. From our perspectives, what can the state regulatory agencies do to enhance our efforts?

Salminen: There are certainly some things that are missing from watershed analysis as it exists right now. Wildlife is not addressed, at least not directly, and that's certainly one area that could be improved.

McHenry: I think the restoration component might be improved. Currently, it's strictly voluntary, and at least the ones I've been involved in, we're not getting a lot of cooperation.

Pess: I think there also should be a wetlands component. Just based on the data we're gathering about fish production, the function of wetlands is critical to whether the various species are making it.

Schuett-Hames: I'd like to make just one point. I guess this isn't necessarily an improvement of the procedure, but I think that we need to do more of it right: The resources that are going into it are fairly limited. I think that's one area where the state agencies need to improve their contribution to the process, because I think we see more effort coming into it from the timber industry and the tribes than the state at this point.

Beechie: I would agree with that, in large part. What we found when we ran the first watershed analysis in our area is that there is no infrastructure within the DNR to handle these. DNR has certain technical people, but there are no computers available, there are no photos available, and there's no budget to get photos. They're just not quite ready for it. It would help if the department were set up to handle one of these.

Pess: I agree with Tim. And the last thing, I think, is the time frame that's been given to actually do these. Actually, we've done a pretty good job of getting the analyses done within the time that had been allotted, but the time frame is short. I believe it's 30 days for a Level-1 assessment and 60 days for a Level 2. If you're talking about 62,000 acres, good luck. So I think that we need to reevaluate how much time it actually takes to do this right, since it's going to result in something that's legally binding for about five years. That's something to consider, as well.

Dickison: Thanks. I think we've heard one theme there, that we all envision the continued use of this process. There have been suggestions for improvement, but I don't believe I heard any suggestions for throwing it away and trying something else. We need to find ways to make it work better, perhaps broaden its application from the forested watershed, down into the lower parts of the system. But I hope we have presented you with something of a perspective on how the tribes are approaching these issues. I think the most important element in our strategy is that we keep things moving ahead, that we improve our management systems, that we bring more information to the table, and that we ultimately make better decisions. The tribes have been here longer than any of us, and they expect to be here in the future longer than any of us.

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PUGET SOUND RESEARCH '95

SESSION 6B

MARINE MAMMALS AND BIRDS

Session Chair:

John Calambokidis
Cascadia Research

MARINE MAMMAL SIGHTINGS AND STRANDINGS IN PUGET SOUND FROM 1980 TO 1994: WHO, WHAT, WHEN, WHERE AND WHY

Jeffrey A. Rash[1]

INTRODUCTION: WHO

The Marine Animal Resource Center (MARC) is an all-volunteer, non-profit organization founded in 1976. MARC is the primary response center for the Northwest Marine Mammal Stranding Network in Washington state, as designated by the National Marine Fisheries Service. We maintain a 24-hour hot line and pager system to monitor incoming calls concerning marine mammal sightings, strandings and deaths throughout the year. MARC is composed of a team of approximately 50 volunteers who are dispatched around the state to respond to calls that come through the hot line. Also, a team of 20 veterinarians volunteer their time, expertise and facilities to assist MARC's efforts. These efforts allow MARC to respond quickly and efficiently to calls about marine mammals in the Washington marine ecosystem.

In 1979, the harbor seal (*Phoca vitulina*) population in Washington state was approximately 8,000 seals. In 1993, the count was approximately 24,000 (Nysewander et al., 1993). This increase is a major factor in MARC's observed increase in deaths, but it is not the sole factor. From 1990-1994, MARC has observed a more dramatic increase in marine mammal deaths. Because this increase is so recent, much of this paper will concentrate on this time period.

From 1990-1994, the bulk of sightings, strandings and deaths were pinniped-related. Necropsies and tests were performed on cetacean tissues, but the numbers were comparatively low compared to pinnipeds. We will explore the five basic questions: who, what, when, where, and why. "Who," as seen above, will briefly discuss MARC investigations. "What" will break down each individual pinniped species MARC has investigated and comment on special events concerning that species. "When and Where" will explore the regions and times of year MARC investigates specific events, where seals are seen during various times of year, and when we observe a variance in sightings and deaths. "Why," the discussion, will try to pull together all of the above factors and give a complete picture of what MARC observes during the year. The goal of this paper is not to draw conclusions or to point fingers at one specific factor or event. The goal is to bring all of MARC's research and observations into clear focus and allow others to use our investigations to aid their own research and findings. In doing this, MARC hopes to prompt more questions and possibly more discussion about the difficult issues that face everyone involved in research not only in Puget Sound, but also in marine ecosystems worldwide.

WHAT

MARC has dealt with five species of pinnipeds over the past 18 years. They are:

Pacific harbor seal — *Phoca vitulina*
California sea lion — *Zalophus californianus*
Northern fur seal — *Callorhinus ursinus*
Northern elephant seal — *Mirounga angustirostris*
Steller sea lion — *Eumetopias jubatis*

The majority of MARC's calls concern pinnipeds. Furthermore, more tissue samples have been gathered from pinnipeds than from cetaceans (though these have yet to be tested toxicologically). For this reason, this paper will focus on harbor seals and California sea lions.

The harbor seal is the most abundant marine mammal in Puget Sound and is therefore the seal that MARC receives the most calls on (Nysewander et al., 1993). The California sea lion has been increasing

[1] Marine Animal Resource Center, 2201 34th Ave. W., Seattle, WA 98199

in numbers and bad press. Most of the calls concerning this species are regarding fishing interactions. The Northern fur seal is an infrequent but somewhat periodic visitor to Puget Sound. Calls to MARC about Northern elephant seals usually relate to sub-adult seals molting and have been increasing in numbers over the past three years. The Steller sea lions are often seen on the coast and on some mid-channel buoys within Puget Sound.

In comparing the pinniped sightings and deaths of 1980 through October 1994 (Figures 1, 2, and 3) the harbor seal and California sea lion are seen most frequently. These observations are confirmed as to species and location, then logged into our records and compiled into yearly reports. This information is then distributed to members of the scientific and governmental communities.

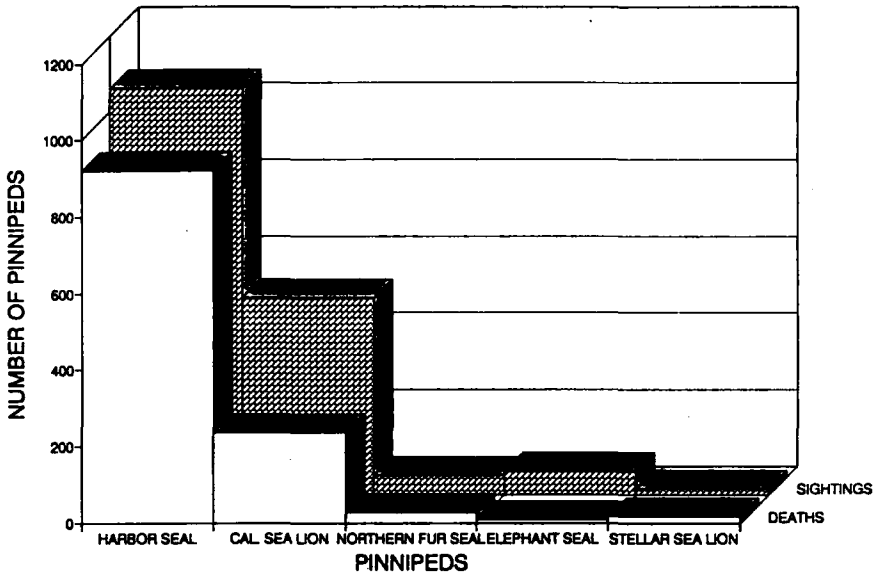

Figure 1. Pinniped sightings and deaths 1980-1994

Harbor Seals

The harbor seals are the most commonly reported marine mammal to our hot line. The majority of the calls concern young pups. The sightings of these seals peaked in 1984 and 1989. The calls have consistently increased during the 1990s. Both live sightings and deaths had been fairly consistent with each other through the 1980s. But beginning in 1991, deaths began to outnumber the sightings. The majority of calls concerning pups occur during the months April through October. Many of these seals are encountered on the beach by a private citizen taking a walk along the beach. The seal is generally thought to be sick or injured and is called in to our hot line. We observe many of these seals over a period of time and check them for any injuries or wounds. The majority of observed pups have left within 24 hours.

Of the seals that are found dead, MARC is able to retrieve about 30 percent-35 percent of them. The remainder are either inaccessible or too decomposed for tissue sampling. A limited budget prohibits us from retrieving many of the seals that offer viable samples but are in areas that are inaccessible by car. These seals are referred to National Marine Fisheries Service.

California Sea Lion

This seal has been the center of controversy in Washington because of its interaction with the salmon fishing industry. Possibly related to this controversy, many of MARC's investigations of this seal have been a result of gunshot injury or death. The live sightings peaked between 1984-85 and 1992-93.

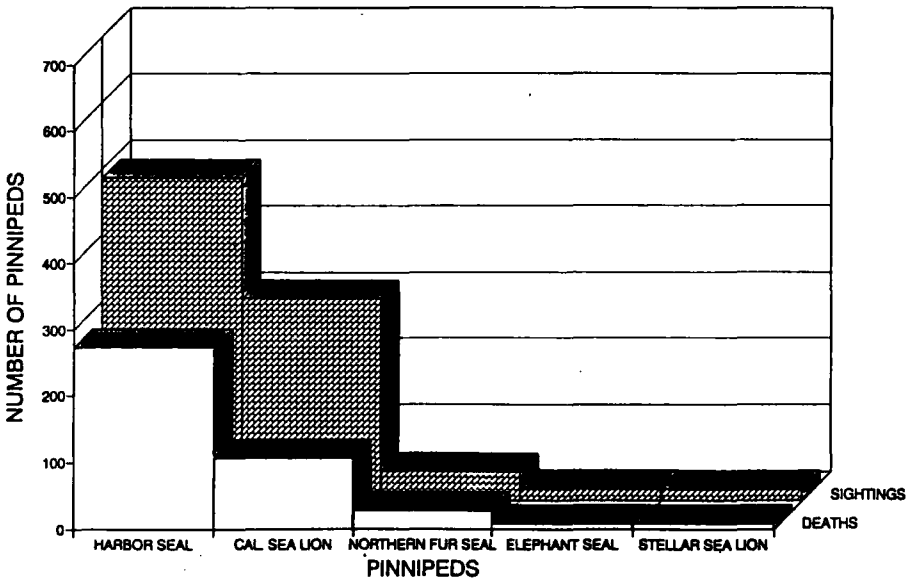

Figure 2. Pinniped sightings and deaths 1980-1989

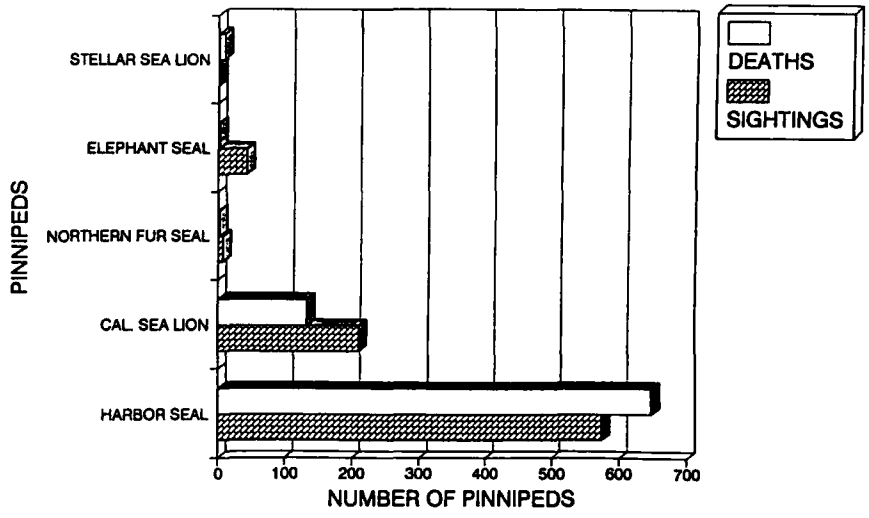

Figure 3. Pinniped sightings and deaths 1990-1994

This coincides with the large amount of press given to the fisheries interaction problem. The deaths during 1980-89 are very consistent in number. 1993 had been the highest total.

Most of the live sightings observed by MARC volunteers were of this seal resting or sleeping when the seal lies in a horizontal position, with one flipper in the air and its nose just above the water's surface. The public often thinks the seal drowning or caught in a net. Most of the sea lions observed during this time have been adult males.

Northern Fur Seal

Most of MARC's sightings of this seal have been along the Washington coast. These seals are pelagic and are rarely seen close to shore. In March 1980, a chemical spill occurred off the Washington coast during the northward migration. A total of 50 female seals were stranded along the coast. More than 40 of these animals died as a result of exposure to the chemical. The others were either released or placed in captivity. Tissue samples were taken from the dead seals and stored for future analysis. During 1993 and 1994, several yearling seals have been observed in Puget Sound, specifically Admiralty Inlet and Elliot Bay. Two of these animals were taken into a re-introduction situation because of signs of weakness and emaciation. One seal was deemed non-releasable by National Marine Fisheries Service and MARC veterinarians and was placed into captivity at the Seattle Aquarium. The other seal died within two days, and tissues were taken for future analysis.

Northern Elephant Seals

As with the Stellers, MARC's dealings with this seal have been minimal. More sightings of this seal have occurred during the period 1990-1994 than in previous years, the peak year being 1994. These seals have been observed molting on several beaches within Puget Sound during the months May through August. The seals are usually 5-6 feet long and weigh approximately 300 pounds. Their skin has been observed to have scars, scabs, and lesions, which are consistent with molting behavior. The elephant seals we investigate are found consistently hauled-out on sandy beaches within the Puget Sound region. Some of these beaches are heavily populated, others remote. The length of stay on the beach ranges from a couple of hours to three or four weeks. If possible, while on the beach, the seal is tagged and bacterial swabs of any lesions are taken for analysis.

Steller Sea Lions

Throughout MARC's history, we have dealt minimally with this species. The population of this species has been declining for several years, and it is now on the endangered species list. Much of the work being done with this seal is taking place within governmental agencies such as the National Marine Fisheries Service.

The most significant event for MARC concerning this seal occurred in March 1993. Thirty-two pinnipeds were found along the Washington coast dead from gunshot wounds. Three of those seals were Steller sea lions. One female was pregnant, and the other female was found half submerged in a stream. Tissue samples were taken from all animals for analysis.

WHEN AND WHERE

This section concentrates on when MARC has seen trends in sightings and deaths and where these have occurred. The calendar year is divided into four quarters: January-March, April-June, July-September and, October-December.

Because MARC covers the entire state of Washington, we divide our coverage area into six regions:

Washington Coastal Region (Ilwaco north to Neah Bay)
Strait of Juan de Fuca (Neah Bay east to Port Townsend)
Hood Canal Region
Northern Puget Sound Region (San Juan Islands south to Admiralty Inlet, Whidbey Island to Everett)
Central Puget Sound Region (Everett south to Seattle)
South Puget Sound Region (Seattle south to Olympia)

Most of the details that are discussed here concentrate on the 1990s, when MARC obtained most of its information on disease factors. The 1980s serve as a comparison. During the 1990s, a steady increase has been observed in both pinniped sightings and deaths. The majority of sightings and deaths occur during the months April-September. This is most likely for the following reasons:

1) This is when harbor seals in Washington waters give birth.

2) This is also the time of year when we see an increase in beach and water recreation by the public, leading to a greater chance of sighting marine mammals.

3) The population of seals in Washington seems to be increasing (Nysewander et al., 1993).

In 1980-1989, 1,121 marine mammal sightings were investigated. Of these, 866 (77.2 percent) concerned pinnipeds. At that same time, MARC investigated 549 marine mammal deaths, 420 of them (76.5 percent) pinniped related. In contrast, 1990 through October 1994 have brought 984 marine mammal sightings into MARC, 823 (83.6 percent) being pinnipeds. Deaths of marine mammals during this period were 861, with 778 (90.4 percent) involving pinnipeds. Looking at the two time periods, a large difference is seen in both sightings and deaths. During the 1980s, the average number of sightings and deaths of pinnipeds were 87 and 42 respectively. The 1990s have seen this rise to 165 and 156 respectively.

Looking at each year of the 1990s separately, an increase in pinniped sightings and deaths occurred each year. Each year had the same peak period for sightings, April-June. The same is also seen for deaths, April-September (the most active times in Washington waters for pinnipeds). But the yearly increases are yet to be explained.

Washington Coastal Region and Straits

This area includes three major harbor seal haul-out areas along the coastal region—Columbia River basin, Willapa Bay, and Grays Harbor (Nysewander et al., 1993). Traditional pupping times for the harbor seals in this region are from early May to late June (Newby, 1978). Many of the seals that are seen in the Strait of Juan de Fuca may come from the Port Angeles area, Eagle Point, Pillar Point, Slip Point or Crescent Bay.

The live sightings and deaths in this region have been on the increase since 1990. Looking at the years separately, 1994 saw a large increase in sightings over prior years. The number of dead pinnipeds rose dramatically in 1993 and is expected to be equal or higher in number in 1994. April-June are seen as peak activity periods for each year. This is consistent with the activity patterns of harbor seals in this region. The seals in this area are mainly harbor seals, although MARC has investigated California sea lions and Steller sea lions in this region as well.

Hood Canal Region

This region consists of several harbor seal haul-out sites, a couple being the Skokomish and Duckabush River deltas. The pupping season, from MARC records, seems to be June until early August. All of the calls received from this area have been related to harbor seals.

The sightings here during the 1990s have been fairly consistent in numbers. Many of the calls from this region come from the southern end of Hood Canal—Hoodsport and Skokomish. The sightings tend to occur at the same time each year. This may be due to a shift to later activity patterns or pupping periods.

Northern Puget Sound

Historically, for MARC, this region is one of the most active in terms of pinnipeds. The San Juan Islands are home to an abundance of marine mammal life. This area also includes Whidbey Island, Camano Island, and Everett. In this region, we begin to see seals in a more urbanized environment, with a greater chance of encountering the public. About 75 percent of the pinniped calls from this area are concerning harbor seals; the other 25 percent concern California sea lions. Most of the calls come from Bellingham, Oak Harbor, Anacortes, and Everett. The San Juan Islands are monitored by a separate research group, and their records are not in this report.

North Puget Sound underwent a steady increase in sightings and deaths from 1990-1994. The majority of both live sightings and deaths consists of harbor seal pups and yearlings. The adults that are examined are usually found dead. The California sea lions are usually adult males, sleeping in the water or hauled out on log booms.

The peak quarter for both sightings and deaths is July-September. Each year has shown a steady increase in sightings, with 1994 being the highest. Almost each year has seen the death count increase, with 1993 and 1994 being about equal in number.

Central Puget Sound Region

Central Puget sound is a unique area. This region is where MARC receives most of its calls. The highly urbanized area has little to offer in terms of traditional harbor seal haul-out areas, so seals use private beaches and public parks. As in other regions, the breakdown of pinniped calls runs approximately 75 percent harbor seal, 25 percent California sea lion. The harbor seal calls are mainly regarding yearlings and pups, and the California sea lions are primarily males resting in the water. Since haul-out space is greatly lacking in this region, defining pupping seasons becomes difficult. In fact, there is no real evidence that harbor seals do indeed give birth in this area. It may be these seals come from the northern and southern regions and are just passing through the area. This region also sees the highest number of sightings and deaths, possibly due to the greater public availability to the beaches.

Most sightings occur in April-June. The number of deaths is fairly consistent from one period to another, except for the period of April-June 1994, when the number of deaths was 35 (compared to 14 deaths during the same three months in 1993). This drastic increase was due to a large number of harbor seal yearlings being found dead along the beach at Lincoln Park in Seattle. Many of these seals were too decomposed for histopathology and were not examined for disease.

Southern Puget Sound Region

Southern Puget Sound holds numerous harbor seal haul-out sites, yet it is also fairly urbanized. The pupping season for harbor seals here is from late July to late August (Newby, 1978). About 90 percent of the pinniped calls from this area regard harbor seals; the rest concern California sea lions. Most of the calls come from Vashon Island, Tacoma, and Olympia.

Both sightings and deaths during the 1990s have followed similar patterns, slightly increasing each year. Most of the sightings are of harbor seal pups resting on shore. The majority of deaths are of harbor seal pups and yearlings. No specific quarter seems to have the highest numbers in terms of sightings, although a slight increase is seen in June-September. The deaths also seem to increase during this same period, with the peak year so far being 1994.

DISCUSSION—WHY

This paper only scratches the surface of the data MARC has compiled over the past 18 years. Outlining the areas and times of year gives you an idea of the ongoing investigations MARC handles everyday. We hope this information will assist others who work with marine mammals in this region and throughout the world.

Trying to give definite answers to why we see certain increases in sightings and deaths is difficult. With little or no budget, MARC has been able to run some testing on the tissues we have collected. We have uncovered some surprising results, such as herpes virus and distemper in harbor seals, toxicological problems in gray whales and a disturbing trend of shootings of harbor seal pups and yearlings. The main obstacle becomes money. The testing is very costly and very time consuming. And unfortunately, the trend toward more dead seals seen than live continues today. A lot of money is spent on rehabilitation and release of these seals, but what about the ones that are found dead? These seals need to be given top priority in terms of investigating causes of death. The population numbers of seals in this region are healthy. This is the time to start investigating possible toxin, immune and disease problems—not when we have a massive die-off, and it's too late.

Future projects MARC is undertaking are 1) to examine methods of rehabilitation that occur in this area and how this affects the general seal population; 2) to investigate immune system problems through histopathology and toxicological testing; and 3) to take a closer look at areas where seals are seen washing up dead and to correlate that to government research projects that are currently under way. Through these

and other daily observations, MARC hopes too enhance our current collection of data and be able to assist others in their research on the marine mammals of Puget Sound.

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PINNIPED PREDATION ON MARINE FISH IN PUGET SOUND

Cyreis C. Schmitt[1], Steven J. Jeffries[1], and Patrick J. Gearin[2]

Over the past decade, several marine fish populations have seriously declined in Puget Sound. Although the causes of these declines are not well understood, overfishing, adverse environmental conditions, habitat loss, and pinniped predation are all likely contributing factors. In this report, we provide an overview of the likely effects of pinniped predation on the abundance of marine fishes.

Pinnipeds are opportunistic feeders, and their diets vary regionally and seasonally depending on local prey availability. Annual prey consumption in Puget Sound is estimated by combining available food habits information with data on the abundance and distribution of pinnipeds and estimates of their daily food requirements.

Pacific whiting and Pacific herring are the primary prey species, although many other marine fishes, such as lingcod and walleye pollock, are commonly taken. For each common prey species, available data on population trends and fishery harvests are compared to estimated annual pinniped consumption.

Pinniped predation is a significant source of mortality for some marine fish species, especially Pacific whiting, and has likely contributed to the decline in abundance of these species. The impacts of these declines on pinniped prey consumption or abundance are not known, but may become important.

INTRODUCTION

Because of the adoption of the Marine Mammal Protection Act in 1972 and curtailment of commercial hunting, some marine mammal populations are well on their way to recovery. For example, the numbers of harbor seals (*Phoca vitulina*) and California sea lions (*Zalophus californianus*) that occur in Puget Sound have risen substantially over the past decade, and they are now a common sight around the sound. Coincident with their increase, several marine fish populations have seriously declined (marine fishes are those species that spend their entire life in salt water). Fisheries for Pacific whiting (*Merluccius productus*), Pacific cod (*Gadus macrocephalus*), walleye pollock (*Theragra chalcogramma*), lingcod (*Ophiodon elongatus*) and surfperches (Embiotocidae) have been stopped or curtailed significantly because of low populations.

In this report, we present a preliminary evaluation of the potential effects of marine mammal predation on marine fish in Puget Sound, those waters south of Port Townsend including Saratoga Passage and Hood Canal. Information about the numbers of seals and sea lions, their diets, and quantities of prey consumed is used to estimate the general level of predation on marine fish. These estimates of predation are compared to population and harvest levels of the primary species of marine fish in Puget Sound.

CALIFORNIA SEA LIONS

California sea lions were not common in Washington waters until the mid-1970s. The first observation of large aggregations within Puget Sound occurred in 1979, when a group of about 100 was observed near Everett (Everitt et al., 1980). Since then, they have numbered in the hundreds during peak months, and occasionally have exceeded 1,000 animals (NMFS and WDFW, 1995).

California sea lions are seasonal migrants to Washington. They occur in Puget Sound primarily from September through June and peak during March through May (Gearin et al., 1986). Males migrate northward along the coast following the summer breeding season in California. This migration can be characterized as a feeding migration in which males fatten for the breeding season. Large body mass is an advantage to breeding males, which must defend their territories from other males and in so doing must

[1] Washington Department of Fish and Wildlife, 600 Capitol Way N., Olympia, WA 98501-1091

[2] National Marine Fisheries Service, National Marine Mammal Laboratory, 7600 Sand Point Way N.E., BIN C15700, Seattle, WA 98115

fast for long periods of time. Even younger non-breeding males fatten for the breeding season during the migration as they learn by play-fighting with other males on the rookeries. Males may increase their body mass by up to 42 percent before the breeding season (Schustermann and Gentry, 1971). California sea lion females and young animals (generally those younger than 4 to 5 years) usually remain near the home rookeries throughout the year, or move only as far north as central California (Melin and DeLong, 1991). Males in Washington usually range in age from 6 to 15 years old.

The diet of California sea lions in Puget Sound has been described briefly by Everitt et al. (1981) and Gearin et al. (1986, 1988). These sources all point out the importance of Pacific whiting, also commonly known as hake, to California sea lions in Puget Sound. Other important prey include Pacific herring (*Clupea harengus*), spiny dogfish (*Squalus acanthias*), squid (*Loligo opalescens*), salmon, cod, and pollock.

Methods

Estimates of food consumption for wild, free-ranging California sea lions have not been made, and we rely on measurements of metabolic rate and captive animal feeding rates to estimate this parameter. To estimate the annual food consumption by California sea lions in Puget Sound, we followed the formula described in Antonelis and Perez (1984). Total food consumption (c) was calculated for each month as: C = N x D x R, where N is the estimated number of sea lions, D is the number of days in the month (30 days were used), and R is the daily food ration. The daily food ration (R) equals M x F where M is the mean body mass and F is the mean feeding rate expressed as a percent of the mean body mass. A range for daily food ration was estimated from data for California sea lions held in captivity (Perez et al., 1990) and from the estimated "field metabolic rate" of otariid seals as described by Costa et al. (1987). To estimate the consumption of particular marine fish species, the food consumption estimates were partitioned across the important prey species, based on published data on the amount and size of prey in 321 scat samples collected from 1986 to 1988 in Puget Sound. The data and methods for determining each of the variables are more fully described below.

Table 1. Monthly estimates of mean population number, biomass (mt), and prey consumption (mt) for California sea lions in Puget Sound, 1986-1994

Month	Mean Count at Everett	Estimated Puget Sound Abundance (N)	Mean Body Mass (M, kg)	Estimated Sea Lion Biomass (NxMxD, mt)	Estimated Consumption, 5%-10% Rate (C, mt)
July	0	0	0	0	0
Aug.	0	0	0	0	0
Sept.	89.5	111	180	599	30 - 60
Oct.	118	146	180	788	40 - 79
Nov.	175	217	180	1172	59 - 118
Dec.	237	293	180	1582	79 - 159
Jan.	131.5	163	277	1355	68 - 136
Feb.	166	205	277	1704	85 - 170
Mar.	334	413	277	3432	172 - 343
Apr.	444	550	277	4571	229 - 457
May	234	290	277	2410	121 - 241
June	23	28	277	233	12 - 23

Population Estimates (N)

Counts of California sea lions in Puget Sound have been made annually for the preceding nine years, from 1986 through 1994, although counts were not made in every month each year. California sea lions were counted during aerial, land-based or vessel surveys. In Puget Sound, the largest proportion of California sea lions is found in the Everett-Port Gardner area. Monthly estimates of the numbers of sea lions at Everett (Table 1) are averages based on the 1986-1994 surveys. The Everett-Port Gardner aggregations are used as an index of the total numbers in Puget Sound when the entire Puget Sound was not surveyed. Survey data showed that the counts at Everett represented 80.7 percent of the Puget Sound total, and the monthly number of sea lions in Puget Sound (Table 1) is estimated accordingly.

The number of California sea lions counted during any given survey is an underestimate of true abundance since not all animals are counted. Although sea lions are gregarious and often gather together on land and in the water, a number of conditions can affect the total count, including: sea state, sun glare, time of day, temperature, precipitation, cloud cover, and human disturbance. All these factors can result in underestimates of true abundance because not all animals are observed or available to be counted. Sea lions also spend time underwater when feeding and traveling, and this behavior reduces the probability they will be counted in a survey. Recent mark-recapture data for the Everett area indicate that the numbers hauled out at Everett represent only about 50 percent to 55 percent of the total animals in Puget Sound. Because these data are preliminary, we have not used them in our report. In summary, we are confident that true abundance is at least as great as we report.

Body Mass (M)

Body mass for California sea lions in Puget Sound was estimated from the weights of 51 sea lions captured at Shilshole Bay during February through April, 1989-1994, and from 26 animals captured at Shilshole Bay during October through December, 1994. Because California sea lions increase their mass significantly before the breeding season, mass was estimated separately for September through December (180 kg) and for January through June (277 kg).

Daily Food Ration (R)

A range for daily food ration was estimated from published data for captive marine mammals and from estimates of the "field metabolic rate" for California sea lions (Costa et al., 1987). Basal metabolic rate, or resting rate as reported in the literature for most mammals, is considered to be much lower than for active, free-ranging marine mammals (Perez et al., 1990). Otariids, the family of pinnipeds containing fur seals and sea lions, have a considerably higher field metabolic rate than resting metabolic rate. Feldkamp (1985) reported that the energy required for extended swimming effort for California sea lions is 2.5 times the resting metabolic rate. Innis et al. (1987) reported values for active metabolic rates, based on captive feeding rates, to be more than four times greater than basal metabolic rates for otariid seals. The reported feeding rates for captive California sea lions range between 3.6 percent to 5.7 percent, but only one of these individuals was a male. Females do not exhibit the seasonal fattening as described for males; therefore, feeding rates for females during the seasonal fattening period would be less than for males. For the purposes of this paper, we used a range of feeding rates from 5 percent to 10 percent of body mass. We assume this range is reasonable for male California sea lions in the wild, especially during the seasonal fattening period.

Estimated Food Consumption (C)

For the 5 percent to 10 percent range in daily food ration, the formula by Antonelis and Perez (1984) yielded annual food consumption estimates of 895 to 1,786 mt, respectively (Table 1). Monthly food consumption is highest during March, April, and May, when the numbers of animals and their body mass are greatest.

Published data on the species composition of sea lion diets in Puget Sound (Everitt et al., 1981; Gearin et al., 1986, 1988) were used to determine the proportion and number of different types of prey consumed

(Gearin et al., in prep.). The mass of prey consumed was estimated from otolith length-fish weight regressions for bony fishes or from estimates of the mean mass of individual prey items in Puget Sound (Hart, 1973; Harvey, 1988).

Pacific whiting, spiny dogfish, Pacific herring, and Pacific cod are the primary marine fish prey for California sea lions in Puget Sound (Table 2). Whiting accounted for more than 30 percent of the total prey biomass consumed.

Table 2. The estimated 5% to 10% range in annual consumption (mt) of each major prey species by California sea lions in Puget Sound

Species	5% - 10% Range in Annual Consumption
Pacific Whiting	286 – 573
Spiny Dogfish	128 – 256
Pacific Herring	51 – 102
Pacific Cod	34 – 69
Shiner Perch	26 – 52
Walleye Pollock	16 – 32
Tomcod	14 – 29
Other Prey	340 – 673
TOTAL	895 – 1786

HARBOR SEALS

Harbor seal numbers have increased substantially in Puget Sound over the last 20 years, from a few hundred to nearly 3,000 by 1992 (Calambokidis et al., 1978; Huber et al., 1993). Annual food consumption by harbor seals in these waters was estimated according to methods in Harvey (1988) and Olesiuk (1993). We used a bioenergetic population model to integrate data on abundance, sex and age structure, feeding rates and diet of harbor seals (Olesiuk, 1993). Population information was obtained from Huber et al. (1993), and body mass was estimated from weights of harbor seals captured in Puget Sound over the last decade (S. Jeffries, unpublished data).

Abundance in Puget Sound during 1992 was estimated at 2,878 harbor seals (Huber et al., 1993). The mean body mass for harbor seals in Puget Sound for both sexes and all age classes was 63.3 kg.

The annual food consumption estimate for all prey species was 2,593 to 2,859 mt. This range represents a consumption rate of 3.9 percent to 4.3 percent of the biomass of harbor seals in Puget Sound. The consumption rates are derived from Olesiuk (1993). We did not estimate the amount of each prey species consumed by harbor seals because available food habits data were inadequate to do so. However, harbor seals within Puget Sound prey upon many of the same species as California sea lions do. Harbor seals feed primarily on Pacific whiting, Pacific tomcod (*Microgadus proximus*), walleye pollock, flatfishes (Bothidae and Pleuronectidae), Pacific herring, plainfin midshipman (*Porichthys notatus*), sculpins (Cottidae), and surfperches (Calambokidis et al., 1978; Everitt et al., 1981).

MARINE FISH

All Species

For most of the major harvested species, the 1970s was a decade of rapidly increasing catches and effort (Figure 1). However, this period of rapid fishery expansion was followed by an equally rapid decline in both the commercial and recreational fisheries. By the mid-1990s, fishery harvests were at their lowest level in more than 55 years (Schmitt et al., 1994).

Harvests were reduced as a result of substantial fishery restrictions for most species to promote population rebuilding. Harvest peaked in 1983 at about 9,500 mt and dropped to about 1,000 mt in 1994 (Figure 1). The main species in the catch included whiting, dogfish, Pacific cod, pollock, lingcod, rockfish, surfperch, and flatfish. Few flatfish were harvested after 1989, when Puget Sound was closed to bottom trawling, the main fishery for flatfish.

In 1989, a research survey using bottom trawl gear was conducted to estimate the biomass of bottomfish in Puget Sound (Quinnell et al., in prep.). Although the survey is not a good measure of the biomass of fish inhabiting midwater or upper layers, the results showed an estimated biomass between 27,000 and 45,000 mt (95 percent confidence intervals). Based on the survey, dogfish, ratfish (*Hydrolagus colliei*), and English sole (*Parophrys vetulus*) were the most abundant species. During the same year, the total harvest by recreational and commercial fishers was 1,397 mt. For those marine fish species important to the fishery, the status of every population, except dogfish and flatfish, is considered low or very low (Schmitt et al., 1994).

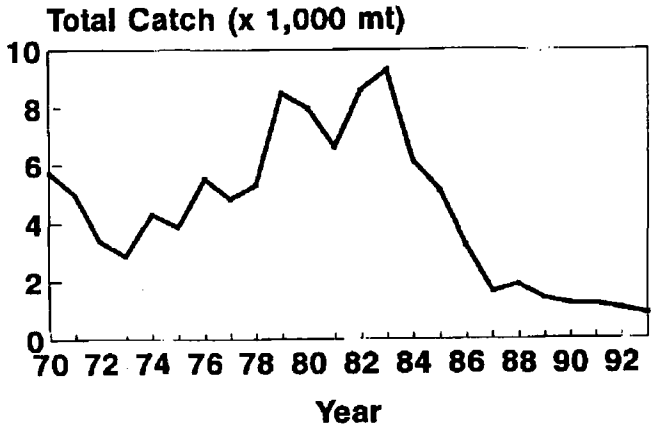

Figure 1. The total annual harvest (mt) of marine fish species by recreational and commercial fishers in Puget Sound, 1970–1993

Pacific Whiting

Pacific whiting was one of the most abundant fishes in Puget Sound. This midwater species forms dense spawning aggregations at specific locations in late winter. By far the largest aggregation occurs in Port Susan, near Everett, Wash. Adult fish migrate to Port Susan from throughout Puget Sound in January, with peak biomass usually occurring in early March. By late May, most fish have left Port Susan and are dispersed throughout the sound.

The whiting resource and fishery were the most intensively managed groundfish resource in Puget Sound. The spawning aggregation in Port Susan supported a large pelagic trawl fishery, which accounted for nearly all the whiting catch in Puget Sound. During the spawning season, research surveys using hydroacoustic and trawl gear were conducted to measure the abundance of adults. Based on the survey data, the fishing industry was notified each week if fishing would be allowed and under what conditions.

Fishery harvests were very large during the 1980s and likely contributed to the subsequent decline in abundance (Figure 2). More than 40 percent of the adult population was harvested in 1984 and again in 1985. Adult abundance dropped from about 12,250 mt in 1984 to 5,450 mt in 1987. The whiting management plan called for no fishing if the adult biomass dropped below 5,450 mt. Little or no fishing has occurred for whiting since 1987 (Figure 2).

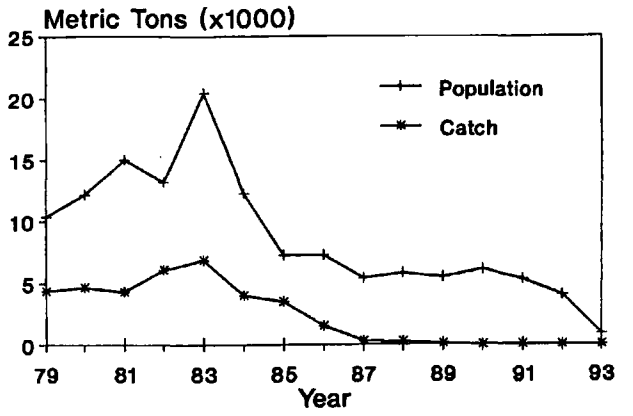

Figure 2. Annual biomass (mt) and fishery harvest (mt) of adult whiting in Puget Sound, 1979–1993

Pacific Herring

Pacific herring is one of the primary prey species for marine and anadromous fish, marine birds, and marine mammals. In Puget Sound, herring is commercially harvested to supply bait for recreational fisheries. Because of its great importance as prey, Pacific herring abundance has been care-

fully monitored throughout Puget Sound. Pacific herring spawn annually by depositing eggs on seaweed, primarily eelgrass, along the shorelines of Puget Sound. The biomass of adults is estimated from the amount of eggs deposited, which is determined from research surveys that comb the shorelines throughout the spring spawning season.

Annual data show that herring abundance has remained nearly constant since 1970. Adult biomass averaged 4,648 mt during 1985-1993, and harvests averaged 542 mt.

DISCUSSION

Although information is imprecise and incomplete, we believe that marine mammal predation likely is an important factor affecting the numbers of some marine fish species in Puget Sound, and ultimately, the numbers of fish harvested in sport and commercial fisheries. We estimate that harbor seals and sea lions consume 3,488 to 4,645 mt of food annually. Although these marine mammals also prey on other species such as squid and salmon, marine fish species constitute the majority of their diets. As a result, marine mammal predation may be two or three times the current total of about 1,000 mt of marine fish taken by sport and commercial fisheries in Puget Sound.

Most prey species are also the species most commonly sought by sport and commercial fisheries. Whiting, herring, cod and pollock are very important to seals, sea lions, and fishers. However, data on the abundance of most marine fish species are inadequate to assess the potential effects of marine mammal predation, and we compared estimates of marine mammal consumption, fish population size, and fishery harvests for only two species: whiting and herring.

Marine mammal predation is likely contributing to the decline in Pacific whiting, which is the primary prey for both seals and sea lions in Puget Sound, Although little or no fishing for whiting has occurred since 1987, the spawning population has continued to decline drastically. Over the past decade, spawning biomass averaged 4,862 mt per year, whereas we estimate that California sea lions consumed between 286 and 573 mt annually during the same period. Although estimates of the amount of whiting consumed by harbor seals are not available, seals may be consuming similar amounts, and perhaps more. In 1994, the spawning biomass of whiting was estimated at only 1,090 mt, compared to 12,250 mt in 1984.

In general, the abundance of Pacific herring has been stable at about 4,648 mt per year over the past decade. During 1985-1993, fishery harvests ranged between 422 and 732 mt, and averaged 542 mt. By comparison, California sea lions consumed an estimated 51 to 102 mt, on average, during this period. Estimates of the amount of herring consumed by harbor seals are not available, but herring is an important prey species for seals in Puget Sound.

CONCLUSIONS

Although the estimates of marine mammal predation are imprecise and inadequate for some purposes, they do demonstrate that marine mammal predation is substantial and increasing as populations continue to grow. The estimates are sufficiently large, in comparison to some marine fish populations and harvests, that marine mammal predation should be considered in the management of marine fish resources in Puget Sound. Factors other than fishery harvests and marine mammal predation also affect the condition of marine fish populations in Puget Sound, and must also be considered.

Most fisheries for marine fish in Puget Sound have been substantially reduced in the past decade to promote rebuilding of depressed stocks. Fishers expect that these harvest restrictions will result in stock recovery and improved fishing in the next several years. However, these expectations will not be met for some fish stocks because marine mammal predation is likely retarding, or perhaps prohibiting, stock recovery to the levels reached when seals and sea lions were much less common in Puget Sound.

For some species, especially Pacific whiting, predation is likely retarding the expected recovery of the whiting population envisioned by the closure of commercial fishing for this species nearly a decade ago. For other species, the available information for seal and sea lion diets and/or fish populations is too limited to determine whether marine mammal predation is a significant factor affecting fish abundance.

This report is only a first speculative look at the relationship between marine mammals and marine fish in Puget Sound, and current circumstances may not hold long into the future. The sustainable population size for harbor seals in Puget Sound is not known. The future numbers of California sea lions migrating into Puget Sound and the duration of their stay are also unknown. Seals and sea lions are opportunistic feeders, and they may prey upon different species in response to changes in prey abundances. Management of marine fish resources and fisheries will need to account for such future changes.

The declining abundances of marine fish may also affect marine mammals. Although these effects are not known, marine mammals may be forced to prey on other, less desirable species, and perhaps, marine mammal abundance could be adversely affected over the long term.

ACKNOWLEDGMENTS

We thank George Antonelis, John Calambokidis, Robert DeLong, and Michael Perez for the thoughtful comments and information they have provided on this topic over the years. We also acknowledge Mark O'Toole, Harriet Huber, and especially Wayne Palsson for the data and assistance they provided for this report.

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THE STATUS OF GREAT BLUE HERONS IN PUGET SOUND: POPULATION DYNAMICS AND RECRUITMENT HYPOTHESES

Donald Norman[1]

INTRODUCTION

The primary focus of research on great blue herons in Puget Sound has been contaminant monitoring (Norman, 1991; Speich et al., 1992; Cobb et al., 1994). Many questions remain, however, about the population-level impacts of contaminants. Basic life history research by Robert Butler at the Canadian Wildlife Service in British Columbia (Butler, 1989, 1991, 1993, 1995) can now be used to address many of these questions. This paper will review the current understanding of heron population biology and outline research issues for Puget Sound.

BACKGROUND INFORMATION ON HERONS

The great blue heron in the Pacific Northwest is a non-migratory sub-species (*Ardea herodias fannini*) that occurs from southeastern Alaska to south Puget Sound. The primary habitat association of herons is eelgrass beds (*Zostera* sp.), where they have adapted to exploiting the large summer populations of fish. An analysis of summer diet found that shiner perch (*Cymatogaster aggregata*) are a major energetic component in the chick and female diet and are possibly related to juvenile survival (Butler, 1993).

Heron colonies range from single nests to colonies with hundreds of nests. Nests occur in a wide variety of trees, with alder (*Alnus rubra*) being the most frequently chosen. The size of heron colonies is related to foraging area (Gibbs et al., 1987); Butler also found this association with eelgrass beds in estuarine colonies. Nest occupancy begins as early as February with the peak incubation period from early March into May. The average clutch size ranges from 3.6 in Puget Sound to 4.0 in the Strait of Georgia; the average number of successful young fledged is approximately two. Data collected over the past 18 years in Canada provide an extensive baseline data on hatching success, fledging success and mortality (Butler, 1995).

A key component of avian population dynamics is juvenile survivorship. From studies of energetics of captive herons (Bennett, 1993), foraging efficiency studies (Krebs, 1979), and the reduction of daytime low tides (Butler, 1991), it has been shown that juvenile herons cannot meet their energetic requirements at coastal estuarine sites in the fall, so they move to locations in upland areas, foraging on small mammals, especially voles (*Microtus* sp.) (Butler, 1991). While accurate measurements of survival can be made during nesting, little information exists on causes of juvenile mortality. To complicate juvenile studies, Butler (1995) also found that juvenile herons disperse widely after fledging, but return as adults to the natal area.

These studies by Butler on juvenile mortality raise questions about the herons in Puget Sound. Puget Sound lacks expansive eelgrass beds such as Padilla Bay and upland areas for overwintering juvenile herons. It can be hypothesized that reproductive success in Puget Sound might be lower and juveniles might be expected to disperse farther, with greater resulting mortality. If either of these situations is true, a declining population would result, unless there is supplemental emigration from the productive areas, resulting in a "source-sink" situation (Pulliam, 1988).

METHODS

Data was compiled from several sources to estimate the current population. The Washington Department of Fish and Wildlife Nongame Data Systems was used as a primary source document (WDFW, 1993). Surveys were made at many colonies to obtain nest counts. Information on the location and extent

[1] Toxicology Task Force, 2112 NW 199th, Seattle, WA 98177

of eelgrass beds (Thom and Hallum, 1990) was used to determine whether an area should have a colony, or whether the existing colony was large enough. Productivity data from Puget Sound was compared with Canadian colonies using similar procedures.

Information from the Christmas Bird Counts (CBC) was used to estimate winter population to relate to heron population estimated from nesting colonies. The area of acceptable heron habitat for the Puget Sound lowlands and southern Strait of Georgia was obtained by subtracting deep water, mountains, heavily forested, and heavily urbanized areas. The mean number of herons observed on 21 CBCs in the region over the most recent 10 years was calculated to derive heron density per square mile in the area of "acceptable habitat." The 21 CBCs covered 48 percent of the acceptable heron habitat. This number was compared to estimates of the number of herons breeding in the region.

RESULTS

From the most current information, there have been more than 100 heron colonies in western Washington in the past 10 years and 4,600 birds (Table 1). Colonies at Grays Harbor and Willapa Bay may be part of the *fannini* subspecies but are likely to be the subspecies *hyperonca* from Oregon. Butler estimates 2000 birds in the Strait of Georgia, not including an estimated 700 birds from the Fraser River and 200 from southeastern Alaska. This first subspecies population estimate is therefore about 6,500 birds. The largest colony, associated with Boundary Bay, is located on Point Roberts with more than 500 nests; the largest colony in Puget Sound is the Nisqually Wildlife Refuge colony with over 100 nests; however, no current estimate is available for the Squaxin Island colony. Canadian colonies are annually surveyed, while more than 40 percent of the Washington state colonies have no data in the past five years, and only 60 percent of the colonies have data of adequate quality.

An analysis of eelgrass bed locations found that Dungeness Spit, Port Gamble, Lummi Bay and western Bellingham Bay, the southeastern corner of Hood Canal and northern Case Inlet appear to be underutilized, as they have extensive eelgrass beds and few if any colonies listed in the WDFW system. Conversely, the scarcity of eelgrass in south Puget Sound does not predict any large colonies; however, more than 500 herons are known to nest in South Puget Sound. Using Butler's eelgrass relationship to heron numbers, an estimate of over 2400 ha of eelgrass could be predicted there (Butler, 1991) if the relationship could be reversed to predict eelgrass from heron numbers.

Little productivity data is available for western Washington, and most is recorded in young per successful nest, which ignores nesting attempts. Though Butler (1989) found that 90 percent of nesting attempts were successful, this number varies widely and includes colony failures. Over many years and many colonies, 1.7 herons fledged per nesting attempt was the average. Only data from Nisqually, Dumas Bay (Federal Way), Auburn, and Maury Island were compiled for the number of active nests (Table 2). Data from Puget Sound is compiled in Table 2.

Taking a grand mean over the four seasons, the mean number of young per active nest for Puget Sound colonies is 1.6 including the nest failure at Maury Island in 1994. This number agrees well with Butler's data.

The Christmas Bird Count data over the past 25 years have shown an index of increasing heron numbers (Norman, 1991; Stern and Feins, 1991). The cause is unknown. Using the crude heron density method from the 21 CBCs, the number of herons for the region is estimated to be 3,700. This estimate is lower than the estimate of 4,600 breeding adults from the colony estimate (Table 1). Assuming the colony estimate is 2,300 pairs, with 1.7 young fledged per nest, and mortality factors, an estimated number of adults and young in December would be more than 5,700, increasing the underestimate of the CBC method to 2,000 birds.

Table 1. Great blue heron colonies in Western Washington

Name of Colony	WDW #	Nests	Year	Data Qual.	Owned By	Status	Total # Birds
Mason County							
Shelton Valley	27	8	1985	1	Private	No recent details	20
Hamma Hamma River	115	?	1992	1	Private	Up watershed?	0
Squaxin Is.	142	80	1985	?	Tribe	No recent details	175
Thurston County							
Woodard Bay	3	75	1992	2	DNR ?	Trees tagged	150
Tenino Road	17	8	1978	?	Private	Unknown	-
Nisqually	53	100	1994	3	FWS	"Moved, eagle predation"	160
Totten Inlet	63	0	1992	3	?	Abandoned 75 nests 1984	-
Pittman Lake	5	5	1979	-	Private	No recent details	
Offut Lake	202	4	1989	-	Private	No trees left 1992	
Scatter Creek	210	24	1989	1	DNR	Unknown	48
Lake Lawrence	221	?	1990	?	Private	In fir trees	6
Scatter Creek	252	20	1991	1	WDFW	Unknown	40
Tenalquet Prairie	66	12	1975	1	Private	Unknown	25
Kitsap County							
Little Clam Bay	209	15	1990	2	DOD	Protected	30
Poulsbo	211	6	1993	2	Private	5 nests with young	10
Port Gamble	105	0	1991	2	Private	Abandoned in 1990 eagles?	-
Miller Bay	204	14	1992	2	Private	"14 active, 28 in 1990"	28
Hansville	242	6	1991	3	Private	Small alders	12
Suquamish	171	8	1986	3	Private	Young heard 1992	28
Bainbridge Is	23	25	1992	3	Private	"Cemetary, 25 active nests"	50
Port Orchard	197	19	1992	2	Private	Active in 1992	30
Tahuya Lake	149	11	1990	2	DNR	"Unknown, logging"	25
Stavis Bay	276	6	1992	3	State	DNR Land	12
Island Lake	300	1?	1993	1	Private	Unknown	-
Brownsville	42	46	1990	2	Private	In hemlock none active 92	-
Ferncliff n. Winslow	193	20	1992	2	Private	Active 92	42
Bangor	238	5	1990	2	DOD	Unknown	10
Clallam County							
Sequim Bay	275	?	1991	1	Private	120 on CBC	80
Canyon Creek	133	10	1985	1	USFS	"In hemlocls, 10 active"	20
Jefferson County							
Zelatched Point	206	6	1989	2	Private	Unknown	12
Dabob Bay	201	?	1989	?	USFS	Unknown	
Pleasant Harbor	205	?	1989	?	Private	Unknown	
Devil's Lake/Quilcene	274	12?	1991	1	DNR	As many as 20?	30
Port Ludlow	198	8	1988	1	State?	Alder trees blown down1991	-
Port Ludlow	239	5	1990	2	Private	Unknown	10
Dosewallips State Park	137	2+	1990	2	State	"Sitka spruce, incubating"	5
Port Discovery	290	?	1993	1	Private	Unknown	
Indian Is.	192	?	1987	?	DOD	Unknown	
Uncas	226	20	1990	2	Private	In fir trees above Hwy 101	40
Beckett Pt	230	10	1990	1	?	E. side Discovery Bay	20
Discovery Bay	229	4	1990	2	Private	Unknown	8
Whatcom County							
Pt. Roberts	69	500	1994	3	Private	Development	1000
Birch Bay	150	200	1994	3	Private	Development	400

Table 1. continued

Name of Colony	WDW #	Nests	Year	Data Qual.	Owned By	Status	Total # Birds
Bellingham Bay	154	?	1984	?	?	Unknown	
Bertrand Creek	58	25	1991	2	Private	Unknown	50
Skagit County							
Samish Island	4	210	1994	3	Private	355 Nests 1988	420
March Point	128	150	1994	3	Trust	Egg predation 92'	300
Cypress Is	175	0	1991	1	State	"3 nests 84, no trees left 91"	-
Ika Is.	109	0	1991	1	Private	"Abandoned, Inact. 91, 92"	-
Conway	173	27	1991	2	Private	English Rd.	54
Frailey-Stimson Hill	302	1	1993	3	Private	At least 3 fledged young	2
San Juan County							
Crescent Bay	134	?	1983	?	Private	Orcus Island	-
Squaw Bay	111	?	1974	?	Private	Shaw Island	-
Lopez Is.	36	?	1978	?	?	May have moved to #291	-
Terrill Beach	254	10	1991	2	?	East Sound	20
Wescott Bay	279	5	1992	2	Private	"In Firs, chicks heard 1992"	4
Mitchell Bay	280	10	1992	2	Private	"San Juan Is, aban. 1992?"	20
Fisherman Bay	291	20	1992	2	Private	Shaw Island	40
Rock Point	299	9	1993	1	Private	Inactive 1993	-
Garrison Bay	310	?	1994	1	Private	Reported active	-
Island County							
Cornet Bay	44/110	?	1976	2	?	Not found 1989	-
Naval Air Station	208	45	1991	3	DOD	60 nests 1989	100
Cultus Bay	7	18	1991	?	Private	"In alder, 18 active nests"	36
Stanwood	52	30+	1978	3	Private	"Developed, moved to #269"	160
Elger Bay	108	?	1975	?	Private	Camano Island	-
Dave Mackie C. P.	282	2+	1992	1	Private	In cedars near Dave Mackie SP	
Langley	196	12	1992	3	Private	Abandoned	40
Davis Slough	269	80	1993	3	Private	At least 50 active nests	100
Indian Hill	292	8	1992	2	Private	Near road	16
Cultus Bay East	297	5	1993	2	Private	"In alder, 4-6 Active nests"	10
Newman Road	308	5+	1994	2	Private	Active	10
Snohomish County							
Tulalip	116	0	1992	3	Tribe	"Abandoned, moved to north?"	-
Monroe	24	7	1991	-	DNR	"Inactive , 12 nests 1978"	-
Cherry Creek	278	8	1992	1	Private	"Mixed stand, status unknown"	16
Sultan River	249	?	1990	?	DNR	Unknown	
Lake Roesiger	207	9	1991	1	Private	Active nests	18
Bothell	224	0	1994	3	Private	Eagle attacks	
Allen Creek	255	?	1990	1	Private	Young seen 1990	
Snohomish Oxbow	270	0	1991	1	Private	"Inactive red-tail nest, 1991"	-
Cemetary Creek	271	5	1994	3	Private	5 Active nests 94	10
Picnic Point	228	4	1990	1	?	Unknown	8
Fortson	288	8	1994	2	Private	"In conifers, not active"	20
Martha Lake	43	?	1991	?	Private	Unknown	
"Hazel, Mt. Higgins"	305	4+	1992	2	DNR	"Nest in Doug. fir, eggshells`"	8
Little French Creek	307	?	1992	1	DNR	No details	
"Swamp Creek, Lynnwood"	309	8	1994	3	Private	Active nests	16
King County							
Black Diamond	122	8	1983	1	Private	Not found 1992	-
Sammamish R.	158	17	1992	2	City	Protected	34

Table 1. continued

Name of Colony	WDW #	Nests	Year	Data Qual.	Owned By	Status	Total # Birds
West Seattle	143	20	1993	3	Private	Development	40
Yarrow Bay	177	6	1991	1	Private	"Trees down 1992, 1993 ?"	-
Renton	178	14	1994	3	City	Eagle attacks	28
Discovery Park	179	3	1988	2	City	New colony	6
Auburn	50	29	1994	3	City?	Growing	8
Dumas Bay	85	46	1994	3	Private	Study Colony	80
Maury Is.	55-1	108	1994	3	County	Nest failure 1994	200
Monroe	287	?	1992		Private	No information	
Stone Brook Trout	285	17	1992	3	Private	Renton	34
Bellefields	283	9	1994	3	City	Nature Park	18
Aeneas Valley Kiwanis Park	217	15	1993	3	City	8 act. 1994	18
North Lake Union	218	1	1989	1	Private	Not found 1993	-
Kenmore Park and Watch	227	28	1994	2	Private	"Active nests, by police station"	48
Battelle Laurelhurst	301	2	1993	3	Private	"Not active 1994, 1995"	-
Pierce County							
Dupont Ft. Lewis	35	50	1978	?	DOD	Mounts Rd. Colony?	-
Mc Neil Is.	2	70	1983	?	State	"Abandoned 93, No birds 1994"	-
Spanaway	160	5	1985	?	?	Unknown	
Fort Lewis	96	50	1985	?	DOD	Failed in 1988 ?	-
McKenna	61	6	1990	?	Private	Training area 9	12
Ft. Lewis	98	20	?	?	DOD	Unknown	
Rhode Lake	157	?	1986	?	Private	38 nests 1985	
Horsehead Bay Fox Island	189	4	1986	1	Private	Not found 1992	
Winchester Swamp	220	?	1990	?	Private	No information	
Flume Electron Reservoir	222	?	1986	?	Private	Active 1986	
Clark's Creek	240	?	1991	?	WDFW	Unknown	
"Park Marsh, Amer. Lake"	232	?	1992	?	DOD	"Ft. Lewis, unknown"	
Dutcher Cove	284	?	1992	?	?	Quad Vaughn	
Lake Loop	298	18	1993	1	Private	No details	36
Burley Lagoon	306	20	1994	1	Private	In alder	40
						Total	4580

WDFW= Dept. Fish Wildlife
DOD=Dept. of Defense
DNR=Dep. Nat. Resources
City=Local City Ownership
State=Parks, Univ.

QA Codes: ? = Unknown
1 = Not clear documentation, reliable source
2 = Mention of chicks in WDFW File
3 = Confirmed Nest Number

Table 2. Great blue heron productivity in Puget Sound colonies 1984-1994

Year	# of Colonies (# of Nests)	Young/ Active Nest	# of Colonies (# of Nests)	Young/ Succ. Nest	Source
1984	3 (61)	2.08	5 (103)	2.05	S. Speich, unpublished
1988	2 (74)	1.63	3 (68)	2.33	Norman, 1991
1992	3 (70)	1.93	4 (100)	2.27	Norman, unpublished
1994	3 (82)	2.02	3 (70)	2.37	Norman, unpublished
1994	4 (157)	(1.2) Including 20 young from 75 active nests at Maury Island			

DISCUSSION

The heron population appears to be stable throughout most of its range. More information is needed from southern Puget Sound to determine what foraging areas herons are using since eelgrass appears to be scarce. Searches for colonies in areas with major eelgrass beds will likely locate colonies currently not on the WDFW Nongame Data List. For example, a colony has been reported at Portage Island in Bellingham Bay but not confirmed, and the large Port Gamble colony was abandoned but has probably moved to a nearby location. Annual surveys of the largest colonies should be made to determine young per nesting attempt and a number of nests.

CBC data can provide a useful indication of heron populations but lacks both precision and accuracy. Additional studies of the definition of acceptable habitat would be necessary to extrapolate CBC data to the entire region. Improvement in the precision of CBCs can be made if additional counts are made on days before and after the CBC so biases of weather, observer differences, and observer skill (though with herons it is assumed to be minimal) can be assessed. An important addition to current CBCs would be the identification of numbers of juvenile and adult herons, similar to data often reported for bald eagles. The CBCs may also be used to locate winter foraging sites. To use CBC data beyond qualitative presence-absence statements requires that trends of reference bird species with known trends be used. For example, the Tacoma CBC shows a decline in heron numbers over the last 17 years (Figure 1); plotting belted kingfisher numbers also shows a similar pattern indicating possible observer or weather biases.

The existing reproductive data indicates that foraging habitat for breeding herons appears to be adequate in Puget Sound for herons to fledge normal numbers of young. Butler (1991, 1993) found that food availablity at large eelgrass beds was not depressed by colonial foraging during breeding to reduce breeding success. Butler (1995) found that 40 percent of the overall mortality occurred after herons left the nest, and most of this occurred in the first six months. There is no information on how this mortality occurs and where. Because this post fledging mortality level is nearly equal to mortality occurring in the nest (48 percent), the wintering locations of juvenile herons in Puget Sound is an important contributor in understanding population dynamics. With the nesting success alone it is impossible to prove a "source-sink" explanation of population dynamics because there is no way to know whether herons nesting at a colony are the same individuals from one year to the next.

FURTHER RESEARCH

Butler (1995) identified disturbance at breeding colonies as a primary area of research. Ignoring human disturbance, the primary source of disturbance has been increased bald eagle population in the Pacific Northwest. In addition to predation by eagles upon heron chicks (Norman et al., 1989), when eagle incursions occur during incubation, temporary nest abandonment can lead to corvid egg predation. The combination of disturbance and egg loss can lead to abandonment of the colony (Butler, 1991). With so

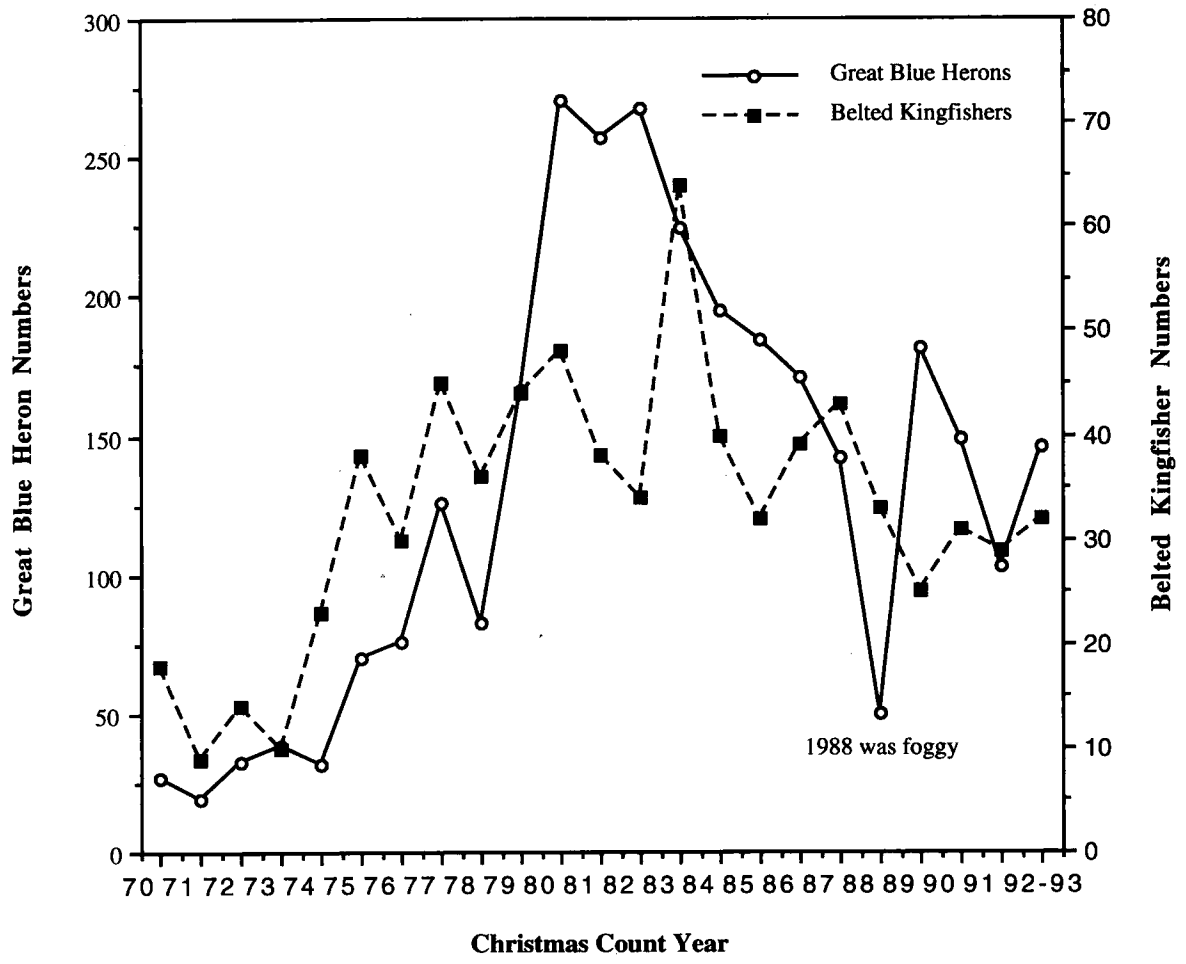

Figure 1. Tacoma Christmas Bird Count

many eagle territories and the large number of non-territorial and immature eagles, it is almost impossible for herons to locate their colony away from eagles. Eagle incursions have increased since 1984, but whether incursion rates will level off will depends upon the population dynamics and food habits of eagles and corvids. The response of herons to this increased predation can provide thrilling research opportunities.

To address juvenile survival, banding of chicks is required. Banding in the nest is the easiest way to obtain the necessary large number of individuals. The evaluation of overwintering habitat areas is also needed to relate juvenile survival in Puget Sound to other areas. Characterization of the wintering sites should include foraging observations and measurement of population dynamics of small mammals. To address a source-sink hypothesis, banding studies of nestlings in colonies with healthy overwintering habitat, such as colonies near Padilla Bay, must also be performed. Initial information on juvenile wintering sites in Puget Sound can be obtained from CBCs. Ecological studies, for example, relating juvenile heron survival and movement to local rodent abundance can provide answers using quantitative

measurements related to known energetic costs. This research requires a long-term commitment, but will not only yield important scientific studies linking survival to specific colonies and upland habitats, but also help land managers plan the best strategies for protecting local populations of herons (see Norman and Holtz, 1995, this volume).

ACKNOWLEDGMENTS

Robert Butler commented on the manuscript, and due to work load and the timing of Canadian Wildlife Service review procedures could not participate as a co-author. He can be reached at P.O. Box 340, Delta, British Columbia V4K 3Y3. Assistance from Ron Thom for data on eelgrass beds and from Tom Owens at the WDFW Nongame Data Systems for current heron colony data is appreciated.

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WINTER SHOREBIRD ABUNDANCE AT GREATER PUGET SOUND ESTUARIES: RECENT CENSUS RESULTS AND IDENTIFICATION OF POTENTIAL MONITORING SITES

Joseph R. Evenson[1] and Joseph B. Buchanan[2]

INTRODUCTION

There is considerable concern that shorebird populations in the western hemisphere are being adversely affected by a variety of factors, the most significant of which is loss of habitat (Myers et al., 1987; Page and Gill, 1994). The degradation and destruction of habitat at wintering and migratory staging sites has been substantial. It has been estimated that 66 percent of the coastal wetlands in Washington have been destroyed (Boule et al., 1983). Additional potential impacts to shorebird populations include chemical and heavy metal contaminants (see Calambokidis et al., 1991, for review) and oil spills (Larsen and Richardson, 1990).

Recent research in eastern North America indicates that a number of migratory shorebird species have experienced population declines (Howe et al., 1989; Morrison et al., 1994). The status of shorebird populations in western North America is currently unknown; intensive long-term monitoring is required to determine whether population changes are also occurring in this region. However, before a monitoring program can be implemented, it is necessary to determine the location of appropriate monitoring sites. The Pacific Flyway Project (PFP) was initiated by Point Reyes Bird Observatory (PRBO) in 1988 to address this need (Page et al., 1990). As part of this effort, our goal was to identify regionally important wintering and migratory staging sites suitable for future population monitoring efforts. Here we make preliminary recommendations for winter monitoring sites based on results of shorebird counts conducted during the winters of 1990-91, 1992-93, and 1993-94. A complete account of species occurrences at Greater Puget Sound (GPS) sites will be presented elsewhere.

STUDY AREA AND METHODS

Study Area

The GPS survey area includes four geographically distinct regions: Northern Puget Sound (NPS), Central and Southern Puget Sound (CSPS), Hood Canal (HC), and the Strait of Juan de Fuca and Admiralty Inlet (SJF/AI) (Figure 1). All of the major estuarine sites within those regions were surveyed. The general location of each site is given in Appendix 1.

Census Methods for Ground-based Counts

A count of this magnitude requires the participation of a large number of volunteer observers. We coordinated with Christmas Bird Count (CBC) compilers to ensure that shorebird count totals for specific sites within the CBC areas were tallied individually. We then recruited a team of volunteers to count shorebirds at the sites not covered by the regional CBCs. We recruited only the most skilled and experienced observers for the project, usually relying on other biologists for recommendations. We assumed that CBC compilers attempted to meet similar standards for their counts.

With few exceptions, single counts were made at each site during the winters of 1990-91 and 1992-93. Site counts were usually conducted in December and January to coincide with the CBC effort as much as possible. A few of the smaller sites were missed in either year, and certain sites were visited multiple times. We coordinated two counts in the 1993-94 winter, the first in late November-early December and

[1] Cascadia Research Collective, 218-1/2 W. 4th Ave., Olympia, WA 98501

[2] Cascadia Research Collective, 218-1/2 W. 4th Ave., Olympia, WA 98501, and Washington Department of Fish and Wildlife, 600 N. Capitol Way, Olympia, WA 98501

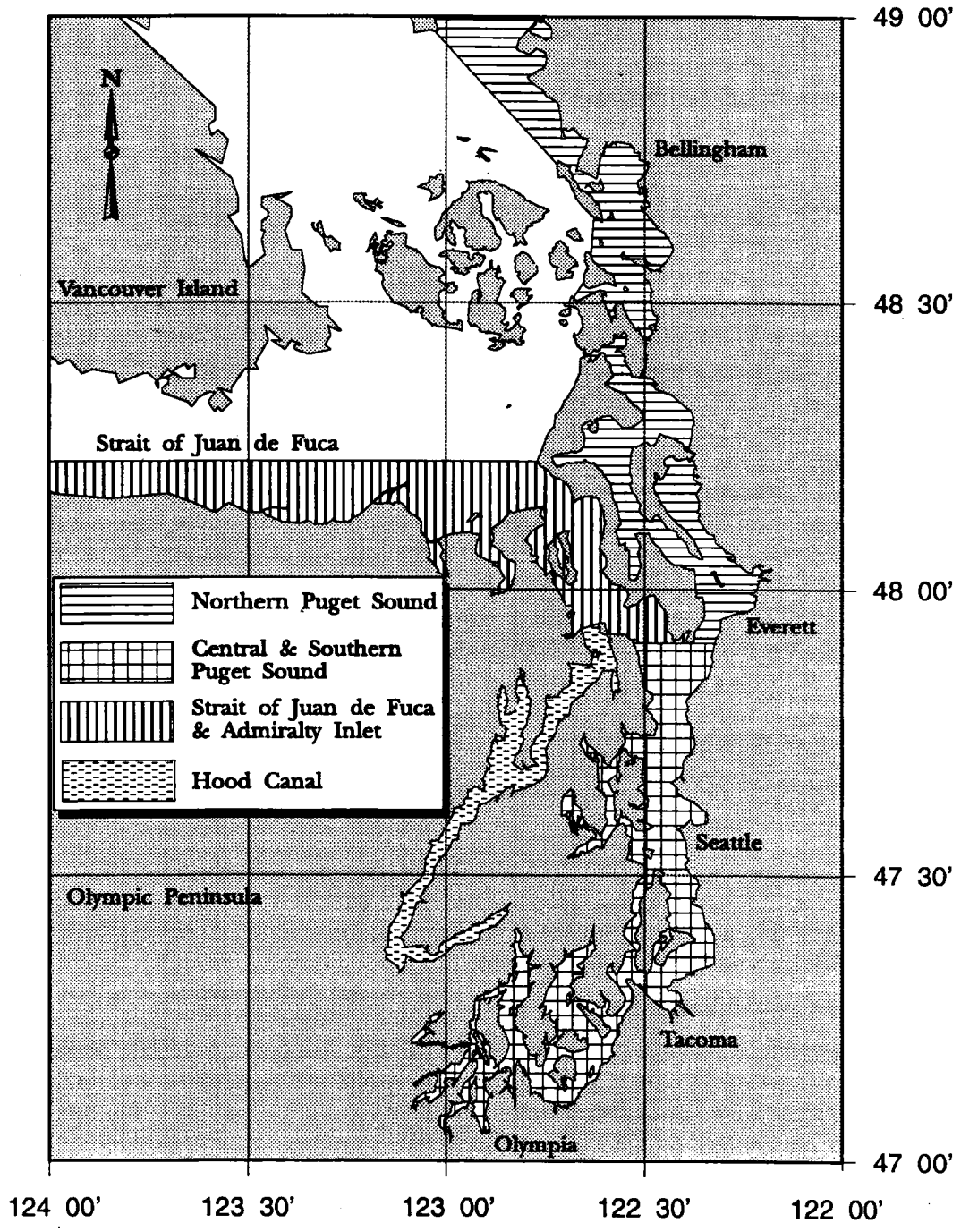

Figure 1. The Greater Puget Sound survey area where shorebird counts were conducted during the winters of 1990-91, 1992-93, and 1993-94

the second roughly coinciding with the late December-early January CBC effort. Census data were recorded on data sheets supplied to each participant.

Census Methods for Aerial Counts

Aerial counts were made in conjunction with the ground-based counts in 1992-93 and 1993-94 to provide better estimates of shorebird abundance at large estuaries with substantial access problems (e.g., Skagit Bay), at sites where large flocks of shorebirds occurred, and in areas where movement between sites was a possibility (e.g., NPS sites). Ground-based counts at these sites provided totals for less common species. Flights were made at an altitude of about 60 meters. All counts were made by JRE and/or JBB. Shorebirds in small flocks were counted individually or estimated by fives or tens; larger flocks were estimated by hundreds or thousands. We made multiple estimates of shorebird abundance in large flocks to derive a more accurate site total. Aerial counts were conducted during the late rising or early falling tide periods.

Identifying Important Sites

The focus of this project was to assess potential monitoring sites based on shorebird abundance. Therefore, we used the highest species site counts to estimate winter shorebird abundance at each site. Because we used the highest counts at each estuary and were unable to adequately track movements of flocks among sites in the NPS, we believe that the count data must not be used to derive total estimates of shorebird abundance for the NPS and SJF/AI regions, except as described below. We emphasized sites that supported ≥1,000 birds, the minimum target for prioritizing PFP monitoring sites.

RESULTS AND DISCUSSION

One hundred and fourteen volunteers conducted shorebird counts at 59 sites in the GPS area during the three winters. Twenty-one sites supported ≥1,000 shorebirds in at least one winter (Table 1, Figure 2). Only eight sites supported ≥1,000 shorebirds in each of the three winters, and of the sites visited all three years (n=16), six had ≥1,000 birds in only one winter. The number of sites supporting ≥1,000 shorebirds was similar each of the three years.

Approximate total counts of shorebirds for the GPS in 1992-93 and 1993-94, derived by combining aerial counts from the NPS and ground-based counts from all other regions, were 57,800 and 68,100, respectively. We did not calculate a 1990-91 GPS total because aerial counts were not made and a major storm resulted in substantial mortality and/or movement at NPS sites.

Nineteen species were encountered during the three winters. Seventeen species were recorded in both 1990-91 and 1992-93, and 18 species in 1993-94. The Dunlin (*Calidris alpina*) was the most common species in the GPS each winter, constituting 93.5 percent and 96.2 percent of all shorebirds in 1990-91 and 1992-93, respectively, and 90.7 percent and 96.3 percent of all shorebirds during the two counts in 1993-94. These proportions are similar to those from an eight-year period at Totten Inlet in CSPS (mean proportion of all shorebirds = 93.9 percent, SD = 1.59, Buchanan, 1988). These data indicate that the Dunlin is the predominant species in the region.

Only four other species had GPS count totals > 500 birds in any year. The black-bellied plover (*Pluvialis squatarola*) was regularly the most common of these species, and area counts exceeded 500 all three years. Total counts of the Western sandpiper (*Calidris mauri*) exceeded 500 in 1992-93 and 1993-94, and counts of the killdeer (*Charadrius vocifer*) and sanderling (*Calidris alba*) exceeded 500 in 1992-93 only.

Northern Puget Sound

Counts were made at 15 sites in the NPS region. Twelve of the 21 GPS sites that supported ≥1,000 shorebirds were in this region; six of these supported >5,000 shorebirds, including three with 10,000-20,000 shorebirds and one with >20,000 shorebirds (Table 1). Six sites supported ≥1,000 birds during all

Table 1. Sites with ≥1,000 shorebirds during winter counts in Northern Puget Sound (NPS), Central and Southern Puget Sound (CSPS), and Strait of Juan de Fuca and Admiralty Inlet (SJF/AI) regions between 1990 and 1994. NC indicates that a count was not conducted.

	High Count		
Site	**1990-91**	**1992-93**	**1993-94**
NPS			
Drayton Harbor	4,800	4,950	6,911
Birch Bay	3,000	0	800
Lummi Bay	3,007	4,894	5,126
Bellingham Bay	300	3,117	3,110
Samish Bay	14,000	8,612	8,510
Padilla Bay	5,000	4,250	10,802
Fidalgo Bay	3,658	330	640
Ala Spit	1,100	0	NC
Skagit Bay	7,000	19,349	13,750
Boz Lake	2	2	1,639
Port Susan	1,094	14,240	31,050
Jetty Island	NC	1,150	3,507
CSPS			
Nisqually River	NC	2,404	425
Totten Inlet	3,245	2,331	4,162
Sinclair Inlet	1,000	429	89
SJF/AI			
Crockett Lake	3,000	134	34
Deer Lagoon	NC	1,646	796
Kilisut Harbor	NC	1,079	557
Sequim Bay	136	46	1,039
Dungeness Bay	1,986	1,241	1,624
Port Angeles Harbor	180	1,945	228
No. Sites With ≥ 1,000	**13**	**14**	**12**

three winters. The highest count in the GPS was 31,050 at the Port Susan complex (Warm Beach, Livingston Bay, Triangle Cove) in 1993-94.

Shorebird counts in the NPS varied greatly within and among years. We believe there are three primary reasons for this (Evenson and Buchanan, 1994). First, shorebirds in the NPS are known to move regularly among sites within a season (Brennan et al., 1985). These flights allow birds to respond to daily or seasonal changes in prey availability (Brennan et al., 1985) and also occur after disturbance by hunting falcons (Buchanan, unpubl. data). Differences between our two aerial counts and in contrast to ground-based counts indicate that movement regularly occurred. Second, adverse weather strongly influenced shorebird abundance during the 1990-91 count period, particularly in the NPS; some counts were 10-30 times lower than in subsequent winters. The 1990-91 count at the Port Susan area occurred during a severe storm; that count was 10-30 times lower than in subsequent winters (Table 1). In fact, several sites were visited after the storm and supported comparatively higher numbers of shorebirds. Third, regular fluctuations in water level influence habitat suitability for shorebirds at sites such as Crockett Lake and Boz Lake.

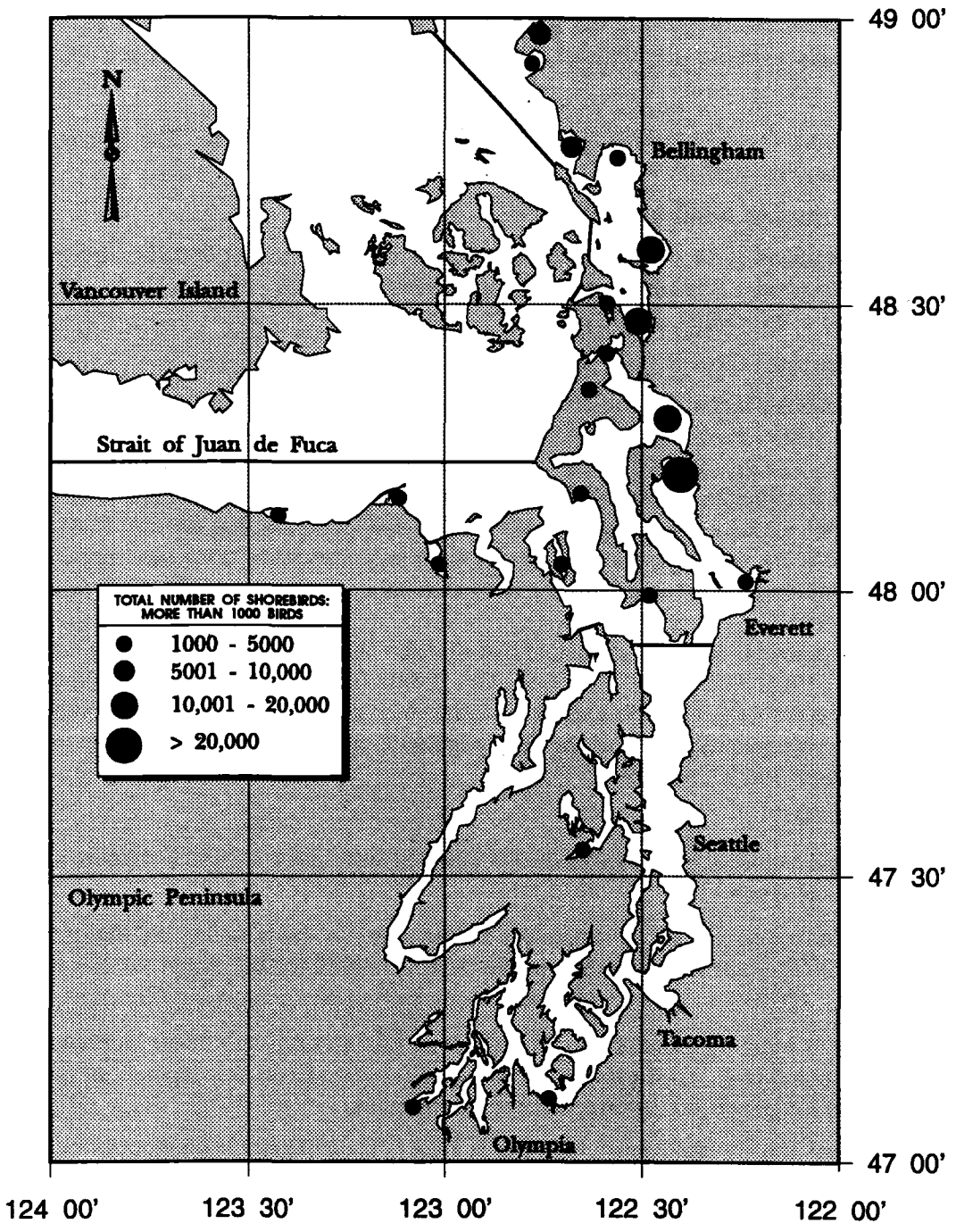

Figure 2. Distribution of sites with ≥1,000 shorebirds in the Greater Puget Sound during the winters of 1990-91, 1992-93, and 1993-94

Central and Southern Puget Sound

Counts were conducted at 18 sites in the CSPS region. Only three sites, Totten Inlet, Nisqually River delta, and Sinclair Inlet, supported ≥1,000 birds. The highest count in the CSPS was 4,165 birds at Totten Inlet in 1993-94, representing about 74 percent of the regional total that year. Annual winter shorebird

counts at Totten Inlet are consistently in the 2,000-4,000 range (Buchanan, 1988), whereas counts at Nisqually are extremely variable and often <1,000 (Brennan et al., 1985; Buchanan, unpubl. data).

Hood Canal

None of the 12 sites visited in the HC region supported ≥1,000 shorebirds. The highest site count was 264 birds at Annas Bay in 1992-93.

Strait of Juan de Fuca and Admiralty Inlet

Counts were conducted at 14 sites in the SJF/AI. Six sites supported ≥1,000 shorebirds during at least one winter. Only Dungeness Bay supported ≥1,000 shorebirds all three years (Table 1). The highest count at any site was 3,000 at Crockett Lake in 1990-91.

Significance of Important Sites

The GPS represents an important complex of wintering shorebird sites that supported >50,000 birds in at least two or three years (see above). High counts of 24,565 and 31,050 shorebirds in 1993-94 at Port Susan (Triangle Cove, Livingston Bay, Warm Beach) exceed the criterion necessary for consideration as a regionally important site (Ian Davidson, Wetlands for the Americas, personal communication). This site is clearly important from a conservation perspective. We believe, however, that the multitude of GPS sites with >1,000 shorebirds are also important for conservation and monitoring purposes. For example, sites with <5,000 shorebirds in 1992-93 and 1993-94 supported about 27 percent of the GPS winter population in both years (see Table 1).

There are many potential disturbance factors that threaten shorebirds and their winter environment (Calambokidis et al., 1991; Mahaffy et al., 1994). Our results indicate that most sites with ≥1,000 birds, including the very largest sites, occur in a cluster situated near major shipping channels, oil refineries, or industrial centers. Consequently, much of the GPS population is highly vulnerable to the impacts of environmental pollution and habitat loss.

RECOMMENDATIONS

1. Conduct additional winter counts. These counts could identify more sites that support >1,000 shorebirds during some winters.

2. Assess factors causing movement of shorebirds among sites. A better understanding of the magnitude of movements and the ecological factors that dictate them is critical for successful implementation of a monitoring program. Movement appears to occur among several of the most significant sites.

3. Begin bi-weekly or monthly monitoring at sites (with >1,000 shorebirds) where assessment of movement is not required (e.g., Totten Inlet). This will allow immediate development of baseline data, resulting in a greater long-term perspective on population trends.

4. Resume ecological and contaminant monitoring studies. Contaminants in shorebird tissues have not been examined in more than 10 years. Shorebirds should be monitored for contaminants to investigate potential impacts at specific wintering sites.

ACKNOWLEDGMENTS

Many people volunteered to count shorebirds for this project. For assistance with logistics or conducting counts we thank D. Adams, P. Alexander, H. Armstrong, A. Arnold, S. Ball, L. Barnes, A. Beelik, J. Bentt, F. Beyer, B. Blackie, T. Bock, K. Brady, A. Brenaman, L. Brenaman, D. Brock, K. Brown, J. Burch, G. Buschmann, A. Calkins, A. Campbell, J. Carroll, K. Carroll, J. Carson, H. Christenson, S. Christenson, T. Cyra, M. Davison, J. De Groot, D. Doss, C. Downing, S. Downing, J. Duemmel, L. D'Veck, R. Edens, B. Ellis, S. Ellis, J. Flavin, G. Geis, G. Gerdts, S. Giles, P. Gill, M. Gray, K. Green, P. Green, D. Gudaitis, M. Hatheway, J. Hein, D. Helseth, S. Herman, C. Howard, E. Hunn, K. Jacobsen, S. John, M. Jones, M. Klope, D. Knoke, E. Kridler, R. Kuntz, N. Ladenburger, G. Lenhart, P.

Little, J. Lyles, J. Malvitch, K. Manning, J. Meche, P. Meehan-Martin, D. Meister, M. Midkiff, J. Morgan, R. Morgan, R. Muskat, J. Nelson, V. Nelson, C. Nichols, D. Nysewander, J. Oakland, J. Partlow, N. Partlow, F. Patterson, H. Pederson, S. Petrie, L. Randolph, S. Ray, A. Rebollo, K. Rigg, N. Salvadelena, L. Salzer, K. Scarbrough, T. Schooley, M. Scuderi, S. Scuderi, M. Schulze, F. Sears, F. Sharpe, D. Smith, M. Smith, S. Smith, T. Spencer, B. Stanton, E. Stanton, J. Stein, B. Sundstrom, R. Thorn, B. Tweit, L. Vail, H. Vail, J. van Niel, S. van Niel, L. Vecincio, V. Vesterby, T. Wahl, G. Walker, J. Wiggers, K. Wiggers, and T. Williams. We also thank any other people who counted shorebirds during Christmas Bird Counts who are not mentioned above. We thank our pilots J. Cubbage, R. Kerns, B. McMahon, and E. Nystuen, and Pearson Air, Puget Sound Seaplanes, and Tumwater Flight Service for their assistance. We thank G. Page and D. Shuford for help with project implementation, and G. Page and G. Steiger for making helpful comments on the manuscript. This project was funded by Cascadia Research Collective, Point Reyes Bird Observatory, and the Washington Department of Fish and Wildlife. This is Point Reyes Bird Observatory contribution number 662.

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Appendix 1. List of sites where shorebird surveys were conducted during the winters of 1990-91, 1992-93, and 1993-94

Site	Location	County	90-91	92-93	93-94
North Puget Sound					
Drayton Harbor	48:58N; 122:45W	Whatcom	●	●	●
Birch Bay	48:56N; 122:45W	Whatcom	●	●	●
Lummi Bay	48:48N; 122:40W	Whatcom	●	●	●
Bellingham Bay	48;46N;122:34W	Whatcom	●	●	●
Chuckanut Bay	48:41N; 122:30W	Whatcom		●	●
Samish Bay	48:34N; 122:28W	Skagit	●	●	●
Padilla Bay	48:29N; 122:30W	Skagit	●	●	●
Fidalgo Bay	48:28N; 122:35W	Island	●	●	●
Similk Bay	48:26N; 122:34W	Skagit	●		
Ala Spit	48:23N; 122:35W	Island	●		
Skagit Bay	48:19N; 122:23W	Skagit/Snohomish	●	●	●
Boz Lake	48:20N; 122:36W	Island	●	●	●
Triangle Cove	48:11N; 122:28W	Island	●	●	●
Livingston Bay	48:14N; 122:26W	Island	●	●	●
Warm Beach	48:11N; 122:22W	Snohomish	●	●	●
Tulalip Bay	48:03N; 122:17W	Snohomish	●	●	●
Snohomish River	48:01N; 122:13W	Snohomish			●
Jetty Island	48:01N; 122:13W	Snohomish		●	●
Central & South Puget Sound					
Yukon Harbor	47:32N; 122:32W	Kitsap		●	●
Commencement Bay	47:18N; 122:25W	Pierce	●	●	●
Nisqually Rv. Delta	47:06N; 122:43W	Thurston		●	●
Henderson Inlet	47:06N; 122:50W	Thurston	●	●	
Budd Inlet	47:03N; 122:54W	Thurston		●	●
Eld Inlet	47:03N; 123:00W	Thurston		●	
Totten Inlet	47:06N; 123:04W	Mason	●	●	●
Skookum Inlet	47:08N; 123:05W	Mason	●	●	●
Oakland Bay	47:16N; 123:01W	Mason	●		●
North Bay	47:24N; 122:49W	Mason	●	●	●
Rocky Bay	47:22N; 122:47W	Pierce	●	●	●
Vaughn Bay	47:20N; 122:47W	Pierce	●	●	●
Burley Lagoon	47:24N; 122:38W	Pierce	●		

Site	Location	County	90-91	92-93	93-94
Central & South Puget Sound (continued)					
Sinclair Inlet	47:31N; 122:41W	Kitsap	●	●	●
Dyes Inlet	47:37N; 122:42W	Kitsap		●	●
Miller Bay	47:45N; 122:33W	Kitsap	●	●	●
Liberty Bay	47:45N; 122:39W	Kitsap		●	●
Hood Canal					
Port Gamble Bay	47:50N; 122:35W	Kitsap	●	●	●
Seabeck Bay	47:38N; 122:50W	Kitsap	●	●	●
Lynch Cove	47:26N; 122:51W	Mason	●	●	●
Annas Bay	47:21N; 123:07W	Mason		●	●
Hamma Hamma Rv.	47:32N; 123:03W	Mason	●	●	
Duckabush River	47:39N; 122:56W	Jefferson		●	
Dosewallips River	47:41N; 122:54W	Jefferson		●	
Quilcene Bay	47:49N; 122:51W	Jefferson	●	●	●
Tarboo Bay	47:51N; 122:48W	Jefferson	●	●	●
Thorndyke Bay	47:49N; 122:45W	Jefferson	●		
Squamish Harbor	47:52N; 122:41W	Jefferson	●		●
Bywater Bay	47:53N; 122:38W	Jefferson	●	●	●
Port Ludlow Bay	47:55N; 122:41W	Jefferson	●		●
Strait of Juan de Fuca & Admiralty Inlet					
Cultus Bay	47:55N; 122:24W	Island			●
Deer Lagoon	48:00N; 122:29W	Island		●	●
Crockett Lake	48:10N; 122:40W	Island	●	●	●
Hansville	47:55N; 122:32W	Kitsap	●	●	●
Oak Bay	48:01N; 122:43W	Jefferson	●	●	●
Kilisut Harbor	48:03N; 122:43W	Jefferson		●	●
Discovery Bay	48:00N; 122:53W	Jefferson		●	●
Sequim Bay	48:02N; 123:00W	Clallam	●	●	●
Protection Island	48:08N; 122:56W	Jefferson			●
Dungeness Bay	48:10N; 123:08W	Clallam	●	●	●
Port Angeles Harbor	48:09N; 123:26W	Clallam	●	●	
Seiqu River	48:17N; 124:24W	Clallam		●	

PUGET SOUND RESEARCH '95

SESSION 6C

TOXIC CHEMICALS: UPTAKE AND BIOEFFECTS

Session Chair:

Bruce McCain

National Oceanic & Atmospheric Administration,
Northwest Fisheries Science Center

CHEMICAL CONTAMINANT EXPOSURE AND PHYSIOLOGICAL EFFECTS IN OUTMIGRANT JUVENILE CHINOOK SALMON FROM URBAN ESTUARIES OF PUGET SOUND, WASHINGTON

Ed Casillas, Mary R. Arkoosh, Ethan Clemons, Tom Hom, David Misitano, Tracy K. Collier, John E. Stein, and Usha Varanasi[1]

INTRODUCTION

Declines in the salmon populations of the northeast Pacific Ocean have been attributed to a variety of natural and anthropogenic stresses. Principal stresses include overfishing, physical degradation of habitats, and climatic conditions. However, the potential contribution of anthropogenic chemicals as stressors that may affect salmon populations is largely unknown.

Estuaries serve as important habitats for salmon during the juvenile stage of their life cycle (Healy, 1982). Estuaries located near urban centers also receive both point and non-point inputs of chemical contaminants from municipal and industrial activities. Many of the chemicals from these sources are known to accumulate in sediments (McCain et al., 1988). Several estuaries within Puget Sound, Washington, are located near urban centers and are used by migrating juvenile salmonids for brief periods during their transition to life in the ocean. During outmigration, juvenile salmon undergo numerous physiological adaptations and adjustments. Concomitant exposure to toxic chemicals while in the estuarine environment could lead to deleterious physiological changes potentially affecting their health and survival. Accordingly, studies were initiated with the following primary objectives: 1) to use a suite of established biological markers (biomarkers) to assess chemical contaminant exposure and biochemical response in outmigrant juvenile chinook salmon (*Onchorynchus tshawytscha*) during their brief residency (two weeks to two months) in urban estuaries, and 2) to determine whether increased exposure induces alterations in immunocompetence or growth.

The following is an overview of our experimental approach to address these questions and a summary of our findings on the evidence for chemical contaminant exposure and effects on juvenile chinook salmon as they outmigrate through urban waterways of Puget Sound, Washington. The data presented are from studies conducted from 1989 to 1993; however, this is an ongoing project.

GENERAL METHODS

Juvenile chinook salmon were sampled from hatcheries and respective estuaries of four river systems in Puget Sound, Washington. River systems that were associated with urban centers included the Green-Duwamish and the Puyallup-Commencement Bay areas; systems associated with rural areas were the Nisqually and Skokomish Rivers (Figure 1). During the sampling periods, juveniles were collected from the hatcheries just before their release into the river. Collections from the respective estuaries were begun a minimum of two weeks after the initial hatchery release to allow time for transit of juveniles to the estuaries (Weitkamp and Campbell, 1980). Juvenile chinook salmon were collected from the hatcheries from late May to early June and from the estuaries in June through early July of each year. Fish at the estuarine sites were captured using a 30-m beach seine.

[1] Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 2725 Montlake Blvd E., Seattle, WA 98112

RESULTS AND DISCUSSION

Chemical Contaminant Exposure

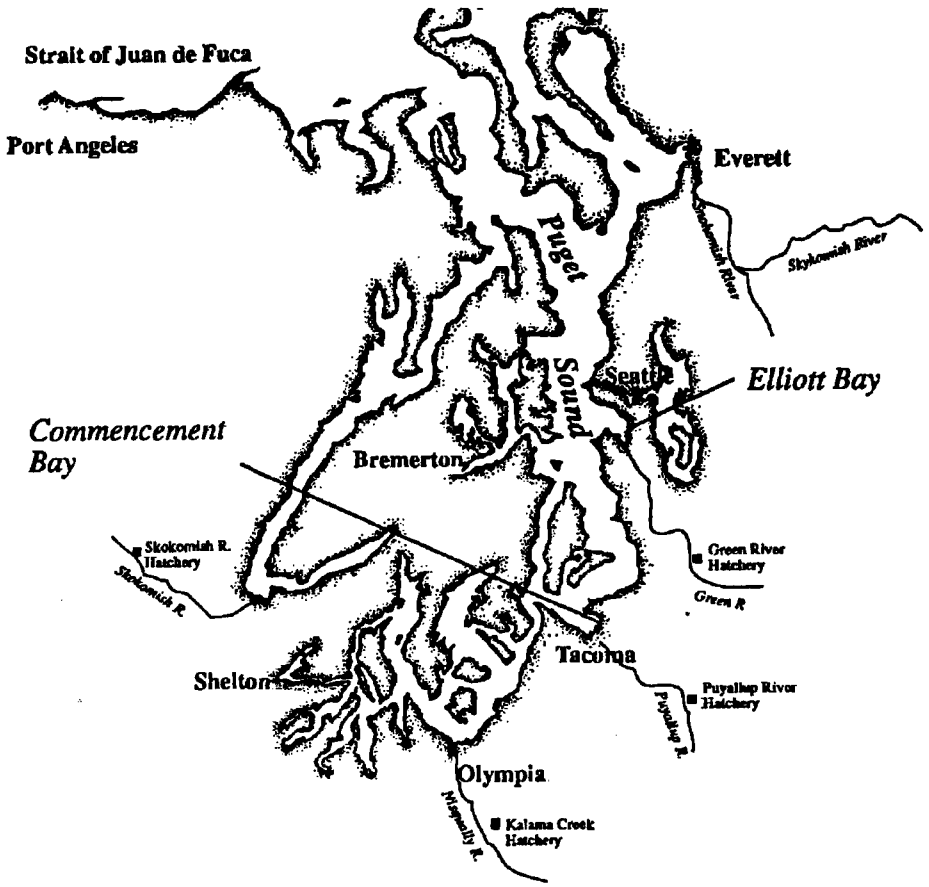

Figure 1. Map of river systems sampled in Puget Sound, Washington

Route of exposure and uptake of chemical contaminants by juvenile salmon was assessed by analyses of composite samples (typically n = 60) of stomach contents, liver, and bile. Chemical analyses of stomach contents (typically composed of small crustaceans and annelids) for selected polycyclic aromatic hydrocarbons (PAHs) and chlorinated hydrocarbons (CHs) (Sloan et al., 1993) were done to assess dietary exposure of juvenile salmon to anthropogenic chemicals. Uptake of chemical contaminants was assessed by measuring concentrations of fluorescent aromatic compounds (FACs) and CHs in bile and liver, respectively. Because fish extensively metabolize PAHs, these compounds do not accumulate in tissues but are found in the bile as metabolites (Varanasi et al., 1989). Measurement of these metabolites provides an estimate of exposure of fish to PAHs (Krahn et al., 1986).

We have consistently found significantly higher concentrations of PAHs and polychlorinated biphenyls (PCBs) in stomach contents of juvenile salmon from the urbanized Duwamish Waterway and Commencement Bay estuary compared to fish from the rural Nisqually River estuary or compared to juveniles from the hatcheries. For example, in 1990 the concentrations of PAHs and PCBs in stomach contents of juvenile salmon from the Duwamish Waterway and Commencement Bay estuary were 27,000 and 250 ng/g wet wt., respectively, whereas concentrations in juveniles from the Nisqually River estuary and the hatcheries were 24 and 76 ng/g wet wt., respectively (Stein et al., 1995). We also have consistently found significantly elevated concentrations of FACs in bile of fish from the urbanized Duwamish Waterway and Commencement Bay estuary compared to concentrations in fish from all the non-urban estuaries and the hatcheries (Figure 2). Similar findings for the bioaccumulation of PCBs in the liver of juvenile salmon are reported in Stein et al. (1995). These observations show that despite the brief residency of juvenile chinook salmon in urban estuaries, significant accumulation of chemical contaminants is evident, as previously reported in the initial study of the Duwamish Waterway by McCain et al. (1990). These observations also show that diet appears to be a source of bioavailable chemical contaminants to outmigrant juvenile chinook salmon in urban estuaries.

Evidence that the level of exposure was biologically significant at the subcellular level was provided by measuring hepatic cytochrome P4501A (CYPIA) activity (AHH), the major inducible cytochrome P450 in fish (Goksoyr et al., 1991; Collier et al., 1995), and levels of hepatic DNA adducts, a marker of the

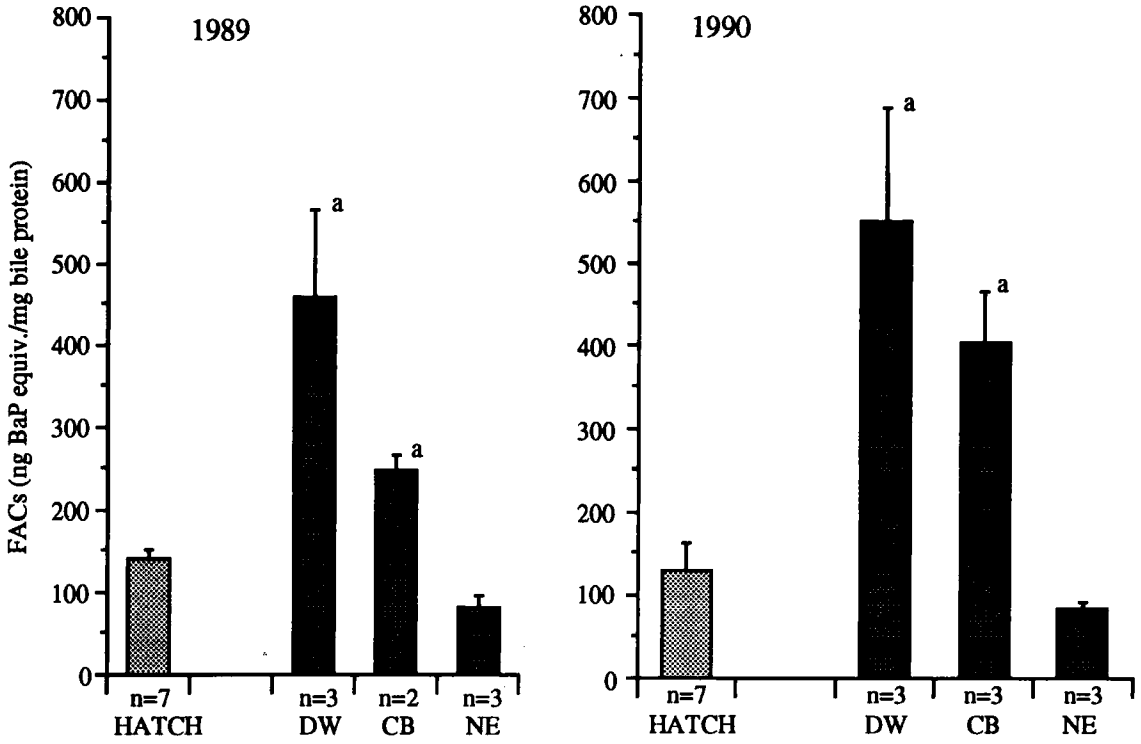

Figure 2. Biliary fluorescent aromatic compounds (FACs) (ng BaP equivalents/mg bile protein) in juvenile salmon from estuaries and hatcheries sampled in Puget Sound, Washington, in 1989 and 1990, BaP = benzo[a]pyrene. The bars represent the mean ± standard error. Site abbreviations are: Hatch = Combined hatcheries of the estuarine systems sampled in 1989 or 1990, DW = Duwamish Waterway, CB = Commencement Bay, and NE = Nisqually River estuary. The letter (a) indicates values that are significantly different from those for salmon from the combined hatcheries and the NE, and (b) indicates values that are significantly different from those for salmon from the NE only. The sample size (n) reflects the number of composites that were analyzed. Each sample represents a composite of material from 60 fish. (Adapted from Stein et al., 1995.)

formation of potentially toxic intermediates (e.g., PAH metabolites) that interact with cellular macromolecules (Stein et al., 1993). Results for 1990 (Figure 3) show significantly higher hepatic AHH activities and DNA adducts in fish from the Duwamish Waterway and the Commencement Bay estuary when compared to AHH activity and DNA adduct levels in salmon sampled from the Nisqually River estuary or from the hatcheries. Similar findings of higher hepatic AHH activities and DNA adducts in fish from the Duwamish Waterway and the Commencement Bay in 1989 are reported by Stein et al. (1995). These findings demonstrate that the exposure was sufficient to elicit biochemical responses, which suggests the potential for other biological effects to ensue.

Immune Function

Immune dysfunction in mammals has recently been recognized as a sublethal effect of chemical contaminant exposure affecting both cellular and humoral aspects of the immune system (Dean et al., 1986). Laboratory studies have extended these findings to fish by demonstrating that their immune system is susceptible to specific contaminants, often resulting in a wide array of immunosuppressive effects (McLeay and Gordon, 1977; Arkoosh and Kaattari, 1987; Rice and Weeks, 1989; Thuvander, 1989).

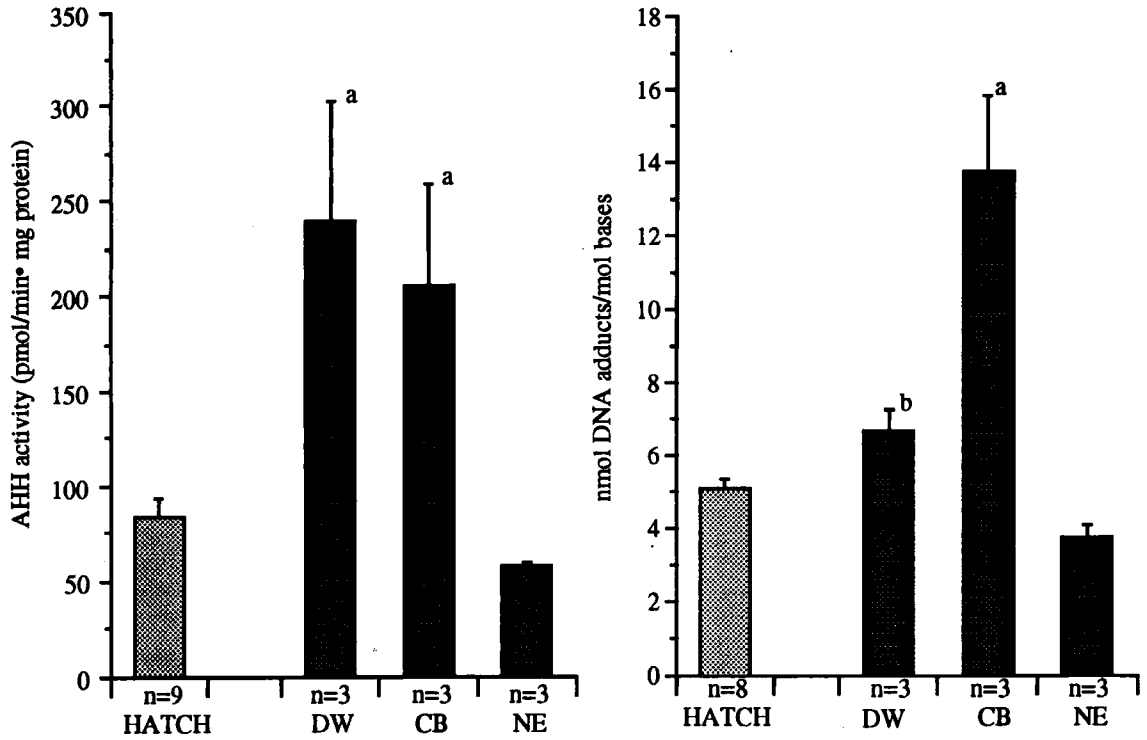

Figure 3. Hepatic aryl hydrocarbon hydroxylase (AHH) activity (pmole/min•mg protein) and DNA adducts (nmole/mole bases) in juvenile salmon from estuaries and hatcheries sampled in Puget Sound, Washington, in 1990. The bars represent the mean ± standard error. Site designations are as described in Figure 2. The letter (a) indicates values that are significantly different from those for salmon from the combined hatcheries and the NE. The sample size (n) reflects the number of composites that were analyzed. Each sample represents a composite of material from 60 fish. (Adapted from Stein et al., 1995.)

However, field studies focusing on the effects of environmental exposure to chemical contaminant on the primary and secondary humoral responses of fish have not been previously performed. In our studies with juvenile salmon, immunocompetence was evaluated by analyzing the functional ability of leukocytes from two different lymphoid organs, the anterior kidney and spleen, to mount an *in vitro* primary and secondary response to a foreign antigen, trinitrophenyl phosphate (TNP), as described by Arkoosh and Kaattari (1987). We showed (Arkoosh et al., 1991) that leukocytes from the anterior kidney of juvenile salmon collected from the Green River or Kalama Creek hatcheries and from the Nisqually estuary were able to generate a significantly higher secondary response (number of plaque-forming cells (PFCs)/culture) against TNP (Figure 4) than that produced during the primary response. However, an enhanced secondary response did not occur with leukocytes from the anterior kidney of primed Duwamish Waterway juvenile salmon (Arkoosh et al., 1991).

Both PAHs and PCBs are known to induce immunoaltering effects in mammals (Ward et al., 1985; Dean et al., 1990) suggesting that PCBs or PAHs or both may be responsible for suppressed B-cell mediated immunity in juvenile salmon from the contaminated urban estuary. Studies examining the effects of PCBs or PAHs on the immune system of fish, however, are limited; thus controlled laboratory studies were needed to further assess whether contaminant exposure in wild fish could causally be related to the plaque-forming cell response. Accordingly, a study was conducted that used the PFC assay to characterize immune function in leukocytes from the anterior kidney and spleen of juvenile salmon exposed to a

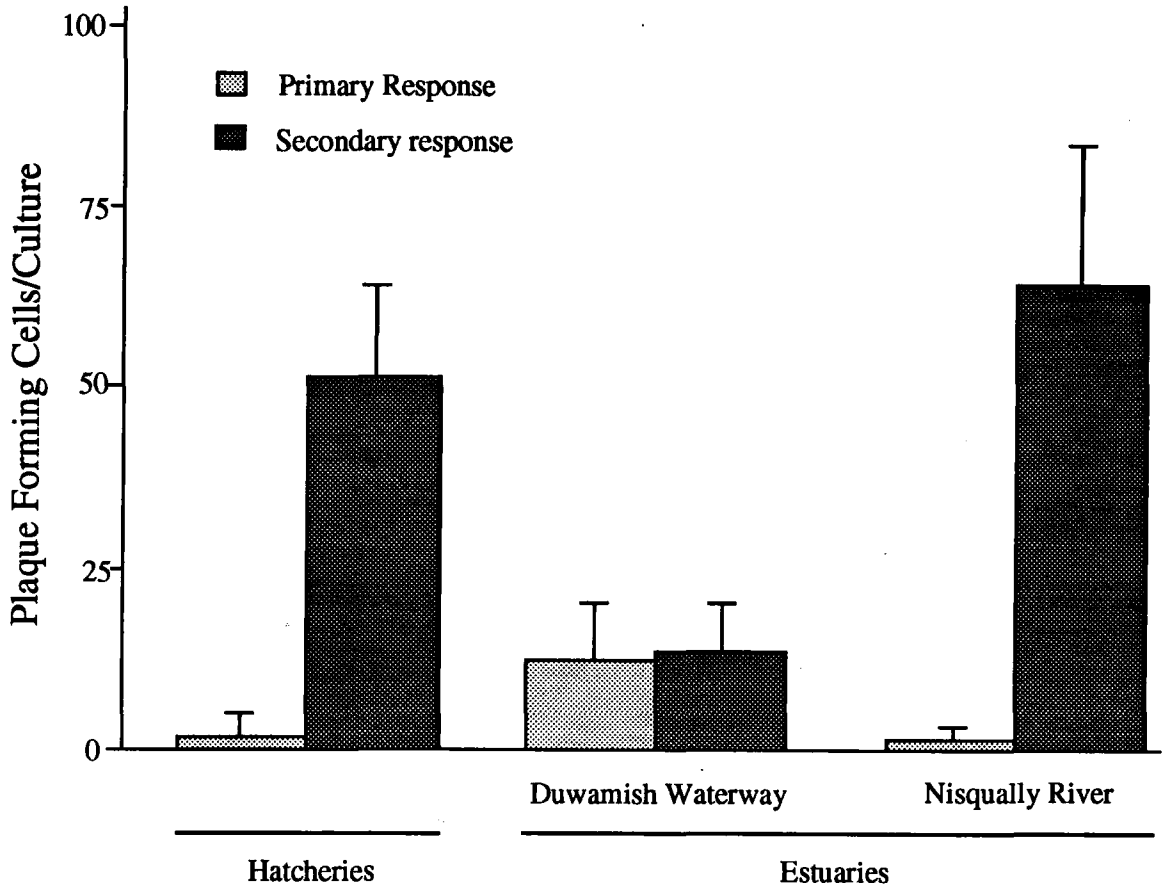

Figure 4. The number of plaque forming cells/culture evaluating both the primary and secondary response of juvenile chinook salmon from the hatcheries, from the reference Nisqually estuary, and the urban Duwamish Waterway to a native antigen, TNP. (Adapted from Arkoosh et al., 1991.)

commercial PCB mixture, Aroclor 1254, and to 7,12-dimethylbenz[a]anthracene (DMBA), a model PAH (Arkoosh et al., 1994). Results of this study are shown in Figure 5. Our findings confirm that when juvenile chinook salmon are administered sublethal doses of contaminants that are representative of the types of compounds they bioaccumulate in urban estuaries, they exhibit suppression of their secondary PFC response. These results showing impaired secondary PFC response by exposure to a PAH and PCB mixture support the putative causal relationship between impaired secondary PFC response and chemical contaminant exposure in juvenile chinook salmon from polluted urban estuaries in Puget Sound, Washington.

Disease Challenge Study

The findings showing a suppressed ability to produce an *in vitro* secondary humoral immune response in juvenile chinook salmon from an urban estuary compared to fish from a rural estuary suggest that juveniles from urban estuaries may be more susceptible to disease. In a recently conducted study, juvenile salmon were collected from the Duwamish Waterway, from rural estuaries, and from the respective releasing hatcheries, and exposed to the pathogen *Vibrio anguillarum*, serotype 1575, to assess whether juveniles from the urban estuary system exhibited increased mortality. A series of disease challenges was

conducted using juvenile chinook salmon sampled in 1993 and 1994. The results showed that juvenile chinook salmon from the contaminated estuary were more susceptible to *V. anguillarum*-induced mortality than were fish from the releasing hatchery (Arkoosh et al., in prep). In contrast, no significant differences in *V. anguillarum*-induced mortality were observed between salmon from the minimally contaminated estuary and its hatchery. The results of this initial disease challenge experiment indicate that in juvenile chinook salmon from an urban estuary, contaminant-associated immunodysfunction appears to lead to increased susceptibility to pathogenesis by a virulent marine bacterium.

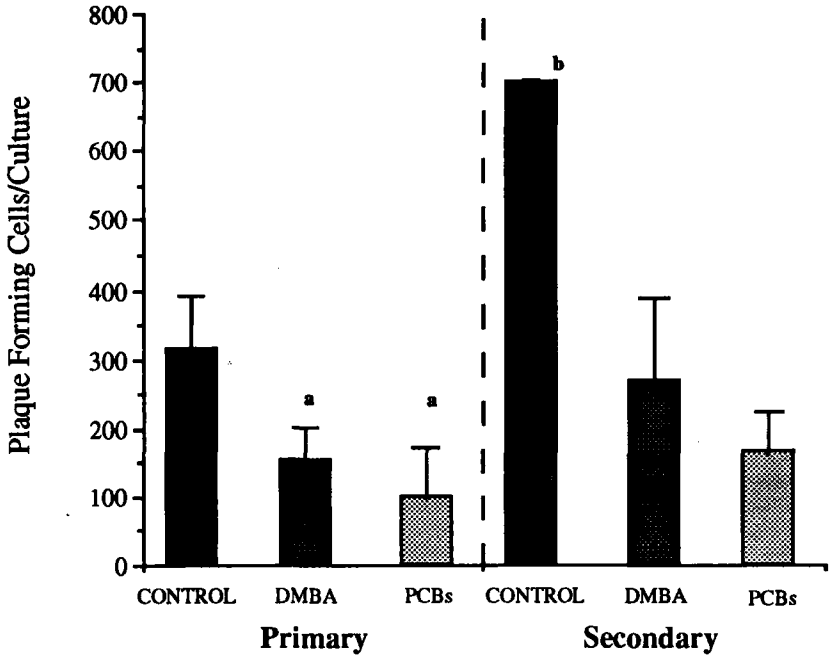

Figure 5. The number of plaque-forming cells/culture evaluating both the primary and secondary response of juvenile chinook salmon exposed to sub-lethal doses of dimethyl benzanthracene (DMBA), a PAH or PCBs, which are known immunomodulatory contaminants. The letter (a) indicates values that are significantly different from those for control salmon, and (b) indicates a significantly enhanced secondary response compared to the primary response. (Adapted from Arkoosh et al., 1994.)

Growth Study

Somatic tissue growth is a highly regulated process integrating the functions of numerous physiological systems. Impaired growth has been observed to be a sensitive, sublethal measure of chemical contaminant exposure, particularly in rapidly developing larvae and juvenile organisms (Rosenthal and Alderdice, 1976; Barron and Adelman, 1984; Casillas et al., 1992). Growth of juvenile fall chinook from the various estuaries sampled in 1990 and 1991 is summarized in Figure 6 (Casillas et al,. in prep). Growth was assessed as the percent increase in fork length of juveniles from the estuary compared to the increase in fork length of juveniles from their respective hatcheries. In 1990 and 1991, a significantly smaller increase in length was observed for juvenile salmon captured in the Duwamish Waterway compared to fish taken from the Green River hatchery during a 30- to 90-day holding period. In contrast, increase in length of juvenile salmon captured in the non-urban Nisqually estuary was not significantly different from the increase in length of juveniles from the Kalama Creek hatchery during the initial 30-day holding period.

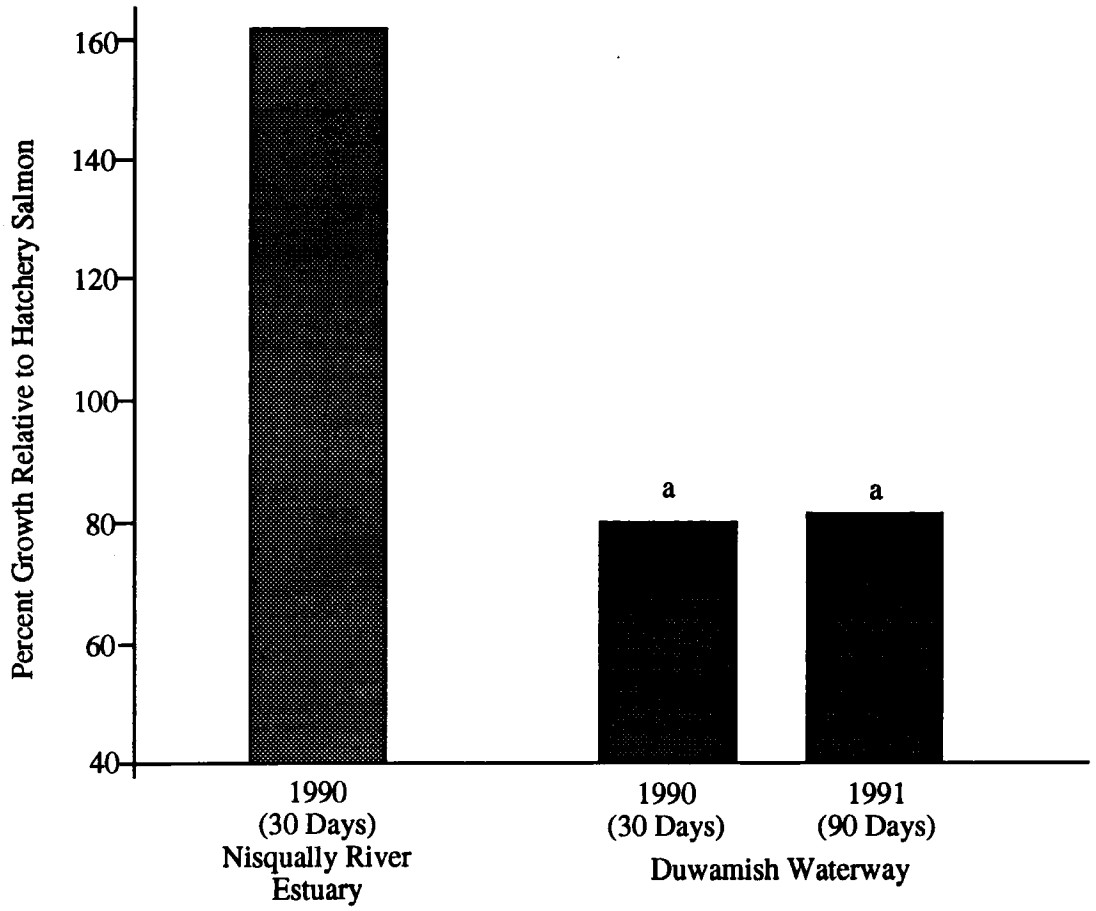

Figure 6. Percent growth (length) of juvenile chinook salmon from the respective hatcheries for a 30-day period in 1990 and a 90-day period in 1991. The letter (a) indicates a significant decrease in growth in salmon from the estuary compared to salmon from its respective hatchery.

Although these results appeared to indicate that there was an effect of chemical contaminant exposure on growth, a constant background mortality was observed throughout the study period and represented a potentially confounding factor. In 1993, following modifications in facilities and husbandry protocols to decrease mortality, we sampled fish from the Duwamish Waterway and the Skokomish estuary and their respective hatcheries and monitored growth. The Skokomish River system, which feeds into Hood Canal in Puget Sound, represented an alternate reference area. In this study, growth of juvenile chinook salmon from the Skokomish estuary was comparable to the growth of fish from the releasing hatchery, whereas growth of juvenile chinook salmon from the Duwamish Waterway was significantly depressed relative to the growth of juveniles from its releasing hatchery as was determined previously. Survival of salmon was greater than 90 percent for all treatment conditions, which strengthens our findings that growth is indeed impaired in juvenile chinook salmon that migrate through an urban estuary and are exposed to a suite of chemical contaminants (Casillas et al., in prep.).

SUMMARY

The findings presented on chemical, biochemical, and biological studies of outmigrating juvenile chinook salmon (*Onchorynchus tshawytscha*) from urban and non-urban estuaries of Puget Sound, Washington, confirm the results of McCain et al. (1990) showing increased exposure of juvenile chinook

salmon to toxic chemicals in contaminated urban estuaries of Puget Sound. In addition, increased exposure to chemical contaminants of juvenile salmon from urban estuaries was sufficient to elicit responses at the biochemical level. Concomitant with the increased chemical exposure and biochemical alterations, juvenile chinook salmon inhabiting these urban estuaries exhibited evidence of immune system alterations and impaired growth relative to juveniles taken directly from the hatcheries or from the non-urban estuaries. The potential for the observed immunosuppression to lead to increased disease susceptibility was indicated by increased mortality in juvenile salmon from the Duwamish Waterway when exposed to the marine pathogen *Vibrio anguillarum.* Overall, the findings from these integrated studies provide evidence of linkage between the presence of elevated levels of complex mixtures of chemical contaminants in polluted estuaries and effects on health and survival of juvenile chinook salmon.

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ACCUMULATION OF MERCURY AND POLYCHLORINATED BIPHENYLS IN QUILLBACK ROCKFISH (*Sebastes maliger*) FROM PUGET SOUND, WASHINGTON

James E. West and Sandra M. O'Neill[1]

INTRODUCTION

Ecotoxicological impacts of persistent pollutants (PPs) in aquatic ecosystems have received much attention in the past few decades. These nondegradable, nonnutritive contaminants are taken up by organisms faster than they are released, resulting in bioaccumulation over time. Metal poisoning of fish by mercury from industrial and agricultural sources has been well documented (Sorensen, 1991), as has contamination by polychlorinated biphenyls (PCBs). PCBs are unusually ubiquitous in aquatic systems (Phillips, 1994), being transported to even remote polar ecosystems via atmospheric processes (Hammar, 1989).

In aquatic ecosystems, persistent pollutants reach high levels in carnivores primarily through the food chain (see Hammar et al., 1993). A number of fish life history and ecological parameters have also been associated with accumulation of PPs in marine fishes. Fish age and size were shown to be important in determining the mercury concentration in muscle tissue of two species of scorpionfish (Monteiro et al., 1991), Atlantic herring (Braune, 1987), swordfish (Monteiro and Lopes, 1990), and the catadromous European eel (Larsson et al., 1991). Larsson et al. (1991) also identified body fat content as an important factor to consider for uptake of lipophilic compounds such as PCBs. Thomson (1985) demonstrated the importance of fish size on concentration of mercury in muscle tissue in some marine species, yet warned that lack of correlation of fish size to mercury concentration in others he tested precluded the use of fish size as a universal, multi-species predictive tool.

The Fish Task Unit of the Puget Sound Ambient Monitoring Program (PSAMP) monitors levels of more than 100 pollutants in five species of marine and anadromous fish from Puget Sound (PSQWA, 1993). The primary goal of the Unit is to monitor average conditions in Puget Sound fishes in terms of temporal and spatial changes in their contaminant levels. The quillback rockfish (*Sebastes maliger*) is one of two *Sebastes* monitored by PSAMP. This species is a long-lived (>50 years), relatively slow-growing, non-migratory, benthic carnivore that inhabits rocky subtidal substrates from California to Alaska. These life history characteristics provide an excellent opportunity to study bioaccumulation of PPs in marine ecosystems. Quillback rockfish is also one of the most abundant *Sebastes* in Puget Sound, and it contributes substantially to Washington's sport-fishing industry as a popular food item for marine anglers.

In this paper, we (1) summarize three years of PSAMP data for mercury and PCBs in quillback rockfish; (2) compare muscle tissue concentrations of these contaminants for three locations in the Puget Sound; (3) assess the importance of fish age, size, lipid content and location on the bioaccumulation of PPs in quillback rockfish; and (4) describe these relationships using linear regression models.

METHODS

Quillback rockfish were collected from Blake Island (BI), Double Bluff (DB), and San Juan Islands (SJ) in 1991, 1992, and 1993 (Figure 1). Fish were taken using hook-and-line gear from September to December, and collection depths ranged from 30 m to 120 m. Upon landing, fish were immediately wrapped individually in aluminum foil, labeled, sealed in plastic bags, and placed on ice. In the laboratory, fish were measured, weighed and sexed. Sagittal otoliths were removed for age estimation. Muscle tissues were excised from skinned lateral muscles in the lab within 10 days of collection. Approximately 50 g of tissue from each of five rockfish was combined to create a single composite-sample. Six composite

[1] Washington Department of Fish and Wildlife, Marine Fish Division, 600 Capitol Way N., Olympia, WA 98501-1091

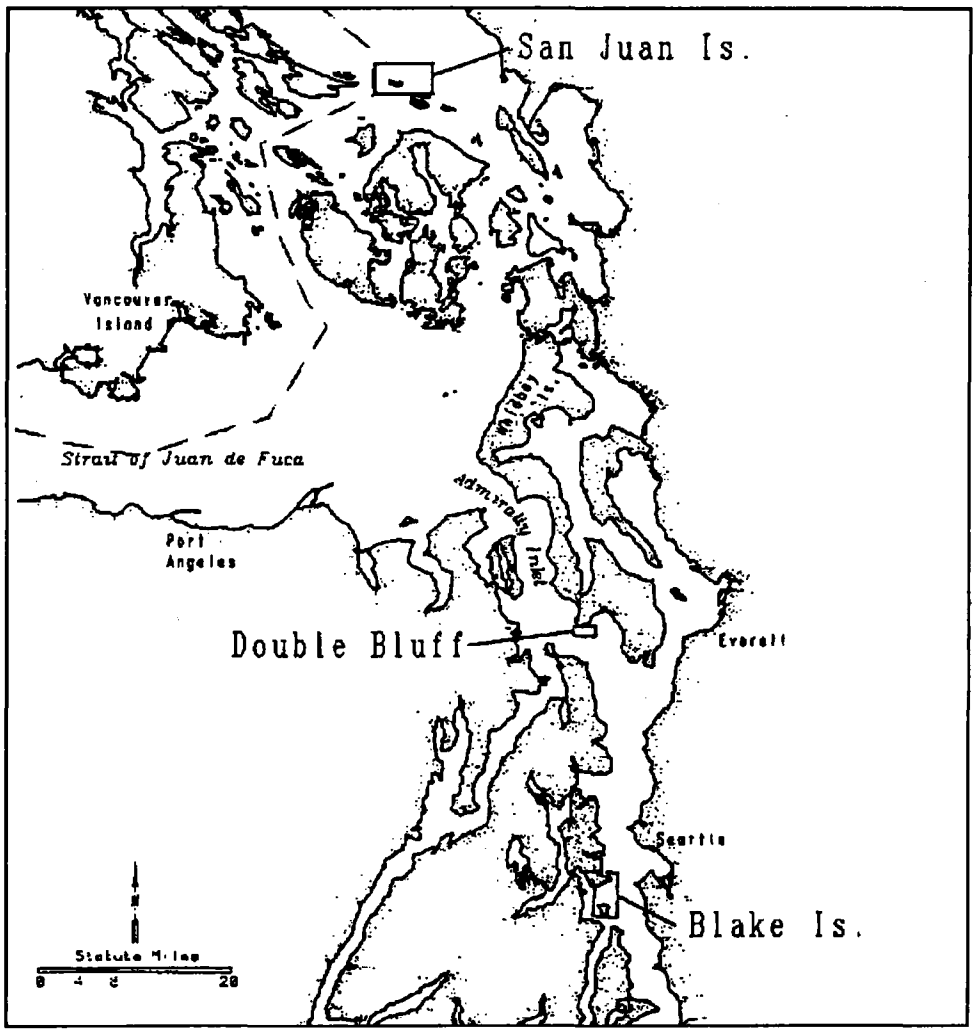

Figure 1. Location of collection sites for quillback rockfish

samples (representing 30 fish) were processed from each location in each year. Composite-samples of muscle tissue were placed in pre-cleaned jars and frozen for later analysis.

Total mercury concentration of composite-samples was determined by cold vapor atomic absorption after digestion with the nitric acid/sulfuric method (PSEP, 1989). PCBs were analyzed using gas chromatography-electron capture detection with a 0.25 mm column (PSEP, 1989). Because of modifications in laboratory procedures in 1992, PCB data from the 1991 muscle samples were excluded from PCB data analysis in this report.

Mean age, mean length and mean %lipids were computed for the five fish that constituted each composite-sample. Hence, all contaminant analyses were conducted using mean composite age (MCA), mean composite total length (MCTL) and mean composite %lipids (MCPL). In 1992 and 1993, we grouped fish in composites based on similarity of size. (1991 fish were not grouped in this manner.)

For comparison of station or year means, data were first assessed for normality, homoscedasticity of variance and quality of residuals. All data met assumptions for parametric analysis, except for minor violations of the homoscedasticity assumption. One-way analysis of variance with Tukey multiple range comparison (STSC, 1991) was used to identify year- or location-differences in parametric means.

Least squares Model I linear regression analysis using dummy (Z) variables (Kleinbaum and Kupper, 1978) were used to model accumulation of PPs and to separate station effects. Values of dummy variables were Z_1=1, Z_2=0 (BI); Z_1=0, Z_2=1 (DB); Z_1=0, Z_2=0 (SJ). For regressions with two stations, only one dummy variable was required (Z=1 for BI and Z=0 for DB). Stepwise (forward) variable selection (STSC, 1991) was conducted with a confidence level of 95%. A log transformation of PCB concentrations was performed to linearize data.

Location-specific growth rates were modeled using the von Bertalanffy length-at-age growth equation (Ricker, 1975) for individual (pre-composited) fish:

$$Length = L_\infty(1 - e^{-k(Age - t_0)})$$

where L_∞ = the asymptotic length,
k = the growth rate constant, and
t_0 = age at length 0 (intercept).

Non-linear least squares analysis (SAS, 1988) was used to generate parameters for fitting von Bertalanffy curves.

Individual (pre-composited) fish length and weight were highly correlated for all locations (sites pooled, n=264, r^2=0.98, p<0.0001). Hence, for all subsequent analyses, length was used as the sole descriptor of fish size.

RESULTS

Mercury

Mercury was detected in all quillback rockfish composite-samples for the three years of this study. Concentrations ranged from 0.10 mg/kg to 0.51 mg/kg. Station mean values (± standard deviation) were 0.25±0.10 mg/kg (BI), 0.24±0.08 mg/kg (DB) and 0.22±0.14 mg/kg (SJ–Table 1). All three stations had at least one composite-sample with a concentration of mercury greater than 0.40 mg/kg. We observed no significant trends in mean mercury concentration between years (ANOVA, p=0.53, stations pooled), or between stations (ANOVA, p=0.81, years pooled).

Mercury concentration increased with age of rockfish for all locations (Figure 2a). Using stepwise multiple linear regression analysis regressing [Hg] with age and location, we computed a mercury age model

$$[Hg] = \beta_1(MCA) + \beta_2 Z_2 + \beta_0,$$

where [Hg] = mercury concentration in mg/kg,
β_i = factor coefficient,
MCA = Mean Composite Age, and
Z_2 = location identifier dummy variable.

Table 1. Summary of contaminant data for quillback rockfish from three stations in Puget Sound, Wash. Results are grand mean values for mean composite ages, mean composite total lengths, and mean composite % lipids

Location		MCA	MCTL	MCPL*	Mercury (mg/kg)	Aroclor 1260 (µg/kg)
	Mean	15.6	296	0.4	0.25	12.9
Blake	Std Dev	6.6	22	0.5	0.10	15.8
Island	Min	9.0	258	0.05	0.10	2.3
	Max	32.4	338	2.3	0.47	65.0
	n	17	17	12	17	17
	Mean	11.9	321	0.3	0.24	4.4
Double	Std Dev	3.7	22	0.2	0.08	3.1
Bluff	Min	7.8	283	0.01	0.10	2.3
	Max	22.4	360	0.6	0.41	15.0
	n	18	18	12	18	18
San	Mean	13.5	341	0.3	0.22	2.8
Juan	Std Dev	7.1	43	0.2	0.14	1.8
Islands	Min	6.4	276	0.1	0.10	2.0
	Max	28.0	400	0.5	0.51	8.9
	n	18	18	12	18	18

* lipid data from 1992 and 1993 only

With this procedure we identified two statistically significant ($p<0.01$) model parameters (Table 2). The mercury age model adjusts [Hg] for age effects common to all locations (β_1), and unmeasured effects specific to Double Bluff (β_2).

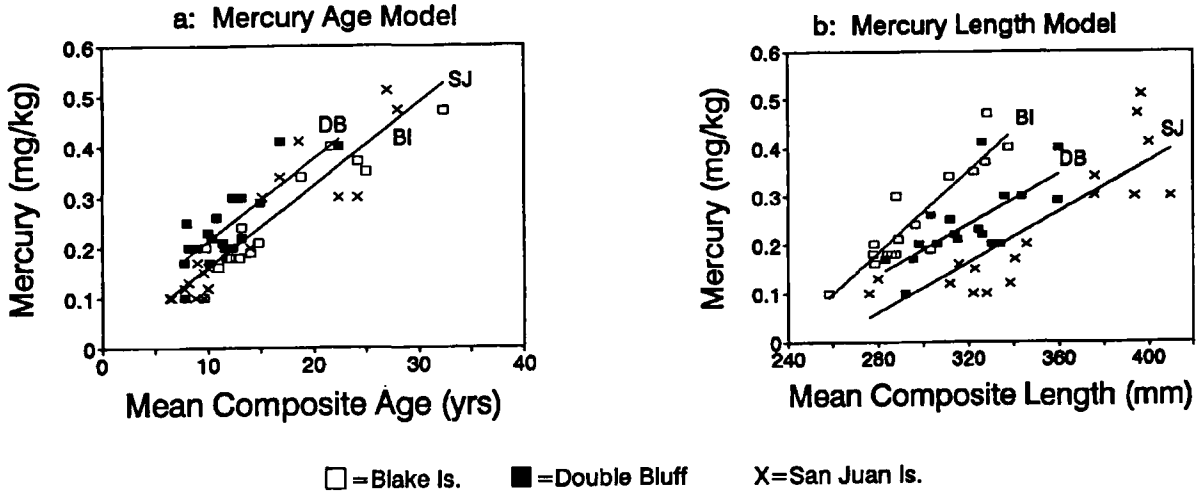

Figure 2. Fitted regression lines for two linear regression models, (a) mercury age model and (b), mercury length model. Model equations and statistics are presented in Table 2.

Table 2. Parameters for full (age-length) and restricted linear regression models used to describe bioaccumulation of mercury in quillback rockfish from three locations in Puget Sound, Wash.

	Mercury Age·Length Model			Mercury Age Model			Mercury Length Model		
	Variable	Coeff.	p value	Variable	Coeff.	p value	Variable	Coeff.	p value
β_0	intercept	0.0249	0.14	intercept	-0.0008	0.96	intercept	-0.726	0.09
β_1	(Z_1)MCTL	0.00013	0.015	MCA	0.0162	<0.001	MTCL	0.0028	<0.001
β_2	(Z_2)MCTL	0.00020	0.0001	Z_2	0.0522	<0.001	Z_2	0.0836	0.021
β_3	MCA·MCTL	0.00004	<0.0001				(Z_1)MCTL	0.0005	<0.001
R^2		0.815			0.811			0.707	
p		<0.0001			<0.0001			<0.001	
Model	$[Hg]=MCTL(\beta_1 Z_1+\beta_2 Z_2+\beta_3 \cdot MCA)+\beta_0$			$[Hg] = \beta_1(MCA)+\beta_2 Z_2+\beta_0$			$[Hg] = MCTL(\beta_1+\beta_3 Z_1)+\beta_2 Z_2+\beta_0$		

Using coding for dummy variables described in Methods above and model coefficients from Table 2, individual simplified equations for each location are:

SJ: [Hg] = 0.0162(MCA)-0.001
DB: [Hg] = 0.0162(MCA)+0.051
BI: [Hg] = 0.0162(MCA)-0.001.

The mercury age model indicates that mercury concentration is strongly associated with fish age from all locations (r^2=0.81), and that fish from all three locations accumulated mercury at an equal rate. In addition, quillback rockfish from Double Bluff exhibited a slightly higher offset in mercury concentration (0.052 mg/kg); however, the difference was associated with an unmeasured parameter.

Mercury concentration also increased with size of rockfish (Figure 2b) at all locations. We used stepwise multiple linear regression analysis regressing [Hg] with fish length and location to compute a mercury length model,

$$[Hg] = MCTL(\beta_1+\beta_3 Z_1)+\beta_2 Z_2+\beta_0,$$

where [Hg] = mercury concentration in mg/kg,
β_i = factor coefficient,
MCTL = Mean Composite Total Length, and
Z_1 & Z_2 = station identifier dummy variables.

With this procedure we identified three statistically significant ($p<0.05$) model parameters (Table 2). The mercury length model adjusts [Hg] for fish length effects common to all locations (β_1), unmeasured effects specific to Double Bluff (β_2), and fish length effects specific to Blake Island (β_3). The model accounted for 70.7% of the variability in mercury concentration observed in these data.

Using coding for dummy variables described in Methods and model coefficients from Table 2, individual simplified equations for each location are:

SJ: [Hg] = 0.00257(MCTL)-0.660
DB: [Hg] = 0.00257(MCTL)-0.582
BI: [Hg] = 0.00417(MCTL)-0.984.

Unlike the age model, uptake patterns of [Hg] with fish size differed significantly among all three locations (Table 2, Figure 2b). The rate of [Hg] uptake was higher at BI than at the other two locations, and significant [Hg] offsets occurred for each location. Hence, for a given length, predicted [Hg] was highest at BI, followed by DB and SJ.

We also compared all measured parameters (length, age, and %lipids) together for all locations in a stepwise multiple linear regression analysis to test their relative effects on [Hg] in quillback rockfish. This model indicates that only age, length and age·length interactions represented significant effects ($p<0.0001$), accounting for 81.5% of observed [Hg] variability. The following mercury age·length model adjusts for these location-specific age and length effects:

$$[Hg] = MCTL(\beta_1 Z_1+\beta_2 Z_2+\beta_3 \cdot MCA)+\beta_0$$

where [Hg] = mercury concentration in mg/kg,
β_i = factor coefficient,
MCA = mean composite age,
MCTL = mean composite total length and
Z_1 & Z_2 = location identifier dummy variables.

The procedure resulted in three statistically significant ($p<0.05$) model coefficients (Table 2, Age-Length Model). Substituting codes for dummy variables described previously in the Methods section, individual simplified equations for each station are:

SJ: [Hg] = MCTL(0.00004 · MCA)+0.0249
DB: [Hg] = MCTL(0.00020+0.00004 · MCA)+0.0249
BI: [Hg] = MCTL(0.00013+0.00004 · MCA)+0.0249

Mercury concentration at each location is defined in this model primarily by the age-length product, indicating that growth rate was an important contributor to the variability in [Hg] for all locations. BI and DB locations have additional slope (Hg uptake) components attributable to location-specific differences in fish length (β_1 and β_2, respectively, Table 2). The age-length model specified no parameters attributable to unmeasured location-specific effects.

Quillback rockfish were significantly larger at SJ than BI (ANOVA of MCTLs with Tukey Multiple Range Test, $p=0.0002$, d.f.=52), even though there were no significant differences in fish age between these locations (ANOVA, $p=0.16$, d.f.=52). This location-specific growth rate difference is illustrated by von Bertalanffy growth curves fitted for these samples (Figure 3). Both the growth rate constant (k) and the asymptotic length (L_∞) increased from BI → DB → SJ. Equations for the lines fitted in Figure 3 are as follows:

$$BI{:}Length = 350(1 - e^{-0.052(Age+21.8)})$$

$$DB{:}Length = 372(1 - e^{-0.096(Age+9.6)})$$

$$SJ{:}Length = 416(1 - e^{-0.119(Age+3.6)})$$

Mercury concentration in quillback rockfish estimated with the age-length model is higher at BI than at SJ for the age and length ranges of our data, which is converse to the trend in growth rate we observed between these two locations (Figure 3). Hence, the fastest-growing fish accumulated mercury at a slower rate than the slowest-growing population. The highest [Hg] of the three locations as estimated by the age-length model was from DB. Growth rate of fish from this location was intermediate between SJ and BI (Figure 3), however, overlap in the 95% confidence intervals for (L_∞), k and T_0 for DB and BI (Table 3).

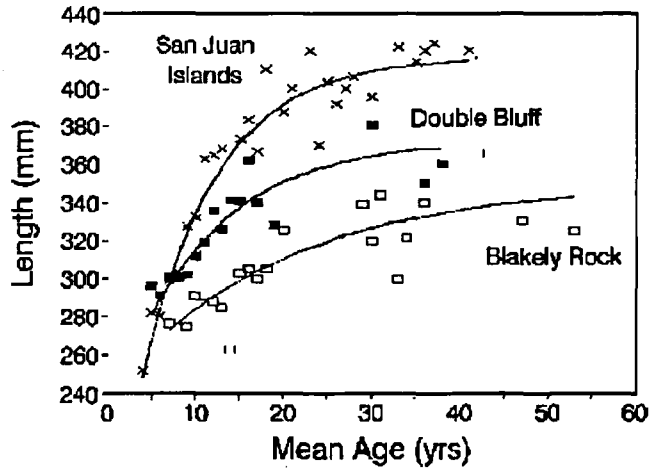

Figure 3. von Bertalanffy growth curves for quillback rockfish from three locations in Puget Sound, Wash. Curves were fitted using raw (non-composited) age and length data (n=264); however, observed data are presented as means in order to simplify graph.

PCBs

PCBs, as Aroclor 1260 congeners, were present in quillback rockfish from 1992 and 1993 samples from all three stations in Puget Sound. Individual sample-composite concentrations ranged from 2.0 µg/kg (the limit of detection) at SJ to 65 µg/kg at BI (Table 1). Mean station concentrations (± standard deviation, years pooled) ranged from 2.8±1.8 µg/kg at SJ to 12.9±15.8 µg/kg at BI. The mean concentration of PCBs was significantly higher at BI than SJ, and there was no significant difference in mean PCB concentration at DB (4.4±3.1 µg/kg) versus SJ or BI (ANOVA of log

[PCB], $p<0.0001$, d.f.=35, with Tukey Multiple Range Test).

Most Aroclor 1260 concentrations were at or near the detection limit (2.0 µg/kg) in samples from SJ; only two composites of 18 exceeded 3 µg/kg (5.9 µg/kg and 8.9 µg/kg) at that location. These two composites also represented the oldest and largest fish from SJ. Because of this, SJ samples were excluded from the following regression analyses.

Like mercury, [Aroclor 1260] increased with fish age (Figure 4a). Stepwise linear regression analysis testing the relative effects of fish length, age, location, and %lipids on [Aroclor 1260] indicates that only age and an unmeasured location-specific parameter contributed significantly to [Aroclor 1260] in quillback rockfish ($p<0.0001$). The following PCB age model, which adjusts for age effects (both locations) and an unmeasured effect specific to the BI location (β_2), accounted for 75.7% of the variability in log-transformed Aroclor 1260.

$$\text{Log [Aroclor 1260]} = \beta_1(\text{MCA})+\beta_2 Z+\beta_0,$$

where β_i = factor coefficient,
MCA = mean composite age, and
Z = dummy (station identifier) variable.

Individual station equations from the PCB age model are:

DB: Log [Aroclor 1260] = 0.044(MCA)+0.163
BI: Log [Aroclor 1260] = 0.044(MCA)+0.356.

The stepwise linear regression for this model showed that age was the primary variable affecting [Aroclor 1260] in quillback rockfish, and that [Aroclor 1260] at BI was elevated as a result of an unmeasured parameter (β_2, Table 3).

Concentration of Aroclor 1260 also increased with size of fish (Figure 4b). A log-linear regression model testing the effects of only length and location on [Aroclor 1260] provided a positive correlation ($p<0.0001$).

The following PCB length model accounted for 57.8% of the variability in log [Aroclor 1260] from BI and DB:

$$\text{Log [Aroclor 1260]} = \text{MCTL}(\beta_1+\beta_2 \cdot Z)+\beta_0,$$

where β_i = factor coefficient,
MCTL = Mean Composite Total Length, and
Z = dummy (station identifier) variable.

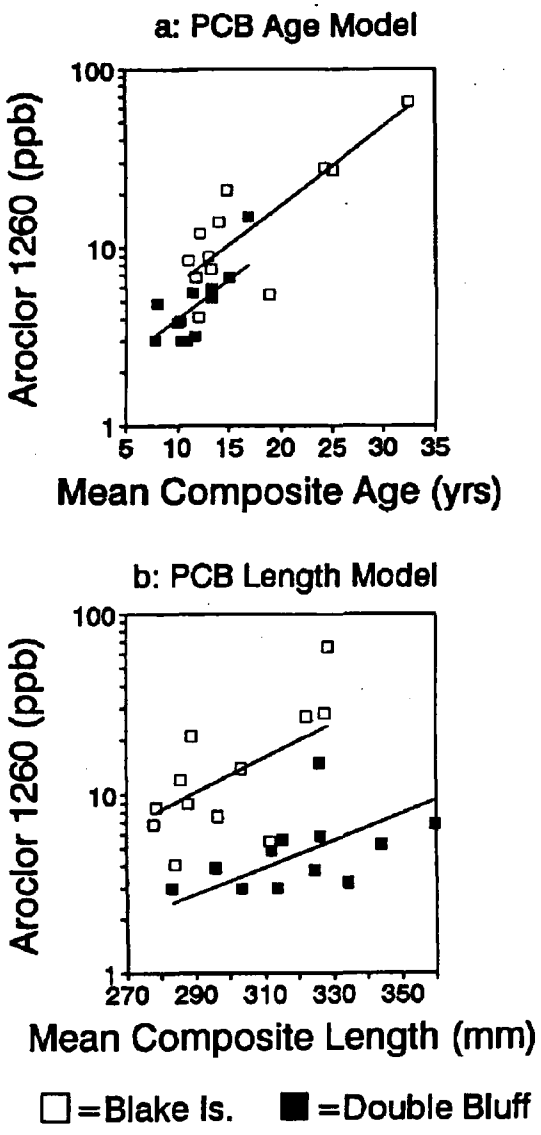

Figure 4. Fitted regression lines for the (a) PCB age model and (b) PCB length model. The y axes are presented in log scales to linearize data. Model equations and statistics are presented in Table 3.

Table 3. Parameters for full (Age) and restricted (Length) linear regression models used to describe bioaccumulation of Aroclor 1260 in quillback rockfish from three locations in Puget Sound, Wash.

	PCB Age Model			PCB Length Model		
	Variable	Coeff.	p value	Variable	Coeff.	p value
β_0	intercept	0.163	0.109	intercept	-1.763	0.032
β_1	MCA	0.044	<0.001	MCTL	0.0076	0.005
β_2	Z	0.193	0.027	MCTL·Z	0.0020	<0.001
R^2		0.778			0.614	
p		<0.001			<0.001	
Model	Log [Aroclor 1260] = $\beta_1(MCA)+\beta_2 Z+\beta_0$			Log [Aroclor 1260] = $MCTL(\beta_1+\beta_2 \cdot Z)+\beta_0$		

This model resulted in simplified individual station equations,

DB: Log [Aroclor 1260]=0.0076(MCTL)-1.763
BI: Log [Aroclor 1260]=0.0096(MCTL)-1.763.

In the PCB Length Model, size of quillback rockfish was a significant determiner of [Aroclor 1260] ($MCTL \cdot \beta_1$) for both locations, and BI showed a significantly greater rate of accumulation than DB as the result of an unmeasured parameter ($\beta_2 \cdot Z$).

DISCUSSION

Both mercury and Aroclor 1260 accumulated in quillback rockfish from all locations we sampled. Mercury exhibited a strong linear relationship with age and size. This is similar to results obtained for two confamilial scorpionfishes (Monteiro et al., 1991), in which both exhibited a strong, positive (exponential or multiplicative) relationship with age. Aroclor 1260 exhibited a moderately strong positive log-linear relationship with age, indicating that a relatively slow rate of uptake for young fish increased with fish age.

The mercury age-length model indicated that most of the variability in mercury concentration among locations can be explained by differences in location-specific growth rate (age-length interactions). Indeed, we observed different growth patterns between the locations, illustrated by the von Bertalanffy growth curves (Figure 3). It is unknown why quillback rockfish exhibited this gradient of growth rates from SJ>DB>BI. Possible explanations include differences in location-specific (1) environmental conditions (e.g., temperature), (2) diet, (3) habitat quality, (4) levels of fishing pressure, and (5) interspecific resource competition.

A significant question remains as to whether contaminants have affected growth rate or growth rates have affected contaminant uptake. Growth "dilution," where faster-growing fish accumulate PPs at a slower rate than slow-growing fish (see Hammar et al., 1993), has been suggested as a factor controlling bioaccumulation of PPs in Atlantic herring (Braune, 1987), two species of Atlantic scorpaenid (Monteiro, 1991) and the catadromous European eel (Larsson et al., 1991) as well as a number of freshwater fishes (Jensen et al., 1982; Thomann and Connolly, 1984; Hammar et al., 1991; Borgmann and Whittle, 1992; Stow et al., 1993). Growth rate has also been suggested as a factor to account for differences observed in mercury concentration between conspecific sexes; however, no one has yet distinguished this from the confounding effects of sexual differences in elimination of PPs through gametes (Monteiro and Lopes, 1990; Monteiro et al., 1991). In any case, the different age- or size-specific Hg and PCB levels and

bioaccumulation rates we observed among our sampling locations is particularly important because they suggest that any predictive models for mercury or PCB concentration in quillback rockfish from Puget Sound should account for population- or location-specific growth or other factors.

The PCB age model indicated that of the input variables tested in the stepwise regression (age, length, %lipids and location), age was the only significant factor that affected [Aroclor 1260]. The model also indicated that an unmeasured factor resulted in the higher [Aroclor 1260] at BI. A simple explanation for the higher [Aroclor 1260] at BI is a source difference of the contaminant at that location. Unfortunately, contaminants are not currently measured at the PSAMP rockfish stations because of the hard-bottom substrate typical of their habitats. However, proximity to source of contaminants has been described as an important factor in uptake of persistent pollutants in flounders (Kiørboe et al., 1983), dogfish and flatfish (Leah et al., 1991), and migrating juvenile salmon (McCain et al., 1990). This effect has also been demonstrated experimentally in a marine shrimp (Palmer and Presley, 1993).

Fat, or lipid content of fish, is an important factor controlling accumulation of lipophilic pollutants in other species (Larsson et al., 1991); however, they were not an important factor in accumulation of mercury or Aroclor 1260 in quillback rockfish. We found low levels of lipids in quillback rockfish (≤0.6%) in all but one case. One composite with a lipid value of 2.3% had the highest concentration of PCB, suggesting that lipids may become important in this species at higher levels.

Composite-samples consisted of an average PP concentration for a group of five fish of varying lengths and ages. Because of this, it is impossible to determine the full range of variability in [PP]s for individual rockfish. At least one composite (from SJ) exceeded the World Health Organization action limit (WHO, 1976) of 0.5 mg/kg mercury, and is close to the U.S. Environmental Protection Agency's screening value (U.S. EPA, 1993) of 0.6 mg/kg. Fish from that composite ranged in age from 9 to 37 years and in length from 330 to 424 mm (the regression was computed using a mean age of 28 years and mean length of 397 mm). If the largest non-composited ages and lengths from this group are applied to the mercury age-length model, resulting [Hg] estimates exceed 0.6 mg/kg. Six composites from BI and one from DB exceeded the U.S. EPA screening value for PCBs. If the oldest individual age (53 years) of quillback rockfish we collected is applied to the PCB age model, the resulting [Aroclor 1260] estimate exceeds 490 µg/kg.

These projections are useful only in estimating potential PP concentrations for individual fish and rely on the assumption that uptake continues in a linear fashion for fish beyond the range of ages and lengths described in our models. Growth in quillback rockfish, however, slows substantially as adults reach their asymptotic length (Figure 3), likely resulting in an increase in rate of uptake of PPs as a fish ages. This increased rate of uptake with age has been described in a confamilial scorpionfish (*Helicolenus dactylopterus*; Monteiro et al., 1991).

Compositing samples of long-lived fish for contaminants that accumulate with age (although more cost-effective for monitoring studies) may mask the effects of important physiological factors (e.g., age), thereby reducing the accuracy of bioaccumulation models. We also did not try to sample very large (or old) quillback rockfish. Maximum length for this species is reported at 61 cm (Hart, 1973), which is substantially larger than any individual we collected. The largest specimen from BI, the location with the greatest rate of uptake of both mercury and Aroclor 1260, was 400 mm. Hence, quillback rockfish with higher PP concentrations than measured in this study likely exist in Puget Sound.

Age and length are both important factors to consider in understanding the accumulation of PPs in quillback rockfish from Puget Sound. Uptake of PPs is undoubtedly nonlinear over the entire lifespan of these fish; however, linear or log-linear models were adequate to describe uptake within the age and length ranges of our data. Location-specific differences in growth rates of fish populations and in factors we did not measure also make it imperative to consider where fish were collected when modeling or estimating PPs in this species. We suggest that a study designed specifically to assess bioaccumulation is warranted to define more clearly the range of mercury and PCB concentrations in quillback rockfish from Puget Sound, and to model more completely and accurately the relationships we have identified here.

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EFFECTS OF CHEMICAL CONTAMINANTS ON GROWTH, AGE-STRUCTURE, AND REPRODUCTION OF *MYTILUS EDULIS* COMPLEX FROM PUGET SOUND, WASHINGTON

Anna N. Kagley, Kyle E. Kardong, Robert G. Snider and Edmundo Casillas[1]

INTRODUCTION

Mussels and other marine bivalves are widely used in environmental monitoring programs for assessing chemical contamination of coastal marine waters. Bivalves are broadly used because they are sessile organisms and can bioaccumulate both organic compounds and toxic elements such as cadmium and mercury. Studies with both laboratory-exposed and field-transplanted mussels suggest that pollutants can cause toxic effects on mussels. For example, reductions in the scope-for-growth (a bioenergetic term reflecting the net energy available for growth) have been reported for field-exposed mussels sampled from contaminated areas (Capuzzo and Leavitt, 1988; Widdows and Johnson, 1988; Widdows et al., 1990). In addition, when mussels from uncontaminated sites were transplanted to contaminated sites, the scope-for-growth decreased, and overall growth was reduced in those mussels placed in the most contaminated regions (Martin et al., 1984; Salazar and Salazar, 1991; Veldhuizen-Tsoerkan et al., 1991). However, impaired growth in indigenous populations of mussels that are chronically exposed to chemical contaminants has not been clearly demonstrated.

We recently reported that mussels from urban areas of Puget Sound, Washington, exhibited altered cellular features in the digestive gland (indicative of a toxic response), when compared to mussels from non-urban areas (Krishnakumar et al., 1994). Changes in these parameters were associated with elevated tissue levels of organic chemical contaminants. Our results also suggested that mussels from urban areas of Puget Sound may not grow as well as mussels from non-urban areas; however, age (an important factor in assessing growth) was not determined.

Accordingly, we initiated a more comprehensive study to evaluate the effect of chemical contaminant exposure on a variety of growth-related parameters in indigenous populations of the blue mussel, *Mytilus edulis* complex, in Puget Sound, Washington. The growth-related parameters assessed included age, shell length, somatic tissue weight, and gonadal tissue weight. Interactions between contaminant body burdens and growth-related parameters, including age-weight relationships and population age structure, were evaluated to demonstrate linkages between chemical contaminant exposure of indigenous mussels in the marine environment and biological effects.

MATERIALS AND METHODS

Sample Collection

Mytilus edulis complex were collected from their natural beds at sites in Puget Sound during a 30-day period in September-October, 1993. The beds consisted of a sand and rock-based medium. Minimally contaminated collection sites included Coupeville, Double Bluff, and Oak Bay in central and north Puget Sound as well as False Bay at San Juan Island (Figure 1). Mussels were also collected from Commencement Bay in Tacoma, Four Mile Rock in Seattle's Elliott Bay, and Sinclair Inlet in Bremerton, which are urban sites known to contain moderate to high levels of anthropogenic contaminants. At each site a 15 cm x 15 cm grid was placed on the substrate at a mean tidal height of approximately 1 m above mean sea level and approximately 200 mussels were removed. They were transported to the Mukilteo holding

[1] Northwest Fisheries Science Center, Environmental Conservation Division, 2725 Montlake Blvd E., Seattle, WA 98112

facility and maintained in flow-through saltwater aquaria prior to sampling. Mussels were necropsied within 24-36 hours after being collected.

Tissue Chemistry

Tissue concentrations of polycyclic aromatic hydrocarbons (PAHs) and chlorinated hydrocarbons were determined from 30 to 40 mussels randomly selected from each site. Whole mussel tissue samples were dissected, pooled, and stored at -20 degrees C until chemical analyses. Samples were analyzed for organic chemical contaminants as described by Krahn et al. (1988) and Sloan et al. (1993). The results are expressed in $ng \cdot g^{-1}$ dry tissue weight. Dry weights were determined from tissue samples heated to 120 degrees C in an oven for 18 hrs.

Biological Measurements

Barnacles and byssal threads were removed from the exterior surface of the mussel shell prior to biological measurements. For each mussel, the length (umbo to farthest posterior margin), total weight, wet and dry weights for somatic and gonadal tissues, sex, and age were determined.

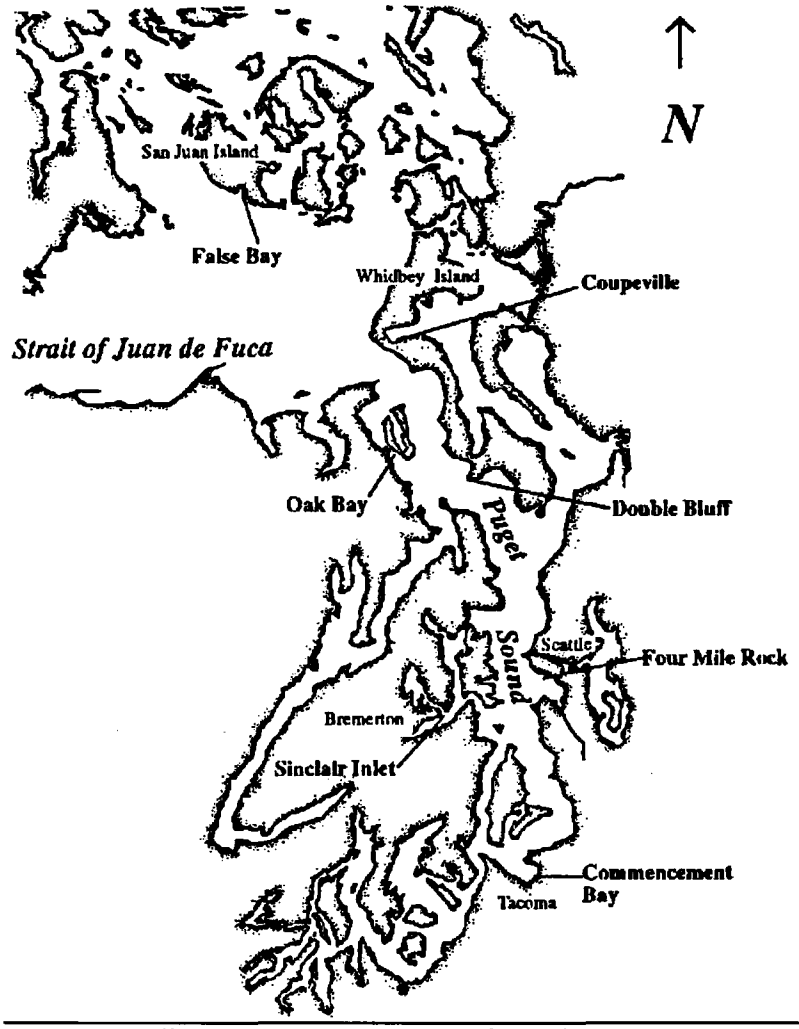

Figure 1. Collection sites in Puget Sound, Washington

Aging Methods

The age of each animal was initially determined by enumerating the growth rings on the exterior surface of each valve (Pannella and MacClintock, 1968; Stansbery, 1961). These measurements were then verified by comparing them to sclerochronological measurements of internal annual bands in a subset of mussel valves from each site. The ages of mussels derived by each method were then compared. If discrepancies between the age measurements occurred, adjustments were made based on findings derived from the sclerochronology method, which has been shown to be the more accurate of the two techniques (Lutz, 1976; Richardson et al., 1990).

Fecundity

The number and volume of eggs were determined on histological sections of the female gonad of mussels using a quantitative computer-assisted image analysis technique. The total number of eggs in female mussels was estimated based on the average number of eggs found in a given volume of gonad tissue and the wet weight of gonad-containing mantle tissue (density to weight relationship).

Statistical Analyses

Growth data were fitted to growth curve equations using Deltagraph Professional 2.02© (Delta Point, Inc.®). Differences in growth curves were determined by analysis of covariance using the SuperANOVA 1.11© statistical program (Abacus Concepts, Inc®). Differences in the age distributions of the different populations from urban and reference sites were evaluated using a generalized linear model (GLMStat 1.1.3©, K.J. Beath, Symantec, Invention Software Corporation®). Findings were considered significantly different at $\alpha \leq 0.05$.

RESULTS AND DISCUSSION

Contaminant Exposure

Higher concentrations of ΣPAHs, ΣPCBs, ΣDDTs and other chlorinated pesticides were found in mussel tissues from the urban sites (Thea Foss Waterway in Commencement Bay, Four Mile Rock in the northern portion of Elliott Bay, and Sinclair Inlet) than in mussels from reference sites (Oak Bay, False Bay, Coupeville and Double Bluff in Useless Bay) (Table 1). For example, mussels from Commencement Bay contained the highest tissue concentrations of ΣPAHs and ΣPCBs (5800 and 490 $ng \cdot g^{-1}$ dry wt, respectively). Elevated levels of ΣPAHs and ΣPCBs were also found in mussels from the urban-associated sites of Four Mile Rock and Sinclair Inlet, but the concentrations in mussels from these two sites were less than in mussels from Commencement Bay. Mussels from the reference sites had relatively low tissue concentrations of ΣPAHs and ΣPCBs; tissue concentrations of ΣPAHs and ΣPCBs in mussels from the reference areas ranged from 110 to 130 and <10 to 110 $ng \cdot g^{-1}$ dry wt, respectively. Differences in the concentrations of ΣDDTs and other selected chlorinated pesticides between mussels from the urban and reference sites were not as pronounced (Table 1). These findings demonstrate that mussels exposed to contaminants in polluted waterways can accumulate relatively high levels of ΣPAHs and ΣPCBs.

Table 1. Concentration of organic contaminants in whole tissue of Mytilus edulis *($ng \cdot g^{-1}$ dry weight) from Puget Sound, Washington*

Site	Polycyclic Aromatic Hydrocarbons				Chlorinated Hydrocarbons		
	ΣHMW	ΣLMW	ΣTotal	Screen*	ΣPCBs	ΣDDT	ΣPesticides
Reference							
Coupeville	50	80	130	na	50	11	12
Double Bluff	50	70	120	0.11	110	11	11
False Bay	na	na	na	0.05	<5	<1	na
Oak Bay	40	70	110	na	60	11	10
Urban							
Commencement Bay	5010	750	5800	na	490	29	33
Four Mile Rock	820	320	1100	1.9	290	19	17
Sinclair Inlet	120	100	220	na	180	15	11

Concentrations of polycyclic aromatic hydrocarbons and chlorinated hydrocarbons in the whole tissue ($ng \cdot g^{-1}$ dry tissue wt) of mussels sampled from Puget Sound and analyzed by GC/MS and GC/ECD respectively. High molecular weight (HMW) PAHs: fluoranthene, pyrene, benz(a)anthracene, chrysene, benzofluoranthenes, benzo(a)pyrene, indeno(1,2,3-c,d)pyrene, dibenzo(a,h)anthracene, and benzo(g,h,i)perylene. Low molecular weight (LMW) PAHs: naphthalene, acenaphthylene, acenapthene, fluorene, phenanthrene, anthracene, and 2-methylnaphthalene. DDTs: DDT, DDE and DDD. Pesticides: aldrin, chlordane, dieldrin, heptachlor and lindane.

* Values represent PAH body burden determined with a newly developed screening technique reported as phenanthrene equivalents ($ug \cdot g^{-1}$, wet tissue weight).

Alterations in Growth

The growth of mussels was similar from reference areas and significantly different (ANCOVA, $p \leq 0.05$) from the growth of mussels from urban areas (Figure 2). These growth curves show a pattern of slower growth in populations of mussels from sites known to contain chemically contaminated sediments. Mussels from these sites have higher tissue burdens of chemical contaminants compared to mussels from reference sites (Table 1). Comparison of shell length and somatic tissue weight between 4-year-old mussels from the urban and reference areas sampled in Puget Sound exemplifies the differences in growth of mussels from urban and reference sites (Table 2). Four-year-old mussels from urban sites that exhibited high tissue levels of chemical contaminants were 50 percent shorter and only 30 percent of the mass of mussels from the reference sites. These findings are consistent with other studies showing general reduction in the scope-for-growth parameter of mussels exposed to contaminants along known pollution gradients (Widdows and Johnson, 1988; Widdows et al., 1990). In transplant studies where mussels were deployed along known pollution gradients, reduction in scope-for-growth was often correlated with reduced somatic tissue mass (Salazar and Salazar, 1991; Veldhuizen-Tsoerkan et al., 1991; Martin et al., 1984). Assessment of the effects of contaminants on growth in transplant studies can be derived using differences in shell length or weight at the beginning and end of a study period. In chronically exposed indigenous populations of mussels, accurate measurements of growth are more difficult to determine because of the inability to effectively monitor changes in length or weight of individual mussels through time. However, a reduction in the scope-for-growth of chronically exposed mussels should also result in a reduction of the metrics that are associated with growth, such as shell size and tissue weight with respect to age (Seed and Suchanek, 1992).

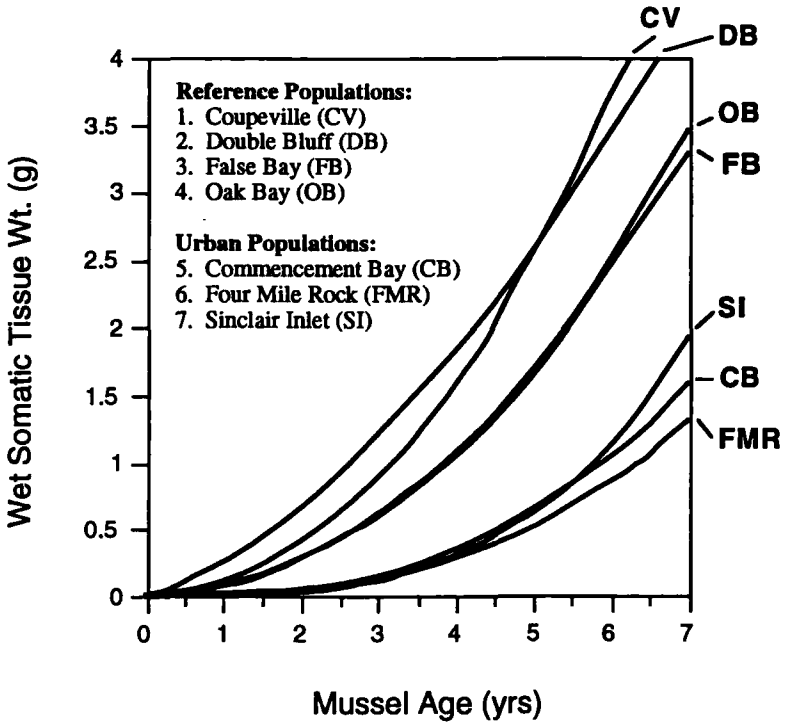

Figure 2. Relationship between the age to somatic tissue weight in mussels from reference and urban areas. Growth curves were generated from data fitted to the sigmoid growth function $y = A/(1+Bx^n)$. Growth curves for mussels from urban areas are significantly different from curves generated for mussels from reference areas.

The observed differences in growth measurements (Table 2) could also be the result of variations in physical oceanographic conditions between the sites. However, this is not likely, as oceanographic conditions throughout the Puget Sound region have been shown to be similar except in selected inlets of southern Puget Sound (Collias et al., 1974). Although other potentially confounding factors such as food availability, time of spawning, and larval settlement period could affect our interpretation, the sampling of a wide diversity of sites with various degrees of contamination likely reduces these possibilities. In addition, even though all the reference sites in this study are in northern Puget Sound and the Straits of Juan de Fuca, Krishnakumar et al. (1994) previously reported that the growth of mussels from Saltwater State Park, a non-urban-associated site in south-central Puget Sound, was similar to the growth of mussels from reference sites sampled in this study.

Alterations in Fecundity

Mussels from urban populations exhibited reduced fecundity compared to mussels of comparable age from reference populations (Table 2), indicating that the potential contribution of sexually mature mussels from the same age class to the reproductive success of the population was less in mussels with a higher tissue chemical contaminant burden. The average fecundity of mussels from the four reference sites was five times as great as that for mussels of comparable age from the three urban sites (690,000 versus 125,000 oocytes/gonad of each mussel, respectively). This observed reduction in fecundity in the urban-associated mussels may be an indirect effect of contamination. Chemical contaminants could affect gonadal recrudescence by affecting the growth of mussels, since a smaller animal may possess a smaller gonadal mass. Although we currently do not have information on the actual reproductive success (hatching success, larval viability, etc.) of mussels from these different areas, our present results suggest that even moderate chemical contaminant exposure could result in a decrease in the contribution of viable eggs from similarly aged mussels to the reproductive potential of mussel populations in Puget Sound, Washington.

Table 2. Shell length, total tissue weight, and fecundity of 4-year-old mussels from Puget Sound, Washington

Sites	n*	Length (mm)	Weight	Fecundity (oocytes/g gonad)
Reference				
Coupeville	185	40.3 ± 4.4	2.3 ±	775000 ± 242000 (83)[a]
Double Bluff	96	44.0 ± 2.1	3.0 ±	1033000 ± 166000 (44)
False Bay	228	34.5 ± 4.8	1.5 ±	446000 ± 146000 (136)
Oak Bay	189	35.1 ± 3.0	1.6 ±	509000 ± 142000 (100)
Urban				
Commencement Bay	187	21.4 ± 2.7	0.34 ±	102000 ± 34000 (85)
Four Mile Rock	208	21.0 ± 3.1	0.32 ±	90000 ± 53000 (95)
Sinclair Inlet	204	22.9 ± 2.6	0.46 ±	184000 ± 53000 (100)

* Sample sizes for length and weight

[a] Sample sizes for fecundity are reported in the parenthesis.

Alterations in Population Parameters

The urban populations of mussels contained a greater proportion of older individuals (> 6 years) compared to mussels in the reference populations (Table 3). More than 15 percent (21 percent, 12 percent, and 13 percent) of mussels from all urban populations were greater than 6 years old, whereas less than 1 percent of mussels from all of the reference populations were greater than 6 years old. It is unlikely that environmental factors are more favorable for a longer life span for mussels in contaminated areas than reference areas. Previously, we found that factors such as water currents, salinity, temperature, and food

availability on biological parameters were not substantially different throughout Puget Sound (Krishnakumar et al., 1994) and therefore could not account for differences in growth of mussels from urban and reference areas. It is possible that competitors or predators in and around the mussel beds may have been excluded or eliminated from urban areas, thus allowing mussels to grow and survive longer due to a reduction in predation and competitive pressures for available resources. Whether or not chemical contaminants could contribute to such putative indirect effects on mussel populations from urban areas is presently unknown, but species diversity has been shown to be reduced in chemically contaminated urban environments. Although human harvesting of mussels could also affect the population age structure of mussels from the sites sampled in this study, the distance of reference sites from urban centers and limited accessibility of some reference sites suggest that harvesting pressure from humans could not account fully for the lowered age structure of mussel beds from all of the reference areas.

Table 3. Population age-structure of mussels from Puget Sound, Washington

Sites	n	Mean Age	% Mussels >6yrs
Reference			
Coupeville	185	4.1 ± 1.4	1
Double Bluff	96	2.1 ± 1.1	0
False Bay	228	3.4 ± 1.1	0
Oak Bay	189	2.8 ± 0.9	0
Urban			
Commencement Bay	187	4.8 ± 2.1*	21*
Four Mile Rock	208	3.9 ± 1.1	12*
Sinclair Inlet	204	4.1 ± 2.0	13*

* Significantly different from reference sites at $p \leq 0.05$

CONCLUSION

The results of this field study demonstrated that *Mytilus edulis* complex from polluted embayments in Puget Sound, Washington, exhibited elevated concentrations of chemical contaminants and showed impaired growth, reduced fecundity, and altered age-structure patterns. These findings indicated potential linkages between exposure of mussels to chemical contaminants and observed biological effects at the individual and population levels. This study also serves to show that the measurement of biological responses and chemical contaminant in indigenous mussel populations can accurately assess habitat degradation in coastal environments resulting from human activities.

ACKNOWLEDGMENTS

The authors would like to thank Gina Ylitalo, Jon Buzitis, Larry Hufnagle, and Dan Mahlum for their assistance in the chemical analyses; O. Paul Olson for assistance in determining fecundity; Corey DeLosSantos for technical support; Tom Hom and Herb Sanborn for many helpful discussions; and Casimir Rice for critical review of the manuscript. We also extend appreciation to Dr. Fred Johnson, Dr. David Armstrong, Dr. Lobo Orensenz, and Raoul Palasios of the University of Washington College of Ocean and Fisheries Science for use of their equipment and laboratory space. And finally recognition must go to Jeff Grim of the Department of Fish and Wildlife for assistance in aging of *Mytilus edulis* complex.

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RELATIONSHIPS BETWEEN HEPATIC LESION PREVALENCE IN ENGLISH SOLE *(Pleuronectes vetulus)* AND SEDIMENT LEVELS OF CHEMICAL CONTAMINANTS IN PUGET SOUND; ESTABLISHING THRESHOLD LEVELS OF SUBLETHAL EFFECTS

Mark S. Myers[1], Lindal L. Johnson[1], Daniel P. Lomax[1], Beth H. Horness[1], Marsha L. Landolt[2], and Sandy O'Neill[3]

ABSTRACT

Sublethal effects of chemical contaminants on marine bottomfish have been studied in Puget Sound by the Environmental Conservation Division (ECD) of the Northwest Fisheries Science Center since 1979, and by the Washington Department of Fisheries as part of the Puget Sound Ambient Monitoring Program (PSAMP) annually since 1989. An approach consistently used in these studies has been to relate levels of chemical contaminants in bottom sediments to site-specific prevalences of toxicopathic liver lesions in the relative nonmigratory sentinel species English sole *(Pleuronectes vetulus)*. Earlier studies by the ECD established strong and consistent statistical correlations between levels of polycyclic aromatic hydrocarbons (PAHs) in sediments and prevalences of hepatic neoplasms, preneoplastic lesions, non-neoplastic proliferative lesions, and unique necrotic/degenerative lesions such as megalocytic hepatosis. Moreover, sole exhibit significantly higher relative risks of lesion occurrence at moderately and highly contaminated urban sites.

Subsequent independent studies of 43 sites by the PSAMP (1989-1993) using similar standardized protocols, diagnostic criteria and statistical methods corroborate these findings. Review of these data suggested liver lesions are first detected at some threshold of exposure to sediment contaminants. A "Hockey Stick" regression model was used to analyze an integrated set of data collected from the ECD and PSAMP studies to estimate effects thresholds in English sole for PAH and other chemical concentrations in sediment. Our results show that most lesions exhibit effects thresholds at 0.5-1 ppm total PAHs in sediment. These concentrations are far lower than those at which significant increases in lesion prevalences are detected using multiple comparison techniques (e.g., No Observable Effect Levels), and are far lower than recommended sediment quality standards (~50 ppm) for Puget Sound.

This technique may serve as a useful tool for assessing species-specific sensitivity to toxicants and for reassessing sediment quality standards that account for the apparent impact of chronic exposure to low levels of contaminants on the health of aquatic organisms.

[1] National Oceanic & Atmospheric Administration, National Marine Fisheries Service, Environmental Conservation Division, 2725 Montlake Blvd. E., Seattle, WA 98112-2097

[2] University of Washington, College of Ocean and Fisheries Sciences, School of Fisheries, Seattle, WA 98195

[3] Washington Department of Fish & Wildlife, 600 Capitol Way N., Olympia, WA 98501-1091

CHEMICAL CONTAMINANTS, FISHING PRESSURE, AND POPULATION GROWTH OF PUGET SOUND ENGLISH SOLE *(Pleuronectes vetulus)*

Lyndal L. Johnson[1], John. T. Landahl[2], Kyle Kardong[1], and Beth H. Horness[1]

INTRODUCTION

Populations of several commercially and recreationally important species of marine fish, including English sole, have seriously declined since the mid-1980s, either throughout Puget Sound, or in selected embayments in the Puget Sound region (Bargman, 1988; Schmitt et al., 1994). The reasons for these declines are not clear, but potential contributing factors include over-harvesting, natural changes in environmental or climatic conditions, and various types of habitat degradation, including the discharge of toxic chemicals into the marine environment.

Various studies (e.g., Malins et al., 1984, 1985; Varanasi et al., 1989; Krahn et al., 1986; PSWQA, 1992, 1993; Stein et al., 1992) show that English sole from industrialized areas in Puget Sound take up and accumulate or metabolize chemical contaminants such as aromatic and chlorinated hydrocarbons. Documented effects of contaminants on English sole in Puget Sound include liver cancer and associated pre-cancerous lesions (Malins et al., 1984, 1985; Krahn et al., 1986; Myers et al., 1990, 1995; PSWQA, 1992, 1993) and reproductive impairment (Johnson et al., 1988, 1993; Casillas et al., 1991; Collier et al., 1992). Both factors could potentially decrease sole abundance by reducing survival and reproductive rates, and in fact, there is evidence of increased mortality in other fish species as a result of toxicopathic liver disease (Baumann et al., 1990). In English sole, however, the impacts of hepatic lesions and other toxicopathic disease conditions on survival and abundance are not known.

Unfortunately, there is little long-term information on English sole abundance in unfished urban bays, so the effects of chemical contaminants on fish populations in such areas cannot be readily determined from trawl surveys or tagging study data (Schmitt et al., 1994). An alternative approach to addressing the question of impacts of contaminants on the English sole population is to formulate and analyze a mathematical model of that population. In preliminary studies (Landahl and Johnson, 1993; Johnson and Landahl, 1994) summarized in this paper, we examined effects of contaminant exposure and related stresses associated with urbanization on English sole subpopulations in Puget Sound using a relatively simple deterministic, age-classified Leslie matrix model (Leslie, 1945). This type of model focuses on age-specific survival and reproduction, which may be affected by a variety of physical, chemical, and biological factors. Analysis of such a model can provide information on long-term population size and the intrinsic rate of natural increase *(r)*, reproductive value or potential, and population resilience and risk of population extinction (Caswell, 1989; Usher, 1972; Barnthouse, 1993).

We based the model on data from field and laboratory studies of English sole conducted in Puget Sound over the past 15 years (Malins et al., 1984, 1985; Johnson et al., 1988; Casillas et al., 1991). Most of these data pertain to four sites (Port Susan, Sinclair Inlet, Duwamish Waterway, and Eagle Harbor; Figure 1) with varying degrees of sediment contamination and include information on survival, growth, and reproductive success. Major sediment-associated contaminants at these sites include polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) (Figure 1).

[1] Environmental Conservation Division, Northwest Fisheries Science Center, NMFS, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112

[2] Office of Center Director, Northwest Fisheries Science Center, NMFS, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112

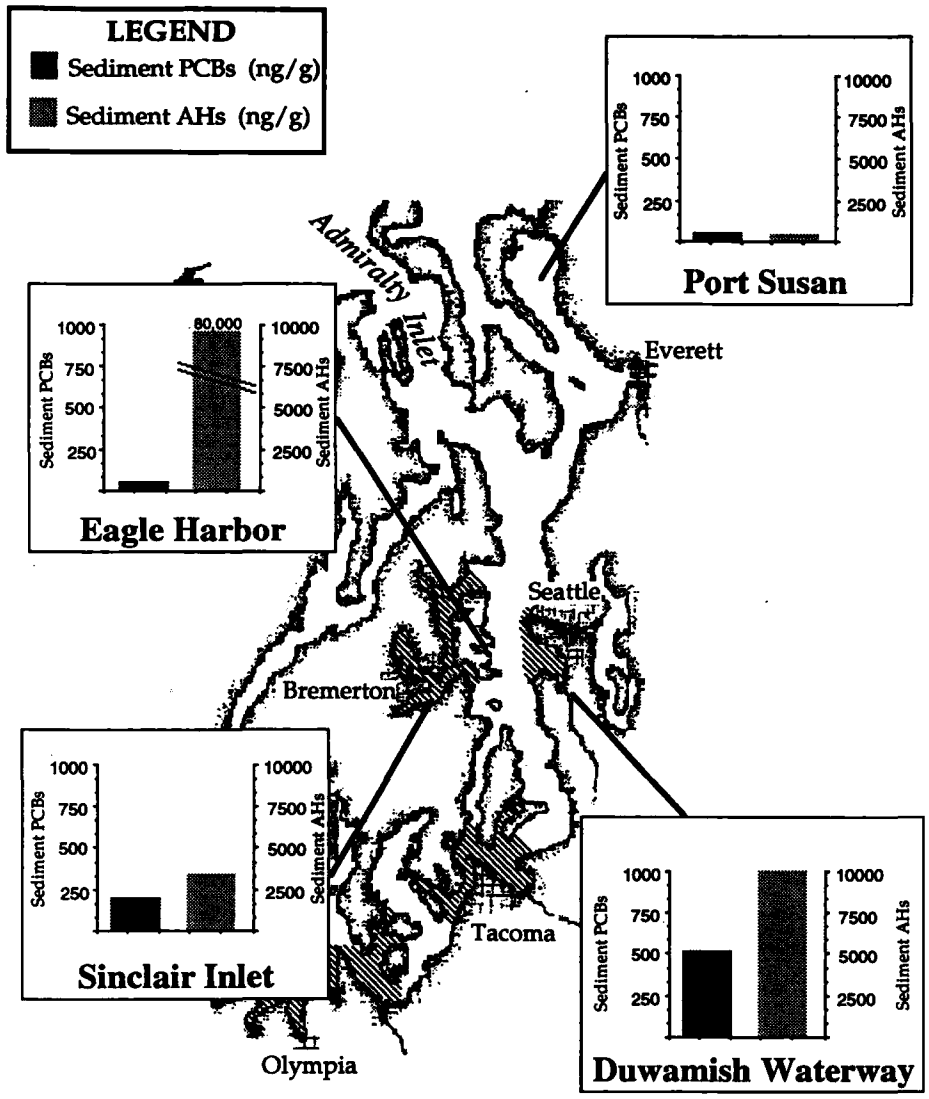

Figure 1. Map of Puget Sound, showing locations of sampling sites included in the model and levels of aromatic hydrocarbons (AHs) (ng/g dry weight) and polychlorinated biphenyls (PCBs) (ng/g dry weight) in sediments collected from these areas. Data from Malins et al. (1984, 1985). Cross-hatched areas indicate sites where commercial fishing for English sole was prohibited between 1979 and 1984, the period when data used for mortality rate estimates in this study were collected (Bargman et al., 1985).

The primary objective of our study was to compare survival rates, reproductive rates, and population growth rates of English sole from sites in Puget Sound with different levels of sediment contamination (see Landahl and Johnson, 1993; Johnson and Landahl, 1994). Initially, we determined total site-specific mortality rates from sole age-frequency data (Johnson and Landahl, 1994) without attempting to subdivide mortality into its component sources (e.g., natural mortality, fishing mortality, and mortality related to contaminants or other environmental stresses associated with urbanization). It is well known, however, that historically there have been considerable differences in fishing pressure between northern Puget Sound sites, such as Port Susan, and urbanized central Puget Sound sites, such as the Duwamish Waterway, Sinclair Inlet, and Eagle Harbor. Moreover, studies by the Washington Department of Fish and Wildlife

(WDFW) suggest that over-harvesting may have contributed significantly to declines in Puget Sound groundfish populations over the past 20 years (Schmitt et al., 1994; Palsson et al., this volume). Consequently, the impacts of fishing mortality should be considered for a realistic analysis of population trends in English sole.

In 1989, the Washington Legislature passed a bill prohibiting groundfish trawling in Puget Sound south of Admiralty Inlet, including central Puget Sound, where Sinclair Inlet, Eagle Harbor, and the Duwamish Waterway are located. Therefore, essentially no English sole are currently harvested from this area. However, throughout the 1970s and 1980s, when much of the data used in this model were collected, there was a significant bottom trawl fishery for English sole in Puget Sound (Bargmann et al., 1985; Schmitt et al., 1991) (Figure 1). This fishery was estimated to account for roughly 30 percent to 50 percent of mortality of adult English sole in northern Puget Sound, where the Port Susan reference area is located (Mensaveta, 1958; Van Cleve and El Sayed, 1969; Holland, 1969). In Sinclair Inlet and the Duwamish Waterway, however, bottom trawl fishing was prohibited even in the 1970s and early 1980s, because the areas were heavily industrialized (Bargman et al., 1985). At Eagle Harbor, the trawl fishery was not officially closed, but the frequent ferry traffic in the area made it unsuitable for commercial fishing (Bargman, pers. comm.). Consequently, there was no commercial fishing pressure at Sinclair Inlet, the Duwamish Waterway, and Eagle Harbor when the survival data used in this model were collected.

To better understand the relative impacts of fishing mortality and mortality associated with chemical contaminants and related anthropogenic stresses on Puget Sound English sole populations, we revised our initial model to subdivide total mortality into fishing mortality and mortality from other sources, so non-fishing mortality rates at contaminated and reference sites could be compared. These data were then used to examine potential changes in population growth rates at the contaminated urban sites if fishing pressure were added to other anthropogenic stresses experienced by these populations. Preliminary results of these expanded models, which are presented in this paper, suggest that it would be difficult for urban fish populations to sustain the level of fishing pressure typically experienced by sole populations at non-urban sites in northern Puget Sound, because of the relatively high non-fishing mortality in sole from contaminated urban embayments.

METHODS

Mortality estimates for adult animals were derived using catch curve analysis and linear regression techniques (Ricker, 1975; Hilborn and Walters, 1992) from age-frequency data on more than 1,000 English sole collected throughout Puget Sound between 1979 and 1985 (see Johnson and Landahl, 1994). Because adult sole are relatively sedentary and leave their normal areas of residence only for a brief period in winter to spawn (Day et al., 1976; Lassuy, 1989), reasonably reliable estimates of survival for adult subpopulations in our sampling areas could be calculated from site-specific age frequency data. Field data for estimating survival rates of juvenile (age 0) fish were not available, and preliminary examination had indicated that estimates of adult survival rate were much too high to be biologically realistic for larval and young-of-the-year fish (Landahl and Johnson, 1993). Consequently, early-age survival was estimated using the method of Schaaf et al. (1987) by calculating a value for age 0 survival which produced a stable, non-varying population trajectory (i.e., r of 0.0) for Port Susan (the minimally contaminated reference site) in specifying the initial Leslie matrix. To check the validity of this estimate, population projections were also performed substituting survival rates for age 0 fish of another flatfish species, plaice (Beverton and Iles, 1992). These investigators calculated a survival estimate of 2.5×10^{-5} for 0-group plaice on their nursery grounds in the North Sea and adjacent European coastal waters, based on the difference between the number of fertilized eggs and the number of age 1 recruits. This estimate incorporates egg mortality and predation loss in the natural environment, which cannot be estimated from our field and laboratory spawning studies (i.e., Casillas et al., 1991; Collier et al., 1992).

As noted above, in our initial analysis, we considered only total mortality, calculated from age frequency data on sole from our Puget Sound sampling sites. However, age-specific mortality rate can be

Table 1. Instantaneous mortality rates (Z) and annual survival rates (S) for adult English sole (age 3+) from the Duwamish Waterway, Sinclair Inlet, Eagle Harbor, and Port Susan in Puget Sound, determined from age frequency data using linear regression techniques. The r^2 values indicate the fit of the age-frequency regression line from which mortality rates were estimated. Survival rate for Eagle Harbor is significantly higher ($p \leq 0.05$) than that for Puget Sound as a whole; others are not significantly different. Adapted from Johnson and Landahl (1994).

Site	n	r^2	Z	S
Duwamish	155	0.86	0.399	0.671
Sinclair	76	0.70	0.401	0.670
Eagle Harbor	78	0.55	0.216	0.806
Port Susan	59	0.98	0.468	0.628
All Puget Sound	1188	0.98	0.474	0.623

viewed as having three components—natural mortality, fishing mortality, and contaminant-related mortality. To further refine our analysis, we attempted to account for the influence of differential fishing pressure among the sites by partitioning fishing mortality from other sources of mortality. Estimates of fishing mortality for English sole populations in north and central Puget Sound were obtained from WDFW reports (Bargman et al., 1985) and the published literature (Mensaveta, 1958; Van Cleve and El Sayed, 1969; Holland, 1969). For northern Puget Sound sites, including the Port Susan area, these estimates ranged from 30 percent to 55 percent. For our calculations, we assumed that the total mortality rate for Port Susan fish included fishing mortality of 30 percent, as this was the most conservative figure of those reported in the literature. Because commercial trawl fishing was prohibited at the Duwamish Waterway, Sinclair Inlet, and Eagle Harbor at the time when the data used in the model were collected, we assumed that fishing mortality did not contribute to the total mortality and survival rates calculated as described above for these sites. To simulate a scenario in which sole populations at the urban sites experienced a level of fishing pressure equivalent to that at Port Susan, we added the 30 percent fishing mortality documented for Port Susan to our original total mortality estimates for Eagle Harbor, the Duwamish Waterway, and Sinclair Inlet. We could not account for recreational fishing mortality due to lack of data; however, records suggest that the majority of English sole harvest is commercial (Schmitt et al., 1994).

Age-specific fecundity (i.e., the number of eggs produced per female) was estimated based on fecundity determinations for 113 female English sole (age range 3 to 12 years) collected at Port Susan, Sinclair Inlet, the Duwamish Waterway, and Eagle Harbor in 1986 and 1989. Fish 2 years of age and below were not sampled because English sole generally do not become reproductively mature until age 3 (Lassuy, 1989; Johnson et al., 1991). Fecundity was estimated using the gravimetric method (Bagenal and Braum, 1971). Age-length curves calculated from length measurements and otolith-based age determinations from more than 1,000 Puget Sound English sole (see Landahl and Johnson, 1993) were used to estimate ages for the 113 fish used in the fecundity analyses.

Fecundity was adjusted to account for effects of contaminant exposure on reproductive output, based on data from field and laboratory reproductive toxicology studies of English sole (Johnson et al., 1988; Casillas et al., 1991). The reproductive parameters examined in the studies included gonadal development, ability to spawn, and egg and larval viability. Using these data, as well as fecundity estimates, age-specific reproductive output (R_x) for female sole was calculated as follows:

$$R_x = m_x \cdot R_O$$

where:

m_x= age-specific fecundity (adjusted for a 50:50 sex ratio), and

R_O= overall reproductive success (by site; see Table 3).

To formulate a Leslie matrix model for English sole, age-specific mortality (l_x) and age-specific reproductive output (R_x) were used to construct a life table (see Caswell, 1989). We then used this generalized preliminary model to compare the instantaneous rate of natural increase (*r*) for English sole populations at Port Susan, Sinclair Inlet, the Duwamish Waterway, and Eagle Harbor. Initially, population trajectories were calculated using an age 0 survival rate of 1.44×10^{-5} for all sampling sites, calculated according to Schaaf et al. (1987), and the site-specific mortality rates shown in Table 1 for fish above 1 year of age. We then conducted a second analysis in which we attempted to account for differential fishing mortality among the sites. In this analysis it was assumed that total mortality for Port Susan included fishing mortality of approximately 30 percent for adult fish, based on estimates from previous studies (e.g., Van Cleve and El Sayed, 1969). At Eagle Harbor, Sinclair Inlet, and the Duwamish Waterway, it was assumed that total mortality rates were composed of natural and contaminant-associated mortality only. To simulate conditions of equivalent fishing pressure, we increased our mortality estimates for adult sole (age 3+) from the Duwamish Waterway, Sinclair Inlet, and Eagle Harbor by 30 percent, then compared the resulting population trajectories for the four sites. The instantaneous rate of natural increase (*r*) was calculated as described above, using the age-specific fecundity and reproductive output values given in Tables 2 and 3.

Table 2. Age-specific egg production estimates for Puget Sound English sole. Egg number was determined by gravimetric analysis on a total of 119 fish collected from Port Susan, Duwamish Waterway, Eagle Harbor, and Sinclair Inlet. Adapted from Landahl and Johnson (1993).

Age	N	No. of eggs per female
3	2	294,000
4	14	404,000
5	27	424,000
6	30	650,000
7	2	824,000
8	13	841,000
9	4	936,000
10	3	1,350,000
11+	2	2,140,000

Table 3. Summary of reproductive success study results for four Puget Sound sites. Sample size is in parentheses.

	Site			
Reproductive effect	**Port Susan**	**Sinclair Inlet**	**Duwamish Waterway**	**Eagle Harbor**
% females maturing[a]	80 (50)	90 (96)	63 (101)	57 (97)
egg production	442,000	485,000	446,000	442,000
% females spawning[b]	90 (60)	75 (23)	54 (53)	35 (21)
% eggs fertilized[b]	52 (54)	35 (17)	44 (24)	24 (7)
% normal larvae[b]	74 (53)	54 (14)	59 (20)	68 (4)
% overall reproductive success	28	13	9	3

[a] Johnson et al. (1988); 1987 data for Port Susan, weighted average of 1986 and 1987 values for other sites

[b] Casillas et al. (1991); 1988 data for Sinclair Inlet and Eagle Harbor, weighted average of 1987 and 1988 values for other two sites

RESULTS

Age-Specific Mortality

Based on analysis of age-frequency data, we estimated a total annual survival rate of 0.62 for sole 3 years old and older (see Johnson and Landahl, 1994). Previously published annual survival rate estimates for English sole range from 0.33 to 0.70, with lower survival rates more typical of heavily exploited stocks (Holland, 1969; Van Cleve and El Sayed, 1969); our estimate is thus comparable to those reported by other researchers. In general, few clear intersite differences in survival rates were found. There was no evidence of reduced survival in fish from urban sites; if anything, survival rates were somewhat higher at contaminated sites such as Eagle Harbor than at the Port Susan reference area (Table 1). Juvenile mortality, estimated using the method of Schaff et al. (1987) was 1.44×10^{-5}. This estimate resulted in a stable population trajectory for fish from the Port Susan reference area that neither increased nor decreased over time.

When total mortality rates were subdivided into fishing and non-fishing mortality, it was clear that non-fishing mortality was substantially higher at Sinclair Inlet, the Duwamish Waterway, and Port Susan than at the Port Susan reference site (Figure 2). These findings suggest that although it was not immediately evident from examination of total mortality rates, factors associated with urbanization, such as toxicopathic disease, contributed significantly to mortality rates at these sites. However, non-fishing mortality rates at these three sites were not clearly correlated with levels of organic contaminants in sediment. For example, sole populations from Sinclair Inlet and the Duwamish Waterway had equivalent non-fishing mortality rates, in spite of substantially higher levels of PAH and PCBs in Duwamish Waterway sediments (Malins et al., 1984, 1985).

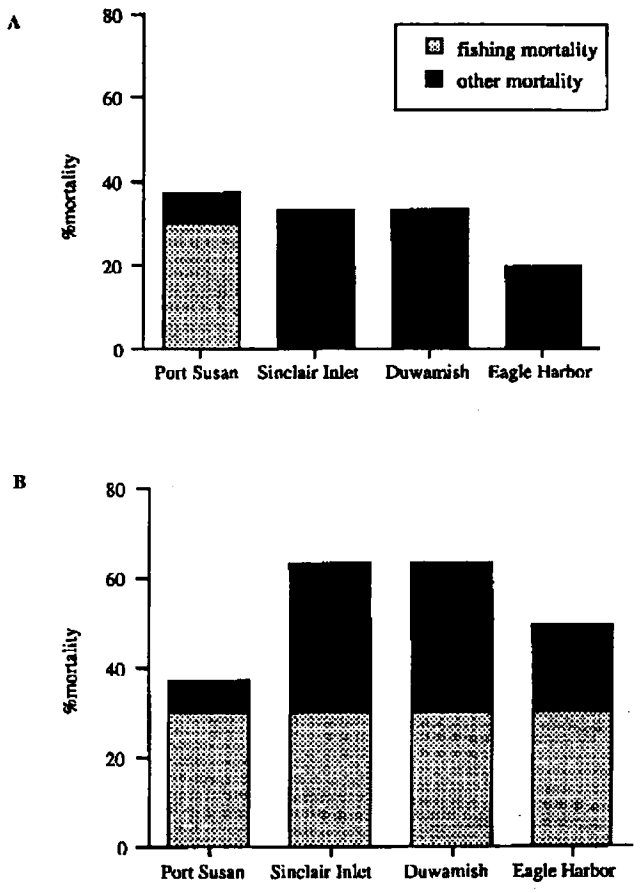

Figure 2. a) Total mortality rates for adult (3+) English sole from four sites in Puget Sound, showing relative contributions of fishing and non-fishing mortality. Fishing mortality level at Port Susan is based on Van Cleve and El Sayed (1969) and Holland (1969). Washington State Department of Fish and Wildlife records (Bargman et al. 1985) indicate that there was no commerical fishing at Sinclair Inlet, the Duwamish Waterway, or Eagle Harbor at the time when the data used to estimate these mortality rates were collected (1979-1984). b) Mortality rates for adult (3+) English sole adjusted to simulate equivalent fishing mortality at all four sites, based on fishing mortality level (30%) at Port Susan.

Age-Specific Fecundity

English sole egg production levels (modified from Landahl and Johnson, 1993) are shown in Table 2. Young females produced about 300,000 eggs their first spawning year, while the oldest and largest females collected produced over 2 million eggs per year. For vitellogenic females, the number of eggs initially produced at a given size or age was fairly similar at all four sites studied. For example, in a 5-year-old female, egg number ranged from 442,000 at Port Susan and Eagle Harbor to 485,000 at Sinclair Inlet (Table 3). However, alterations in gonadal development and spawn-

ing success substantially reduced the overall reproductive output of fish from the urban sites in comparison to Port Susan. Based on the estimates of ovarian recrudescence, spawning, fertilization, and larval development, overall reproductive success was 28 percent for Port Susan, 13 percent for Sinclair Inlet, 9 percent for the Duwamish Waterway, and only 3 percent for Eagle Harbor (Table 3). It should be noted that site-related differences in growth rates and size at age that may affect fecundity were not taken into account in these calculations, but will be addressed in future studies when both precise age determinations and fecundity measurements are available for a larger sample of fish.

Application of the Model

Having generated estimates for both fecundity and mortality, we were able to construct a generalized Leslie matrix model for Puget Sound as a whole. These data permitted calculation of the dominant eigenvalue for the appropriate Leslie matrix (see Caswell, 1989), and from that, the intrinsic rate of increase, r. In our initial analysis, site-specific survival rates shown in Table 1 were used to estimate survival of sub-adult and adult animals, while the juvenile survival rate was estimated as described above. Using these data, when age 0 survival was set at 1.44×10^{-5}, the level that yielded $r = 0.00$ for Port Susan, r was -0.06 for Sinclair Inlet, -0.08 for Eagle Harbor, and -0.10 for the Duwamish Waterway. As can be seen from Figure 3, this difference in r resulted in a pronounced divergence over a period of 10 years between the projected population trajectories for fish from Port Susan and the urban sampling sites. When the value for plaice was used for age 0+ survival, r values were fairly similar; $r = 0.08$ for Port Susan, 0.01 for Sinclair Inlet, and -0.04 for both the Duwamish Waterway and Eagle Harbor (data not shown). Because survival rates at the urban sites were equivalent to or slightly higher than survival rates for Port Susan, projected populations declines shown in Figure 3 could be attributed exclusively to reduced reproductive output in fish from the urban sites.

In our second analysis, in which survival rates were altered to simulate equivalent intersite fishing mortality, r was 0.00 for Port Susan, -0.31 for Sinclair Inlet, -0.37 for the Duwamish Waterway, and -0.39 for Eagle Harbor. Resulting population trajectories for Sinclair Inlet, the Duwamish Waterway, and Eagle Harbor diverged markedly from that for Port Susan, with populations at the contaminated sites declining to very low levels in less than 10 years (Figure 4). This result suggests that sole populations at the contaminated sites would not be able to sustain the level of fishing pressure typical of Port Susan and other non-urban sites, because of high non-fishing mortality rates at these areas.

DISCUSSION

Our analyses indicate that contaminant effects, particularly reproductive impairment, could substantially reduce the intrinsic rate of increase (r) of English sole populations from contaminated sites in Puget Sound, assuming that regulatory mechanisms do not compensate for reduced recruitment. This could be a cause for concern, especially if fish inhabiting contaminated estuaries or embayments such as the Duwamish Waterway or Eagle Harbor have historically contributed a significant proportion of recruits to the English sole population of Puget Sound.

In contrast to reproductive rates, total mortality rates in sole from heavily contaminated sites were generally similar to or slightly lower than those for English sole from the Port Susan reference site and for Puget Sound as a whole (Johnson and Landahl, 1994), and did not substantially affect population trajectories of sole subpopulations from contaminated sites in our initial analysis. At the time the data used in this model were collected, however, there was an active commercial trawl fishery for English sole at Port Susan, but no commercial fishing at Eagle Harbor, Sinclair Inlet, or the Duwamish Waterway. When these differences in fishing mortality were taken into account, non-fishing mortality was actually substantially higher at the contaminated sites than at the Port Susan reference area. Levels of non-fishing mortality, however, did not show a direct correlation with sediment contaminant levels at Sinclair Inlet, the Duwamish Waterway, and Eagle Harbor; non-fishing mortality was as high in sole from Sinclair Inlet as in sole from the Duwamish Waterway, in spite of substantially lower levels of organic contaminants at Sinclair Inlet. This finding was somewhat unexpected, particularly as the prevalence of toxicopathic

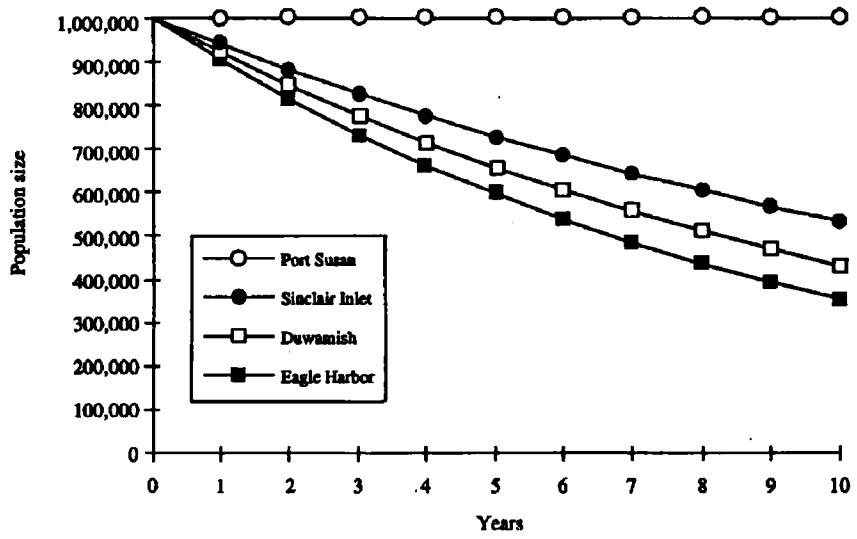

Figure 3. Projected population trajectories over a period of 10 years for English sole at four sites in Puget Sound on the basis of intrinsic rates of increase (r) computed from a Leslie matrix model. Initial population size is 1 million. Age-specific reproductive rates for fish from the four sampling sites are based on data from Johnson et al. (1988), Casillas et al. (1991), and Landahl and Johnson (1993). Age 0 survival rate is 1.44 x 10^{-5} and age 1-2 survival rate is 0.62 for fish from all sampling sites. Survival rates for fish age 3 and above are 0.62 for Port Susan, 0.67 for Sinclair Inlet and the Duwamish Waterway, and 0.80 for Eagle Harbor. Using this information computed r values are 0.00 for Port Susan; -0.06 for Sinclair Inlet; -0.08 for Eagle Harbor; and -0.10 for the Duwamish Waterway.

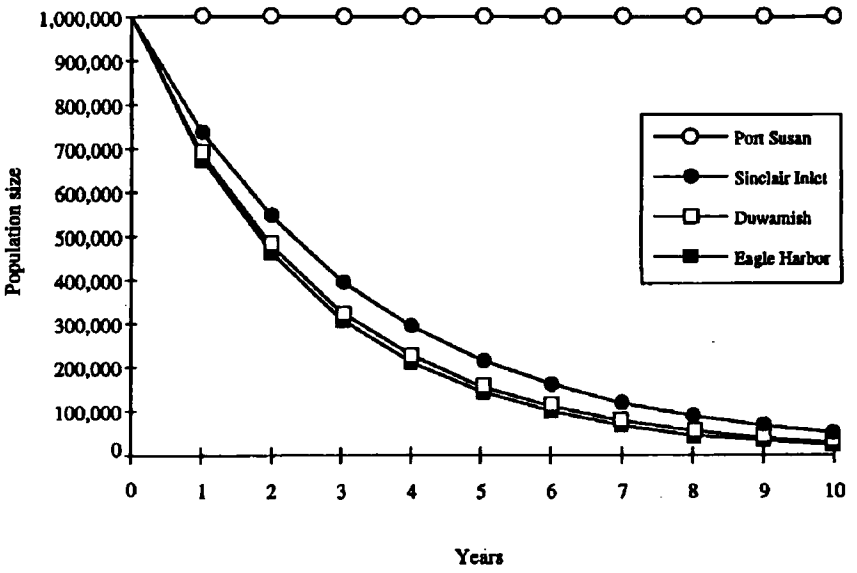

Figure 4. Projected population trajectories over a period of 10 years for English sole at four sites in Puget Sound on the basis of intrinsic rates of increase (r) computed from a Leslie matrix model, with survival rates adjusted to simulate equivalent fishing pressure (30% fishing mortality) at all sites. Initial population size is 1 million. Age-specific reproductive rates for fish from the four sampling sites are based on data from Johnson et al. (1988), Casillas et al. (1991), and Landahl and Johnson (1993). Age 0 survival rate is 1.44 x 10^{-5} and age 1-2 survival rate is 0.62 for fish from all sampling sites. Survival rates for fish age 3 and above are 0.62 for Port Susan, 0.37 for the Duwamish Waterway and Sinclair Inlet, and 0.50 for Eagle Harbor. Using this information computed r values are 0.00 for Port Susan; -0.31 for Sinclair Inlet; -0.39 for Eagle Harbor; and -0.37 for the Duwamish Waterway.

disease is considerably lower at Sinclair Inlet than at either Eagle Harbor or the Duwamish Waterway (Malins et al., 1984; Johnson et al., 1988; Myers et al., 1990). It is not clear why non-fishing mortality rates were elevated at Sinclair Inlet. However, other contaminants, such as certain metals, that are found at this site (Malins et al., 1984), other environmental changes associated with urbanization, or natural factors that have little to do with anthropogenic impacts may all have contributed to increased mortality rates in Sinclair Inlet sole.

Although chemical contaminants alone cannot explain the intersite differences in English sole survival rates observed in this study, the results nevertheless suggest that factors associated with urban development, including toxicant-related death due to disease or other impairment, contribute significantly to the mortality rates at the urban or contaminated sampling sites. Historically, however, the lack of fishing in urban bays of central Puget Sound appears to have mitigated the impact of this increased mortality on sole populations. When differential fishing mortality was taken into account in our simulation model by increasing fishing mortality at the urban sites to a level comparable to that at Port Susan, sole populations from the Duwamish Waterway, Eagle Harbor, and Sinclair Inlet showed much more marked declines. These findings suggest that declines in urban fish populations might be considerably more severe if animals were subjected to heavy fishing pressure as well as to the detrimental effects of chemical contamination and associated anthropogenic stresses. Further, although populations in undeveloped areas may be able to withstand historical levels of fishing pressure at the present time, these results imply that this might not be the case if these areas become increasingly urbanized.

While our present results give some insight into the population-level impacts of fishing pressure and chemical contamination on Puget Sound English sole, the information base currently available to us for estimating site-specific fishing mortalities and age-related mortality rates permitted us only a very preliminary and incomplete assessment of the impact of contaminant stress on sole populations. Only more accurate estimates of intersite variations in both natural and fishing mortality can reduce the uncertainty inherent in these assessments. Test fishing to monitor changes in mortality rates following recent or proposed closures of trawl fisheries in central and northern Puget Sound could also provide substantial information on the relative importance of fishing pressure and other anthropogenic disturbances on sole populations in Puget Sound, and provide a means of testing hypotheses generated from this study. Some of these types of studies are now under way in limited areas of the Sound (e.g., Eaton and Dinnel, 1993) and hopefully such work will continue.

Critical data for model refinement also include more accurate estimates of early-age survival in natural populations of English sole. Studies of this nature are particularly important because it has been suggested that larval mortality rather than egg production is the primary determinant of recruitment success (Magnuson, 1991). Also, although it has been established that intersite migration of adult sole is minimal (Day, 1976; Lassuy, 1989), much less is known about juvenile immigration, emigration, and density-dependent survival in Puget Sound sole populations. English sole have pelagic eggs with a hatching time that varies from three to 12 days (Alderice and Forrester, 1968; Orsi, 1968), while the larvae have a planktonic period ranging from six to 10 weeks (Ketchen, 1957; Laroche et al., 1982). Consequently, movement of eggs and larvae between non-urban and urban areas of Puget Sound is certainly a possibility. On the basis of water circulation patterns in Puget Sound (Cokelet et al., 1988), transport from southern to central and northern areas seems particularly likely, though there may be substantial recirculation especially around Vashon Island and Admirality Inlet. However, the mechanisms regulating the transport of English sole larvae into nursery grounds are poorly understood, and recruitment patterns within Puget Sound are not well-characterized (Toole et al., 1987; Lassuy, 1989). Consequently, it is difficult to evaluate the extent to which increased recruitment from non-urban areas could compensate for decreased reproductive output by sole sub-populations from contaminated sites such as Eagle Harbor and the Duwamish Waterway.

Finally, it should be emphasized that our current model focuses on differences in population growth rates among sites with different levels of chemical contamination in sediments, and assumes that observed changes in population trajectories result from the direct effects of chemical contaminants on survival and fecundity of English sole. While this analysis provides some insight into the ways in which chemical

contamination may affect English sole populations, it clearly does not adequately account for all intersite differences in mortality or population growth rates of sole from Puget Sound. In the results reported here, for example, the relatively high mortality rate of sole from Sinclair Inlet is somewhat surprising, as chemical contaminant levels in this area are moderate in comparison to those at Eagle Harbor and the Duwamish Waterway. Clearly, fishing pressure and marine pollution are not the only environmental stressors affecting English sole populations; other anthropogenic stressors, such as destruction or alteration of nearshore nursery habitats (Thom and Halum, 1990), may presumably have a significant impact on sole populations. Moreover, chemical contaminants themselves may also affect English sole populations indirectly, through their predators, prey, and competitors. Such impacts could either diminish or exacerbate the direct effects of the toxicants (Kimball and Levin, 1985; Menge and Olson, 1990; Olson and Straub, 1994), but our current model provides no information on these relationships. Eventually, we hope to incorporate the population data into a more complex model that will take into account community-level interactions such as effects of contaminants on predators and prey of English sole, as well as impacts of anthropogenic stressors other than chemical contaminants.

ACKNOWLEDGMENTS

We would like to thank Greg Nelson for performing the egg counts for the fecundity estimates; Greg Bargman of Washington Department of Fisheries for providing information on historical levels of fishing pressure in Puget Sound; Annette Olson of the University of Washington School of Marine Affairs for helpful discussions on community-level interactions and model development; and Bruce McCain, Sin-Lam Chan, and Tracy Collier for reviewing the manuscript.

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PUGET SOUND

RESEARCH '95

SESSION 7A

LANDSCAPE AND SCALE CONSIDERATIONS IN RESTORING PUGET SOUND HABITATS

Session Chair:

Charles Simenstad

University of Washington, Fisheries Research Institute

PANEL: LANDSCAPE AND SCALE CONSIDERATIONS IN RESTORING PUGET SOUND HABITATS

CHAIR

Charles Simenstad, University of Washington, Fisheries Research Institute

PANELISTS

Ron Thom, Senior Research Scientist, Battelle Northwest Laboratories
Speaking on: Landscape Ecology and Habitat Restoration
Jim Lovvorn, Assistant Professor, Department of Zoology, University of Wyoming
Speaking on: The Interconnectivity of Wetland Use by Waterfowl
Ann Soule, Groundwater Specialist, Clallam County Water Quality Program
Speaking on: Restoration Planning at County/Watershed Scales
Curtis Tanner, Fish and Wildlife Biologist, U.S. Fish & Wildlife Service
Speaking on Habitat Restoration across an Urbanized Estuary
Patrick Cagney, Environmental Resources Section, U.S. Army Corps of Engineers
Speaking on: Practical, Site-Specific Considerations for Habitat Restoration

Charles Simenstad, University of Washington, Fisheries Research Institute:

Unlike most of what has been presented at this meeting so far, this panel discussion will address more of what we're not doing in Puget Sound than what we are. In this case what we're not doing is conducting research and formulating management and policy strategies for habitat restoration that consider the probability that many, if not most, habitat functions relate in some way to the setting, structure, and processes of the landscape.

Just one example is an observation the seagrass habitat session (see Session 5A). Regardless of all we know about the limiting factors on the growth and productivity of field grasses, most of the ecological functions of seagrasses in Puget Sound don't in fact operate at the habitat level. Instead they operate as a function of their setting, their structure, and the larger scale of the landscape. It was evident from the seagrass session that we are missing the forest for the trees.

Even our policy recommendations stop at the habitat level. We still aren't dealing with the fact that the systems operate to a large degree because of the way habitats are configured, relate to each other, and are set in a larger landscape.

In assembling this session I have drawn together a group of people who in one way or another, through their research or through habitat management, particularly habitat restoration, are starting to realize the need to restore habitats in a landscape context.

After an introduction to the concept of landscape ecology by Ron Thom, the other panelists will follow a hierarchy of landscape scales. Jim Lovvorn will take a look at water fowl from a large-scale perspective that considers habitat interconnectivity in the whole northern Puget Sound/Strait of Georgia region. Ann Soule will discuss restoration planning at the county and the watershed scale. Curtis Tanner will discuss the trials and tribulations of habitat restoration at the scale of an urbanized estuary. And Pat Cagney will conclude at the habitat level, describing some practical site-specific considerations.

I've asked the panelists to address two questions. One is how the landscape setting, structure and processes impose constraints upon the long-term success of habitat restoration. The second is how planning, design, and implementation of projects can feasibly incorporate hydrologic, geomorphic, ecologic and other processes that operate at that landscape scale.

As a lead-in to Ron's talk, I present an illustration of this issue. In this diagram of Commencement Bay, both the historic shoreline of the emergent marsh and the original mudflat boundary are superimposed over the modern configuration. The "special aquatic sites" are a euphemism for what's left of remnant habitat

patches in a very extensive dominant matrix of urbanization and commercialization of the delta. Also here is the infamous Gog-Le-Hi-Te Wetland restoration site.

I leave you with the question: Are we deluding ourselves to expect any approximation of habitat function in a restoration site in this fragmented landscape? And if so, can we design it better by understanding the landscape perspective? With that, I'll turn things over to Ron Thom, who will introduce the concepts of landscape ecology.

ESTUARINE RESTORATION: A LANDSCAPE PERSPECTIVE

David K. Shreffler and **Ronald M. Thom**, Battelle Northwest Laboratories (presentation by Thom)

INTRODUCTION

Estuarine systems are tremendously dynamic, complex, and difficult to restore because of the wide array of functions they perform and because of their location within the landscape. Puget Sound, Hood Canal, and the Strait of Juan de Fuca form a complex fjordal inland sea composed of more than 56 sub-estuaries (Simenstad et al., 1982). While population growth and development are rapidly diminishing the ability of these urban estuarine systems to assimilate cumulative human impacts, management of urban estuaries in Puget Sound is constrained by the lack of a scientific foundation for decisions about intervention to improve these degraded ecosystems. Furthermore, despite growing support from the scientific community, the concept of estuary-wide restoration planning is constrained by a regulatory process that fosters a fragmented, permit-by-permit approach to ecosystem management (Kunz et al., 1988; Clark, 1990; Tanner, 1990; Soule, 1990; Rylko and Storm, 1991; Shabman, 1993). The National Research Council committee (NRC) on Restoration of Aquatic Ecosystems (NRC, 1992) believed very strongly that the spatial and temporal scope of most restoration efforts was far too small, and that too many restoration decisions were made in a fragmented fashion unlikely to produce self-maintaining aquatic ecosystems integrated into the larger ecological landscape. The NRC (1992) advocated giving top priority to systems that can be significantly restored with appropriate intervention.

A 1993 review (Jamison, 1993) by the Washington Department of Natural Resources (WDNR) revealed that the prevailing approach for estuarine restoration in the Puget Sound region focuses on "available sites," such as vacant or slightly developed shoreline property. The fundamental flaw of this approach is that selecting only available sites that are easily acquired may not result in the most ecologically sound restoration. To address the growing need for a more scientifically defensible estuary-wide restoration approach, we evaluated the alternatives through a rigorous review of the restoration literature, as well as through telephone interviews and a workshop with regional and national restoration experts.

IDENTIFICATION OF RESTORATION APPROACHES

We found in on our review of the literature and in interviews with restoration experts from around the country that restoration scientists are using four distinct estuarine restoration approaches: 1) restoration to historic condition, 2) enhancement of selected attributes, 3) creation of a new habitat or ecosystem, and 4) no intervention. These approaches for restoration of degraded urban estuaries are synthesized from Bradshaw, 1987; Lewis, 1988; Cairns, 1989, 1991; Clark, 1990; Berger, 1991; Kentula et al., 1992; NRC, 1992; Simenstad and Thom, 1992; Aronson et al., 1993, as well as from personal interviews with more than 30 restoration practitioners. The first three of these approaches involve human intervention, and all try to exploit the estuary's capacity for self-adjustment to change, but they operate at different spatial and temporal scales. Intervention becomes necessary when an estuary is degraded to the point that it no longer has the capacity for self-maintenance and repair. The fourth restoration approach—no intervention—assumes that a degraded estuary will naturally recover over time, even without intervention.

Restoration to Historic Condition

Based on historic or recent paleoecological research, historic condition is the condition known to have existed in the estuary at a given point in time after non-native settlers first appeared. The goal of restoration to historic condition is to establish a community that has a higher level of functional performance than the present degraded system and that resembles the historic system in structure and function (Cairns, 1988). Restoration to historic condition is a holistic process that cannot be achieved through the isolated manipulation of individual elements. Simenstad and Thom (1992) noted that the opportunity for successful restoration to historic condition is greatest if the primary processes (e.g., salinity intrusion, sedimentation sources and processes, corridors to other natural estuarine and upland habitats) delineating the habitat type are still effective at that site. If some, or all, of these processes have been altered or lost, the prospects for restoration to historic condition are diminished. Several examples of restoration to historic condition in Pacific Northwest estuaries are: 1) the Salmon River estuary dike breach (Frenkel and Morlan, 1990; Morlan and Frenkel, 1992); 2) the Elk River estuary dike breach (Simenstad and Thom, 1992); and 3) the Gog-Le-Hi-Te wetland complex in the Puyallup River estuary (Simenstad and Thom, 1994).

Enhancement of Selected Attributes

We have adopted the NRC (1992) definition of enhancement to mean any improvement of a structural or functional attribute. Attributes are characteristics that are correlated with and can serve as indicators of ecosystem structure and function. The goal of enhancement is to improve one or more structural or functional attributes that are critical to the support of target resources using the system. In the Puget Sound region, the Estuarine Habitat Assessment Protocol (Simenstad et al., 1991) was among the first scientific documents to promote an attribute-oriented approach to assessment of restoration, enhancement, and creation of estuarine habitats. As noted by Simenstad and Thom (1992), the probability of successful enhancement is greater if we first understand which structural and functional attributes sustain the integrity of the ecosystem. Beach nourishment at Lincoln Park, the Duwamish River estuary benches, and the Slip-1 gravel beach in Commencement Bay are examples of enhancement in Puget Sound (Simenstad and Thom, 1992). Simenstad and Thom (1992) suggested that estuarine habitat attributes can be integrated as elements of modified habitats of urbanized estuaries and might provide some function, such as fish and wildlife support, despite the fact that they are not operating within the matrix of a self-maintaining natural habitat.

Table 1. Ranking of different approaches for restoration in degraded urban estuaries (numbers signify which approach is best (1) to worst (4) for each scientific evaluation criterion)

	Restoration Approach			
Scientific Evaluation Criteria	**Restoration to Historic Condition**	**Enhancement of Selected Attributes**	**Creation of New Ecosystem**	**No Intervention**
Predictability of Success	2	1	3	4
Short-Term Expediency	3	1	2	4
Long-Term Self-Maintenance	1	2	3	4
Habitat Composition in Landscape Context	1	2	3	4
Reduction of Fragmentation	1	2	3	4
Maximization of Direct/Indirect Benefits to Resources	1	2	3	4
Optimization of Restoration in View of Physical/Chemical Modifications to Estuary	1	2	3	4
Dependency on Water Quality	1	2	3	4
Preservation of Viable	3	2	4	1
Scientific Support:				
Data	3	1	2	4
Theory	1	4	3	2
Provides Benefits Outside Estuary	1	3	2	4

Creation of a New Habitat or System

Creation involves bringing into being a new habitat or ecosystem that did not exist on the site before (NRC, 1992). In urban estuaries, this approach generally involves implanting such a created habitat into a coastal shoreline (Simenstad and Thom, 1992). The goal of this approach is to emulate the present condition of an existing, functioning reference habitat or ecosystem. Created habitats or ecosystems typically require substantial ongoing maintenance (Class C restoration, Cairns, 1991; Simenstad and Thom, 1992). Examples of habitat creation in the Pacific Northwest include the Grays Harbor slough (Simenstad et al., 1992) and Jetty Island (Pentec, 1993).

No Intervention

The goal of the no-intervention approach is to allow natural processes to determine the path of the system, while resisting the human penchant for a quick, technological "fix" via intervention. The outcome of this approach is unpredictable and may not resemble a previously existing condition (Class D restoration, Cairns, 1991). DeWitt (1989) espoused a "let it be" restoration approach and suggested that "corrective actions" taken to restore a habitat or ecosystem are misdirected, when typically the restorationist is limited in time by the granting period, the length of a graduate student's program, his or her own patience, or even a lifetime. The case histories from a symposium on recovery and restoration of damaged ecosystems (Cairns et al., 1977) provided evidence that damaged ecosystems may recover naturally if given enough time. No comparable studies have been conducted for estuarine systems.

Scale of Restoration Approaches

There are four primary considerations regarding the scale of a restoration project. The project area must be large enough to 1) limit deleterious effects that boundary conditions may impose on interior aquatic functions and 2) allow managers to monitor the important effects of the project. In addition, the project site must at the same time be sized and situated such that 3) project managers can exert influence over zones in which major causes of ecological disturbance to the project are occurring, and 4) the project is affordable (NRC, 1992). Allen and Hoekstra (1987) suggested a hierarchical approach, in which the size of the landscape to be restored determines the lowest frequency process that is relevant to a given restoration effort. For example, if the restoration is targeted at migrating waterfowl, the size of the landscape must be large enough to attract these birds. Restoration, in this sense, is limited by scale, not so much by how much area can be restored, but by which processes can be included and which cannot. Hence, restoration would be restricted to those processes that fit into the available area. The key point is that restoration is scale-dependent; thus the restorationist must explicitly state first whether ecosystem function or community composition is to be restored and second the scale of the processes that will apply to achieve that end.

In urban estuaries, the appropriate scale for restoration is likely to be defined by the target ecosystems and species groups. Restoration to historic condition involves large-scale, long-term efforts to return either the entire estuary or a particular self-maintaining habitat to a pre-existing, self-maintaining condition. Enhancement of selected attributes generally involves small-scale, short-term efforts, although long-term maintenance may be required. Creation of a new ecosystem can involve efforts at several spatial scales, such as habitat or estuary, depending on the reference system that is being replicated, but it almost always requires long-term maintenance.

EVALUATION OF RESTORATION APPROACHES

Each of the four restoration approaches was evaluated based on our review of the restoration ecology literature and discussions with experts on estuarine restoration and resource management (Table 1). This summary table allows the reader to quickly compare the ranking of each approach relative to the scientific evaluation criteria. The four restoration approaches differ in their ability to satisfy the overall goal of all three forms of restoration involving human intervention, which is to increase the number of robust, self-maintaining habitats that are carefully sited in optimal locations. Careful siting will ensure that restored habitats are linked to existing viable natural habitats and are integrated functionally and structurally into the watershed.

Although experts differed in their opinions about specific rankings for the various evaluation criteria, there was consensus on the following overall ranking for three of the four approaches: restoration to historic condition was ranked above enhancement of selected attributes, which was ranked above creation of a new ecosystem. Based on the literature and on expert interviews, the remaining restoration approach—no intervention—is not feasible in degraded urban estuaries. In addition to its being politically, economically, and socially unacceptable, the no-intervention approach is precluded in urban estuaries of the Puget Sound basin because of past as well as present physical and chemical modifications to these estuaries.

RESTORATION POTENTIAL

The hypothesized restoration potential for estuarine wetlands and the most appropriate restoration approaches are illustrated in Figure 1, as a function of disturbance to the site and to the surrounding landscape (modified from NRC, 1992). If the degree of disturbance of both the restoration site and the surrounding landscape is high, then the potential for successful restoration is low, and enhancement of selected attributes is the best approach. In contrast, if the landscape is relatively intact, the chances of successful restoration are higher even if the degree of disturbance of the restoration site is high, and restoration to historic condition is the favored approach. The potential for successful restoration is higher still if the restoration site is not greatly disturbed, but the region lacks a large number of natural wetlands. In this scenario, restoration to historic condition is again the preferred approach. Finally, restoration to predisturbance condition is the approach of choice only if both the landscape and the restoration site are relatively undisturbed. The conclusion is that the greater the level of human disturbance and consequent degradation, the more difficult restoration becomes. Hence, rigorous evaluation of the degree of disturbance of the restoration site and the surrounding landscape can dictate which restoration approach has the highest potential for success.

LANDSCAPE ECOLOGY PRINCIPLES

Landscape ecology principles are intertwined within each of the four estuarine restoration approaches. The following section is a discussion of some of the most important aspects of landscape ecology relative to

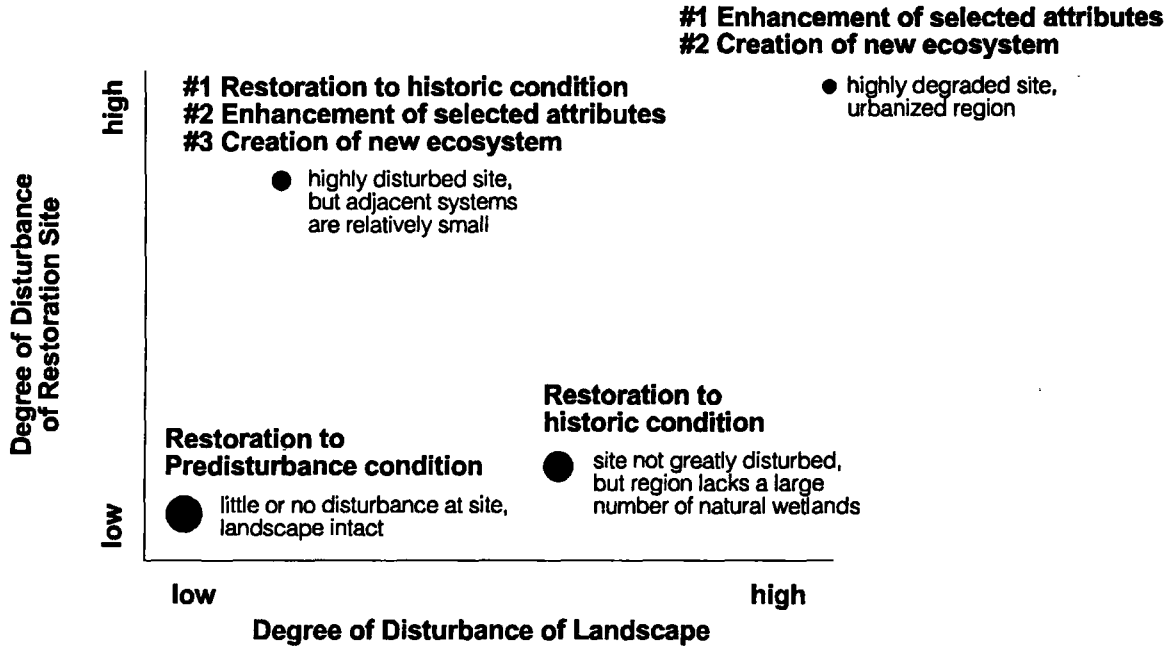

Figure 1. Restoration potential and most appropriate restoration approach for estuarine wetlands differing in degree of disturbance and landscape condition (modified from NRS, 1992); size of dot indicates potential for successful restoration (large dot=high potential; small dot=low potential): numbers indicate ranking of recommended restoration approaches

estuarine restoration. Much of this discussion is based on Forman and Godron (1986), Jungman et al. (1987), Turner and Ruscher (1988), Turner (1989), Turner et al. (1989), and Gosselink and Lee (1989). The work of Gosselink and Lee represents perhaps the most comprehensive contribution to understanding the landscape ecology of wetland systems.

Landscape ecology is a field of science that deals with the effect of the spatial extent, heterogeneity, and geometry of elements of the landscape, such as animals, plants, nutrients, and soils, on the flow of energy, animals, and materials through the landscape. The field represents an integrated approach to understanding how large ecosystems function (Forman and Godron, 1986). Principles are emerging from the study of landscape ecology that can be directly applied to the planning and design of estuarine restoration in urban and non-urban conditions.

Human activities are fragmenting natural landscapes at an increasing rate (Weins, 1985; Karr, 1994). Fragmentation and habitat shrinkage decrease the flow of materials and species among habitats and result in local extinction of some populations. Landscape ecology recognizes that most elements within a landscape function best when they are linked with all other elements of the landscape. In other words, landscapes are heterogeneous matrices of smaller elements, and the arrangement, size, productivity, and resilience to disturbance of these elements within the matrix will affect the flow of energy, animals, and materials through the landscape. Removal, degradation, or relocation of one or more elements may lead to dysfunction of the remaining elements.

Landscape ecology is the basis for cumulative impact assessment by the Wetlands Research Program of the U.S. Environmental Protection Agency (Leibowitz et al., 1992). This program specifically encourages resource managers responsible for wetlands protection to view wetlands from a landscape perspective. Analysis of cumulative impacts on a landscape scale can be used to understand the relationship between changes such as landscape fragmentation and alterations in biological populations (Gosselink and Lee, 1989).

Landscape ecology principles present a framework for reducing fragmentation and its effects on the ecosystem. Of particular relevance to site selection and design in estuarine restoration are the concepts of habitat size, shape, structure, buffers, accessibility, connectance, and self-maintenance.

Size

Larger systems are more stable, persistent, resilient, and resistant than smaller systems and offer predictably more niches for species (Gosselink and Lee, 1989; Noss, 1991a). A minimum of two acres of aquatic habitat, which is closely associated with a river, and which includes extensive buffer, has proven functional for fisheries resources in the Pacific Northwest (Shreffler et al., 1990, 1992; Simenstad et al., 1992). Larger systems are probably needed for waterfowl and shorebirds. Although habitats smaller than two acres can offer some benefits, large, stable, and complex habitats offer considerably more benefit in the long term.

Size estimates are a function of the minimum area needed to attract the species of interest, the size of the species, the behavior of the species within the habitat, and the buffers required. Based on 10 years of monitoring at a restored salt marsh in the Salmon River estuary, Morlan and Frenkel (1992) concluded that the potential of estuarine wetland restoration does not lie in small-scale mitigation projects, but in large restoration efforts to compensate for historic wetland losses on a landscape scale.

Shape

The shape of a patch of contiguous habitat can affect the types and number of species in the patch. The number of species within a patch is a function of a number of factors as follows: patch area, patch age, disturbance patterns, degree of isolation from sources of species, heterogeneity within the patch, and the heterogeneity of the surrounding area. Species show preferences for interiors or edges of patches (Forman and Godron, 1986); small patches may act as edges depending upon the size of the animal occupying the patch. The number of "interior" species or "edge" species in a patch will depend to a certain extent on the ratio of interior to edge measurements, which is a quantitative metric of patch shape. For example, round patches

have a large interior-to-edge ratio relative to that of narrow, linear patches. Processes such as benthic productivity and nutrient flux also depend on shape. For example, net productivity can be greater at the edges of a vegetated habitat compared with the interior, partially due to higher input of nutrients and light energy at the edge (see for example Forman and Godron, 1986).

Structure

Landscapes can be divided into matrices of patches and corridors. A matrix represents the most extensive and connected landscape element, and therefore it plays a dominant role in the functioning of habitats within the landscape. Geography provides a powerful tool for determining existing habitat types, as well as for defining the locations and dimensions of habitats that previously existed in the system. The NRC (1992) recommends that historical records, including maps of resources, hydrology, and geomorphology, be consulted when planning restoration efforts. The primary assumption behind this recommendation is that the natural forces that resulted in the structure of the landscape will still be active and will tend to push the system toward historic structure. Hence, the system will "function" if properly located in the context of the landscape. A second and more pragmatic reason is that we cannot possibly know all of the chemical, physical, and biological interactions that shape the system and control its stability and functional performance. Historical information on the natural state provides the best template for siting and design of restoration projects in urban estuaries.

Buffers

Vegetated buffers provide many benefits to fish and wildlife; most important among these are habitat, corridors of access, protection from disturbance by movement and sound, cover from predators, and shade. Buffers also filter sediment and contaminants in water draining from surrounding areas and contribute to the organic loading and food base of the system (reviewed in Castelle et al., 1992).

A review of wetland buffers in Washington state showed that buffer widths of 100 feet–200 feet are required to remove sediments potentially entering a wetland, and buffers of 200 feet–300 feet are required to retain wetland-dependent wildlife (Castelle et al., 1992). The most effective buffers include dense vegetation cover. On steep slopes, buffers with dense shrub and forest vegetation are very effective against human disturbance; on gentle slopes, low, dense vegetation may be the most effective water-quality buffer. Buffers can be considered interfaces between human settlement and aquatic habitats and should be designed as gradual transitions, not as sharp boundaries (Mitsch and Jorgensen, 1989).

Accessibility

Direct, free access of target resources to the restored habitat or habitat complex is essential. Such access is accomplished through the siting of restoration efforts directly within the pathway of movement of the major portion of the population in the region. Conspicuous examples include the Pacific Flyway for migratory waterfowl or shorebirds and a salmon spawning river for anadromous Pacific salmonids. Corridors form important routes of migration between habitats for many species. If corridors between sources of species and the restored habitat are not present, the restoration effort has little chance of success, no matter how well planned.

Narrow strips of sedge marshes along river banks, narrow ravines leading from uplands to intertidal areas, channels from deep areas to marsh flats, bands of eelgrass and kelp, and even drainage ditches represent corridors for animals in estuarine environments in the Pacific Northwest. These corridors are generally rich in food resources or cover that increase the probability of an animal's being able to benefit from two or more habitats in an estuary (see for example Simenstad and Wissmar, 1985; Kline et al., 1990). Restored habitats must ways in and out to be fully functional within the estuarine landscape.

Connectance

To assure maximum exchange of species, materials, and energy, connectance among habitats within the system matrix should be maximized by proper siting and design. Study of natural reserves has shown that a few large habitats connected to many smaller habitats may be the best configuration for maintaining a total

system, promoting gene flow across the landscape, and maintaining a high diversity of non-opportunistic species (Noss, 1991b).

Self-maintenance

The physical structure of the restored system in terms of buffer zones, elevation, allometry, geomorphology, and corridors of access should conform as closely as possible to natural conditions. A close fit will enhance the probability of stability, persistence, functionality, and long-term self-maintenance.

SITE LOCATION AND DESIGN

Site selection criteria for the three restoration approaches that require human intervention were ranked in importance on a scale of 1 to 5, from highest to lowest, based on our review of the literature and discussions with restoration experts (Table 2). For each of these approaches, all of the following criteria were given the highest ranking of 1: size/scale, landscape position, suitability for meeting objectives, amenability to planned design, and prospects of long-term self-maintenance. These criteria must be reviewed as essential considerations for site selection. Presence of stressors was also considered a very important criterion, with a rank of 2 for each of the four approaches. Degree of degradation was considered important, ranked 2, for restoration and enhancement, but less important, ranked 3 to 5, for creation. Existing information suggests that availability of a reference ecosystem varies in importance with approach from a ranking of 2 for creating a new ecosystem to a ranking of 3 to 4 for restoration to historic condition. Similarly, the availability of vacant property was ranked as a somewhat important criterion for creation and enhancement (rank of 2 to 3), but unimportant for restoration to historic condition (rank of 4). The criterion of preservation of viable habitat received uniformly low rankings (3 or below) for all restoration approaches. Here, viable does not necessarily connote a habitat that is optimal within the landscape. Hence, restoration is intended to improve the entire landscape at the expense of less-than-optimal existing habitats.

RESEARCH NEEDS

Very little data directly quantify the relationship between estuarine landscape features and biological resources or system functions. Critical questions remain regarding 1) minimum and optimum size required to attract and benefit significant numbers of plants and animals, 2) minimum conditions, such as size, optimal habitat configuration, and buffers for maintaining viable populations, 3) minimum initial conditions and predicted time frame for stability and self-maintenance of restored systems, and 4) the optimal location for a restored habitat within the landscape.

Table 2. Site selection criteria versus approach to estuarine restoration

	Restoration Approach [a]		
Site Selection Decision Criteria	**Restoration to Historic Condition**	**Enhancement of Selected Attributes**	**Creation of New Ecosystem**
Size	1	1	1-2
Shape	1	1	1
Structure	1	1	1
Landscape Position [b]	1	1	1
Long-term Self-maintenance	1	1-3	1-3
Suitability for Meeting Objectives	1	1	1
Amenability to Planned Design	1	1	1
Presence of Stressors	2	2	2
Degree of Degradation	2	2	3-5
Availability of Reference Ecosystem(s)	2-3	2-3	2
Preservation of Viable Habitat	3-4	3-4	4
Availability of Vacant Property	4	2-3	2-3

(a) Ranks (1=highest, 5=lowest) Indicate the relative importance of the criteria within each approach.
(b) Landscape position includes buffers, accessibility, and connectance.

SUMMARY

The challenge of restoration in degraded urban estuaries is especially acute because of the overall reduction in biological diversity, habitat diversity, and the environment's natural ability to assimilate cumulative human impacts without sustaining harm. In the Puget Sound basin, the complexity of restoration is magnified by the diversity of land uses, the historical misuse of natural resources, limited economic and biological opportunities for viable restoration, and the number of people now living in the basin (PSWQA, 1992; Simenstad and Thom, 1992).

To succeed, estuarine restoration must take a systematic approach based on landscape ecology principles, which goes beyond focusing on a single project or permit to understanding the cumulative effects of incremental degradation of estuarine environments. The NRC report (1992, pages 347-348) viewed landscape ecology as a method for designing integrated aquatic ecosystem restoration and concluded that "Wherever possible ... restoration of aquatic resources ... should not be made on a small-scale, short-term, site-by-site basis, but should instead be made to promote the long-term sustainability of all aquatic resources in the landscape." Restoring, enhancing, or creating a self-maintaining ecosystem is more likely when the restoration effort is planned in the context of the landscape.

The primary goal of our landscape-based approach to system-wide restoration planning is to ensure that restored habitats are linked to existing viable habitats and functionally and structurally integrated into the watershed. To achieve this goal, in site selection and design greater emphasis must be placed on habitat size, shape, structure, buffers, accessibility, connectance, and self-maintenance. We suggest that such an approach would reduce habitat fragmentation, or at the very least promote more ecologically sound uses of the landscape.

ACKNOWLEDGMENTS

This research was funded by the Washington Department of Natural Resources and would not have been possible without the efforts and critical input of Dave Jamison. We wish to recognize our many colleagues from the Society of Wetland Scientists and Pacific Estuarine Research Society for their input at a workshop we held at their annual meeting in Long Beach, Washington on May 14, 1993. We also extend our sincere thanks to the following individuals who willingly shared their knowledge and experiences with estuarine restoration during telephone or in-person interviews: B. Aberle, J. Baldwin, M. Boule, K. Brunner, M. Burg, J. Cairns, J. Collins, R. Emmett, K. Ewing, R. Frenkel, W. Jordan III, M. Josselyn, J. Houghton, T. Hruby, M. Kentula, R. Kickert , K. Koski, K. Kunz, L. Kunze, S. Leibowitz, C. Levings, J. Lovvorn, K. MacDonald, L. Mitchell, R. Orth, R. Rubesaman, S. Schaumann, C. Simenstad, F. Sklar, J. Strand, J. Suhayda, C. Tanner, G. Thayer, F. Weinmann, G. Williams, and J. Zedler.

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Jim Lovvorn, Assistant Professor, Department of Zoology, University of Wyoming, speaking on:

THE INTERCONNECTIVITY OF WETLAND USE BY WATERFOWL

Over the last 100 years or so, there have been at least two major changes in the habitats of ducks wintering in Puget Sound. First, there's been an expansion of crop land near marine bays, especially in northern Puget Sound and the southern Strait of Georgia. This expanded crop land has probably greatly increased the amount of food available to dabbling ducks in mid- to late winter.

Second, in the last 25 years or so, the exotic seagrass *Zostera japonica* has colonized large areas of formerly unvegetated tidal flats, providing an important food for ducks in autumn and spring. These new food sources differ in seasonal availability, with *Zostera japonica* available mainly in the fall and spring, and crops such as winter wheat available mainly in the winter. This seasonal difference in availability means that both intertidal and farmland habitats must be present to provide food during the entire non-breeding period at a given site.

Furthermore, *Zostera japonica* produces a huge amount of organic matter, which is exported from the intertidal zone. This organic matter produced in the intertidal might be very important to the food webs of birds that feed in the shallow subtidal zone. So for waterbird communities there are important interactions between farmland, intertidal, and shallow sub-tidal habitats at the same site. Because birds are so mobile, especially in response to weather, it's also important to realize that birds depend on a regional system of habitats at different sites. In the Puget Sound area, these regional habitat systems quite often span international boundaries.

The Fraser River delta is one of the most important areas for migratory birds in the Puget Sound region. Most of the waterbirds in the delta occur in Boundary Bay, so called because the international boundary cuts across its southern edge. Much of the surrounding area in the delta is crop land. Farmers plant winter cover crops in these areas to keep heavy rains from compacting the soils.

When dabbling ducks arrive in the Fraser delta beginning in late September, they feed almost exclusively in the intertidal flats. But with the onset of winter storms in late November, dabbling ducks begin feeding mostly in nearby farmland at night and resting on Boundary Bay during the day.

Table 3 shows the contributions of tidal versus upland habitats to the food requirements of the three main species of dabbling ducks from September to March. Depending on which habitat is being used by ducks at the time when a particular duck species reaches its greatest numbers, the amount of food obtained from uplands varies from 30 percent to 95 percent. In the fall, when American wigeon, Northern pintails, and mallards feed mostly in intertidal flats, eelgrass of the genus *Zostera* makes up 50 percent to 90 percent of their diet. Of the eelgrass consumed by ducks, 95 percent is not the native species *Zostera marina*, but rather the exotic species *Zostera japonica*. But with the onset of winter storms and heavy rains in late November, dabbling ducks stop feeding mainly in the intertidal zone and begin feeding in nearby farmland.

Table 3. Percent contribution of intertidal versus farmland habitats to the daily food requirements of common dabbling ducks in the Fraser River delta, British Columbia, September 1990 to March 1991

	American wigeon	Northern pintail	Mallard
Intertidal flats	43	70	5
Farmland	57	30	95

We followed 49 radio-tagged wigeon in the Fraser delta from late November 1991 to March 1992. After they had mostly stopped feeding in intertidal areas, during the day wigeon stayed mainly in flooded intertidal areas or in a few inland sites that were protected from hunting and were in effect refuges. At night, however, they moved from these areas and spread out over the farmland. An important point here is that there is farmland throughout this area, but the birds appeared to feed at night near places where they stayed during the day.

Of the dabbling ducks in the Puget Sound region, 86 percent are found at intertidal sites with nearby farmland. But although ducks use farmland, do they actually need it in addition to intertidal flats? To investigate the actual need for farmland, we calculated the total amount of food the ducks would eat if they fed only in the intertidal zone all winter and compared that estimate to the amount of food available in the intertidal.

Our results show that there was far too little *Zostera japonica* to meet their needs, but there might be enough food if the ducks shifted to an entirely invertebrate diet. One of the most common species, however, the American wigeon, is a strict vegetarian that seldom eats invertebrates. So without adjacent farmland, wigeon and probably other species would have to move to alternative sites at some time during the winter.

On a regional basis, radio-tagged wigeon and pintails often moved between our intensive study area in the Fraser delta and other sites in the northern Sound. But during a survey in southern Puget Sound and in Grays Harbor in February, we located none of our radio-tagged ducks. This suggests that individuals captured in the Fraser delta generally restricted their movements to northern Puget Sound and the southern Strait of Georgia.

Almost all our radio locations were from the very mild winter of 1991-92, which was the main year of our telemetry studies. But during the preceding severe winter of 1990-91, when we had only 15 ducks radio-tagged, as opposed to 60, alternative sites were much more important. During that preceding winter, heavy rains had flooded most of the farmland in the Fraser delta, and then both Boundary Bay and the flooded farmland were covered with ice continuously for 25 days.

During this period, ducks in the Fraser delta could not feed in either intertidal or farmland habitats. Most ducks left the area, although a few did come back after the ice melted. So it's clear that wigeon and pintails from the Fraser delta often move between sites even in very mild winters such as 1991-92. But in some cold winters such as 1990-91, they probably depend entirely on alternative sites for a period of some duration because of ice conditions. These results emphasize the importance of a regional habitat system that includes a variety of sites to accommodate dabbling ducks in all years.

We've seen the importance of local links between upland and intertidal habitats, and of regional links between different upland intertidal complexes. But what about links between intertidal and shallow subtidal habitats, and among subtidal habitats at different sites? At no time during our study did the organic matter content of sediments in Boundary Bay exceed 2 percent. So it's obvious that when the huge biomass of *Zostera japonica* was uprooted in late November, it was exported from the intertidal zone.

Much of this detritus accumulates in large piles of wrack above the high tide line. It apparently decomposes there for most of the winter, releasing dissolved and particulate organic matter either gradually or during especially high tides. Another unknown fraction of *japonica* detritus is exported directly to subtidal areas when it is first uprooted in late November. In either case, a very large biomass of intertidal *Zostera*

japonica, about 520 tons in Boundary Bay, is eventually exported to the subtidal zone. Thus, *Zostera japonica* probably plays an important role in supplying organic matter to food webs in subtidal habitats.

Wetland restoration is often done mainly to benefit wildlife, and many inshore and aquatic mammals feed in the shallow subtidal zone. So the function of intertidal wetlands in supporting subtidal food webs should perhaps be an explicit objective in intertidal wetland restoration. For example, throughout Puget Sound and the Strait of Georgia, surf scoters are the most common diving duck. Scoters feed mainly on mussels and other bivalves in lower intertidal and shallow subtidal areas. In Padilla Bay it was estimated that almost 40 percent of the food of common mussels in December was derived from eelgrass. So the quality of subtidal habitat for scoters and other diving ducks during the winter might depend rather strongly on vegetation in intertidal wetland habitats.

How do effects of intertidal wetlands on subtidal habitats fit into a regional habitat scheme? Also, how might such effects influence regional assessments of contaminant risk to wildlife? Levels of contaminants in scoter tissues appear to reach a maximum in Commencement Bay, where levels of cadmium in scoters eating bivalves were 50 times higher than in western grebes eating fish in the same area. In contrast, contaminant levels in scoter foods in Boundary Bay are probably quite low.

Some recent telemetry work, which Mary Mahaffey discusses in Session 9a (Measures of Contamination and Biological Effects), showed that radio-tagged scoters were fairly sedentary throughout the winter in the area of Commencement Bay. Based on that evidence for lack of mobility among scoters, Canadians might say that scoters wintering in the Fraser delta don't have a contaminants problem. But I showed earlier that individual ducks that normally winter in the Fraser delta are not infrequently forced to leave that area and move to other sites in Puget Sound. So depending on the number of sites with subtidal foraging habitat of adequate quality, ducks displaced from Canada might be attracted to areas in Puget Sound with rather high contaminant levels in foods. From the perspective of a regional population, the number of alternative sites available during extreme weather affects the potential contamination of birds forced out of relatively uncontaminated areas.

To summarize, first, farmland adjacent to intertidal areas is an important and probably essential component of coastal habitat for American wigeon especially, and probably for other dabbling ducks wintering in this region.

Second, refuges from hunting and other disturbance are important to the attractiveness of coastal habitat complexes. Refuges can either be protected upland areas or undisturbed intertidal areas.

Third, *Zostera japonica* has an important direct role as food for dabbling ducks in intertidal wetlands. But it might also serve an important indirect role, by exporting organic matter for the food webs of diving ducks in subtidal areas. So restoring or enhancing intertidal eelgrass probably affects the viability of adjacent farmland habitats, as well as adjacent subtidal habitats.

And fourth, a number of sites should be maintained within a regional habitat system, so that ducks can move to alternative sites, depending on variable weather and food availability. Movement of birds among sites and between countries should also be recognized in evaluating the exposure of birds to contaminants.

What is needed to improve our ability to plan habitat restoration on a regional landscape scale? First, we need more studies on regional movements of waterbirds to identify subpopulations, the relative mobility of different subpopulations, and their resulting vulnerability to habitat impacts in particular areas of the Sound. Such studies of movements need to be done in both mild and severe winters. For example, in a mild winter, wigeon and pintails often move among sites in northern Puget Sound, but there appears to be little interchange of birds in the northern Sound with those in the southern Sound. This would imply that wetland restoration in the southern Sound has little consequence for birds in the northern Sound, and vice versa. But in severe winters, there might be much more interchange among birds throughout the Sound. In that case, the scale at which we plan habitat restoration needs to encompass the entire Sound rather than selected subregions. This idea applies to both sides of the border, so movement studies should span the entire international region.

Second, we need to understand the interdependence of intertidal and shallow subtidal habitats in determining habitat quality for diving ducks or other animals that feed in the subtidal zone. In the Puget Sound

area we know very little about invertebrate communities in soft-bottom, shallow subtidal habitats, or how to assess habitat quality for the birds that feed there. In particular, I recommend studies of the organic matter sources used throughout the year by subtidal organisms, studies on seasonal changes in populations of such organisms, and especially studies that define the minimum densities of subtidal foods that allow profitable foraging by diving ducks.

Ann Soule, Groundwater Specialist, Clallam County Water Quality Program, speaking on:

RESTORATION PLANNING AT COUNTY/WATERSHED SCALES

This talk is divided into two main parts. First, research from my thesis project several years ago and then some experiences and perspectives I've gained since from working for local government, Clallam County. I'll conclude with a take-home message and recommendations.

I. Thesis Research

My thesis work began with EPA Region X in Seattle. The problem I was going to address was why the end-products of several compensatory creation restoration enhancement type projects didn't match the original objectives of those projects. It was clear to us from the beginning that we had two possibilities: either there was a problem or shortcoming in the technology or the scientific understanding of the process or the project; or maybe it was the implementation of that design, which relates to several human factors—misinterpretation, inexact execution of the design, or perhaps miscommunication.

In my examination of mitigation files for 404 permits at EPA, I noticed that there was a very consistent lack of communication—or at least it looked that way in the records—among various players at various stages of mitigation projects. I suspected these communication gaps could be a factor in why project outcomes weren't matching the original project objectives. I examined the problem using a survey, which was sent to all the players involved in mitigation projects. Figure 2 shows the three groups of survey respondents and some of the topics of the questions. Responses were to be based both on their experience and on their opinions of how they thought things should be done.

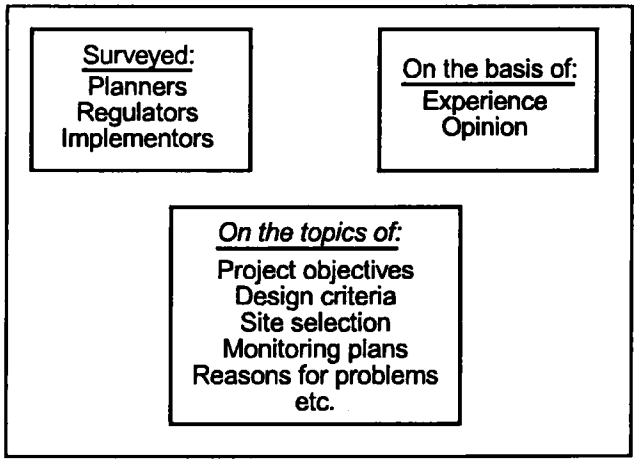

Figure 2.

I got a lot of information out of the survey data, which was evaluated using standard statistical methods. One interesting result was that for the group of planners—not so much for the regulators—there was a significant difference between, on the one hand how projects had been designed and implemented and on the other, their opinion of how things ought to be done.

Another interesting result of the survey was how my respondents answered the question, "What are the most common reasons for problems?" (See Figure 3.) One of the most common reasons was an unanticipated hydrologic regime. The water was doing something different from what had been expected.

Most common responses from Planners and Regulators to the question *"Reasons for Problems"*

- Unanticipated hydrologic regime
- Improper excavation
- Lack of communication between planner and construction contractor
- Insufficient time allowed for construction

Figure 3.

Sometimes there was too much of it, sometimes too little; sometimes the timing of the variations in quantity was other than expected. This was fairly consistent between planners and regulators.

Improper excavation was another common problem, which may be directly related to the next one, lack of communication between planners and construction contractors. This confirmed my discovery that communication gaps contributed to the problems with these projects. The fourth common problem was insufficient time allowed for construction.

II. Clallam County

Now I'd like to talk about my experiences working for a county government. Clallam County is on the north Olympic Peninsula. A lot of my discussion relates to areas that are higher in the watershed compared to those of the other speakers you've heard in this session. So we're moving into the fresh-water environment. Still, I think my concepts and basic points will relate to estuaries as well.

There have been numerous citizen-based planning processes conducted in the eastern part of Clallam County: watershed planning in accordance with WAC 400-12 has been conducted for both the Sequim Bay watershed (1991) and the Dungeness River area watershed (1993). (These are watershed management plans for the control and management of non-point pollution.) A similar planning effort was conducted for groundwater and resulted in a Groundwater Protection Strategy in 1994. Also in 1994, the Dungeness-Quilcene project was finished, and the project's water-resource management plan was completed. The plan was concerned mainly with management options for Dungeness River water and arose in response to competing interests. The planners identified many research and stewardship activities to pursue in the watershed and contributed greatly to the characterization of the environment in eastern Clallam County.

With all this planning there exists clear direction regarding what projects are needed and what the priorities were for both the public and the agencies involved. One of the highest priorities is responsible resource management, which led to Clallam County's becoming a pilot area for the State Wetland Integration Strategy (known as the SWIS pilot project). From SWIS, Clallam County will have an idea of what management strategies would fit its various wetlands. I want to give a simplified overview of the SWIS project because it's interesting and because it's relevant to the session as a whole. I've heard similar ideas expressed earlier at this conference; Joel Freudenthal and Steve Gray of the Clallam County Planning Division gave a talk on this process in Session 2b, and they should be credited for its success.

As Figure 4 shows, the process started with existing characterizations. Information was field checked where necessary, including vegetation and soil and wetland. Information was added to the GIS and processed, and this yielded numerous outputs. We got a lot of maps, obviously, including an updated wetland inventory. The data was then examined closely to see whether characteristic functions could be identified for both hydrology and habitat. Eight hydrologic functions and 10 habitat functions were identified. (I will expand on these two groups in the next figure.) We were able to identify wetlands at risk based on land uses upgradient from the wetlands, and proposed changes to land uses, as per GMA comprehensive planning, which is being conducted intensively in this area.

The project has also helped us identify priorities for restoration projects, as well as situations where the best option might be acquisition.

SWIS process (simplified)

- started with existing characterization, using GIS coverages, NWI, recent aerial photos, other information
- field checked
- digitized new info, processed all using GIS
- resulted in
  - updated wetland inventory
  - i.d. 8 distinct hydrologic functions*
  - i.d. 10 distinct habitat functions*
  - management recommendations for stormwater, water quality, fish and wildlife
  - priorities for restoration, enhancement, acquisition

Figure 4.

In identifying hydrology types, we had to take a holistic view of the flow of water through the watershed (see Figure 5). We did this by looking closely at various things. Soils, geology, and well logs were examined to determine the aquifer use in a given area and the location of the water table. Streams, irrigation ditches, springs, the entire hydrologic picture—we looked at all these things to see where that water was coming from and going on to, where the wetland was and what its role was in the scale of the watershed.

An example of management for a particular wetland might be, if you've got a wetland that's receiving groundwater from an aquifer contaminated with nitrates, you might need to manage that wetland for cleaning up those nitrates, especially if it feeds a salmon-bearing stream. But the other implication would be that you need to manage the land uses in the watershed upgradient from the wetland to keep the groundwater contamination from getting any worse, or, preferably, to improve the groundwater quality in the long term.

Expanded process for using GIS results to separate wetlands into functional groups for:

- HYDROLOGY
  - ▶ based on overall watershed processes
  - ▶ looked at geology, soils, well logs, streams, irrigation ditches, springs
- HABITAT
  - ▶ based on scale of species' home range—local regional, or global—and use of corridors
  - ▶ used functional indicators such as documented species' use, habitat size and diversity, plant communities, upland habitat, water availability

Figure 5.

Habitat types were categorized based on the scale of the species' home range—local, regional, or global—and their use of corridors. Functional indicators were also used, such as documented species' use, habitat size and diversity, plant communities, upland habitat, and water availability.

III. Conclusions

Because of my background in geology and hydrology, my thinking has always been biased toward viewing water as the bottom line. Water is where it all starts. It influences the soil, which then influences the vegetation. And water—whether surface water or groundwater—connects your restoration site or any point on the landscape directly to the watershed as a whole (see Figure 6).

So in planning, we need to look at the source of water. What is its quantity? What is its quality? Is it primarily coming from the subsurface, the surface, or both? What soil types does it pass through along the way? And what are the land uses upgradient from your wetland? These questions must be addressed if we're going to ensure the long-term success of restoration projects. If we're thinking along these lines, we can improve predictability. But without this type of evaluation, "unanticipated hydrology" will continue to be a common source of problems, as it was in my survey five years ago.

Another question should be, what are the character and destination of the discharge from your site? Restoration planning can be directed so that beneficial uses of the water discharging from a wetland or a restoration site can at least be maintained, or possibly improved.

My recommendation, though a bit of a departure, also came from my thesis research. One of the survey questions asked how best to achieve habitat protection. The most common answer by far was through a combination of several levels of government. In my work experience I have seen first-hand that a local government can gain tremendous familiarity with a watershed, and understand technically and politically what is going on there, given the time and given the chance. So I advocate empowering local groups with technical expertise.

In closing, if you look at a color areal photo of the Dungeness River, you can see how water flowing through the landscape connects all the points together. Riparian corridors are visible, which are either irrigation ditches or streams. Of course, the wetlands don't jump out, and neither does the groundwater. So there

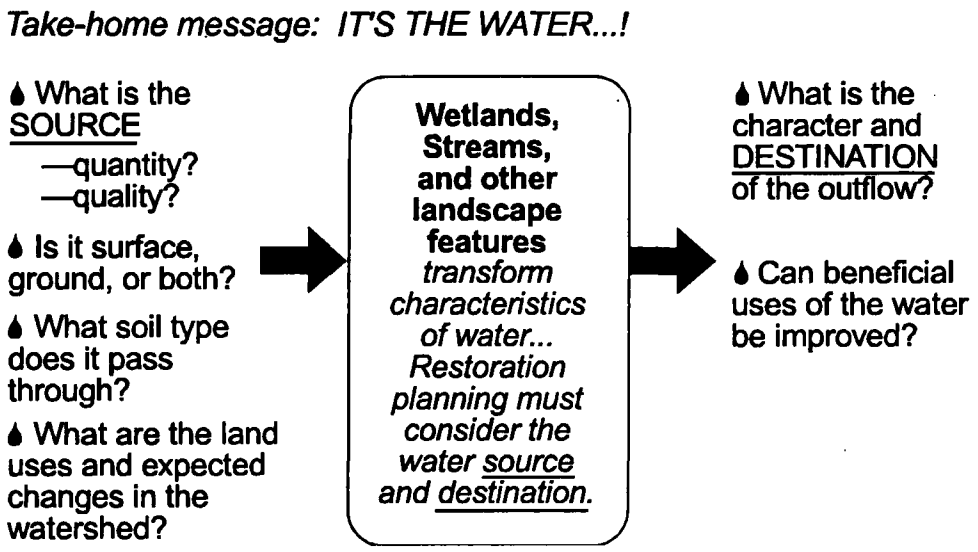

Figure 6.

are a few hidden landscape elements you don't necessarily see. Yet the water is still tying all these landscape features together.

Readily noticed is urban encroachment—areas of one-acre lot densities, commercial and industrial areas. These are important factors in your restoration planning that will affect the quantity and quality of your water, and should be considered.

Curtis Tanner, Fish and Wildlife Biologist, U.S. Fish & Wildlife Service, speaking on:

HABITAT RESTORATION ACROSS AN URBANIZED ESTUARY

I would like to talk a little bit about applying concepts of landscape ecology in overcoming some of the challenges of restoration in the urban environment. In preparing my talk, I have to confess that I'm probably going to leave you with very few answers and quite a few questions, but that's O.K. because this is a panel discussion, so you're supposed to have questions. Besides that, I've got quite a few of the latter and very few of the former, quite frankly.

With that in mind, I'm going to be drawing on some of my experience in habitat restoration in the Duwamish River estuary, the estuary around which Seattle is located. I'm going to be very fuzzy on specific projects, who did what and why it was done, so I'm going to use the vernacular "we" a lot, and be very vague about where these projects were and what they were supposed to do. My objective is to provide you with examples of what kind of landscape-scale challenges exist in habitat restoration, as well as some of my own ideas about how to incorporate some of the concepts Ron Thom discussed into the design and implementation of some of these projects.

Without repeating too much of what Ron Thom said, I just want to put the idea of landscape ecology back into your head. When I read Forman/Godron, my take-home message was, landscape ecology is the examination of the relationship between landscape forms and ecological functions. Form, function: It's simplistic in some ways, but it's a useful philosophical approach to habitat restoration. Some of those elements of form are size, shape, accessibility, and the connectivity of various landscape elements across a large landscape. The key concept is the relationship between the shape or the form of a particular landscape element, and how that landscape element functions in a larger context.

I'm sure everyone at this conference is aware of the large-scale loss of intertidal habitat in the Puget Sound region. These effects have been felt most acutely in urban environments. Despite the large-scale wetland loss in urban systems—systems like the Duwamish, the Puyallup, and the Snohomish—it's important to keep in mind that the urban estuaries remain very important gateways between the up-slope watershed and Puget Sound, and that they perform unique, essential and irreplaceable functions. We can't afford to write off our urban estuaries. Simply because we've lost 99 percent of the habitat in the lower Duwamish doesn't mean we can turn our backs on that system and walk away. We've got to find some way to meet the challenges in that system, to help preserve those important functions.

Looking at an aerial photo of the Duwamish River estuary gives one a sense of the large-scale human effects on urban landscapes. Some of the challenges we have to overcome are due simply to the scale of anthropogenic effects. The Duwamish is obviously not a natural system; this is a landscape dominated by human land-use activities. This is a significant challenge—one that can seem overwhelming.

Another challenge is the lack of buffers: There's no transition between the built and the natural environment. So there is an inappropriate flow of information and of energy between these landscape forms, which aren't adapted to being adjacent to each other. An example is the problem of contaminants in the urban environment. One of the surprises that we found at a recent restoration project were buried contaminants, artifacts from past civilizations of 10 or 20 years ago.

There are changes in the physical processes. There are changes in the flow patterns of energy regimes in the other drivers of natural systems. We see wave energy environments and wave regimes that didn't exist before. We see areas that used to buffer wave energy that have been removed. We see anthropogenic sources of wake, such as boat wake, contributing wave energy that wasn't historically there. We see blockages in historic conduits of energy. Again, it's a system that is largely dominated by human effects.

Some of you may well remember the fact that I was standing here about four years ago as a naive recent graduate. One of the things that I spoke of at that time, and I still try to remember occasionally, is the need for developing estuary-wide habitat restoration plans. I still feel strongly that what we need to do, particularly in the urban environment, is develop large-scale restoration plans that look at the physical factors that constrain us, as well as provide opportunities, in an urban environment. And there's a variety of good reasons for doing that, both ecological and policy reasons.

I have to confess we haven't gotten to that. I still work with some of my colleagues on trying to get to that stage. Getting there is difficult, and I'm still not sure we know all the questions to ask in developing a plan like that. One of the first steps, and one thing that we have done, is begin to identify the range of potential opportunities. We've mapped potential habitat restoration sites in a GIS format. At the very least, on the large scale, we're beginning to identify where our opportunities are. So perhaps that's the beginning of applying landscape ecology theory in addressing the problem of habitat restoration in an environment like the Duwamish.

There is another thing that may be useful in applying these concepts. One of the projects I'm involved in is looking at that broad range of potential habitat sites, looking at that menu site by site, and evaluating those different sites for implementation. One of the things you can do to promote a landscape ecology approach is to select criteria that drive you toward the landscape setting. You can look at criteria such as size, proximity of the habitat, adjacent land uses, and location within the estuary. If you put those types of criteria high on your list and weight them heavily, then you are developing, almost de facto, a landscape approach.

One of the things we've done in Elliott Bay is begin to look at geographic focus areas. We're beginning to concentrate habitat restoration projects in specific portions of the system. This focuses our efforts in areas that seem to be of relatively high importance to the fish and wildlife that we're trying to support. Perhaps these areas have remnant habitat features that can serve as keystones to build on, or perhaps they're merely a concentration of potential sites with a high potential for success. But in any event we're beginning to concentrate those efforts and provide projects with greater connectivity and size that is meaningful at the scale of an estuary.

The Elliott Bay/Duwamish Restoration Program has developed a concept drawing for the Turning Basin that identifies a variety of potential opportunities in this geographic focus area that could be implemented by

a variety of mechanisms (see Figure 7). It shows one project that's already been completed there, as a non-compensatory project and the potential expansion of that project for mitigation purposes. The Turning Basin shoreline improvement fund project and the Hamm Creek shoreline improvement fund project would provide some additional riparian habitat benefits. The concept depicts a large-scale restoration project that provides a daylight for Hamm Creek, and the expansion of a tidal marsh at its mouth. Another possibility is the improvement of the shoreline by a private property owner, the Boeing Company, which has specific plans to redevelop its shoreline properties in the Duwamish. Doing so would trigger specific requirements for shoreline improvements. So you begin to see how different mechanisms work together, and you begin to have, again, projects of scale to make a significant difference.

This might be a bit of a leap, but I would also argue that institutional arrangements in partnering are also a means of achieving landscape scale processes. Like many of you, I am wrestling with the notion of ecosystem management. It seems to be the mandate that many of us are under, particularly those of us at the federal level. At one level ecosystem management is the shift to a larger scale management structure. But another component of ecosystem management, if you look at the literature, is restructuring institutional relationships. Rather than having very separate management regimes divided along natural resource (fish vs. wildlife), level of government (federal vs. state vs. local) and/or ownership lines, we should strive for the creation of meaningful partnerships. That's as important a component of ecosystem management to my mind as the expansion of the scale. So I think it could be successfully argued that changes in institutional arrangements and the establishment of partnerships is one way that you can go about landscape-scale restoration.

Landscape theory can also be used in approaching individual sites. By taking advantage of natural models, remnant features, and site-specific aspects of an individual restoration site, you can get back to ideas of size and connectivity. Hamm Creek, the creek we spoke of earlier, disappears into a culvert. One of the things we can do is a daylighting of Hamm Creek, and a creation of a natural channel for that creek. We can work with site-specific features to get an approach consistent with landscape ecology theory.

When looking at a site it's helpful to look for some remnant features that give you clues about how the natural system might function in that particular area—clues based on elevation, slope, and so on. You can

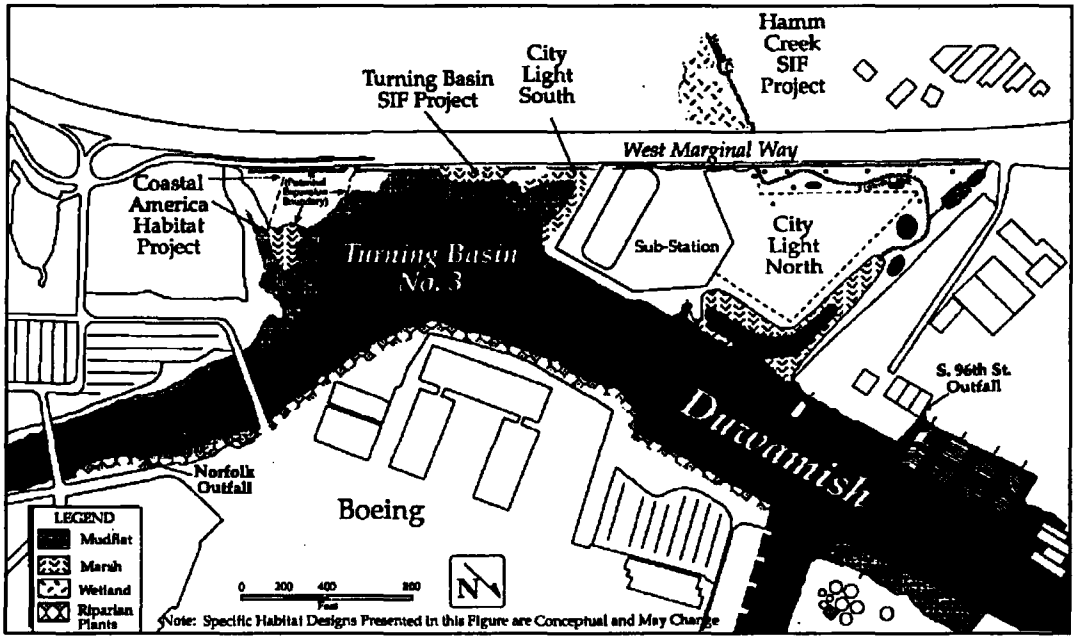

Figure 7. Turning Basin Geographic Focus Area - Potential Habitat Restoration Projects. Elliot Bay/Duwamish Restoration Program

pick up that same slope and that same elevation, but excavate to expand that site—again, working with natural features as models.

Another thing that you can do is try to overcome some of the anthropogenic effects. We talked about wave energy, and we talked about changes in the physical forces. At one site we're installing log booms to protect the habitat area from the effects of vessel wake. These structures dampen that energy, and thus create areas of sediment deposition.

Finally, I think a landscape approach needs to consider novel approaches to incremental improvements, especially concepts with wide-scale applicability. In the urban and estuarine environment we see a lot of the shoreline dominated with riprap, a rock-reinforced substrate. By the creation of "benches" in these slopes, we've returned a small increment of intertidal mudflat habitat. Obviously, that's not a natural mud flat, but we hope it will provide some of the same benefits of the natural landscape element. If this concept works, you could apply it on a large scale within the system.

In summary, I'd like us to remember there are big things we can do—we can develop large plans that look at the system. There are also smaller steps we can take in the interim—we can develop criteria that drive decisions toward landscape considerations; we can design projects that optimize site-specific opportunities. And finally, let's remember that successful landscape restoration may also depend on changes in institutional processes and better cooperation.

Patrick Cagney, Environmental Resources Section, U.S. Army Corps of Engineers, speaking on:

PRACTICAL, SITE-SPECIFIC CONSIDERATIONS FOR HABITAT RESTORATION

I would like to deviate somewhat from the previous presentations and discuss some of the more practical aspects of habitat restoration. Many of the topics included in this presentation should be considered, regardless of the location within the landscape or restoration project. This discussion is not intended to encompass all aspects of implementing a restoration project. We will focus on a few key points. Most of the information presented will be opinions obtained through interviews with professionals who have experience in the field. In the short time we have here today, I would like to provide an overview of three critical elements that I consider to be some of the more problematic in completing a restoration project. They are project management, access to land, and project cost.

To provide some context for this presentation, let's assume we have already gone through the ecological evaluations that will define a restoration project. The goals, objectives, and preferred locations have already been decided. The project is at the beginning of the implementation phase.

As we have discussed, a lot of consideration goes into where a restoration project should occur. The same level of effort should be devoted to the project planning. Most restoration projects these days involve a consortium of agencies, tribes, and organizations. Planning a restoration project with a group of people can be perplexing. This is why it's important to identify key project components that will drive the implementation, such as timing of funds, permits, etc. Incorporating a critical path diagram that includes project milestones and schedules can provide a framework to plan around.

Identifying project milestones and objectives will also help define the roles, responsibilities, and expectations of the project partners as the undertaking proceeds. Although it's difficult at the beginning of our project, it's best to draft some sort of agreement or document, such as an interagency agreement or a contract, that details project specifics. For example, specify who will act as project manager, who will be the banker or steward once the project is completed. This can be especially useful when new players get involved later in the process.

One final comment on the project management before moving on: Spend the time to do advance coordination. From the outset, get information and comments from the many people that will be involved, including regulators, special-interest groups, and tribes that may be located in the project area. If you allow for constructive input early in the process, the project will benefit in the long run.

It's long been my view that the two most arduous tasks in the habitat restoration arena are obtaining funding and gaining access to property. Access to land involves both permitting and real estate actions. I won't spend any time on the permit part but will focus on real estate considerations. Remember, this is an overview; the points I will make are addressed in greater detail in the references I'll provide at the end of the presentation.

Foremost, it's important to develop a real estate strategy at the earliest practical point in the project. Questions to be addressed include: Who will manage the land? Does the project or do the terms of the funding require the property be in fee title, or will some sort of an easement be sufficient? How will the property be transferred, and to whom?

If you are fortunate, the property is currently in some form of government ownership, and the land managers are supportive of and involved in the project, but this is seldom the case. More than likely, the property is in private ownership. The process of acquiring property with federal funds can be drawn out and expensive.

If an agency intends to pursue acquisition of property, it is recommended that instead of acting in a regulatory role, such as in condemnation procedure, you approach the situation as a market participant, such as a vendor or vendee. This provides additional flexibility. Specific regulations dictate an agency's procedures for acquisition of land, and relocation costs to the owner may be included in any settlement. Fortunately, groups such as the Trust for Public Lands and The Nature Conservancy can sometimes facilitate the process. But this also demonstrates the need to consider all the variables for the project in developing a strategy.

Concurrent with this process, you will want to gain some preliminary information on the property to help in your decision-making. This information includes: Who are the current and past owners? What is the local jurisdiction, zoning, and so on? What is the site use and adjacent uses? What were the past uses? Is there reason to suspect contamination? Is the site located near a Superfund Model Toxic Control Act (MTCA) or storm drain? Are there any other underground storage tanks? What is special about the site? Does it contain any endangered species or archeological sites? And does the property itself have any deed restrictions or liens on it?

Obtaining this and other relevant information will help you evaluate which real estate options are best suited to the particular project. Authorization to restore a particular piece of property can be gained in a variety of ways, including direct purchase.

- Land exchanges. For agencies that have surplus properties, this may be a convenient way to swap one piece of property for a desired restoration site. The process may be easier than outright purchase. If the two properties to be exchanged are of similar value, no actual money need be transferred.
- Easements. By purchasing an easement from a land owner, the right to perform specific work on the property is granted. These can be temporary or permanent.
- Covenants. These are deed restrictions that can be placed on land. They are meant to work in conjunction with the easement or acquisition but do not provide authorization to perform work in and of themselves.

Finding sufficient funding to gain entry to a site for restoration purposes is sometimes a dilemma. Depending on the situation, benefits other than money can provide an extra incentive to the land owner. Usually, they are in some form of tax reduction. Examples include:

- Public benefit rating system. King County offers a property tax break to owners who are willing to leave some of their land in a natural state.
- Open space tax act. The Washington state law allows property owners to reduce their property taxes for private lands classified as open space.
- Exempted donations. A deduction from federal income tax is allowed for donated property.

I would like to spend the rest of the time discussing some facets of project costs. It seems to me that's where the other hang-up usually is: We never have the money to do what we want to. The focus will be in

three main areas—project budget, cost savings recommendations, and construction equipment in the related expenses.

Budgeting and project savings are especially critical when you consider how much it costs to restore habitat. Excluding the price of land, a recent estuary project that involved excavation, filling, and culvert replacement in a 50-acre setting cost about half a million dollars. Urban environments are especially high-priced. Again, excluding land costs, three small restoration projects in the Duwamish that we just saw cost more than $600,000. This is why a cost estimate and a budget are essential to any project. This should be done at the outset, and it provides a reality check for the project's environmental goals and objectives.

Excluding land and permitting expenditures, budgets are typically broken into four main sections. They are:

- Pre-project assessment. This may include the initial site survey, baseline studies, and chemistry and geotechnical testing.
- Design. This would incorporate all the work from the conceptual stage to a final design and preparation of plans and specifications.
- Construction. This is project-specific, but includes mobilization, site preparation such as clearing and grubbing, excavation, placement, grading, the materials that you'll need, contracting cost. Always put in a contingency.
- And finally, post-construction. This includes items such as preparing an as-built drawing, maintenance, and monitoring.

In preparation for this presentation, I interviewed several specialists in the field of habitat construction and asked them to provide recommendations on ways to cut project costs or improve on efficiencies. The consensus was that good communication is the key to getting a project constructed as it was designed. That means that the biologists must make the ecological goals clear to the engineer, and the engineer must relay the same goals to the contractor.

The people polled for this presentation provided the following recommendations:

- Have an engineer or project manager who is committed to the project in the field at all times during construction. This person is responsible for arranging the sequence of construction orchestrating how equipment operators will perform their work. This person should also be flexible and be able to deal with unforeseen circumstances.
- In the survey and design phase, consider using a computer-aided design system that facilitates design changes and quickly allows for the cost of the design changes to be determined. Such a system is useful in comparing the pre-project survey to the as-built survey.
- Know your site attributes. Make sure the equipment does not overload the site-bearing capabilities. Don't work slopes that exceed the equipment abilities, and use special equipment such as kevlar mats and the like, as needed, as the site dictates. If possible, do all your construction at one time to minimize mobilization costs.
- Limit haul distances, and try to determine whether excavated material can be used on site. Locate sources as material as close to the construction site as feasible. Salvage and recycle as much of the material from the project site as possible. This worked well for a project Curtis Tanner showed earlier; it really does lower your costs if you can do it right.
- Hold both a pre-bid and pre-construction meeting. At the pre-bid meeting, have a technical person explain the project in detail. Include all the details in the plans and specifications, because this will minimize change orders and cost overruns. The pre-construction meeting should be facilitated by an on-site engineer. At this meeting you can establish clear lines of communication, coordinate related activities, and identify the sequence of operations to minimize equipment time. The project goals and objectives should also be defined at this meeting, and any special procedures required should be identified.

restoration project. Again, the recommendations from those interviewed: Be familiar with the tolerances of your restoration site. Dimensions of access roads, internal levees, gates, slopes—all affect the size and type of equipment that can be used. This then influences the production rate and mobility.

- Please remember that the prices I'm about to give are just estimates, and just to give you a rule of thumb. For large restoration projects, the most typical types of equipment are:
- Hydraulic excavator with track and thumb. This was the unanimous favorite, due to its mobility and for the variety of functions it can perform, such as grubbing, excavation, filling and placing. With an experienced operator, access to difficult places is legendary. An excavator with half a cubic yard bucket has a production rate of about 60 cubic yards an hour; cost, with an operator, is about $100 an hour.
- Bulldozer with track and pat laid. This is used for grading and moving material around. The production rate is about 45 to 60 cubic yards an hour; the cost, with an operator, is about $80 an hour.
- Backhoe loader. This is a 4x4 with wheels, 2-cubic-yard loader, and half-cubic-yard backhoe. This is another versatile piece of equipment that can be used for filling dump trucks, excavation, removing and replacing culverts. The production rate is about 60 cubic yards; the cost, with operator, is about $75 an hour.
- No project can be done without a dump truck. The sizes range from 5 to 12 cubic yards. Production rate and the size of the access will determine the best size truck for your project, but a 12-cubic-yard truck, with an operator, is about $65-75 an hour.
- If restoration work is in the near shore, and site access from land proves difficult, barge and a crane that is maneuvered by tug may be useful.

Finally, the restoration of Puget Sound habitats depends on proper environmental evaluation to determine the proper scale and location within the landscape. But this is only the first step in the process. Once restoration projects have been identified, they need to be implemented. Project-specific difficulties such as access to land and limited project funds can make this burdensome. Planning, competent project management, and effective communications can help to offset these difficulties.

Simenstad: It's all fine and good to take Forman/Godron and examine landscape patterns to infer ecological and other processes. But we need people like Pat Cagney to bring us back to reality. The bottom line is, can you really do it as planned? And how much will it cost? So I would ask those in the audience to feel free to address any questions about the application of the landscape to restoration at any of those scales, from regional to the backhoe.

Q: Given the historic importance or perceived importance of large woody debris inputs, from terrestrial to estuarine and marine environments, can we conceive of a way to restore some of that function?

Thom: The woody debris issue has been talked about lately in terms of streams—the effect of removing woody debris from streams and what that's done to habitat upstream. But in the estuaries, how important is woody debris? I think that's still a controversy.

Simenstad: The deposition and the presence of structure such as large woody debris in the intertidal is an important patch feature and adds tremendous structural complexity to marsh landscapes. While we may not be able to restore the process whereby a lot of that large woody debris gets there, we should at least consider it a potential design feature.

Q: We had some kind of practical experience with that on the Jetty Island (Snohomish River estuary) project, where we built this brand new berm of dredged sand, and it was really remarkable how fast most of that berm got coated with logs. I saw the figures yesterday; even in the first spring after construction, I was

amazed at some of these really big logs that had accumulated, such that outside of the berm is maybe 50 percent armored with real good accumulation of logs.

Simenstad: We should remember that Puget Sound does have the advantage, still, of a large number of unrestricted sources of large woody debris.

Tanner: I think that's a good point. Particularly in some urban systems, depending on the watershed, restoring the process of large organic debris (LOD) input to an estuarine system may simply not be possible. We may not have the source in a river, such as the Duwamish for instance, downstream of any diversions or dams. The ideal situation would be to be able to restore the process of LOD or any other estuarine process that used to occur. So our next step is to look at the specific function that LOD may serve in the estuary. One of the ways we've used LOD in the Duwamish is for shoreline stabilization. Besides using it to provide increased structure or roughening of the substrate, we've used it for trapping fine-grain sediments. So we have attempted to recapture that function of sediment trapping, shoreline stabilization and structure by keying these logs into the bank. I don't think we've come up with a complete list of all the. But we certainly haven't come up with any ideas on how to restore that process to the Duwamish.

Cagney: You're right: There wasn't a lot of emphasis put on it at this presentation. At Watersheds '94, there was a lot of emphasis, especially for the people who were doing the forest and watersheds evaluations. King County has at least a couple of demonstration projects on the upper green or middle green, where large woody debris has been keyed in, with copra matting and willow binding all these things together. So, we haven't touched on it today, but in fact, people have considered it and are using it to work in the restoration arena today.

Cagney: I might also mention that on the Lake Sammamish project we put them in. They cost $400 apiece. It happens from the top of the watershed down. This is one restoration option that we should consider.

Q: If large woody debris is an important estuarine function, how do we decide whether to devote our limited restoration resources to LOD placement or to restoring previously common habitats, such as mudflats, or to "retrofitting" subtidal riprap shorelines with constructed mudflat benches?

Simenstad: There are two questions that could be addressed. One is the potential role of fine woody debris in the estuary. The other is habitat trade-offs.

Lovvorn: I'm glad you phrased it that way. Woody debris is not a function. It performs functions, but it's not a function in itself. I think whenever you have a limited amount of space, land, whatever you want to call it, you have to decide what your priorities are. If you have an estuary where, in the big picture, you want salmon habitat, or you want shorebird habitat, or you want some kind of emergent habitat for birds to nest in, you have to decide whether that's more or less important than providing whatever habitat woody debris provides. There may be some functions in terms of ultimate organic matter provision, if it decomposes, which is going to be really slow; it may also provide some habitat structure for fish that are not mudflat species, or perhaps for mammals. But you have to decide whether those particular habitats, whether those functions that the woody debris provides, are limiting relative to some other functions you might want to provide. I think to say, "Well, we've got to restore woody debris fields," or something like that, because that is a function of the estuary is the wrong way to look at it. It may be that trapping sediments is an important function. It may be that trapping smaller organic matter that can then decompose and provide finer organic matter for that particular area is an important function, biologically. But again, I think there always has to be some consideration of what the priorities are within that watershed, what habitats do we want to exist within this entire watershed, and then put in the perspective of what the priorities are.

Simenstad: I could take an easy out to your question on subtidal habitat with the bench and say, in that particular instance, we basically just reshaped that riprap slope, and made it steeper, so we could have a bench in it. But I suggest that habitat restoration is also partially a scientific question, and partially a social question. It's ultimately an issue involving trade-offs. As a society, we may feel the habitat that supports juvenile salmonids is more important than the habitat that supports bent-nose clams, or nematode worms, or whatever. And we may make a conscious decision to use the limited amounts of area in an urban environment that we're willing to set aside for habitat purposes, and institute restoration efforts that favor the establishment of a certain type of habitat that supports this range of species over habitat that supports these others. That's a social policy decision. If the taxpayers tell us they're more interested in nematode worm habitat than they are salmonid habitat, then I'm sure that will become our mandate and our charge. But understand that in Elliott Bay, for instance, we may choose alternatively to do some of the type of artificial reef and kelp forest habitat establishment that we heard about earlier this week in the presentation from the Washington Department of Fish and Wildlife, to support juvenile rockfish and their recruitment, at the expense of unvegetated sandy bottom habitat that might support nematode worms, or sand dollars, or other benthic organisms associated with that habitat. So we may make that conscious decision as a part of a social policy decision.

Q: [inaudible]

Simenstad: Getting back toward the landscape perspective, it's also important to understand the processes, and also the change in the processes, that might make your restoration self-maintaining. You may have to accept the fact that some habitats may not be sustainable anymore, given the changes in the processes. In the case of the Duwamish River, we're still not sure those benches will be self-maintaining, because we've altered the sediment flow into the system so much that the time scale of mudflat maintenance is going to be a lot longer than we knew about it before.

Tanner: Is it realistic to assume that in a system like the Duwamish, where I think we would all agree that anthropogenic forces dominate the system—is it realistic to assume that natural processes can still provide self-sustaining habitat? If we've already gone in and mucked up the system severely enough that humans dominate the processes that drive this system, is it reasonable to assume that we will not have to do ongoing maintenance in a system like that if we want to provide "natural" habitats?

Q: What I'm wondering about is the advisability of adaptive management as a paradigm for restoration. The reason I say this is that the largest restoration project in the Pacific Northwest was one that coined the adaptive management paradigm, and that's the restoration of the salmon fisheries of the Columbia River. I remember when they were first starting out with that, and I went in and talked with the Northwest Power Planning Council, and I asked them what their plans were going to be for the National Forest. The whole goal of the restoration plan was to maintain the habitat in the Salmon River. It happened to be the National Forest that this river flowed through. The upshot was that previous logging had damaged salmon habitat. So you had a situation where the Northwest Power Planning Council had made a decision to spend $30 million in restoration in that basin, and was giving up $110 million in lost power generation revenues at the same time, but not halting continued degradation. And they decided that because the effects of the forest plan couldn't be evaluated by adaptive management, they were unsure about what they felt would be good habitat preservation or habitat management schemes for the forest. What I'm saying is, if we are thinking truly in a landscape perspective, we are going to see no more pristine landscapes or pieces of a landscape that essentially can be duplicated. Nor can we hope to restore an ecosystem when at the same time we're tearing them all apart. Because we can't evaluate success when we have nothing to compare it to. The upshot is, it makes sense to me to do things you can do, but not trust adaptive management as a management paradigm.

Cagney: I have a much simpler view of adaptive management. I look at it very practically. You build a system and see how it works; if it's not working, you try to figure out why, and you fix it. And people agree at the outset that we don't know everything. What we're talking about is much broader than that, I think. It's in building the technology, I guess—we don't know how to do it very well. Your point about tearing down the models is a very good point. I guess don't want to do that; you want to maintain the models and build from there.

Q: Just how effective is habitat restoration, i.e., what percentage of projects are successful? I doubt that it really works.

Thom: Well, it's a fact that there are projects out there of constructed marshes and rehabilitated eelgrass beds. That's a fact; you can go out and measure them. If you're talking more philosophically about restoration to some predisturbance condition in an urbanized estuary, you're probably right; I don't think it's ever been demonstrated that we can go back to the way it. In certain small increments, we can do it; over a large scale, in a very difficult situation, it hasn't been proven.

Simenstad: The point is, it really hasn't been applied over a large scale, and probably not until the Florida example [Kissimmee River project] is implemented will we know whether it can be done on a large scale.

Cagney: I'd just like to repeat what Curtis Tanner said earlier. It probably isn't as successful as an original system, a natural system. But the other thing is, there are opportunities out there, and I think a lot of us would rather do the best we could and implement it, even if it isn't completely successful, than to do nothing at all.

Soule: I would add to that, it all depends on what you're measuring. You can measure success as: Are the fish back? Or are the fish 100 pounds yet? Or did we get the logs in like we thought we would? Or are we achieving some change in public attitude and behavior because of this project? You need to understand what you are measuring and acknowledge that there will be success in some things, and possibly failure in others.

Tanner: I also ask, what choice do we have? I would never suggest that restoration is a substitute for preservation of those important intact ecosystems. But in a place like the Duwamish, where there is essentially no habitat left, you have a salmonid run depended upon by tribes and by people who have a legal right to harvest those fish. You can't just turn your back on it and say we can't do it. I think we can add increments of habitat function to that system. We can add amounts of prey resources that juvenile salmonids can forage on. They may not be self-sustaining natural systems. They may require periodic human intervention. They may not function at 100 percent of what natural systems do. But they add a measurable increment, and I think that in highly degraded systems we have no choice but to attempt to improve the success record. And I believe it is through thinking about things at the landscape scale that you increase your chances for success.

Q: Are there any opportunities and what might they be for incorporating landscape ecology concepts into mitigation and regulatory specifications?

Lovvorn: I think it comes back to some things that were brought out by a report that Dave Shreffler and Ron Thom did a couple of years ago. In terms of an entire estuary, I think there has to be kind of a listing or inventory of what you think the original functions were. Probably in an estuary the (historic) size of the Duwamish River estuary, there was habitat for salmon, and for shorebirds, dabbling duck, and geese, and perhaps habitat for otters and that sort of thing. All of it probably can't be provided in the same site. We tend to construct little microcosms—the Gog-Le-Hi-Te marsh in Tacoma is a good example. There, we want

a little bit of songbird habitat, and we want a little bit of salmonid habitat, and we want some emergent habitat, and it's all stuffed in an area the size of this room. The same is happening at Kellogg Island and at a lot of places. It might not necessarily be practical to get all those functions in a very small area. It might be more suitable in some other areas where there's a little more space, and more of a gradient in elevation, in salinity, in sedimentation, and other large scale characteristics, you might have the space to allow some accumulation of logs, as well as provide bare mudflat for shorebirds and migrating salmon. I think the plan on the scale of the watershed needs to be: What is the array of functions that this landscape at one time provided? And it may be that once you have that list and you've satisfied some of those functions at a variety of sites, the number of options goes down in terms of the kinds of mitigation you'll accept. If you've got a number of mud-flat sites already, then if somebody wants to trade land or something that will provide a mud-flat site, maybe they have to provide a lot more mud-flat site than the first person had who came up with the mitigation project, because you've already satisfied that function on your list, and what you're looking for is maybe some salt marsh function or some emergent plant function. And at that point, the rules change a little bit if you're in any kind of a banking or point system. So it seems to me that on both an estuary scale and on a regional scale, e.g., the southern end of the Sound, there must be some listing of priorities. And those priorities are going to change as certain of those functions are met.

Soule: I would add that, in an urban situation, you're starting from scratch in a lot of cases. So the story is different. But in an area like—for example, we heard from Richard Gersib of Ecology yesterday, with the Puget Sound restoration program—they're going to be coming up with management strategies for individual basins as a whole. And I think if you're coming up with these landscape plans, as Jim Lovvorn said, or a watershed functioning map or guidelines to how the watershed is functioning, then you've got some ideas already laid down on paper before anyone is even suggesting making an impact on a wetland. These will be ideas you can work from, incorporating those functions you think are important in that watershed and making sure you're not losing any. So I think the mitigation banking opportunity is also a big one, and I would think that would affect mitigation policies and regulations in the future.

Cagney: I would second that. From a regulatory standpoint—at least from a federal Clean Water Act perspective—I think the ways regulations are written allow for exactly what people are talking about. What it really takes is the resources and the diligence to make those documentations, then to provide those to the regulatory agencies to demonstrate that on this particular given watershed or this particular county, we have lost these types of functions and this type of a special aquatic site. The regulatory agencies don't have the resources to gather this kind of information themselves; the way the regulations are written, they have to work with the best information possible. So once they're documented, things like cumulative effects, indirect effects, energistic effects now become involved in the regulatory evaluation. But it does take a commitment; it takes people to do those inventories and assign those functions, and then to monitor the regulatory application of those land uses as they come about.

Simenstad: In closing, I might add that there's another aspect to our regulatory mandates, and that is: Landscape ecology can also point us to areas where we need to just basically draw the line about preservation. A good example is provided by Dan Penttila and the WDFW group working with baitfish in the Washington Department of Fish and Wildlife. They identified very restricted, specific and unique baitfish spawning sites. It is vital to understand the role of baitfish in the large Puget Sound food web and the fact that probably a significant portion of Puget Sound fish species, as well as some of the marine mammals, depend upon those baitfish species. This suggests that restoration isn't going to do any good if we continue to lose those sorts of critical sources of energy into the system. So it can't be just restoration; it has to address preservation as well.

I hope this discussion will continue, in some form, over the next few months or years. I want to thank the panel, the audience, and also the Puget Sound Water Quality Authority for its participation and support.

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PUGET SOUND RESEARCH '95

SESSION 7B

INTEGRATED SOLUTIONS

Session Chair:

Andrea Copping
Washington Sea Grant Program/University of Washington

GREAT BLUE HERONS AS A MANAGEMENT TOOL FOR GROWTH MANAGEMENT IN PUGET SOUND: HOW MANY HERONS DO WE WANT?

Donald Norman[1] and Rayna Holtz[2]

INTRODUCTION

Great blue herons are a well known species in the Pacific Northwest that use estuarine areas and wetlands, and nest in forested areas near foraging locations (Butler, 1989; Butler, 1995; Norman, 1995). The heron population in the Pacific Northwest is healthy, and because they are a predator at the top of the food chain, their populations reflect a healthy local environment. However, with the reduction of available foraging habitat, the decrease in nesting sites due to coastal development, and the loss of upland wintering habitat for juveniles, there is a potential for strains on heron survival in the next 25 years. The purpose of this paper is to review the effectiveness of existing regulations related to the protection of great blue herons in western Washington.

EXISTING REGULATORY PROCEDURES TO PROTECT HERONS

There are several regulatory actions that can be taken if herons are threatened. Under federal law it is illegal to shoot herons or to destroy active nests. The primary focus of Washington state law has been to protect colonies. Forest practices regulations provide for the protection of heron nesting sites and stipulate buffers around colonies. The State Environmental Policy Act (SEPA) has a checklist that includes wildlife and calls for an Environmental Impact Statement (EIS) if significant impacts to wildlife occur from a proposed project. It is the Growth Management Act (GMA) that provides the first basis for protection of heron foraging areas. The GMA specifies the development of critical area ordinances by major cities and counties to protect wildlife, but no details of specific guidelines are provided, and the management and enforcement has been delegated to local planning departments. The Washington Department of Wildlife (now Fish and Wildlife) (WDFW) has prepared management recommendations for the protection of great blue herons and other species classified as "priority species" (WDW 1991). These recommendations outline components of habitat management plans (HMPs) to provide solutions to potential development conflicts. We examined several case studies to demonstrate how well herons can be protected. The case studies are followed by a discussion of a HMP written for the Maury Island heron colony that addresses some of the regional issues in the "proactive" manner that we think is necessary to provide long-term protection of herons.

CASE STUDIES

Butler (1995) has shown that disturbance plays a critical role in breeding success, and he has also demonstrated that winter foraging locations are important. We found no case study dealing with heron foraging grounds. Because herons do nest close to roads and houses, colony disturbance issues provide the best known cases. It is important to understand the historical context of the colony in relation to the existing houses and roads, as well as foraging locations. All of these components may play a role in the outcome of a disturbance. Heron colonies, especially smaller colonies located inland on fresh water, are very dynamic, and this makes protection difficult.

In Renton, an industrial park was planned along the Black River adjacent to a heron colony. A work order luckily prevented colony tree cutting, and the EIS stipulated the timing of the construction and distance of the buildings in relation to the colony. The project also created a vegetation buffer. However, before any of these recommendations could be enacted, eagles began to invade the colony on a regular basis, and the herons deserted the site.

On Whidbey Island, a landowner legally began the construction of a driveway to his house, but the operation of a small bulldozer under a colony caused the herons to desert the colony. Neighbors were outraged,

[1] Toxicology Task Force, 2112 NW 199th, Seattle, WA 98177

[2] Vashon-Maury Island Land Trust, Vashon Island, WA

but no laws were broken. The WDFW biologist effectively educated the landowner about restricting his activities to a period when the herons were not present in the colony. Unfortunately, the birds did not return the next year. At another colony on Whidbey, the owners of property adjacent to a small colony cleared trees right up next to the colony outside the nesting season, inside buffer limits. Neighbors were outraged and began legal proceedings. An appeal of the enforcement order was made, giving the Island County planning director the opportunity to set up an agreed order to establish a restoration plan with the help of a local biologist. The birds returned in 1994 and nested successfully.

In rural Snohomish County, a forest tract was planned for clearing with a heron colony nearby. The trees are cleared outside the nesting seasons, and a buffer is retained. The birds remain nesting at the colony, but move their nests away from the cleared area. On Camano Island, a subdivision planned near a large colony retained a woodlot buffer and placed houses as far away as possible from the colony.

Disturbance guidelines are difficult. The WDFW recommends a range from 250 meters for a year-round buffer at times of no activity to 1000 meters for a breeding season buffer (WDW 1991). There are certainly heron colonies that exist less than 100 meters away from houses and disturbance, because birds grow accustomed to the disturbances when it causes no direct threat. Herons nest at the rear of the Ault Field runway at the Whidbey Island Naval Air Station, along the launching ramp at Lake Sammamish State Park, and near freeways and highways. None of these vehicles ever directly threaten the birds; however, when individuals leave the vehicles near the colonies, the herons may be more sensitive than birds in colonies with people moving in the open farther away. It is easy to find examples from other colonies to support a position for strict or lax buffers. It is more important to address the larger issues of alternative nesting sites and foraging locations. This information is generally lacking in the case studies.

These site specific projects are typical and demonstrate that the current regulations are helpful in protecting nesting areas if notification is made to the landowner early in the planning phases. There are few cases where a requirement of follow-up monitoring was performed to assess the HMP outcome. None of the case studies address a more regional approach for the heron colony of concern.

THE MAURY ISLAND HABITAT MANAGEMENT PLAN

The Vashon Maury Island Land Trust bought the 15-acre Mileta Creek Refuge on Maury Island with $225,000 that had been raised for the purchase. A monitoring program was then started to protect the investment. The community also wanted the management plan to include an educational, stewardship, and volunteer component. A contract was signed to write a HMP for the heron colony with all of these components (VMILT, 1995). This plan included a description of the site, history, and status of the colony. Volunteers were trained to monitor productivity at the colony. Because five lots are within 820 feet of the colony, a letter was written to nearby landowners with information about disturbance issues. A key component of the plan is the use of volunteers. Activities such as the tagging of nesting trees during the winter, identification of foraging grounds, and monitoring of colony reproductive success brought volunteers together with biologists. The plan includes a slide show in January coupled with a winter visit to the colony, since it is not visible from a distance for safe viewing at other times of the year. More than 50 people attended the slide show, and 35 people visited the colony. Notification of neighbors prevented chain saw activity within 300-400 feet of the colony the week the herons returned. A map locating the nesting trees was made to assist volunteers monitoring the colony.

The 1994 nesting season, however, was a disaster. During the monitoring for productivity, it was discovered that the majority of the nests had been preyed upon, with evidence of crows on the eggshells on the ground under the colony. A few young did fledge, but the colony was empty for the final June productivity measurement. Local residents had noticed herons swirling above the colony, indicating a disturbance. Whether the birds will return this spring is unknown. Volunteers will guard the colony to ensure that no human interference was responsible. And if the birds do not return, an effort to locate the new nesting site, perhaps near the old Dockton site, will be made. (As of May 1995, no birds had returned.)

PROPOSED NEXT STEPS

The example of the heron colony on Maury Island is not atypical. Heron colonies move. In the future, there may not be adequate nesting sites or foraging locations. From the baseline information presented earlier (Norman, 1995), local monitoring groups need to be established at seven of the 10 largest colonies in western Washington, which contain an estimated 70 percent of the birds (Table 1). Only three of the 10 colonies—March Point, Maury Island and Nisqually—are specifically designated as protected, and yet all of these colonies still face disturbance from developments outside the protected areas. Three of the seven colonies evaluated for disturbance criteria are easily disturbed, indicating a potential for nest predation. Nest predation did occur at March Point in 1992. No alternative nesting sites have been identified for protection, and though many of these colonies probably have adequate winter foraging areas, none have been assessed and designated for such a purpose.

Table 1. Current status of major heron colonies in western Washington

Colony Name	Eagle impacts?	Disturbance criteria*	Land ownership	Local monitoring
Point Roberts	Yes	Low	Private	Yes
Birch Bay	Nest nearby	High	Private	No (DMN)
Samish Island	Yes	Medium	Private	No (DMN)
March Point	Nest in colony	High	Land trust	No (DMN)
Stanwood	Yes	Unknown	Private	No
Ault Field	Unknown	Medium	Navy	(Navy?)
Maury Island	Nest nearby	Low	County	Yes
Nisqually	Yes	High	FWS refuge	Yes
Woodard Bay	Nest nearby	Unknown	DNR land?	No
Squaxin Island	Unknown	Unknown	Tribal land	Unknown

** Disturbance criteria are based on heron response to humans during productivity monitoring. Low means little tendency for herons to flush while humans are in the colony. High means birds flush even before humans enter the colony.*

The original guidelines for the protection of herons were initiated to protect nesting colonies. To provide long-term protection of herons, summer and winter foraging locations need to be protected, and alternative nesting nests need to be located and protected. To date, no study to identify the wetland sites associated with the heron colonies has been completed. Both summer and winter feeding locations for each colony should be added to the current maps used by the Washington Department of Fish and Wildlife for monitoring the GMA. We also propose than an annual census of major heron colonies be included as part of the Puget Sound Ambient Monitoring Program (PSAMP).

Butler estimates there are more than 100 sites that have been used for nesting by herons in the Strait of Georgia, though only 35 are in current use. With at least 75 active heron colony sites in western Washington and at least an equal number of foraging sites and alternative nesting sites, there are more than 300 potential conflicts with development. The development of a local proactive approach of notifying landowners, educating local residents, and training volunteers for monitoring can be successful in integrating heron colonies into the local planning process. If we designate the 4,500 herons in western Washington as the current baseline, a proactive stance must be taken to prevent their decline in the future into a threatened status.

ACKNOWLEDGMENTS

This project has been funded by the Vashon Island Park District, the Vashon Maury Island Land Trust and the Audubon Society. Assistance from Ruth Milner and Greg Schirato at the WDFW and from Debbie Young is greatly appreciated.

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INTEGRATED COASTAL MANAGEMENT

Alan J. Mearns[1]

ABSTRACT

It is proposed that an integrated coastal management (ICM) process be implemented for Puget Sound. ICM, as proposed by a 1993 National Research Council committee, is defined and briefly described. Examples of overlooked, but dramatic, inconsistencies between pollution control and status and trends in contamination and resource status are presented to provoke consideration of the dynamic planning process that is at the heart of ICM. This process closes the gaps that continue to exist among research, monitoring and management action.

INTRODUCTION

In the opening statement of this conference Usha Varanasi asked how we can ensure that management heeds the results of research and monitoring. This paper provides a method: integrated coastal management (ICM). ICM is an ecologically based iterative process for identifying on a regional scale environmental objectives and cost-effective strategies for achieving them. It is an approach that moves away from the mandated technology-driven approaches of the recent past and toward an approach that manages by environmental objective. It provides a framework for explicitly incorporating research, monitoring, criteria development and waste load allocation into the waste-management decision process.

BACKGROUND AND ISSUES

Integrated coastal management is the product of the National Research Council (NRC) Committee on Wastewater Management in Urban Coastal Areas. The committee of 14 professional coastal scientists, engineers and managers focused its attention on the future management of domestic and industrial wastewaters, combined sewer overflows and storm runoff. Between 1990 and 1993 the committee and its sub-committees met on numerous occasions across the United States, consulted with more than 150 scientists, engineers, public officials, regulators and citizens, and visited various facilities.

The committee then identified eight main issues of concern in managing coastal environmental quality in urban areas:

Regional Differences

Variations in assimilative capacity (e.g., Curl, 1988) have been ignored by a technology-driven (treatment mandated) approach with the result that protection is failing in some areas but is excessive and unnecessary in others.

Nutrient Overload

Eutrophication, especially in coastal waters and estuaries of the northeast United States, has not and will not been solved by mandated treatment technologies.

Source Control

Even where implemented many years ago, source control has been ignored as a cost-effective tool that in many cases has already eliminated the need for expensive treatment plants.

Water Conservation

As a corollary objective to wastewater management, water conservation has been integrated into wastewater management decision processes, particularly as technology-driven wastewater treatment approaches over-emphasize effluent concentration-based criteria (including toxicity) and ignore the alternative mass-emission and waste load allocation approaches, which can save water.

[1] Biological Assessment Team, Hazardous Materials Response and Assessment Division, National Oceanic and Atmospheric Administration, Seattle, WA 98115

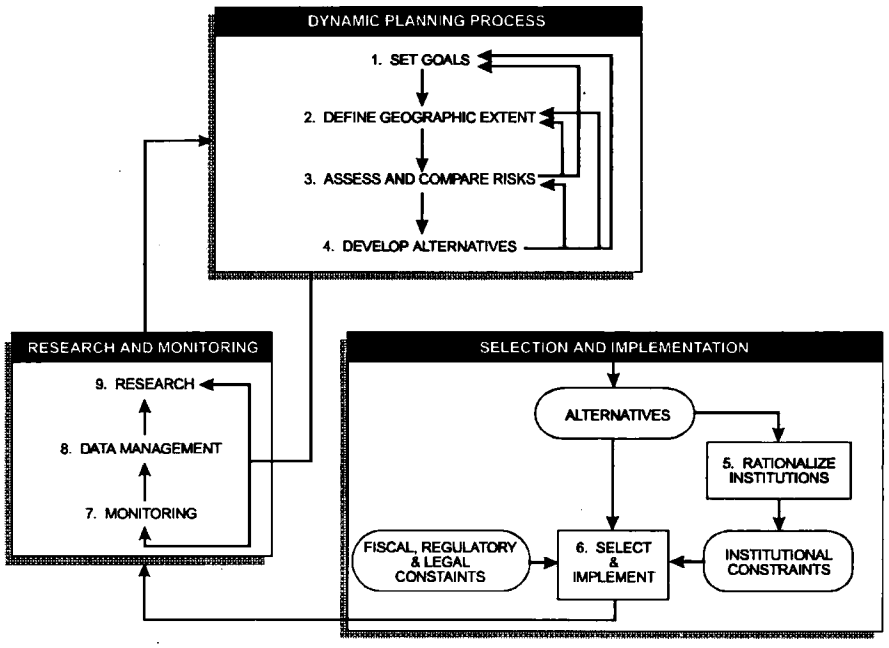

Figure 1. The three processes of Integrated Coastal Management (NRC, 1993)

Level of Treatment

Treatment systems are being implemented not only without regard to environmental need but in spite of it.

Stormwater and Combined Sewer Overflows (CSOs)

Now recognized as of greater concern than even minimally treated sewage effluents, the non-point sources have been ignored or given only nodding concern. Now their control is being mandated by a plethora of poorly tested so-called "best management practices."

Human Pathogens

They continue to be ignored as the actual cause of public health risk. Meanwhile, shellfish beds and beaches continued to be closed based on coliform concentrations or, in many cases, no measurements at all.

Inflexible Management

Actions and criteria get "set in stone," and there is resistance to making changes based on new information. There are few opportunities to revisit issues or change the course of actions or criteria to accommodate new information. Success is measured more by progress in implementation than by improvements (or even impacts) on environmental quality.

Based on the most available recent data, the committee also concluded that:

(1) Not all contaminants are of equal concern. Least important but most regulated are BOD and suspended solids. Metals are non-problems except in a few localized areas. Pathogens, certain synthetic organic chemicals and PAHs are the contaminants of most concern.

(2) Where they were once high, contaminant concentrations in sediments and marine life have been decreasing for many years due primarily to effective source control actions.

(3) Our ability to monitor, measure and identify pollution problems and impacts is now sufficiently advanced to support an environmental-quality approach to management. That was not the case 20 years ago.

WHAT IS INTEGRATED COASTAL MANAGEMENT?

The committee addressed these issues and observations by proposing a new approach to coastal management, ICM. ICM is a three-part process, which should be implemented incrementally and on a continuing basis: (1) dynamic planning, (2) selection and implementation and (3) research and monitoring (Figure 1). Each of these processes is described below and in considerably more detail in NRC (1993).

Dynamic Planning

The dynamic planning process leads to priority setting and involves clear definition of the regional scales of concern, the environmental goals to be achieved, assessment and comparison of the actual and perceived risks and development of alternative management actions. Dynamic planning results in two products: (1) a set of management alternatives to be considered for selection and implementation and (2) an agenda for research and monitoring that is needed to improve understanding and provide feedback on how well the selected management actions are working.

Selection and Implementation

It is within the selection and implementation process that alternative management actions are weighed and prioritized with respect to the environmental goals and objectives and the fiscal, regulatory, legal and institutional constraints. Costs and benefits are weighed across all issues, not by each in isolation of the others. The product of this process is the selection and implementation of one or a few alternative actions for each issue.

Research and Monitoring

The research and monitoring process drives the system into the future. Actions are implemented together with environmental monitoring to document effectiveness and research to resolve remaining uncertainties. Additional region-wide monitoring is implemented to document effectiveness at larger scales and to avoid surprises. The research and monitoring effort brings the new information back into the dynamic planning process, where the results are hotly debated and alternative mid-course corrective actions proposed and evaluated. The research and monitoring process also leads to the development of new operational methods and techniques for measuring the effectiveness of ecological and public health actions and for bringing new uncertainties into focus. ICM mandates that the managers call the researchers back to the table and that the researchers respond.

ICM is not unique. Its intent has appeared before as "adaptive management," "dynamic comparative risk assessment" and "area-wide planning studies" (mandated under section 208 of the Clean Water Act). ICM differs from these past efforts in several ways: (1) It is carried out by agencies that have many, not just a few, water quality responsibilities; (2) it confronts the permitting and facilities-planning process, which in the past happened so rapidly that it could not be influenced by any planning process; and (3) it requires closing the gaps among research, monitoring and planning.

How ICM Works From the Research and Monitoring Point of View

Dynamic planning is at the heart of ICM. Unlike previous regional approaches where management and technical advisory committees operate separately (such as in the National Estuary Program), ICM requires public representatives, lawmakers, scientists, and engineers to sit at the same table to develop and evaluate management alternatives on a continuing basis. Environmental goals are periodically reviewed and revised as understanding of issues, resources at risk, geographic scales of concern, contaminant trends, human expectations and economic realities change from year to year.

From a scientist's perspective, the key to effective dynamic planning is management action that is responsive to the research and monitoring. This means that scientists should be reporting directly to managers about the local and regional effects of specific implemented actions and about the uncertainties that remain to be resolved. From the manager's perspective, the key is commissioning research and environmental monitoring activities that will provide direct measures of the effectiveness of specific actions and resolve existing uncertainties. Therefore, an effective dynamic planning process is one where there is a continuing interplay

between scientific information and management action. The research results are presented not only in a conference forum (such as this) but more importantly in front of the environmental managers during the actual decision and evaluation process.

Impact of ICM and the NRC report

Since publication in spring 1993, the NRC report has been widely distributed in the United States and the world. It is apparently having an impact. For example, it is currently a textbook at the U.S. Naval Academy. In 1993-94 the Sydney, Australia, Water Board was among the first public agencies to implement the ICM process through a region-wide comparative risk assessment of 17 wastewater treatment alternatives (Parametrix, 1993). This assessment identified the most effective options for reducing risk to marine life and public health from sewage plants, combined sewer overflows and storm drains. In San Diego, a U.S. federal court used and cited the report in a decision that allows the City of San Diego to divert attention from mandated secondary treatment, evaluate the effectiveness of a new deep-water municipal wastewater outfall and focus planning on the primary regional issue: water reclamation (Mearns, 1994). The Technical Advisory Committee of the Santa Monica Bay Restoration Program, an EPA National Estuary Program (NEP), is using the report to help focus research and monitoring on determining the effectiveness of CCMP Action Plans and to move technical advisory capabilities directly into the policy and decision process. Finally, Canadian public agencies are using the report to support efforts to evaluate wastewater treatment options and priorities in British Columbia.

APPLICATIONS TO PUGET SOUND

After reviewing information from this and the last two Puget Sound Research conferences, numerous articles and stories in the press and information about the state of the Sound and the progress of management actions, the author is of the opinion that parts of ICM are in place in Puget Sound. What is apparently missing is a dynamic feedback at both the local and regional level. For example, it is not clear that there is any management mandate to heed the findings presented at these Puget Sound research conferences, to follow up each relevant finding with a review of the effectiveness and effects of various management actions.

To underscore the potential impact of ICM on Puget Sound, I elected to explore several of many possible scenarios. These focus on the kind of interplay that should go on between research, monitoring and management in an ICM Dynamic Planning process.

Sewage Treatment

All sewage discharges to Puget Sound are being converted to secondary treatment at a public cost of several billion dollars. The new construction and operation was required under state interpretation of national laws. The working assumption has been that primary treatment does not adequately protect marine resources and public health. Presumably secondary treatment will be protecting environmental and public health.

Is secondary treatment offering increased protection? Unfortunately, there are no environmental monitoring programs directed at evaluating the ecological and human health effectiveness of secondary treatment. Current law requires that shellfish beds in proximity to sewage outfalls remain closed, without monitoring, regardless of the level of treatment. So short of some policy change, that situation will remain regardless of actual risk. Effluent composition and toxicity testing is done, but the results are not widely known, including to the participants of this conference. The only monitoring apparent to the public is periodic reporting of the implementation process itself: Who has built plants and who hasn't? (Anon., 1994). The Puget Sound Ambient Monitoring Program (PSAMP) does not monitor sites specifically designated to clearly document the effectiveness and effects of the conversion. This also means that there are no clear measures of the effectiveness of other actions such as source control (including household chemical programs). When PSAMP reports positive changes on a regional basis, how will we know what the effective action was?

This situation may be tolerable at present, but what about in the future when waste flows will increase? Should secondary treatment capability increase as well? Or are there other control and treatment alternatives that should be considered?

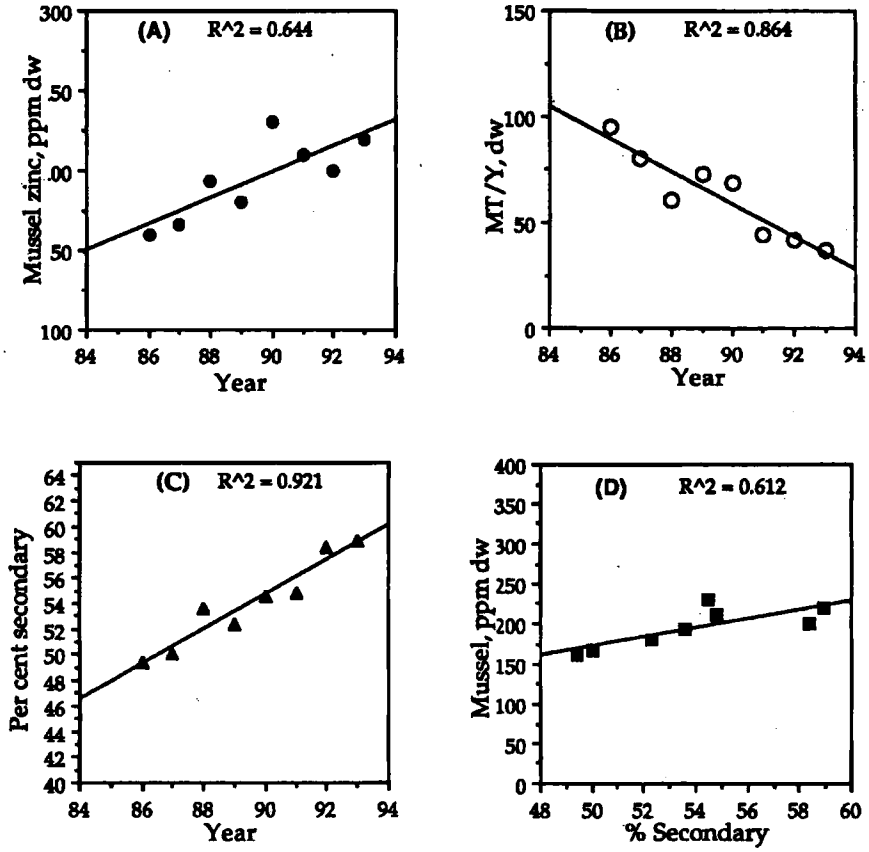

Figure 2. Trends in zinc at the Los Angeles County outfall, 1986-93. (A) Concentration (ppm dw) in mussels (Mytilus californianus), (B) Mass emission rate (metric tons per year) in final effluent, (C) Percent of effluent receiving secondary treatment, and (D) correlation between zinc concentration in mussels and percent secondary treatment. Zinc has been decreasing in mussels at remote (reference) sites. Effluent data from Southern California Coastal Water Research Project Annual reports, 1987-93. Mussel data from NOAA NS&T Program, Silver Spring, Md.

In the absence of secondary-treatment effectiveness information from Puget Sound, I explored information from elsewhere where both monitoring and research is being conducted at sites experiencing conversion to secondary treatment. From site-specific monitoring data I was surprised to discover that at the Los Angeles County Whites Point outfall concentrations of metals have not only not been decreasing in shellfish (mussels) but several metals (zinc, chromium, cadmium) have been increasing as secondary treatment facilities have been coming on line (Figure 2). This increased contamination is occurring despite the fact that bulk metal loads in the effluent have been decreasing as a result of effective source control. Metal contamination of sediment is decreasing, as it should with reduced bulk input. But not the shellfish. After seeking research data, a possible explanation for this situation became apparent: while reducing bulk-load (solid-bound) metals, past studies revealed that secondary treatment actually may increase concentrations (and therefore mass inputs) of some dissolved metals (Chen and Hendricks, 1974), the form most amenable to tissue contamination.

Curious, I returned to Puget Sound, knowing that many discharges have already converted and there is, at least on a regional level, data on metals in shellfish. Using the NOAA National Status and Trends mussel watch data, I discovered that during the past decade, levels of zinc have been increasing in mussels from Commencement Bay, Elliot Bay and Sinclair Inlet whereas levels have remained unchanged or decreased slightly in southern Puget Sound and at Possession Point, Whidbey Island. These trends have been occur-

ring during a period of great reduction in inputs and increased implementation of secondary treatment. Could this increased metal contamination be due to the increasing conversion to secondary treatment at plants in Tacoma, Bremerton and Seattle?

These observations do not prove secondary treatment is unleashing biologically available metals into Puget Sound. That must be tested with focused research. However, this situation does clearly focus on a need to evaluate the effectiveness of secondary treatment in protecting against metal accumulation in marine life. If it is not only having no beneficial effect, but also possibly a detrimental one, shouldn't we stop and evaluate this action? That is exactly what the dynamic planning process is designed to prompt us to do.

Use of Models

Dynamic planning urges that we evaluate and compare the effectiveness of alternative actions before choosing one. The NRC Committee noted that the "Puget Sound model" (see Cokelet, this volume) is in one of the most effective planning tools available for any region of the United States. However, after reviewing many documents, I am forced to conclude that the model has not been and is not being used to evaluate potential regional effectiveness of management options such CSO capping, stormwater discharges, treatment facilities or even source control. Paulson et al. (1993) convincingly demonstrated the predictability of the model for copper, yet it is nowhere obvious that this is leading to an evaluation of alternate action plans, if indeed any are needed.

Under a dynamic planning approach, there are numerous other kinds of mathematical, physical, statistical and risk-assessment models and strategies that could be used to evaluate and prioritize management options. For example, Mearns and Word (1982) provided a statistical model of the effectiveness of suspended solids controls on the abundance and size of benthic communities affected by treated sewage. The model is actively used in California to evaluate treatment alternatives and has also been used to evaluate CSOs in San Francisco Bay. I applied the model to a controversial Victoria (British Columbia) outfall and predicted that the scale of changes of the benthic infauna is on the order of two soccer fields (testimony presented to the Washington/B.C. Task Force). This result is consistent with actual monitoring data (see Taylor, this volume). This alteration is smaller by several orders of magnitude than changes that may accrue to benthos surrounding METRO's West Point outfall once full secondary treatment is implemented. Neither condition is ecologically significant, and both are reversible. But it seems ludicrous to focus so much public attention on such a small impact relative to the other issues that we face in the region. An effective dynamic planning process would allow for such comparisons and stimulate the use of the tools necessary to make them.

Sources

As actions are implemented the importance of various pollutant sources changes. That is reason enough to periodically review and compare sources in terms of mass inputs. But where do we find such information? With a few single-source exceptions, no comprehensive pollutant mass input data has been presented in any of the Puget Sound Research conferences. Is that because it is not being monitored or simply because it is not presented? How can we measure success and compare risks without it? Can we assume the decreasing sediment contamination reported in this and previous conferences (i.e., Crecelius, this volume; and Crecelius and Curl, 1988) is a measure of decreasing mass inputs and therefore of increasing success? If so, what are the most important actions that have led to this? If not, why not (note the discussion on mussel contamination, above)?

Are there sources we have yet to reckon with, such as the copper from the Skagit reported by Paulson et al. (1993)? Or perhaps arsenic and other metals from Tacoma slag used to fill the caissons that anchor the "new" Hood Canal Bridge (Carson, 1982)? My calculations indicate that at least 174 metric tons of arsenic and 160 metric tons of antimony accompanied the slag that was transported from Tacoma to Hood Canal in the early 1980s. Dynamic planning forces us to revisit and compare sources.

Measures of Effectiveness

If pollution was damaging the abundance and proclivity of marine life in Puget Sound, then one might expect healthier, more abundant populations as pollution declines. Why then is just the opposite taking

place? Why are fish populations declining (Bargmann, 1988) and toxic algal blooms increasing (Horner, this volume) as contamination (generally) has been decreasing (Crecelius and Curl, 1988; and Crecelius, this volume)? Why would resident marine fish populations be more abundant in the past (1950s and 1960s) when the Sound was considerably more polluted, than now, when it is considerably less? Is the incidence of liver lesions increasing or decreasing, and why don't we know the answer? Alternatively, why has the abundance, diversity and biomass of infauna in the Puget Sound Main Basin been increasing (Nichols, 1988) in the face of decreasing pollution? Are we controlling the wrong "pollutants"? Or are there other explanations such as overfishing, or even large-scale ecological interactions between growing populations of piscivorous pinnipeds (Calambokidis et al., 1988), the declining abundance of infaunal-feeding bottom-fish and the increased abundance of the infauna itself? Sooner or later, the public, lawmakers and managers who have invested considerable funds and energy into reducing pollution are going to discover these puzzling trends and ask why things are not getting better. Dynamic planning, involving continuing feedback and assessment of the monitoring and research information, would raise these subjects long before they become issues, and seek to resolve them.

CONCLUSION AND RECOMMENDATIONS

The intent of Integrated Coastal Management, as presented by the NRC Committee on Wastewater Management for Coastal Urban Areas, is, among other things, to close the loop between research, monitoring and management. There is now a large body of provocative and important information about the status, trends and health of Puget Sound from which it may be possible to evaluate the effectiveness and effects of management actions. There is also, unfortunately, a dearth of information about trends in pollution inputs from which to judge the efficacy of the actions.

It is good that so much information is presented at this conference. However, it is critical that this information be used. I strongly urge regulatory and oversight agencies to adopt at least the concept of Integrated Coastal Management for the immediate purpose of evaluating the effectiveness and potential hazards of already-implemented management actions and for the longer-range purpose of directing research and monitoring to more clearly document the effectiveness of new or revised actions. In so doing, the public, lawmakers, managers and the scientific community will be well served at reasonable cost to all.

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INTEGRATED SOLUTIONS FOR PROTECTING WATER RESOURCES ON THE TULALIP INDIAN RESERVATION: A WATERSHED-BASED MANAGEMENT PLAN

Patty Lynch[1], Gillian Mittelstaedt[2] and Julia Gold[2]

INTRODUCTION

The Tulalip Tribes are taking an integrated, comprehensive approach to protecting the quality of water resources on reservation lands. While the tribes have long been involved as leaders in instituting protection measures to preserve fishery habitat throughout the Puget Sound basin, they are now facing increasing urban growth pressures on their reservation. The tribes are subsequently taking a proactive approach to institute environmental protection measures and to preserve the integrity of the reservation's water resources.

The system for managing these resources is dependent on a web of several programs either currently under development or in the initial phases of implementation. These programs will ultimately provide protection for water quality, fish and wildlife habitat, aquifer recharge areas, sensitive areas, and cultural resources. This paper focuses on the development of a watershed-based management plan that integrates many of these programs, and that stands alone by fulfilling several roles—part non-point pollution protection plan, part basin plan, and part wetlands protection plan. This paper will examine key findings of the research, identify limitations of the planning process, and offer recommendations for successful completion of similar projects by other tribal governments or jurisdictions faced with large tasks on small budgets.

ON-RESERVATION ENVIRONMENTAL ISSUES

The Tulalip Indian Reservation is located near the geographic center of the eastern shore of Puget Sound in Snohomish County, Washington. Of the 7,000-plus residents who live on the reservation, roughly 5,000 are non-Indian, while just over 2,000 are Indian. The reservation's land base is about 35 square miles, most of which has historically been characterized by agricultural, forestry, and rural residential land use. The character of the reservation reflects the tribes' once heavy, though gradually diminishing, dependence on fisheries and forestry resources. However, as the tribes continue to diversify their economic base through business and industrial development, commercial, industrial, and higher-density residential land use activities are increasing on reservation lands. The sustainability of Tulalip's natural resources and the rural character of the interior of the reservation is under increasing pressure because of these economic interests and the need to provide housing for a growing population of residents. Thus, the tribes have recognized that they too are faced with the challenging task of balancing urban growth on reservation lands with environmental protection measures for treaty-protected water resources.

Surface water is an integral resource for the Tulalip Tribes, supporting fish hatchery operations, serving as a mainstay of the tribal economy, and providing many recreational and cultural uses. Several programmatic efforts are under way that are designed to address the reservation's water-related issues in a comprehensive and coordinated fashion. These efforts include the development of regulations, administrative procedures, education outreach and data collection programs. Combined, these efforts represent a holistic approach to the issue of water pollution and depletion. For example, in addition to managing a state-certified water quality laboratory and an ambient water quality monitoring program, the Tulalip Natural Resource Division staff have recently completed a wellhead protection program and are currently drafting tribal water quality standards. The tribes have been progressive with their standards program in that they recently completed one of the first tribal fish consumption surveys. Data from the survey will result in a more accurate assessment of human health risks from exposure to bioaccumulative and persistent compounds. Other developments empowering the tribes to take an active role in managing their surface water resources include the recent adoption of a Comprehensive Land Use Plan (Tulalip Tribes, 1994), which calls for the protection,

[1] Washington Department of Transportation, P.O. Box 47331, Olympia, WA 98504; formerly planner with Tulalip Tribes

[2] Tulalip Tribes, Environmental Department, 7615 Totem Beach Rd., Marysville, WA 98271

conservation and enhancement of the reservation's fresh water resources, groundwater, and marine waters.

Yet as the tribes initiated these programs, they recognized areas of deficiency in their program to protect the reservation's surface water resources. A primary concern was the absence of a thorough understanding of the reservation's wetland systems. A secondary concern was the desire to integrate land use planning activities more closely with environmental protection efforts. The third area of concern was the need to incorporate a watershed approach into existing resource protection programs governing reservation resources. To address these problems, the tribes sought funding from the Environmental Protection Agency (Clean Water Act 104(b)) to develop a watershed-based protection plan that addresses these deficiencies and provides long-term guidance for water resource protection issues.

ELEMENTS OF THE MANAGEMENT PLAN

The watershed boundaries served as the basic planning units for development of protection policies for Tulalip Reservation. The bulk of the reservation's land base is contained in three distinct watersheds: Tulalip Creek, Battle Creek and Quilceda Creek. Two smaller watersheds, Spee-Bi-Dah and White Rock, are comprised of numerous smaller sub-basins, which were grouped together for planning purposes. Battle Creek, Spee-Bi-Dah and White Rock are the only watersheds to be contained entirely within the reservation boundaries.

Development of policy recommendations in the management plan are based on a technical foundation that includes a wetland inventory, the use of GIS, an assessment of wetland functions and values, the application of stormwater runoff models to define water quality/quantity problems in developing sub-basins, the use of hydrology models to estimate wetland water level fluctuations (WLF) from basin development, land use inventories, and the development of a wetland classification and ranking system for implementation of regulatory measures. Also key to development of the plan was the desire to incorporate public participation into the planning process. A citizen advisory committee and a technical advisory committee were established early in the planning process to help with the assessment of basin conditions and the development of management recommendations.

While the plan does not undergo formal adoption procedures by the Tulalip Board of Directors, the tribes will refer to the plan when responding to development proposals potentially affecting the surface water resources, when preparing grant proposals for future projects affecting the surface water resources, when developing ordinances or other measures to provide protection for the surface water resources, and when reviewing other plans and policies that affect the surface water resources.

Wetlands

One of the primary objectives of the management plan was to develop a greater understanding of the extent, location and function of the wetland systems. A wetland inventory was completed using the 1989 Federal Manual for Identifying and Delineating Jurisdictional Wetlands. The inventoried wetlands were then categorized by plant community type as defined by Cowardin et al. (1979) and digitized on a geographic information system (GIS).

Using GIS, several pieces of information relating wetland acreage to land use activity within each basin and within the reservation as a whole were characterized. The analysis revealed that approximately 20 percent of the reservation may be considered wetland, and that approximately 23 percent of tribal-owned land is wetland versus 13 percent of reservation land in fee status. Given that approximately 55 percent of the reservation is not Indian-owned, the amount of land suitable for development for tribal interests is less than one quarter of the total land base when ownership and wetland protection issues are accounted for. The implications of the data are that the reservation is abundantly rich in wetland resources, but that in order to achieve a goal of "no net loss," development would have to proceed cautiously, and that both regulatory and non-regulatory wetland protection measures would have to be developed and implemented to prevent loss of wetland acreage and functional values.

Additional work was completed to determine how certain wetland systems may be functioning within a basin. A "Wetlands Characterization Method" (Granger, 1993) was chosen as a planning tool to provide a

general characterization of wetland functions and values in each of the five basins. The characterization method provided guidance for interpreting inventory information to determine whether there is a higher, medium, or lower probability that a wetland is performing certain functions. Information derived from the characterization work helped planning staff identify wetlands that support certain functions and determine how the various wetlands function within their respective watersheds. The assessment methodology was coordinated with planners from Snohomish County who were involved in collection of wetland data for development of a non-point action plan for Quilceda-Allen basin. Data gathered in the Quilceda basin were shared between the tribes and the county.

Wetlands were also categorized using a three-tier system developed by the technical advisory committee (TAC) for the purpose of identifying performance-based buffer requirements. The participants of the TAC included natural resource managers (forestry, fish hatchery, stream ecology, and shellfish biology) and planners (water quality, watershed, and land use). The committee developed the criteria for the wetland categories and assigned ranking values (critical, high, or moderate) to the systems. While the criteria for wetland ranking and buffer requirements followed state models, the TAC customized the criteria and buffer requirements to reflect the unique values of the tribes' culture and to adequately protect the resources. Recommendations for wetland and stream buffers and a variance process to allow flexibility in administering the proposed requirements were incorporated directly into the Tulalip zoning ordinance as part of the environmentally sensitive lands protection measures. The zoning ordinance was adopted by the Tulalip Board of Directors within six months of the protection measures proposal.

Stormwater and Non-point Pollution Assessment

The basins on the Tulalip Reservation differ with respect to surface water traits, development levels, and current and potential problems resulting from non-point pollution. An assessment of existing and potential non-point pollution problems was completed for each basin. Results indicated that in the majority of the basins rural development, agricultural practices, failing septic systems, and encroachment into wetland buffers posed significant threats to the integrity of the surface water resources. However, other problems more characteristic of urbanized areas were identified in Quilceda basin. The amount of proposed commercial and economic development in the basin is high because of its proximity to Interstate 5 and other urban centers. This presented a host of additional problems that had to be considered for this portion of the reservation.

Predictive models were applied in different basins to examine impacts from two types of development concerns on reservation lands: (1) increasing levels of commercial and industrial urbanization in a developing watershed (Quilceda), and (2) cumulative effects of increasing levels of single family residential housing development in a rural watershed (Battle Creek). In Quilceda basin, hydrologic and water quality models[3] were used to assess the potential impacts of proposed high-density urbanization on the Quilceda Creek system. These data were used to make recommendations for development of a stormwater management program, to provide specific recommendations for water quality retention/treatment and to identify appropriate best management practices within the study area. A model used to estimate wetland hydroperiod characteristics from wetland and watershed characteristics was used to assess the potential impacts of rural development on a wetland system in Battle Creek basin.[4] Data from the model were a major consideration in making recommendations for reducing the allowable density of residential development in some areas of the basin in order to provide adequate protection for the wetland system.

[3] Storm runoff was estimated using the Santa Barbara Urban Hydrograph (SBUH) methodology. The King County HYDRO software provided a module to generate a SBUH using pervious and impervious area, pervious and impervious curve numbers, and time of concentration as input parameters. Pollutant loadings were estimated using two methods: (1) the unit loading method and (2) USGS regression models (Driver and Tasker, 1990).

[4] Taylor (1993) developed models that related wetland and watershed characteristics to wetland water level fluctuations (WLF). Taylor's research was completed for the Puget Sound Wetlands and Stormwater Management Research Program.

Environmental Education and Outreach

A major objective of the plan was to identify, develop, and promote educational programs to assist local residents with understanding watershed protection issues and to institute stewardship opportunities. Recommendations presented in the plan are designed to prevent the degradation of aquatic resources by (1) increasing the public's awareness of the ecological and economic values of healthy wetlands and good water quality, and (2) assuring that local residents and business owners understand how their daily activities may positively or negatively affect the quality of the reservation's water resources.

The management plan proposes that these goals be accomplished by developing a public education program that conveys watershed-related information to the citizens, that works cooperatively with local schools on reservation to develop environmental curriculums that address the relationship of Native American culture to watershed protection issues, and that ensures environmental education opportunities are incorporated into other existing programs. During development of the management plan, Tulalip Natural Resource Division staff began working with teachers at Tulalip Elementary by conducting wetland field trips and by assisting with class projects focusing on watershed-related issues. It is the opinion of the authors that long-term implementation of the educational outreach should be provided through institution of a watershed coordinator position.

LESSONS LEARNED

The management plan was developed with minimal resources and within a relatively short time frame.[5] While the plan may not have undergone the intense scrutiny characteristic of a basin plan or non-point action plan under WAC 400-12 guidelines, its benefit and contribution to the long-term management of Tulalip's surface water resources should not be discounted. A great deal of information about the Tulalip's surface water resources was gathered and evaluated in a watershed context. A wetland inventory and assessment of wetland function and values was completed. Existing and potential sources of non-point source pollution were identified, and recommendations for protection measures were made based on the data collected. In addition to proposing non-regulatory approaches to protecting wetlands and surface water resources, the plan also lays the foundation for building the regulatory infrastructure necessary for protecting environmentally sensitive areas. Regulations for wetland and stream buffer requirements were developed and will be implemented through the zoning ordinance, demonstrating that one of the greatest benefits of the plan is that it provides the link between the tribes' Natural Resources Division, where the need for protection is identified, and the Community Development Department, where the rules are implemented through project approval or denial and enforcement action.

The management plan also provides tribal managers with a valuable reference to help establish priorities for future projects. For example, proposals for performing watershed analysis within reservation basins are being examined to fine-tune some of the analysis performed for the management plan. The plan serves to integrate many of the environmental programs that are already under development by presenting the big picture and by serving as a reference to tie together a number of grant proposals for water quality protection, groundwater protection, wildlife habitat protection, wetlands protection, and watershed analysis. In an environment where continuity among environmental staff is difficult to maintain because the reliance on grant funding support is so high, the plan can help ensure that priorities remain focused despite frequent personnel transitions.

RECOMMENDATIONS

There were several goals that were difficult to meet given the time constraints and funding limitations of the project proposal. Because the project was funded for less than one year, involving the public in each step of the planning process proved to be extremely difficult. A citizens advisory committee was formed

[5] Funding support for the management plan totaled $75,000 from 104(b) funds and $25,000 in match funds from the tribe. Primary project personnel included one watershed planner (75 percent time), one watershed biologist (50 percent time), and one land use planner (25 percent time). The project was funded for one year.

early on and involved in various aspects of the plan development. However, given the project's tight schedule and ambitious goals for data collection and analysis, it was difficult to actively involve local residents with all phases of the project. Much of the staff's time with the public was spent educating residents about watershed issues, not developing recommendations to problems. Sufficient time must be allowed if citizens are going to actively participate in developing solutions to complex problems. Most of the problem solving for this management plan was left to the planning staff and members of the Technical Advisory Committee. Agencies funding similar types of management plans should also consider extending project schedules to provide neighboring governments and jurisdictions an opportunity to comment on management plan recommendations.

Long-term success of the management plan depends on the tribes' ability to implement the recommendations. Key to implementation is the dedication of staff to initiate and oversee these efforts. Staff must have the time to pursue funding for new programs, to evaluate and edit the management plan as social, economic, and environmental conditions change over time, and to account for many of the smaller watershed steward duties identified in the management plan. Tulalip has secured funding for a watershed coordinator to ensure these objectives are met. For other governments initiating similar management plans, funding agencies can contribute to the success of new plans by supporting staff dedicated to stewardship roles.

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LABORATORIES AND FIELD STATIONS OF THE INLAND MARINE WATERS OF WASHINGTON AND BRITISH COLUMBIA

John W. Armstrong[1] and Kali Rembold[2]

INTRODUCTION

While one gets the sense that there are numerous aquaria, aquaculture facilities, marine laboratories and field stations (hereafter collectively referred to as labs or field stations) on the inland marine waters of Washington and British Columbia, finding the names and locations of all of these labs is not an easy task. With the ever-growing interest in our inland marine waters, we decided to prepare a list of the regional labs along with their primary functions, equipment and facilities available. This information should be useful to anyone interested in marine biology or water quality-related research, education, monitoring, volunteer activities or environmental conditions in Puget Sound, the Strait of Juan de Fuca or the Strait of Georgia.

APPROACH

We attempted to determine the names and addresses of all field stations dealing with marine biology (broadly defined to include work involving fish, birds, marine mammals, and so on) or water quality in the inland marine waters of Washington and British Columbia. We developed our initial list of labs through personal knowledge, phone calls to some labs, and the use of various directories. We then asked each lab to complete a brief survey about their primary functions, activities and facilities. Each lab was also asked to note its location on a map and to provide us with the names of any labs that were not on the preliminary list of labs we provided to them. As expected, a number of follow-up phone calls and mailings were necessary to gather the information on all the labs. Of the 50 labs we contacted, 37 indicated that they dealt with some aspect of marine biology or water quality.

We decided to include only non-profit labs in our survey. These were labs we felt might share information and make space available to those wishing to do research at or near the facility. We have included tribal labs in Washington that do, or currently have the capability to do, marine biology or marine water quality work. Non-tribal aquaculture labs, hatcheries dealing strictly with freshwater parameters, consulting firms and industrial facilities with labs have not been included.

RESULTS

The names, addresses and phone numbers of the 37 labs we identified from the inland marine waters of Washington (24 labs) and British Columbia (13 labs) are provided in Table 1. These names and addresses are followed by codes (explained in Table 2) that provide specific information about each lab.

Table 1. Marine laboratories and field stations in Puget Sound, the Strait of Juan de Fuca and the Strait of Georgia

Washington:

1. **Battelle/Marine Sciences Laboratory**
   1529 West Sequim Bay Road
   Sequim, Washington 98382
   (206) 683-4151
   C,H,R,O,RS,B,M,PM,NS(79)

2. **Center for Whale Research**
   1359 Smugglers Bay Cove Road
   Friday Harbor, Washington 98250
   (206) 378-5835
   R,O,PM,NS(2)

3. **Thomas B. Crowley Laboratory**
   Biology Department, Seattle Pacific University
   Seattle, Washington 98119
   (206) 281-2200
   C,H,R,S,RA,B,NS(7)

4. **Diru Creek Hatchery**
   Puyallup Tribe Fisheries Management Division
   6824 Pioneer Way East
   Puyallup, Washington 98371
   (206) 593-0254

[1] Environmental Protection Agency, Region 10, WD-139, 1200 Sixth Ave., Seattle, WA 98101

[2] University of Washington, Seattle, WA. Mailing address: 7215 NW Penridge Rd., Portland, OR 97229

5. **Arthur D. Feiro Marine Laboratory**
C/O Peninsula College
1502 East Lauridsen Blvd.
Port Angeles, Washington 98362
(206) 452-9277
C,H,S,NS(3)

6. **Friday Harbor Laboratory**
University of Washington
620 University Road
Friday Harbor, Washington 98250
(206) 378-2165
H,R,O,RA,RS,B,SQ,PS,NS(18)

7. **Lower Elwha Fish Hatchery**
Lower Elwha S'Klallam Tribe
2997 Lower Elwha Rd.
Port Angeles, Washington 98363
(206) 457-4012
T,R,O,RA,M,PS,NS(18)

8. **Lummi Tribal Fisheries**
2616 Kwina Road
Bellingham, Washington 98226
(206) 738-2316
T,R,O,RA,RS,B,M,PM,PS,NS(4)

9. **Marrowstone Field Station**
National Biological Survey
616 Marrowstone Point Road
Nordland, Washington 98358
(206) 385-1007
R,O,RA,RS,B,SQ,NS(4)

10. **Manchester Environmental Laboratory**
Environmental Protection Agency, Region 10
Washington Department of Ecology
7411 Beach Drive East
Port Orchard, Washington 98366
(206) 871-8700
R,O,RS,B,M,NS(22)

11. **Manchester Field Station**
National Marine Fisheries Service
Box 130
Manchester, Washington 98353
(206) 553-0633
R,O,RA,RS,B,M,NS(23)

12. **Mukilteo Field Station**
National Marine Fisheries Service
10 Park Avenue, Bldg. B
Mukilteo, Washington 98275
(206) 743-3307
R,O,RA,RS,M,PM,NS(12)

13. **Marine Science Center of Poulsbo**
P.O. Box 2079
Poulsbo, Washington 98370
(206) 779-5549
C,H,O,RA,RS,B,M,PS,NS(11)

14. **Nisqually Reach Nature Center**
4949 D'Milluhr Road Northeast
Olympia, Washington 98516
(206) 459-0387
C,O,NS(0)

15. **Padilla Bay National Estuarine Research Reserve**
1043 Bayview-Edison Road
Mount Vernon, Washington 98273
(206) 428-1558
C,R,O,RA,B,SQ,M,PS,NS(14)

16. **Point Whitney Shellfish Laboratory**
Washington Department of Fish and Wildlife
1000 Point Whitney Road
Brinnon, Washington 98320
(206) 796-4601
C,R,S,RA,M,PM,PS,NS(34)

17. **Port Townsend Marine Science Center**
532 Battery Way
Port Townsend, Washington 98368
(206) 385-5582
C,H,S,RA,RS,B,M,PS,NS(5)

18. **Sea-Tac Occupational Skills Center**
18010 8th Ave. S.
Seattle, Washington 98148
(206) 433-2107
H,O,RA,RS,B,NS(1)

19. **Seattle Aquarium**
Pier 59
Seattle, Washington 98101
(206) 386-4332
C,R,O,RA,RS,M,NS(55)

20. **Shannon Point Marine Center**
Western Washington University
1900 Shannon Point Road
Anacortes, Washington 98221
(206) 293-2188
C,R,O,RA,RS,B,SQ,M,NS(19)

21. **Simpson Marine Laboratory**
Point Defiance Aquarium
5400 North Pearl Street
Tacoma, Washington 98407
(206) 591-5337
C,H,R,O,RA,RS,B,M,PM,PS,NS(6)

22. **Tulalip Water Quality**
10610 Waterworks Road
Marysville, Washington 98270
(206) 659-4130
T,R,O,RA,B,M,PM,NS(4)

23. **Walla Walla College Marine Station**
Walla Walla College
College Place, Washington 99324
(509) 527-2481
C,H,R,O,RA,RS,B,SQ,M,NS(10)

24. The Whale Museum
62 First Street North P.O. Box 945
Friday Harbor, Washington 98250
(206) 378-4710
C,R,S,RA,RS,B,NS(11)

British Columbia:

25. Bamfield Marine Station
Bamfield, B.C. VOR 1BO
(604) 728-3301
C,H,R,O,RA,RS,B,SQ,NS(24)

26. Capilano College
P.O. Box 1609
Sechelt, B.C. VON 3AO
(604) 885-9310
H,R,S,RA,B,NS(3)

27. Institute for Ocean Sciences
Canada Department of Fisheries and Oceans
P.O. Box 6000
Sidney, B.C. V8L 4B2
(604) 363-6442
R,H,C,O,RA,B,PS,NS (about 150)

28. Lester B. Pearson College
Marine Laboratory
RR #1 Pearson College Drive
Victoria, B.C. V9V 5T7
(604) 478-2767
H,R,O,RA,RS,B,M,NS(25)

29. Malaspina University College
Fisheries and Aquaculture Department
900 Fifth Avenue
Nanaimo, B.C. V9R 5S5
(604) 753-3245
C,H,R,O,RA,B,M,PS,NS(7)

30. Marine Ecology Station
(a divison of Cowichan Bay Maritime Centre)
P.O. Box 787
Duncan, B.C. V9L 3Y1
(604) 746-4955
H,C,O,RA,RS,B,NS(2)

31. Pacific Biological Station
Canada Department of Fisheries and Oceans
3190 Hammond Bay Road
Nanaimo, B.C. V9R 5K6
(604) 756-7041
R,O,RA,RS,B,M,PS,NS(135)

32. Royal British Columbia Museum
675 Belleville Street
Victoria, B.C. V8V 1X4
(604) 387-3685
C,R,O,RA,NS(2)

33. Royal Roads Military College
Chemistry Department
FMO Victoria, B.C. VOS 1BO
(604) 363-4601
H,R,O,RA,B,M,PS,NS(40)

34. Simon Fraser University
Department of Biological Sciences
Barnaby, B.C. V5A 1S6
(604) 291-4475
H,R,O,RA,RS,B,M,NS(35)

35. University of British Columbia
Department of Oceanography
6270 University Blvd.
Vancouver, B.C. V6T 1Z4
(604) 822-5940
H,R,O,RA,B,PS,NS(45)

36. Vancouver Aquarium
Murray A. Newman Field Station
P.O. Box 3232
Vancouver, B.C. V6B 3X8
(604) 631-2526
C,R,O,RA,RS,B,M,PS,NS(170)

37. West Vancouver Laboratory
Canada Department of Fisheries and Oceans
4160 Marine Drive
West Vancouver, B.C. V7V 1N6
(604) 666-7911
H,R,O,RA,RS,B,PS,NS(37)

Table 2. Key for letters used in Table 1

C:	Community education emphasized or part of program
H:	Higher education high school or college training emphasized or part of program
R:	Research emphasized or part of program
T:	Tribal aquaculture emphasized
O:	Open year-round
S:	Seasonal opening
RA:	Research by others is allowed or encouraged
RS:	Facility has running sea water
B:	Boats are available
SQ:	Sleeping quarters are available
M:	Conduct repeated marine monitoring (special—one time only—studies and sampling not included here)
PM:	Publish monitoring reports
PS:	Publish special studies reports
NS:	Approximate number of staff (full- and part-time employees; volunteers not included). These numbers generally represent the entire lab staff and in some cases include administrative staff as well as physical oceanographers, chemists, etc.

The approximate locations of the field stations are presented in Figures 1 (Washington) and 2 (British Columbia).

SUMMARY

The information presented here should be used as a starting point to gather more specific information about the labs. Although we have tried to be as thorough and accurate as possible in describing the labs and field stations, we may have inadvertently omitted some labs or misrepresented the capabilities of others. While some labs gave us long lists of the equipment they had available, we decided this type of detailed information could best be sought from each lab on a case-by-case basis. The willingness of these labs to accept a researcher's request for assistance will certainly depend on the equipment and space needs of the researcher as well as the amount of time for which space or equipment is needed.

The locations of the labs in Figures 1 and 2 are approximate, and some of these labs are capable of gathering information at considerable distances from their locations (for example, researchers from the Bamfield Marine Station on the west coast of Vancouver Island may on occasion do some work in the Strait of Juan de Fuca or the Strait of Georgia).

Twenty-four labs were identified in Washington and 13 in British Columbia. The major categories of the labs included university-associated labs, community education-associated facilities and tribal aquaculture-associated labs. Most of the labs seemed to provide some level of community education. Of the labs surveyed, about half have fewer than 15 paid staff members. About a quarter have between 15 and 25 staff, and the remaining quarter of the labs have between 25 and 170 staff. At all the labs identified, and especially at the larger labs, many of the staff work on issues other than marine biology and water quality.

The vast majority of the labs are open all year, and approximately 85 percent would allow researchers to use their facilities. In some cases there is a fee charged for the use of the lab and its equipment. Commercial aquaculture operations, consulting firms and industrial facilities with labs were not included here but still may agree to share information and make space available for those considering research near their location.

Approximately half the labs responding to our survey have running seawater available and 65 percent noted that boats were available at their facilities. Only 20 percent of the labs had sleeping quarters which could be used by visiting researchers. While about half the field stations we contacted stated that they monitored environmental conditions near their facilities, only about 45 percent of those gathering monitoring information actually issue reports on the results of the monitoring.

CONCLUSIONS

We found there are many more marine field stations in Puget Sound, the Strait of Juan de Fuca and the Strait of Georgia than we had expected. In addition, these marine labs are widely distributed throughout our shared waters. Most of these labs promote or encourage community or higher education, and many will try to accommodate researchers hoping to do work in the vicinity of the lab. However, the potential benefits from these labs working together to support coordinated education, volunteer activities (such as beach clean-up or general environmental surveys) and/or marine monitoring activities remain to be realized.

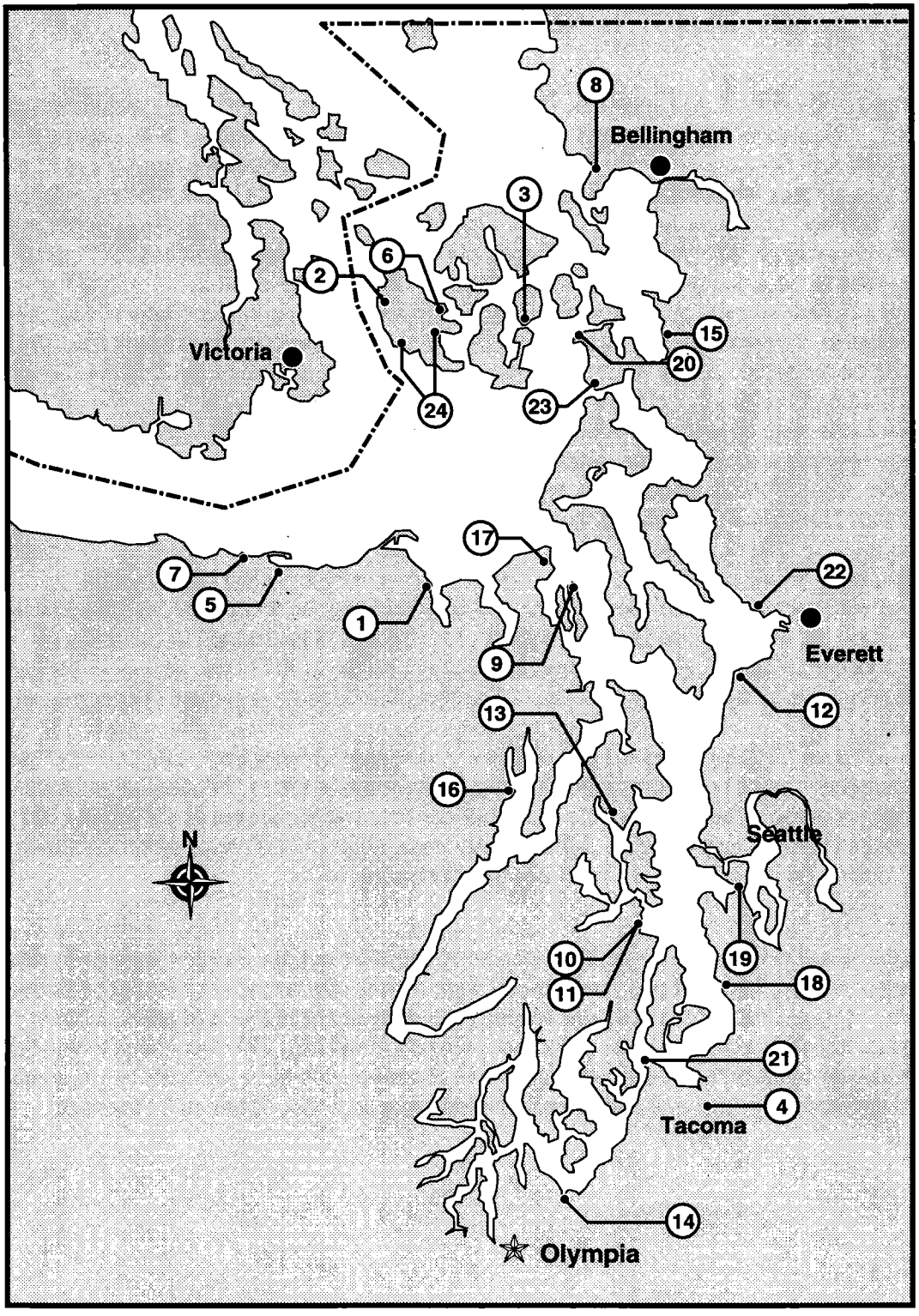

Figure 1. Washington's marine laboratories and field stations in Puget Sound and the Strait of Juan de Fuca

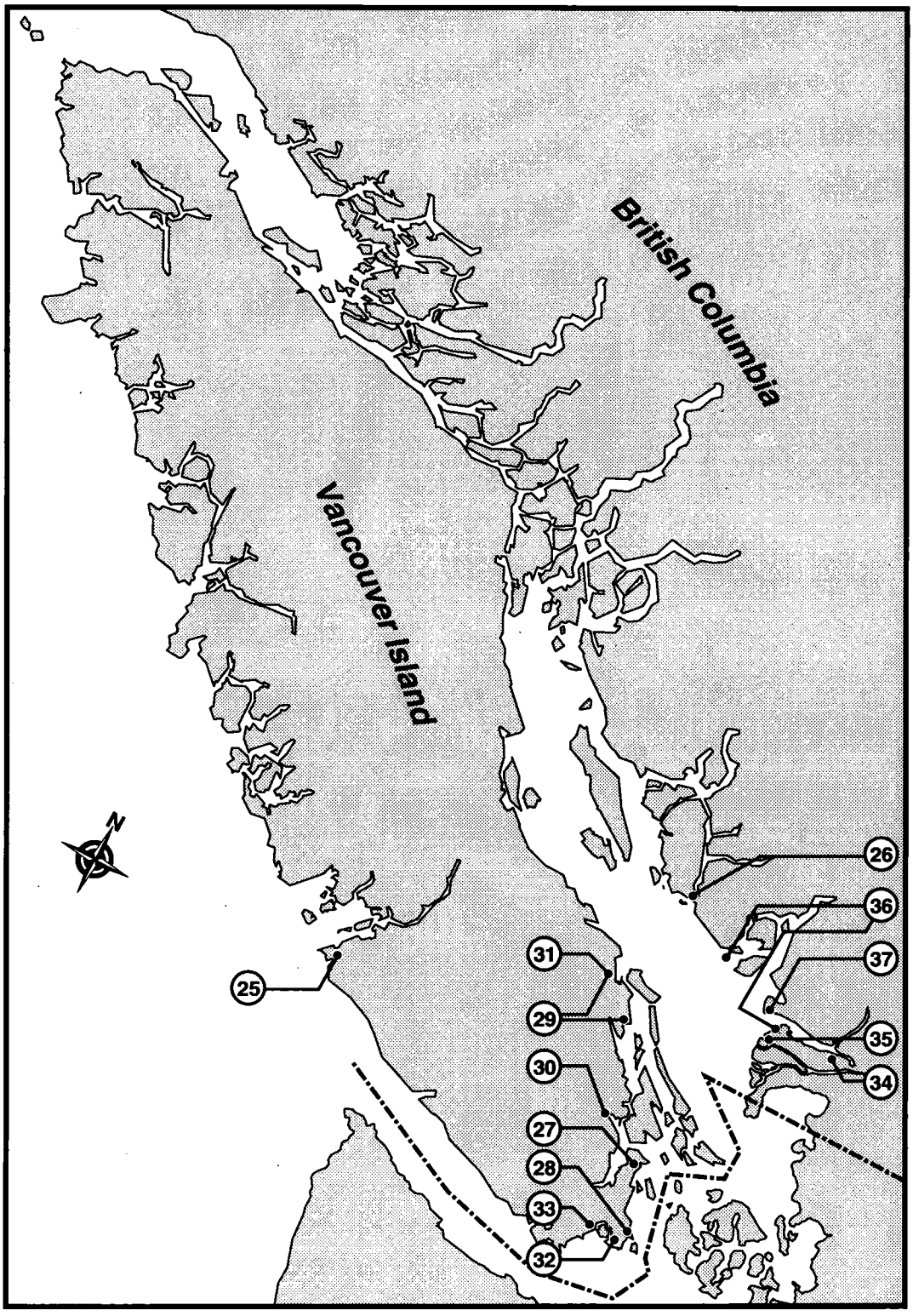

Figure 2. British Columbia's marine laboratories and field stations in the Strait of Georgia and the Strait of Juan de Fuca

PUGET SOUND RESEARCH '95

SESSION 7C

EMERGING RESOURCE ISSUES

Session Chair:

Duane Fagergren

Deputy Director, Puget Sound Water Quality Authority

PANEL: EMERGING RESOURCE ISSUES

CHAIR

Duane Fagergren, Deputy Director, Puget Sound Water Quality Authority

PANELISTS

Jim Rochelle, Senior Wildlife Biologist, Weyerhaeuser Company
Bob Turner, Director, Washington Department of Fish & Wildlife
Chuck Clarke, Regional Administrator, U.S. Environmental Protection Agency
Bill Robinson, Chief of Fisheries Management, Northwest Regional Office, National Marine Fisheries Service
John Dohrmann, Director of Compliance & Planning, Puget Sound Water Quality Authority
Jim Karr, Director, Institute for Environmental Studies, University of Washington

Duane Fagergren, Deputy Director, Puget Sound Water Quality Authority:

This is a group of various astute people who are going to talk about emerging resource issues and their effects on research. They're going to give their perspectives, from both the public sector and the private sector, on issues like modern forestry, new salmon initiatives, the Endangered Species Act, the Clean Water Act, other watershed initiatives, risk-based management and ecosystem approach, and maybe a little on transboundary concerns and habitat destruction.

As general procedure, we're going to ask each of the speakers to spend five to eight minutes talking about what they see as major issues, and how research ties into the future. Then we're going to open up the discussion for questions.

Jim Rochelle, Senior Wildlife Biologist, Weyerhaeuser Company:

I have a fairly long career in working with forestry environmental issues from the research perspective, having been with Weyerhaeuser in environmental research for more than 25 years. I've been one of the chairpersons of the Timber-Fish-Wildlife research program since it was established at the time of the agreement in 1986. So I find myself having been involved in many of the regulatory and research issues associated with natural resource management, especially in the Pacific Northwest.

What I'd like to do is talk about forestry and forest management in the Northwest, from the perspective of industrial forest management—as opposed to what's being done on the federal or state lands. How do we carry that out effectively in light of the multiple resource values present? What are the research elements that are important to address as we try to do that?

The resource situation we're concerned with is continually changing. We have changing expectations on the part of the public to integrate other resources into our management. At the same time, we have an obligation and an obvious requirement to be financially successful in order to stay in business. But we are modifying our goals, and we're changing our practices. We're trying to increasingly incorporate a range of natural resource values in our management approaches.

The issues are changing. The changes bring a new set of research needs, which I will talk about later.

I think the biggest change we've been encountering—and it's one that's been very apparent at this conference—is the increase in the scale at which we now try to think about forest management and other land uses. We've shifted a long way from looking at a forest practice at a time—a specific harvest area, a specific road—to looking at landscapes. The change has been driven largely by questions about the cumulative effects, both in space and in time, of multiple management practices. New methodologies are surfacing. We just had a panel session on watershed analysis, a methodology that came out of the TFW research program. Watershed analysis is being used quite broadly. It needs further improvement, but it's a tool that allows us to

look at forestry activities and their relationship to aquatic resources in a more comprehensive way than before.

The whole idea of ecosystem management, landscape management, whatever you want to call it, has arrived, and we're trying to understand what it means. I think, in part, what it means is as we look at things like salmon, we're going to have to look more broadly at a whole range of land uses. Forestry's obviously one of those you look at, but we don't manage resources like salmon by looking only at forestry.

These shifts in how we view the environment are spawning a whole bunch of new research questions. To move ahead we need to employ adaptive management. It's as if we're building the bike as we ride it. There are many relationships we don't completely understand. But we've got to address them, even though we don't have all the information. Our need to practice adaptive management makes our research and monitoring efforts critical. We're not only trying some new things on the ground, but also measuring results so we can improve them over time. When I talk about research needs, I'm talking really about research, monitoring, and in some cases very basic survey work to come up with information we often find we're lacking. We've been doing a lot of survey work in managed forests, looking at what wildlife is there. There are lots of perceptions about that, but very little data. Our surveys are expanding the data base.

I think the one issue that heads the list of concerns is that of threatened and endangered species, and how we deal with them in the long term. We've learned, I think, that we can't do it successfully a species at a time. We may find solutions for the spotted owl, only to find that then we've got to deal with the marbled murrelet. And dealing with these species pales in significance next to the issue of declining salmon stocks. So we're moving toward trying to address the problem of species declines on a bigger scale. That means addressing biodiversity in general—not just those species that are currently threatened or endangered, but also those that have the potential to be. The emphasis needs to be on preventing populations from getting to that point.

Ecosystem management or landscape management is another current issue. It's easy to say it, but it's very complex when you start digging into it. We're doing some pilot work now in which we are taking a big piece of land—100,000 acres—and looking at all the relationships that are important out there, from an ecosystem/multiple-resource point of view. It's readily apparent that we're lacking a lot of information. There are spatial and temporal aspects of ecosystem management we haven't thought about. It's hard enough to try to manage forests over a 50-year period, with all that can go on related to just the trees. But we're adding additional resources layers of, for example, 260 wildlife species in our pilot area. We're trying to understand now how forestry relates to habitat and in turn to species occurrence. We have some real challenges in doing that.

These large-scale approaches require GIS—geographic information systems. GIS lets us display, analyze, look at options, look at what-if scenarios. GIS is a vitally important tool for looking at things on a scale we really haven't attempted before.

Because of the complexity of these resource relationships, modeling is one of the tools we have to use. But modeling is only as good as the data we use in the model. This is where basic surveys can help us relate habitat to wildlife species preservation, for example. These data are needed to validate and improve the models. Models are helpful, but they're not the final answer to a lot of these questions.

A lot of people have said—and I agree—that we have a great opportunity in habitat or ecosystem restoration. Certainly there is a great need for restoration, particularly of fish habitat, as a result of past practices. I'm not sure we know how to do that most effectively. I think we have some opportunities as we develop methodologies to tie them in to some of the other approaches we're using, such as watershed analysis.

The questions also go beyond some of the traditional resource questions—questions about fish, wildlife, and water. For example, we're trying to address aesthetics. For a long time, we felt we could ignore aesthetics, that it was not an environmental problem. But it certainly is a problem with the public, which often equates the appearance of a harvested area with resource damage. There are numerous research and management opportunities to be addressed in this area.

Aside from some of the research questions, there are important social issues that present challenges. We're practicing forestry in a changing socioeconomic environment. There is a smaller and small proportion of the public with any economic connection to forestry. And I think it's going to be a real challenge for us to continue operating without the support of that society. We're working pretty hard at defining how we're going to do that.

And finally, I'll just say that as we think about needs, we ought to think about how to go about meeting those needs. Although the TFW program is a small one, it has been a very effective way for us to address some of the technical questions, because it gets all the stakeholders involved. As a result we tend to get broad-based endorsement of the findings and recommendations that come out of the program. I think arrangements like TFW will continue to be very important to us in the future.

Q: I was wondering, sir, if Weyerhaeuser in particular, or the timber industry in general, is doing much research right now on the symbiotic relationships between the standing trees that are very noticeable when they're cut down and the productivity of the soil.

Rochelle: The answer is yes. I confined my comments largely to traditional resource relationships, i.e., forestry as related to fish, wildlife and water quality. But yes, long-term productivity is really the bottom line. If we don't maintain the productive capacity of the soil, we might as well not be in business. We are looking at our past practices to better understand their relationship to soil productivity and to assess whether changes are needed.

Fagergren: The next speaker, Bob Turner, will give his perspective.

Bob Turner, Director, Washington Department of Fish & Wildlife:

I looked at the suggested topics for this panel and saw that our agency is involved in all of them. I don't know which ones to hit, so I won't hit any of them. I'll talk a little bit about what I view as the challenges facing natural resource managers and scientists as we move forward in a dramatically changing natural resource management environment.

In this state and indeed throughout the West, I believe we as a society have a strong public value for fish and wildlife. We also have a strong public value, as is common, for economic development and prosperity. We have felt, as part of our heritage, that we could have both at the same time. Never have we spent much time recognizing that the reconciliation of those two public values is really what's necessary if we're to sustain both into the future.

We're faced today with increasing growth and increasing demand on all of our resources,. And we now know that economic public value comes at an expense in the natural resource public value. Likewise, we know the pursuit of our natural resource value has a significant cost in the form of lost economic opportunity.

Yet we do not have a lot of skill in the reconciliation of those two values. We continue to try to believe that we can build a subdivision and still sustain our natural resource fish and wildlife values; that somehow, the national forest will take care of the habitat needs in this watershed and we don't have to worry about it in the lowlands; or some other kind of it's-not-my-problem-it's-my-neighbor's approach. I think there's a growing recognition that what we need in the future is the skill required to reconcile that subdivision with those fish and wildlife values; that somehow we can pursue the economic development values, but do it in a way that's friendlier to fish and wildlife than it has been in the past; and that neither value will be able to be sustained unless that reconciliation takes place.

We are struggling at the policy level to develop the form within which these necessary changes can occur. As we do so, we are having to face a couple of harsh realities. One of them is the staggering population growth projected for Washington. If you look up the statutes that give my agency its authority, what you see

reflected there are the variables people used to think would determine the health of fish and wildlife. So we can open and close a hunting season or a fishing season in a heartbeat, and we are very good at it. We can enforce it. We can put people in jail if they hunt or fish out of season. We can do all kinds of things like that—because season-setting used to be considered the big variable that determined whether we were going to have fish and wildlife. Likewise, we can run fish hatcheries and game farms, because production was another variable that was thought to determine the vitality of fish and wildlife.

But as you sit here today and imagine the region's future after 20 years of staggering growth, you recognize that neither one of those two variables is really what will dictate the future of fish and wildlife. It's habitat protection—not habitat restoration, but habitat protection. As badly as the habitat has been degraded in the past, including the construction of the hydroelectric system in the Columbia River, I'm much more concerned about potential habitat degradation in the future. If we could just stop today and protect what we have from further degradation, I would consider that a success. To the extent that we can restore what's been degraded, it's a home run.

So habitat is the key. Yet looking again at the statutes that guide our agency, you'll find we have virtually no authority to affect the crucial variable of habitat protection. All we have is a little permit that we issue on a case-by-case basis to protect fish life in water—the hydraulic project approval. When it comes to protecting wildlife habitat, our agency has no authority whatsoever. And that's not uncommon. Across the table here you'll find agencies with lots of presumed responsibilities without the authority to implement them.

So what do we have to do to be successful? What we have to do is to affect the decisions of others. We have to affect the decisions of those who do affect habitat. Like the Weyerhaeuser Company in the development of a habitat conservation plan in southwest Washington. Or the Forest Practices Board in the development of rules that apply statewide. Or in dealing with a public utility district that needs a license from the Federal Energy Regulatory Commission. Or county commissions that have to adopt protected area ordinances under the Growth Management Act.

What that means is that our agency's success depends on our ability to translate our values for fish and wildlife into language that can be used by people who are making decisions that do affect the habitat. And that brings us to the talents that I think the research community must have in the future. First, it has a great asset to peddle, and that's science. We have the science that people want in order to promote their fish and wildlife value, and to pursue their economic value. But we need to do a better job on translating that science into language that can be used not just by the people in this room, but also by the people outside this room who are making those decisions that affect habitat.

We know the jargon and the alphabet soup we all deal with. But not everybody outside this room does. We in resource management have to be sensitive to that language barrier that exists between us in the natural resource management arena and those on the outside who may be in agriculture, or industrial forest management, or construction. Because we want them to listen to us and understand what we're saying.

The other thing we have to recognize is that if they're going to listen to us, we've got to listen to them. We have to understand what their objectives are, what this other public value is, because we need to understand that prosperity and economic development in this democracy are things that few people criticize. They are strongly held public values. And if we deny that public value, we're telling people something they don't want to hear.

So we've got to make sure they know we understand their objective. We don't have to agree with it, but they have to have a sense that we understand it. Then we have to communicate with them in a such a way that they at least believe they can achieve their goals but do it in a way that allows us to achieve our goals, as well. Because in the end, we in the Northwest all share those two public values—one for fish and wildlife, and one for economic development. Over time, I think we will have a greater respect for the need to integrate those two public values.

The last point that I wanted to make is that I have a much greater appreciation now for the skills in our agency that deal with scientific uncertainty, that identify scientific uncertainty. Those skills let us put aside the argument over which side of the issue should prevail. Rather, they help us construct an adaptive man-

agement approach, as some people call it, or a risk-management approach that seeks to resolve the uncertainty over time without one side's having to prevail over the other. After all, there's an awful lot of science out there with varying levels of confidence within it.

What I have found is that for species that are at risk, those that become candidates under the Endangered Species Act are the ones we know the least about. That's why they get listed. If we know about a species, we usually are managing it in a way to keep it out of that kind of trouble. So when you're dealing with a species that we don't know very much about, you have very high levels of scientific uncertainty, and therefore, huge arguments with the interest groups about the impacts of this measure or that measure.

This is a chronic problem in the Columbia River. The scientific uncertainty is huge, and the consequences of error are huge, too, with enormous financial implications. So, with this scientific uncertainty, you have proponents able to argue all manner of sides to an issue. The skills that help me as a manager get through that are the skills that help reconcile that uncertainty, and adapt our management to kick the can down the road, in a sense, and resolve it over time.

Fagergren: Next I'd like to introduce Chuck Clarke and have him give the Environmental Protection Agency's perspective.

Chuck Clarke, Regional Administrator, U.S. Environmental Protection Agency:

Before I came back to Region 10 of EPA, I ran the natural resources agency for the state of Vermont. That agency is structured differently from its counterparts in most other states. It has fish and wildlife, forest and parks, and the environmental organization all within one agency. I believe an emerging trend in public policy is to construct institutions that can bring together the conflicting requirements that we're faced with in making policy decisions. In Vermont I saw the benefits of getting the technical and science employees in that agency together in the same room to reach an agreement before making a policy decision. If I had one hope for the next five years, it would be that we could find the right way to use science and technology in making policy decisions.

One of the biggest issues in the federal area is funding. I wonder how many of you will be funded to do your jobs next year. This morning I heard on the radio two of the committee chairs in Congress talking about eliminating all biological systems staff within the Department of Interior. Both of them said, "That's a done deal. That's not going to be a big issue at all. We're going to be able to crank that through." That's about $1.3 or $1.4 billion a year, and it includes a majority of the science folks in the Department of Interior. And it includes a lot of the research money they use in their efforts.

Now, whether or not that comes to pass, that is typical of the investment discussions that are going to be held over the next year that will have the most significant impact on our work. EPA's budget cuts, I would assume, will be somewhere between 10 percent and 35 percent. There are budgets floating around that feature a 45 percent cut to EPA's budget, including the Office of Research and Development. Now, their privatization goal is worthy—to put investments into educational institutions, investments in private hands. But if there isn't money to do that, there isn't going to be a lot of funding for the research activities that have occurred in the past.

If you look at the discussions that have been going on in some of the educational institutions about potential budget cuts in grants for research and development, again, you see a trend that doesn't look too promising for the next several years. If the issue becomes a balanced budget amendment by 2000 or 2002, without any discussion of cuts, what you're really talking about is $1.3 trillion in cuts over that period of time. If you hold harmless things like Social Security, the only place they're going to take that money at the federal level is from investments in what they call the smaller agencies, and in a lot of the research areas. I think that is one of the areas that we need to watch carefully as we consider how to continue the research we're doing now, within the educational institutions, and in both the public sector and in the private sector.

At the same time there are arguments in favor of depending more on science. It's the risk-based argument that we ought to spend more time being scientifically rigorous in policy setting and spend more of our limited investments in the science arena. So that's a positive trend. Unfortunately, a lot of people are supporting this argument because they think it's going to do away with regulations. Still, it's a hopeful trend to try to base decisions on better science.

A second issue, which Bob Turner mentioned earlier, is the translation of science to action. Taking the policy debate and the science discussion and merging those into a discussion that results in a rational policy is going to be the significant challenge for us in the policy-making arena over the next several years. That means we're going to be putting more pressure on the scientific folks in our organizations to be able not only to translate the things they're doing, but also to take a leap into forecasting the implications of the science. One of the big trends nationally now is environmental indicators. Everybody wants to figure out how you determine whether you're successful. In Vermont we produced first indicators report in the country. We wanted to take the science we'd collected over the last 50 years and convert it to indicators we could give to the public. The argument is that quality analysis/quality control does not allow us to take that information and convert it into some assumptions about what's going on. But if we follow that line of reasoning, why then should we invest in any science? If we can't use it today, it probably means we're not going to like the QA/QC next year or the year after. We're getting to that crux where people want to take the research that's been done and apply it to day-to-day activities. As a policy-maker, I've been hearing more and more about accountability from legislators and from the public. We'll be looking to you for help in figuring out how to explain to people the importance of our policy decisions.

Finally, the emerging trend in ecosystems is trying to determine the relationship between past regulatory initiatives and exactly what's happening with the environment in the present. We chose a line of attack in the early '70s that based everything on managing industry. What we discovered was that because of growth and several other factors, there isn't necessarily a direct link there. We may have done better on individual industries, but we certainly haven't had the impact we'd hoped on protecting or enhancing the environment. We're trying now to get back and look at what the actual implications are for the environment. In Vermont, they had taken a leap of faith and adopted ambient air standards for the state. Then they figured out that they couldn't do it, because they exceeded background in almost every place in the state. But it is a direction that we're taking. And as you look at the implications are, we need to know more about the consequences of our day-to-day activities for our environment. We need to know more about toxic standards, because toxics tend to be involved in every one of those. We need to know more about total maximum daily loads and how we make individual decisions. We need to know more about ecosystems and what the implications are for the various geographic areas we're dealing with. We need to know more about geographic systems and others. These are all areas where additional research is needed if we are to determine the effect of our work on the environment. It's not that we haven't had successes over the last 20 years. But to go to the next level, we'll be looking to you to help us make that work.

Fagergren: Bill Robinson with National Marine Fisheries Service, if you'd please give your thoughts.

Bill Robinson, Chief of Fisheries Management, Northwest Regional Office, National Marine Fisheries Service:

As far as emerging resource issues, it should come as no surprise that the single most visible, most contentious, and most important issue for the National Marine Fisheries Service right now is the potential listing of a variety of salmon populations under the Endangered Species Act. Since 1991, the National Marine Fisheries Service has listed three Snake River salmon stocks in the Columbia River basin as either threatened or endangered, and we're in the process of reclassifying some of our prior listings from threatened to endangered. We've been petitioned, or have otherwise taken status reviews, to determine whether listing

should be proposed for both coho salmon and steelhead coastwide, including Puget Sound, and for various populations of chinook, chum, pink, and sockeye salmon, which also occur in Puget Sound.

Under the Endangered Species Act, the National Marine Fisheries Service must first determine which salmon populations meet the definition of a species under the act, whether their status warrants listing, what their critical habitat needs are, and what modifications to human activities are necessary for their recovery, so that they can be de-listed. In order to make these determinations, the agency must have a thorough understanding of the many factors that affect natural spawning populations of salmon and how they interact with each other. In doing this, we embrace some of the same concepts that we've already heard today—ecosystems, adaptive management, watershed analysis, risk-based management. These concepts have begun to shape the way we look at the world, replacing the single-issue, single-species view of the world that we've relied on in the past.

But in dealing with these concepts—ecosystems, watershed analysis, biodiversity—we're going to have to approach our research from a somewhat different angle than we have in the past. The emphasis is going to have to be on integrated research. It must be integrated in several ways. It must encompass many species. It must integrate different types of research. It must also integrate research among the various agencies that conduct that research. It's going to require improved collection of baseline data, as well as centralization of that data so it can be used and analyzed by more than one agency. And it's going to require a team approach to doing the analysis, because we're downsizing our agency, even though we have a dramatically growing workload as a result of the forest planning process and the Endangered Species Act petitions.

The fact of the matter is, our resources to meet that workload in fiscal year 1995 and beyond are going to shrink. So we're not going to be able to carry the full scientific load, make some of the critical scientific decisions, and do some of the critical scientific research that has to be done in meeting the terms of the law. Those activities are going to have to be shared through a team approach with state agencies, tribal groups, regional agencies and municipal agencies.

I would like to turn from the general to a couple of specific areas of potential research. The first area of fertility for research has to do with the ocean environment. The second area of research has to do with the genetic and ecological effects of hatchery-produced salmon on native naturally spawning populations of salmon, and particularly, the relative reproductive success of hatchery-reared versus naturally spawned salmon. It's well known that salmon populations are highly volatile, and that the productivity of the ocean environment is one of the major factors that influence the ultimate number of adult fish produced from each spawning population. Biological oceanographer Bill Pearcy wrote in his 1992 book, Ocean Ecology of North Pacific Salmonids, "In a sense, the marine ecosystem has been neglected as an unfathomable black box into which young salmonids disappear and from which, if all goes well, some adults emerge."

Since 1976, a major change has occurred in the northeast Pacific Ocean, with unfavorable ocean conditions for salmonids that originate off Washington, Oregon, and southern British Columbia, and highly favorable conditions in the far northern Pacific, primarily off Alaska. Some biologists have suggested that the carrying capacity in the migration corridor for southern stocks, both estuary and ocean, may be limiting, and in fact may have already been exceeded. They speculate that the large numbers of hatchery smolts released since the 1970s, combined with the greater size of release when compared to wild stocks, wild smolts, has resulted in excessive biomass for the ecosystem, which in turn has resulted in reduced survival and a decline in returning adults. Despite these hypotheses and some evidence to support it, there really is no definitive evidence to support this hypothesis that ocean carrying capacity is limiting. On the other hand, some evidence points to either predation, starvation, or other environmental factors encountered during the smolts' first month at sea as a determining factor in ultimate marine survival.

In order to determine whether to list a salmon population and to identify appropriate recovery measures, NMFS must determine whether recent trends of declining stock abundance are likely to continue, or whether the declines that we've seen over the last decade and a half are going to stabilize at some low level, and whether the recovery measures that we recommend will have the intended effect. Research is absolutely essential to determine whether the carrying capacity is limited, or what other factors influence survival, and

to develop a method of forecasting impacts on future populations from such factors as interactions between hatchery and wild stocks.

Most major Puget Sound watersheds have a long history of hatchery-stocking in order to support high sustained levels of harvest. In determining whether to list salmon populations under the ESA, we are concerned primarily that the naturally spawning population be self-sustaining. Returning adults from high sustained levels of hatchery stocking can mask declines in naturally spawning populations. In other words, the species may still be in trouble, despite the absence of a decline in overall stock abundance. It's important to be able to evaluate the reproductive success in the natural environment of both hatchery-reared and naturally produced salmon for each watershed, to determine whether naturally spawning populations are in fact self-sustaining. Genetic studies associated with these reproductive success studies would also provide further insight into the effects of outbreeding on reproductive vigor and adaptability.

The Endangered Species Act listing is considered by many to be a court of last resort. It's really an imperfect court of last resort because the emphasis is on federal activities. There is not the same emphasis on activities on private lands, state lands, and other lands, as there are on federal. In our view, the way to avoid this court of last resort is for those groups that have the authority and the capability to work together to do so. I'm thinking of state and municipal governments and authorities. They should work together to address some of these core issues that affect the productivity of salmon, for example, and to develop conservation plans that address the basic needs of the species. The conservation plan can then be used in lieu of listing a species under the Endangered Species Act, and we can avoid having the federal government come down the top with a recovery plan.

I'll close by emphasizing the importance that National Marine Fisheries Service places on making decisions under the Endangered Species Act, based on the best available science, supported by sound research. The impacts of the ESA decisions that we make on human activities, such as fishing, land and water use, and hatcheries, are controversial enough. We don't need the further controversy about the underlying science.

Fagergren: The next speaker is somebody I have the pleasure to work with just about every day, John Dohrmann.

John Dohrmann, Director of Compliance & Planning, Puget Sound Water Quality Authority:

I want to touch on three trends I see in resource management decision-making that I think affect how some science should be done in the future, and some of the kinds of studies we need more of in the future. The three areas are the issues of science-based decision-making, watershed-based decision-making, and private property rights.

I think it's clear, as we understand better the effects of human society on the natural system, that we need good scientific information on which to base our decisions. But that's becoming more complicated today. We used to be able to do a comparative study and collect sediments from a rural bay and compare them to sediments from an urban bay. Today, we're working with a lot of new kinds of controls, behavior changes. In some watersheds, storm water is being controlled; in other watersheds, it's not. To be able to make storm water management decisions, we need to start documenting the difference that makes. What we need are studies that compare sediments in a drainage that has good BMPs with those in a drainage that has bad BMPs. The researcher is going to have to team up with somebody who can document the level of human activity and the level of pollution controls in place, so that we can start to reveal those links. I see that as sort of a new form of what we used to consider synoptic sampling. We were pretty proud when the sediment triad was developed, and we would collect sediment chemistry and benthic community information, and then run bio-assays on sediments from one place, pretty much collected around one day, and have a snapshot. Now we have to expand that snapshot to know more about the human activities that are going on, the management decisions being made on the species you're looking at, and the flow of contaminants and

other effects through the system. Otherwise, we'll never be able to puzzle out the real effects of some of our decisions.

Similarly, there's a big move on to do everything in watersheds. Everything's going to be watershed-based now. Yet, many of our decision processes are based on laws and rules that lead us to fairly straightforward kinds of decisions. I think we need to step back and get some additional research support, probably comparing watersheds, that helps us really think through those decisions that need a strong watershed component. We're never going to find a watershed where it's O.K. to drain all the water out of the stream and still have fish; that's pretty basic. But there are a lot of other decisions that should differ by watersheds, and we're going to need a lot of research in each watershed to help us make those. I don't think we can tell those apart yet.

The third issue I wanted to touch on is this issue of people arguing about private property rights. To me, this is not tending to lead us to any new kinds of research. I think we have done and continue to do research that identifies those situations where what you and I do on our private property may have environmental resource effects beyond our property line. But I think we need to design careful studies and write up the results in a way that won't allow us to ignore this basic truth—studies that poke us in the eye with it, in fact.

Searching for an example here, I looked at one of the first sessions of this conference. The session featured an excellent series of papers dealing with urbanization effects on wetlands, and why some of those things are bad for the wetlands. But the abstract uses language like this: "when the percentage of impervious area in the watershed exceeded 3.5 percent." Somehow, we have to start saying: "When the public and private property owners in the watershed paved 3.5 percent of their land, this bad stuff happened beyond their property lines." Because only then will we all start to better understand the obligations we have in how we treat our private property.

So this is a place where I think the researchers, by being aware of some of the debates going on, can be more sensitive in how we design and report projects, to feed more effectively into decision-making.

I don't know whether you were hoping this panel would say, there are four hot areas of research. Because of the complexity of this business, when I think of the full diversity of research being reported on at this conference, it's all relevant, and it's all needed. We continue to need long-term data sets. We continue to need basic mechanisms and models. I'm afraid, even though we won't be able to afford it, we need all the research we can get.

Fagergren: Jim Karr, could you talk from the perspective of the University and what you see as emerging issues and needs down the road for research.

Jim Karr, Director, Institute for Environmental Studies, University of Washington:

My spin on some of these issues is a bit different from those of my predecessors on this panel. I don't have any particular agency or organizational context that I'm going to put this in. I'm going to use the phrase major resource issue, rather than emerging resource issue. The major resource issue is the degraded state of the biota and the biology of Puget Sound. That's at the core. And that is not an emerging issue; that is an issue that has been recognized as a problem for at least a couple of decades.

Many of the topics that were listed in the charge to us—endangered species, ecosystem management, and so forth—reflect a piecemeal approach to dealing with this problem of degradation and the biology of Puget Sound. The real emerging issue is how we can bring those together and get a focus on them all at the same time, so that we stop fiddling with little dials and tuning at the margin, but in fact address the issue.

Society behaves toward Puget Sound as if it were an ignorant car owner trying to save gas by removing parts. A car owner might be able to do without a rear seat, but won't go far without a transmission. Much as rubber bands cannot substitute for an auto transmission, fish ladders, hatcheries, barging and spawning channels to support salmon cannot substitute for the lost parts and connections in the regional landscapes that support the biology of salmon in Puget Sound.

We damage Puget Sound by asking how much can it absorb, as opposed to asking what can we do to prevent it from having to absorb. I think the solution is only in part research. More of it is not in research than is in research. To resolve this problem, we need to see the Sound in a different way—as a terrestrial, aquatic, and marine landscape. Failure to do that means that much of what we do is ineffective because we're unable to ask the right questions.

We spend too much time tuning at the margins on narrow issues like the Endangered Species Act. Listing is not the problem. The recognition that a species is endangered is a symptom, and we should be treating the problem, rather than that symptom. Our failure to develop an appropriate conceptual framework is at the heart of the problem. In the case of salmon, we switch from issue to issue. It used to be water quality and getting passage around the dams; today, it's woody debris. What will it be tomorrow when that one doesn't fix the problem because it's narrowly conceived and inadequate to deal with the issue?

Education, of course, is at the heart of all of this. As long as we train people with a narrow disciplinary focus, they will conceive narrow disciplinary solutions. We know much about the critical parts of the landscapes and their interactions. We know the integrity of Puget Sound is being degraded, and the most obvious manifestation of that is depleted Northwest salmon stocks. Each new round of research and monitoring reinforces the obvious: We are responsible. Each new round of research reinforces yet another point: Solutions will not come from narrowly conceived techno-fixes. Transplant a human heart and fail to connect it to the patient's arteries and veins, and the patient will die. And I think that's not so different from the way we treat these systems when we "fix" them.

We know what's wrong. We know how it happened. We know enough to act. Why, then, have our actions failed to reverse this decline? We form too many fact-finding committees. We refuse to face the facts once they've been found. As Lily Tomlin said, if we would learn from history, she wouldn't have to keep repeating herself. We simply do not use existing scientific knowledge in the policy process.

There's an imbalance in expenditures. How much are we spending on three to five fish in Red Fish Lake, while how many other stocks of salmon are going to go down the tube? How much are we spending on hatcheries? One third of the Department of Fisheries' budget goes to hatcheries. Lots of serious questions are raised. How much do pollution-control agencies spend monitoring National Pollution Discharge Elimination System permits without adequately dealing with non-point sources of pollution? There's an imbalance of expenditures in research—a singular focus on chemical contaminants, where much of the degradation is due not to chemical contaminants, but to other activities of human society.

And then, we talk about research. There are two sets of scoundrels. Bureaucrats delay difficult and unpopular decisions under the guise of more study, and scientists delay actions to continue their research. Their actions maintain the status quo. Our collective need for more study makes us modern-day Neros, fiddling with our research, with study committees, or with techno-fixes. We tinker at the margins while Puget Sound continues to be degraded.

The science-policy interface is seen as simple, if we could just get those two things together. But it needs to be done in a much broader conceptual context. We talk about values, but some values aren't realistic; they aren't possible. We need to integrate knowledge and science with values, to define what the possible is. And from that, we need to define societal goals. When we define societal goals, we then can address policy. We project that policy by passing laws and regulations, and developing incentives that will allow us to accomplish those goals through those policy instruments. The management is not of salmon or of Puget Sound. The management must be of people.

And then we have to re-check the goals and make sure we're going in the right direction. An excellent example of integrating values and knowledge or science is the mandate from the legislature to double salmon harvests by the year 2000. Why not quadruple it? Or 10 times it? We do research in this larger context of integrating science and policy in a more effective manner. Use the science we have, rather than call for more science.

Communication between scientists and managers is poor, while communication with the public is almost non-existent. Managers neither manage resources nor educate the public adequately. Scientists often do not do the right research, and they don't communicate the consequences of the right research to the groups with-

in society that ought to understand it, because they're running too fast down the track to get the next pile of money that will allow them to do the next piece of research, which may or may not be relevant to the policy dimensions of the issue.

We need to know more—I don't mean to underemphasize the importance of the need for more knowledge. Most importantly, I would argue, we ought to know what a healthy Puget Sound would be like. It's not very healthy anymore, but we ought to measure to the best of our ability what that healthy Puget Sound is like. Then we have a model that we can look toward to define our restoration goals and our protection goals. Talk of restoration is hollow if we don't know what we're restoring it toward.

The main point, then, that I would like to make is that research is important, but research is not the solution. A more effective policy process that uses the knowledge we have today would get us further in the next decade than big bucks for more research.

Question and Answer Period

Q: Who is researching impacts on salmon while they're in the Pacific Ocean, and the effects of El Niño or temperature changes, and increased sea lion populations?

Robinson: I don't think I could go right down the list of who particularly is doing the research, but there is certainly substantial research being done by NOAA and the universities on El Niño and oceanographic conditions. A lot of it's out of the new facilities down in Monterey Bay. There's some being done in academic institutions. There is not enough research done, as I mentioned in the example I gave earlier, to identify the important factors in the ocean environment that determine salmon survival. It's expensive research to do. Very little oceanic research is being done on salmon.

Karr: I'd like to make a comment. I think the insight of the last decade that the oceanic environment is extremely important in governing salmon populations is a really major advance. But I think it's also very important for us to recognize that the salmon dealt with those variations for millennia. What they can't deal with are those variations in the context of what we've done to them in a harvest context, in their near-coastal environment context, and in their freshwater environment context. So while it's important for us to understand that marine environment issue, understanding that will provide relatively little insight, I bet, into how we manage the resource in the future, because it doesn't remove the things that have challenged the salmon beyond their capacity to deal with it. That comes from our actions.

Q: It's easy to say that forest practices are changing in western Washington, where there is a strong public ethic for environmental protection. Yet many of these older forest practices are now being applied by Weyerhaeuser and others in Siberia because they're less costly. What commitment does Weyerhaeuser have to manage resources in other countries in a responsible way? Please give examples.

Rochelle: Let me clarify first, we're not operating in Siberia. We're looking at opportunities there, but we're certainly not there yet. One of the technologies that we will take there is the ability to re-forest, which we think is a critical underpinning to any kind of a successful operation there. We're operating in Canada on a fairly large scale, on provincial land, basically under the provincial forestry rules and regulations in place. As we develop methodologies such as habitat management, and the habitat conservation planning efforts we've undertaken, we expect that we will be able to apply them elsewhere. And that doesn't confine us, necessarily, to the United States.

Q: This is a question addressed to the whole panel, and Chuck Clarke in particular. What are some specific actions we can take to ensure that research and protective measures for Puget Sound are funded, given the current political trend?

Clarke: You may have to wait for a couple of years. I think what you're going to have to do, if you think it's essential, is you're going to have to work with your Congressional delegation, work with the University, and work with others who have a high level of interest in research issues and research implications. There is going to be, I think, a significant debate over the investments in the future for the federal government, and you ought to be part of that discussion or debate. If you leave that to others, many of the others who are going to have that debate aren't going to have the same interest, and you can lose very quickly. There is not going to be much money left. It is not bad that we're going to be restructuring the federal government; it needs restructuring. Our agency needs to be restructured, as do others. But given the significance of this, and the implications for all our future decision-making, I think it's critical to our long-term success. The politics of merging the science and the policy elements are also going to be critical in long-term success. Whether we have all the science or not, I disagree a little bit on how good some of the science may be in some of the decisions we have to make. But the political rhetoric around the decisions, the hard decisions that are going to have to be made for Puget Sound are ones that I think you all can be actively involved in, particularly when it comes to issues like non-point source issues, like growth management issues.

One example: When I was at Ecology the industry had done a significant analysis—and I don't know how much time and effort they spent—looking at the implications of wetlands rules for job loss and timber harvest. There were no studies that laid out the implications to salmon production, to flood damage within the state because of loss of wetlands, nor to the protection of groundwater. There were no counterstudies done, either economically or scientifically, that weighed out at that point the other side of the issue related to the consequence of natural resource damage assessment. Every agency has maybe one economist and may have scientific people. But nobody is looking as heavily as they should at the consequence of our actions as individuals on the environment. If there's one area that I think could use more work or support, even if it's just pulling together available information, it's to have a much better articulated argument on the cost of growth, the cost of what we do to live in this society. I don't see that.

Q: Are the Department of Fish and Wildlife's non-salmonid fisheries programs shrinking? Assuming that the answer is yes, how can the Department adequately manage these species, given the increased recreational harvest of non-salmonid fish and some marine invertebrates?

Turner: Some of the programs are shrinking. I hazard to guess that our shellfish management division is going to grow dramatically, here, in short order. But the way you manage in a constraining economic environment is more conservatively. And we've been doing that. But this applies to the salmon management staff as well; it's been constrained for the better part of six years. We have accommodated that by adopting the policy that we don't have to put every last fish in somebody's boat. Because the final increment of management—that final 5 percent of the harvest—is an extraordinarily expensive 5 percent, we have consciously backed away from that. With political implications in this state that revolve around ensuring that we and the tribes each get our 50 percent share of this pie that we have to divide up, we no longer assure people that we're trying to put 50 percent of the non-Indian share into a boat. We have weathered that storm, and now manage those resources more conservatively than we did four years ago.

Q: How will new information technologies, i.e., interactive CD-ROM, Internet, Worldwide Web, desktop computing, and scientific visualization, affect energizing resource issues?

Dohrmann: We only have two people in our agency who are on Internet at this point. I think those technologies will let us work better, but I don't know that any huge breakthrough is likely to come from it. If the decision-makers to get closer to things or be able to see things that, in the past, they've had to take somebody's word for, that will be a very powerful effect. Earlier I said we should look further afield in our studies because of the interrelatedness of things. That effort is bound to be enhanced by improvements in communications technology.

Karr: I spent several years at the Smithsonian Institution, and those kinds of technologies, I think, have been really important for scientists. But the place that I think they have the greatest potential is when you go before a Congressional committee, a state legislative committee or a citizen group, and try to communicate what you've learned about the consequences of a decision and how that will affect citizens. I think we can create graphics in new ways that are tremendously powerful in communicating with citizens. That's where we should put a lot of energy in using those technologies.

Clarke: The one caution I would mention is, if you have a dysfunctional decision-making system, the technologies will just give you a faster dysfunctional decision-making system.

Robinson: To use an example from our office in terms of having access to decision-makers. We're hooked up to the Internet, and one thing that I've noticed in hooking up to the Internet is that there are questions going out from people like the Congressional Research Service that are researching things for Congressional staff and Congressional Committees. And there's a marvelous opportunity on the Internet to actually provide input to these people that you might otherwise never have the chance to do. Perhaps that's one example of an advantage.

Turner: I think the point is that all of those technologies are going to enhance our ability to communicate and move information. Maybe the dysfunctional comment was that the system may not be able to handle all that. As it is, we see seem to have trouble making decisions with the data we have already. The other thing that's of some concern to me is that we tend to get more and more impersonal in our relationships with people, and I'm not sure we discuss things to the extent we would when we send an electronic mail message to the person who's sitting down two doors from us as we do when we walk down and talk to them. I'm not sure you communicate in the same way.

Q: Implied in the talk that hatchery vs. wild stocks is the major issue, is this of greater relative importance in the listing than habitat degradation or harvest management? Are you reflecting some discussions at a Congressional level?

Turner: I don't think it's a surprise that for coho salmon coastwide, and particularly for Puget Sound, our agency and the National Marine Fisheries Service were in discussions about the evolution of the scientific review of coho stock status in Puget Sound, where the issue of hatchery operations in Puget Sound became and remains an issue. Our point is that if you have a proposed list, whatever your decision about a proposed listing on coho in Puget Sound might be, if you are doing it based on an analysis of a stack of data that we have kept because we're good at running hatcheries. If that's all you do to determine whether a stock ought to be listed, you can reach whatever decision you want. But Rome is burning behind you in the form of habitat degradation. We can deal with hatchery operations, but if we take the public's view of our issues and focus them on only one component of the problem, and allow them to lose sight of this habitat issue, then we've done ourselves a disservice. We may have won this little battle over hatcheries, but we've lost the war because we have lost focus on the long-term issue that is related to the growth in this state. So I don't know what NMFS is going to do with that issue in its decision, but we have urged them that if they're going to make a decision one way or another, put all of the factors on the table—don't just focus on one that is easy to analyze because the data is available. Hatcheries are easy; habitat is hard. But don't make that the reason why we focus solely on hatcheries.

Robinson: I just add, for those of you who are not familiar with how we organize the activities that affect potentially listed species, we have kind of a shorthand for them that we call the four H's: hydropower, habitat, harvest, and hatcheries. And we group all of these factors into one of these four H's. All four H's are of concern and are areas where we place considerable emphasis with respect to Puget Sound. In our recent sta-

tus review on coho, of the four H's, the two H's that tended to have the most influence on the state of the resource is the hatchery issue that I brought up, and the habitat issue that Bob Turner mentioned. Those two issues are probably more in the forefront in our thinking than hydro and harvest at the moment.

Q: Noting the frequent references to interdisciplinary/interagency research, what is the atmosphere at the University of Washington presently concerning undergraduate and graduate interdisciplinary study in the environment?

Karr: I'm a biased observer, but I think the prognosis is not very good. I think if one looks at those agencies or those programs within the University that were targeted for cutting, they are dominated by programs and organization that have significant interdisciplinary responsibilities and interactions. It reflects the conventional disciplinary departments' strengths and powers in academia. I think it's a tragedy for academia. We have in K-12 education the responsibility to have environmental education, but our Universities don't understand that's relevant for their activities as well. Communications, applied math, speech communication, Institute for Environmental Studies are some of the programs that were targeted. Not very insightful, in my view.

Clarke: You heard from every one of us that we're trying to come up with a broader systems approach to dealing with environmental issues. The thing that struck me is the going exactly back to the old stove pipes and doing away with exactly what we're all trying to figure out a way to move to. And so when we throw out the areas where we need to do some investigation, some research, some applied science, it's kind of all a different direction from the way the University is going.

Karr: There is an opportunity to comment now on all of those. If you have an opinion, one way or another, please communicate that to the powers that be. I put on the table an action alert/press release kind of thing about IES, but there are other programs as well that are threatened. If you have interest in and concerns about those programs, communicate them to relevant people.

Q: Please comment: No resource agency will succeed in its long-term missions unless rapid population growth is addressed with stronger tools than the Growth Management Act.

Clarke: I don't know if it's 100 percent accurate. I can't tell exactly what all the implications are of growth. I spent two years of my life actually writing and being part of the Growth Management Act, back when Booth [Gardner] was governor. We were actively involved, and one of the reasons for that was we saw population growth as the largest environmental issue that had faced the state in the last three or four decades. I still believe that if you strengthen that even more, you have a tool that goes way beyond the tools available to the resource agencies—Fish and Wildlife, or Ecology, or EPA, or others. I think it is the issue that we're going to have to deal with, whether it's in the form of transportation, or subdivision developments, or stormwater—it covers all of those. I don't know what the long-term implications are, and whether that statement is fully accurate or not. Having lived in Washington since 1949, with one stint away for a year and a half, I can tell how much easier it was to manage resources in Vermont, which is known as an environmental state, because the state's population is 560,000 people. There's a significant difference in managing in an arena like the Northwest. There are just fundamental changes going on around us that we do not understand. One of the things I would attribute them to is growth. But how much, I don't know.

Turner: As people who care about natural resources, we have to keep in mind that we've dealt with a toolbox for upholding these public values. I don't mean to sound trite, but we do live in a democracy, and it's the democracy that gives us the rules for pursuing the public values that this democracy wants to see go forth. I spoke earlier about our trying to pursue the dual track of economic development and natural

resource protection. The natural resource protection side was pursued largely through a regulatory approach. And in this democracy, a regulatory approach to natural resource management is no longer in favor. We're seeing this not just in natural resources, but everywhere. That doesn't necessarily mean that the natural resource public value is out the window. What it means is, we've got to find a different approach to instilling that natural resource public value. And right now, in 1995, we're in a period of transition where you and I are pretty anxious, because in this transition we don't know what the rules are. We're comfortable with regulation because that's the world we used to live in, and we knew what that was about. But let me challenge you. How well do you think regulation has worked?

Q: What alternative approach can we take?

Turner: Incentives. Tax incentives. Why does the estate tax—to take a timber example—penalize people who have held a family tree farm, without cutting it, for years and years and years; and then mother and dad die—the tax code requires that tree farm to be harvested, in order to generate the money to pay the estate tax. Now, that's crazy.

Q: Mr. Turner. I think a lot of the successes we've had would not have happened without the toolbox you have with your hydraulic project application. And the ESA, which has been around for a long time, has made a substantial difference. So I'm feel the new stuff is going to be very difficult. But if we keep the things we have very good and strong, I think—as the gentleman from Weyerhaeuser was saying—that will help in preventing more degradation.

Turner: Don't misunderstand me; the status quo is unacceptable. We have to do better. In the status quo we have all kinds of regulations. I'm not suggesting doing away with regulation. I am saying the status quo is unacceptable, and we have to change and improve. Do we honestly believe regulation is going to bring about that improvement? The legislature is not going to give the Department of Fish and Wildlife, in 1995, new regulatory authority to protect wildlife habitat. Yet the status quo is unacceptable. So what do we do? We've got to come up with incentives. The point that I keep making to the people who are making these decisions—who say they want an incentive-based approach to habitat conservation planning or whatever—is I'm all for it, but the problem is, incentives are expensive. And therefore, they don't pass muster very often. But in the absence of an incentive, we cannot allow the status quo to be the default position. So what are we going to do if we don't come up with a satisfactory incentive? One option is a regulation. And regulations are expensive, but they're expensive to the person regulated, not to the public. So it's a question of opportunity cost. Regulation is a decision by the public to place the cost of protection on an individual, as opposed to distributing it among taxpayers, as an incentive might do.

Q: You can just say no.

Turner: But don't think saying no doesn't have a cost.

Clarke: The hardest regulations for an environmental agency to deal with are not against business. The hardest regulations for an environmental agency are the ones that go after the taxpayer, and the ones that seek to change behaviors, whether in transportation, or wood stoves, or what have you. I may have disagreements with industry, but it's been a lot easier over the last 20 years to get regulations to deal with industry because it is an issue of passing it on to somebody else. Whereas, when we really get down to the nitty-gritty of growth management, the area where we have the biggest rate of return for environmental protection, we're into the toughest arena for us as environmental agencies. And that's in dealing with the general public. We're all struggling to figure out how to handle that. It's not just that this is where we get the biggest gain, but it's also where we start getting to fairness. We have gone after industry for years, and that doesn't

mean that we still shouldn't have strong requirements. But we've never gone after a lot of the other people who contribute to pollution, whether it be the agricultural community, us as individuals, or others. It's time that we introduced some balance.

Rochelle: A lot of this more extensive planning we're trying to do at Weyerhaeuser is, in fact, aimed at an incentive, and that's regulatory stability. Regulatory stability would give us some predictability out in time. That's a tremendous incentive to us.

Karr: I think we should see this as an arsenal of tools, rather than focusing on whether this tool or that tool is the appropriate one. I worked for 20 years in non-point source agricultural land management in the Midwest, largely volunteer. And it was substantially unsuccessful.

Dohrmann: I guess I'm the institutional memory of the Water Quality Authority staff, and as we've struggled to work with the Authority Board on the Puget Sound Plan process, we've come to see that the effort to protect Puget Sound is really a big sociological experiment. In our modern technological society, we have human activities and behaviors that do bad stuff to the environment. If we want to keep living here and have the environment, we have to change. But regulation is not the only way that we, as a society, govern our behavior. Look at the panel up here; the variation in dress is very narrow. There's no rule about that, but society—or rather, we, as part of society—decide this is what we're going to do. So the trick is to try to think of all the levers that we, as a society, impose on one another to regulate our behaviors, and apply that to these issues. It takes a bit of a split-brain activity here, because on the one hand you're advancing the realm of science at the very limits of knowledge. On the other you've got to back way down to some of the most basic issues, and remind your neighbors that gravity's still there and we can't ignore it. In the same way, for many of these management issues, the basic science is not widely enough understood by society, and that is a factor in all this.

Q: If government funding for research declines, how will that affect the role of the private sector, such as the timber industry?

Rochelle: We have been supporting the Timber-Fish-Wildlife research program for some time. The support comes from both public and private sources. The Washington Forest Protection Association budget has dedicated $200,000 a year to that program. That's an indication of the program's importance to us, as well as our willingness to help pay for a portion of it. I think there's a financial commitment there as well as commitment through active involvement.

Q: Do you foresee more partnerships between public entities and private entities to get the research done?

Rochelle: Yes, I'd say so. I think we need to be looking for any way we can extend resources.

Clarke: I think you're just going to lose some of the research. Partnership, I think, is an approach. I just don't think it's in the realm of the possible to replace the huge amounts of money that have been contributed by individual taxpayers in this country. And what you're going to see is some kind of an accompanying change in the regulatory structure to accommodate the lack of the ability to continue to do the same kinds of science or research that's been done before. I don't know what that will mean. And it will take probably several years for it to play itself out. Remember, the argument is: Be more scientifically based and risk-based so that you can do less regulation. But if you haven't done the rigorous science, there's a tug and pull there. I'm just not sure where the break's going to occur. I think what we're going to see is that a lot of that can't be replaced. I think we ought to accept that Now maybe we can live for a while on what we've already done. But I think we're going to really start running into a wall.

Karr: I think that reinforces the point I made earlier that we have to redouble our efforts to get more out of the research that's already been done. We know enough to make more well informed decisions. Failure to make those decisions, despite some risk due to uncertainty, guarantees that current downward trends will continue. So if we take a little bit of risk and use the best information we have and integrate that with good policy, there's a probability, non-zero, that the situation may improve. If we don't do anything, the probability is that the current downward trend line will cross zero.

Clarke: I've been back in the environmental agencies for the last five years, and getting to truth is a major problem in this. Over-research, over-design, over-analysis, over-assessment, time delays—I mean, we create no's by just drawing out the process. And we prolong things over five or six years. Some people may like that, because they wanted a no decision. But that does not meet my fairness test. Part of it is because we don't adequately use the science that's available because nobody has the guts to make tough decisions. And until we can make tough decisions, I think we're probably going to stay in that spiral.

Q: Along the interdisciplinary line, every single person up there is talking about sharing resources, scientists working together, and interdisciplinary work. And I know a lot of scientists, in a lot of different talks at this conference have been trying to do that. But I have a plea for the agency directors up here, and that is: You have to consider reorganizing those fiscal and administrative systems within the agencies to allow us to do this.

Clarke: You make a good point. Where you can help on some of that is probably going to be with Congress and others. EPA was scrutinized closely three or four years ago about its contracting procedures, and what was termed wasteful investments in doing unneeded research in science. As such, they came up with a new contracting procedure, and I can tell you it's probably one of the cleanest procedures around now. We will never get in trouble because we can't do contracts. And that is not atypical of what's happened in other places. The system is growing more and more averse to risk. As far as I'm concerned, if I could throw all the rules away, I'd figure out a way to do that and still be ethical. But it's going to be a struggle. If you're running into specific problems with us, I'd plead with you to give me a call and see if we can break through it.

Q: I wonder if the floods that are going on now in California could be shown to be the result of bad drainage and land management.

Turner: Yeah, I'm sure it is, but my point is that it's not necessarily a cost of regulating, per se, as it is a strategy for accomplishing the resource management techniques that we want. Regulation is one thing that's in the toolbox. Whatever's in the toolbox, whether you use or don't use it, there are costs on both sides of the equation. That's all I'm saying. It's not a good or a bad attribute of regulation, it's just a conscious thing we have to all recognize.

Clarke: I think the answer to your question is yes, and you can go look at the Nooksack. You don't have to go all the way down to California. When I was at Ecology, we were trying to run some assessments on the Nooksack to see the nature of the change in hundred-year flood ways, to try to sort out what the potential dollar implications were for the loss of natural drainage areas. There's no reason that we shouldn't be focused, as resource agencies, more on those kinds of issues. EPA has one economist in our regional office; we're trying to add another one. But we ought to have many more than that, just to try to look at what the consequences on both sides of the issue are. I think you're exactly right.

Q: I would like to know when the government biologists and the government agencies are going to pay attention to two more public values that haven't been mentioned here, and that is the unorganized citizens' desire for affordable lumber and electricity; and women's and girls' love for horses, all of which are the very opposite of resource preservation. You have to cut trees for horse pastures. You can't preserve the natural vegetation if you're going to have a horse pasture. When will you people stop being so one-sided?

Clarke: I don't think we're one-sided at all, or we wouldn't be having the environmental problems we have right now. I think that we ought to be looking at multiple-use values, and we ought to be trying to be reasonable and rational on the way we deal with land-use issues and others. But this state doesn't have very particularly significant land-use laws, when you compare Washington to a lot of the other states in the country. In many instances, local governments are making a lot more of those decisions than either state or federal government is.

Q: Why is local government doing that?

Clarke: They're having those debates and discussions for the Growth Management Act and others. That's back to Bob Turner's point on the democracy, to making the choices and making changes in elected officials.

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PUGET SOUND RESEARCH '95

SESSION 8A

OCEANOGRAPHY OF PUGET SOUND: MODELS & OBSERVATIONS

Session Chair:

Curt Ebbesmeyer
Evans-Hamilton, Inc.

PREDICTING IDEALIZED EFFLUENT CONCENTRATIONS IN PUGET SOUND DUE TO VANCOUVER, VICTORIA AND SEATTLE SEWAGE DISCHARGES

E.D. Cokelet[1]

INTRODUCTION

Recently concern has been expressed that Puget Sound could be polluted by sewage effluent originating in British Columbia. The purpose of this paper is to contrast idealized sewage effluent concentrations in the Strait of Juan de Fuca and Puget Sound due to discharges from three municipalities—Vancouver, Victoria and Seattle—based upon predictions of the Puget Sound Reflux Model (Cokelet et al., 1985, 1990a-d, 1991). It is the only tool currently available to begin to model such effects. The reflux model predicts the concentration and age of conservative tracers in the Puget Sound/Strait of Juan de Fuca system based upon mass conservation and historical salinity and current observations.

METHOD

The estuarine system is modeled by nine advective reaches connected by mixing zones (Figures 1-2). The reflux model design focusses on Puget Sound and the Strait of Juan de Fuca with Canadian waters included in an approximate way. Georgia and Haro straits are lumped into one large mixing zone (MZ1) that receives runoff from the Fraser and other British Columbia rivers. Being large scale, the model apportions Vancouver's and Victoria's sewage effluent in the same way as the Fraser River runoff (R_1 in Figure 2). Simulations represent the time-independent, mean state of the circulation.

In model runs sewage effluent is considered to be a marked tracer, e.g., yellow dye, that is well-mixed within reach layers and behaves conservatively (nonreactively) in the estuary. No attempt has been made to account for the fact that one discharge may contain more contaminants than another or to account for a given constituent. In reality many pollutants are nonconservative in salt water. For example, nutrients are taken up by phytoplankton. Flotables such as oil, grease and buoyant organic aggregates can be driven ashore by the wind. Trace metals and toxic organics can undergo chemical and physical changes adhering to particles and moving with suspended particulates and sediment. No models exist, however, that can estimate the effects of nonconservative processes for the entire Puget Sound system.

To predict effluent concentrations the reflux model requires the discharge volumes from each municipality as given in Table 1. This shows that Vancouver discharges about 11 times more effluent than Victoria and 1.2 times more than Seattle.

RESULTS

Predicted effluent concentrations are shown in Figure 3. The error bars represent the standard error of the mean due to the combination of uncertainties in the effluent inputs (assumed to be ± 10%) and temporal variations in the runoff, salinities and currents upon which the model is based.

Strait of Juan de Fuca

Effluent concentrations in the outer Strait of Juan de Fuca (layer 2) contributed by Vancouver, Victoria and Seattle are 100, 9 and 83 parts per million (ppm) by weight, respectively (Figure 3). These values are in direct proportion to their effluent discharge rates because all inputs to the estuary of conservative substances must pass through this layer on their way out to sea. Concentrations in landward-flowing layer 1 are identically zero because it is assumed that no substances re-enter the estuary after being transported to the Pacific Ocean.

[1] NOAA/Pacific Marine Environmental Laboratory, 7600 Sand Point Way NE, Seattle, WA 98115-0070

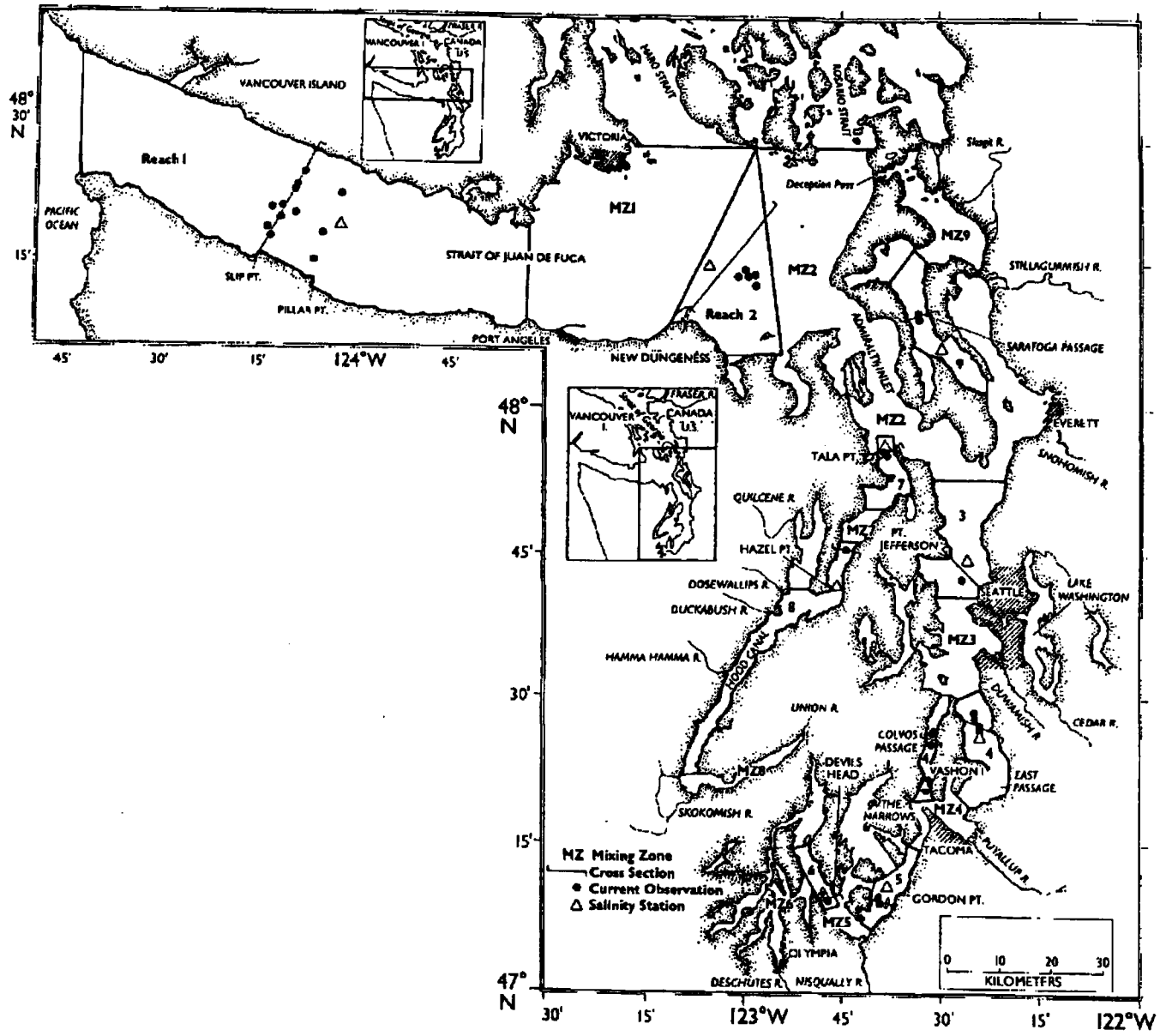

Figure 1. The reaches (bold outlines) and mixing zones (MZ) of the Puget Sound/Strait of Juan de Fuca estuary. Sites of current and salinity observations are shown.

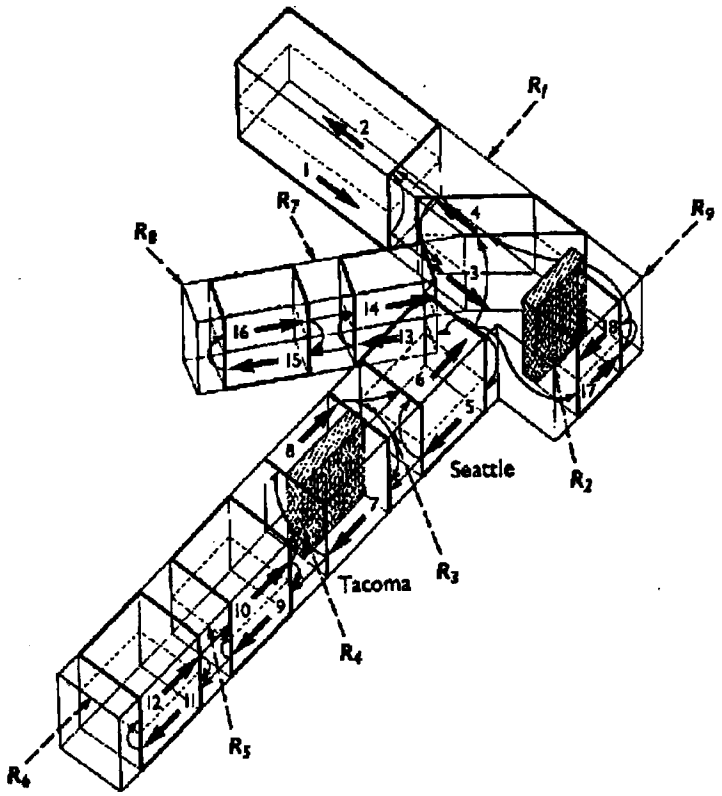

Figure 2. Schematic diagram of the Puget Sound Reflux Model. Odd-numbered layers flow landward and even-numbered layers flow seaward. Rivers are denoted by R_i where the index i refers to the mixing zone. Bold arrows denote two-layered reach flows, and thin arrows denote the efflux/reflux coefficients in the mixing zones. Not all arrows are shown in mixing zone 2.

Table 1. Effluent discharges From major sewage outfalls

Site	m^3/d	Reference
Vancouver:		
Iona Island	397,000	Paul West and Blair King, Dec. 1993, Draft Report, Environmental Studies and Chemistry Depts., Univ. of Victoria, Victoria, BC.
Annacis Island STP	380,000	
Lulu STP	54,000	
Lion's Gate N.S.	87,600	
Total	918,600	
Victoria:		Thurber Environmental Consultants Ltd., 10 Jun 1992, *Capital Regional District Source Sampling Project*, Report to Capital Regional District, File: 17-210-39, Victoria, BC.
Macaulay Point	41,243	
Clover Point	44,379	
Total	85,622	
Seattle:		
West Point STP	534,000	Puget Sound Water Quality Authority, 1988, *State of the Sound 1988 Report*, Olympia, WA.
Renton STP	231,000	
Total	765,000	

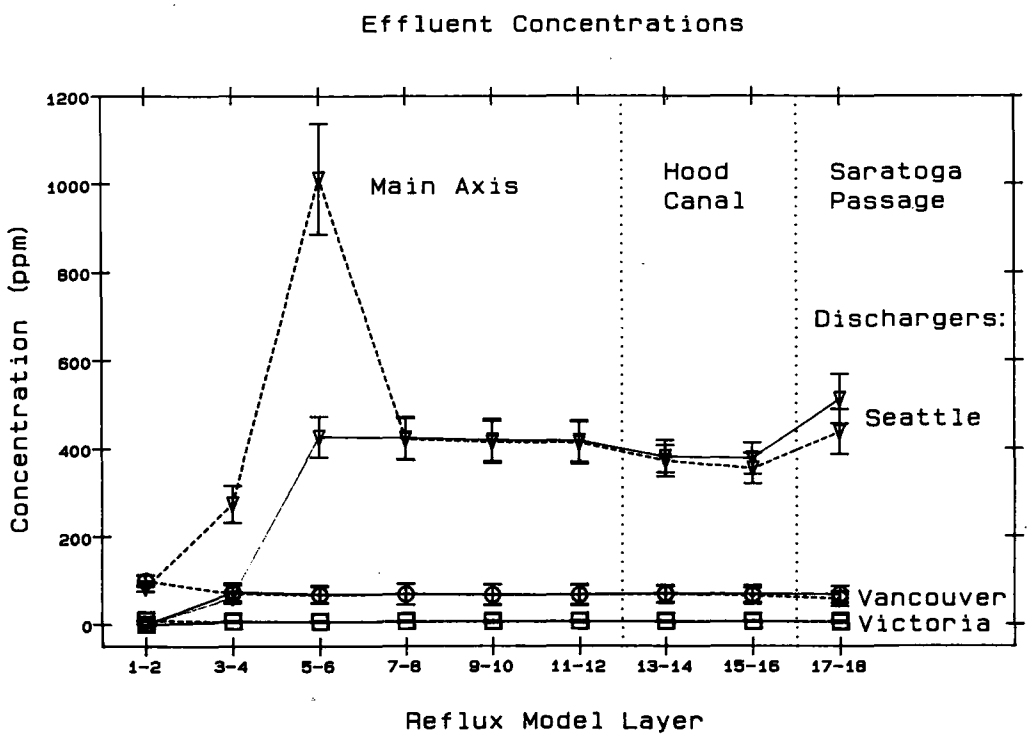

Figure 3. Puget Sound Reflux Model predictions of effluent concentrations in the Strait of Juan de Fuca and Puget Sound due to discharges from Vancouver, Victoria and Seattle. Solid lines represent landward-flowing layers, and dashed lines seaward-flowing layers.

In the inner Strait (layers 3-4), concentrations due to Vancouver and Victoria average 72 and 7 ppm. The only way these sites can contribute effluent is through recirculation or refluxing in mixing zone 1 (MZ1, Figures 1-2), where on average 22 percent of the less-saline surface water dominated by the Fraser River inflow mixes down and flows landward in layer 3 (Cokelet et al., 1990c). Seattle contributes 61 ppm to layer 3 due to refluxing in mixing zone 1 and 274 ppm to layer 4 as it receives water from Puget Sound.

Puget Sound

In Puget Sound (layers 5-18) Vancouver effluent concentrations average 67 ppm, Victoria 6.3 ppm and Seattle 455 ppm (Figure 3).

Vancouver's contribution is 11 times that of Victoria because it discharges 11 times more effluent, and the model distributes each in the same way. The effluent enters Puget Sound since 17 percent of layer 3's water enters layer 5 through mixing zone 2 in Admiralty Inlet (Cokelet et al., 1990c).

Seattle is responsible for about seven times more effluent in the Sound than is Vancouver and about 73 times more than Victoria even though it discharges only 0.8 and nine times as much, respectively. This is due to three factors. First, Seattle discharges directly into layer 6; therefore its effect is greatest there. Second, refluxing primarily in Admiralty Inlet retains substances injected into the main basin. Thirty-one percent of the seaward-flowing upper layer off Point Jefferson (layer 6) refluxes landward in Admiralty Inlet mixing zone 2 (Figures 1-2), bringing Seattle effluent back into the main basin through layer 5. In total 52 percent of the Puget Sound water (main basin, Hood Canal and Saratoga Passage) entering Admiralty Inlet refluxes landward. Third, 78 percent of the Vancouver and Victoria effluent entering mixing zone 1 flows directly out of the estuary in layer 2 without refluxing into the Sound (Cokelet et al., 1990c).

Sensitivity to Mixing Zone 1 Apportionments

The reflux model has been validated (Paulson et al., 1993) for an independent tracer, dissolved copper, landward from reach 2 (layers 3 and 4), but insufficient dissolved copper measurements and source strength data exist to extend the validation seaward to mixing zone 1 and layers 1 and 2. Therefore it is prudent to consider how the predictions could change if the reflux coefficients in mixing zone 1 were allowed to take on extreme values.

Conservation of water and salt mass show that from 0 percent to 37 percent of the Fraser River runoff could enter layer 3, as compared to 22 percent based on additional physical reasoning and used in the predictions above (Cokelet et al., 1990c). Using either extreme, the predictions are qualitatively similar to the earlier results: Concentrations in the outer Strait remain unchanged, and Seattle discharges dominate in Puget Sound. At one extreme, if no Vancouver or Victoria effluent enters the Sound, then concentrations due to those sources vanish and Seattle-caused values rise from 455 to 618 ppm. At the other extreme in which 37 percent of the Canadian sources enter layer 3, then Vancouver and Victoria sound-wide contributions rise from 67 and 6 ppm, respectively, to 90 and 8 ppm. Likewise, Seattle's share falls from 455 to 400 ppm.

CONCLUSIONS

The Puget Sound Reflux Model predicts effluent concentrations as a function of input and observation sites assuming the effluents to represent conservative tracers. In Puget Sound, Seattle (Metro) discharges dominate the predicted effluent concentrations with Canadian sources contributing much less. In the Strait of Juan de Fuca, Seattle and Vancouver contribute about equally with Victoria accounting for about one-tenth as much. Whether or not these relative predictions hold true for individual contaminants depends upon their concentration in the separate discharges and upon their reactivity in the estuary, neither of which were considered here. Further research needs to be undertaken to develop estuary-wide models to predict the transport and fate of nonconservative substances, especially those associated with particulates as are many contaminants.

ACKNOWLEDGMENTS

I thank Dr. C.C. Ebbesmeyer for his encouragement. This is contribution No. 1613 of NOAA's Pacific Marine Environmental Laboratory.

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A THREE-DIMENSIONAL CIRCULATION MODEL OF THE GEORGIA-FUCA-PUGET SOUND WATERWAY

J.A. Stronach[1]

INTRODUCTION

Modern numerical hydrodynamic models are capable of providing accurate three-dimensional descriptions of the total current field in coastal regions with the spatial and temporal resolution required to meet the demands of ecological simulation and contaminant fate modeling. The model to be discussed here, GF8, treats successfully the complex bathymetry and strong tides characterizing the Georgia-Fuca-Puget system, as well as the effect of wind and river runoff and forcing from the open ocean. It also allows for nested submodels so that specific areas can be examined in greater detail.

An accurate tidal and circulation model such as GF8 can contribute in a fundamental way to coastal management by providing the ability to generate and analyze a number of realistic scenarios, both as nowcasts and as forecasts. The application of GF8 to an oil spill risk evaluation and to the simulation of the dispersion from a submerged outfall will be discussed.

DESCRIPTION OF GF8

Figure 1 shows the basic configuration of GF8. Horizontally, the grid consists of 2-km square elements. Elevations, density, and scalar fields are assigned to the center of the cell, and horizontal velocities are stored at the edges. In the vertical, GF8 uses a number of fixed levels, which can have variable spacing over the water column.

GF8 is solved implicitly, using a 600-s timestep for the 2-km version. Tidal forcing is typically provided by using harmonic constants for the reconstruction of water levels at the open boundaries, but observed water levels could also be used. GF8 incorporates wind stress forcing, typically using the network of coastal lighthouses for wind data. Rivers are included in the model, and the flow from each river is tidally modulated, based on the tidal water level history at the adjacent grid cell. Horizontal friction is implemented using the Smagorinsky (1963) formulation, which depends on the local rate of strain. This formulation has proven to be effective when simulating complex flows in which the non-linear terms of the model lead to eddy shedding and vortex generation.

Vertical eddy viscosity is a function of the local vertical shear and Richardson number. This formulation is effective in terms of allowing realistic velocity profiles to develop, even in energetic areas such as the entrance to Admiralty Inlet. This formulation is quite general, so that flow fields in models with grid sizes ranging from 200 m to 5 km can be realistically simulated with minimal adjustment of the parameters for vertical eddy viscosity.

For the simulation of the advection and diffusion of passive scalars, such as wastewater from a submerged outfall, GF8 is combined with a transport-diffusion (TD) module, which is based on a flux-corrected formulation (Zalesak, 1979). The flux-corrected algorithm provides accurate solutions in which numerical dispersion is well-controlled, a prime concern when the source function is of limited spatial extent, such as a submerged outfall. The TD model has been proven to replicate the dispersion observed in dye studies, and also provides realistic distributions in response to such flow features as eddies and fronts.

A more complete description of GF8 can be found in Stronach et al. (1993), and applications to specific situations are discussed in Hodgins et al. (1993) and Hodgins and Stronach (1994).

[1] Seaconsult Marine Research Ltd., 8805 Osler Street, Vancouver, B.C. V6P 4G1 Canada

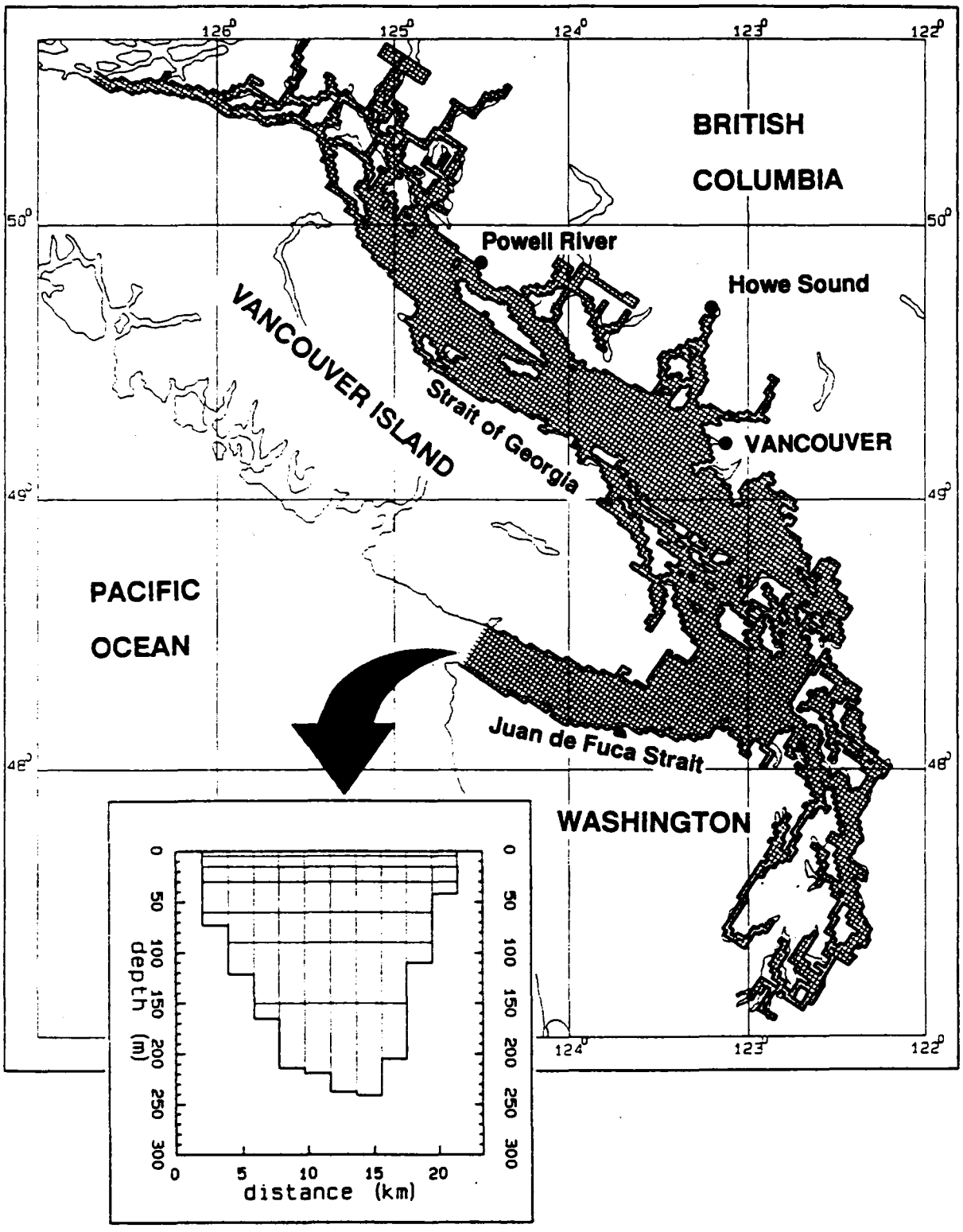

Figure 1. Map of the Georgia-Fuca-Puget system, overlain with the 2-km GF8 grid. Also shown are the vertical layer parameters corresponding to the bathymetry at the entrance to Juan de Fuca Strait.

VALIDATION

GF8 has been extensively validated using a number of different approaches. The first validations were done by comparing the reproduction of tidal water levels and tidal currents with observations, using the network of tide gauges and current meter observations readily available in the Georgia-Fuca-Puget system. The model successfully reproduced all features of the system, including the extensive modifications that the semi-diurnal tide undergoes as it passes through the system. For instance, the M_2 tidal amplitude had a 6% rms error throughout the system, and the rms error in M_2 currents was of similar magnitude.

For modeling the movement of contaminants and naturally occurring substances such as phytoplankton, a more important validation is to compare the observed evolution of scalar fields with that calculated by GF8. This has been done in several dye-tracing studies, such as Hodgins and Webb (1995) and Hodgins et al. (1993). In this paper, a validation with respect to the advection of denser water from the Pacific Ocean into Juan de Fuca Strait will be discussed. The process to be simulated is the annual renewal of bottom water in the system. An early investigation of the process was discussed in Crean et al. (1988), based on measurements between March 5 and April 16, 1973. It was observed that over this six-week period, denser water, which was originally at depths of 200 m in the offshore, moved up onto the sill at the inner end of Juan de Fuca Strait.

A severe test of GF8 is to determine to what extent it can simulate this density intrusion. Based on the six CTD sections obtained near the entrance to Juan de Fuca Strait over this six-week period, a time-series of sigma-t sections was generated to provide boundary conditions for a GF8 simulation of the event. Although GF8 requires data at intervals as small as its 600-s timestep, the boundary conditions for density are implemented so that the slowly varying signal from boundary data such as the CTD observations can be smoothly blended with the tidally varying processes occurring in GF8, similar to the sponge technique sometimes used as a boundary condition for the momentum equation. In addition to the density data at the mouth of Juan de Fuca, winds from a network of coastal lighthouses including Cape Beale and Race Rocks were also used in the simulation.

Figure 2 presents a comparison of the observed and modeled intrusion at the end of the observation period. In both cases, water with a salinity of 33 ppt was original located at depths greater than 200 m off Cape Flattery but has ultimately moved up over the sill at Victoria. The agreement between model and observations is excellent, especially considering that there were no observations between March 16 and April 13, so the model relied on linear interpolation in time over this interval. This close agreement lends considerable credibility to the use of GF8 for long-term simulations. It is remarkable that this process was simulated without the use of observed water level data, the water level boundary condition being derived solely from tidal harmonic constants. The realistic simulation provided by GF8 illustrates that the intrusion process is primarily a baroclinic one, and information on the density field at the mouth is required to drive intrusive processes.

OIL SPILL RISK ASSESSMENT

One of the important marine issues in the Georgia-Fuca-Puget waterway is the impact of oil spills arising from accidents either at sea or at a loading terminal. Although reduction of risk by improvements in ships and shipping infrastructure is the first line of defense, it is also important to know the relative risk of various shipping alternatives. A prime application of this methodology would be the selection of preferred shipping routes, for example. Relative risks can be evaluated by combining oil spill trajectory modeling with a statistical description of the probability of an accident occurring and the probability of damage expressed in a quantitative unit such as dollars. The complete methodology is described in Hodgins et al. (1991). Here, only an example from the trajectory modeling component will be described. In this example, GF8 is used to provide the surface current field for the simulation of a spill originating at the eastern end of Haro Strait. The spill history, including both the trajectory and the weathering aspects, is simulated using the oil spill model SPILLSIM. A Monte Carlo technique is used for the simulation, and 10000 particles were used to simulate an instantaneous release. Two snapshots of the spill,

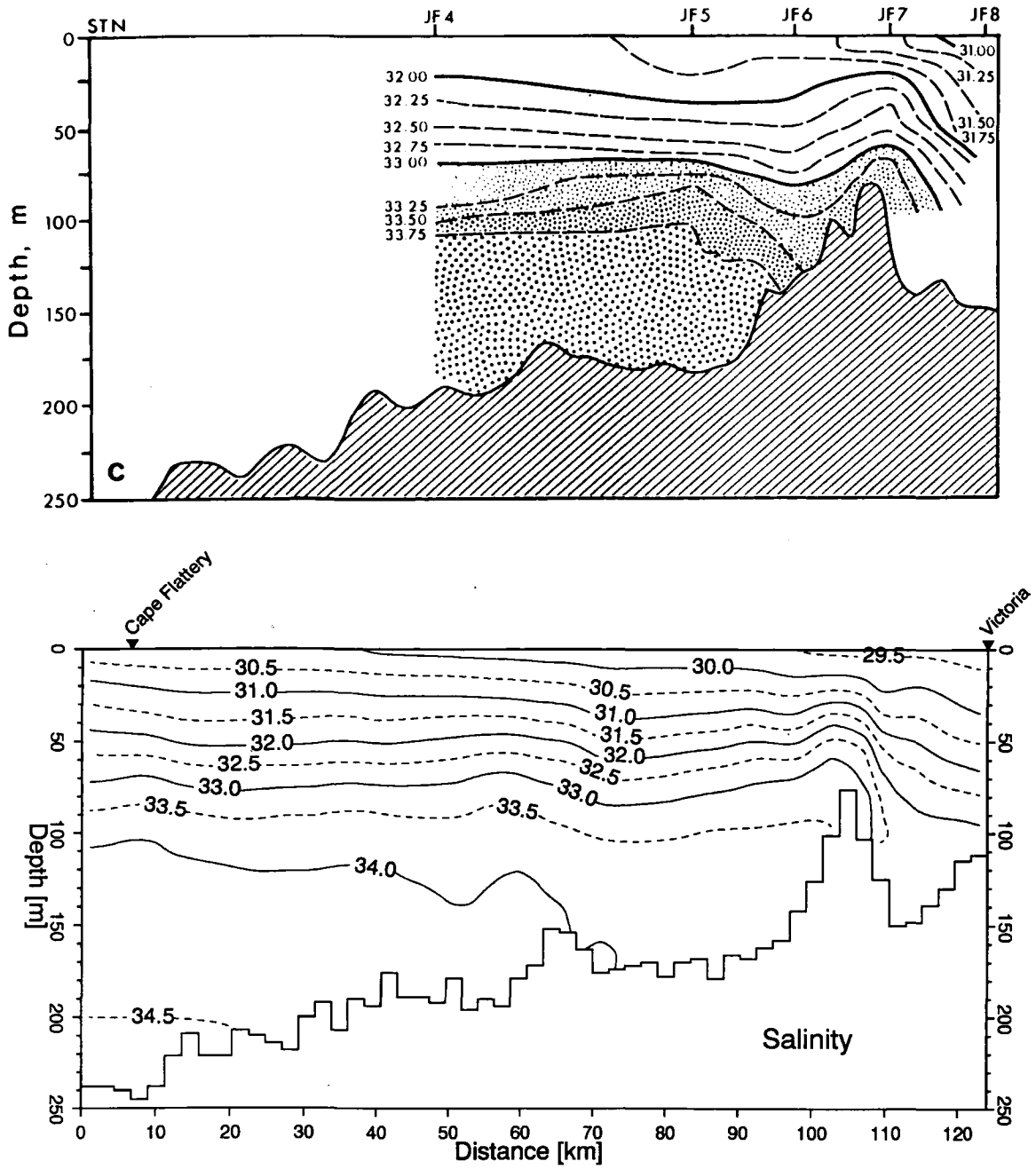

Figure 2. Observed (top) and modeled (bottom) salinity structure in Juan de Fuca Strait at the end of an intrusion event observed between March 5 and April 16, 1973

nine and 18 hours after the release, are shown in Figure 3. Figure 3 (top) shows that after nine hours, the slick is confined to a narrow filament, lying off the southeast corner of Vancouver Island, and has oiled an extensive area along San Juan Island. After 18 hours, following a flooding tide, this filament has been broken into two major fragments, and the spill has undergone extensive dispersion, a result of the shear in the flow field.

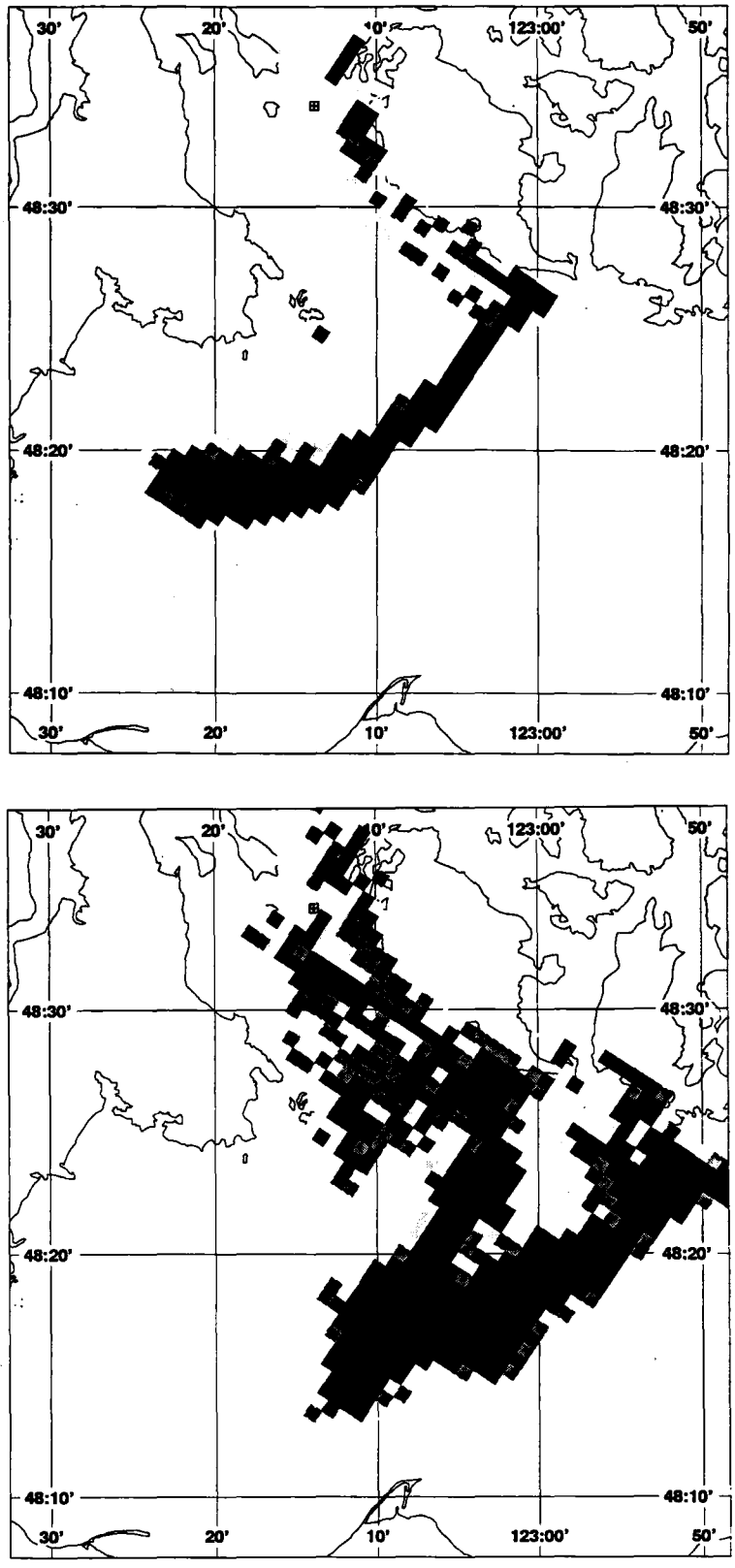

Figure 3. Distribution of oil computed by SPILLSIM using GF8 flow fields, 9 hours (top) and 18 hours (bottom) after the initial spill. The location of the spill is shown by the small box located at approximately 48° 34'N, 123° 13'W.

Diverse as these two snapshots of the spill distributions are, there would undoubtedly be a considerably different one if the spill site were moved a few kilometers, or if the release schedule were changed. However, when the complete range of spill scenarios is adequately sampled, patterns do emerge so that one can arrive at quantitative differences between a range of shipping alternatives (Hodgins et al., 1991).

WASTEWATER DISPOSAL

GF8 and the TD module are powerful tools for evaluating the operation of a wastewater disposal system. Although a number of packaged models are available to estimate the initial dilution from a submerged outfall, they cannot adequately describe the spatial distribution of contaminants in the far field, nor are they suited to determining long-term chronic conditions. GF8 is well-suited to these tasks, and is particularly useful when it is used at two different spatial scales. Typically, a high-resolution grid is embedded within the overall 2-km grid, so that conditions in the immediate vicinity of the outfall are simulated with a resolution governed by the expected spatial gradients in the contaminant distribution. For this high-resolution simulation, the overall model provides much better boundary condition data than could be obtained by observation. Moreover, by carrying the contaminant distribution from the high-resolution model into the overall model, effects in the extreme far field can be calculated as well. A case study of the

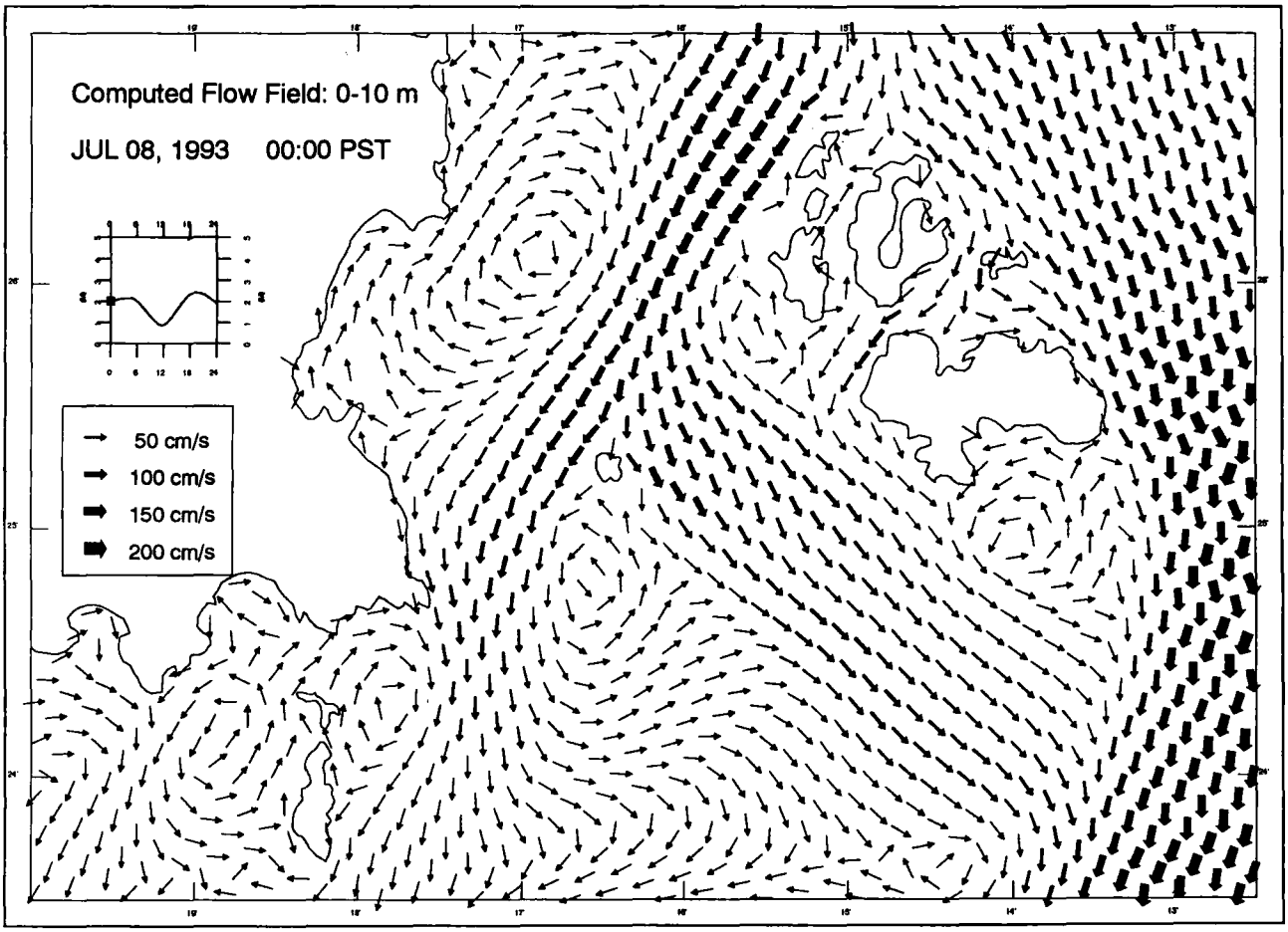

Figure 4. Flow field in the vicinity of Trial and Discovery islands, computed by GF8 using a 200-m grid

wastewater distribution in Ganges Harbor on Saltspring Island is described in another paper at this conference (Hodgins and Webb, 1995). Here, we will present only a snapshot, Figure 4, of the flow field from a similar high-resolution model for the CRD discharges at the south end of Vancouver Island, using a 200-m grid. The vector plot shows currents around Trial and Discovery Islands on an ebbing tide. Notable features in this flow field are the numerous eddies and strong shear lines, which would not be resolved with a coarser grid. This highly resolved flow field will allow CRD to examine both near field impacts, such as on local beaches, and far field impacts. The simulation of the transport and dispersion of contaminants from the outfalls is carried over from the 200-m fine grid model and the overall 2-km model, so that the fate of these contaminants can be examined out to the Pacific Ocean.

CONCLUSIONS

GF8 has been briefly reviewed, and examples of its application in local waters discussed. Within the past few years, sufficient computer resources have become readily available to make these extensive long-term, three-dimensional calculations practical. Furthermore, more recent observational tools, such as HF radar and sophisticated current meters, will provide the ability to validate the complex flow features produced in models such as GF8.

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HIGH-RESOLUTION OBSERVATIONS OF SILL DYNAMICS IN PUGET SOUND

James A. Turner and Michael C. Gregg[1]

INTRODUCTION

As the principal connection between Puget Sound and the Strait of Juan de Fuca, Admiralty Inlet is the pathway for new ocean water entering the sound and for freshwater runoff leaving. Mixing is particularly complex because the inlet is relatively long, has rugged topography, and is the junction for several basins of the sound. Various investigators have hypothesized that the inflowing ocean water and outflowing fresh water are strongly mixed together in Admiralty Inlet by turbulence and vertical advection (Ebbesmeyer and Barnes, 1980; Geyer and Cannon, 1982). There were no direct observations of specific mixing processes in these studies, however, owing to the coarse resolution of the available data. Data we recently collected at the landward end of Admiralty Inlet revealed a variety of processes related to mixing. A particularly dramatic one was the formation of large internal waves by the interaction between the flowing water and bottom topography. These waves lead to intense turbulence and downward advection from the surface. This study is valuable because it is the first of sufficient spatial and temporal resolution to identify the mixing mechanisms at a sill of the Puget Sound that up to now have been inferred.

BACKGROUND

The Puget Sound is a complicated estuary that consists of various basins interconnected by shallower sills and inlets (Figure 1). The 60 km long main basin is about 200 m deep and 3 to 5 km wide. The main basin is bounded by two sills at its north and south ends, Admiralty Inlet and the Tacoma Narrows. Unlike most estuaries, nearly half of the freshwater input enters near its seaward end, coming from the Skagit, Stillaguamish, and Snohomish rivers (Ebbesmeyer and Barnes, 1980). Currents throughout the sound are dominated by the twice-daily tides. The time-averaged circulation in the main basin is typical of estuaries, with seaward flow above about 50 m and landward flow below (Cannon, 1983).

Admiralty Inlet is approximately 30 km long and has an average depth of about 125 m. It has a complex topography featuring turns, lateral constrictions, ridges, and bottom depressions. This rough topography has been attributed to tectonic processes acting along the South Whidbey Island fault line (M. Holmes, personal communication, 1994). There are two shallower zones at its north (seaward sill) and south (landward sill) ends with minimum depths of 65 m and 100 m, respectively. It has been recognized that strong tidal currents, typically exceeding 1 m s^{-1}, along Admiralty Inlet produce significant mixing and that understanding these dynamics is an important step in understanding the overall circulation of the sound.

Previous studies have indicated that there is a conveyor belt-type circulation pattern at the landward end of Admiralty Inlet, where the outflowing surface water is returned to the main basin with the inflowing deep water. It has been hypothesized that between one-half and two-thirds of the outflowing water is returned to the main basin through a combination of mixing and vertical advection known as refluxing (Ebbesmeyer and Barnes, 1980; Cokelet et al., 1991). Refluxing is important because it can significantly increase the residence time of an average parcel within the estuary. The residence time is a primary factor in predicting the concentration of pollutants discharged into an estuary or determining the availability of nutrients and light to phytoplankton.

The flow of ocean water across Admiralty Inlet into the main basin seems episodic, usually at two-week intervals. Geyer and Cannon (1982) hypothesized that mixing at the sill reduces the density of the intruding water and the strength the inflow. They explained the period of the intrusions by assuming that

[1] University of Washington College of Ocean and Fishery Sciences, Applied Physics Laboratory and School of Oceanography, 1010 NE 40th St., Seattle, WA 98105

the mixing intensity is proportional to the tidal current amplitude, which varies with the spring-neap tidal cycle (two-week period). Other work related the inflow events to the horizontal density gradient across the sill (Cannon et al., 1990). Higher-resolution observations revealed specific processes such as mid-depth shear instabilities and large internal waves at the landward sill (Seim and Gregg, 1991).

OBSERVATIONS

Cruise Description

With funding from the Office of Naval Research, we collected data for nine days between April 17 and 28, 1993, from the *R/V Miller*. The purpose of this cruise was to follow up on the observations of an earlier study that revealed vigorous mixing at the landward sill of Admiralty Inlet (Seim and Gregg, 1991) and to identify the processes. The primary area of study was the southern 10 km of Admiralty Inlet which encompassed the landward sill. Like the rest of Admiralty Inlet, this region has a complex topography that includes constrictions, turns, and rough bathymetry. The bathymetry features two pronounced ridges near Double Bluff with depths near 90 and 100 m. This study period coincided with the second spring tide of April.

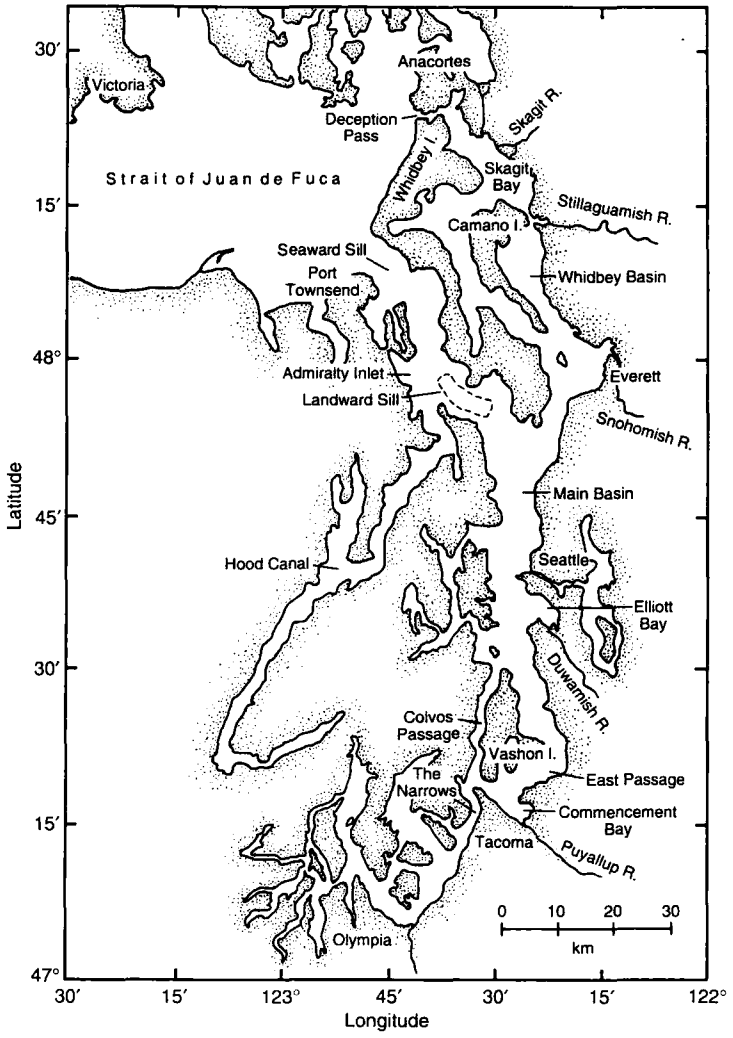

Figure 1. Map of the Puget Sound. Our study area at the landward sill of Admiralty Inlet is indicated with the dashed line.

The scheme for data collection for five of the nine days was to run SWIMS (Shallow-Water Integrated Mapping System) repeatedly over the same track throughout one of the two daily tidal cycles. The first three days were spent running sections along the centerline of the landward sill. Two days were spent running across-channel sections, one day each just north and south of the landward sill. The tides were mostly flooding during the along-channel data collection while the transition from ebb to flood occurred during across-channel data collection.

The SWIMS, developed with funds provided by Washington Sea Grant Program, included a vessel-mounted RD Instruments 150 kHz narrowband acoustic Doppler current profiler (ADCP), a BioSonics echosounder equipped with 120 and 200 kHz transducers, a Sea-Bird CTD (conductivity, temperature, depth), and Global Positioning System receivers for navigation. The ADCP measures a vertical velocity profile using the Doppler shift of acoustic pulses, which scatter from particles in the water. The ADCP was run in bottom-track mode so that absolute velocities could be calculated. Two-minute averaged profiles were recorded, which had a vertical resolution of 4 m and generally covered the upper 85 percent of the water column. Our estimates of transports from the ADCP measurements are within a few percent of

those calculated with the NOAA tidal model (Lavelle et al., 1988). The echosounder collected acoustic backscatter data, which could then be used as flow visualization measurements. Acoustic backscatter profiles were taken at 1 second intervals with a vertical resolution of 0.5 m.

The CTD was mounted in a heavy towed body and had two pairs of temperature and conductivity sensors. A shipboard winch was used to tow the CTD in and out while the ship steamed, thereby producing a sawtooth path. The towed body was also equipped with a DataSonics altimeter, which measured distance from the bottom. The altimeter allowed us to sample to within a few meters of the bottom, which was necessary for us to study intrusions of bottom-water, which were expected to be relatively thin. A complete depth cycle of the towed body typically required several minutes in depths of 125 meters. Because the tidal velocities at our study location typically exceeded 1 m s^{-1}, the number of cycles possible over a fixed horizontal distance varied between steaming with and against the currents. At typical ship speeds in weak tidal currents and depths near 125 m, a cycle took 300-400 m along the ship track. Typical climb and fall rates were near 1 m s^{-1}.

Physical Oceanography of the Landward Sill

As a result of the topography, the confluence of different water masses, and unsteady tidal forcing, the density and current structure at the landward sill exhibited complicated and often confusing behavior. Despite this complexity, some features were consistently observed. Flow past topographic projections at the channel sides often led to the formation of large vortices or eddies. Figure 2 shows the structure of the current and density field across the channel during decelerating ebb flow. Each current vector shown is the vertical average of an ADCP profile. The current and density data were taken simultaneously as the ship ran across the channel from the northeast to the southwest side. The flow direction reversed near the channel sides, which indicates the presence of closed horizontal circulation cells or vortices. These vortices are related to flow separation and are important because they change the effective cross-channel area for transport and may lead to turbulence. In the section of Figure 2, the distance between the 40 m depth contours is about 5.5 km, but the cross-channel width of the northward flow is only 3.5 km.

The contour plot of density is also noteworthy for the steep slopes in the upper 50 m near the channel sides (1 MPa pressure = 100 m depth). If the flow through this section were laterally uniform and were not being mixed, we would expect to see horizontal contours across the channel. The steep slopes imply that there is a destabilizing mechanism at the channel sides, such as velocity shear, or that the water mass exiting the main basin is not uniform. In fact, it is probably a combination of mixing and non-uniformity of the water that produced this density structure. The vortices would be a likely source of turbulence and mixing. The lateral non-uniformity could stem from a river plume that originates in Whidbey Basin and flows north through Admiralty Inlet along the northeast bank during ebb tide.

A striking feature that was frequently seen in the data was the internal response to the bottom topography, particularly at the two ridges and the exit slope from the inlet into the main basin. This response was generally observed during the peak and decelerating stages of flood tide and included wavelike displacements on the downstream side of the ridges or slope. Figure 3 is an example of such a wave at the exit slope, which was observed shortly after peak flood. The acoustic image shows a horizontal scattering layer, which is depressed about 50 m over a distance of 400 m. The contoured density plot features a region of displaced contours at the same location. The velocity profiles also show a response at the same location. The vectors displayed are the along-channel component of the measured velocities. There is a reduction in the velocity magnitudes in the upper 50 m of the profile taken at 2155 UTC. If this velocity structure is steady and the across-channel velocities are negligible, from continuity we would expect downward velocities (downwelling) on the upstream side of the wave where there is horizontal convergence and upward velocities on the downstream side where there is divergence.

At times, the topographic response was accompanied by large overturns and other evidence of downwelling. Figure 4 is the contoured density field and acoustic backscatter image overlaid with density profiles for a section taken along the channel after peak flood tide. The density profile near 2240 UTC shows large density inversion overturning between 25 and 75 m depth. Density overturns are formed in a

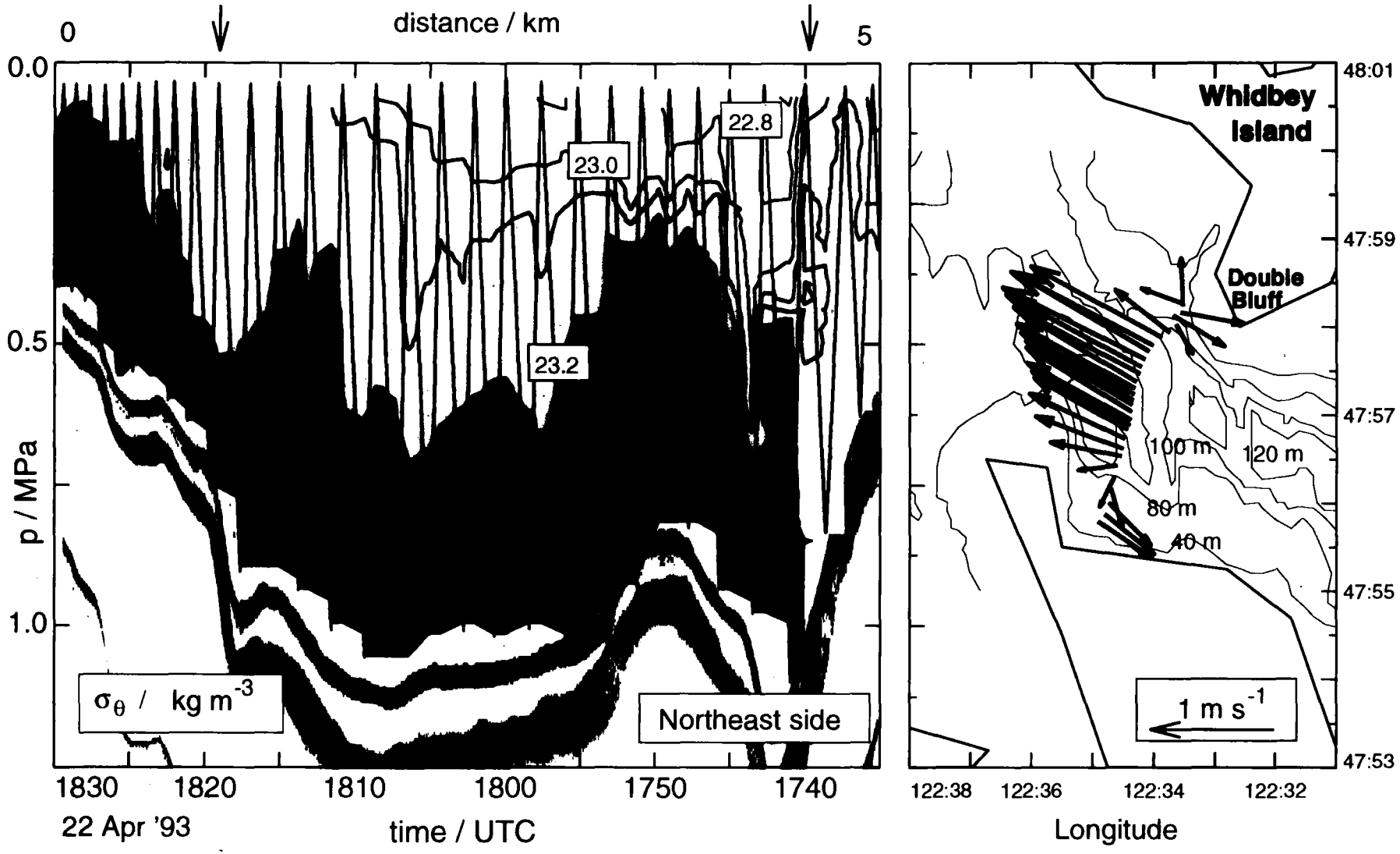

Figure 2. Contoured density (σ_θ = ρ - 1000 [kg m^{-3}]) and vertically averaged ADCP velocities from a cross-channel section. The base of the current vectors corresponds to the track of the ship. The map of the sound includes the 40, 80, 100, and 120 m depth contours. The sawtooth path of the towed body is shown on the density plot which has been overlaid onto an acoustic backscatter image indicating the bottom. The arrows on the distance axis mark the edges of seaward flow zone.

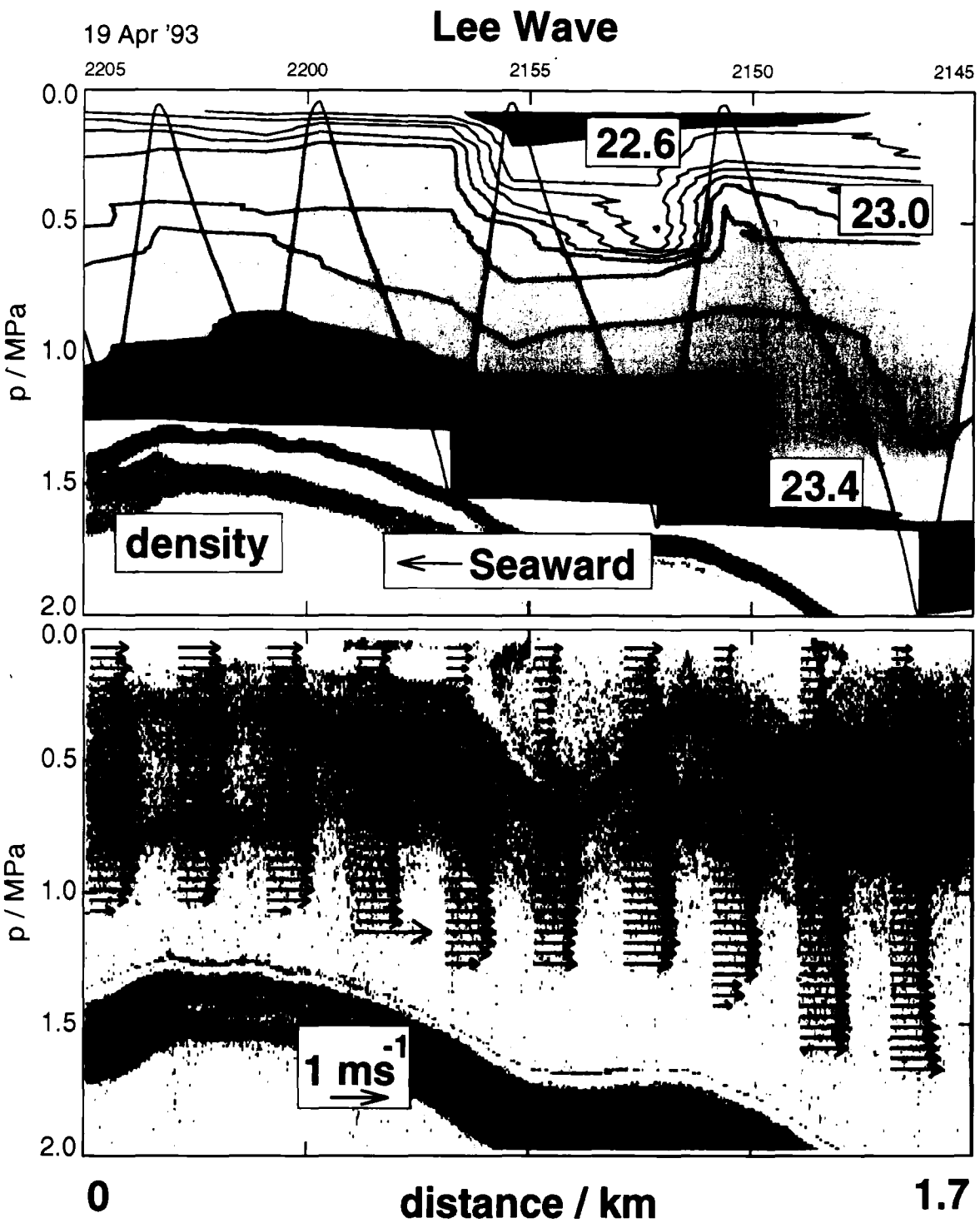

Figure 3. Contoured density (top panel) and acoustic backscatter (bottom panel) from an along-channel section which shows an internal wave that was crossed about 2155 UTC. The backscatter plot is overlaid with profiles of along-channel velocity. The sawtooth path of the towed body has been overlaid onto the density plot. A plot of the ship track is shown in the lower left-hand corner of the backscatter image.

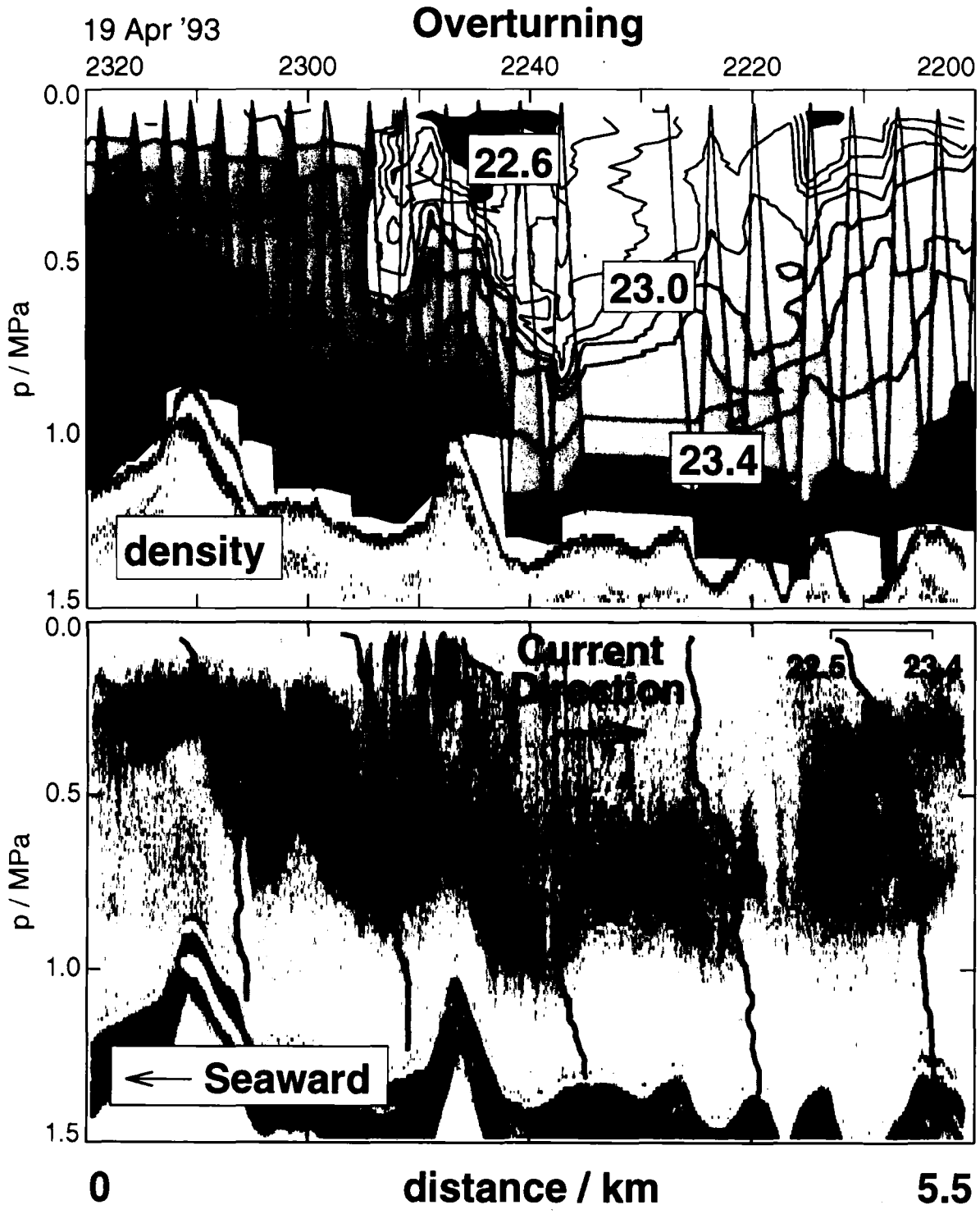

Figure 4. Contoured density (top panel) and acoustic backscatter (bottom panel) which show overturning on the downstream side of the large ridges. The backscatter plot is overlaid with 5 density profiles. The ship track is shown in the lower left-hand corner of the backscatter image.

stratified fluid when turbulent eddies vertically displace a water parcel from its stable position. The overturning we observed is likely caused by internal waves that become unstable and break, much like surface waves breaking onto a beach. An acoustic scattering layer is also present in the upper 25 meters directly above the 100 m deep sill we crossed at 2245 UTC. In the density plot, it can be seen that this scattering layer coincides with steep contours in the upper 50 m at the upstream edge of a core of lighter water. This structure is consistent with the expected response to downwelling from the surface. Downwelling would displace contours and transport air bubbles or other floating particles to the interior, thereby producing increased acoustic scattering.

Our observations of internal wave activity and the associated turbulence and downwelling are important because these mechanisms have been inferred from larger-scale studies without direct observation. Models of the Puget Sound have been formulated that require refluxing of surface water at the landward sill of Admiralty Inlet for their predictions to match the observed salt and mass fluxes (Cokelet et al., 1991). The mid-depth overturns caused by the waves would be efficient in mixing the seaward-flowing surface water and landward-flowing deep water. Downwelling of the surface water during flood tide would also contribute to the refluxing of water back into the Main Basin. Because these structures were consistently observed at the ridges and slope, we believe their dynamics are related to the flow of stratified fluid over topography.

TOPOGRAPHIC INTERNAL WAVES

The fundamental parameter describing the response of the flow of a stratified fluid over topography is the internal Froude number, F_i:

$$F_i = u/c_i \qquad (1)$$

where u is the vertically averaged upstream velocity and c_i is the phase speed of a mode-I internal wave (Farmer and Freeland, 1983). The internal Froude number is the ratio of the flow to the phase speed of the internal waves of the i-th mode. When $F_i > 1$, the flow is said to be supercritical to the mode-i internal wave. It is critical and subcritical for $F_i = 1$ and $F_i < 1$, respectively. Because the phase speed is determined by the vertical density structure, we could compute values for c_i with our CTD data. We calculated u using the ADCP measurements. We also assumed that the ridges provided the forcing for the internal waves. Because the ridges at the landward sill are oriented with their axes north-south, only the east-west component of flow was used to determine u.

The hydraulic theory of steady flow predicts that a mode-i stationary internal wave (lee wave) is not possible whenever $F_i > 1$ because disturbances that propagate at the phase speed, c_i, are swept downstream by the faster current (Long, 1955). The response of steady flow over a sill which is supercritical to a mode-1 wave will feature density contours rising as the crest is approached with a subsequent return to their upstream position (Figure 5). The upper panel of Figure 6 is a contour plot of density taken while crossing the ridges during peak flood. The Froude number calculated for a mode-1 internal wave was about 2.3. There is a pronounced displacement in the density contours on the downstream side of the ridges, between 2210 and 2225 UTC. Steady supercritical flow across the sill should feature density contours that rise and fall over each ridge. The density contours from this section, however, clearly do not follow the bottom topography. Although the Froude number would indicate that the flow is supercritical, the density structure is not consistent with steady supercritical flow.

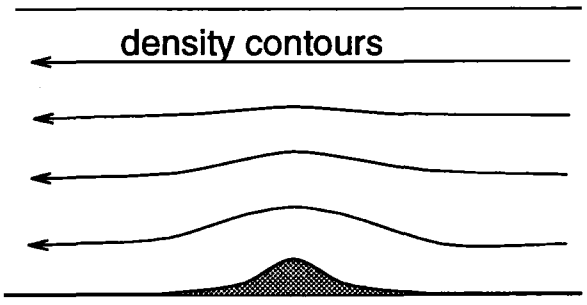

Figure 5. Schematic diagram of stratified flow over a sill that is supercritical to the mode-1 internal wave

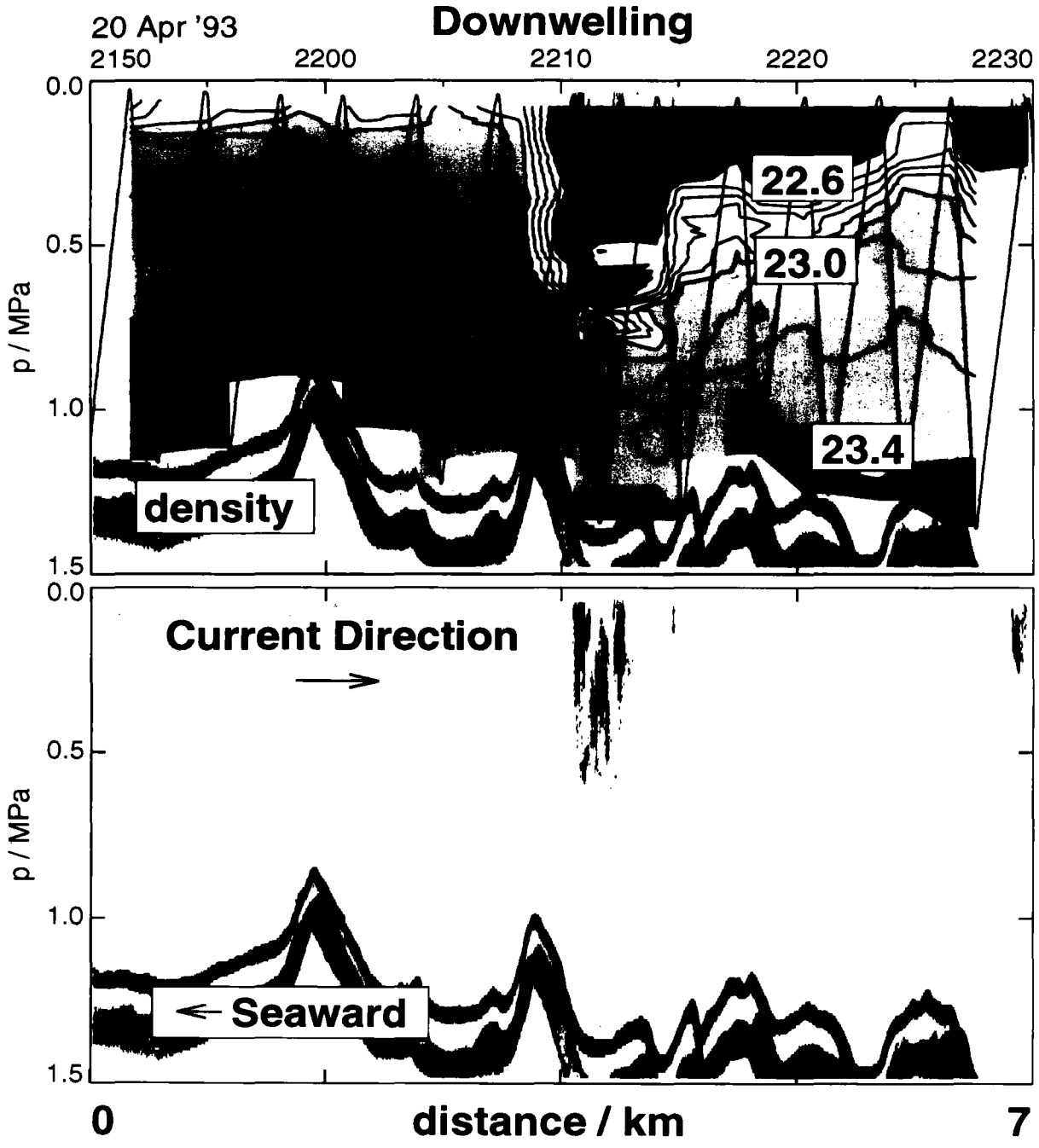

Figure 6. Contoured density (top panel) and acoustic backscatter (bottom panel) from an along-channel section during peak flood tide. The contoured density plot does not always match well with the bottom depth of the acoustic image because of the contouring algorithm used.

The evolution of the density structure throughout a tidal period also indicates that the response is unsteady. Hibiya (1986) notes that "if the internal wave is a quasi-steady wave, it should stay over the sill with its amplitude slowly decreasing with time" as the tide goes slack. Figure 7 is a series of density contours along the channel during flood tide. Part (a) corresponds to accelerating currents, (b) to peak flow, and (c) and (d) to the decelerating stage. The internal response is weak in the accelerating stage and is greatest during peak and decelerating flow. The largest contour displacements are seen in plots 7(b) and

(c) on the downstream side of the ridges in the upper 75 m. A stronger response during decelerating currents was the fundamental difference between steady and unsteady flow as shown by Lansing and Maxworthy (1984) and Hibiya (1986).

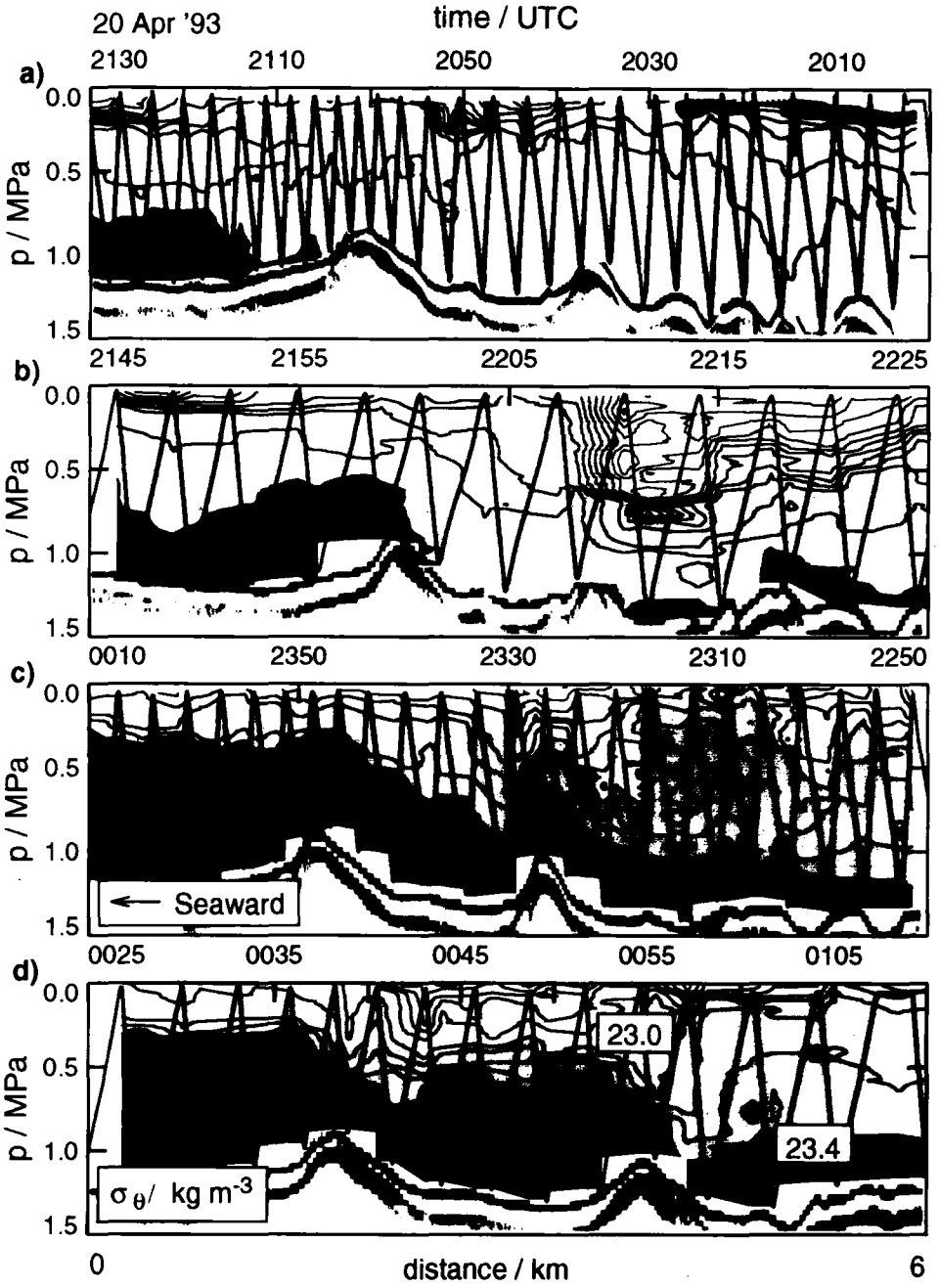

Figure 7. Time-series sequence of contoured density plots taken during flood tide. Note that the time axes of parts (a) and (c) have been reversed so that all of the plots are aligned with the seaward end on the left side. The tide is accelerating for part (a), is at peak for (b), and is decelerating for (c) and (d). The ship track for each is the same as that of Figure 6.

Our data indicate that there is a strong internal response to the bathymetry of the landward sill, which is not well described with steady hydraulic theory. The overturning and downwelling associated with the waves were most pronounced when the flood tide was at its peak and during deceleration. Because mixing and downwelling at the landward sill will have an impact on refluxing water back into the main basin, quantifying the rates and magnitudes of these processes is important.

MIXING

There are a number of different mechanisms that could lead to vertical mixing at Admiralty Inlet, such as a turbulent bottom-boundary layer, shear instabilities, or the previously mentioned unstable internal waves. To quantify the mixing intensity at the landward sill, we can use the CTD data along with a few assumptions to estimate the dissipation rate, ε, and a vertical eddy coefficient, K_ρ. Turbulent dissipation, ε, is the rate at which kinetic energy is extracted from the flow by viscosity. The eddy coefficient, K_ρ, is a parameter that can be used to calculate turbulent fluxes.

A fundamental length scale which is formed with measurements of ε and the buoyancy frequency, N, is the buoyancy or Ozmidov scale, L_B:

$$L_B = (\varepsilon/N^3)^{1/2} \tag{2}$$

A related length scale is the overturning or Thorpe length scale, L_T:

$$L_T = [d'^2]^{1/2} \tag{3}$$

where d' is the displacement of a parcel computed by comparing an unstable density profile to a resorted, stable one and the brackets denote an appropriate averaging interval (Thorpe, 1977). If it is assumed that $L_T = L_B$, we can estimate ε by substituting L_T for L_B into equation 2. From observations taken in a variety of environments, the value of L_B / L_T has been shown to be about 1 (Dillon, 1982; Seim and Gregg, 1994; Wesson and Gregg, 1994). Thus, an assumption of equivalence is valid for the purposes of demonstration with our data. With the CTD data, we computed values for L_T and N in a manner similar to Dillon's (1982). Based on the quality of the data, we estimate that the minimum ε resolvable is about 10^{-8} W kg^{-1}.

The calculation of ε is useful for determining what regions of the flow are turbulent, but ε itself is not a measure of the process we are interested in, namely mixing. Mixing a stratified fluid increases its potential energy, thereby producing a negative buoyancy flux, J_B. Given a buoyancy flux, we can calculate a vertical diffusivity, K_ρ, with the equation:

$$K_\rho = -J_B/N^2 \tag{4}$$

where N is the buoyancy frequency. The ratio of buoyancy flux to turbulent dissipation has been determined experimentally so that we can use $K_\rho = 0.2(\varepsilon / N^2)$ as an upper bound for the eddy diffusivity. Although this diffusivity was defined for the flux of density, it is reasonable to assume that it is representative of the fluxes of other properties such as salt or heat.

Figure 8 shows profiles of displacement d', rms overturns L_T, ε, and K_ρ for two different conditions. Figure 8(a) corresponds to a profile made several kilometers north of the ridges in weak, accelerating flood currents. The largest rms overturns have values up to 5 m and are located in the lower half of the column. The dissipation is also relatively weak with peak values of 10^{-7} W kg^{-1}, and the diffusivities are between 10^{-3} and 10^{-2} m^2s^{-1}. Because most of the profile is relatively quiet with only a few turbulent sections, we could describe this as patchy turbulence. Figure 8(b) corresponds to a profile taken a few hundred meters south of the ridges during the decelerating stage of the flood tide. This profile has larger overturning throughout the column with rms values exceeding 10 m. Most of the profile is actively mixing, and the rates are decades higher than the other section, with peak values exceeding 10^{-5} W kg^{-1}. The corresponding eddy diffusivities are also higher with peaks up to 10^{-1} m^2s^{-1}. For comparison, typically measured values of dissipation in the oceanic thermocline are near 10^{-9} W kg^{-1} and its reference diffusivity is 10^{-4} m^2s^{-1} (Munk, 1966).

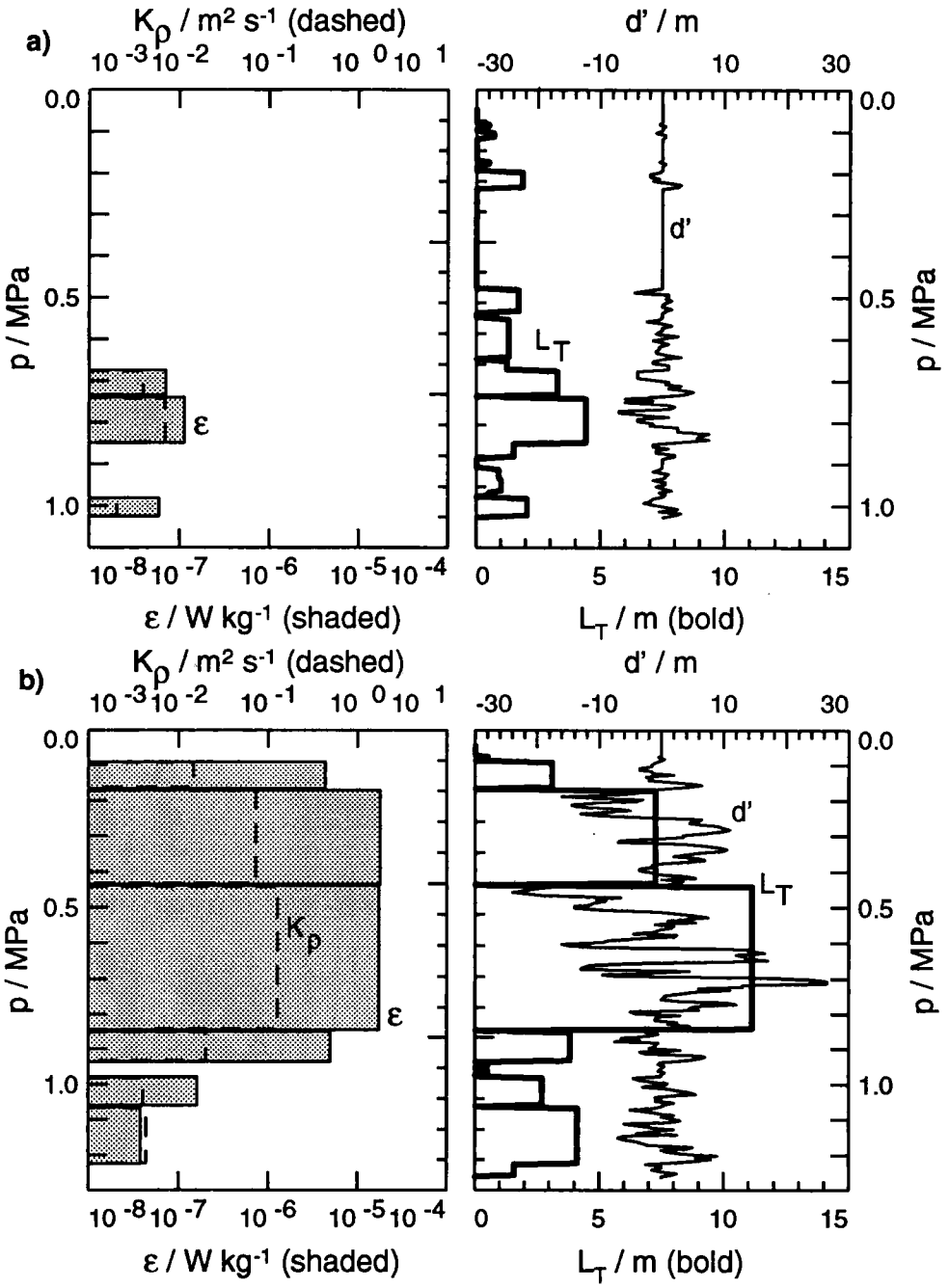

Figure 8. Profiles of displacement (d'), rms overturns (L_T), turbulent dissipation (ε), and vertical eddy diffusivity (K_ρ). Profile (a) was taken several kilometers north of the large ridges in weak, accelerating flood currents. Profile (b) was taken a few hundred meters south of the ridges during a decelerating flood tide.

Figure 9 is a contour plot of ε and density made with data collected along the channel during the decelerating stage of flood tide. The structure in dissipation along this section is typical of the along-channel sections at this tidal stage: There is intense turbulence on the downstream side of the ridges between 2300 and 2320 UTC with weaker dissipation in the surrounding areas. Typical dissipation rates away from the sills are near 10^{-7} W kg^{-1} while values peak at over 10^{-4} W kg^{-1} on the downstream side of the sills.

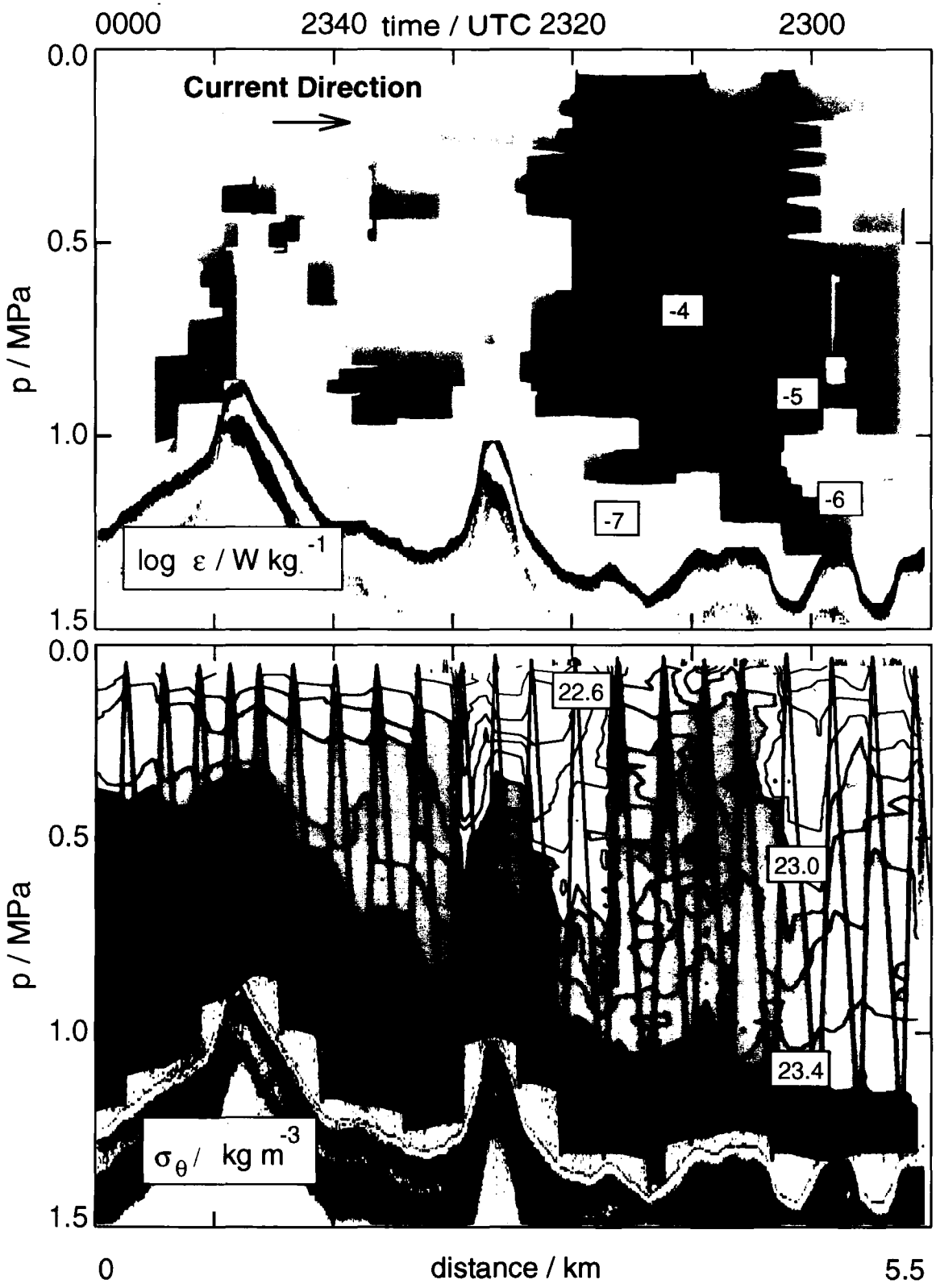

Figure 9. Contoured dissipation (top panel) and density (bottom panel) from data taken along the channel during decelerating flood tide. The dissipation values were calculated using the measured density overturns. There is intense turbulence throughout the water column on the downstream side of the ridges. The density plot shows large overturning in the same region.

These estimates compare reasonably well with direct measurements of turbulence at the landward sill, which have also given dissipation rates exceeding 10^{-4} W kg^{-1} (Seim and Gregg, 1991). Because our estimates of ε were based on measurements of density overturns, it is not surprising that there are large overturns at the same location in the contoured density plot. This structure in ε is consistent with the idea of turbulence caused by unstable internal waves generated at the ridges.

With these estimates, it is clear that the mixing is often intense and is concentrated at specific locations. The observed structure is consistent with the idea of a breaking lee wave. Surface downwelling was another important result of these unstable internal waves.

DOWNWELLING

Downwelling is the sinking of water to greater depths. In the open ocean it is usually associated with areas such as the Norwegian Sea in the North Atlantic, where cooling and evaporation increase the density of the surface water such that the column becomes statically unstable. It may also occur at fronts between different water masses when the heavier water plunges beneath the lighter one. The downwelling we have observed at Admiralty Inlet, however, appears to be related to the response to the bottom topography. Vertical transport of air bubbles and other floating material is the likely cause of narrow acoustic scattering layers that coincide with steeply-sloped density contours. An additional source of backscattering at these downwelling zones could be density microstructure resulting from turbulence (Seim et al., 1995).

We frequently observed regions of enhanced acoustic scattering that coincided with downward sloping density contours. These features were seen in the along-channel sections during flood tide and were located either directly above or on the downstream side of the ridges and at the exit slope. Figure 6 is typical of the downwelling structure. There is a narrow acoustic scattering zone in the upper 50 m at about 2210 UTC. The contoured density has steeply sloped contours and a core of lighter water at the same location. As described earlier, downwelling from the surface would displace density contours as is shown and could produce increased backscattering if air bubbles or flotsam were downwelled. We also observed changes in sea surface roughness at these downwelling sites, presumably due to the straining of the surface waves. ADCP measurements in these areas often revealed downward velocities, but the velocity data are more difficult to interpret than the acoustics or density structure. This is because of the high noise level in the velocities, several cm s^{-1}, and the fact that the ADCP profiles are two-minute averages. In two minutes the ship would move several hundred meters, and if the downwelling zones are narrow their signal could be averaged out.

Downwelling is an important process for a number of reasons. As mentioned before, it has been invoked in models of the Puget Sound circulation to balance salt and mass budgets. It is also interesting scientifically because it demonstrates the real effects of flow over complex topography, which is a poorly understood process. Finally, strong downward flow would provide a mechanism for the vertical transport of materials from the surface. This has obvious implications for the distribution of buoyant pollutants such as oil. This transport of buoyant material is magnified by the fact that the downwelling seems to result from a convergence in the horizontal flow field. Thus, the downwelling sites originate in surface convergence zones, which tend to accumulate floating debris.

CONCLUSIONS

Because Admiralty Inlet connects the main basin of the Puget Sound to the Strait of Juan de Fuca and the Pacific Ocean, it plays a major role in the flushing and overall circulation of the sound. The structure of the current and density fields is a function of the various water masses present, external forcing, and interaction with topography. Detailed observations at the landward sill of Admiralty Inlet reveal specific processes related to vertical mixing and downwelling.

Most prominent are the large amplitude internal waves generated by flow over the bottom topography. These waves were associated with strong density overturning and downwelling. The structure and time-evolution of the waves appears to be most consistent with an unsteady lee wave. The large overturns

associated with these waves indicate intense turbulence. Downwelling is implied by acoustic scattering layers near the surface, which coincide with displaced density contours.

The identification of a particular mixing mechanism is important because there are a number of possible processes operating at the landward sill which can have different effects. For example, the larger overturns associated with the topographic internal waves observed at the sills typically spanned a depth range from 10 - 100 m. The height of the turbulent bottom-boundary layer as inferred from the ADCP profiles generally did not exceed 30 m above the bottom. If we assume that mixing can only take place over the depth range of the overturns and that the level of no motion is 50 m depth, the mid-depth overturns would be much more efficient at mixing seaward flowing surface wave with landward flowing bottom water. Mixing in the bottom boundary layer would only serve to homogenize the landward flowing mass but would not dilute it with surface water. Exchange between the two layers would tend to reduce the flushing of water out of the main basin.

Obviously, one cruise is not enough to completely understand a complicated place such as the landward sill, let alone all of Admiralty Inlet. Although it is a small region by open-ocean standards, its rapid response to the tides, cross-channel variability, and number of different water masses makes the formation of a synoptic picture with observations from a single vessel impossible. In our future work, we will use these observations to determine which processes are important and can be studied thoroughly. For example, the localized response to the topography was an unexpected discovery. Additional microstructure measurements and more accurate velocity data from a broadband ADCP would be necessary for better quantifying the mixing and downwelling. In addition to being important to the sound, these are basic processes that undoubtedly take place in other coastal environments.

ACKNOWLEDGMENTS

We would like to thank the Office of Naval Research for funding this cruise and the Washington Sea Grant Program for supporting the development of SWIMS. We also thank Jamie Morison for letting us borrow his ADCP. The data could not have been collected without the efforts of Earl Krause, Jack Miller, Steve Bayer, Gordy Welsh, and Harvey Seim. Finally, Paul Zibton helped with the figures of this manuscript.

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OBSERVING AND MODELING SEATTLE'S WEST POINT OUTFALL PLUME

James A. Turner and Michael C. Gregg[1]

INTRODUCTION

Since 1966, Seattle has discharged sewage effluent from its West Point wastewater treatment facility into the Puget Sound via the West Point Outfall. As the sewage is discharged, it becomes diluted with the ambient water and forms a plume that is carried with the currents. Quantifying the dilution and location of the plume is a necessary step in predicting the environmental impact of the outfall. During a cruise in April of 1993, we obtained simultaneous measurements of temperature/salinity, acoustic backscatter, and velocity in the vicinity of Seattle's West Point outfall. The data were then used as input to an EPA computer plume model, PLUMES, and as direct observations of the sewage plume. This study was important because we could find no documented comparisons between PLUMES predictions and field observations from a full-scale outfall.

SITE AND CRUISE DESCRIPTION

The effluent discharged at West Point currently receives primary treatment, but an upgrade to secondary treatment is in process and should be completed in 1995 (J. Harvey, personal communication, 1993). The outfall is located about 1 km west of the shore in a water depth of about 70 m (Figure 1). The 185 m long diffuser has 100 ports per side spaced about 2 m apart. The ports are built into the sides of the pipe and have diameters ranging from 11 cm to 14 cm. The rate of discharge is typically near 4.5 m^3s^{-1} but may be as high as 15 m^3s^{-1} during rainy weather. Sewage discharge conditions during our data collection period as recorded by the King County Metropolitan Services Division (Metro) were a flow rate of 4.8 m^3s^{-1} and an effluent temperature of 12.8° C. Based on previous studies of the outfall (Bendiner, 1976), we assume that the density of the effluent is 1002 kg m^{-3}.

We collected data near the outfall on April 17 and 28. Our instrumentation included a BioSonics acoustic echosounder, a Sea-Bird CTD (conductivity, temperature, depth) mounted in a towed body, an RD Instruments acoustic Doppler current profiler (ADCP), and Global Positioning System (GPS) receivers for navigation. A complete dataset was not available for each day because the CTD was not used on April 17. A description of the CTD and ADCP systems is given in Turner and Gregg (1995). Acoustic backscatter data were obtained with the BioSonics model 102 echosounder equipped with 120 and 200 kHz frequency transducers. The transducers have a beamwidth of 4.5° and a source level of 230 dB. The BioSonics system was set up to sample a vertical profile in 0.5 m bins every second. At typical ship speeds, this translates into a horizontal spacing of about 2 m. Thus, we have the possibility of resolving structures with vertical and horizontal dimensions on the order of meters.

PLUMES

The PLUMES model established by the EPA predicts characteristics such as rise height, thickness, and dilution of buoyant plumes in a stratified, flowing environment (Baumgartner et al., 1993). The predictions are made using data that describe the initial discharge conditions at the diffuser and the ambient current and stratification. PLUMES includes two near field models, UM and RSB. The near field is the region where mixing is dominated by turbulence generated at the diffuser. The RSB model is based on the experimental results of a scale-model diffuser study (Roberts et al., 1989). The other, UM, is a more theoretical model which is based on mathematically predicting the evolution of a single plume originating from a point source. Beyond the initial mixing zone, PLUMES will estimate additional dilution with a far field model

[1] University of Washington College of Ocean and Fishery Sciences, Applied Physics Laboratory and School of Oceanography, 1010 NE 40th St., Seattle, WA 98105

based on lateral diffusion parameterized with a horizontal eddy coefficient (Brooks, 1960). The far field is where mixing is dominated by the turbulence of the background environment.

The data required for running the PC-based PLUMES program include the basic outfall characteristics (length of diffuser, orientation, number of ports, etc.), the effluent flow rate, and a current and density profile. We ran the model using the current and density profiles shown in Figure 2 (1 MPa pressure = 100 m depth). These data were collected near the outfall during an ebb tide. The predictions for two PLUMES model runs are given in Table 1. One run was made using the density and current profiles shown in Figure 2 while the other used the same density profile with a vertically averaged current of 0.15 m s^{-1} northward. A vertically averaged current was used because the RSB model was empirically formulated with a uniform current, and the effects of a non-uniform current were unclear. Only the north-south component of the measured current was used in the modeling because the east-west velocities varied near the outfall, and PLUMES does not account for 3-dimensional flow.

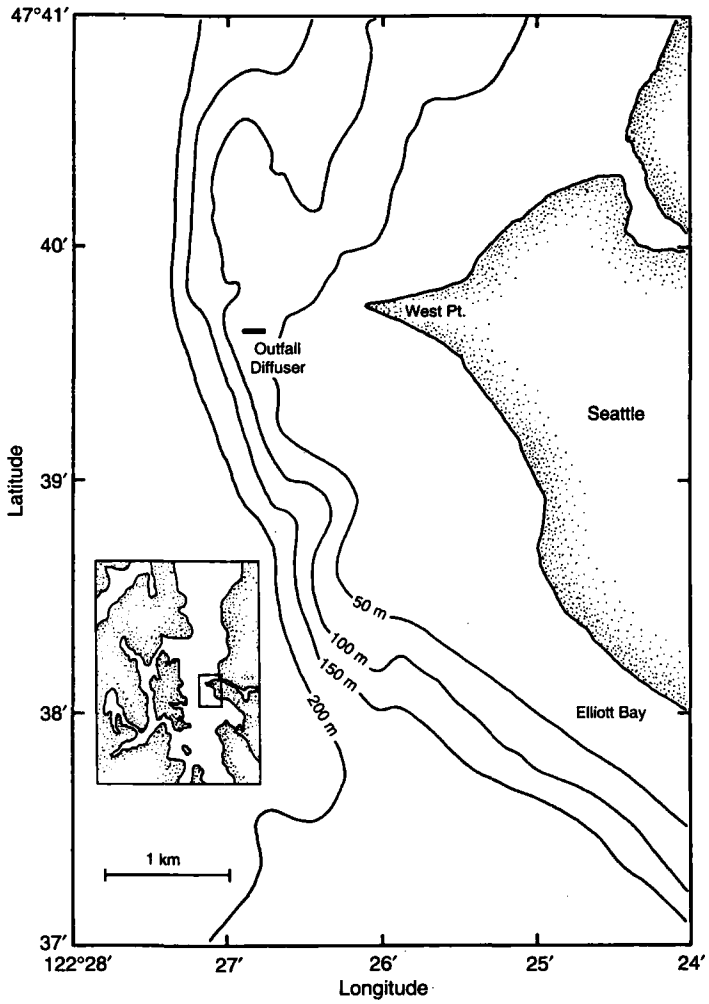

Figure 1. Map of the West Point outfall and Puget Sound, including the 50, 100, 150, and 200 m depth contours

Table 1. PLUMES model results for West Point outfall

	RSB		UM	
	Meas. Current	Avg. Current	Meas. Current	Avg. Current
Depth C_{max} (m)	30.2	25.5	31.1	34.4
Thickness (m)	42.1	46.8	64.5	70.6
C_{max} (%)	0.64	0.41	—	—
C_{avg} (%)	0.56	0.36	0.23	0.22
$L_{Init.\ Mix.}$ (m)	46.8	173.2	31.1	54.3

For the calculations using the measured current and density profiles, RSB predicted that the maximum effluent concentration at the end of the initial mixing region would be 0.64 percent of the initial concentration and that this maximum concentration would be located 30.2 m below the surface. The length of the initial mixing region was predicted to be a little less than 50 m. The thickness of the plume field, defined in RSB as the distance between 5 percent of maximum concentration contours, was predicted to be 42.1 m. The average concentration across the plume cross section at the end of initial mixing was predicted to be 0.56 percent. Running RSB with the vertically averaged current of 0.15 m s^{-1} and the same density profile produced a longer initial mixing zone and greater dilution of the plume. Specifically, the length of initial mixing increased to 173.2 m, and the maximum and average concentrations within the plume were 0.41 percent and 0.36 percent, respectively. The thickness also increased to 46.8 m, but the location of maximum concentration was closer to the surface at 25.5 m depth.

Qualitatively similar results were obtained with the UM model. Using the measured current and density profile, UM predicted an average concentration of 0.23 percent across the plume at the end of initial mixing. UM estimated the length of the initial mixing zone to be 31.1 m. The plume diameter was predicted to be 64.5 m with its center 31.1 m below the surface. The UM plume element is modeled with an average concentration that is constant across the plume section, so a maximum value is not reported. With the average current of 0.15 m s^{-1}, UM predicted a slightly longer initial mixing region and greater dilution. The average concentration dropped to 0.22 percent and the initial mixing region length increased to 54.3 m. The plume center was located 34.4 m below the surface and had a diameter of 70.6 m.

In general, UM predicts greater dilution that takes place over a shorter initial mixing region than RSB. The amount of mixing varies depending on the conditions and model used, but the concentration of effluent in the plume was not predicted to be greater than 1 percent at the end of initial mixing. This value is in reasonable agreement with the 1 percent effluent concentration measured within 100 m of the outfall by Bendiner (1976). The far field algorithm predicted a 20 percent increase in dilution over 2.5 hours using a horizontal diffusion coefficient of 600 cm^2s^{-1}.

DIRECT PLUME OBSERVATIONS

Attempts at directly measuring effluent concentration and plume location have produced mixed results. A frequently used method is to add dye to the effluent and then tow a dye-sensing instrument through the plume field (Bendiner, 1976). A similar approach is to take CTD measurements and use the temperature and salinity anomaly of the effluent to infer the plume characteristics (Washburn et al., 1992). A third method is to measure acoustic backscatter and assume a correlation between backscattering intensity and effluent concentration (Dammann et al., 1991). Each of these methods has its limitations. Using a towed instrument may produce an inaccurate description owing to poor spatial resolution. Acoustic measurements have much better resolution, but the presence of multiple backscattering sources can make plume identification difficult.

Acoustic Backscatter

Acoustic backscatter has been used in the study of zooplankton (Wiebe and Greene, 1990), suspended sediment (Proni et al., 1975), and industrial wastes dumped in the open ocean (Orr and Hess, 1978). Attempts have also been made to track sewage plumes using acoustic backscatter (Lohrmann and Ebbesmeyer, 1991; Dammann et al., 1991). An important distinction between our study and that of Lohrmann and Ebbesmeyer is that they used a 150 kHz ADCP to collect their data while ours were obtained with a 120/200 kHz instrument designed specifically for measuring acoustic backscatter. Figure 3 displays the contoured salinity and acoustic backscatter in units of decibels (dB) collected between 2210 and 2225 UTC on April 28 during ebb tide. It clearly shows the diffuser and a scattering layer between 50 and 75 m depth on the upstream side of the diffuser. The ship track for this segment was southward against a northward flowing ebb tide. Because the scattering layer seemed to originate at the diffuser, we hypothesized that it was related to the effluent plume. A secondary feature is the faint scattering layer that appears to be rising vertically from the diffuser.

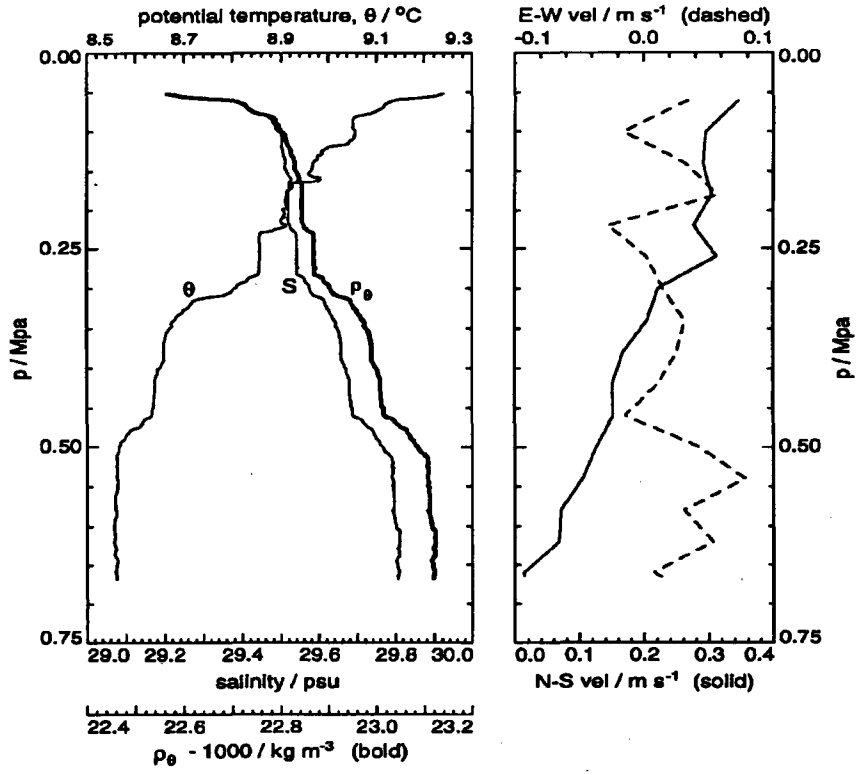

Figure 2. Profiles of salinity (S), potential temperature (θ), and potential density (ρ_θ) from data taken near the outfall during an ebb tide (1 MPa pressure = 100 m depth)

Using a procedure documented in Turner and Gregg (1994), we predicted the scattering strength of the effluent plume assuming that it was caused by Rayleigh scattering from the effluent particulates. These predictions used a size analysis of the particles in an effluent sample. Using this approach, we predicted backscattering of about -120 dB for a 1 percent effluent concentration plume. A signal of -120 dB, however, is well below the observed background level of about -75 dB (Figure 3). This analysis implies that the effluent plume is more acoustically transparent than the ambient water. Although our analysis included several important assumptions about the acoustic characteristics of a sewage plume, other data support the assertion that the backscattering layer between 50 and 75 m depth is not the effluent plume.

A simple mixing argument can be used to demonstrate that the observed backscattering layer is not consistent with the equilibrium position of a dilute effluent plume. An estimate of the density of an effluent-ambient water mixture, ρ_{mix}, can be calculated using the following equation:

$$\rho_{mix} = a\ \rho_{PS} + (1\text{-}a)\ \rho_{eff} \qquad (1)$$

where ρ is density, mix represents the mixture, PS the ambient Puget Sound water, eff the sewage effluent, and a is the fraction of Puget Sound water in the mixture. Using 1023.1 kg m^{-3} for the density of the ambient fluid at 70 m (Figure 2), 1002 kg m^{-3} for the effluent density, and 0.99 for a yields ρ_{mix} = 1022.89 kg m^{-3}. Comparing this value with the density profile taken near the plume shows that the equilibrium depth of this mixture would be about 30 m, significantly shallower than the depth of the scattering layer observed. Other evidence arguing against the effluent particulates as the scattering source is that no such scattering layer was observed at the same location on April 17.

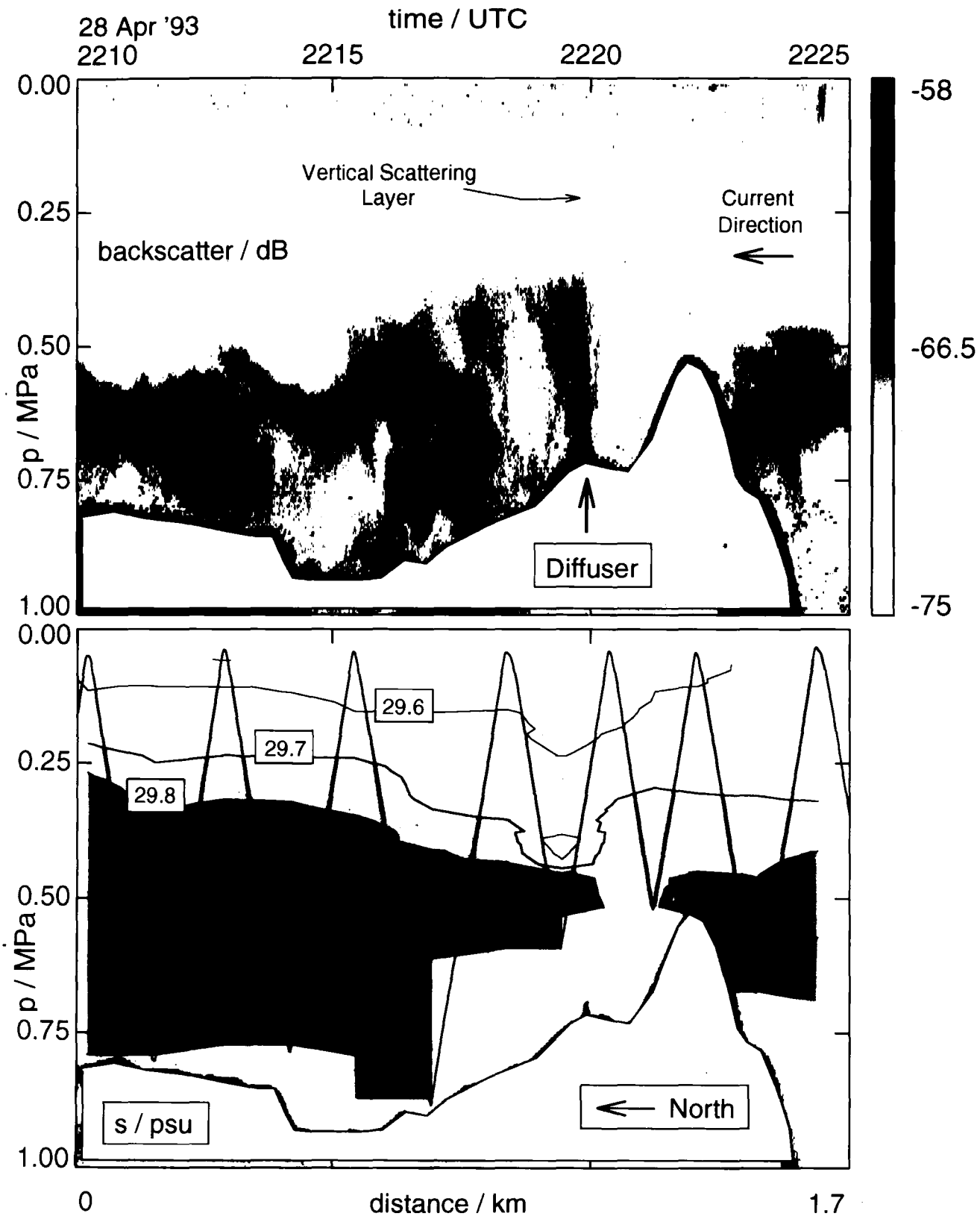

Figure 3. Acoustic backscatter (upper panel) in units of decibels (dB) and contoured salinity (lower panel) from data taken while crossing the diffuser during a southward ship track. The sawtooth path of the towed body has been overlaid onto the contour plot.

A more likely source of the observed scattering layer is zooplankton. This explanation is consistent with the high productivity of Puget Sound and acoustic scattering characteristics of zooplankton. A common zooplankton in the Puget Sound is the copepod, which ranges from 1 mm to 1 cm in size and can have patch densities as high as 100 copepods m^{-3} (Strickland, 1983). Using the same Rayleigh scattering analysis, a backscattering signal of -47 dB was predicted for the copepods (Turner and Gregg, 1994). This value is comparable to the measured peaks, so a biological source seems more plausible.

CTD Data

Contoured salinity from the same section used in the acoustics analysis show a distinct freshening signal centered above the diffuser, which likely indicates the presence of the fresher effluent plume (Figure 3). Profiles of the CTD data also indicate a mid-depth low-salinity signal, which is strongest near the diffuser. Because there is a significant temperature and salinity difference between the effluent and ambient Puget Sound water, it is possible to describe the plume using CTD measurements.

One method of using the CTD data is with θ-S plots where θ is potential temperature and S is salinity (Washburn et al., 1992). Water that is formed as a mixture of ambient water and effluent will fall on a line between the two end member properties (Figure 4). If the properties of the end members are known, the ratio of the two can be determined with the equations:

$$S_{mix}=b\ S_{eff} + (1\text{-}b)\ S_{PS} \quad (2)$$

$$\theta_{mix} = b\ \theta_{eff} + (1\text{-}b)\ \theta_{PS} \quad (3)$$

where PS designates Puget Sound, eff the effluent, mix the mixture, and b is the fraction of the mixture that is effluent. One important assumption in this approach is that the temperature and salinity of the end members are fixed. Thus, it may be difficult to apply this idea to the sound, where water characteristics are highly variable.

This method was applied to CTD data taken between 2210 and 2225 UTC on April 28. The θ-S curves and profiles of θ and S are shown for three casts in Figure 5. These solid-line θ-S plots are overlaid onto a dashed-line curve formed with data from a reference cast upstream of the diffuser, which are assumed to be representative of ambient conditions in the main basin of the sound. If the water flowing across the diffuser was uniform, the θ-S curves from each cast would lie directly on top of the ambient θ-S curve.

The data from cast (a) of Figure 5, taken about 1 km downstream of the diffuser, coincide with the ambient water data below about 20 m depth. The data from cast (b), which was within 200 m of the diffuser, produce a θ-S curve that is fresher than the ambient water above 45 m depth. Finally, the data from cast (c), which is very near the diffuser, display a pronounced fresh-water signal between 35 and 45 m as well as at the surface. The corresponding profile plots of cast (c) indicate finestructure in that depth range, an indicator of turbulent activity.

The general pattern in the CTD data is that of a fresh signal that fades with downstream distance from the diffuser. Further, we can use equations 2 and 3 to estimate the amount of mixing that has occurred. Because the fresh water signal at the surface in all the casts could be due to factors other than the outfall (runoff, precipitation, etc.), we neglect the data in the upper 20 m for our

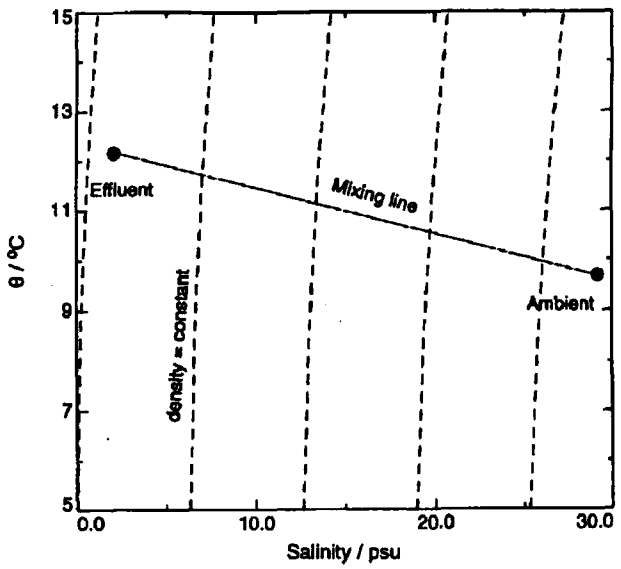

Figure 4. A schematic diagram of the mixing line between the sewage effluent and ambient Puget Sound water

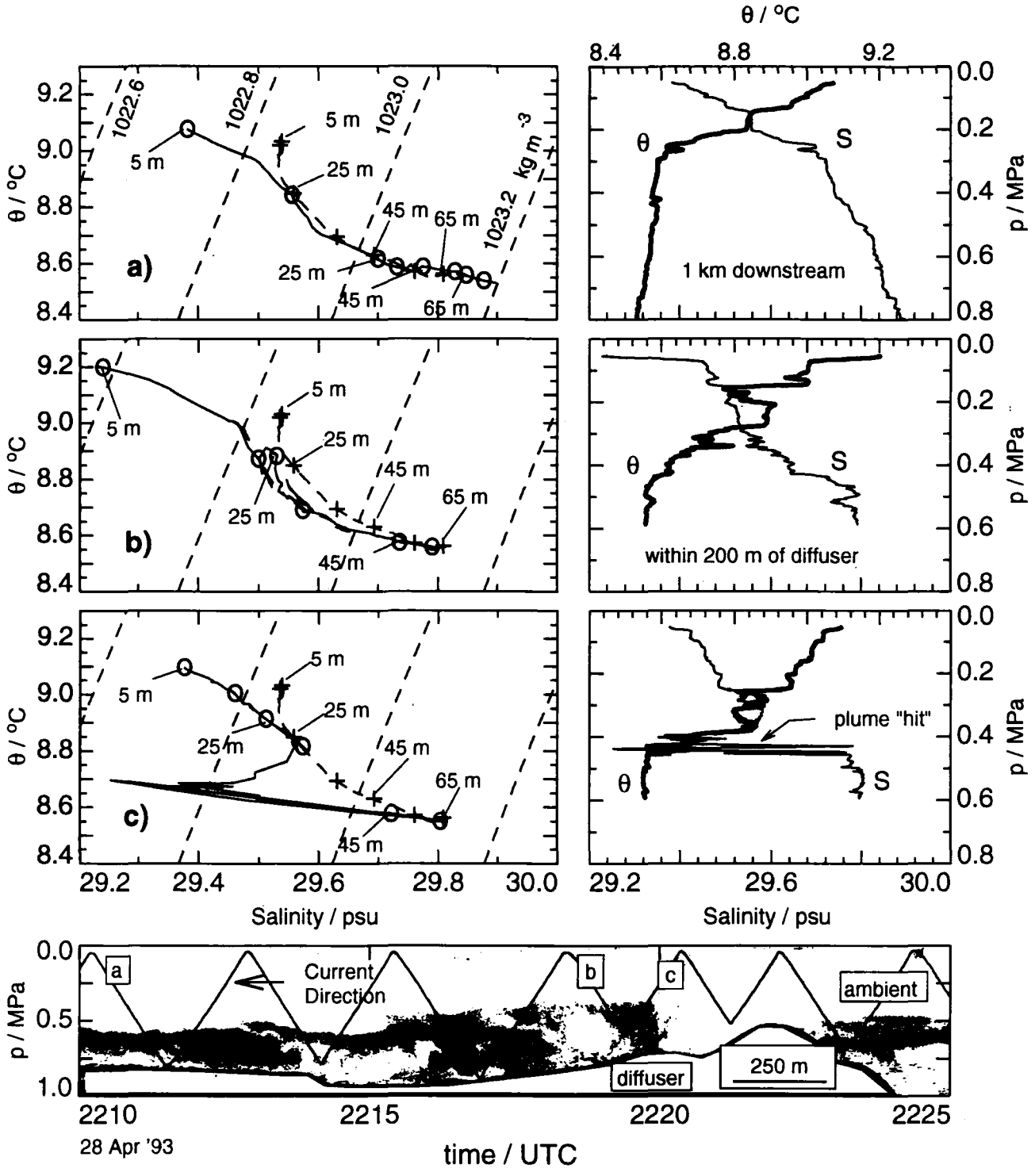

Figure 5. CTD data from three casts showing the fresh-water effluent plume signal. Data from each cast are displayed with a θ-S curve (left panel) and a corresponding profile plot (right panel). Depths at 10 m spacing are indicated on the solid-line θ-S curves with 0's for casts a, b, and c and +'s for the ambient dashed-line curve, which was taken upstream of the diffuser.

estimate of mixing ratios. In addition, we make our estimate only with the salinity data because the salinity contrast between the effluent and Puget Sound water is much greater than the temperature contrast.

The slight freshening signal at about 20 m depth in cast (a) is too small for a reliable mixing estimate. For cast (b), using the data from near 30 m where S = 29.52 psu, we estimate an effluent concentration of about 0.3 percent. For cast (c), using a salinity of 29.4 psu from near 40 m depth, we estimate a concentration of approximately 1 percent. We can also estimate the depth and thickness of the effluent by noting the areas where the θ-S curves diverge from those of ambient water and correlating with depth. In cast (b), the greatest salinity difference (or maximum effluent concentration) occurs at 30 m depth, and the difference is completely gone by 45 m depth. An estimate of the depth of the established wastefield farther away than cast (b) is not possible because of the unknown origin of the fresh-water signal at the surface. From cast (b), an estimate of the maximum plume thickness is about 40 m.

CONCLUSIONS

From the previous discussion of the CTD and acoustic data, it is clear that a direct comparison between the model predictions and field observations is difficult to make. We have shown that the acoustic data do not provide a reasonable measure of the effluent plume field away from the diffuser, so our comparisons are based solely on the CTD observations. The depth of maximum concentration predicted by both the RSB and UM models and that observed in the CTD data are similar at about 30 m. The maximum measured effluent concentration of 1.0 percent within 100 m of the outfall is the same order of magnitude as the RSB model's prediction of 0.64 percent. Finally, the observations also indicate that the plume thickness is not greater than 40 m, comparable to the RSB predictions. Beyond these rough comparisons, there is little we can say about how well the model predictions and observations match.

Despite the difficulties in making comparisons, the observations are still useful because they bring attention to limitations of the PLUMES model. For example, RSB was based on the results of a model diffuser in a highly idealized environment. These idealizations included a linear stratification, vertically uniform current, and steady-state flow conditions (Roberts et al., 1989). UM is similarly limited by its theoretical framework of an ideal plume element in steady state (Baumgartner et al., 1993). Our observations show that the Puget Sound is much more complex than the model environments, not a surprising discovery. What remains unclear is the importance of these complications.

The data also seem to indicate the possibility of some features not expected from conventional plume theory. For instance, the acoustic backscatter image of Figure 3 shows a faint scattering stream rising vertically over the outfall, indicating that a portion of the sewage might reach the surface and form an effluent layer directly above the outfall. Such a feature could be related to an heterogeneous effluent which contained some fraction of buoyant material. This type of behavior seems possible based on the findings of a model study of the vertical distribution of secondary effluent discharged from a submerged diffuser into a stratified environment (Word et al., 1990).

ACKNOWLEDGMENTS

We would like to thank the Office of Naval Research for funding the cruise and the Washington Sea Grant Program for supporting the development of the SWIMS instrumentation. Jody Deming of the University of Washington School of Oceanography allowed us to use her Coulter Counter instrument for the effluent sample analysis. Useful information was provided by James Harvey of Metro and Walter Frick of the U.S. Environmental Protection Agency.

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MODIFICATION OF PUGET SOUND'S SURFACE SALINITY BY HYDROELECTRIC RESERVOIRS: CASE STUDY OF THE SKAGIT RIVER'S INFLUENCE ON WHIDBEY BASIN

Curtis C. Ebbesmeyer[1] and Wendell Tangborn[2]

INTRODUCTION

Tides, winds, rivers and the Pacific Ocean power the movement of Puget Sound's water bodies, thereby influencing their quality. Previous physical oceanographic research, using field observations and mathematical models, established a number of relationships between these driving agents and estuarine circulation (Ebbesmeyer et al., 1989). If the drivers vary with time, trends in the Sound's salinity and circulation will occur.

Although a number of the physical linkages between selected estuarine parameters and river discharge have been established, many connections remain to be investigated (Ebbesmeyer et al., 1989). This paper relates water storage in the five reservoirs influencing the Skagit River—the largest river feeding Puget Sound—to sea-surface salinity measured over a number of years at some distance from the river's mouth (Figures 1a, 1b). Surface salinity was chosen for examination because it is a parameter important in determining the state of Puget Sound's physical and biological regimes.

Five reservoirs in the Skagit River basin store a portion of the snow melted during spring and summer. During the following winter, additional snowmelt is released through turbines to generate hydroelectric power. Before the reservoirs were built, the snowmelt entered Puget Sound within weeks after melting in the mountains. As reservoirs were added in the Skagit's watershed, however, increasing volumes of snowmelt were stored, delaying the arrival of significant quantities of fresh water in Puget Sound. During the winter season, increasing amounts of Skagit River water dilute the estuarine receiving waters, lowering the salinity of the water near the sea surface. During the summer season, surface salinities rise as reservoirs retain a portion of the snowmelt.

Ten hydroelectric reservoirs in Puget Sound's watersheds

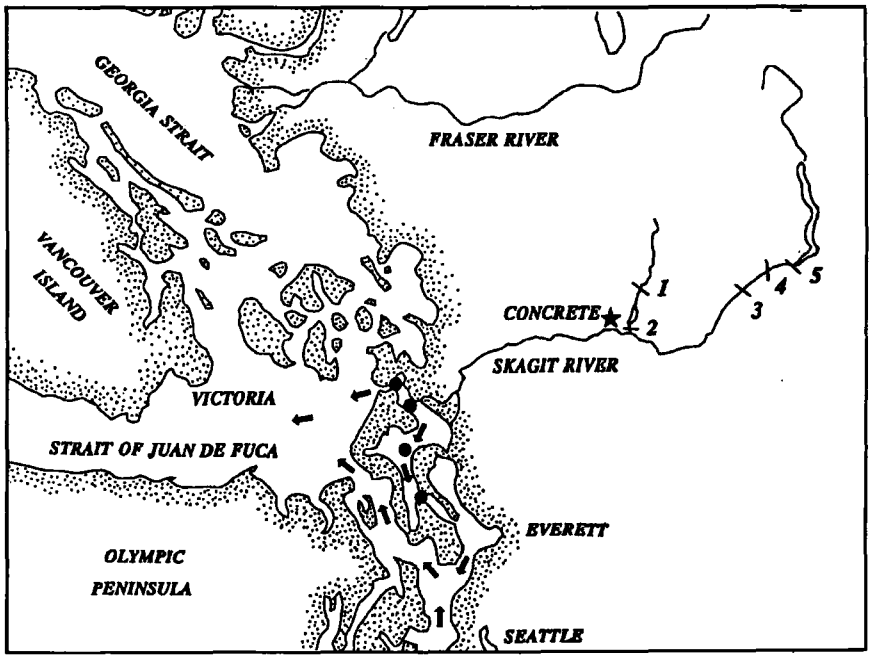

Figure 1a. Locations of reservoirs in the Skagit River watershed. Notations for reservoirs: 1—Upper Baker Lake; 2—Lower Baker Lake; 3—Gorge Lake; 4—Diablo Lake; and 5—Ross Lake. Discharge of the Skagit River was monitored at Concrete (star). Dots near current arrows in Puget Sound indicate surface salinity observation sites (see Figure 1b). Arrows indicate long-term average sea surface currents.

[1] Evans-Hamilton, Inc., 731 N. Northlake Way, Seattle, WA 98103

[2] HyMet Company, 2366 Eastlake E., Seattle, WA 98102

store more than two cubic kilometers of fresh water (Puget Sound Task Force, Pacific Northwest River Basins Commission, 1970). More than half the total reservoir storage is contained within the Skagit's five reservoirs (see also Wolcott, 1973): Ross dam (1952), 1.26 km^3; Upper Baker reservoir (1959), 0.27 km^3; lower Baker reservoir (1925), 0.18 km^3; Diablo reservoir (1936), 0.08 km^3; and Gorge dam (1924), 0.009 km^3.

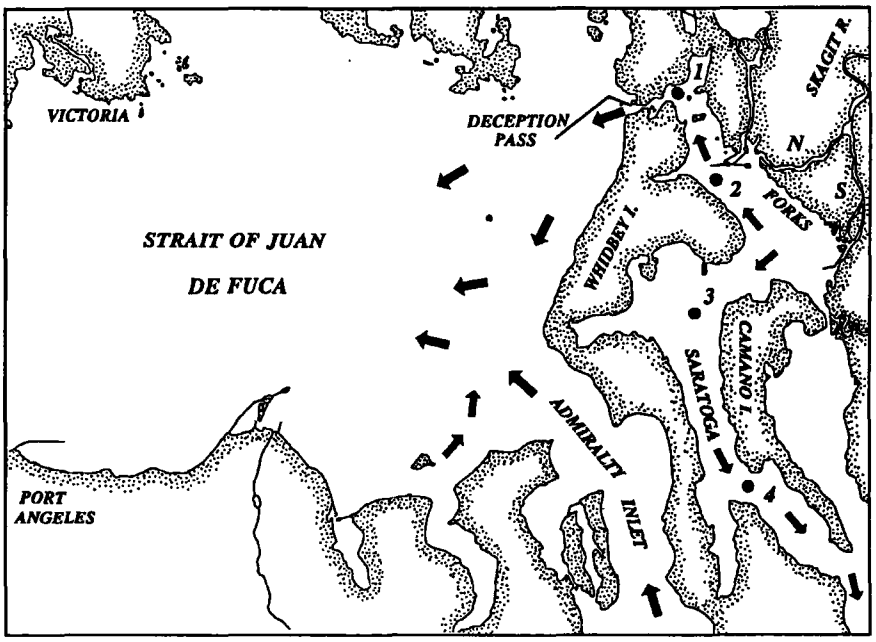

Figure 1b. Locations of sea surface salinity samples. Notation for sea surface salinity sampling sites (dots): 1—Dewey; 2—Goat Island; 3—Demock Point; and 4—East Point. Arrows indicate long-term average sea surface currents. N, S, indicate the Skagit River's North and South forks, respectively.

METHODS

To monitor the Skagit River, the discharge at Concrete, Wash., recorded downstream of the five reservoirs was examined. Daily records have been maintained since 1925, early in the development of the reservoir system. Approximately 50 percent of the water passing the Concrete gauge flows through at least one of the five reservoirs and enters Puget Sound through the Skagit's North and South forks. Coincidentally, the Skagit River forks where Puget Sound's long-term average surface currents diverge in Whidbey Basin (Barnes and Ebbesmeyer, 1978). Water from the North Fork travels mostly northward, leaving Puget Sound through Deception Pass. South Fork water travels mainly southward along Whidbey Basin, leaving Puget Sound via Admiralty Inlet.

Discharge at Concrete was compared with surface salinities measured at varying distances along the current pathways in Whidbey Basin. Sampling locations in Puget Sound along the main axis of Whidbey Basin, where the influence from other rivers is minimal, were selected for analysis. Four hydrographic stations during 1952-1971 were sampled by the University of Washington (Table 1; Figure. 1). Data at one location (East Point) were supplemented with observations made during 1978 and 1993 obtained by the Washington Department of Ecology.

All salinity samples were drawn from approximately the upper meter of the water column using water sampling bottles. Because wind waves caused the water bottles to oscillate vertically, the samples represent averages approximately in the uppermost meter of water depth.

Relationships between surface salinity and river discharge were determined, using the statistical method of linear regression, applied as follows. Linear regressions between surface salinity (S) at one of the four hydrographic stations and river discharge (R) were expressed as: S=A+B*R(T), where: A is constant salinity at zero discharge; B is the slope of the relation between salinity and discharge; and T is the time interval, or lag, over which discharge data were averaged, prior to the date of a given salinity observation. The lag accounts for the time required for water to flow from the river gage to the hydrographic station.

The regression for a given hydrographic station was optimized by repeatedly computing the correlation coefficient for increasing values of lag from one to thirty days. As the lag increased, the correlation coefficient increased to a maximum, then decreased. This paper deals with the regressions at lags producing maximum correlation coefficients.

Table 1. Whidbey Basin sampling locations and statistical results

Station	ID No.	No. salinity observations	Lag (days)	squared corr. coefficient	Maximum A (ppt)	B (ppt/m^3/sec)
a. Dewey	621	85	6	0.39	29.18	-0.0076
b. Goat Island	619	85	6	0.27	26.23	-0.0144
c. Demock Point	614	79	6	0.70	29.28	-0.0140
d. East Point (1952-71)	612	74	16	0.78	30.34	-0.0132
e. East Point (1978-93)	SAR003	127	10	0.73	30.23	-0.0140

For entries a–d all data are from Collias (1970). Entry (e) is from Washington Department of Ecology data. Lag refers to the number of days, prior to the salinity measurement, over which the discharge was averaged. Linear regression parameters: squared correlation coefficient (r^2); A, constant; and B, slope (see text).

RESULTS

This study addresses: long-term trends in Skagit River discharge; statistical comparison of river discharge and surface salinity; and long-term trends in surface salinity.

Long-term Trends in Skagit River Discharge

Daily discharge averaged during the first (1925-1934) and the last (1984-1993) 10 years for which data are available at Concrete are shown in Figure 2. By the first decade of river gaging, Skagit discharge already had been influenced by storage in Lower Baker and Gorge reservoirs. During the earliest decade of gaging, the peak discharge associated with the melting of snow in summer reached approximately 800 m^3/sec. By the most recent decade, the snowmelt peak decreased by approximately 30 percent to 560 m^3/sec and, in winter, the peak discharges rose approximately 50 percent from 430 to 650 m^3/sec.

Contrasting the seasonal discharge for the earliest and latest decades illustrates some aspects of reservoir operations. Before the trout fishing season (approximately July first through Labor Day), the reservoirs are filled as much as possible. These levels are maintained during June through October. During the winter season, the reservoirs are lowered to produce power. In Figure 2, reservoir storage is shown by the smaller discharge during April through September in the most recent decade. Power production corresponds to increased discharge during October through March. Therefore, averaging the discharge into two six-month intervals provides a measure of the overall operations of the five reservoirs.

Daily discharge averaged during halves (October-March; April-September) of the water years 1925 through 1993 are shown in Figure 3. Before the installation of Ross dam, the October-March discharges were substantially smaller than the April-September values. As the reservoir system matured, the discharges in the halves of the water year became approximately equal.

Comparison of Salinity and Discharge

Linear regression parameters associated with the four hydrographic stations are listed in Table 1. At the two hydrographic stations closest to the river forks (Dewey; Goat Island), the regressions explain 27 percent to 39 percent of the scatter in the data (sample variance). With increasing distance, the percentage of the variance increases to 70 percent to 78 percent at Demock and East points, respectively. The lower percentages occur near the river mouth because Dewey and Goat Island stations lie in relatively shallow channels having vigorous tidal currents.

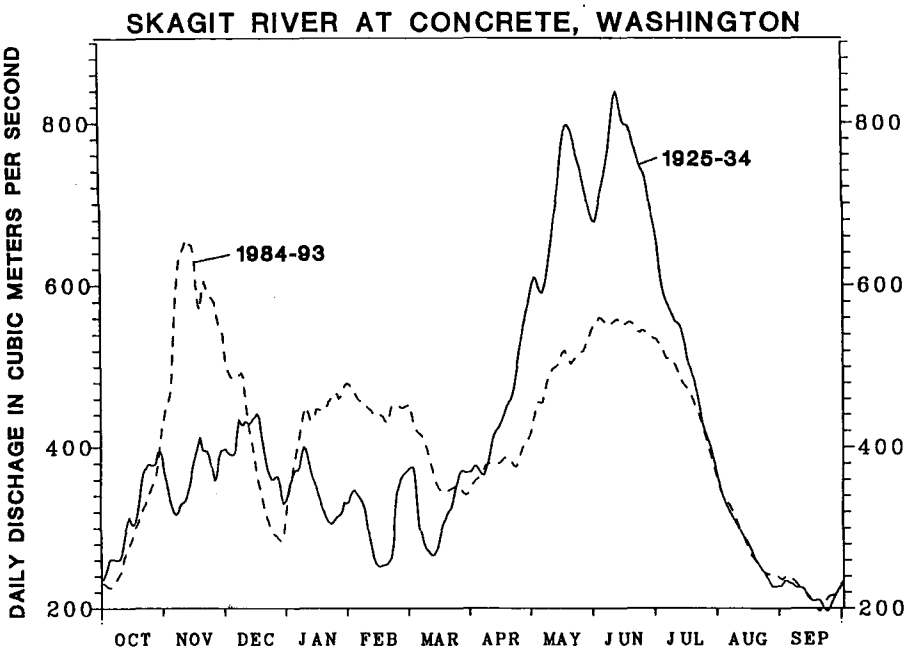

Figure 2. Daily discharge on the Skagit River during two 10-year average water years. Daily discharges at Concrete, Wash., averaged during 1925-1934 (solid line) and 1984-1993 (dashed line).

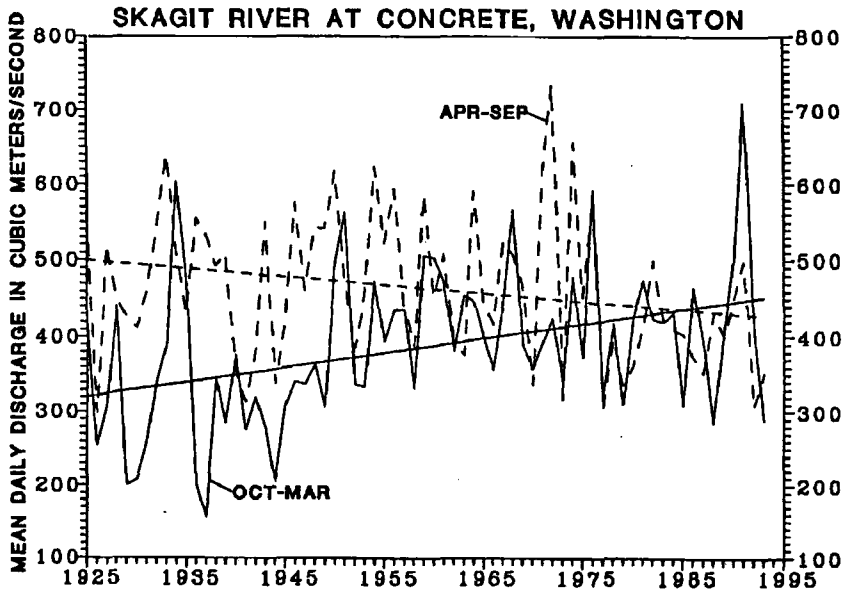

Figure 3. Long-term trends of discharge from the Skagit River, 1925-1993. Daily discharges at Concrete, Wash., averaged during two six-month intervals of the water year: October through March (solid line); and April through September (dashed line). Lines represent linear regressions.

The tidal currents draw water from a number of sources within the estuary that have relatively large salinity variability. Therefore, the variance unexplained by river discharge is mostly attributable to tidal variability. The relationships between salinity and tides in the vicinity of these stations have been investigated by Collias et al. (1973).

Although the Demock and East Point stations lie farthest from the Skagit River mouth, the Skagit River discharge explains most of the salinity variability. Contributions from winds, tides, and oceanic variability provide minor fractions. At East Point, approximately 15 nautical miles (28 kilometers) from the Skagit's South Fork, surface salinity varies linearly with discharge (Figure 4). Linear regression parameters for the 1952-1971 and 1978-1993 salinity data are not significantly different. The correlations appear to have remained approximately constant during most of the interval of the discharge data.

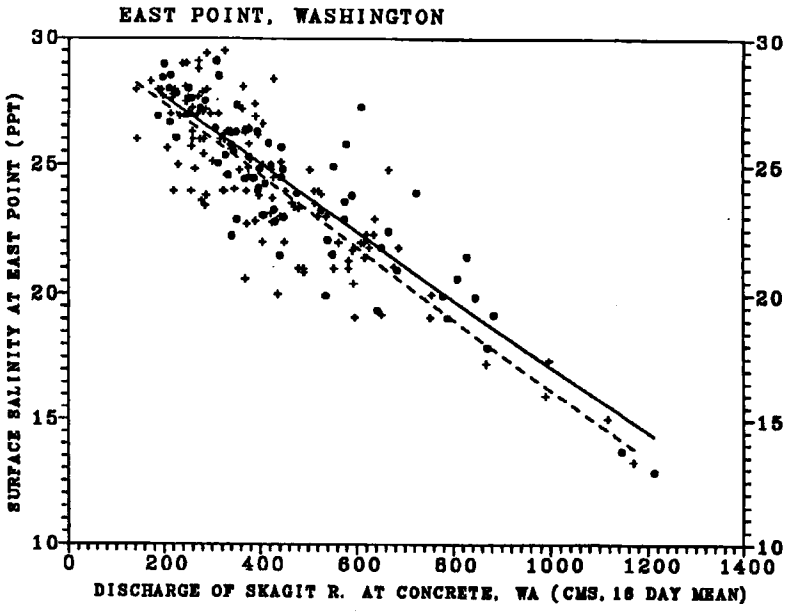

Figure 4. Relationship between skagit river discharge at Concrete, Washington and East Point surface salinity. Skagit River discharge averaged for 10 and 16 days before salinity observations for two periods of time: dots, 1952-1971, University of Washington data; +, 1978-1993, Washington Department of Ecology data (see Table 1 for regression coefficients). Lines represent linear regressions for the intervals of time: solid line, 1952-1971; dashed line, 1978-1993.

Long-term Surface Salinity Trends

Skagit River daily discharge data are available at Concrete since 1925. Unfortunately, relatively few salinity observations were obtained during this period; therefore, the sample size of surface salinity data is too small to permit the examination of long-term trends (Table 1). However, given the statistical correlations at distances removed from the Skagit River forks, salinity trends may be reconstructed using the relationships with river discharge.

The regression having the highest correlation was applied to the discharge data to generate daily salinities at East Point, 1925-1993, assuming that the correlation remained constant during this interval. Reconstructed salinities averaged during the earliest (1925-1934) and latest decade (1984-1993) of the water year are shown in Figure 5 (top panel), and averaged during halves of the water years in Figure 5 (lower panel; cf Figures 2, 3 respectively). These reconstructions illustrate the salinity changes for the longest span of time for which river gage data are available.

Salinity observations from two decades were compared with salinity reconstructed from the river gage records. Salinity data available during 1952-1961 and 1983-1992 were superposed on salinity reconstructions for those decades (Figure 6, upper and lower panels, respectively). Data from 1952-1961 were obtained by the University of Washington, and those from 1983-1992 were obtained by the Washington Department of Ecology at the same location, as described previously. Though the observed and reconstructed salinities are in general agreement, differences occur in part because salinities were not observed consistently in each month of the decades.

The salinity observations and reconstructions both suggest that during the earliest decade the lowest salinities occurred during May and June in association with melting snow. In the most recent decade, the lowest salinities occurred during November and December in association with hydroelectric power

generation. Since some of the reservoirs were operating before daily operations of the gage at Concrete, salinities before 1925 during May and June might have been lower than shown in the reconstructions, and the contrast between the historical (pre-reservoir) and present records is probably larger than shown in this report.

DISCUSSION AND CONCLUSIONS

It is apparent from the available data that the monthly progression of Skagit River discharge during the water year has been altered since the reservoirs began operating. At distances exceeding 15 miles from the river forks, surface salinities are correlated with discharge measured downstream of the reservoirs. The correlations and long-term discharge trends correspond with long-term changes in Whidbey Basin's surface salinity.

The present study indicates that reservoir operations affect surface salinities at certain Puget Sound locales. As this is a preliminary study addressing only five of Puget Sound's hydroelectric reservoirs, a logical question is: Which reservoirs might produce the greatest changes of surface salinity? For an approximate answer, consider fractional regulation (F) expressed as: $F=[R_a-R_r]/R_t$, where R_a is the discharge added during October through March; R_r, the discharge removed April through September; and R_t is the long-term annual average discharge from a given drainage basin.

If there were no long-term trends in discharge, the fractional regulation would equal zero. As the slopes of the discharge trend lines increase in magnitude (e.g., Figure 3), the fractional regulation increases.

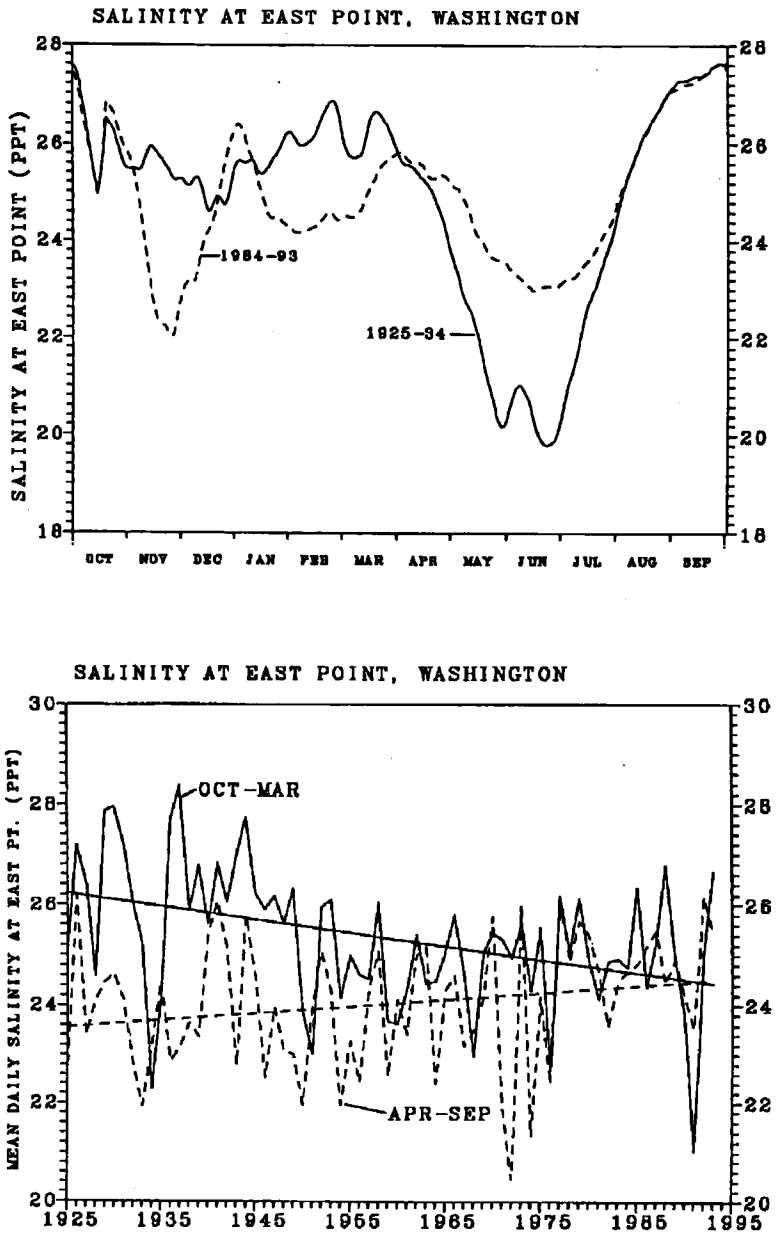

Figure 5. Reconstructed surface salinity variations at East Point, 1925-1993, Whidbey Basin, Puget Sound. Top panel: daily average salinity during 1925-1934 (solid line) and 1984-1993 (dashed line); and lower panel: six-month average salinity during October-March (solid line) and April-September (dashed line), where lines represent linear regressions.

Values of R_a and R_r were obtained as follows. For the Skagit River, R_a equals the change over 1925-1993 between the beginning and end of the October-March long-term trend, and R_r equals change of the April-September trend line, as shown in Figure 3. For the Columbia River, they equal respective changes

of the long-term trends (1931-1990) shown by Ebbesmeyer and Tangborn (1992). For Hood Canal, the R_a and R_s values were assumed equal to the storage in Cushman Reservoir discharged uniformly over six months. Finally, for the entire Puget Sound region, the total usable reservoir storage was used.

The fractional regulations for Puget Sound's drainage basins are less than for the Columbia River (Table 2). The Hood Canal fraction is large because of Lake Cushman's sizeable storage in relation to the minor rivers discharging into Hood Canal. These calculations indicate that Hood Canal surface salinities may have been significantly altered by the Cushman Reservoir.

The long-term trend of increasing surface salinities during the spring-summer season implies changes in Whidbey Basin's marine biology. A parameter important in determining plankton growth is the degree of stratification (vertical stability) of the water column, expressed as the difference in water density between the sea surface and the bottom of the photic layer. In Whidbey Basin, water density is primarily controlled by salinity variations, and secondarily by temperature fluctuations. Therefore, stability may be approximated by salinity differences over the depth range of the photic layer.

Historical salinity observations near the base of the photic layer, taken as 20 meters during May and June, average approximately 29 ppt (Collias, et al., 1974). In those months, early in the development of the reservoirs, salinity near the top of the photic layer averaged approximately 20 ppt. In the most recent decade, surface salinities rose to approximately 23 ppt. Therefore, stability has decreased during May-June by approximately a third during the gaged period of reservoir operations; larger changes occurred compared with the historic interval prior to constructing the first reservoir.

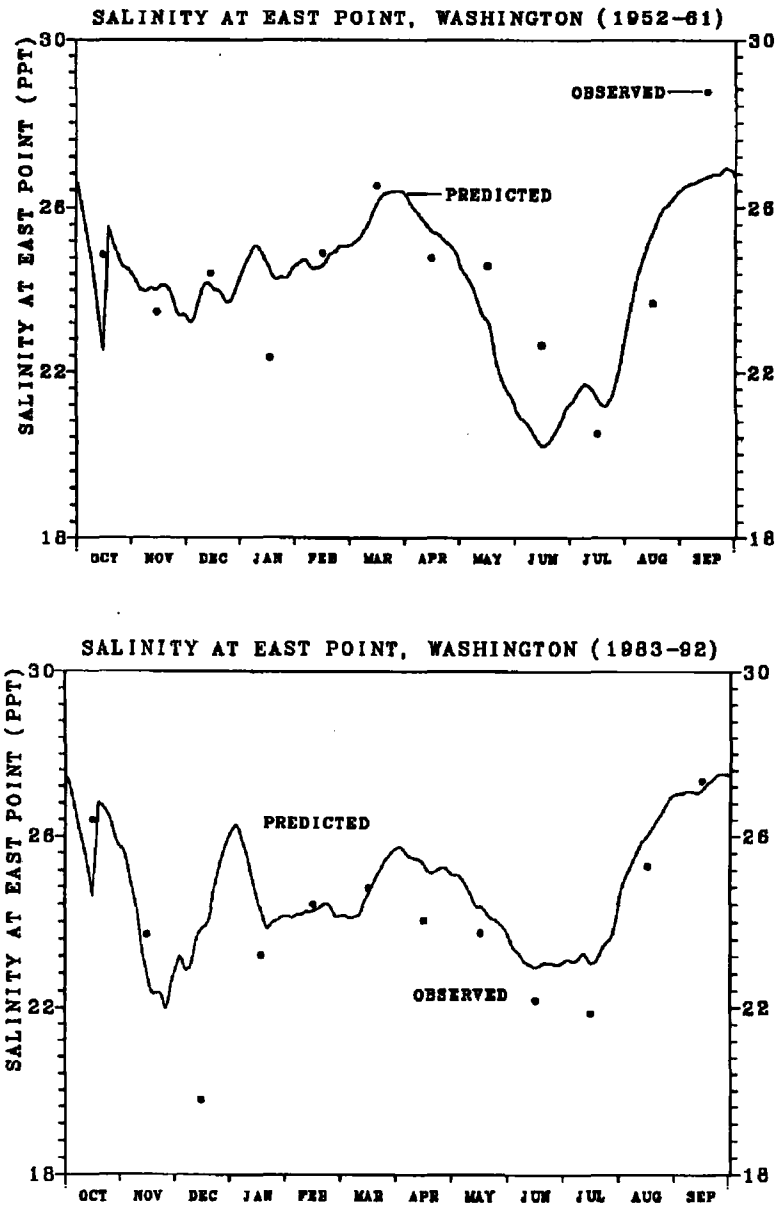

Figure 6. Comparisons of reconstructed and observed salinities during two decades: 1952-61 (Top Panel); 1983-92 (Lower Panel). Notation: solid line, 10-year average surface salinity reconstructed (predicted) from discharge data; dots, surface salinity observation averaged within months.

Finally, we note that modifying the sea surface salinities alters the seasonal movement of water both in Whidbey Basin and throughout Puget Sound. The effect of the reservoirs extends to the entire Puget Sound because the freshwater is refluxed by tidal mixing in Puget Sound's constrictions (Cokelet, Stewart,

and Ebbesmeyer, 1988). The overall effect of reservoirs on Puget Sound's circulation requires further examination.

Table 2. Regulated river discharge in the Hood Canal, Skagit River, and Columbia River drainage basins

Watershed Discharge	Mean Annual Discharge (m^3/sec) (1)	Regulated discharge (m^3/sec) *removed* April–Sept (2)	*added* Oct.–March (3)	Fractional regulation (dimensionless) [(2)+(3)]/(1)
Skagit River	440	70	135	0.47
Hood Canal	120	29	29	0.48
Entire Puget Sound	1,174	170	170	0.29
Columbia River	7,117	2,220	2,400	0.65

ACKNOWLEDGMENTS

We thank Robert S. Barnes, Puget Power and Light, and Prof. Dora P. Henry, University of Washington, for reviews and editing; and Dr. Jan Newton, Washington Department of Ecology, for supplying salinity data and reviewing the paper.

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PUGET SOUND RESEARCH '95

SESSION 8B

SEDIMENTS

Session Chair:

Sheri Tonn
Puget Sound Water Quality Authority

HISTORICAL TRENDS IN THE ACCUMULATION OF CHEMICALS IN PUGET SOUND

E.A. Crecelius[1], V.I. Cullinan[1], L.F. Lefkovitz[1], and C. Peven[2]

INTRODUCTION

Human activity in and around the Puget Sound is reflected in the discharge of concentrated organic and inorganic contaminants into the sound's sediments. As industrial-age human activity has increased, so have the contaminant levels in the sediment. Sediment cores collected in 1982 (Bloom and Crecelius, 1987) revealed that inputs of chemicals to the sound, including lead (Pb), mercury (Hg), silver (Ag), copper (Cu), and hydrocarbons, began to increase above background levels in the late 1800s. The maximum concentration of these chemicals appears to have been discharged into sediments between 1945 and 1965. Synthetic organic compounds, such as polychlorinated biphenyls (PCBs), dichlorophenyltrichlorethane (DDT), and chlorinated butadienes, first appeared in sediments deposited in the 1930s and reached a maximum in the 1960s. The presence of the subsurface maximum concentrations in fine-grained, deep-water sediments suggests that pollution-control strategies have improved the sediment quality of central Puget Sound.

The purposes of this study are 1) to continue monitoring historical trends in the concentration of contaminants in Puget Sound sediments and 2) to quantify recent trends in the recovery of contaminated sediments. It is hypothesized that changes recorded in the cores reflect changes in the sediment contaminant loading and are a result of changes in industrial practices and in laws restricting disposal of contaminants. A statistically significant reduction in sediment contamination over the past 20 years would provide empirical evidence that regulation has had a positive impact on the water quality in Puget Sound.

METHODS

Field Sampling

Sediment cores were collected from six locations in the main basin of Puget Sound during September 1991 using a stainless steel, open-barrel gravity corer (kasten corer), 2.5 m long, with a square cross section of 15 x 15 cm (Figure 1). Sites in proximity to those used in the Bloom and Crecelius (1987) study were chosen, because core samples from these locations indicated little disturbance. Sediment cores were processed on board the research vessel.

ANALYTICAL METHODS

Approximately 25 2-cm sections were analyzed from each core. Sediment concentrations of metals and radionuclides, lead-210 (^{210}Pb) and cesium-137 (^{137}Cs), were analyzed from equally spaced intervals from all six cores. For cores 3, 5, and 6, sediments from the adjoining 2-cm sections were analyzed for polynuclear aromatic hydrocarbons (PAHs), PCBs, chlorinated pesticides, nutrients (phosphorous [P] and nitrogen [N]), and butyltins. In addition, adjoining sections from cores 3, 5, and 6 were analyzed for grain size and total organic carbon (TOC). The methods used for analysis of sediments for the chemical parameters are described in the National Oceanic and Atmospheric Administration (NOAA) methods publication (Lauenstein and Cantillo, 1993).

METALS

Metals analyzed at the Marine Sciences Laboratory (MSL) in Sequim, Wash., are silver (Ag), aluminum (Al), arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), manganese (Mn), nickel (Ni), lead (Pb), antimony (Sb), selenium (Se), silicon (Si), tin (Sn), and zinc (Zn).

[1] Battelle Marine Sciences Laboratory, 1529 West Sequim Bay Road, Sequim, WA 98382

[2] Battelle Ocean Sciences, Duxbury, Massachusetts

Metals were analyzed using Zeeman graphite furnace atomic absorption (GFAA), inductively coupled plasma mass spectrometry (ICP/MS), cold-vapor atomic absorption (CVAA), and energy-dispersive x-ray fluorescence (XRF).

The activity of ^{210}Pb in sediment was determined by counting the alpha particles from the granddaughter polonium-210 (^{210}Po), a method similar to that of Koide et al. (1973). Polynuclear aromatic hydrocarbons were analyzed using gas chromatography/mass spectrometry (GC/MS) operated in the selective ion mode (SIM). A total of 20 specific PAH compounds and a number of alklylated PAH compounds were reported. In addition, linear alkylbenzenes, steranes, and terpanes were analyzed.

Polychlorinated biphenyls were quantified as 18 individual congeners, and 16 chlorinated pesticides were reported. Butyltin compounds were analyzed at the MSL using gas chromatography/flame photometric detection (GC/FPD), following the methods of Unger et al. (1986).

Sedimentation (cm/yr) and deposition rates ($g/cm^2/yr$) were estimated using a steady-state ^{210}Pb dating technique (Lavelle et al., 1985, 1986; Nevissi et al., 1989). This method assumes 1) that sedimentation rate is constant; 2) that loss of ^{210}Pb from sediment layers occurs only by radioactive decay; 3) that mixing is confined to the surface mixed layer; and 4) that intervals of sediment used for analysis have well-defined depositional times that are short compared with the overall dating period. Only data from below the surface mixed layer were used to calculate the sedimentation rate. The mixed layer within Puget Sound has been observed to vary in thickness from depths of 2 cm to 30 cm (Carpenter et al., 1984,1985).

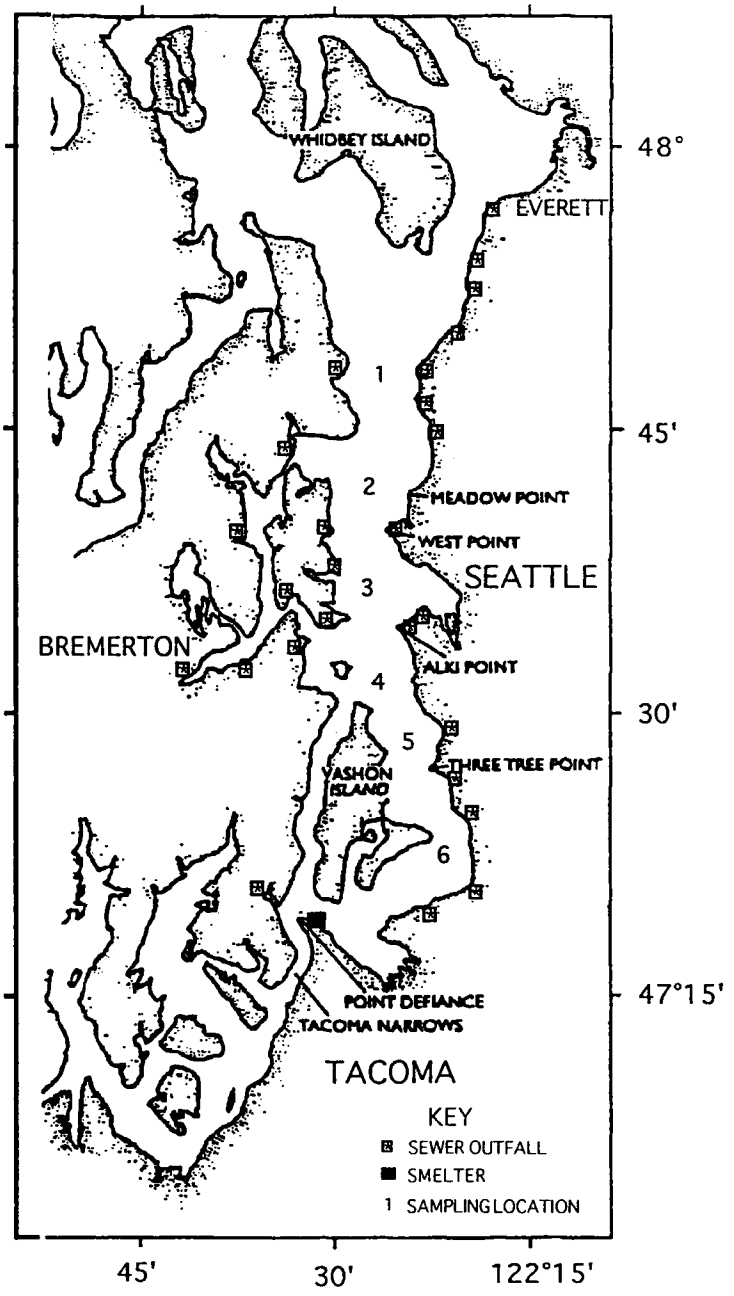

Figure 1. Sediment coring station locations (1 - 6) and sewer outfalls in the main basin of Puget Sound in the summer of 1991.

A trend analysis was conducted on metals, PCBs, and DDT concentrations, which displayed a potential decline after a maximum value attained. In order to determine the correlation between the strengthening of environmental laws and sediment contaminant loadings, the linear correlation coefficient (r) was used to evaluate the significance of the relationship between the concentrations of Ag, As, Cu, Hg, Pb, Sb, Zn, total PCBs, and DDT against year from 1970 to 1991 individually for cores 3, 5, and 6. A least squares analysis would be inappropriate, since neither axis can be assumed to be known without error. A

significant negative correlation (i.e., a decrease in concentration of these contaminants with increasing year) provides empirical evidence that the strengthening of environmental legislation in the past 20 years has had an influence on the water quality in Puget Sound.

RESULTS AND DISCUSSION

A sedimentation rate of approximately 1 to 2 cm/yr in the deep region of central Puget Sound determined in this study agrees with the results found in an earlier study by Lavelle et al. (1985, 1986). Deposition rates ranged from 480 to 1000 mg/cm^2/yr, with the lowest accumulation found in core 6, which was located just north of Tacoma. These rates agree well with data from past studies within the same region and water depth of Puget Sound, where mass accumulation rates ranged from 98 to 790 mg/cm^2/yr (Carpenter et al., 1985), 340 to 1400 mg/cm^2/yr (Bloom and Crecelius, 1987), and 260 to 1200 mg/cm^2/yr (Lavelle et al., 1985, 1986).

A temporal trend for some metals (Pb, Ag, As, Cu, Hg, Sb, Sn and Zn) showed a reproducible pattern of increasing concentrations to a maximum, followed by decreasing concentrations through the present (Figure 2). This trend has been detailed in a number of other studies from sediment cores taken from Puget Sound (Bloom and Crecelius, 1987; Romberg et al., 1984).

Arsenic concentrations (μg/g dry wt) reached a maximum between the early 1950s and 1960s (Figure 2). The highest levels of As were found in cores 5 and 6, the southernmost cores and those closest to the ASARCO smelter, which operated from approximately 1889 to the 1980s. Concentrations of antimony, a byproduct of smelter operations at ASARCO, followed a similar pattern, reaching a maximum concentration of between 2 and 4 μg/g between the 1950s and 1960s. Both metals showed a greater than 25 percent decrease from the maximum to the surface concentration.

Mercury reached a maximum concentration of 0.5±0.01 μg/g in the late 1940s. An average 50 percent drop from the maximum to the surface concentration was observed in cores 3, 5, and 6 (Table 1) with a significant ($\alpha = 0.05$) average sediment recovery of 0.006±0.005 μg/g per year. However, the concentrations of Hg over the last 20 years remained fairly constant and did not produce a significant negative correlation.

Silver, Cu, and Zn all appear to have reached maximum concentrations in the early 1960s followed by decreasing concentrations in the late 1960s. Silver reached a maximum of 0.91±0.004 μg/g in mid-1960; however, it displayed an average drop of only 17 percent from the maximum to the surface concentration.

Total PAH concentrations ranged from approximately 100±21.6 ng/g in the deepest sections of the cores to a maximum of up to 6788 ng/g in the early 1940s, and then declined to an average of 1300 ng/g in the surface sediments (Figure 2). An average 59 percent decrease in concentration of total PAHs was observed between the maximum and surface concentrations (Table 2); however, a significant negative correlation between year and concentration was not obtained for sediments deposited after 1970 for any of the cores.

Combustible PAHs are the higher-molecular-weight PAH compounds, consisting of the 4-, 5- and 6-benzene-ring compounds. The concentrations of combustible PAHs generally parallel the total PAH concentrations in the sediment cores. An average 60 percent reduction in concentration between the maximum and surface concentrations was observed; however, sediments deposited after 1970 did not produce a significant negative correlation between year and concentration.

The percentage of combustible PAHs out of the total PAHs has remained approximately 80 percent since the 1920s. Before 1900, it averaged about 50 percent. As the use of fossil fuels increased, the percentage also increased, reaching a maximum of approximately 85 percent in the 1940s, when the greatest number of households in the Seattle-Tacoma area used coal as their heat source.

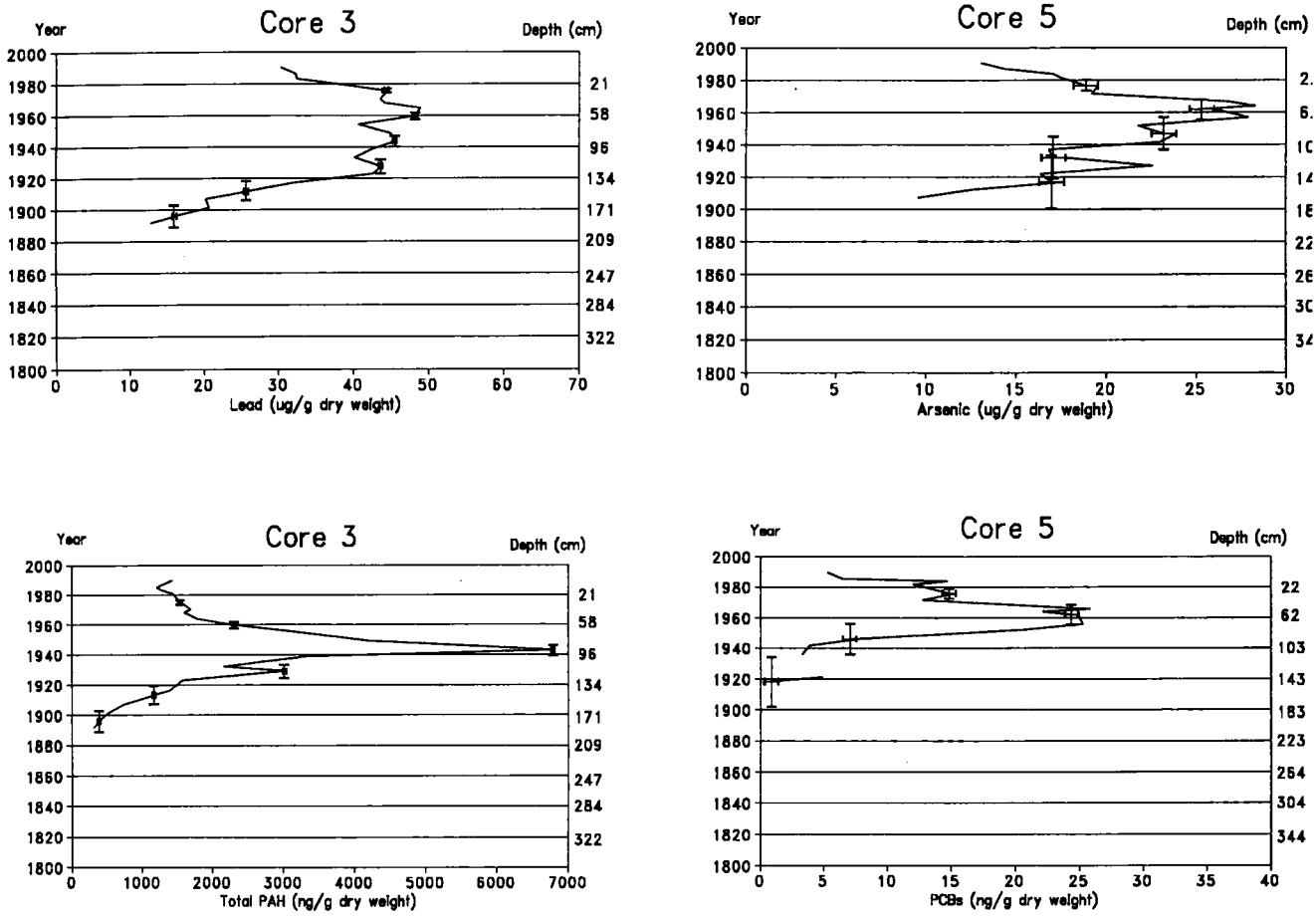

Figure 2. Historical trends of contaminants in sediment cores from Puget Sound

The maximum concentrations of both total and combustible PAHs occurred in sediments deposited between 1930 and 1950. These patterns were observed in cores collected in 1981 as part of a study on the distribution of toxicants in the Puget Sound (Romberg et al., 1984).

Linear alkyl benzenes (LABs) are used in the production of linear alkyl sulfonates (LASs), which are anionic surfactants widely used in detergents. These products became commercially available in the early 1960s, and their use rapidly became widespread. The source of LABs to the environment is exclusively anthropogenic, primarily from municipal sewage. A dramatic increase in concentrations occurred in the early 1980s in all cores to a maximum of 184 ng/g. In general, concentrations do not appear to be decreasing in surficial sediments, and there is no negative correlation between year and concentration for sediments deposited after 1970. A decreasing trend in LAB concentrations is not evident, which suggests that sources of these compounds are still being actively discharged.

Temporal trends in the contamination of central Puget Sound by synthetic organic chemicals, such as PCBs and pesticides (e.g., DDT), are similar to those of metals and hydrocarbons, except that these chemicals did not appear until about the 1930s (Figure 2). Since these compounds are anthropogenic in origin, no background levels occurred in sediments before their introduction at that time. A rapid increase in concentrations occurred until the mid-1970s, when significant regulations, such as the Toxic Substance Control Act (enacted 1976), limited their use and greatly reduced the amount of PCBs released into the environment. Even though an average 68 percent reduction between the maximum and surface concentra-

tions of PCBs was observed, only core 3 had a significant (α = 0.05) negative correlation between year and concentration for sediments deposited after 1970. DDT concentrations for cores 3 and 6 showed a depositional pattern similar to that of PCBs, increasing in the 1930s and producing a maximum in the 1960s. In core 5, however, DDT reached its maximum concentration in the 1980s.

CONCLUSIONS

The temporal trends in central Puget Sound described in this report were based on the chemical composition of age-dated sediment cores. The sedimentation rates used to estimate the dates of the various sediment fractions are in agreement with sedimentation rates obtained from similar locations in other studies. Trace metal contamination (Ag, As, Cu, Hg, Pb, Sb, and Zn) began in the late 1800s, reached a maximum in the mid-1900s, and began to decrease in the last two decades. Concentrations of Cu, Pb, Sb, and Zn declined significantly in the last 20 years. This supports the hypothesis that the strengthening of environmental regulation since 1970 has influenced the water quality of Puget Sound.

Table 1. Maximum and surface concentrations (µg/kg) of selected metals for three cores collected from Puget Sound during the summer of 1991

	Core 3							
	Ag	As	Cu	Hg	Pb	Sb	Sn	Zn
Max Year	1965	1965	1960	1949	1965	1960	1965	1965
Max	0.91	19.5	54.6	0.479	48.9	2.05	4.9	134.6
Surface	0.68	12.5	42.7	0.179	30.3	1.28	3.94	114.7
%change	25.3%	35.9%	21.8%	62.6%	38.0%	37.6%	19.6%	14.8%
Correlation for Past 20 Years	-0.96	-0.81	-0.96	-0.46	-0.93	-0.92	-0.83	-0.97

	Core 5							
	Ag	As	Cu	Hg	Pb	Sb	Sn	Zn
Max Year	1982	1964	1947	1947	1922	1952	1962	1962
Max	0.84	28.3	70	0.505	69.4	3.9	4.85	167.7
Surface	0.69	13.1	49.3	0.213	36.7	1.6	3.96	119.2
%change	17.9%	53.7%	29.6%	57.8%	47.1%	59.0%	18.4%	28.9%
Correlation for Past 20 Years	-0.62	-0.94	-0.99	-0.89	-0.98	-0.94	-0.26	-0.96

	Core 6							
	Ag	As	Cu	Hg	Pb	Sb	Sn	Zn
Max Year	1965	1950	1963	1950	1954	1963	1963	1954
Max	0.65	23.5	64.7	0.403	62.3	2.43	4.25	128.8
Surface	0.59	17.3	52.7	0.277	44.7	1.52	2.78	115.5
%change	9.2%	26.4%	18.5%	31.3%	28.3%	37.4%	34.6%	10.3%
Correlation for Past 20 Years	-0.87	-0.17	-0.94	-0.90	-0.94	-0.99	-0.70	-1.00

Table 2. Maximum and surface concentrations (ng/g) of selected organic compounds for three cores collected from Puget Sound during the summer of 1991

	Core 3						
	PCB	DDT	TPAH	CPAH	LABS	Terpanes	Hopane
Max Year	1960	1960	1943	1943	1983	1943	1953
Max	34.5	4.71	6788	5917	101	2260	235
Surface	9.00	1.19	1434	1162	80.7	1570	158
% Change	73.9%	74.8%	78.9%	80.4%	19.8%	30.5%	32.8%
Correlation for Past 20 Years	-0.87	-0.92	-0.78	-0.79	0.87	-0.83	-0.92

	Core 5						
	PCB	DDT	TPAH	CPAH	LABS	Terpanes	Hopane
Max Year	1966	1984	1942	1942	1986	1990	1962
Max	25.8	5.76	3430	2898	184	2360	227
Surface	5.33	4.77	1303	1050	29.3	2360	224
% Change	79.3%	17.2%	62.0%	63.8%	84.0%	0.0%	1.1%
Correlation for Past 20 Years	-0.71	0.67	-0.68	-0.72	0.32	0.21	-0.17

	Core 6						
	PCB	DDT	TPAH	CPAH	LABS	Terpanes	Hopane
Max Year	1961	1961	1935	1935	1977	1923	1965
Max	15.5	4.25	1883	1516	69.4	2290	203
Surface	7.39	2.80	1212	977	63.9	1860	183
% Change	52.2%	34.2%	35.6%	35.5%	7.9%	18.8%	9.5%
Correlation for Past 20 Years	-0.78	-0.83	-0.71	-0.72	0.35	-0.38	-0.33

Trends in organic chemicals in the sediments over time also show a subsurface maximum. Hydrocarbon contamination appears to parallel that of heavy metals. PAH concentrations, although decreased over fourfold from maximum concentrations, appear to be relatively constant over the past several decades. Synthetic organic contaminants appear in sediments deposited more recently, in the mid-1930s and 1940s, and reached a maximum in the observed concentrations, with two- to fourfold decreases in surficial sediment concentrations. Concentrations of compounds such as PCBs and DDT appear to be continuing to decrease.

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PSDDA: FIVE YEARS OF PROGRAM IMPLEMENTATION

Stephanie Stirling[1], David Kendall[1], David Fox[1], Therese Littleton[1], Justine Barton[2], John Malek[2], Rachel Friedman-Thomas[3], Tom Gries[3], Gene Revelas[4], and Deborah Lester[5]

INTRODUCTION

The management of clean dredged material and open-water disposal in Puget Sound is accomplished through the Puget Sound Dredged Disposal Analysis program (PSDDA). This program is a cooperative venture of the four agencies with jurisdiction over dredging and disposal: Corps of Engineers (COE), Environmental Protection Agency (EPA), Washington Department of Natural Resources (DNR), and Washington Department of Ecology (Ecology). The PSDDA program grew out of a common need and emphasizes consensus decision-making and shared resources to accomplish common goals.

In 1984 several events took place that focused attention on the environmental health of Puget Sound. A number of activities that had been seen as "business as usual," including the disposal of dredged material, were called into question. Out of these events grew the political support for the creation of a new agency, the Puget Sound Water Quality Authority. In addition, concern over the potential presence of chemicals in dredged material and their effects on fish and other marine life led to the closure of two major disposal sites within Puget Sound.

These closures, as well as the general concern for the health of the Sound, led to a comprehensive interagency study on future dredging activity and the need for unconfined open-water disposal sites. The four agencies with jurisdiction launched a Puget Sound-wide effort to identify locations for open-water disposal, define the evaluation procedures for material to be placed there, and develop site management plans. The study was completed in two overlapping phases, each lasting 3½ years (4½ years total), at a total cost of $4.5 million. The process was an open one and involved input from all stakeholders, including tribes, ports, environmental groups, state and federal agencies, and research scientists. These studies resulted in two Environmental Impact Statements. These documents, and the technical appendices that accompany them, form the basis of the PSDDA program.

The program identified eight open-water disposal sites, five of which are non-dispersive and three dispersive. (At non-dispersive sites, environmental conditions are such that the material will stay on site; at dispersive sites, stronger currents dissipate the material.) The PSDDA management plan emphasizes cooperative implementation and management of the open-water disposal sites. The Corps works cooperatively with DNR to conduct periodic chemical, biological and physical monitoring of the non-dispersive sites. The Corps is responsible for conducting physical monitoring at the three dispersive sites. Agency responsibility and authority is spelled out in the PSDDA management plan:

Corps

Lead PSDDA agency
Section 10/404 permits
Permit compliance and enforcement
Dredging and disposal site inspections (with DNR and Ecology)
Initial project data quality assurance

[1] U.S. Army Corps of Engineers, Seattle District, P.O. Box 3755, Seattle, WA 98124

[2] U.S. Environmental Protection Agency, Region 10, 1200 6th Avenue, Seattle, WA 98101

[3] Washington Department of Ecology, P. O. Box 47600, Olympia, WA 98504

[4] Striplin Environmental Associates, 6541 Sexton Dr. NW, Suite E-1, Olympia, WA 98502

[5] Washington Department of Natural Resources, P. O. Box 47000, Olympia, WA 98504-7000

Dredged material data management—Dredged Analysis Information System
Physical monitoring of disposal sites
Disposal site identification (with EPA)
Biennial PSDDA report (testing and site use)

Ecology

Section 401 Water Quality certification
Coastal zone management consistency determination
Coordination of state response
State sediment management data—SEDQUAL
Dredging site inspections (with Corps and DNR)
Biennial PSDDA Report (Management Plan Assessment)

DNR

Disposal Site use permits and site use records
Collection of disposal site user fees
Disposal site inspections (with the Corps)
Chemical and biological monitoring of the disposal sites
PSDDA biennial report (monitoring of disposal sites)
Shoreline permits for disposal sites

EPA

Section 10/404 review
Disposal site identification (with the Corps)
Refinement of assessment (testing) methods

Each of the PSDDA agencies participates directly in evaluation of permits, review of disposal site monitoring data, and decisions regarding program modifications through the annual review process.

Procedures for the evaluation of material proposed for dredging were developed during the PSDDA study. Urban embayments in Puget Sound were evaluated based on existing data and known sources of contamination, and these areas were given one of four ranks (low, low-moderate, moderate and high). In addition, some types of facilities, such as marinas, were given a specific ranking. The site ranking determines the amount of testing required for the sampling effort.

Applicants may choose to do a partial characterization (PC) survey before doing a full characterization in order to re-evaluate the area rank (and reduce the amount of testing required). This is a cost effective measure for the applicant if: 1) they believe the area is cleaner than the ranking would indicate; and 2) the project is of a sufficient volume that the lower rank would justify the cost of the PC. Full characterization ranks and minimum analysis requirements are reported in Table 1.

Project volumes are divided into dredged material management units (DMMU), that is, the smallest volume of dredged material for which a separate disposal decision can be made. Each DMMU must be capable of being independently dredged.

Chemical testing is conducted on 58 chemicals that have been identified as being of concern in Puget Sound. Testing for additional analytes may be required if there is reason to believe they may be present, e.g., tributyltin near marinas or areas of boat maintenance activities. "Tiered" chemical and biological testing is required. Screening levels and maximum levels have been established for each chemical of concern. If any chemicals exceed the screening level, biological testing is required. If two or more analytes exceed the maximum level, the material is generally considered unsuitable for open-water disposal. The current bioassay suite consists of the amphipod 10-day acute test, the *Neanthes* 20-day chronic

Table 1. General sampling for full characterization and DMMU volume analysis guidelines based on area rank

Area Concern Rank	Surface Sediment (< 4 ft)		Subsurface Sediment (> 4 ft)	
	Analysis requirements	Sampling requirements	Analysis requirements	Sampling requirements
Low	48,000	6	72,000	9
Low-moderate	32,000	4	48,000	6
Moderate	16,000	4	24,000	6
High	4,000	1	12,000	3

sublethal test, and the sediment larval (echinoderm/bivalve) bioassay. The Microtox® bioassay, which has been a part of the suite, is currently under evaluation, and the use of Microtox has been suspended for a year while the PSDDA agencies evaluate the relative merits of the solid phase versus the saline extract test.

PROGRAM IMPLEMENTATION

Both the development of PSDDA and its implementation have emphasized cooperative management and decision-making. The Corps of Engineers' Dredged Material Management Office (DMMO) acts as a one-stop office for coordination with dredging proponents. In other parts of the country applicants must deal with each agency separately. While agencies have not relinquished any of their mandated authorities and responsibilities, the consensus approach has eliminated duplication of review for both the applicant and the agency.

Successful implementation involves close interagency coordination. On a project-specific basis, the agencies review all existing information and sign a suitability determination memorandum (SDM). The suitability determination provides the mechanism for a technical review of the sediment characterization results for each project, and for consensus agency judgments regarding sediment suitability for unconfined open-water disposal.

PERMIT PROCESS

PSDDA sampling and testing is undertaken as part of the requirements for a permit under Section 404 of the Clean Water Act. Each applicant follows a series of steps:

1) Submit application for permit, receive permit number.
2) Prepare sampling and analysis plan (SAP) for characterization of proposed dredged material.
3) Receive approval of SAP from PSDDA agencies.
4) Perform sampling and chemical/biological analysis.
5) Submit testing results to PSDDA agencies.
6) Receive suitability determination for open-water disposal from PSDDA agencies.
7) Complete application details required to issue public notice.
8) Issue public notice, undergo 30-day public comment period.
9) Perform public interest review and issue permit decision.

These steps are coordinated with the four PSDDA agencies through the Corps' DMMO. Data submitted upon the completion of testing are given to each of the agencies for concurrent review. Additional coordination of data also occurs with Indian tribes, when their usual and accustomed fishing places occur in the vicinity of the dredging and/or disposal activity. PSDDA agency review of the data normally occurs within two to three weeks. If the data are acceptable for decision-making, the DMMO prepares an SDM, which documents the PSDDA agency consensus on the suitability of the material for unconfined open-water disposal. The SDM is coordinated with each agency and is signed by each agency

representative. Federal navigation projects are subject to the same guidelines and evaluation procedures and must meet the same suitability guidelines as permitted dredging projects before any disposal action.

The Dredged Analysis Information System (DAIS) was developed by the Corps for the PSDDA program as a part of program implementation. This is a relational database designed to track all aspects of data associated with projects tested under PSDDA guidelines. The chemical testing modules include all sample information as well as relevant quality assurance/quality control (QA/QC) data. The bioassay module includes test data, water quality measurements and reference toxicant data. Automated quality assurance routines provide checks on accuracy and precision and on quality control coverage for chemical analyses. For biological analyses the QA routines cover test conditions, sensitivity and validity. The administrative tracking system within DAIS allows the management of project milestones, dredged material volumes, points of contact and other valuable information for project managers. Extensive reporting capabilities have been built into DAIS. In addition, it is completely compatible with a geographic information system and is being used for site-specific spatial analysis of chemical data, as well as in broader investigations.

ANNUAL REVIEW MEETING—PUBLIC RESPONSIVENESS

Each year the PSDDA agencies conduct an Annual Review Meeting (ARM), moderated by the Corps, and hosted by one of the four agencies. The ARM provides a forum for airing program concerns and problems, receiving public input, clarifying and proposing changes to the PSDDA Management Plan, discussing disposal site management, and discussing the status of any on-going agency actions. Proposed revisions to the program can be relatively minor, such as a new reporting requirement, or they can be major, such as the requirement to conduct a new bioassay. Papers covering these issues are mailed one month before the annual review meeting to all interested parties, including tribes, environmental groups, ports, dredgers, and other agencies. Both oral and written comments and questions are encouraged.

REPORT PREPARATION—PUBLIC ACCOUNTABILITY

The PSDDA program prepares a biennial report documenting all aspects of the program. Included are project testing overview summaries, testing cost evaluations, PSDDA program/regulatory processing evaluations, documentation and summaries of disposal site monitoring, program protocol clarifications and refinements, and updates to the PSDDA management plan.

SITE MANAGEMENT AND MONITORING

All four PSDDA agencies cooperatively manage the disposal sites and participate in data review and management decisions affecting the sites. Initial baseline monitoring studies were conducted at each of the five non-dispersive sites: Bellingham Bay, Port Gardner, Elliott Bay, Commencement Bay, and Anderson/Ketron. Each site has its own monitoring schedule, determined primarily by the amount of material deposited at the site.

DNR generally takes the lead on disposal site monitoring. It is responsible for contracting for chemical and biological monitoring services. Major funding for the contract is generated by site use revenues collected by DNR. In cases where special studies are required, funding can come from the other PSDDA agencies. The Corps accomplishes physical monitoring at all eight disposal sites in lieu of paying a site use fee to DNR for its unsponsored federal maintenance projects. The PSDDA agencies review the request for proposals, contractor bids, and other documents related to the monitoring effort. Monitoring reports are prepared by the contractor who conducts the chemical and biological testing. This information is reviewed by the four PSDDA agencies to determine whether management standards have been met, whether additional studies are needed, or whether adjustments should be made to site use conditions, site standards, or other program elements.

Monitoring at a PSDDA site is not triggered by a specific disposal event, but rather is triggered by the cumulative volume disposed at a site. Only dredged material that meets the PSDDA guidelines is allowed at the site (no guns, no bridges). No attempt is made to isolate physical types of material (sand from clay).

DNR is the land management agency for the state of Washington, and holds the shoreline permit for each of the PSDDA disposal sites. These permits are for five year periods, and all were renewed within the past year and a half, with the exception of the Anderson/Ketron Island site, which is up for renewal in January 1995. As the holder of the permit, DNR is potentially liable for any damages resulting from a disposal at a PSDDA site. The Corps and DNR were jointly named in a lawsuit in 1992. All four agencies worked cooperatively to address litigation issues, and the lawsuit was ultimately resolved in the agencies favor.

Monitoring Data: Non-dispersive Sites

The chemical, biological and physical monitoring conducted at the PSDDA non-dispersive sites is designed to answer three questions to determine whether the site management objectives outlined in the management plan have been achieved. The questions are:

1. Does the dredged material stay on site?

2. Is the biological effects condition (minor adverse effects) for non-dispersive sites exceeded as a result of dredged material disposal?

3. Are unacceptable adverse effects occurring on biological resources immediately off site as a result of dredged material disposal?

Five post-disposal site monitoring events have taken place to date, covering three of the five non-dispersive sites. These are 1990-1992 monitoring of the Elliott Bay site, 1990-1994 monitoring of the Port Gardner site, and 1993 monitoring of the Bellingham Bay site. The results of these monitoring events have confirmed that the site management objectives have been met.

If site management objectives are not met, the PSDDA agencies meet to consider a range of management options to remedy the problem, which could range from modification of evaluation procedures to additional data collection or possibly to site closure.

A brief review of the monitoring efforts at Elliott Bay illustrate the program. Baseline studies of the site were completed by the Department of Ecology in 1988. In Dredging Year 1990 (DY90)[1], 103,000 cubic yards were placed at the site, triggering a partial monitoring. In DY92, 230,241 cubic yards were placed on-site, triggering a full monitoring event.

The results showed that the disposed dredged material stayed on site. Chemistry data collected along the site perimeter indicated that some metals concentrations were higher than original baseline data. Given this information, sediment samples from benchmark stations (located within Elliott Bay but well away from any influence of dredged material) were collected and analyzed. Analysis of these samples indicated a bay-wide elevation of metals, unrelated to dredged material disposal. Results of the on-site chemistry and bioassay data showed sediment quality to be well within the allowable "minor adverse effects" level. In general, sediment contaminant concentrations were observed to be at the low end ranges reported in the baseline survey. Since 1988, the disposal site has shown an appreciable decrease in contamination.

The monitoring plan also evaluated the potential for offsite biological effects through an assessment of sediment chemistry and benthic infaunal abundance at three stations located downslope and downcurrent of the disposal site perimeter. The sediment chemistry data did not indicate any evidence of offsite migration of dredged material. The abundances of major taxa (e.g., annelids, crustacea, molluscs) observed in 1992 were similar to those found during baseline studies. The results showed no indication of adverse environmental effects beyond the disposal site boundary.

[1] A dredging year (DY) begins June 16 of any given year and ends June 15 of the following year.

Monitoring Data: Dispersive Sites

At the three dispersive sites, monitoring requirements are limited to bathymetry for verification that dispersion of the material is taking place. Guidelines used to evaluate material proposed for dispersive site disposal are more restrictive than those used to evaluate material for non-dispersive sites. The only monitoring question for dispersive sites is: Is the dredged material mounding on site, or is it being effectively dispersed?

Post-disposal bathymetry monitoring of the Rosario Strait site in 1991 and 1994 indicated that the site is highly dispersive, with no discernible mounding of material compared to initial baseline bathymetry.

FIVE-YEAR REVIEW

Projects

The number of projects evaluated under the PSDDA program are shown in Figure 1 and have averaged 12 per year, with a range of five to 17 projects each year. The number of suitability determinations has averaged 10 per year. The difference reflects, in part, the completion of several partial characterizations during DY93. In addition, there are a few projects where, based on the results of the PSDDA testing, the applicant withdrew the project or opted for a different disposal option. In some of these cases, the data were not submitted to the PSDDA agencies, and a suitability determination was not made.

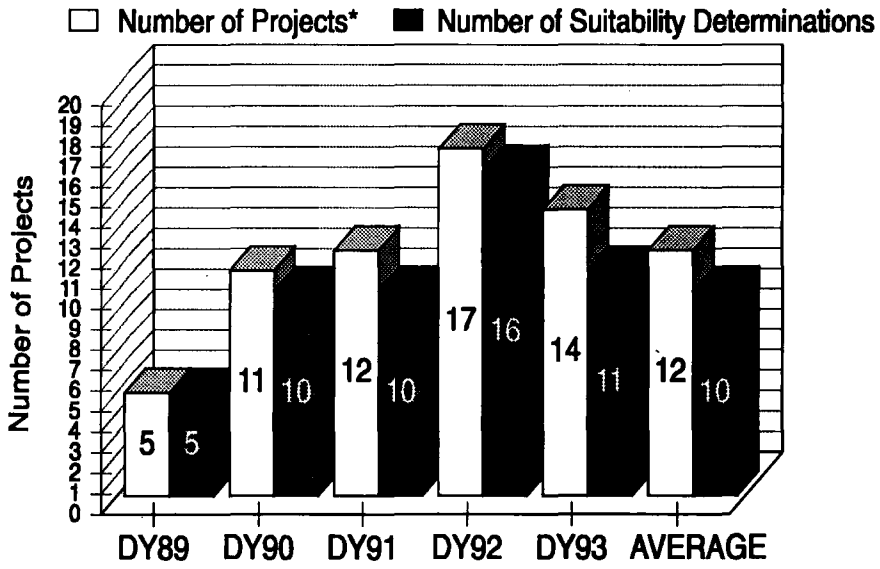

Figure 1. Number of projects evaluated under PSDDA

Between 1990 and 1993, the average time required for PSDDA evaluation was 166 days (Figures 2a and 2b). This included the time for agency review of sampling and analysis plans (average 14 days), sampling and testing by the applicant (average 136 days) and data review/suitability determination by the agencies (average 16 days). The agency review times are well within the agency established guidelines of three weeks.

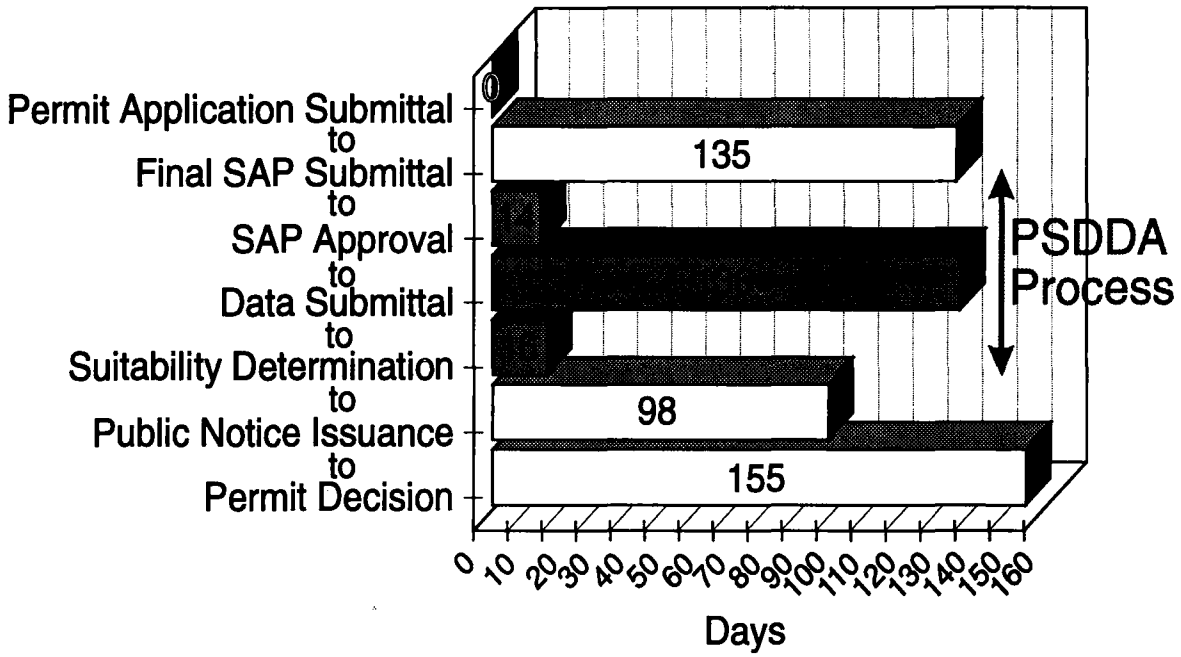

Figure 2a. Regulatory processing time. Retrospective summary (1990-1993)

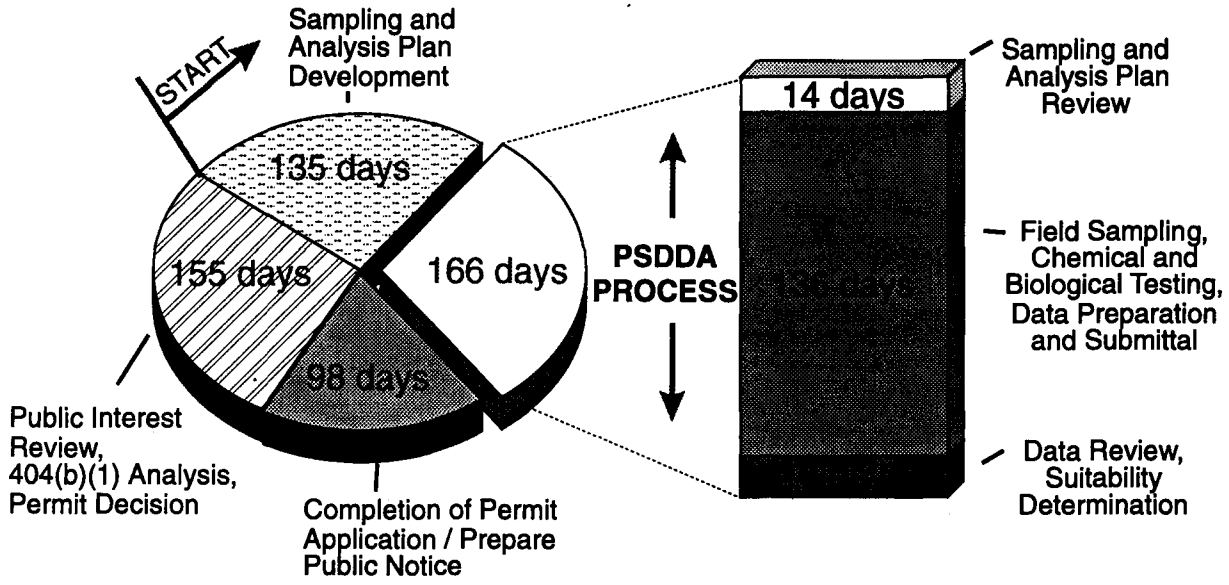

Figure 2b. PSDDA processing time. Retrospective summary (1990-1993)

Chemical and Biological Testing

Figure 3 shows the dredged material management units undergoing chemical and biological testing since the PSDDA program was initiated. There was a large increase in the number of DMMUs tested in DY92, even though the number of projects remained relatively constant. This is the result of several large-volume projects, as well as more projects being located in high- and moderate-ranked areas. The number of DMMUs requiring the biological testing tier (those that had one or more exceedances of PSDDA screening levels) varied considerably, from a high of 72 percent in DY92 to a low of 19 percent in DY93. Approximately 59 percent of DMMUs undergoing chemical testing have required bioassay testing during the program's implementation.

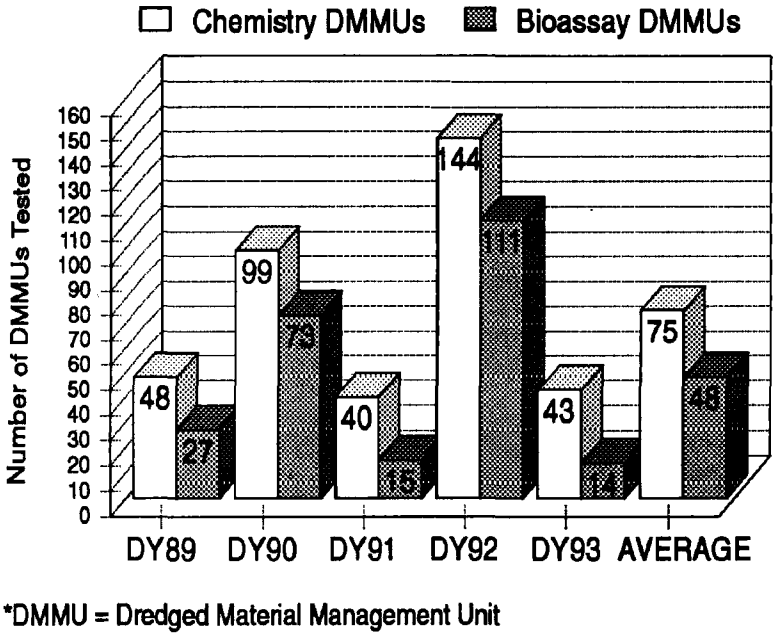

Figure 3. Number of chemistry and bioassay DMMUs tested*

Site Use and Capacity

As part of the disposal site technical evaluation under the PSDDA study, site capacities were estimated for each site. Boundaries of the sites were drawn so that each will retain adequate capacity for 15 years, given the projected use. Figure 4 depicts the total volume of material undergoing PSDDA characterization, and the volume found suitable each dredging year. In general, most of the material (96 percent) tested was found suitable for unconfined open-water disposal. Over the five years of PSDDA implementation, approximately 2,378,200 cubic yards have been placed at the PSDDA open-water sites, averaging 518,279 cubic yards per year. A total of 240,000 cubic yards of material has been found unsuitable for unconfined open-water disposal during the past five years. Five-year summaries of site use show that site capacities appear to be sufficient for at least 50 years (Table 2).

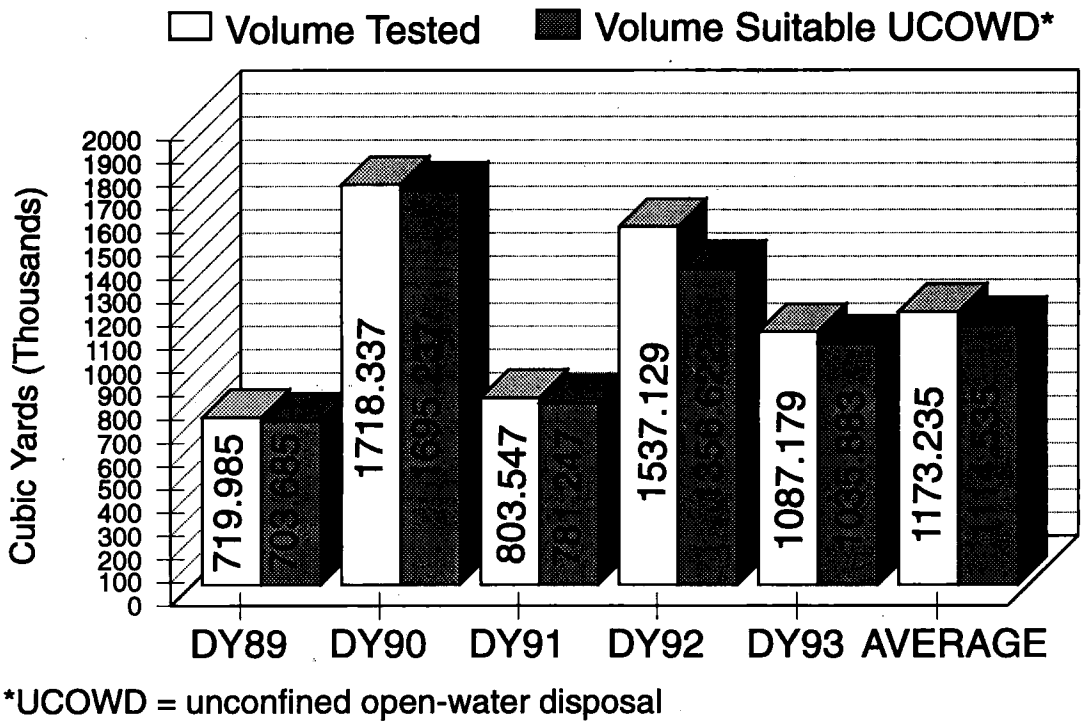

Figure 4. Testing outcome summary

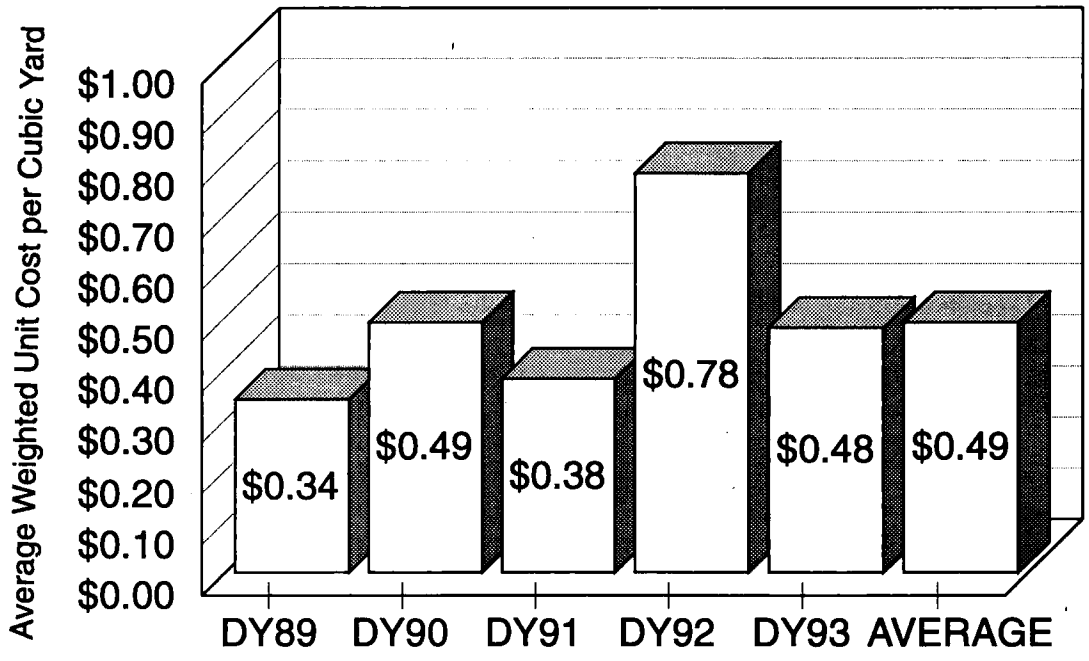

Figure 5. Average sampling and testing costs

Table 2. Five-year site use summary

Non-dispersive Disposal Site	Cumulative Volumes (CY)	Average Volume (CY/YR)	15-Year Predictions MPR Phase I/II (CY)	Percent of 15-Year Prediction	Estimated Time to Exceed Site Capacity[1] (Years)
Port Gardner (1989-1993)	1,118,835	223,767	8,243,000	13.6	40
Elliott Bay (1989-1993)	389,065	77,813	10,525,000	3.7	>50
Bellingham Bay (1990-1993)	32,883	8,221	1,181,500	2.8	>50
Commencement Bay (1989-1993)	17,548	3,510	3,929,000	0.45	>50
Anderson/Ketron Island (1990-1993)	10,197	2,549	785,000	1.3	>50
SUBTOTALS:	1,568,528	315,860	24,763,500	6.3	N/A
Dispersive Disposal Site	**Cumulative Volumes (CY)**	**Average Volume per Year (CY/YR)**	**15-Year Predictions MPR Phase I/II (CY)**	**Percent of 15-Year Prediction**	**Estimated Time to Exceed Site Capacity[2] (Years)**
Rosario Strait (1990-1993)	787,030	196,758	1,801,000	43.7	N/A
Port Townsend (1990-1993)	22,642	5,661	687,000	3.3	N/A
Port Angeles (1990-1993)	0	0	285,000	0	N/A
SUBTOTALS:	809,672	202,419	2,773,000	29.2	N/A
GRAND TOTALS:	2,378,200	518,279	27,536,500	8.6	N/A

[1] Site capacity estimated in Phase II Disposal Site Selection Technical Appendix for nondispersive sites is approximately 9,000,000 cubic yards.

[2] Actual site capacity for dispersive sites is not limited, assuming complete dispersal of dredged material off site.

COST DATA

One aspect of the PSDDA program that is not found in many other regulatory programs is a commitment to monitor program costs. By tracking these costs, the agencies can give new applicants an estimate of the cost of conducting testing for a proposed project. In addition, it allows the agencies to keep an eye on the cost implications of any proposed program changes. Higher unit costs tend to be associated with smaller projects, which lack the ability to spread the QA and sampling costs over several DMMU. Over the past five years, sampling and testing costs have averaged $0.49 per cubic yard (Figure 5) and have remained fairly uniform, with the exception of DY92. Due to more biological testing than usual, and higher ranking of projects, the average cost for DY92 year was $0.78 a cubic yard.

THE FUTURE

Because of resource limitations, the PSDDA program has focused on the management of unconfined open-water disposal of clean dredged material. It is becoming evident that both agencies and project proponents are increasingly involved in complex projects that include the potential dredging and disposal of contaminated sediment. No single agency has complete and unilateral authority to cover all contaminated sediment issues. Furthermore, no one agency has the resources to tackle these issues.

In recognition of these facts, the PSDDA agency directors (with the addition of the Puget Sound Water Quality Authority) signed an interagency/intergovernmental agreement (IAG) in May 1994. The IAG formalizes interagency cooperation and coordination to establish regional priorities, jointly develop technical and policy responses, and implement solutions for the management of clean and contaminated sediments. To succeed in crafting solutions to these problems, the initial joint actions require the

participation of all stakeholders, including state and federal regulatory agencies, resource agencies, environmental groups, Indian tribes, industry and the public.

The initial actions identified by the agency directors included the following: initiation of sediment clean-up strategy, preparation of an action plan for multi-user confined disposal sites, and the establishment of interagency/intergovernmental policies for the beneficial use of dredged material. Work groups have been formed to accomplish these goals. The sediment clean-up work group (convened in July 1994) has focused on developing approaches to facilitate the clean-up of contaminated sediments in the aquatic environment. The group reported the results of its efforts to agency directors on December 20, 1994.

The beneficial uses work group begins meeting in January 1995 and will focus its efforts on the identification of existing agency policy and regulations regarding beneficial uses. The group will recommend ways to encourage the beneficial use of dredged material in a coordinated and environmentally sound manner.

The action plan for multi-user confined disposal sites received a substantial boost through a congressional appropriation to the Corps to conduct a feasibility study on multi-user sites. This effort (coupled with additional funds from the Department of Ecology) will complement existing efforts and identify the steps necessary for the development of one or more multi-user sites in the Puget Sound region.

CONCLUSION

Five years of implementation have confirmed the success of the PSDDA program. The cooperative management approach has provided predictability to the regulated dredging community. The program has provided technical feedback to the resource agencies and the public on the environmental acceptability of the evaluation procedures and management plans. It has developed tools, such as DAIS, that are being used in other areas of the country in dredged material management, and serves as a paradigm for other sediment evaluation efforts in Washington state. The program is now evolving to deal with complex dredging projects, with hopes that the same spirit of cooperation can speed the clean-up of contaminated sites in Puget Sound.

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CHARACTERISTICS OF BENTHIC INFAUNAL COMMUNITIES ALONG A GRADIENT OF SEDIMENT CONTAMINATION IN ESQUIMALT HARBOR, BRITISH COLUMBIA

Doug A. Bright and Kenneth J. Reimer[1]

ABSTRACT

Sediments in Esquimalt Harbor, near Victoria, B.C., are contaminated with PAHs, PCBs, organotins and inorganic elements (including arsenic, cadmium, copper, lead, mercury, and zinc). All contaminants are highly inter-correlated in their distribution; localized inputs associated with the building, maintenance and repair of ships at four sites have resulted in a well-defined gradient from highly to minimally contaminated sediments over a small area. Use of sediment quality criteria developed for Puget Sound or NOAA effects ranges suggests that individual organisms and biotic assemblages in parts of the harbor should be highly affected; however, considerable scientific uncertainty exists over cumulative effects of sediment-sorbed contaminants, disparity between different sets of numbers, chronic effects associated with food-chain mediated contaminant transfer, and applicability to different sites.

The site-specific impact associated with seabed contamination in Esquimalt Harbor was measured directly using sediment bioassays; histopathology in small infaunal clams, English sole livers and Dungeness crab hepatopancreas; and characteristics of benthic infaunal communities. Benthic communities' responses to sediment contamination in the harbor are discussed here. It is, perhaps, not surprising that univariate and multivariate measures of soft-bottom community structure in the harbor were not linearly related to the concentrations of individual or combined contaminant concentrations. A highly depauperate zoobenthos occurs in the entire harbor relative to reference areas with similar substrate outside of the harbor mouth. Apparent threshold community responses are compared to sediment quality criteria and effects ranges.

[1] Environmental Sciences Group, Royal Roads Military College, FMO Victoria, B.C. VOS1B0

BENTHIC COMMUNITIES IN URBAN AND NON-URBAN AREAS IN PUGET SOUND

Margaret Dutch, Roberto J. Llansó, and Henry Dietrich[1]

ABSTRACT

The Marine Benthic Monitoring Program of the Puget Sound Ambient Monitoring Program was initiated in 1989 to assess trends in sediment quality throughout Puget Sound. Objectives of this long-term monitoring program are to document patterns of spatial and temporal variation of abundance and species composition of macrobenthos in relation to pollution inputs in Puget Sound. We compare data from selected stations collected from 1989 through 1993, and examine the relationships between sediment chemistry and the benthos in some urban and non-urban areas. An attempt is made at discriminating the effects of natural phenomena from the effects of pollution. Data analyses are in progress, but preliminary results suggest that much of the variation in community structure at those locations examined is driven by habitat type rather than sediment quality.

[1] Washington Department of Ecology, P.O. Box 47710, Olympia, WA 98504

PUGET SOUND

RESEARCH '95

SESSION 8C

FISH POPULATION ASSESSMENT METHODS & STATUS AND TRENDS

Session Chair:

Sandra O'Neill
Washington Department of Fish & Wildlife

PUGET SOUND HERRING, A REVIEW

Mark O'Toole[1]

INTRODUCTION

The Pacific herring, *Clupea harengus pallasi*, is an important and abundant fish species in Puget Sound. The status of herring stocks is of considerable interest to the citizens of the Puget Sound region because of the species' value as salmonid forage, its popularity as recreational fishing bait, its significance to local commercial fisheries, and its importance as an indicator of the general health and productivity of the Sound.

Herring were included in the 1974 Boldt Decision regarding Native American fishing rights, and local stocks and fisheries are cooperatively monitored and managed by Washington Department of Fish and Wildlife (WDFW) and Puget Sound area tribal governments.

LIFE HISTORY

Most Puget Sound herring stocks spawn from late January through early April (Figure 1). The notable exception is the Cherry Point stock (the largest in the state), which spawns from early April through early June. Herring deposit transparent, adhesive eggs on intertidal and shallow subtidal eelgrass and marine algae. Eggs may be deposited anywhere between the upper limits of high tide and a depth of -40 feet, but most spawning takes place between 0 and -10 feet in tidal elevation. Eggs hatch in about 14 days, producing slender, transparent larvae about ¼ inch long. At this stage, they are at the mercy of currents and subject to heavy predation by larger organisms. At about three months of age and at about 1¼ inches in length, herring metamorphose into their adult form and coloration. They will mature and return to their spawning ground in their second or third year. Herring do not normally die after spawning, and continue to spawn in successive years. Some stocks appear to have an annual migration from inshore spawning grounds to open-ocean feeding areas, while others appear to be more resident, remaining inside the Puget Sound basin year around. Adult herring feed primarily on planktonic crustaceans, and in turn are food for many marine animals such as seabirds, marine mammals, and other fishes. Natural mortality is quite high, and approximately 50 percent to 70 percent of the adult herring from Puget Sound will fall to predation each year. Thus the typical Puget Sound herring is relatively short lived, rarely surviving to age 5.

SPAWNING STOCKS

Herring spawn at about 18-20 known specific sites or grounds throughout Puget Sound each year (Figure 2). Although homing is not absolute, and is less specific than salmon returning to a river or stream, spawning populations appear to maintain some biological separation from other populations. Each spawning ground is thought to represent a discrete stock. Stock separation data based on biological characteristics such as timing of peak spawning, growth and age composition, scale pattern, and incidence of internal parasites increases as distance between spawning grounds increases. For example, Strait of Georgia (Cherry Point) and extreme south Puget Sound (Squaxin Pass) herring exhibit the most distinct characteristics.

HABITAT ISSUES

The specificity of this species' spawning grounds and the location of herring spawn deposition in lower intertidal and upper subtidal habitats makes these grounds vulnerable to shoreline development. Documented herring spawning grounds are protected from net habitat loss by the Washington Administrative Code Hydraulic Code Rules.

[1] Washington Department of Fish and Wildlife, Mt. Vernon, WA, 98273

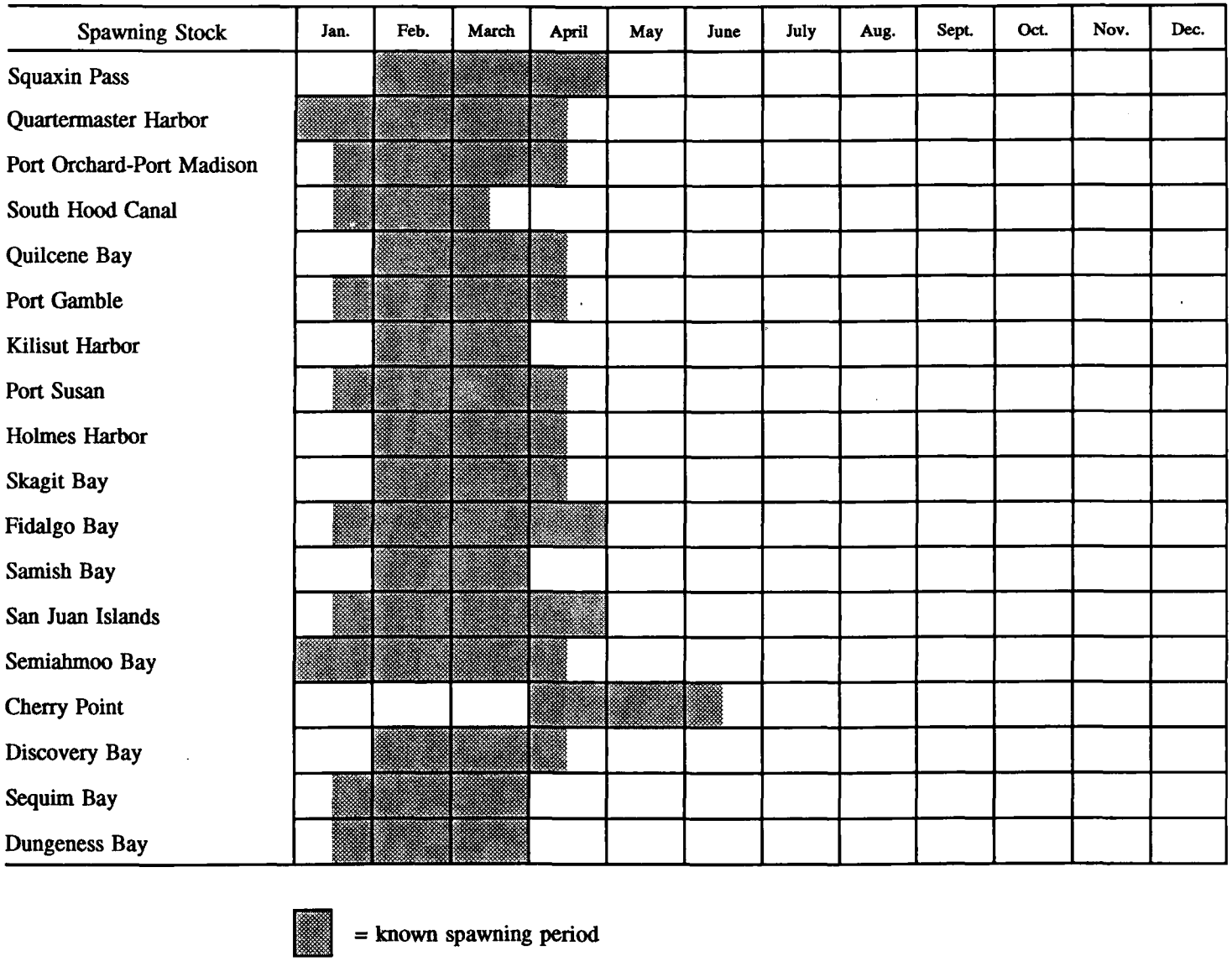

Figure 1. Documented spawning periods for Puget Sound herring stocks

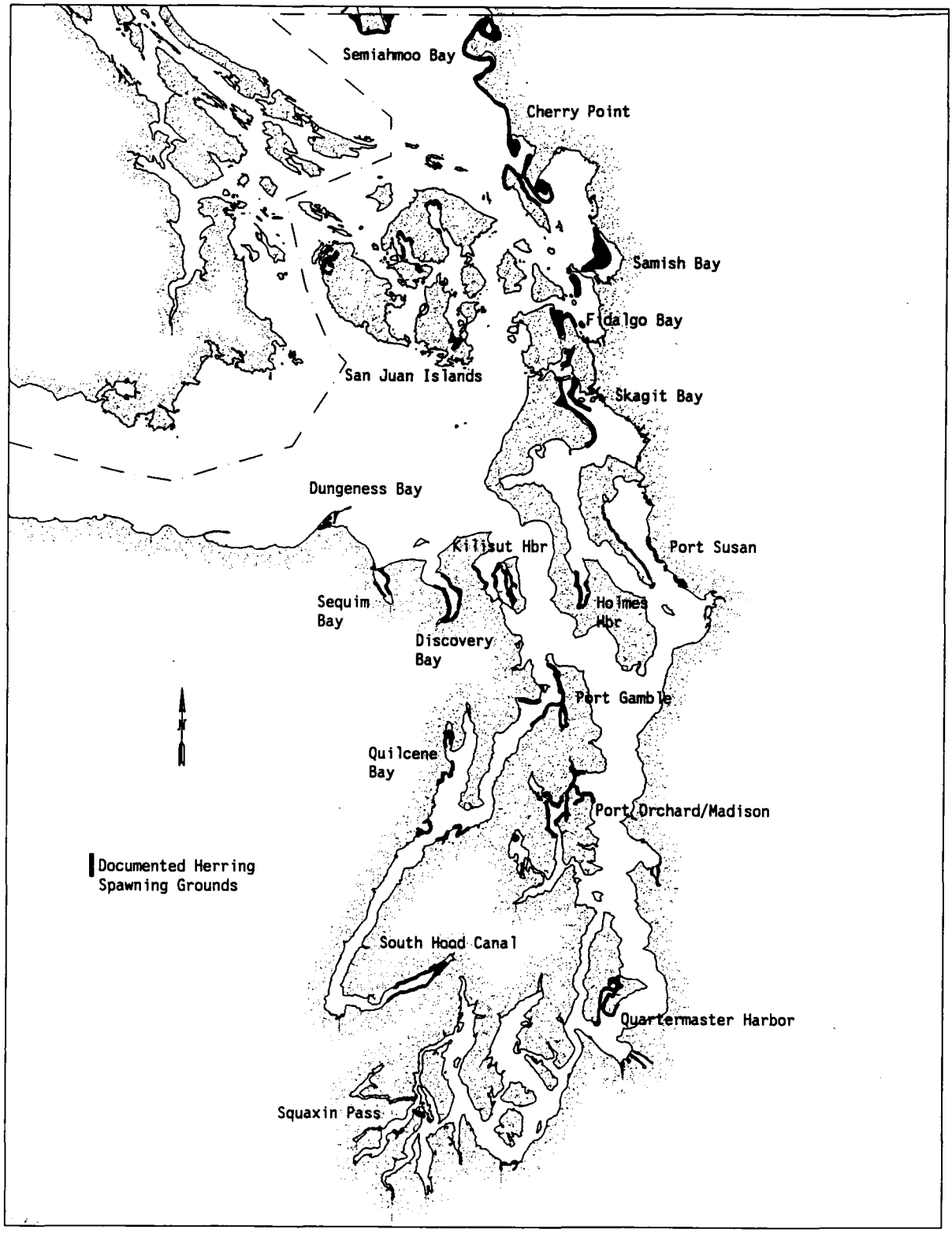

Figure 2. Documented herring spawning grounds in Puget Sound

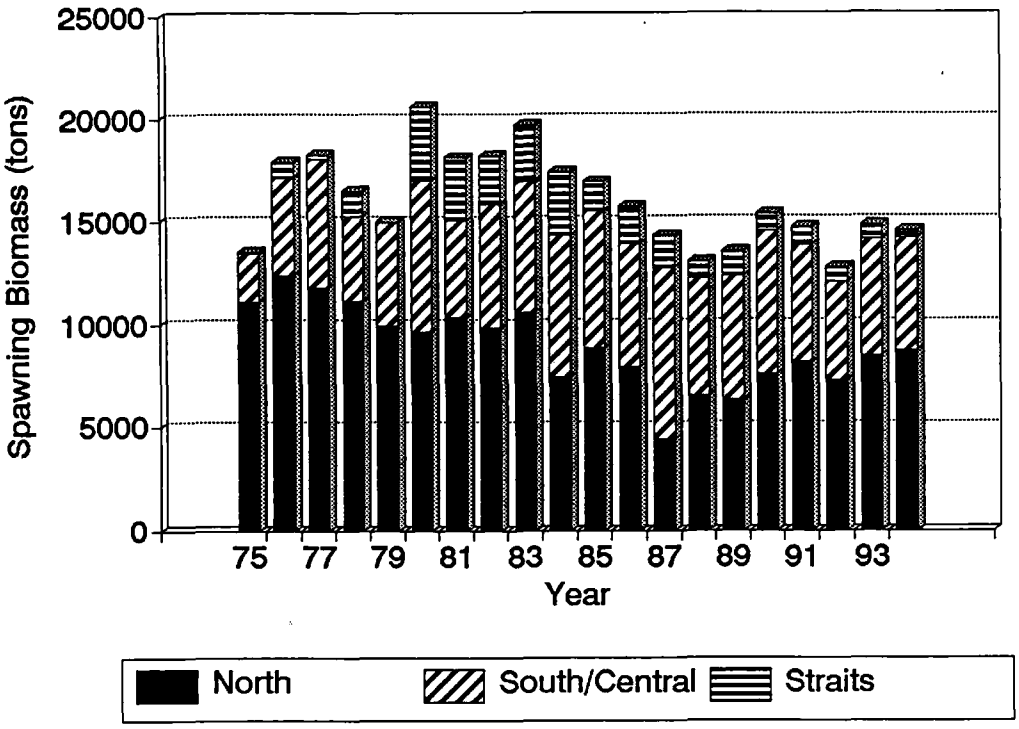

Figure 3. Cumulative Puget Sound herring spawning biomass estimates, from spawn deposition surveys, 1975-94

STOCK ASSESSMENT

Two methods are used by WDFW to provide quantitative estimates of herring abundance: spawn deposition surveys and acoustic-trawl surveys. Spawn deposition surveys provide an estimate of spawner abundance. Marine vegetation on spawning grounds is sampled for density and areal extent of spawn deposition, and those data are converted to an estimate of spawning biomass (Stick, 1994). Acoustic-trawl surveys also provide a quantitative estimate of herring abundance. This method uses computer-aided echosounding equipment that gives a real-time estimate of total fish abundance, and concurrent trawl net sampling that provides species, size, age, and maturity composition (Burton, 1991). WDFW currently estimates the abundance (spawning biomass) of about 12 of the 18-20 known herring stocks each year. Certain stocks are surveyed every year, while others are assessed on a rotating basis.

FISHERIES

From the early 1930s until the late 1950s, herring caught commercially in Puget Sound were primarily used as bait for halibut, crab, and shark fisheries. During the early 1950s, fishing emphasis began shifting to supply bait needs for a rapidly growing recreational salmon fishery. In addition, beginning in the late 1950s overall herring catches rose substantially due to an expanding reduction fishery in north Puget Sound that processed herring into fish meal. In 1972, a large-scale fishery for herring sac-roe began in the Strait of Georgia. Total landings of herring in Puget Sound peaked by the mid-1970s. Participation in non-treaty herring fisheries was limited by legislative action in 1977. Harvest levels decreased in the late 1970s when north Puget Sound stocks began to decline, and both the reduction fishery and the sac-roe fishery were closed in the early 1980s.

Currently, Puget Sound herring are fished at an extremely conservative level, as the total annual exploitation rate is about 6 percent (20 percent is generally considered to be the "safe" sustainable harvest rate for herring worldwide). There are at present two commercial herring fisheries in Washington. The principal one is the fishery for sport salmon bait, which occurs primarily in south and central Puget Sound. Annual landings from 1985-94 averaged 643 tons, with most of the harvest taken by small (200-foot) lampara seines. This predominately non-treaty fishery targets almost exclusively on 1½-year-old plug herring. The other commercial fishery, a limited spawn-on-kelp fishery (treaty and non-treaty) is allowed in north Puget Sound. In this fishery, purse seine-captured ripe herring are placed in floating pens hung with lines of a specific type of kelp (*Macrocystis integrifolia*). The herring spawn on the kelp, then are released, and the spawn-laden kelp is harvested. In another variation of this fishery the kelp is hung from floating lines near the spawning beaches, where it is spawned upon naturally, then harvested. In addition to north Puget Sound, small treaty-only spawn-on-kelp fisheries are occasionally conducted in central Puget Sound.

Table 1. Relative sizes of Puget Sound herring stocks. Based on 10-year (1985-94) means of spawn deposition survey estimates.

Spawning Stock	1985-94 Mean Spawning Biomass Estimate (tons)
South/Central Puget Sound:	
Squaxin Pass	614
Quartermaster Harbor	869
Port Orchard-Port Madison	1,288
South Hood Canal	251
Quilcene Bay	123
Port Gamble	2,214
Kilisut Harbor	452
Port Susan	753
Holmes Harbor	662
Skagit Bay	1,446
North Puget Sound:	
Fidalgo Bay	946
Samish Bay	248
San Juan Islands	477
Semiahmoo Bay	1,776
Cherry Point	4,782
Strait of Juan de Fuca:	
Discovery Bay	1,030
Sequim Bay	10
Dungeness Bay	234
Sum	18,175

POPULATION TRENDS

The cumulative herring spawning population for Puget Sound as a whole has been relatively stable (Figure 3). Individual Puget Sound herring stocks vary greatly in relative size (Table 1), and some have undergone significant fluctuations. On a regional basis, the combined south/central Puget Sound spawning population appears stable, the Strait population is decreasing, and the north Puget Sound population is steadily increasing from a low point in 1987.

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INVESTIGATIONS OF THE SPAWNING HABITAT OF THE PACIFIC SAND LANCE, *Ammodytes hexapterus*, IN PUGET SOUND

Daniel E. Penttila[1]

INTRODUCTION

The Pacific sand lance, *Ammodytes hexapterus*, also known locally as the "candlefish," is a common but poorly known nearshore schooling forage fish in Washington waters. Sand lances are an important trophic link between zooplankton and larger predators in the local marine food webs (Field, 1988; Emmett et al., 1991). The abundance and broad distribution of planktonic sand lance larvae throughout the bays and inlets of Puget Sound in late winter suggested that their spawning habitats and spawning activity were widespread in the region (WDFW, unpub. data). However, unlike other Puget Sound baitfish species under the jurisdiction of the Washington Department of Fish and Wildlife (WDFW) (i.e., Pacific herring, surf smelt, and northern anchovy), no data were available regarding the sand lance's actual spawning habitats, contexts or locations in Puget Sound before 1989.

Field observations of Pacific sand lance spawn deposition or incubation had been virtually absent from recent life history synopses of northeast Pacific sand lance populations (Garrison and Miller, 1982; Field, 1988). Dick and Warner (1982) included a report of sand lance spawning activity on an intertidal gravel beach on Afognak Island, Alaska. Pinto (1984) described *A. hexapterus* eggs and larvae from lab tanks at Battelle-Sequim Bay. Williams et al. (1964) described eggs attributed to *A. hexapterus* from littoral zone tidal channels on Long Island, N.Y.

During the 1983-89 period, a type of non-osmerid fish egg was occasionally found with surf smelt spawn in substrate samples collected during the course of WDFW baitfish studies at several sites within the Puget Sound basin. In November 1989, we found the first clear evidence of intertidal mass spawning activity attributable to Pacific sand lance in the Port Gamble Bay area. The characteristic sand-covered eggs collected from fresh spawn patches in the field were lab-cultured to produce identifiable sand lance larvae. Sand lance spawn deposits in similar intertidal habitat contexts were subsequently found in several additional areas of the Puget Sound basin.

Since 1991, WDFW baitfish investigators have undertaken systematic intertidal beach substrate sampling surveys along a significant proportion of the shoreline of the Puget Sound basin. Evidence of sand lance spawning activity has now been documented at numerous locations throughout the region. This report briefly summarizes our recent discoveries regarding various aspects of the spawning ecology of Puget Sound sand lance populations.

METHODOLOGY

Our initial sand lance spawn observations relied on visual detection of eggs in the field. This approach was adequate only with sufficient surveyor training and experience, and only when spawn deposits were fresh and had not been subject to dispersal by wave action. A more effective survey method was clearly needed to detect visually cryptic sand lance eggs in the usual dispersed condition.

Currently, sand lance spawning habitat studies are undertaken by the WDFW Baitfish Unit under the auspices of the Intertidal Baitfish Spawning Beach Survey Project (IBSBSP). (This survey project is detailed elsewhere in this volume—see Session 2A, "WDFW's Puget Sound Intertidal Baitfish Spawning Beach Survey Project".) Briefly, the IBSBSP effort is a systematic beach substrate sampling program to survey all upper intertidal sand-gravel shorelines within Washington's "inside waters" east of Cape Flattery for the eggs of the surf smelt, *Hypomesus*, Pacific sand lance and other marine fish species. Surveys yield collecting bulk samples of upper intertidal beach material from charted/GPS-positioned stations placed at

[1] Washington Dept. of Fish and Wildlife, Baitfish Unit, 1702-4 Anderson Rd., Mt Vernon, WA 98273

intervals along the shoreline. A typical survey consists of 20-30 such samples, collected along several miles of beach. Individual sections of shoreline are surveyed several times over two consecutive years.

The bulk samples are screened to recover material between .5mm and 2mm in size, which is further processed to recover a light-weight fraction for preservation and microscopic examination. Eggs present are identified, counted, and aged within a series of embryological stages. When fresh spawn deposits are encountered in the field, visible spawn is sampled directly, the site is photo-documented, and additional bulk samples of spawn-bearing material may be collected for sediment grain-size analysis.

Since October 1991, about 50 IBSBSP field surveys have been conducted annually, involving 1,000-1,400 sampling stations each survey year. To date, about 40 percent of the greater Puget Sound basin region has been surveyed for sand lance spawning habitat.

RESULTS

Geographical Distribution Of Sand Lance Spawning Activity

Evidence of upper intertidal sand lance spawn deposition/incubation has now been found the length and breadth of the Puget Sound basin, from southernmost Puget Sound to the Canadian border and west to Dungeness Bay, the present western limit of IBSBSP survey effort (Figure 1). All subregions appear to support sand lance spawning activity. Outside the IBSBSP survey area, Grays Harbor and Willapa Bay also have sand lance spawning habitats, judging from the occurrence of yolk-sac sand lance larvae in those areas (WDFW, unpub. data).

Sand Lance Spawning Habitat Context

Sand lance spawning activity takes place over a wide range of habitat contexts, including very sheltered locations with little wave action or current, current-swept beaches on narrow tidal passages, and exposed beaches with occasional heavy wave action. Sand lance spawn deposits may be more easily detected in sheltered locations, perhaps as a result of less dispersal of the eggs to densities below our limits of detection. Depending on the geomorphology and sedimentary history of a shoreline, potential sand lance spawning habitat may occur variously, from a continuous band along the beach to scattered patches of substrate. Spits and cuspate forelands are types of shoreline landforms that commonly support sand lance spawning habitat.

Sand Lance Spawning Substrate Grain-size Characteristics

Sand lances deposit eggs on a rather broad range of beach surface substrate textures. Spawning can occur on soft, pure, fine-sand beaches, mixed sand-gravel material, or beaches armored with gravel up to 3 cm in diameter. Most spawning appears to occur on the finer-grained substrates within this range. Sand lance eggs characteristically acquire a partial coat of adherent sand grains during deposition, which may serve to anchor them and assist in capillary moisture retention during low-tide exposures. Sand lance eggs are only weakly adherent to gravel surfaces and cannot remain in place through their incubation period on such material.

Tidal Elevation of Sand Lance Spawn Deposition

IBSBSP observations of fresh, impact sand lance spawn deposits have generally shown deposition to occur from +5 feet in tidal elevation (Seattle District) up to about the mean higher high water line. After deposition, sand lance eggs may be scattered over a wider range of the intertidal zone by wave action. They are commonly present in the "swash" zone of light material that accumulates at the waterline, under light wave-action conditions, as the tides advance and retreat across the spawning substrate.

Sand Lance Spawning Behavior and Incubation

Pacific sand lance spawning behavior has not been observed in the field during the course of our investigations. Fresh, intact sand lance spawn deposits commonly consist of small (< 10cm diameter)

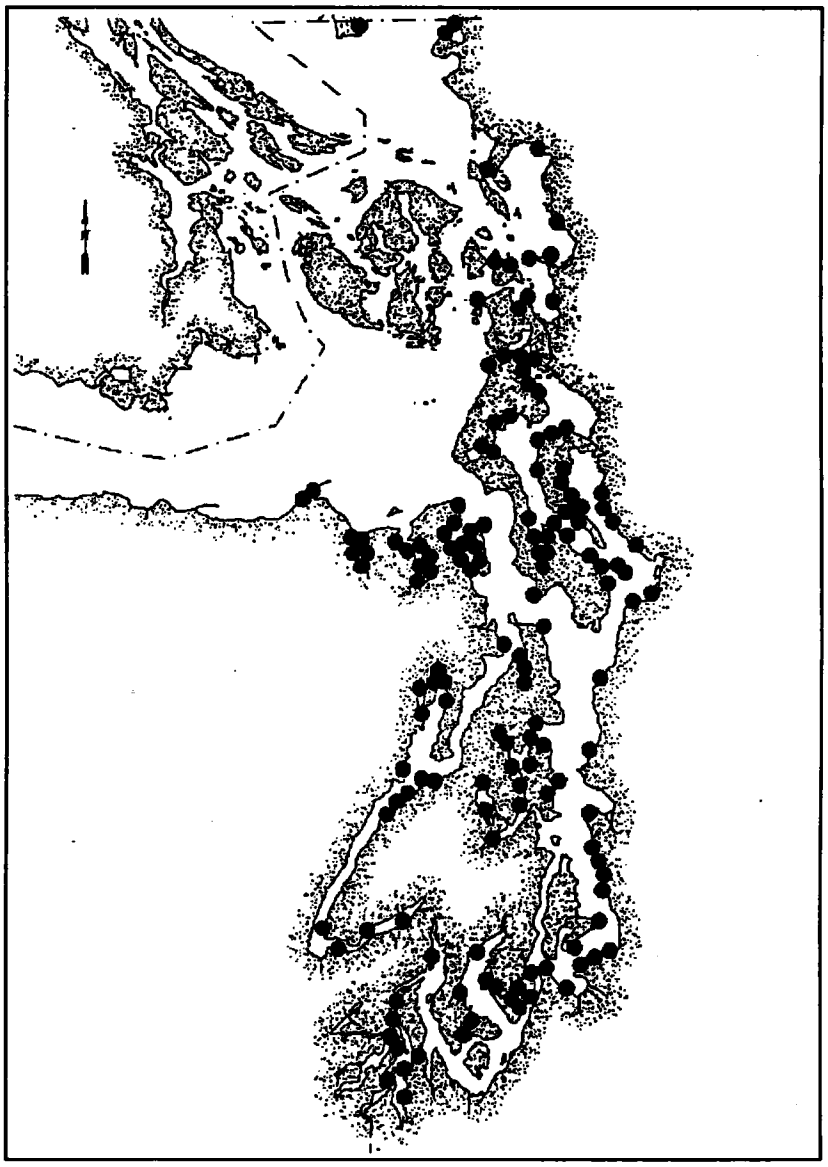

Figure 1. Distribution of known spawning beaches of the Pacific sand lance, Ammodytes hexapterus, *in the Puget Sound basin*

patches of eggs, either resting in the bottoms of shallow pits in the beach or scattered irregularly over a broad zone of "disrupted-looking" beach surface. Spawn patch density may range from single spawn-pits to pock-marked zones of beach 10 meters wide and 200 meters or more in length. Occasionally, synchronous mass sand lance spawning appears to occur during the same high tide period along several miles of contiguous spawning beach. In some sectors, such as the series of bays from Dungeness Spit eastward through Kilisut Harbor, virtually every existing sandy-gravel beach has been found to support sand lance spawning activity.

Transient beach surface features in the immediate vicinity of fresh spawn patches suggest a certain degree of vigor in the sand lance mass-spawning act, which takes place in a few feet of water around high tide periods. Fresh sand lance spawn appears to be confined to the surface 3 cm of beach material.

Spawning appears not to be directly associated with this species' burrowing behavior, although there have been a number of reports of sand lances observed in middle-intertidal sand-gravel substrates in the general vicinity of their spawning beaches before the start of the spawning season (WDFW, unpub. data).

Initial sand lance spawn densities may reach several hundred eggs per gram of substrate in fresh patches, where the sand-coated eggs may form a layer 1 cm or more in thickness on the beach surface. Sand lance spawn deposits commonly contain two or three distinct ages of eggs, indicating that spawning activity may occur at intervals of a few days during the spawning season. Spawning sites are commonly used year after year. Perennial use of isolated patches of suitable habitat suggests some degree of active searching, if not "homing" ability, by pre-spawning sand lances.

Puget Sound sand lance spawn may incubate in the spawning substrate for about one month before hatching. The characteristically moist, mixed sand-and-gravel substrate and cool ambient seasonal temperatures may serve to shelter the eggs from desiccation and thermal stress. Sand lance spawn appears well-adapted to incubation in the upper intertidal zone, where it is often exposed to the air twice daily during low tides. Mixed-age sand lance spawn deposits commonly contain less than 5 percent dead eggs. Processed samples of late-eyed eggs commonly include newly-hatched yolk sac larvae as well, suggesting that hatching is abetted by agitation of the substrate, or that new larvae entrain in the substrate for a period after hatching.

Sand Lance Spawning Season in Puget Sound

The factors triggering the inception of sand lance spawning activity in the Puget Sound basin are unknown. Whatever their nature, they result in a rather closely timed commencement of spawning activity in many areas around November 1. Local sand lance spawning and spawn incubation occur from that date through about February 15, with spawn persisting in some areas until late March. Our studies have discerned no consistent differences in sand lance spawning seasons between subregions of Puget Sound, as are found for other local baitfish species.

DISCUSSION

As of October 1994, we had documented Pacific sand lance spawning activity along about 84 lineal statute miles (135 km) of upper intertidal shoreline within the Puget Sound basin. Clearly, Pacific sand lance spawning habitat must now be considered an important ecological function of this outwardly barren and "expendable" zone of many Puget Sound beaches. As details of the regional spawning ecology of this species come to light, a more complete and rational view of the distribution, abundance and management of this resource can be developed.

Our sand lance spawning habitat investigations have been almost wholly confined to the intertidal zone. Fresh sand lance spawn deposits generally appear to have a well-defined lower limit of tidal elevation, and do not extend into more silty substrates found lower on the beach. Van-Veen grab-sampling in the vicinity of fresh sand lance spawn deposits has found no evidence of coincident subtidal spawn deposition. Further research is needed to confirm the degree to which the Pacific sand lance is an obligate intertidal spawner. Hypothetically, an additional local sand lance spawning habitat context might be the bottoms of current-swept tidal channels. Such sites might have relatively silt-free sand-gravel substrates with spawn aeration conditions approaching those of upper intertidal beach material. Unlike upper intertidal beaches, however, such tidal channel habitats are also commonly well-populated with pelagic, epifaunal and infaunal potential predator organisms.

The location of the sand lance's spawning habitat within the upper intertidal zone has fostered concern for the vulnerability of their spawning sites to impacts from shoreline development practices that intrude seaward of the high tide line. The Pacific sand lance is currently among those marine species listed by name in the Washington Administrative Code (WAC) Hydraulic Code Rules as a species of "special concern." Consideration is to be given to the occurrence and location of documented sand lance spawning habitat when Hydraulic Permit Applications (HPAs) for shoreline projects are analyzed by WDFW habitat managers. In general, projects proposed for known sand lance spawning sites are to be designed and

constructed to avoid impacts to the existing spawning habitats on site. A primary function of the IBSBSP activity has been to proceed with the important task of completing an initial inventory of existing Puget Sound sand lance spawning habitats, to which WAC habitat-protection policies can be applied.

The discovery of the sand lance's spawning habitat could lead to both new fisheries and a more meaningful management framework for the regulation of such activities. Spawning in a consistent manner very near-shore over wide areas of Puget Sound, the species appears amenable to harvest by localized small-scale beach seine, dip-net or weir fisheries resembling those that have historically been undertaken on local herring and surf smelt stocks. The salmon sport bait market might be the most likely recipient of initial landings, although sand lances are also harvested for human consumption elsewhere in the world (Reay, 1970).

The biology and life history of Pacific sand lance populations in the Puget Sound region remain virtually unknown. Taking advantage of consistent intertidal spawning activity may finally afford investigators an opportunity for comprehensive biological sampling of this species. Conceivably, development of a biological data base, along with index surveying of spawning density, frequency, and geographical extent could lay the groundwork for routine stock-status monitoring of Puget Sound sand lance populations.

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RELATIVE ABUNDANCE AND DISTRIBUTION OF PUGET SOUND TRAWL-CAUGHT DEMERSAL FISHES

Robert F. Donnelly[1] and Robert L. Burr[2]

INTRODUCTION

Demersal fish constitute the majority of the estimated 211 species of Puget Sound fishes (Delacy et al., 1972; Hart, 1973). Their variability by season and depth, however, is not well known. This ignorance is primarily a consequence of biases imposed by methods of sampling. Otter trawls, the preferred sampling gear for demersal species, are restricted to substrate that is open, generally flat and devoid of large obstacles. Consequently, many abundant demersal species that predominate beyond these conditions escape capture and enumeration.

Biases also exist among different types of otter trawls, adding further uncertainty to data sets obtained by trawling. It is well known that changes in the gear or sampling methods can severely impact the selectivity of the sampling gear (Ancellin and Desbrosses, 1963; Brandt, 1963; Creutzberg et al., 1987; Engas and Godo, 1989; Kimura, 1987; Klein, 1985; Margetts, 1963; Pope et al., 1975; Treschev, 1963). Although direct comparison between gears and methods has been dealt with in some instances (Margetts, 1963; Zupanovic, 1963), such relationships are not available for trawl data from Puget Sound. Thus, reliable estimates of even relative abundance obtained by trawling are not available for this area.

This study addresses the need for a comprehensive examination of standardized trawl data within Puget Sound. Over a six-year period, 559 samples were collected by common gear and methods at a wide range of depths throughout the Puget Sound basin. The abundance and distribution of species by season and depth are described and discussed.

MATERIALS AND METHODS

Methods and Gear

All samples in the chosen data set were collected with a 7.6 m otter trawl fished from the *R.V. Kittiwake* (12 m displacement hull vessel). Each trawl haul was towed at 4.6 km per hour for a distance of 470m. Catches were placed on a sorting table and processed on board (in the case of small catches and calm weather) or put on ice and transported to the laboratory where they were frozen for later processing (in the case of large catches and/or stormy weather).

Table 1. List of the seasons and depths used in this study. Dates are given in Julian day (jday) and depths are listed in meters (m).

Season		
	winter	jday 1-90
	spring	jday 91-150
	summer	jday 151-230
	fall	>jday 230
Depths		
	depth 1	5m - 20m
	depth 2	21m - 50m
	depth 3	51m - 100m
	depth 4	>100m

[1] School of Fisheries, University of Washington, Seattle, WA 98195

[2] Psychosocial Nursing, University of Washington, Seattle, WA 98195. All inquiries should be directed to the first author.

Data

The data were collected throughout each year of a six-year period (1983-1988) at depths from 5m to 200m. In all, 559 samples were collected from the Strait of Georgia in the north to Nisqually Reach in the south (Figure 1). The data were grouped into four seasons that generally corresponded to the annual seasons but with a shortening of spring and summer and lengthening of autumn. The data were also grouped into four depth intervals, 5m to 20m, 21m to 50m, 51m to 100m, and 101m to 200m (Table 1).

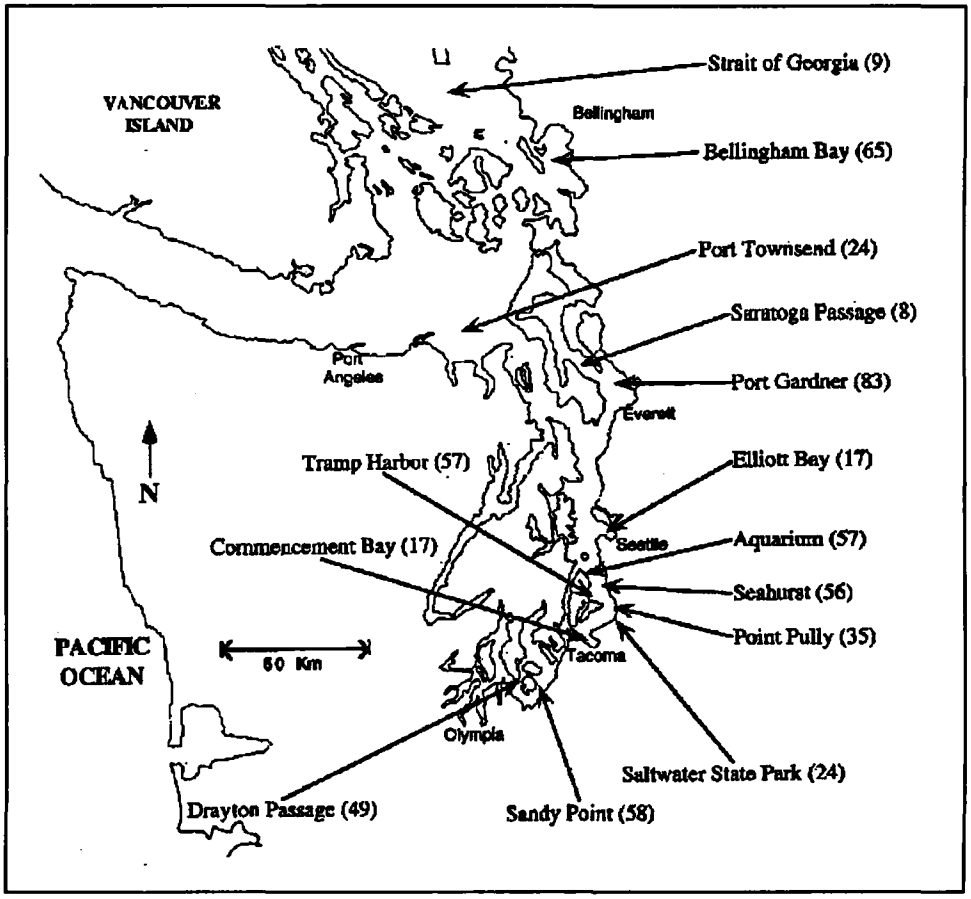

Figure 1. Map of Puget Sound, from Olympia to Bellingham and west through the Strait of Juan de Fuca (Port Angeles). Sampling locations and sample sizes (in parentheses) are shown.

RESULTS AND DISCUSSION

General Description of Data

More than 100 species of fish were captured during the entire sampling period. Seventy-seven species, taken in two or more samples, form the basis of this study (Table 2). Some individuals were classified only to the genus or the family level. The additional species were represented by single occurrences and are excluded from the analysis. The number of species caught over each season or depth stratum never varied by more than 20 percent of the mean value (Table 3). In contrast the number of species in each season/depth cell occasionally varied by more than 100 percent. This difference may be related to

movement of fish between depths within seasons or to the much smaller number of samples collected in each season/depth cell compared with those of either seasons or depths (Table 4). Because the number of samples within each season/depth strata was small, no attempt was made to further subdivide the data by year, thus reducing the average sample size within each strata sixfold. The average catch per trawl (CPUE) of each species was highly skewed. The occurrence per sample ranged from less than 1 to 10 or more individuals per sample for four species.

Table 2. List of fish species used in this study. The table is organized by scientific name, common name and average abundance in the samples. The Families are listed by taxonomic order (Hart, 1973) and species by decending order of abundance within each family.

Species	Common Name	Average abundance
Family Squalidae		
Squalus acanthias	spiny dogfish	0.74
Family Rajidae		
Raja rhina	longnose skate	<0.1
Raja stellulata	starry skate	<0.1
Family Chimaeridae		
Hydrolagus colliei	ratfish	6.33
Family Clupeidae		
Clupea harengus pallasi	Pacific herring	1.01
Family Engraulidae		
Engraulis mordax mordax	northern anchovy	<0.1
Family Osmeridae		
Spirinchus thaleichthys	longfin smelt	44.39
Thaleichthys pacificus	eulachon	<0.1
Family Batrachoidae		
Porichthys notatus	plainfin midshipman	1.37
Family Gadidae		
Microgadus proximus	Pacific tomcod	12.35
Theragra chalcogramma	walleye pollock	8.99
Merluccius productus	Pacific hake	1.39
Gadus macrocephalus	Pacific cod	0.28
Gadidae unk	cods	<0.1
Family Ophidiidae		
Brosmophycis marginata	red brotula	<0.1
Family Zoarcidae		
Lycodopsis pacifica	blackbelly eelpout	10.4
Lycodes brevipes	shortfin eelpout	0.68
Lycodes diapterus	black eelpout	0.15
Lycodapus mandibularis	pallid eelpout	<0.1
Zoarcidae unk	eelpouts	<0.1
Family Aulorhynchidae		
Aulorhynchus flavidus	tube-snout	<0.1
Family Embiotocidae		
Cymatogaster aggregata	shiner perch	8.11
Rhacochilius vacca	pile perch	1.12
Embiotoca lateralis	striped perch	0.35
Family Trichodontidae		
Trichodon trichodon	Pacific sandfish	<0.1

Table 2. continued

Species	Common Name	Average abundance
Family Bathymasteridae		
Ronquilus jordani	northern ronquil	<0.1
Family Stichaeidae		
Lumpenus sagitta	snake prickleback	1.97
Lumpenus maculatus	daubed shanny	0.36
Plectobranchus evidus	bluebarred prickleback	<0.1
Family Scorpaenidae		
Sebastes maliger	quillback rockfish	0.89
Sebastes caurinus	copper rockfish	0.62
Sebastes auriculatus	brown rockfish	0.1
Sebastes elongatus	greenstripe rockfish	<0.1
Family Anoplopomatidae		
Anoplopoma fimbria	sablefish	<0.1
Family Hexagrammidae		
Hexagrammos spp.	greenling	0.17
Hexagrammos stelleri	whitespotted greenling	<0.1
Ophiodon elongatus	lingcod	<0.1
Oxylebius pictus	painted greenling	<0.1
Family Cottidae		
Chitonotus pugetensis	roughback sculpin	2.31
Leptocottus armatus	staghorn sculpin	0.67
Radulinus asprellus	slim sculpin	0.16
Dasycottus setiger	spinyhead sculpin	0.1
Artedius spp.	Sculpin	<0.1
Enophrys bison	buffalo sculpin	<0.1
Gilbertidia sigalutes	soft sculpin	<0.1
Icelinus borealis	northern sculpin	<0.1
Myoxocephalus polyacanthocephalus	great sculpin	<0.1
Nautichthys oculofasciatus	sailfin sculpin	<0.1
Psychrolutes paradoxus	tadpole sculpin	<0.1
Cottidae unk	Sculpin	<0.1
Family Agonidae		
Xeneretmus latifrons	blacktip poacher	0.35
Agonus acipenserinus	sturgeon poacher	0.12
Agonopsis emmelane	northern spearnose poacher	0.1
Asterotheca pentacanthus	bigeye poacher	<0.1
Bathyagonus nigripinnis	blackfin poacher	<0.1
Odontopyxis trispinosa	pygmy poacher	<0.1
Xeneretmus triacanthus	bluespotted poacher	<0.1
Agonidae unk	poachers	<0.1
Family Cyclopteridae		
Liparis spp.	snailfish	<0.1
Liparis dennyi	marbled snailfish	<0.1
Liparis fucensis	slipskin snailfish	<0.1
Liparis palchellus	showy snailfish	<0.1
Cyclopteridae unk	snailfish	<0.1
Family Bothidae		
Citharichthys spp.	sanddabs	1.79
Family Pleuronectidae		
Parophrys vetulus	English sole	24.46
Lepidopsetta bilineata	rock sole	6.98

Table 2. continued

Species	Common Name	Average abundance
Lyopsetta exilis	slender sole	6.06
Microstomus pacificus	Dover sole	3.52
Hippoglossoides elassodon	flathead sole	2.03
Glyptocephalus zachirus	rex sole	1.82
Isopsetta isolepis	butter sole	1.61
Platichthys stellatus	starry flounder	0.71
Psettichthys melanostictus	sand sole	0.31
Pleuronichthys coenosus	C-O sole	0.2
Atheresthes stomias	arrowtooth flounder	<0.1
Pleuronichthys decurrens	curlfin sole	<0.1
Pleuronectidae unk	righteye flounders	<0.1

Table 3. The number of species caught in each season/depth stratum

	SEASON				
DEPTH	1	2	3	4	TOTALS
1	36	25	32	36	51
2	55	45	44	52	64
3	41	38	37	52	59
4	27	23	28	42	50
TOTALS	66	57	59	69	75

Table 4. The number of samples collected in each season/depth stratum

	SEASON				
DEPTH	1	2	3	4	TOTALS
1	15	11	27	40	93
2	24	21	42	55	142
3	25	21	37	59	142
4	27	32	49	74	182
TOTALS	91	85	155	228	559

Variability in Abundance by Season and Depth.

Only the 25 most abundant species (based on overall abundance) were considered because it was apparent that most of the species within a given season/depth cell were represented by very few individuals. Most species have a depth preference, and some have season preferences. The largest total catch of any species was longfin smelt, which occur in each season, but not at each depth. Their greatest abundance occurred in depth 2 with numbers diminishing considerably in depth 1, and only an occasional occurrence in depth 4 (Table 5). English sole, in contrast, occur frequently at all depths and seasons. Pacific tomcod, ratfish, Dover sole, and plainfin midshipman, though less abundant than English sole, also occurred at each depth and during each season. During the winter Dover sole was distributed through all depths; however, during the rest of the seasons abundance shifted to deeper depths. Ratfish prefer depths 3 and 4, while rock sole are associated primarily with depths 1 and 2. Species absent from the deeper depths during all seasons included shiner perch, butter sole, pile perch, Pacific herring, starry flounder and staghorn sculpin.

Table 5. The 25 most abundant species in decending order. The numbers in the season/depth columns are the ranking.

Latin Name	Common Name	Winter Depths				Spring Depths				Summer Depths				Autumn Depths			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Spirinchus thaleichthys	longfin smelt	9	1			7	1		23	3	1				1		40
Parophys vetulus	English sole	1	2	1	4	2	2	1	1	2	3	2	1	2	2	1	1
Microgadus proximus	Pacific tomcod	10	4	5	8	1	4	8	9	4	4	5	15	16	4	2	5
Lycodopus pacifica	blackbelly eelpout	32	16	2	13		3	2	17	22	2	1	10		14	5	15
Thegagra chalcogramma	walleye pollock	3	10	10	10		45		18		16	16	13	28	3	4	2
Cymatogaster aggregata	shiner perch	6	3	3		10	11	14		14	25	21		3	5	8	
Lepidopsetta bilineata	rock sole	2	5	20	26	5	8	6		1	12	19		1	6	16	34
Hydrolagus colliei	ratfish	12	38	4	1	9	26	5	4	12	26	3	3	11	27	3	4
Lyopsetta exilis	slender sole	22	19	6	2		19	3	2	21	10	4	2	21	13	6	3
Microstomas pacificus	Dover sole	8	14	8	5	21	23	13	3	10	6	6	4	29	7	7	6
Chitonotis pugetensis	roughback sculpin	4	7	15		13	14	4		6	14	10	23	5	16	14	13
Hippoglossoides elassodon	flathead sole	28	15	9	14	12	6	10			9	8	17	27	12	13	27
Lumpenus sagitta	snake prickleback		36	27		4	5	15		7	5			36	24	51	33
Glyptocephalus zachirus	rex sole	13	16	12	7		18	9	7	32	7	7	5	17	9	11	10
Citharichthys spp.	sanddabs	7	8	26		6	12	19		5	18			4	15	19	30
Isopsetta isolepis	butter sole		6	21		3	9	40		11	15	37			10	25	
Merluccius productus	Pacific hake		44	7	3		44	12	5			9	7		29	12	8
Porichthys notatus	plainfin midshipman	27	21	14	9	16	24	7	8	13	22	15	28	13	17	10	7
Rhacochilus vacca	pile perch	15	11	25			33	22						6	8	22	
Clupea harengus pallasi	Pacific herring		13	18			10	29		27	19	18		19	11	52	
Sebastes maliger	quillback rockfish	31	20	13	6		27	16	6		23	11	8	12	21	15	12
Squalus acanthias	spiny dogfish		37	16	16		16			20	20	12	6		23	9	21
Platichthys stellatus	starry flounder	35	12	24		17	22				17			26	19		
Lycodes brevipes	shortfin eelpout				24		7	38			8		9		28	50	39
Leptocottus armatus	staghorn sculpin	16	9			11	31	27		25	36			35	22	31	

Generally depth 2 has the most species. In spring and fall it is the only depth that had all 25 species present. During winter it had all but one species and during summer all but 2. The only other season/depth stratum having all but a few of species represented is depth 3 during fall. Depths 1 and 4 contain the fewest species during the annual cycle. Other studies (Donnelly et al., 1984; Donnelly et al., 1984; Donnelly et al., 1988; Lauth et al., 1988; Miller et al., 1974; Miller et al,. 1976; Miller et al., 1977; Moulton et al., 1974) have also shown similar results.

Interpretation of Variability

These results reflect the apparent dynamic nature of species abundance through the course of the annual cycle (year). It does seem reasonably clear that many of the species undergo movement (migrations) throughout the year, perhaps related to spawning and/or feeding migrations. These migrations may be as simple as seasonal movement from one depth to another, or they may be migrations both vertically and horizontally over distances measured in many kilometers (Ketchen and Forrester, 1955; Manzer, 1946). One interesting feature of the analysis is the abundance of species that occur at depth 2, and to some degree at depth 3 throughout the year. It appears that the species sampled preferred water depths from 21 to 100 m. The reasons for this behavior are unknown, although with the obvious abundance of species and consequent biomass, one probable reason might be food sources—that is, bottom-dwelling crustaceans and

infauna, none of which the trawl gear captured in any substantial or consistent fashion. The trawl did catch some of the larger crustacean fauna such as *Crangon spp.*, but rarely caught the smaller invertebrates.

Another source of variability resides in the nature of the fishing (capture) process. The trawl was towed a distance of 470 m and has an effective fishing width of 3.5 m (based on unpublished data collected by the first author), which means that 1645 m^2 were covered each time a sample was collected. Trawls are not precise sampling tools, and it is entirely possible that many species could be moving through the sampling area without actually being resident. Investigators should take this into account when interpreting data collected with trawls.

Gear Selectivity

Gear selectivity is important to this study because the fish captured were those vulnerable to the gear and methods used during sampling. If the capture efficiency for each species differed, then we might expect the use of another capture gear to give different species compositions and abundances when sampling the same areas. There is a large literature (examples are: Kimura, 1987; Pope et al., 1975; Treschev, 1963) on the subject of trawl selectivity; in fact, commercial net manufacturers attempt to make their gear as selective as possible to minimize bycatch (William West, personal communication). In general, it can be stated that trawls of different design are more alike in contents of catch than are different gear types (e.g., trawls vs. gillnets). Therefore we would expect differences between trawl types, but not the extreme differences that might be found across different gear types. The results of this study, while they differ somewhat from the results of other studies using small otter trawls, are consistent with expected differences between trawl types. Change the trawl and the results will change, at least to some degree. For long-term monitoring we recommend the use of one standardized gear, without regard to its efficiency and any new technologies. If, however, the gear or methods must be changed, we recommend extensive comparative studies so that monitoring with the changed (new) gear and/or methods can be related to the data collected before the change(s).

CONCLUSIONS

Some species showed little change in relative abundance over time or space while others underwent large changes. The overwhelming impression from the data is one of a dynamic system. Species and individuals appear to be in almost constant motion, probably to avoid predators and obtain food. In addition, there are probably annual spawning considerations that contribute to movement, both horizontally and vertically.

Trawls are not ideal sampling tools to obtain information on demersal species; however, they are one of only a few practical ways of sampling the demersal fish fauna. Other sampling gears are much more expensive and more time consuming (e.g., submersibles or divers). The gear sweeps something on the order of 1645 m^2 for each sample. In that space there can be considerable variation in substrate and thus habitats and species composition. Trawl samples do, however, give a broad view and provide a guide for future studies.

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THE DEVELOPMENT OF TRAWL-BASED TOOLS FOR THE QUANTITATIVE ASSESSMENT OF DEMERSAL FAUNA (MACROINVERTEBRATES AND FISHES): A SUMMARY OF PHASE I AND PHASE II

Charles M. Eaton[1]

INTRODUCTION

Steps have been taken in the Puget Sound region to assess relationships between pollution and the health and status of the marine benthos (PSWQA, 1992). Very detailed sediment data—including information on chemistry, toxicity and infaunal populations—are being collected for the Puget Sound Ambient Monitoring Program (PSAMP) as well as for various urban bay, dredge disposal and Superfund action programs. Missing, however, are similar efforts to quantitatively define populations of demersal fauna (macroinvertebrates and fishes) that live and feed on these sediments, and to gain an understanding of how these populations are responding to the environmental stresses associated with a contaminated substrate. A significant amount of research has documented the impacts of pollution on the health of key flatfish species in urban estuaries (Varanasi et al., 1989). Washington Department of Fisheries and the University of Washington have collected valuable information on foodweb relationships and important "biological marine resources," many of which are components of the demersal fauna. But no one has attempted to document demersal populations in their entirety as an integral part of the benthos, relating this information to sediment chemistry, toxicity and infauna.

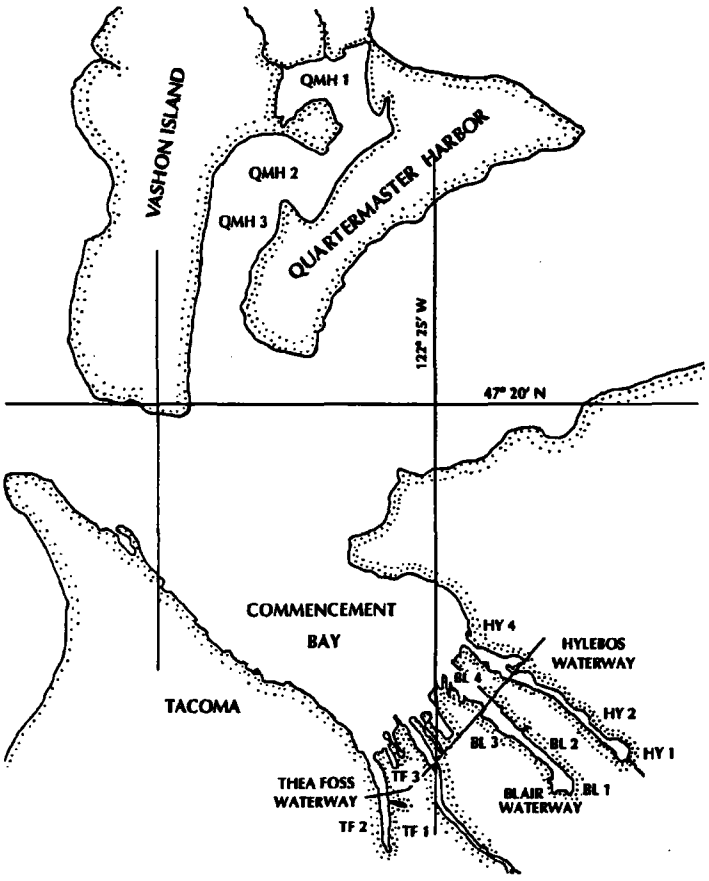

Figure 1. Location of the study area and stations sampled in Phase I and Phase II

The pilot study (Eaton and Dinnel, 1993) is in its second year of funding to begin this process in Puget Sound by assessing the utility of using two different sampling trawls to quantitatively define these populations at a given point in time. By documenting population patterns that reflect environmental stress, it is hoped that metrics can be developed that will help to build a biological index for the rapid and economical assessment of stress in subtidal biotic marine communities. J.R. Karr et al. (1986) have had success in the development of such an index (the Index of Biological Integrity or IBI) for the quantitative measurement of "ecological integrity" in freshwater streams with an emphasis on fish populations, and similar efforts are now under way in Chesapeake Bay using benthic infaunal data

[1] Bio-Marine Enterprises, 2717 3rd Ave. N., Seattle, WA 98109

(Ranasinghe et al., 1993). The development of quantitative methods for sampling demersal fauna is also essential in defining these populations at a given point in time for routine diagnostic monitoring.

METHODS

Gear and Navigation

Research-sized beam and otter trawls were used on board the *R/V Kittiwake* to sample the demersal fauna. With its "tickler" chain, the 3-meter beam trawl (Gunderson and Ellis, 1986), towed at 1.5 knots, is very effective for sampling most demersal invertebrates and small or juvenile fishes, while the 7.6-meter SCCWRP otter trawl, towed at 2.5 knots, is best suited for sampling larger and more mobile marine fishes and invertebrates (Figure 4). Trawl lengths were determined using the reverse-waypoint function of the Northstar LORAN/GPS as described by this author in the PSEP protocols (PSEP, 1990), and in the Phase I report (Eaton and Dinnel, 1993). The present activation of differential GPS (DGPS) satellite navigation by the USCG will now make the determination of trawl length, location and speed even more accurate.

Live Sampling

All catches were immediately placed in tubs of running sea water and then sorted into other seawater containers for identification, counting, measuring and weighing. Fine-meshed netting and small food containers of known weight were used to hold the animals for the weighing. All animals were then released on station. While many individual lengths and weights were recorded both in 1993 and 1994, more effort went into collecting biomass data in 1994 by weighing all species as a group.

Sites

The sampling in 1993 focused on two of the Tacoma waterways, the contaminated Hylebos Waterway (a Superfund site) and the adjacent, less-affected Blair Waterway. The 1994 sampling compared another Tacoma Waterway and Superfund site, Thea Foss (City) Waterway, with a much cleaner and more natural reference condition in Quartermaster Harbor on Vashon Island, just six miles to the north (Figure 1). Bottom depth, sediment grain-size analysis (either historical information or wet-sieving technique for percent fines) and bottom temperature and salinity data were collected at all stations to ensure meaningful pairing.

Survey Design

Dr. Loveday Conquest of the University of Washington, an environmental statistician, recommended good spatial coverage of the waterways using a stratified random design (Gilbert, 1987). The Hylebos and Blair waterways were divided into four strata, the Thea Foss into three strata, and Quartermaster Harbor into two. One station was located in each stratum, except in mid-Quartermaster Harbor with two stations—one being an historical sediment monitoring station (MSMT, Station 303R). The two stations in the single stratum of Quartermaster Harbor were chosen to compare the variability between two stations of close proximity with similar depth and sediment grain-size.

In Phase I (June, 1993), three replications for both the otter trawl and beam trawl were conducted at each station except for HY 4 and BL 4 with a total of seven otter trawl replications. In addition, 10 consecutive otter trawls were conducted in rapid sequence at BL 4 over a period of three hours to evaluate the perturbation effects of consecutive trawling at a single station. Evaluation of the 10 consecutive and seven non-consecutive otter trawl replications in 1993 led to the conclusion that four (preferably five) otter trawl replications were needed to quantitatively define the demersal fish at a given station, and that these should not reoccur in less than four hours.

The sampling design in Phase II (September, 1994) incorporated these recommendations with five otter trawl and three beam trawl replications per station. Station TF 2 in the middle of the Thea Foss Waterway was sampled only once with each gear after a barge with mooring anchors blocked the trawl path. BL 4 at the mouth of the Blair Waterway was resampled in 1994 with three otter trawl and two beam trawl replications.

Data Input and Analysis

The intensive trawling effort produced voluminous data, which were entered into computer spreadsheets as catch files. These were sorted, averaged, statistically analyzed and graphed in various combinations to look for patterns. The null hypothesis for the study was: There are no significant differences between contaminated and uncontaminated sites for the parameters measured. The data were then tested for statistical significance using either a parametric test (Student's two-tailed, two-sample t-Test, paired or independent) or a non-parametric test (two-sample Kolmogorov-Smirnov Test) depending on the outcome of the test for normality (one-sample Kolmogorov-Smirnov normality test). Species diversity was calculated using the Shannon-Wiener Index (H') with the natural logarithm.

RESULTS

The coverage of the results will focus on the best-matched comparison of the QMH 1 reference station in upper Quartermaster Harbor and the contaminated TF 1 station in the upper end of the Thea Foss Waterway. The average grain size of surface sediments along the 1994 TF 1 trawl path was reported by Tetra Tech (1985) at 78% fines. This result closely matches the grain-size analysis at QMH 1 (80% fines) using the wet-sieving technique. Bottom temperatures (14 degrees C) were identical at both stations on 11 September 1994, and bottom salinities were closely matched with 31 ppt at TF 1 compared with 32 ppt at QMH 1. Bottom depth (MLLW) is only slightly deeper at QMH 1 (6 m.) than at TF 1 (5 m.).

Fish Abundance, Biomass, and Mean Individual Weights

Figure 2 and Table 1 highlight the differences in fish abundance and biomass measurements for the two stations with a pattern that proves to hold generally for any comparison of the reference conditions in Quartermaster Harbor with the contaminated conditions in the Thea Foss Waterway—fish abundance is either lower in Quartermaster Harbor or very similar to that found at the Superfund site, but fish biomass is significantly greater at the reference site. This must mean, of course, that the mean individual weights of the fishes at the reference site are considerably higher than that found at the contaminated site, or that sensitive fish species found at the reference site, but which do not occur at the contaminated site, tend to be much larger (Table 2). Both factors contribute to the differences, because the cartilaginous fishes (spiny dogfish, spotted ratfish, and the skates), tentatively classified as sensitive species (Table 3), are only rarely encountered in the contaminated waterways and are very large compared to the bony fishes. Figure 2b demonstrates, however, that bony fish alone show significantly greater (P=0.0001) biomass at the reference station despite their smaller numbers. Also, the average individual weight of almost every numerous species tested was significantly higher at the reference site compared to the contaminated site (Figure 3a and Table 2).

Sensitive and Tolerant Species

With quantitative sampling, tolerant species can be defined as those species whose relative abundance at contaminated sites is significantly greater than or indistinguishable from those collected at reference sites of comparable depth, salinity, dissolved oxygen, sediment grain-size, slope, and density of structures (e.g., eelgrass). Sensitive (or intolerant) species, on the other hand, are defined as those species whose relative abundance is significantly greater from a reference area than from a comparable contaminated site. Table 3 is a preliminary list of tolerant and sensitive demersal species for the Tacoma waterways and Quartermaster Harbor based on these criteria and both Phase I and Phase II sampling.

The sensitivity index (Figure 3b, and the bottom of Table 1) is based on the proportion of sensitive abundance or biomass from a total of sensitive plus tolerant. Such an index, if tested independently for annual and seasonal variation, could be very useful in following the recovery of an area after cleanup, or to help classify impacted sites as to their relative degradation.

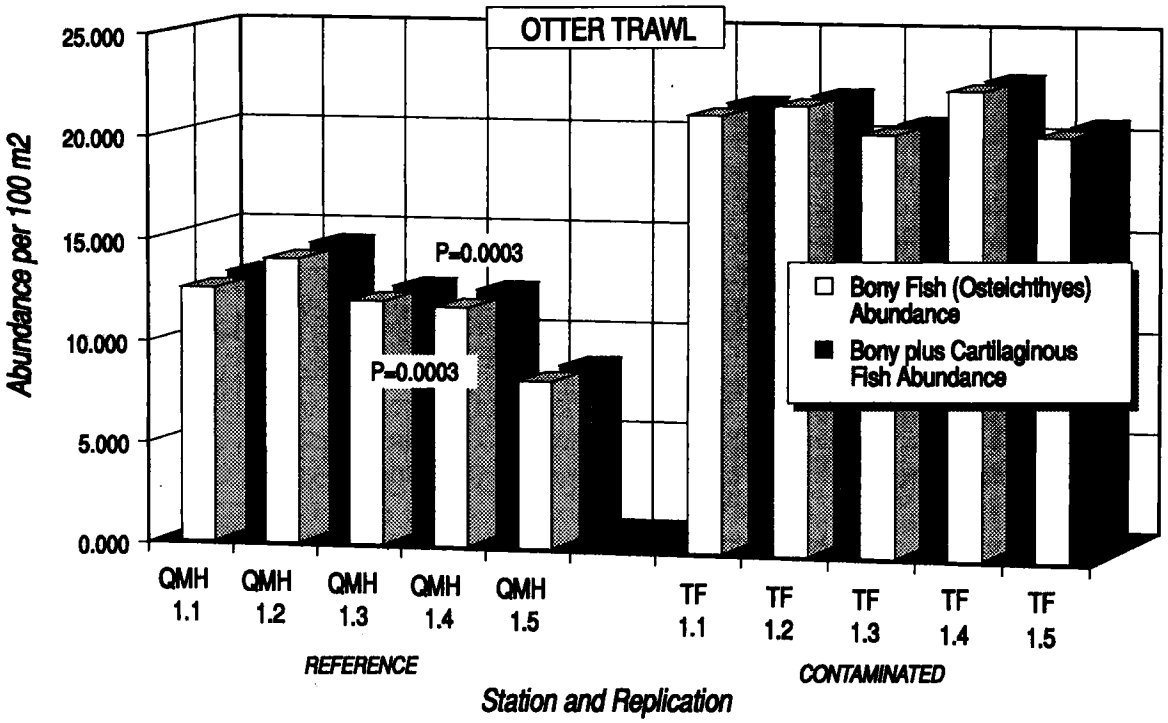

Figure 2a. Bony fish abundance and total fish (bony plus cartilaginous) abundance for reference (QMH 1) and contaminated (TF 1) sites

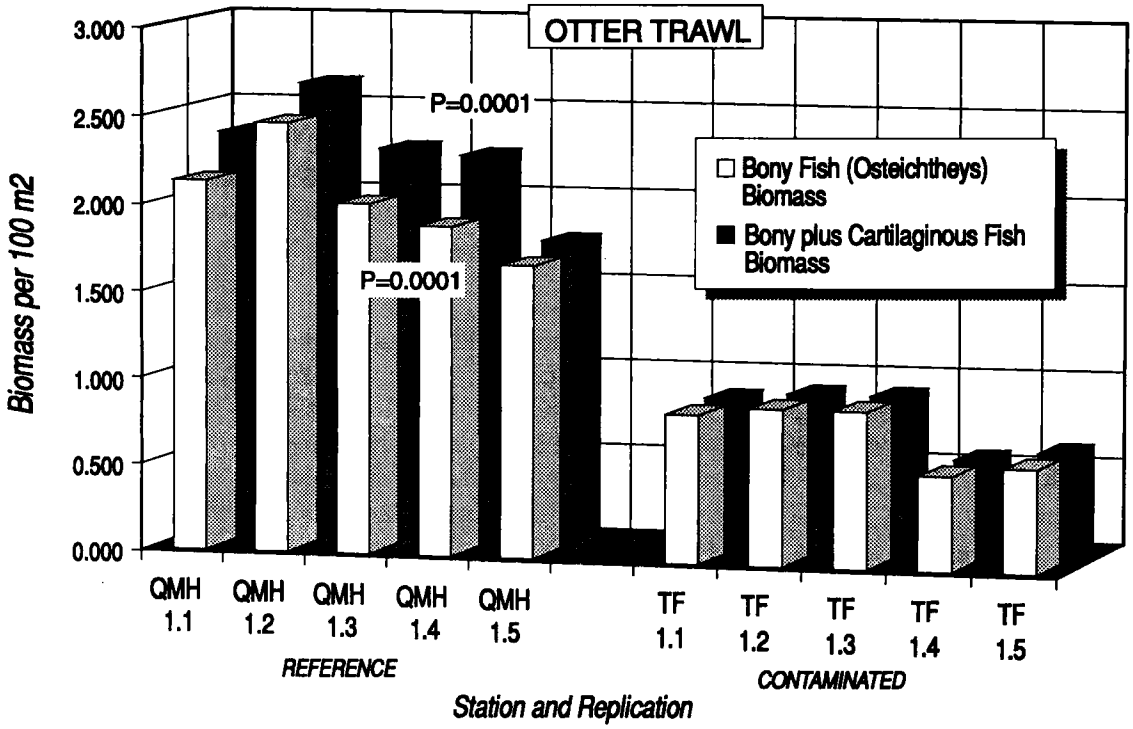

Figure 2b. Bony fish biomass and total fish biomass for reference (QMH 1) and contaminated (TF 1) sites

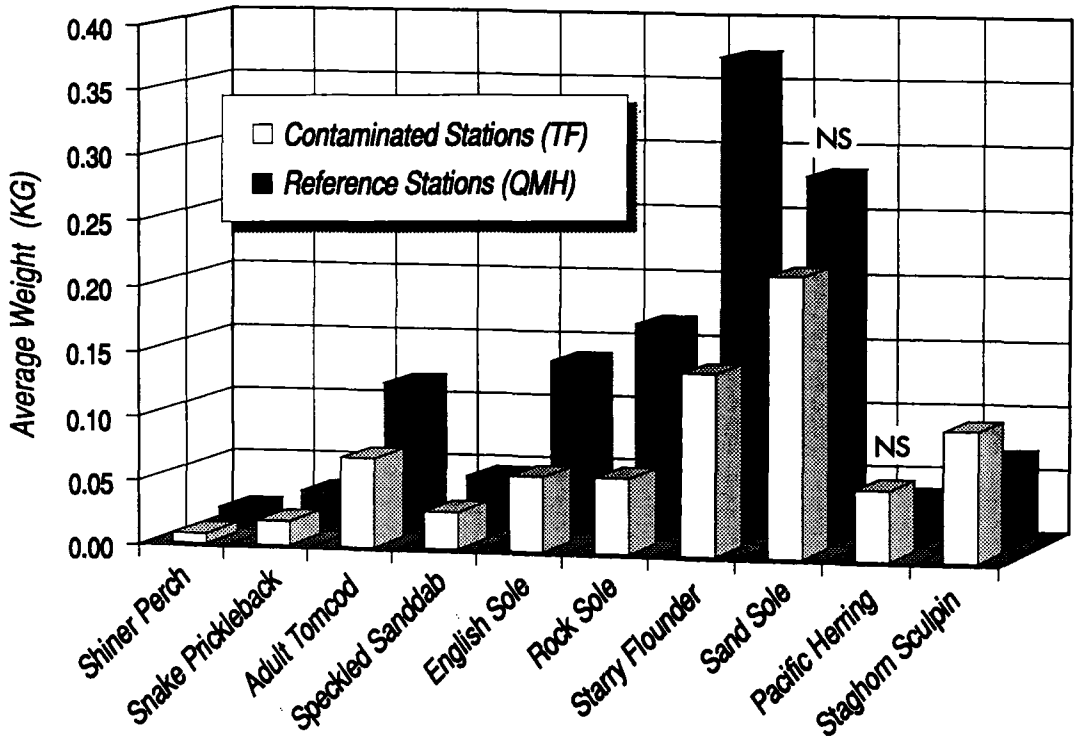

Figure 3a. Mean individual weights of fish species from contaminated (TF) and reference (QMH) sites

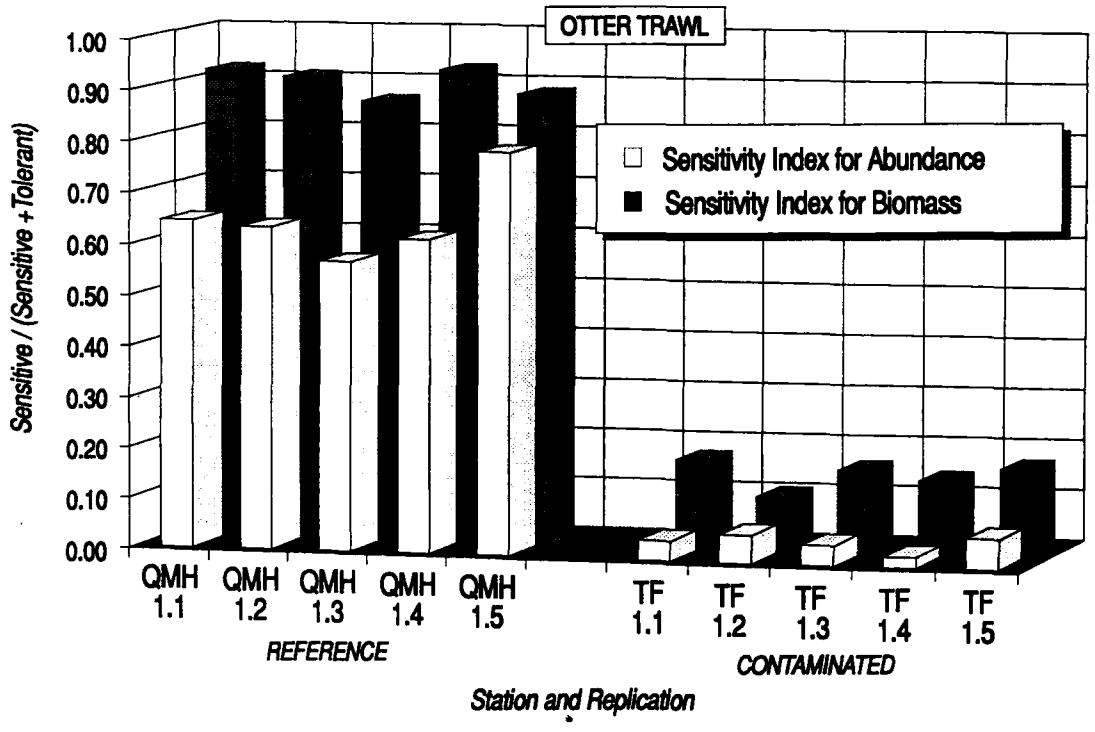

Figure 3b. The sensitivity index for animals from the reference (QMH) and contaminated (TF) sites

Table 1. Abundance and biomass data comparisons from the QMH 1 reference site and the TF 1 contaminated site

ABUNDANCE or BIOMASS / 100 m2 Otter Trawl (n=5); Beam Trawl (n=3)	SEPT. 1994			t-Test: Paired Two Sample for Means or Kolmogorov-Smirnov Test*		
QUARTERMASTER HARBOR (Reference Station) versus THEA FOSS WATERWAY (Contaminated Station)	Sampling Gear	Station Comparison	Greatest Abundance or Biomass	Highly Significant Difference (P<0.01)	Significant Difference (P<0.05)	Not Significant (P>0.05)
Demersal Fish Abundance	Otter Trawl	QMH 1 vs TF 1	TF 1	0.0006		
Demersal Fish Biomass	Otter Trawl	QMH 1 vs TF 1	QMH 1	0.0002		
Demersal Fish Abundance	Beam Trawl	QMH 1 vs TF 1	QMH 1		0.0172	
Demersal Fish Biomass	Beam Trawl	QMH 1 vs TF 1	QMH 1			0.830*
Total Flatfish Abundance	Otter Trawl	QMH 1 vs TF 1	TF 1		0.0446	
Total Flatfish Biomass	Otter Trawl	QMH 1 vs TF 1	QMH 1	0.0001		
English Sole Abundance	Otter Trawl	QMH 1 vs TF 1	TF 1	0.0018		
English Sole Biomass	Otter Trawl	QMH 1 vs TF 1	TF 1	0.0049		
Starry Flounder Abundance	Otter Trawl	QMH 1 vs TF 1	QMH 1	0.0005		
Starry Flounder Biomass	Otter Trawl	QMH 1 vs TF 1	QMH 1	0.0002		
Staghorn Sculpin Abundance	Otter Trawl	QMH 1 vs TF 1	TF 1			0.704
Staghorn Sculpin Biomass	Otter Trawl	QMH 1 vs TF 1	QMH 1			0.9657
Staghorn Sculpin Abundance	Beam Trawl	QMH 1 vs TF 1	TF 1	0.000*		
Staghorn Sculpin Biomass	Beam Trawl	QMH 1 vs TF 1	TF 1			0.667*
Shiner Surfperch Abundance	Otter Trawl	QMH 1 vs TF 1	TF 1		0.0212	
Shiner Surfperch Biomass	Otter Trawl	QMH 1 vs TF 1	TF 1			0.6131
Total Pacific Tomcod Biomass	Otter Trawl	QMH 1 vs TF 1	TF 1	0.000*		
Total Pacific Tomcod Abundance	Otter Trawl	QMH 1 vs TF 1	TF 1	0.000*		
Snake Prickleback Abundance	Otter Trawl	QMH 1 vs TF 1	TF 1			0.704
Snake Prickleback Biomass	Otter Trawl	QMH 1 vs TF 1	QMH 1			0.2302
Bay Goby Abundance	Beam Trawl	QMH 1 vs TF 1	QMH 1		0.0101	
Bay Goby Biomass	Beam Trawl	QMH 1 vs TF 1	QMH 1		0.0161	
Invertebrate Abundance	Beam Trawl	QMH 1 vs TF 1	QMH 1			0.0781
Invertebrate Biomass	Beam Trawl	QMH 1 vs TF 1	QMH 1		0.0289	
Sand Shrimp (Crangon spp) Abundance	Beam Trawl	QMH 1 vs TF 1	QMH 1			0.8947
Sand Shrimp (Crangon spp) Biomass	Beam Trawl	QMH 1 vs TF 1	QMH 1			0.4592
Purple crab (Cancer gracilis) Abundance	Beam Trawl	QMH 1 vs TF 1	TF 1		0.0234	
Purple crab (Cancer gracilis) Biomass	Beam Trawl	QMH 1 vs TF 1	TF 1		0.029	
Sensitive Fish Abundance	Otter Trawl	QMH 1 vs TF 1	QMH 1	0.0002		
Sensitive Fish Biomass	Otter Trawl	QMH 1 vs TF 1	QMH 1	0.0002		
Sensitive Fish Abundance	Beam Trawl	QMH 1 vs TF 1	QMH 1		0.0110	
Sensitive Fish Biomass	Beam Trawl	QMH 1 vs TF 1	QMH 1			0.2771
Tolerant Fish Abundance	Otter Trawl	QMH 1 vs TF 1	TF 1	0.0000		
Tolerant Fish Biomass	Otter Trawl	QMH 1 vs TF 1	TF 1	0.0018		
Tolerant Fish Abundance	Beam Trawl	QMH 1 vs TF 1	TF 1	0.000*		
Tolerant Fish Biomass	Beam Trawl	QMH 1 vs TF 1	TF 1	0.000*		
Sensitive Fish & Invert Abundance	Beam Trawl	QMH 1 vs TF 1	QMH 1		0.0101	

Table 1. continued

ABUNDANCE or BIOMASS / 100 m2 Otter Trawl (n=5); Beam Trawl (n=3)	SEPT. 1994			t-Test: Paired Two Sample for Means or Kolmogorov-Smirnov Test*		
QUARTERMASTER HARBOR (Reference Station) versus THEA FOSS WATERWAY (Contaminated Station)	Sampling Gear	Station Comparison	Greatest Abundance or Biomass	Highly Significant Difference (P<0.01)	Significant Difference (P<0.05)	Not Significant (P>0.05)
Sensitive Fish & Invert Biomass	Beam Trawl	QMH 1 vs TF 1	QMH 1	0.000*		
Sensitivity Index: Fish Abundance	Otter Trawl	QMH 1 vs TF 1	QMH 1	0.000*		
(Sensitive) / (Sensitive + Tolerant)						
Sensitivity Index: Fish Abundance	Beam Trawl	QMH 1 vs TF 1	QMH 1	0.0048		
Sensitivity Index: Fish Biomass	Otter Trawl	QMH 1 vs TF 1	QMH 1	0.000*		
Sensitivity Index: Fish Biomass	Beam Trawl	QMH 1 vs TF 1	QMH 1			0.0585
Sensitivity Index: Fish & Invert Abund	Otter Trawl	QMH 1 vs TF 1	QMH 1	0.000*		
Sensitivity Index: Fish & Invert Abund	Beam Trawl	QMH 1 vs TF 1	QMH 1	0.000*		
Sensitivity Index: Fish & Invert Biomass	Otter Trawl	QMH 1 vs TF 1	QMH 1	0.000*		
Sensitivity Index: Fish & Invert Biomass	Beam Trawl	QMH 1 vs TF 1	QMH 1	0.000*		

Table 2. Mean individual weights of species common to both the contaminated site (TF) and reference site (QMH), and species present at one site and absent from the other

MEAN INDIVIDUAL WEIGHT				t-Test: Paired Two Sample for Means or Kolmogorov-Smirnov Test*		
QUARTERMASTER HARBOR (Reference Stations) versus THEA FOSS WATERWAY (Contaminated Stations)	Method	Station Comparison	Greatest Mean Individual Weight	Highly Significant Difference (P<0.01)	Significant Difference (P<0.05)	Not Significant (P>0.05)
ENGLISH SOLE	Biomass / Abundance (n=5/5)	QMH 1 vs TF 1	QMH 1	0.000*		
STARRY FLOUNDER	Biomass / Abundance (n=5/5)	QMH 1 vs TF 1	QMH 1	0.0007		
ROCK SOLE	Biomass / Abundance (n=5/5)	QMH 2 vs TF 3	QMH 2	0.0001		
SPECKLED SANDDAB	Biomass / Abundance (n=5/5)	QMH 1 vs TF 2 & 3	QMH 1	0.0042		
SAND SOLE	Biomass / Abundance (n=5/5)	QMH All vs TF All	All QMH			0.4068
STAGHORN SCULPIN (OT)	Mean Individual Wts. (n=30/28)	QMH 1 vs TF 1	TF 1		0.023	
SNAKE PRICKLEBACKS	Mean Individual Wts. (n=8/8)	QMH 1 vs TF 1	QMH 1		0.0489	
ADULT PACIFIC TOMCOD	Biomass / Abundance (n=4/4)	QMH 3 vs TF 3	QMH 3		0.0110	
SHINER SURFPERCH	Biomass / Abundance (n=5/5)	QMH 1 vs TF 1	QMH 1		0.0252	
PACIFIC HERRING (Pelagic)	Biomass / Abundance (n=5/5)	QMH 1 vs TF 1	TF 1			0.173
CRANGON SPP. (Sand shrimp)	Biomass / Abundance (n=3/3)	QMH 1 vs TF 1	QMH 1			0.1941
CRANGON SPP. (Sand shrimp)	Biomass / Abundance (n=6/6)	QMH 1&2 vs TF 1&3	QMH 1&2		0.017	
CANCER GRACILIS (Purple Crab)	Mean Individual Wts. (n=14/14)	QMH 1 vs TF 1	QMH 1			0.2257

Table 3. A preliminary list of tolerant and sensitive fish and invertebrate species from the Tacoma waterways and Quartermaster Harbor

Tolerant Fish Species:	**Sensitive Fish Species:**
ENGLISH SOLE	SPINY DOGFISH
SAND SOLE	SPOTTED RATFISH
FLATHEAD SOLE	LONGNOSE SKATE
PACIFIC TOMCOD	BIG SKATE
SHINER SURFPERCH	ROCK SOLE
SNAKE PRICKLEBACK	STARRY FLOUNDER
PACIFIC STAGHORN SCULPIN	SPECKLED SANDDAB
	PILE SURFPERCH
	STRIPED SURFPERCH
	BAY GOBY
	BLACKBELLY EELPOUT
	BAY PIPEFISH
	PLAINFIN MIDSHIPMAN ?
Tolerant Invertebrate Species:	**Sensitive Invertebrate Species:**
PANDALUS DANAE: Coonstripe Shrimp	CUCUMARIA MINIATA: sea cucumber
CRANGON SPP.: Sand Shrimp	CUCUMARIA PIPERATA: spotted sea cucumber
CANCER GRACILIS: Purple Cancer crab	PENTAMERA POPULIFERA: crescent sea cucumber
CANCER PRODUCTUS: Red rock crab	PARASTICHOPUS CALIFORNICUS: sea cucumber
CANCER MAGISTER: Dungeness crab	SOLASTER STIMPSONI: sunstar
LOPHOPANOPEUS BELLUS: crab	HERMIT CRABS
EVASTERIAS TROSCHELLI: Mottled seastar	NASSARIUS MENDICUS: Snail
METRIDIUM SENILE: Plume (or Pile) anemone	

Species Richness

The total or cumulative species richness in the otter trawls was much higher at the reference station with 20 total species than at the contaminated station with 12 total species (Table 4). When testing for significance on a trawl-by-trawl basis (i.e., the mean number of taxa per sample), however, the significance was lost both for demersal fish richness (P=0.0586) and for total species richness including the invertebrate species (P=0.0525). The beam trawls displayed very little difference in species richness between sites for either fish or total richness.

External Abnormalities

External abnormalities, such as fin erosion in English sole, were so rare in both the Phase I and Phase II studies as to show very little usefulness in reflecting environmental stress. Tetra Tech (1985) reported no skin tumors and only 0.9 % confirmed cases of fin erosion in 1,020 subsampled English sole from the Tacoma waterways and Commencement Bay. Weitcamp and Schadt (1981) also reported few if any external abnormalities from their otter trawl sampling of the Tacoma waterways and Commencement Bay shoreline.

A Comparison of the Blair and Hylebos Waterways (Phase I, 1993)

The Phase I study had two objectives: 1) to determine the sampling effort needed to quantitatively define the demersal fauna, and 2) to identify population patterns and external health indices that would reflect pollution problems in the sediments. The adjacent waterways were chosen for comparison based on their close proximity, length, sediment grain size and historical information (Tetra Tech, 1985). Table 5 gives a summary of the results of the Blair-Hylebos comparison.

Table 4. Total species richness for otter trawls and beam trawls from the QMH 1 reference site and the TF 1 contaminated site

QMH 1/OTTER TRAWL: Total Species Richness (5 replications)	DEMERSAL FISH = 15 SPP. INVERTEBRATES = 5 SPP. **TOTAL RICHNESS = 20 SPP.**	P=0.0586 NS P=0.0525 NS
TF 1/OTTER TRAWL: Total Species Richness (5 replications)	DEMERSAL FISH = 9 SPP. INVERTEBRATES = 3 SPP. (not including Metridium senile) **TOTAL RICHNESS = 12 SPP.**	
QMH 1/BEAM TRAWL: Total Species Richness (3 replications)	INVERTEBRATES = 8 SPP. DEMERSAL FISH = 7 SPP. **TOTAL RICHNESS = 15 SPP.**	
TF 1/BEAM TRAWL: Total Species Richness (3 replications)	INVERTEBRATES = 7 SPP. DEMERSAL FISH = 7 SPP. **TOTAL RICHNESS = 14 SPP.**	

All of the smaller species were significantly more abundant in the beam trawl catches per unit area swept than in the otter trawl catches including all invertebrates as well as sanddabs, juvenile flatfish, all sculpins, eelpouts, snake pricklebacks and bay gobies (Figure 4). The otter trawl was more effective at sampling the larger, more mobile demersal fishes. An analysis of trawl variability led to the recommendation of at least four (preferably five) replications with the otter trawl per station with a rest period of several hours or days between replications.

The English sole, Pacific tomcod, snake pricklebacks and purple crabs (*Cancer gracilis)* were significantly larger in the Blair Waterway catches than in the contaminated Hylebos Waterway. Sublethal health indices and raw or averaged abundance and diversity data were not useful in differentiating the contaminated Hylebos Waterway site from the Blair reference. A sensitive-species index was developed, which was useful in differentiating the sites, and this index was more powerful for the beam trawl data than for the otter trawl data.

DISCUSSION

Abundance, Biomass and Mean Individual Weights

The conclusion drawn from Phase I indicated that raw or averaged abundance data were not useful in differentiating contaminated from reference sites. This fact led to an increased effort in recording biomass data in Phase II, and to the study of a more natural reference condition than was represented by the Blair Waterway in Phase I. Figure 2 and Table 4 clearly confirm these initial conclusions about the raw abundance data, while emphasizing the ecologically more important fact that the reference site is supporting more than twice the fish biomass than the contaminated site, despite the fewer number of fish. Because of the five replications per station, significant data on mean individual species weights could be collected simply by weighing each species as a group and then counting them as they are being released. With an emphasis on economy and speed (as well as animal survival), future sampling does not need to include individual weights for numerous species. Species encountered more rarely (i.e., not on every replication) should be individually weighed to get enough data points for the statistical comparisons.

Almost every fish species common to both areas was significantly larger (mean individual weight) at the reference site (Figure 3a, Table 2). Pacific herring (not a part of the demersal fauna) and sand sole did not show a significant difference, and only Pacific staghorn sculpins were larger at the contaminated site than at the reference. It is assumed that these larger fish were older fish, and that these older year classes (with the exception of staghorn sculpins) were missing or underrepresented at the contaminated sites.

Table 5. Abundance and size data comparisons from the Blair (reference) and Hylebos (contaminated) Waterways, Phase I, 1993

ABUNDANCE / 100 m2 or SIZE (mm)		JUNE, 1993		t-Test: Two-tailed, indep. samples or Kolmogorov-Smirnov Test		
BLAIR WATERWAY (BL) (Impacted but cleaner) versus HYLEBOS WATERWAY (HY) (Contaminated)	Sampling Gear	Station Comparison	Greatest Abundance or Size	Highly Significant Difference (P<0.01)	Significant Difference (P<0.05)	Not Significant (P>0.05)
English Sole Abundance (n=12/12)	Otter Trawl	All BL vs All HY	Hylebos Wtv			0.764
English Sole Abundance (n=3/3)	Otter Trawl	BL 1 vs HY 1	HY 1		0.019	
English Sole Abundance (n=3/3)	Otter Trawl	BL 3 vs HY 3	BL 3		0.044	
English Sole Size (mm), males (n=141/133)	Otter Trawl	All BL vs All HY	Blair Wtv	0.000		
Rock Sole Abundance (n=12/12)	Otter Trawl	All BL vs All HY	Blair Wtv			0.434
Rock Sole Abundance (n=7/7)	Otter Trawl	BL 4 vs HY 4	Blair Wtv		0.012	
Rock Sole Size (mm) (n=54/28	Otter Trawl	All BL vs All HY	Hylebos Wtv			0.082
Flathead Sole Abundance (n=12/12)	Otter Trawl	All BL vs All HY	Blair Wtv			0.109
Flathead Sole Size (n=14/5)	Otter Trawl	All BL vs All HY	Hylebos Wtv			0.42
Bay Goby Abundance (n=12/12)	Beam Trawl	All BL vs All HY	Blair Wtv	0.008		
Bay Goby Size (n=150/39)	Beam Trawl	All BL vs All HY	same			0.812
Staghorn Sculpin Abundance (n=12/12)	Beam Trawl	All BL vs All HY	Hylebos Wtv		0.033	
Adult Pacific Tomcod Abundance (n=12/12)	Otter Trawl	All BL vs All HY	Hylebos Wtv			0.241
All Pacific Tomcod Abundance (n=3/3)	Otter Trawl	BL 1 vs HY 1	HY 1		0.012	
All Pacific Tomcod Abundance (n=3/3)	Otter Trawl	BL 2 vs HY 2	HY 2		0.043	
Adult Pacific Tomcod Size (n=49/71)	Otter Trawl	All BL vs All HY	Blair Wtv		0.011	
Snake Prickleback Abundance (n=12/12)	Beam Trawl	All BL vs All HY	Hylebos Wtv			0.085
Snake Prickleback Abundance (n=3/3)	Beam Trawl	BL 2 vs HY 2	HY 2		0.022	
Snake Prickleback Abundance (n=3/3)	Beam Trawl	BL 3 vs HY 3	HY 3	0.005		
Sand Shrimp Abundance (n=12/12)	Beam Trawl	All BL vs All HY	Blair Wtv			0.276
Sand Shrimp Abundance (n=3/3)	Beam Trawl	BL 1 vs HY 1	BL 1	0.003		
Coonstripe Shrimp Abundance (12/12)	Beam Trawl	All BL vs All HY	Hylebos Wtv			0.482
Coonstripe Shrimp Size (12/12)	Beam Trawl	All BL vs All HY	Hylebos Wtv	0.004		
Purple Crab Abundance (n=12/12)	Beam Trawl	All BL vs All HY	Hylebos Wtv	0.001		
Purple Crab Size (n=172/318)	Beam Trawl	All BL vs All HY	Blair Wtv		0.039	
All Animals Abundance (n=12/12)	Beam Trawl	All BL vs All HY	Hylebos Wtv			0.968
All Animals Abundance (n=12/12)	Otter Trawl	All BL vs All HY	Hylebos Wtv			0.338
All Animals Abundance less juv Tomcod	Otter Trawl	All BL vs All HY	Hylebos Wtv			0.058
Debris Abundance (n=12/12)	Beam Trawl	All BL vs All HY	Hylebos Wtv	0.000		
Debris Abundance (n=12/12)	Otter Trawl	All BL vs All HY	Hylebos Wtv		0.036	
Species Diversity (H') (n=4/4)	Otter Trawl	All BL vs All HY	Blair Wtv			0.888
Species Diversity (H') (n=4/4)	Beam Trawl	All BL vs All HY	Hylebos Wtv			0.487
Sensitive Species Abundance	Beam Trawl	All BL vs All HY	Blair Wtv	0.000		
Sensitive Fish Abundance (n=3/3)	Otter Trawl	BL 3 vs HY 3	BL 3		0.042	
Sensitive Fish Abundance (n=7/7)	Otter Trawl	BL 4 vs HY 4	BL 4		0.02	
Sensitive Species Richness	Beam Trawl	All BL vs All HY	Blair Wtv	0.005		
Sensitive Species Richness	Otter Trawl	All BL vs All HY	Blair Wtv			NS

Sensitive and Tolerant Species

The identification of sensitive (or intolerant) and tolerant demersal marine species is in its infancy compared with freshwater streams (Karr et al., 1986) and benthic marine infauna (Word, 1979). This stems from a paucity of data on demersal marine communities due in part to the lack of the development of quantitative sampling methods for the demersal fauna. Weitcamp and Schadt (1981) reported that English sole, flathead sole, Pacific staghorn sculpin, Pacific tomcod, shiner perch and snake pricklebacks were more

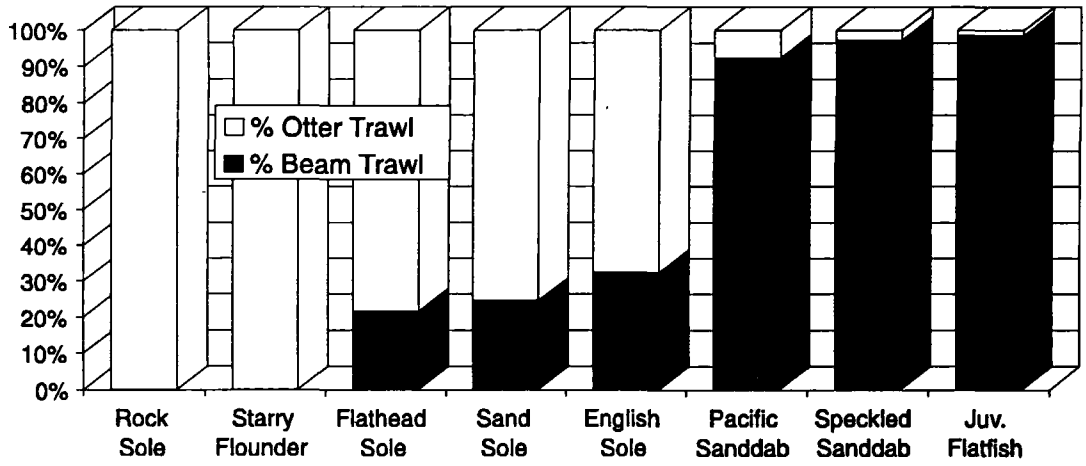

Figure 4. Percentage catch per unit area swept: otter trawl versus beam trawl, Phase I (1993)

abundant in their otter trawl samples from the Tacoma waterways than from the shorelines of Commencement Bay. Rock sole, c-o sole, speckled sanddab, and white-spotted greenling, on the other hand, were reported to be more abundant in samples from Commencement Bay than from the Tacoma waterways. Weitcamp and Schadt speculated that these differences in abundance perhaps indicated a preference of one type of habitat versus another. This may explain some of the abundance differences noted, since the habitats are different, but many of the species observed to be more abundant in the waterways are also the ones identified by this study as being "tolerant species" at contaminated sites.

As stated above, many of the older fish year classes are missing (older and wiser?) from the contaminated sites, and the fish biomass per unit area is significantly reduced. Tetra Tech (1985) demonstrated that hepatic lesions in English sole (a tolerant species) were significantly more prevalent in samples from the Tacoma waterways than from reference sites in Carr Inlet. It is interesting to note that the incidence of hepatic lesions was also elevated in the Blair and Milwaukee waterways with relatively clean sediments, and showed no significance in fish taken from the St. Paul and City (Thea Foss) waterways, the latter being designated a Superfund site and the location of the present study. The incidence of English sole hepatic lesions does not seem to be as well focused as is the sediment chemistry data, a source of frustration we encountered to a lesser degree when trying to differentiate patterns in demersal fauna between the Blair and Hylebos waterways. At the same time, these broader indices may be reflecting more than just sediment chemical contamination, such as physical oceanographic stresses or the effects of channelization and loss of ancillary habitat.

An Index of Demersal Integrity?

The need for ecologically based indices of pollution has been well argued by Karr (1991), and any effort to develop and apply them as an objective tool for measuring ecological integrity makes a great deal of intuitive and economic sense. Although quantitative sampling of demersal fauna is in its infancy, and there is still much to be learned about natural as well as stress-induced variation in demersal biotic patterns, information on the demersal fauna needs to be included in any broad-based ecological index. Candidate attributes that show promise and deserve further study are shown in Table 6.

Table 6. Candidate attributes of demersal fauna to be included in an index of demersal integrity

Candidate	Preliminary Expectation of Contaminated Site Relative to Reference Site
Demersal fish abundance per 100 m2 (OT)	Increase
English sole abundance & biomass (OT)	Increase
Pacific staghorn sculpin abundance and biomass (BT)	Increase
Pacific tomcod abundance & biomass (OT)	Increase
Purple crab (*Cancer gracilis*) abundance and biomass (BT)	Increase
Evasterias troschelli (mottled seastar) abundance (BT)	Increase
Metridium senile (Pile Anemone) abundance and biomass (BT)	Increase
Pacific staghorn sculpin mean individual weights (OT)	Increase
Shiner surfperch abundance and biomass (OT)	Increase or no difference
Snake prickleback abundance (OT)	Increase or no difference
Total flatfish biomass (OT)	Decrease
All flatfish mean individual weights (except sand sole)	Decrease
Starry flounder abundance and biomass (OT)	Decrease
Rock sole abundance and biomass (OT)	Decrease
Bay goby abundance and biomass (BT)	Decrease
Cartilaginous fish abundance and biomass (OT)	Decrease or absent
Sea cucumber abundance and biomass (OT&BT)	Decrease or absent
Prickleback, tomcod, surfperch, and sand shrimp mean individual weights	Decrease
Sensitivity Index (proportion of sensitive to sensitive + tolerant)	Decrease
Total species richness	Decrease or no difference
External fish abnormalities	No difference (or very small)

ACKNOWLEDGMENTS

This project was supported by funds from the Estuarine/Near Coastal Bioassessment/Biocriteria Project, U.S. Environmental Protection Agency, Washington, D.C. Phase II was supported by EPA, Washington, D.C., Order No. 4642. George Gibson provided insightful guidance and direction for both Phase I and Phase II. Ken Dzinbal (WDOE), Dave Armstrong and Karen Keeley (U.S. EPA, Region X) and Pete Striplin reviewed the Phase I manuscript. A special thanks goes out to all the volunteers who spent so many hours pulling in nets and sorting though trawl catches, including all the staff from Striplin Environmental Associates (SEA), the eager volunteers from the University of Washington, and my wife and son, April and Sam Eaton. Thomas L. Eaton generously provided travel funds to Washington, D.C. Paul Dinnel, co-investigator for Phase I, provided much-appreciated technical advice for the Phase II study. I thank each of these individuals for their valuable assistance.

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STATUS AND TRENDS IN THE SURVIVAL AND DISTRIBUTION OF RESIDENT COHO AND CHINOOK SALMON IN PUGET SOUND, WASHINGTON

Andrew E. Appleby and Daniel C. Doty[1]

INTRODUCTION

The sport salmon fishery of inner Puget Sound is exceptional. There are few other places where as many people can find excellent salmon fishing in a beautiful protected inland sea. This region, as defined here, includes Admiralty Inlet and Whidbey Island south to Olympia, including Hood Canal (Figure 1).

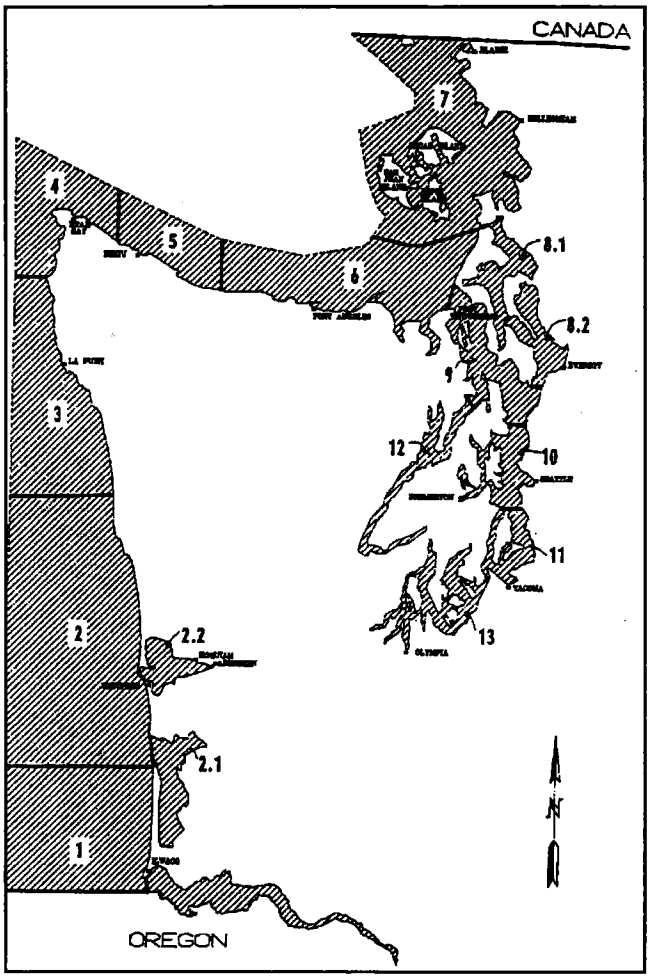

Figure 1.

The Washington Department of Fish and Wildlife (formally Washington Department of Fisheries) has been monitoring, evaluating and enhancing this salmon fishery for many years (Haw et al., 1967; Buckley, 1969; Buckley and Haw, 1978; Appleby et al., 1989). Although there are five species of Pacific salmon

[1] Washington Department of Fish and Wildlife, 600 Capitol Way N., Olympia, WA 98501-3154

available to the Puget sound sport fishery, the most popular are chinook (*Oncorhynchus tshawytscha*) and coho (*Oncorhynchus kisutch*).

The inner Puget Sound sport fishery (WDFW catch areas 8-13; Figure 1) declined significantly beginning in 1958 and remained low throughout the 1960s (Haw et al., 1967; Figure 2). The agency began experimenting with hatchery rearing programs in the late 1960s and early 1970s in an effort to improve the catch in this fishery. These efforts resulted in rearing strategies called "delayed release" and "yearling release" (Buckley and Haw, 1978).

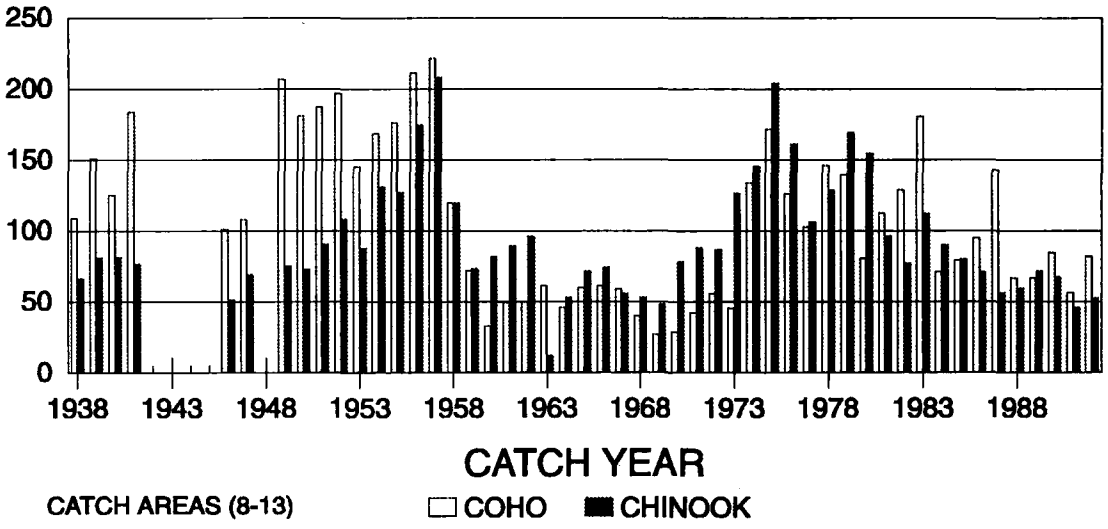

Figure 2. Sport salmon harvest from inner Puget Sound

The term "delayed release" is used in connection with coho salmon. It involves releasing smolts in June rather than their normal outmigration time of April and May. "Yearling release" applies to chinook rearing and involves rearing fall chinook for an additional year past their normal release time. Essentially, both involve "extended rearing"—holding fish past their normal migration time. Extended rearing suppresses the normal ocean migration tendency and increases the proportion of fish that remain in Puget Sound their entire life. Thus, these fish are available to sport fishers year round, rather than only during the time of adult returns (Buckley and Haw, 1978). Extended rearing programs have been conducted from both freshwater and saltwater sites. Traditionally, the coho programs have been conducted in saltwater net pens and the chinook programs conducted in freshwater hatchery ponds. Based on recoveries of coded-wire tagged (CWT) fish, these techniques have enhanced the Puget Sound sport fishery and were directly responsible for the catch increase in the mid-1970s (Figure 2). However, a general decrease in the inner Puget Sound sport catch since the early to mid-1980s caused WDFW to reevaluate extended rearing programs (Figure 2).

This paper will review the changes in survival and catch distribution seen in resident coho and chinook populations. We also present results of recent rearing experiments aimed at enhancing these populations. In addition, we attempt to correlate changes in the number of fish released, location of release and rearing techniques used in these extended rearing programs with observed changes in performance.

METHODS AND MATERIALS

Our investigation had two phases. Phase 1 consisted of a review of historic production and CWT data to determine the past and recent performance of the coho and chinook rearing programs. Phase 2 involved

using the results of phase 1 to develop and implement rearing experiments intended to increase the number of resident coho and chinook in inner Puget Sound.

Coho Methods and Materials

Phase 1

Historical and current production levels of delayed-release coho in Puget Sound were gathered from WDFW planting records. Survival and catch distribution data were gathered from the files of the Pacific States Marine Fisheries Commission (PSMFC) recoveries of CWT fish. Historical survival and catch distribution data were collated from releases of CWT fish from the South Sound Net Pen Complex (SSNP). This facility was chosen because it produces the most delayed release coho and also has the longest set of CWT releases. The SSNP complex is a large (66 net pens) rearing complex operated cooperatively by WDFW and the Squaxin Indian Tribe. Smolt-to-adult survival and catch distribution estimates are available for this facility beginning with the 1974 brood.

Phase 2

Experiments designed to test alternate rearing strategies involved coho salmon from the 1986-1989 broods. The experimental design entailed altering the date of release around the control (normal) date of June 1. Dates of release both before (April) and after (July, August) as well as a 2-year-old smolt program were tested. Fish from treatment groups were identified with unique CWTs, and the resulting recoveries were compared to control groups to determine the effects of treatments.

Chinook Methods and Materials

Phase 1

Historical and current production levels of yearling fall chinook in Puget Sound were gathered from WDFW planting records. Survival and catch distribution of CWT fish from the Percival Cove rearing complex in Olympia were used to establish historic performance levels (PSMFC date files). This facility was the largest producer of yearling fall chinook in Puget Sound, releasing about 1 million yearling fall chinook per year. It was considered the "backbone" of the Puget Sound sport chinook fishery because it contributed about one-third of the total yearling chinook released annually.

Phase 2

Experiments design to test the current effectiveness of the Percival Cove site (freshwater) against saltwater rearing sites, such as SSNP, were implemented using fish from the 1986-1989 broods. In order to monitor the survival and catch distribution, fish from both the freshwater and saltwater sites were tagged with CWTs before release.

RESULTS AND DISCUSSION

Coho

A review of the production of delayed release coho in Puget Sound is presented in Figure 3. Survival and distribution data specific to the SSNP are presented in Figures 4 and 5. The result of date-of-release experiments are briefly summarized in Figures 6 and 7. The SSNP data appear to show a change in the catch distribution over time (Figure 4). Until the 1980 brood, approximately 15 percent to 20 percent of the total recoveries could be accounted for in the Puget Sound sport catch. After the 1980 brood there appears to be a drop in this component and an increase in the proportion of recoveries in the British Columbia catch (all gear types). Interestingly, during much of this time, smolt-to-adult survival remained high by freshwater hatchery standards. This has been the trend since the beginning of the program. A more detailed analysis by catch area also supported the change in catch distribution. Contribution to the sport catch in the Strait of Juan De Fuca (catch area 5,6) showed a steady increase for brood years after 1980 (Figure 5). Some of this may be a result of increased effort; however, increased effort normally is in response to increased catch.

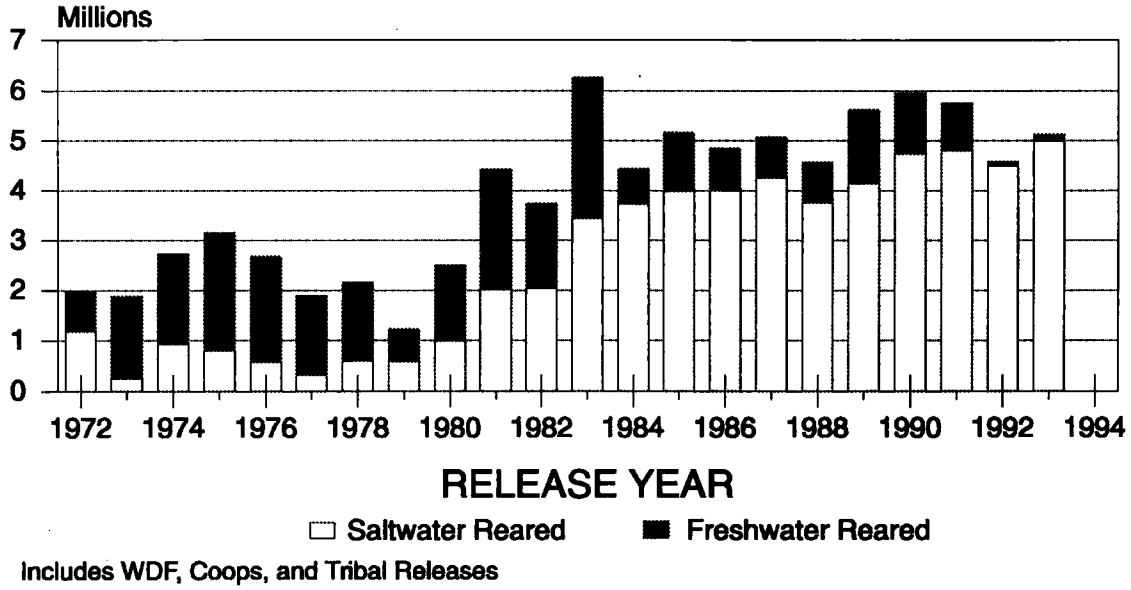

Figure 3. Number of delayed release coho salmon released from Puget Sound hatcheries by release type

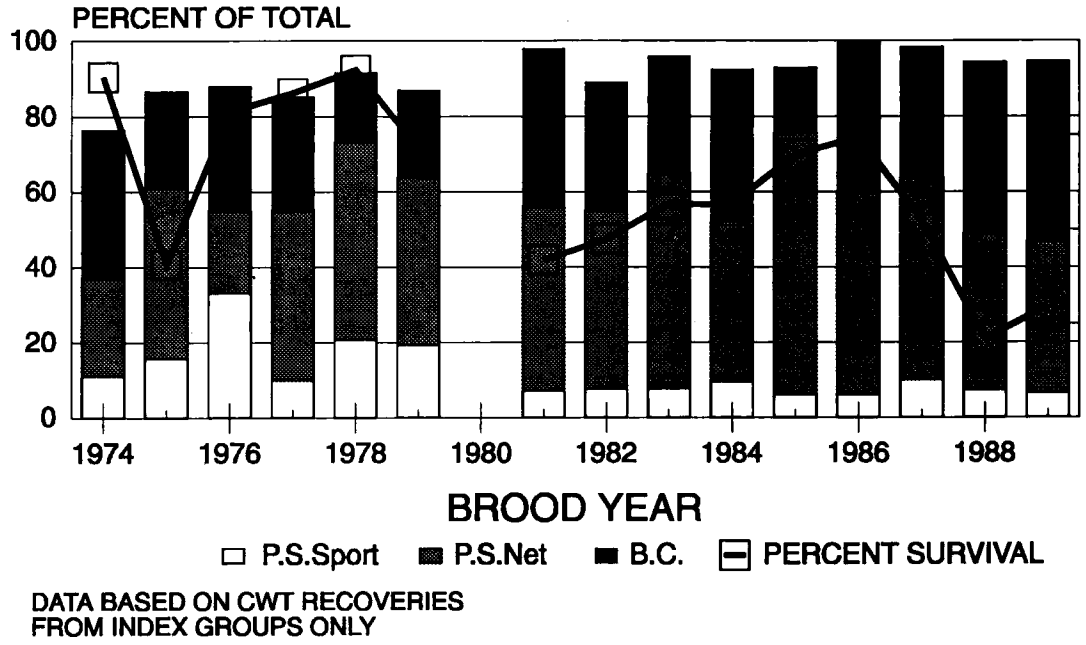

Figure 4. Percent Squaxin Island coho contributed to selected fisheries

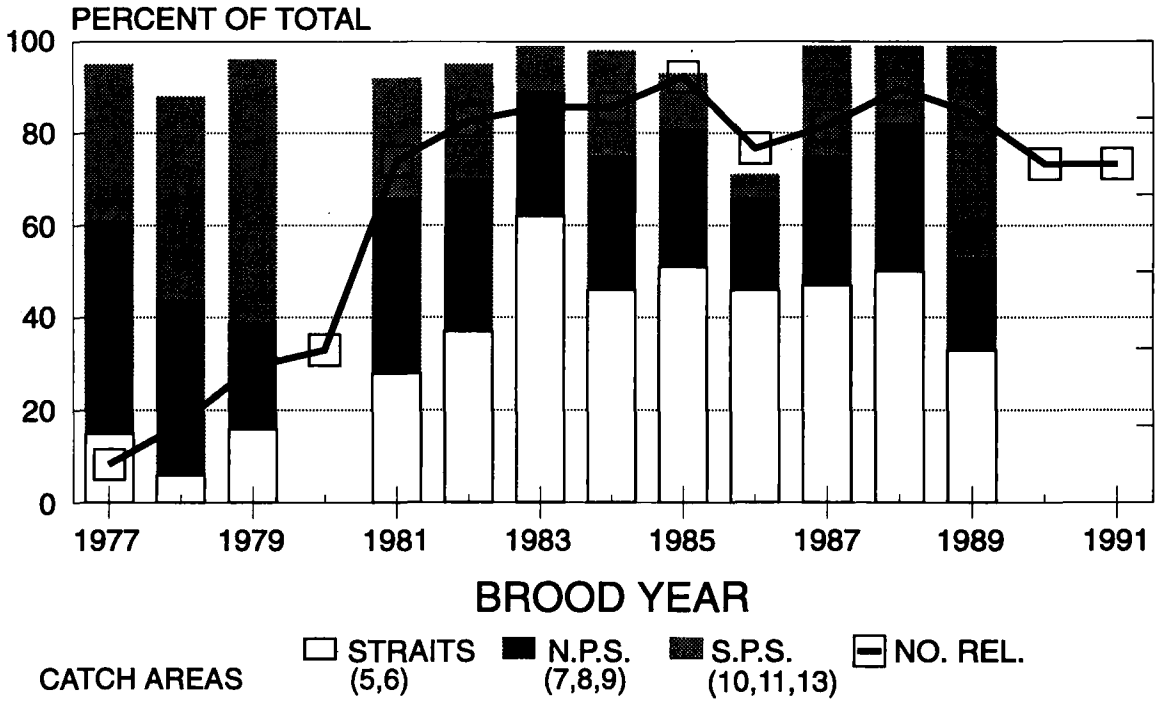

Figure 5. Change in sport catch of Squaxin coho by catch area over time

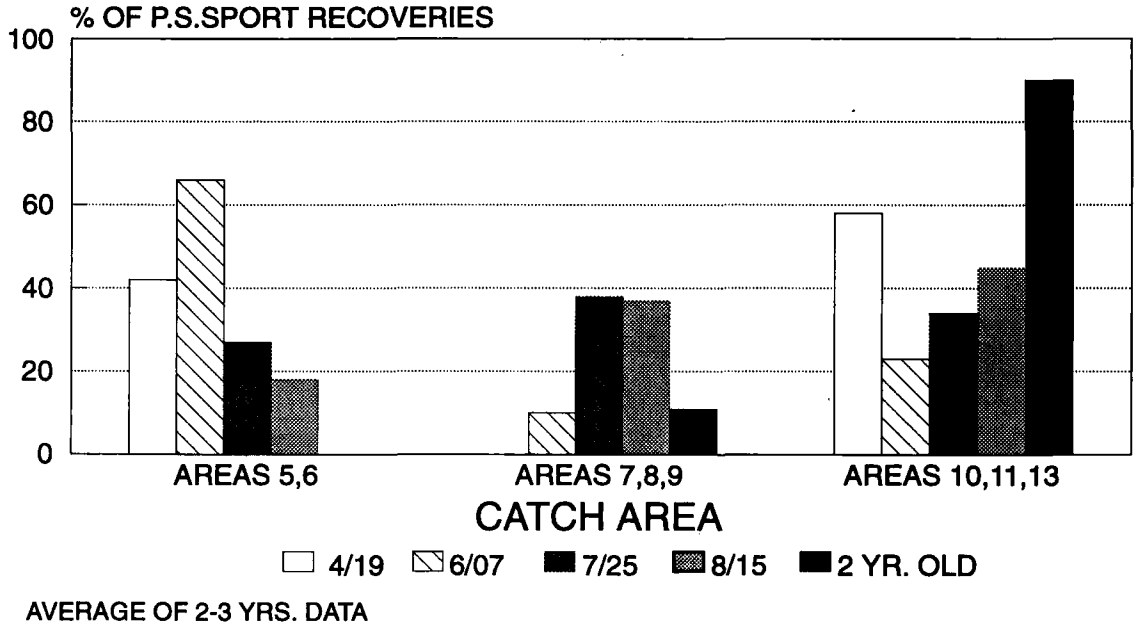

Figure 6. Average Puget Sound sport catch of 1986-1988 brood SSNP coho

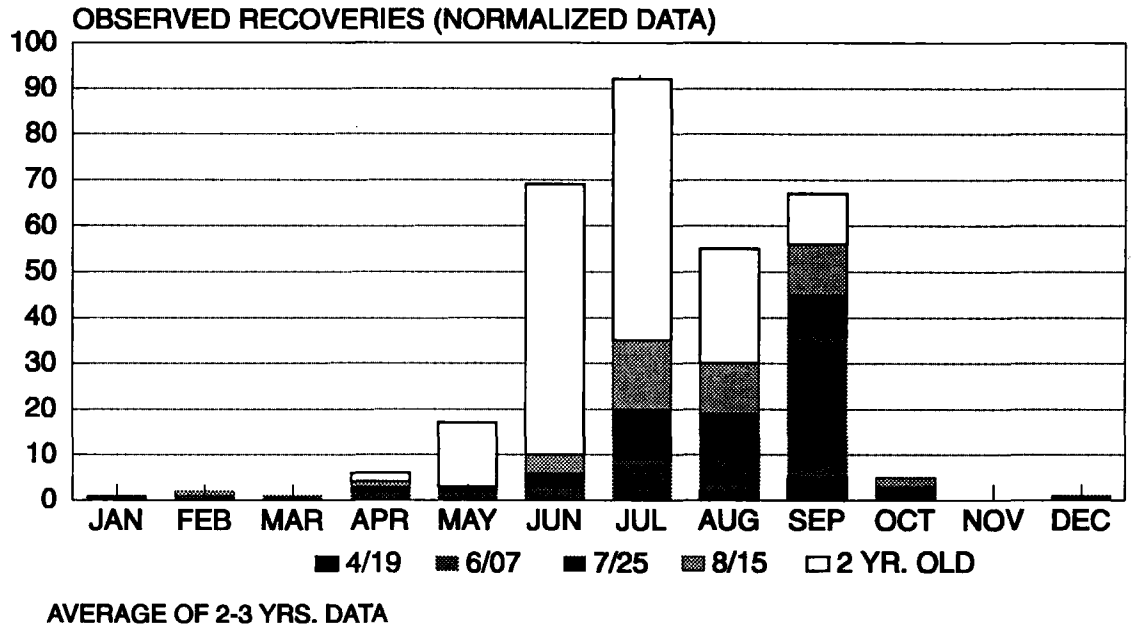

Figure 7. Average Puget Sound sport catch of 1986-88 brood SSNP coho

We believe these data show a change in the behavior of these fish, possibly in response to an environmental factor. From a practical standpoint, this change in migration pattern is cause for concern because of the impact on total harvest. The mixed stock nature of the Straits sport catch requires limits on the total number of fish caught (quotas). Citizens are forced to forego harvest of the delayed release coho while they remain in this area. Furthermore, the increased harvest by British Columbia fishers represents a direct loss to local fisheries.

Results of the date-of-release experiments show the control groups continuing to produce fish that contribute more heavily to the Straits sport catch and catches in British Columbia (Figures 6 and 7). Contributions to inner Puget Sound by the control groups were, for the most part, limited to late summer and early fall. Catches at this time indicate harvest of returning adults, not residents. A cursory analysis indicated a change in catch distribution for groups released later (in July and August), indicating that additional extended rearing did increase the contribution to the inner Puget Sound sport catch, especially catch areas 10, 11 and 13. The percent smolt-to-adult survival rate decreased, however, making these later release groups no more effective at putting fish into the targeted fishery than the controls. One treatment group, the 2-year-old smolts, did show strong contributions to central and southern Puget Sound (catch areas 10, 11 and 13), as shown in Figure 7. This group was reared an additional 10 months before release. While total smolt-to-adult survival was better than for yearling smolts from the same brood year, it was lower than expected, ranging between 5 percent and 15 percent. Even with these lower-than-expected survival rates, the high contribution rates to the inner Puget Sound sport catch made this an effective alternative to the normal program.

Our background investigations did uncover one variable that correlates well with the change in catch distribution of these fish. Production numbers were doubled between the 1979 and 1980 brood years and appear to coincide with the shift in distribution (Figure 5). Unfortunately the 1980 brood from SSNP was not tagged because of budget restrictions. The data for the 1981 brood forward show the change in catch distribution just discussed. Broods before 1980 (when production from SSNP was around 1 million fish) show the typical distribution.

Chinook

Our original analysis of the historical production yielded a great surprise. Production of yearling fall chinook had dropped by more than 50 percent from its historic high (Figure 8). A number of issues were identified as possible causes for the drop in production. We believed significant losses to predation (mostly by birds) and a general degrading of the watersheds that supplied rearing water to several of the south sound facilities forced a reduction in the rearing program. When combined, these factors significantly reduced the number of yearling fall chinook produced. This change in production correlates well with the decreasing sport catch of chinook in south Puget Sound, especially catch areas 11 and 13. Because the drop in catch appeared closely linked with production, emphasis was placed on quickly increasing production. This emphasis created the desire to use the SSNP complex for additional rearing space.

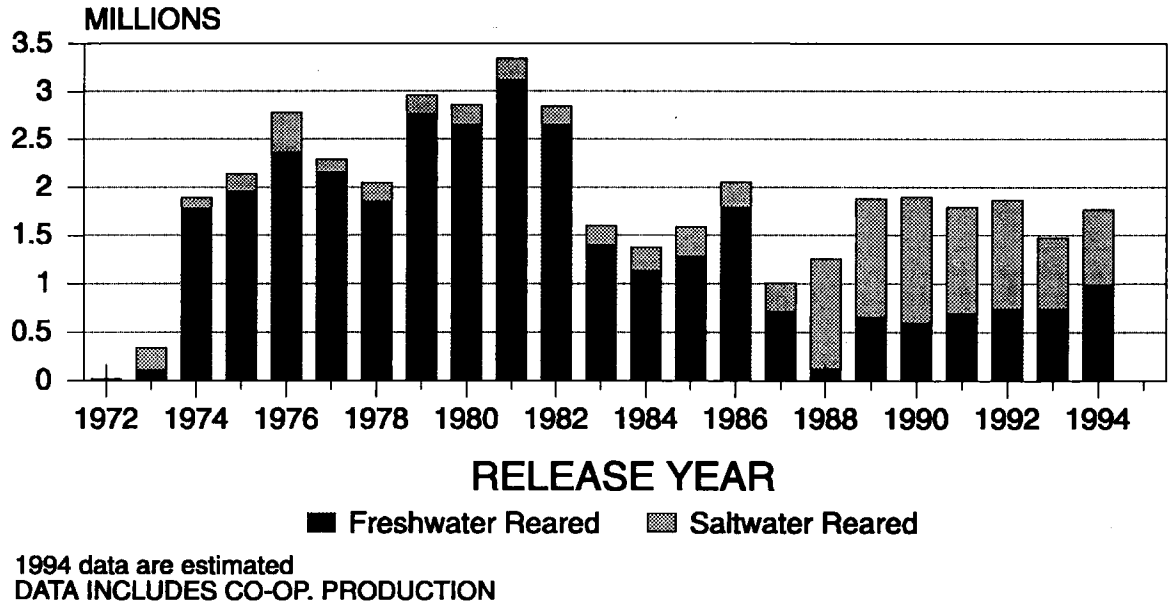

Figure 8. Number of yearling fall chinook released in Puget Sound by release type

Survival and catch distribution data from CWT recoveries of fish from both rearing sites are displayed in Figures 9 and 10. Three results became evident: 1) Smolt-to-adult survival from freshwater-reared fish appeared lower than historical averages (1.6 percent vs 4.0 percent-6.0 percent). 2) Survival of the saltwater-reared fish appeared to be lower than that of freshwater-reared groups (0.77 percent vs 1.6 percent). We have no explanation for this difference in survival. Ongoing research is addressing this difference; however, we have not yet identified the cause. 3) The catch distribution of fresh- and saltwater-reared fish is similar to historic values. That is, while smolt-to-adult survival had decreased, the distribution of these fish appears to have remained the same.

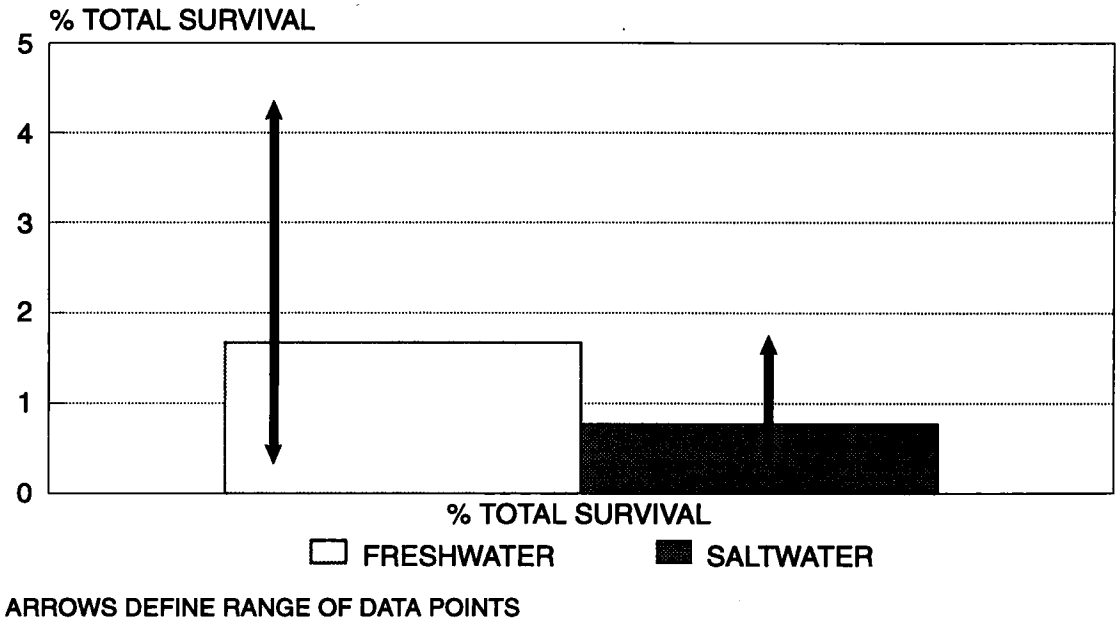

Figure 9. Results of 1986-1989 brood chinook rearing study

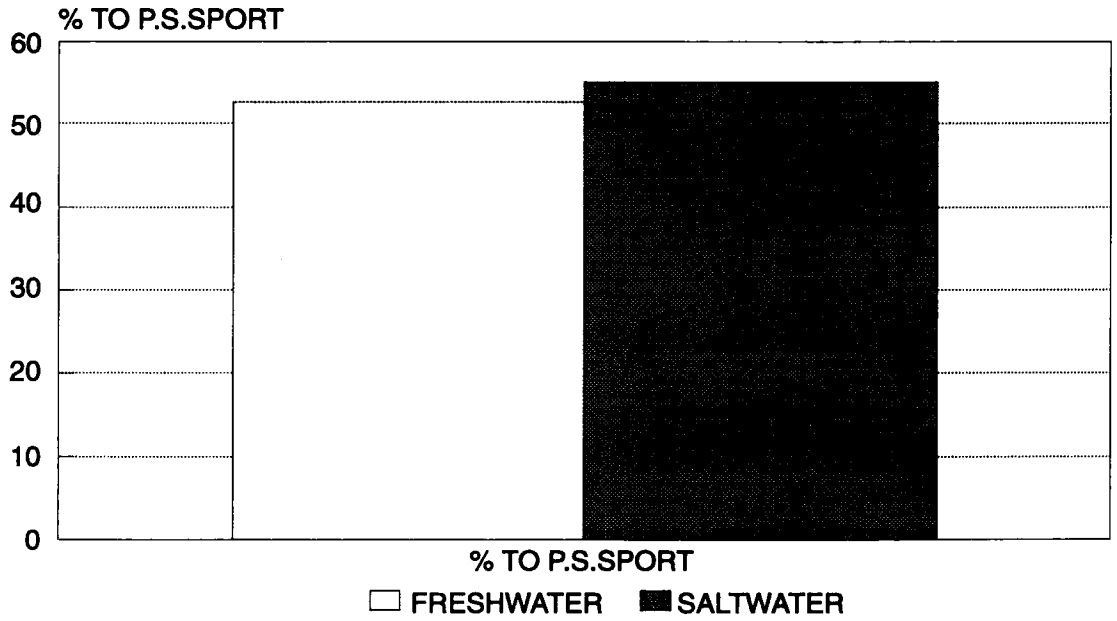

Figure 10. Results of 1986-1989 brood chinook rearing study

SUMMARY

We have identified changes in survival of chinook and distribution patterns of coho salmon resulting from extended rearing in Puget Sound. During the mid to late 1980s, delayed release coho shifted their migration pattern north and westward, while maintaining high smolt-to-adult survival. Yearling chinook populations maintained historic distribution patterns but suffered from poor smolt-to-adult survival.

We believe the changes identified in resident salmon populations represent species-specific responses to a reduction in abundance of prey species in inner Puget Sound. While quantifiable data supporting this supposition are lacking, circumstantial data abound. Data on Pacific herring (*Clupea harengus pallasi*) in central and southern Puget Sound indicate a decreases in biomass of local populations during the mid to late 1980s. These data, coupled with field observations, suggest overall productivity was below expectations during these years.

Beginning in 1992, informal field observations suggested increased numbers of juvenile Pacific herring and juvenile sand lance (*Ammodytes hexapterus*) in this region. Preliminary data indicate a corresponding increase in catch of resident chinook and coho during 1992, 1993 and 1994. Future recoveries of CWT fish will verify these findings.

Currently, no definitive explanation for the change in prey abundance or change in performance of resident salmon can be offered. Attempts to correlate changes in survival and catch distribution with El Niño events (ENSO), indices of freshwater runoff in Puget Sound, sea surface temperature or hatchery production levels have been only partially successful.

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FACTORS AFFECTING THE PRODUCTION OF CHINOOK AND COHO SALMON IN THE STRAIT OF GEORGIA

Richard Beamish and Brian Riddell[1]

ABSTRACT

The abundance changes that occurred in the chinook catch in the Strait of Georgia occurred for natural reasons and because of harvest rates that were too high. Now this statement is not all that new and probably applies to most situations where there have been major changes in abundance. The important message is that efforts to "rebuild" stocks need to be tailored to the carrying capacity of the marine environment. This is difficult for some to accept because we have not yet been able to sort out and agree on the underlying mechanisms that are regulating the abundance of chinook and coho in the strait.

Total catches of chinook in the Strait of Georgia (sport and commercial) averaged 284,000 pieces from 1952 to 1969. Beginning in the 1970s, catches increased rapidly to a maximum of 775,000 in 1976 and then averaged 755,000 from 1976 to 1978. The reasons for the increase are unknown, but the increase is associated with declines in average size and probably represents an increase in abundance as well as an increase in fishing effort. Beginning in 1979, catches declined steadily to 175,000 in 1987 when new regulations limited the catch. From 1987 to 1991 catches averaged 168,000. At the same time the average weight of individuals in the catch increased. The reasons for the size increase are unknown but could be related to declining abundance. There were a number of regulation changes at the time as well.

Using the otolith microstructure to identify hatchery and wild smolts, we found there are about twice as many smolts as in the late 1970s, but the catch is only about one-quarter of the 1976-1978 catch. This indicates that there was an eightfold reduction in marine survival, which is exactly what we see in the hatchery survival data.

At exactly the same time as the abrupt decline in catch started and the abrupt change in the marine survival of hatchery-reared fish occurred, there was a shift in the climate and ocean regime in the Strait.

The increase in bottom and surface temperatures represent a significant step up in the time series (intervention analysis). The average increase of about 0.5°C for the bottom water and 0.7°C for the surface water represents a significant change to the ecosystem. At the same time the flows from the Fraser River had been declining. The decline since 1976 has been almost 25 percent. Also, the April discharges have been increasing relative to the total annual flow.

At this time we can only compare the synchrony of the change in abundance and the change in the ocean environment. We cannot identify the changes that would directly result in reduced survival of chinook salmon, but I think there is strong circumstantial evidence to indicate that the decline in chinook abundance was associated with a change in the environment in the Strait.

Our results indicate that the marine environment can have a major effect on annual chinook production, but the average capacity of the marine environment to produce chinook changes over time remains an important topic for investigation. It may also be critical to our efforts to conserve chinook salmon in the face of increasing human population size, and possibly, changes in climates (for example, what is the appropriate harvest rate, what is the role for hatchery production, etc.).

We believe our study indicates that management of chinook requires an understanding of fishing effects and ocean effects. When the productivity changed in the late 1970s, the management required was a reduction in harvest rate. But did we need the large increases in smolts? It is clear that the consequences of not considering the marine environment can be important in terms of the costs of rebuilding programs and the expectations of all the people responsible for managing and using the resource.

[1] Department of Fisheries and Oceans, Biological Sciences Branch, Pacific Biological Station, Nanaimo, B.C. V9R 5K6 Canada

PUGET SOUND RESEARCH '95

SESSION 9A

MEASURES OF CONTAMINATION AND BIOLOGICAL EFFECTS

Session Chair:

Ed Long
National Oceanic and Atmospheric Administration/National Ocean Service

THE INFLUENCE OF A MARINA ON FECAL COLIFORM BACTERIA LEVELS IN CLAMS

Valerie I. Cullinan and Eric A. Crecelius[1]

INTRODUCTION

A survey of fecal coliform bacteria in littleneck clam (*Protothaca staminea*) tissue was conducted to evaluate the influence of the construction and increased use of a marina on fecal coliform levels in the pristine waters of Sequim Bay on the Olympic Peninsula, Washington. The Sequim Bay watershed is classified as AA-Extraordinary, which defines the bay as suitable for all beneficial uses by Washington's water quality standards (Department of Social and Health Services, WAC 173-201). Water quality standards are based on fecal coliform bacteria, temperature, oxygen, and pH levels, which are monitored regularly by the departments of Ecology and Social and Health Services.

The current estimated annual economic value of shellfish in Sequim Bay is more than $170,000. Only 25 percent to 30 percent of usable subtidal clam beds, however, are commercially harvested. There are also opportunities for increased commercial harvest of crabs and oyster culturing. The economic value of tourism is estimated at more than $125,000. The shellfish industry has the potential for significant economic growth, but population growth and the resulting increase in non-point pollution could threaten water quality and suitability of the shellfish for human consumption. The state of Washington requires the Port of Port Angeles, the marina operator, to monitor levels of fecal coliform and assess the marina's impact on water quality in the bay. This study was conducted to determine whether the marina caused increased levels of fecal coliform bacteria in Sequim Bay.

Fecal coliform bacteria are indicator organisms that may be associated with viral, bacterial, and parasitic pathogens that can cause a variety of serious illnesses. Fecal coliform bacteria originate only in the intestinal tracts of warm-blooded vertebrates (Levitan, 1991). Consequently, the major source of this type of bacterial contamination is human sewage and animal or bird fecal matter in the water. Survival of fecal coliform in water, however, is greatly influenced by temperature. Faust et al. (1975) showed that at 9°C (the average for Sequim Bay), multiplication of bacteria is slow and that a 50 percent reduction in viable cells could occur in slightly less than three days.

Shellfish feed by filtering microorganisms from large quantities of water; their uptake and elimination of fecal coliform bacteria and microbial pathogens vary by species, contaminant, and season (Richards, 1988). Littleneck clams have been shown to concentrate *Escherichia coli* in their tissues at levels on average 10 times greater than those in the water (Presnell et al., 1963). Depuration in clean water during the summer and fall may occur within 48 hours but can take more than 96 hours in the winter (Beck et al., 1966).

METHODS

Fifteen to 45 littleneck clams, *Protothaca staminea,* were collected from six locations in Sequim Bay on the Olympic Peninsula, Washington, at approximately two-week intervals from October 1977 through October 1992 (Figure 1). Sampling began before the construction of the marina in 1984 at Pitship Point. Fecal coliform counts were made following the procedures adopted by the U.S. Food and Drug Administration for shellfish (APHA, 1971) and are expressed as most probable number (MPN). Fecal coliform levels above 230 MPN/100 g shellfish tissue are unacceptable for the marketing of fresh and frozen oysters according to the Public Health Service under the National Shellfish Sanitation Program (DHEW, 1965).

[1] Battelle/Marine Sciences Laboratory, 1529 West Sequim Bay Road, Sequim, WA 98382

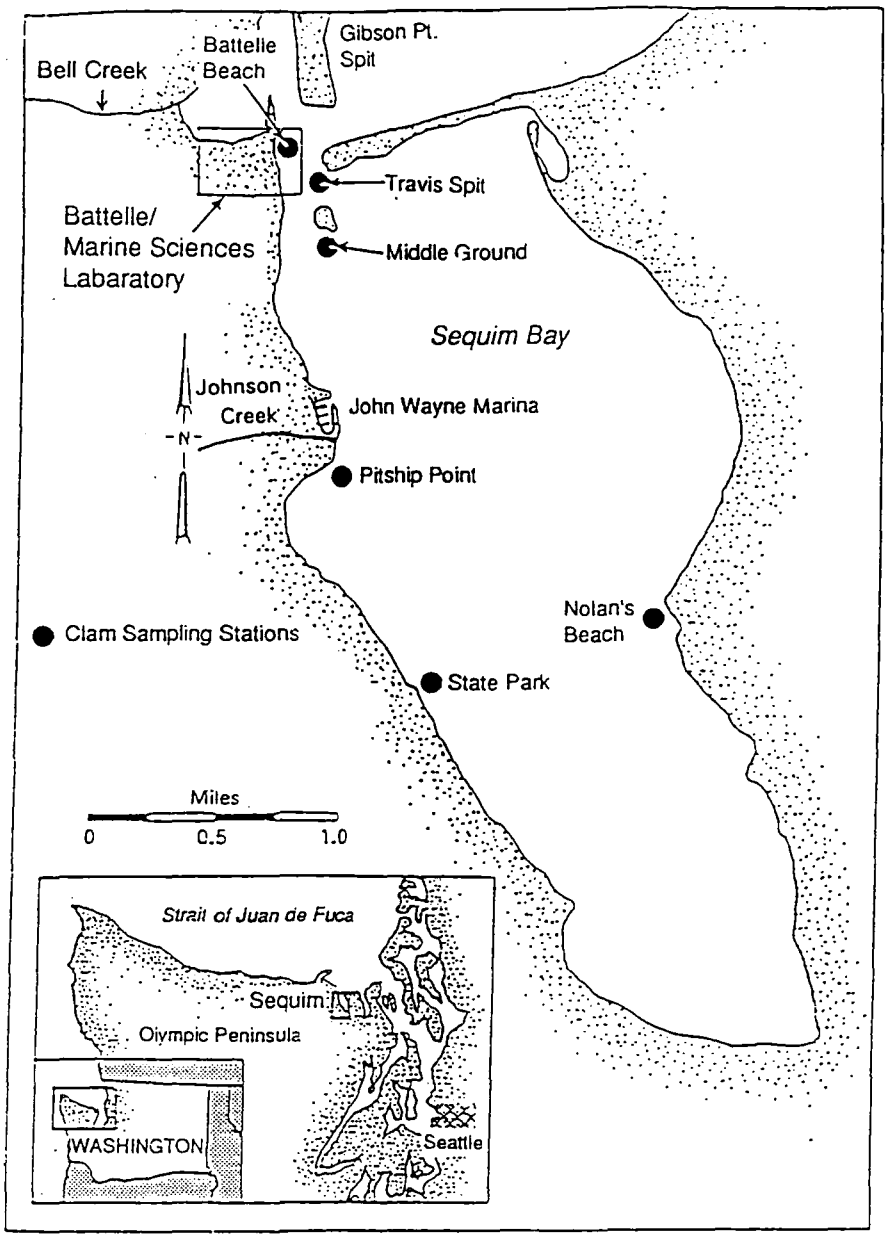

Figure 1. Clam sampling stations in Sequim Bay

Raw fecal coliform counts represented as MPN per 100 grams of wet tissue were transformed to a fecal coliform score based on the magnitude of the MPN in order to evaluate seasonal and yearly variation in contamination. MPNs equal to 20 or less were given a score of 1, which represents levels of fecal coliform below detection; MPNs greater than 20 and less than 230 were given a score of 2, which represents levels of fecal coliform detected but below a level of concern; and MPNs of greater than or equal to 230 were given a score of 3, which represents levels of fecal coliform signaling a potential threat to public health via shellfish consumption. This numerical transformation of MPN data, which varied from less than 19 to

24,000, facilitates interpretation of the results. Local environmental factors may greatly influence the magnitude of the MPN over short time periods and distort seasonal and yearly variation.

The distribution of fecal coliform scores were evaluated for each site using histograms of all of the data from 1977 to 1992 and for each year individually. The histograms are useful for the development of hypotheses regarding potential cause of contamination. Seasonal data were created by averaging the MPN scores from three consecutive months; February, March, and April, for example, are averaged and denoted as spring. Note that January is pooled with November and December of the preceding year to create the winter seasonal average for each year. For example, the winter of 1977 includes November and December of 1977 and January of 1978. Thus all plots of yearly averages contain February through December of that year plus January of the next.

For each site, the means for each season were compared using a one-way analysis of variance using the average MPN score with successive years as replicates. Seasons were created by pooling data from three consecutive months as described above. A chi-square analysis of goodness-of-fit was used to test the null hypothesis that the probability of having a MPN score within a given class is the same for all sites.

Fecal coliform counts were also determined in Bell Creek water from 1986 to 1992 by Clallam County. Bell Creek enters the mouth of Sequim Bay at the northern end of Battelle Beach (Figure 1). This creek drains farmland used primarily for grazing cattle, and the creek is a major contributor of fecal coliform bacteria to Sequim Bay (Brastad et al., 1987). Farming practices were changed between 1985 and 1990 to reduce fecal contamination of the creek. Grab samples of creek water were collected approximately weekly between September 1986 and May 1987, then monthly between August 1987 and March 1989. Between April 1989 and March 1992, 14 samples were collected. The sampling location in Bell Creek was approximately 1 km from the Battelle Beach site. The concentrations of fecal coliform bacteria in creek water samples were determined by the membrane filtration (MF) technique, Standard Methods No. 909 (APHA, 1971).

In order to correlate possible seasonal patterns in Bell Creek fecal coliform levels with those in clams from Sequim Bay, the raw MF counts represented as counts per 100 mL were also transformed to a fecal coliform score based on the magnitude of the MF counts. The creek water raw fecal coliform counts were given scores of 1 for samples containing less than 500 counts, a score of 2 for 500 to 999 counts, and a score of 3 for greater than 999 counts. These score assignments were chosen to reflect the distribution of raw MF counts, which had two distinct modes and were heavily skewed to the right with values ranging from 30 to 86,000. Fecal coliform bacteria levels greater than 50/100 mL exceed Class AA water quality standards.

RESULTS

A histogram of the percent of MPN scores obtained from 1978 through 1991 in each of the three categories (i.e., MPN $\geq$ 230, 20 < MPN < 230, and MPN $\leq$ 20) shows that slightly more than 10 percent of Battelle Beach shellfish could result in a threat to human health via shellfish consumption. For all of the remaining sites, including the marina (Pitship Point), less than 5 percent out of 339 observations were in the highest MPN value category. Only slightly more than 30 percent of observations from the marina were above detection.

At Battelle Beach the proportion of MPN scores greater than 230 rose sharply in 1980 to slightly more than 30 percent (out of 25 observations per year) but has declined to approximately 5 percent since 1988. Travis Spit and Pitship Point each had the second highest maximum annual proportion of MPN scores greater than 230, which was four of 24 samples (17 percent) in 1980 and 1987 for Travis Spit and the marina, respectively. The proportion of MPN scores greater than 230 for all other sites and years remained less than or equal to two of 24 samples (12 percent). For all sites except Battelle Beach and Travis Spit, results were below the detection level for at least 50 percent of the observations for at least 12 out of the 14 years. For Sequim Bay State Park and Nolan's Beach sites, at least 72 percent of the observations were below detection for at least 11 of the 15 years sampled.

A plot of the average MPN score for each month and clam sampling location (maximum n = 25, pooled s = 0.51) showed that only the Battelle Beach site had a strong seasonal pattern (Figure 2). Battelle Beach average MPN scores show a sharp increase starting in March, followed by a slow decline after June. The average MPN scores remain low (<1.5) for November through March. The average 95 percent confidence interval for each of the mean scores is ±0.2.

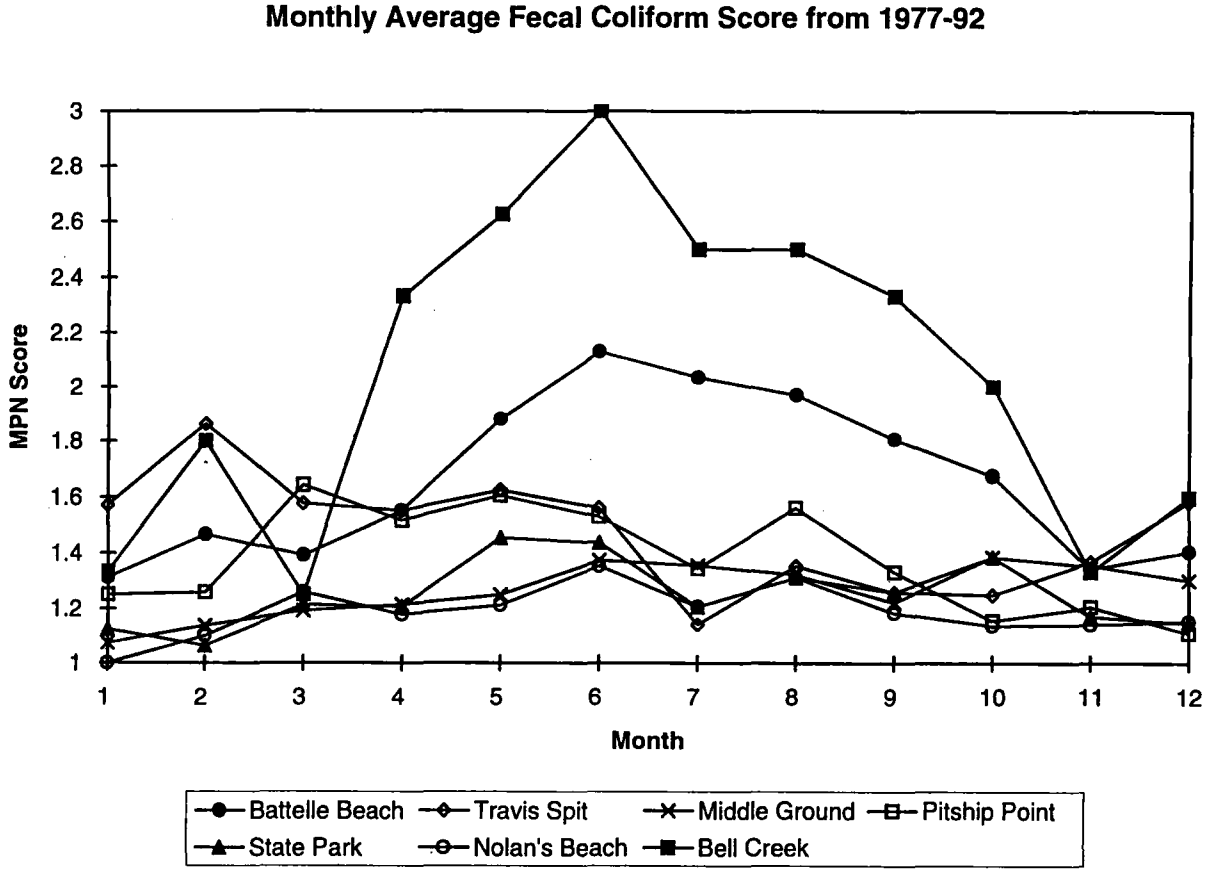

Figure 2. Average monthly most probable number (MPN) score for clam tissue at each site (a 95% confidence interval about each mean is ± 0.2) [The Bell Creek data are water samples collected between 1986 and 1992.]

The fecal coliform results for Bell Creek, covering the time period of 1986 to 1992, are also plotted on Figure 2. The Bell Creek data indicate a strong seasonal pattern ($p < 0.02$) similar to the pattern observed in clams from Battelle Beach ($r = 0.934$, $n = 12$). An average 47 percent decrease in fecal coliform scores was observed between the summer and winter seasons.

Travis Spit, Pitship Point, and the state park displayed a minor seasonal pattern. Battelle Beach averaged a 33 percent decrease from summer to winter. Travis Spit averaged a 22 percent decrease from spring to fall, and Pitship Point averaged a 21 percent decrease from summer to winter. The state park averaged a 17 percent decrease between winter and summer. All of these seasonal differences are statistically significant ($p < 0.05$). However, only Battelle Beach has a significantly greater number of MPN scores that exceeded the coliform detection limit than would be expected if the probability of obtaining values in these ranges were equal for all sites ($p < 0.001$; Table 1). Middle Ground and Nolan's Beach did not have a statistically significant seasonal pattern ($p > 0.2$).

Table 1. The observed and expected number of observations in each class for each site of most probable number (MPN) scores. The expected number (in parentheses) is based on the null model of equal probabilities of falling within a class for each site.

	MPN Class			
Site	MPN ≤ 20	20 < MPN ≤ 230	MPN > 230	Total
Battelle Beach	174 (247)	137 (92)	46 (17)	357
Travis Spit	203 (238)	124 (88)	18 (17)	345
Middle Ground	264 (236)	73 (88)	5 (16)	342
Pitship Point	248 (250)	97 (93)	16 (17)	361
State Park	280 (249)	70 (92)	10 (17)	360
Nolan's Beach	295 (241)	44 (89)	10 (17)	349
Total	1464	545	105	2114

DISCUSSION

Classifying MPN scores into categories for analytical purposes removed the observed high variability possibly associated with seal activity and sporadic influxes of sewage or fecal matter. Raw tissue observations taken 14 days apart, for example, varied from MPN values of 24,000 (on June 30, 1987) to less than detected (on July 14, 1987). This type of variability distorts yearly and monthly site means, can cause uncontaminated sites to be misclassified as contaminated, and can mask seasonal patterns.

Sources of fecal contamination for the Battelle Beach site include the Sequim city sewage outfall and cattle in Bell Creek, both just north of the sampling location. Measurements of the concentration of fecal coliform in effluent taken by personnel at the treatment facility from December 1979 through 1991 ranged from less than detectable to 12,500 MPN/100 mL in September 1988. Out of 153 monthly maximum MPN counts (per 100 mL), only 20 percent (or 30) were greater than 100, of which six were greater than 1000. All observations greater than 1000 occurred during mechanical problems. The flow rate averages 0.35 million gallons of effluent per day. A chi-square null hypothesis of equal probabilities of observing values, less than or equal to 100 (below detection), and greater than 100 across seasons could not be rejected, suggesting no seasonal influences on observed MPN values ($p > 0.25$).

A seasonal influence on fecal coliform concentrations at Battelle Beach could be dairy cow access to Bell Creek. Beef cattle are allowed to roam freely all year on two upstream farms, but dairy cattle are kept in barns from October to April, thus removing their access to Bell Creek (Gary Smith, owner of Maple View Dairy Farm located along Bell Creek; personal communication). This management practice corresponds to the rise in both clam tissue fecal coliform counts and Bell Creek fecal coliform counts in April and decline in November (Figure 2). The practice of limiting dairy cattle access to the creek began in 1985, so it is clear that dairy cattle are not the only seasonal influence on fecal coliform concentrations. Fencing along Bell Creek to further reduce access began in 1990, but it is still too early to observe an effect.

Irrigation of residential and farmlands adjacent to Bell Creek may also produce a seasonal influence on fecal coliform concentrations in clam tissues at Battelle Beach. Lands are typically irrigated from mid-April to mid-September, increasing the likelihood that sewage or effluent from cattle and faulty septic systems reaches the creek. Bell Creek drains approximately 3,189 acres, of which 56 percent is animal pasture and agricultural land. The average flow is 5.46 cu ft/sec. Water quality sampling conducted over the last six years in Bell Creek suggests that 90 percent of the fecal coliform loading can be traced to the lower two miles. MPNs in this section of the creek ranged from 1,000 per 100 mL in 1987 to 300 per 100 mL in 1992.

This pattern of high fecal coliform levels in the summer months is unusual in the Puget Sound basin. Typically, fecal coliform levels are highest in the winter months, when saturation of soils allows for surface water runoff that flows across pastures and overloads sewage lagoons, resulting in high fecal coliform

loading to streams. Our results indicate that in relatively low rainfall locations with permeable soils, direct cattle access to streams may be the most important factor in contribution of fecal coliform to streams.

Pitship Point has not shown a significant increase in fecal contamination following marina construction in 1984, indicating that the marina has not influenced this aspect of the water quality in Sequim Bay. Middle Ground, Nolan's Beach, and the state park (with possible exception of the latter) have remained at low levels of fecal coliform contamination, suggesting that activities at these sites are not a threat to shellfish production. Because the state park does display a seasonal pattern in contamination, this site may be of concern in the future if use increases, and if waste treatment capabilities are not maintained in proportion to use.

ACKNOWLEDGMENTS

We wish to acknowledge the Port of Port Angeles, Richard Parker of the City of Sequim, and the Clallam County Department of Community Development for providing data, and Gary Smith for providing a history of farming practices along Bell Creek.

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CONTAMINANTS IN PUGET SOUND MARINE MAMMALS: TEMPORAL, SPATIAL, AND SPECIES-RELATED PATTERNS

John Calambokidis[1]

INTRODUCTION

High concentrations of contaminants have been found in marine mammals from different parts of the world (O'Shea et al., 1980; Reijnders, 1980; Wagemann and Muir, 1984; Risebrough, 1978). Chlorinated hydrocarbons, particularly PCBs and DDT, have been the most widely studied and have attracted the greatest concern. These contaminants have been linked to a variety of disorders in marine mammals (Addison, 1989) including premature births (DeLong et al., 1973; Gilmartin et al., 1976), reproductive failure (Helle et al., 1976a, 1976b; Reijenders et al., 1988), and immunosuppression (Brouwer et al., 1989; De Swart et al., 1994).

Though research on contaminants in marine mammals in Puget Sound has been relatively limited, a number of studies have been conducted since 1972. Concentrations of PCBs in harbor seals from Puget Sound in the 1970s were among the highest reported worldwide (Arndt, 1973; Calambokidis et al., 1984) and were implicated in reproductive problems in Puget Sound seals (Arndt, 1973; Newby, 1973; Calambokidis et al., 1985, 1988). Deaths of gray whales in Puget Sound in 1984 and the 1990s also has raised concern about the role of contaminants in this mortality (Fouty, 1984; Calambokidis, 1992).

I review some of the principal studies that have been conducted on contaminants in marine mammals in Puget Sound and examine patterns in concentrations of chlorinated hydrocarbons among species, among locations, and over time. For consistency, all concentrations reported here are in ppm (mg/kg) in blubber on a wet weight basis, unless otherwise noted.

REVIEW OF STUDIES CONDUCTED

Harbor Seals

Contaminants concentrations have been examined in Puget Sound harbor seals starting in 1972. Arndt (1973) determined concentrations of DDT and PCBs in the blubber and liver of 32 harbor seals from three sites in 1972. Calambokidis et al. (1978, 1984) reported on concentrations of PCBs and DDT in the tissues of 73 harbor seals as well as analyses of a broader range of contaminants including metals and trace elements in the tissues of 15 animals. Some limited analyses of contaminants in blood have also been conducted (Kopec et al., 1991).

Concentrations of PCBs were highest among the chlorinated hydrocarbons and ranged up to 750 ppm in blubber. Concentrations of PCBs and DDT varied significantly by region, age class, and sex. Highest concentrations of both PCBs and DDT were found in southern Puget Sound with lower concentrations in Hood Canal, the waters north of Puget Sound (Strait of Juan de Fuca and San Juan Islands), and the Washington outer coast (including Grays Harbor) (Table 1). Within each region, concentrations were highest in adult males and lowest in pups, with intermediate concentrations in subadults and adult females. Chlorinated hydrocarbons increased with age in adult males, but not adult females because females were able to purge some of the contaminants through trans-placental transfer and lactation.

PCB concentrations in the blubber of adult male harbor seals were 50 to 100 times higher than the concentration (by lipid weight) in the prey they were consuming in two different regions (Calambokidis et al., 1984). This reflected the high proportion of the contaminants these seals were absorbing from their prey and their limited ability to excrete or metabolize these compounds.

[1] Cascadia Research, 218½ W. 4th Ave., Olympia, WA 98501

Table 1. Mean concentrations of PCBs and DDE in blubber of harbor seals from 1972-81 (from Calambokidis et al., 1984)

	Pups			Subadults			Adult Males			Adult Females		
	n	PCB	DDE	n	PCB	DDE	n	PCB	DDE	n	PCB	DDE
S. Puget Sound	7	76.8	9.4	10	217.8	18.6	3	242.7	17.5	1	20.5	1.3
Hood Canal	7	13.2	2.0				2	93.2	12.8			
Straits & San Juans	7	9.8	2.8				2	26.8	9.5			
Outer Coast	8	11.0	5.0	13	16.0	9.4	6	26.4	12.8	7	24.4	9.0

Calambokidis et al. (1991) examined trends in contaminants concentrations in the blubber of harbor seal pups from two regions of Puget Sound using previous data going back to 1972 as well as new samples from 1990. There was a significant decline in both PCBs and DDT concentrations in harbor seal pups in southern Puget Sound over the 18-year period (Figure 1). Concentrations from a site in the Strait of Juan de Fuca also declined significantly, but only when other covariates (blubber thickness and age in days) were included in the regression model.

As in previous studies, the concentrations of PCBs and DDT were significantly higher in the pups collected in 1990 from southern Puget Sound than in those from the Strait of Juan de Fuca (Calambokidis et al., 1991). Concentrations of metals and trace elements, however, did not follow the same pattern. Most showed no significant difference by site, and lead and silver were significantly higher in seals from the Strait of Juan de Fuca than in those from southern Puget Sound.

Killer Whales

Concentrations of contaminants in killer whales that have died in waters off Washington, British Columbia, and Alaska have been examined by several groups in the United States and Canada. Calambokidis et al. (1990) compiled information on contaminants in 16 killer whales that died between 1976 and 1989. Concentrations of PCBs in blubber ranged from 0.9 to 250 ppm and total DDTs from 1.7 to 640 ppm. Average concentrations were higher in adult males compared to other age and sex classes, as well as higher in animals from transient pods (known to feed on other marine mammals) compared to animals from resident pods (known to feed on fish), although the differences were not statistically significant (Figure 2).

Unlike harbor seals, with killer whales spatial and temporal trends were not apparent. The two killer whales found dead in Alaska, for example, showed dramatically different results. An adult female had relatively high concentrations of PCBs and DDE (71 and 125 ppm in blubber) while an adult male had very low concentrations (0.93 and 1.7 ppm). Also unlike harbor seals, in killer whales levels of DDT compounds were higher than PCBs, indicating these animals were primarily feeding outside the greater Puget Sound region (where PCBs predominate) or feeding on prey that came from outside this region. This is consistent with resident killer whales feeding primarily on salmon and transient killer whales feeding on other marine mammals outside this region (Bigg et al., 1987).

Harbor Porpoise

Concentrations of PCBs and DDE were examined in harbor porpoise stranded and entangled in nets from along the coasts of California, Oregon, and Washington to examine the discreteness of harbor porpoise populations (Calambokidis and Barlow, 1991). These studies revealed distinct differences in contaminant concentrations and ratios among regions. The most dramatic pattern was a consistent increase in concentrations of DDT compounds with proximity along the coast to the Southern California Bight.

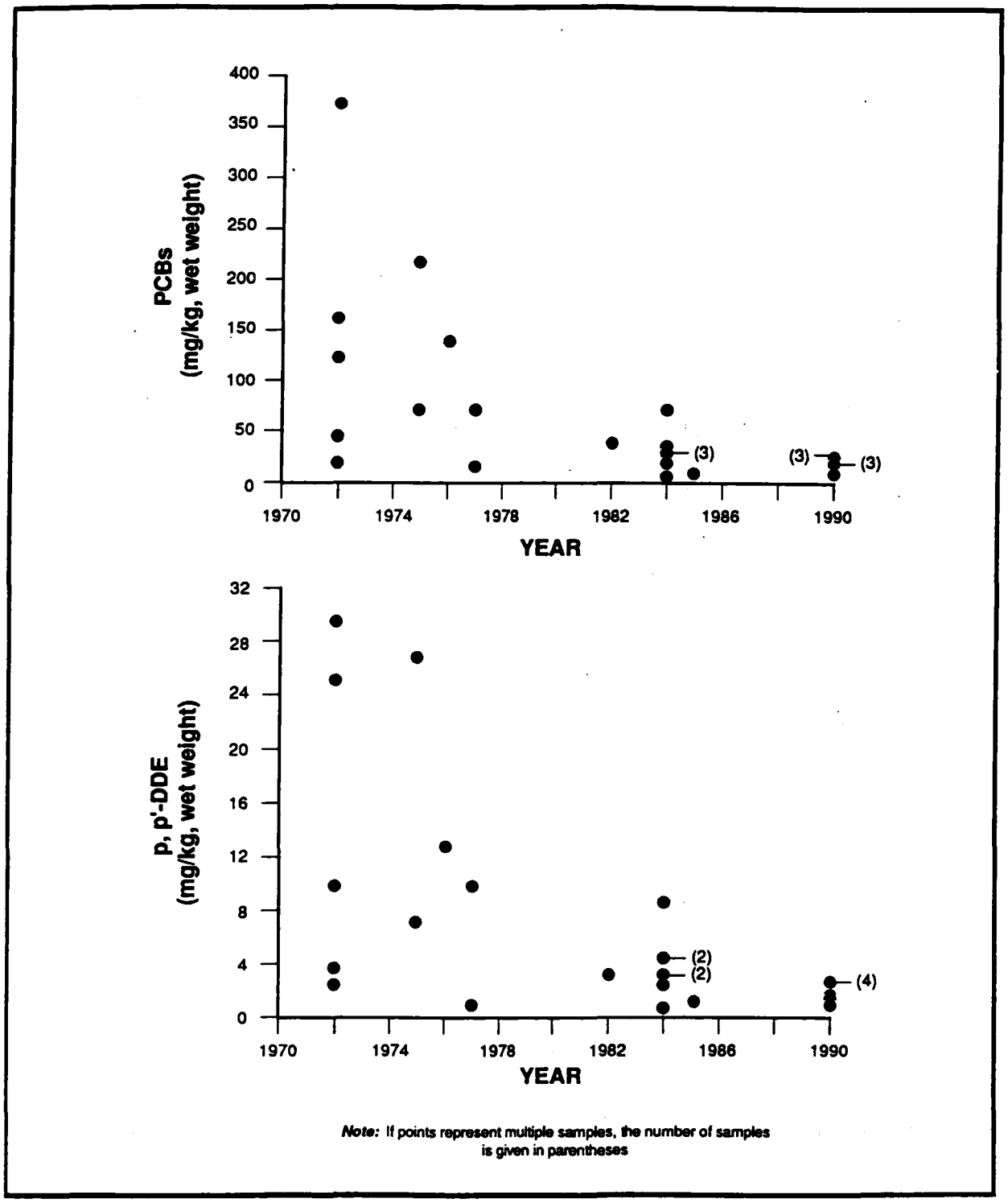

Figure 1. Temporal changes in PCB and DDE concentrations in blubber of southern Puget Sound harbor seal pups (from Calambokidis et al., 1991)

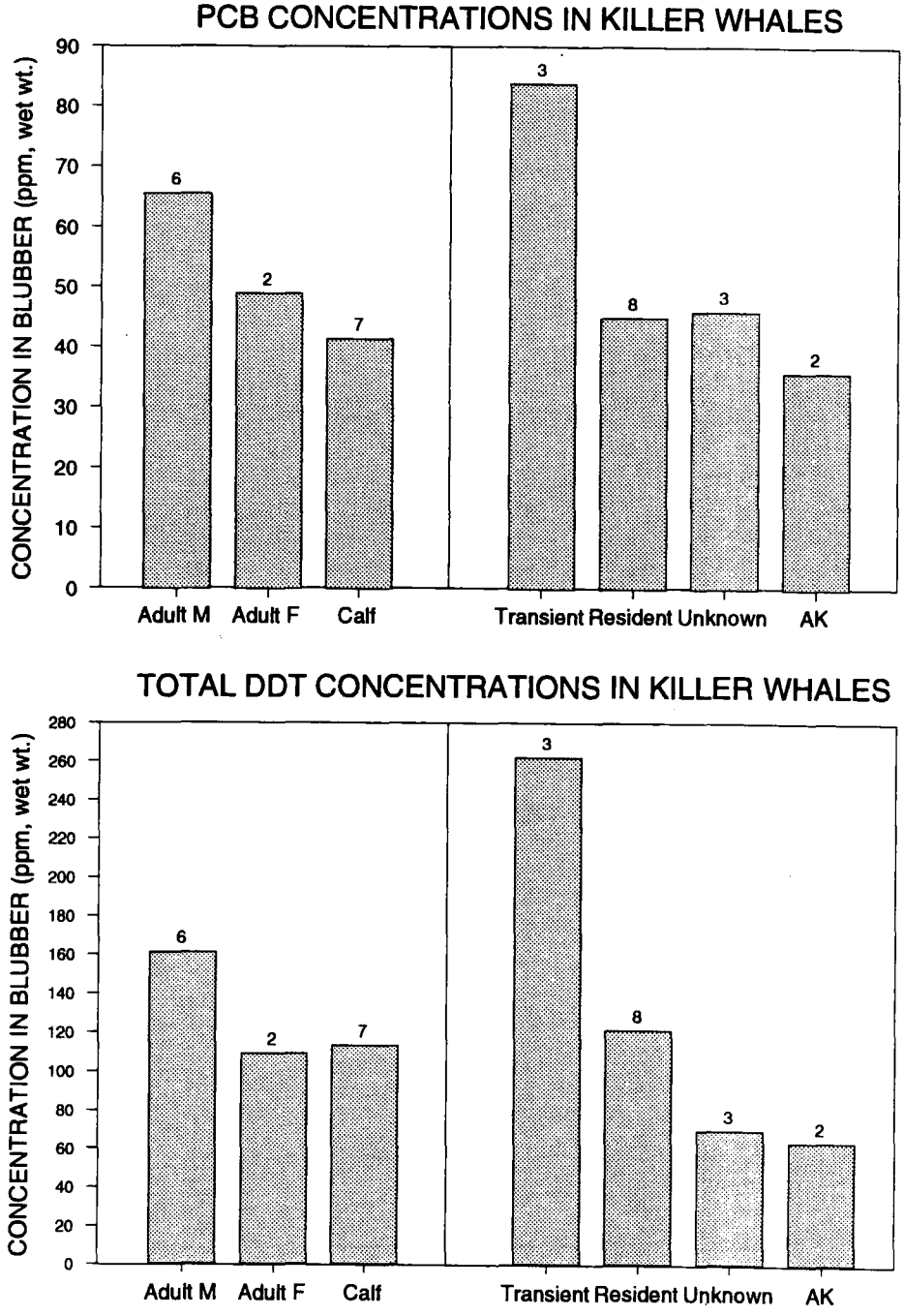

Figure 2. Mean concentrations of PCBs and DDT in killer whales by age class, sex, and pod type (from Calambokidis et al., 1990)

Eight of the samples from these studies were from Washington, including one from Puget Sound. Additionally, Calambokidis et al. (1984) report on contaminant concentrations in two harbor porpoise from the Puget Sound area. Among these 10 samples from Washington waters, concentrations of PCBs in blubber ranged from below 1 ppm in an animal recovered on the Washington coast to 55 ppm in the only

animal recovered from southern Puget Sound. Concentrations of DDT compounds ranged from less than 1 ppm, from the same harbor porpoise with low PCB concentrations, to 26.7 ppm in both an outer coast harbor porpoise and one from northern Puget Sound.

Gray Whales

Fears about the role of contaminants in deaths of gray whales in Puget Sound (Fouty, 1984; Malins et al., 1984; Calambokidis, 1992) has prompted research on contaminant concentrations in stranded gray whales. Varanasi et al. (1993) reported on concentrations of a broad range of contaminants in tissues of 22 gray whales that died in California, Washington, and Alaska. Concentrations of chlorinated hydrocarbons were generally low, with levels of PCBs in blubber ranging from 0.1 to 10 ppm and total DDT from 0.01 to 3 ppm. Concentrations of some trace elements, especially aluminum, in several internal organs were higher than usually found in other species, a finding initially reported by Malins et al. (1984). There were no significant differences in contaminant concentrations, by region, however (Figure 3).

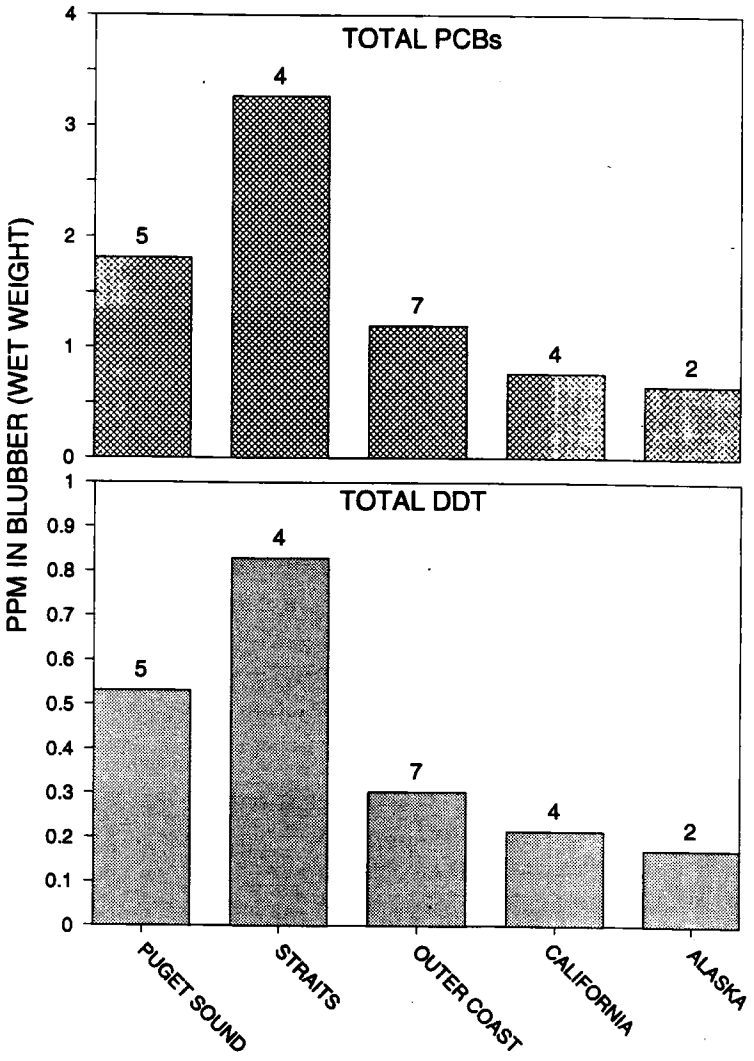

Figure 3. Mean concentrations of PCBs and DDT in gray whales by region (based on data from Varanasi et al., 1993)

The majority of the samples (16) came from animals found dead in Washington waters, and five of these were from animals found dead in Puget Sound. At least four of these animals were known to have spent periods of at least 33 to 67 days in Puget Sound based on biological studies tracking live gray whales (Calambokidis et al., 1992, 1994). Though some gray whales return year after year to the Puget Sound area to feed, the gray whales that died had not been seen previously and therefore appeared to be animals coming to this area for the first time (Calambokidis et al., 1994).

Extremely low lipid (oil) levels were found in the blubber of most of the gray whales that were analyzed. All but one of the gray whales found dead off Washington state had lipid levels of less than 30 percent in blubber, and most had lipid levels of less than 5 percent. Although gray whales had decreased lipid content after their fast during the winter breeding season, these levels are well below those reported in other healthy gray whales sampled during the northbound migration (Rice and Wolman, 1971).

Other Species

A small number of samples from other marine mammals species in the Puget Sound area have been analyzed and reported. Calambokidis et al. (1984) report PCB and DDT concentrations in a few samples from Dall's porpoise, pygmy sperm whale, minke whale, sea lion, and river otter. Concentrations of PCBs

and DDT compounds in blubber were lowest in the minke whale (0.15 and 0.55 ppm, respectively) and the pygmy sperm whale (0.15 and 1.3 ppm, respectively). Concentrations of PCBs and DDT in Dall's porpoise were 9.0 and 5.0, respectively, and in the river otter 6.7 and 0.6 ppm.

OVERALL PATTERNS

Species Differences

Highest contaminant concentrations of chlorinated hydrocarbons have been observed in two species in the Puget Sound area, harbor seals and killer whales. High concentrations in harbor seals were primarily associated with animals found dead in southern Puget Sound. Harbor seals are resident in Puget Sound and feed on fish, sometimes in proximity to urban embayments, where contaminant concentrations are highest. Killer whales, especially transient pods, prey high on the food chain, including feeding on other marine mammals. Even killer whales from Alaska waters had high concentrations of contaminants.

Intermediate concentrations of contaminants were found in harbor porpoise and some of the other small cetaceans (Dall's porpoise) and pinnipeds (sea lions) that have been analyzed. Harbor porpoise may be exposed to lower concentrations of contaminants in part because of their elimination from Puget Sound proper, where they were once common. Most marine mammals other than harbor seals are feeding in Puget Sound only on a seasonal or occasional basis.

Lowest concentrations were found in baleen whales, including gray whales and minke whales. This is consistent with patterns observed world-wide (O'Shea and Brownnel, 1994): Low concentrations of contaminants have been observed in baleen whales because they feed low on the food chain and usually away from areas of highest contamination.

Regional Patterns

Clear regional patterns were apparent only in two species, harbor seals and harbor porpoise. The two species are not migratory and appear to be resident in particular areas. Regional patterns with harbor seals provided that greatest level of detail about geographic patterns of contamination. Concentrations of contaminants, particularly PCBs; were highest in animals found dead in Puget Sound proper compared to Hood Canal, the Strait of Juan de Fuca, or the Washington coast.

No regional patterns were apparent in more migratory species such as gray whales or in species that travel more widely, such as killer whales. Although these whales are not resident to a particular location, some subgroups of both these species show consistent patterns of movement, such as the resident killer whales that have a defined range, or the gray whales that return to specific areas to feed. It is likely that these consistent movement patterns would result in differences in contaminant levels, although this would only be statistically discernable if the movement patterns of the individuals being sampled were known.

Temporal Patterns

There were adequate data to examine temporal trends only in harbor seals. In order to evaluate temporal trends, regional and age/sex differences among animals sampled have to be taken into account. Harbor seal pups consistently sampled from the same sites over almost a 20-year time period have provided clear evidence of decreases in concentrations of some contaminants in Puget Sound.

CONCLUSIONS

Although efforts to examine contaminant concentrations in marine mammals in Puget Sound have been limited, these studies have revealed some important patterns. Studies of the impact of contaminants are best aimed at harbor seals and killer whales, the two species exposed to the highest contaminant concentrations. Monitoring of contaminant trends and patterns is best conducted with harbor seals, where existing data have already demonstrated clear regional and temporal patterns in contamination.

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DEVELOPMENT OF A SCUBA-BASED PROTOCOL FOR THE RAPID EVALUATION OF BENTHIC DEGRADATION DUE TO ORGANIC ACCUMULATION IN THE NEAR SHORE SOFT-BOTTOM HABITAT OF PUGET SOUND

S.A. Miller[1], B.S. Miller[1], G.P. Jensen[1] and H.H. Hill[2]

INTRODUCTION

Infaunal species sampling has been used historically to determine the effects and extent of organic deposition. The analysis of invertebrate samples using this method can be time consuming and prohibitively costly when used for annual monitoring. We hypothesize that environmental impact monitoring and assessment using quantitative and standardized scuba techniques can potentially provide the same information concerning the impacts of organic deposition as infaunal sampling with reduced expense and time needed. This study focuses on the development of an assessment protocol for marine assemblages at sites effected by organic waste discharges such as salmon net-pen facilities, and an investigation of epibenthic macroinvertebrates as indicators of biological integrity. The developed protocol will use epibenthic macroinvertebrates in a way that is analogous to the way infaunal organisms are used in current assessment protocols. Using this developed protocol, a list of potential metrics for use in a future marine epibenthic Index of Biotic Integrity (IBI) was created. A marine epibenthic IBI would provide: (1) a means for regulatory agencies to assess the effects of organic deposition; (2) a first-tier assessment to identify sites where more intensive surveys may be needed; and (3) a quick way of categorizing sites where further study may be warranted.

The IBI represents both a conceptual framework and a useful tool for biological monitoring (Karr et al., 1986). The original IBI was designed to include a range of biological attributes, or metrics from three categories: species richness and composition, trophic composition, and abundance and condition. Development of an appropriate IBI is a three-step process, the first of which is the identification of potential metrics that reflect biological attributes or characteristics of the community and its response to changes in the degree of impact. These hypothesized metrics are then tested at sites with a wide range of impacts; those metrics that can reliably measure changes in the community from a particular impact are then incorporated into a model IBI, which is then tested for its ability to measure the relative effects of impact on an independent set of sites.

Commercial salmon net farms can provide a classic example of organic deposition and have the additional advantage of having few if any associated toxins, unlike a sewage or commercial outfall. These net-pen sites deposit organics on the benthos in the form of fish food, both as uneaten pellets and feces.

This study seeks: to identify metrics of subtidal soft-bottom (10 to 30 m depth) marine communities in Puget Sound that are potential indicators of the biological integrity of the epibenthos; to develop scuba-based underwater recording techniques for documenting these metrics; and to develop an accurate and inexpensive scuba-based visual protocol for assessing the environmental impacts of organic deposition using these identified metrics and recording techniques.

METHODS AND MATERIALS

Indicator Metrics

Information was gathered on large, benthic organisms visible on the nearshore sea floor of Puget Sound, Washington (Hart, 1973; Gotshall and Laurent, 1979; Wingert and Miller, 1979; Miller and Borton,

[1] Fisheries Research Institute, School of Fisheries, WH-10, Seattle, WA 98195

[2] U.S. Environmental Protection Agency, Region 10, Office of Coastal Waters, 1200 Sixth Avenue, Seattle, WA 98101

1980; Kozloff, 1987; Dethier, 1990). Personal interviews with Puget Sound biologists (C. Mahnken, National Marine Fisheries Service, Manchester, Wash.; J. Word, Battelle Marine Science Lab, Sequim, Wash.; J. Armstrong, Environmental Protection Agency, Seattle, Wash.; J. Rensel, School of Fisheries; R. Anderson, Seattle Aquarium, Seattle, Wash.) familiar with the soft-bottom habitat were used in order to incorporate as many species in the general indicator list as possible. These indicators were evaluated based on whether they were (a) easily and accurately observed and identified, (b) common to Puget Sound and reliably present (or absent) at least seasonally at undegraded (reference) sites, and (c) indicative of degraded conditions.

Testing of Underwater Recording Techniques

Visual observations were greatly facilitated by the use of the Metrics Underwater Transecting Tool (MUTT). This device was designed to allow for variable-length, constant-width strip transects without the need for permanent transect markers, providing visual transects of a known area with a minimal amount of disturbance. The MUTT is inexpensively constructed using PVC pipe and plastic lids from 5-gal buckets after Miller et al. (1994). Underwater, it has slightly negative buoyancy and is highly maneuverable so that it can be easily moved over obstructions such as debris piles, mooring cables, or pilings. For this project, paired transects of 1 m by 50 m were used with data transcriptions every 5 m segment. Survey dives were made at 10, 20 and 30 m depths.

Field Research Site Locations

Three locations were used as reference stations for this project: Alki Point, Seattle; Fay Bainbridge State Park, Bainbridge Island; and Picnic Point, Everett. Sediment composition at these sites is 88 percent medium and fine sands 0.5 mm-0.125 mm in size. In addition, there were two test locations at commercial salmon net-pen facilities: Global Aquaculture in Clam Bay, Manchester, Wash.; and Birding Seafoods in Port Townsend, Wash. The Global Aquaculture facility historically produced 620 metric tons of salmon annually, with an estimated annual fecal and waste feed deposition of 250 t yr^{-1} (Weston, 1990); however, the current facility is considerably smaller than the net-pen configuration for which these estimates were originally calculated.

The Birding Seafoods site is a recently installed net-pen at a location that was previously occupied by Paradise Bay Co. net-pens (using the same mooring buoys and cables). One block of pens became operational in January and the other in June 1993. Dives were made on the inland edge of the more recently installed pen. The sediment at this location was significantly different from that at the other sites, comprising a 99 percent silt/clay fraction. This facility is also notable for being located close to a pulp mill.

Sampling Methods

Species abundance and presence data were collected on these transects; in addition, information was recorded concerning height of tide, currents, and any unusual observations or occurrences for the dive. All species seen were recorded on the diver's slate, except in the case of organisms considered too small (< 2 cm) to be accurately sampled on a day with average visibility. For highly mobile species such as crabs, individuals within the boundaries of the projected transect were counted. In cases where species were too numerous to accurately measure, counts were made up to 25 per 5 m^2 segment and recorded as >25.

At the net-pen facilities three 50 m long transects were made at distances of 0 and 50 m from the net-pen blocks at each site, with an additional set of three transects at the 100 m distance at Birding Seafoods. Transects began immediately adjacent to the pens and alternated in direction. In addition to species data, information was collected on the presence/absence of food pellets, mats made up of the filamentous sulfur bacteria *Beggiatoa* spp., and any pen-associated debris such as net piles, cables, etc.; data on these measures were recorded as presence/absence for each 5 m^2 segment.

Methods of Data Analysis

To determine the sample size needed to accurately record at least 90 percent of the species present in a location, cumulative species totals for all transects were plotted against cumulative area sampled for the 10 and 20 m depths at Alki Point and Fay Bainbridge State Park. Auto-correlation tests were performed to determine the distance at which each species was independent of itself. For species with no significant correlation at any lag, or where auto-correlation tests could not be run, abundance was calculated as the mean for all observations. All data were calculated per 5 m^2 and then standardized to 100 m^2 for comparison. For all species that could not be considered independent for each 5 m section, only every n^{th} sample was used to calculate means and confidence intervals (where n = number of significant lags +1). The starting points for these subsamples were randomly assigned to the first or second data point.

RESULTS

Testing and Validation of the Transect Recording Technique at the Reference Stations

A total of 47 species representing 36 families were observed at the three reference stations. These observations range from sightings of one individual to totals of over 5,000 (bivalves) in all 10 m and 20 m reference station transects combined. Of the 47 species, 58% were represented in 10% or fewer of the transects, including two species (*Dermasterias imbricata,* and *Urticina crassicornis*) that were observed only at the 30 m reference site station; 27% were observed >10% to ≤50% and 7% were observed >50% to ≤75%. Four taxa were in more than 75% of the transects (*Armina californica* 77%, *Metridium* spp. 85%, *Pagurus armatus* 92%, and bivalves 96%).

With the exception of the 10 m depth station at Alki, for which only 16 species were recorded, 20-24 species were recorded at each of the reference site depth stations. Analysis for each of the sites indicate that a minimum of 90 percent of the species at a given site were encountered within the first six paired transects of 20 5-m^2 segments (600 m^2). An increase in areal survey coverage at Fay Bainbridge State Park from 644 m^2 to 1,520 m^2 (an additional six paired transects) accounted for only three additional species, all single individuals (Fig. 1).

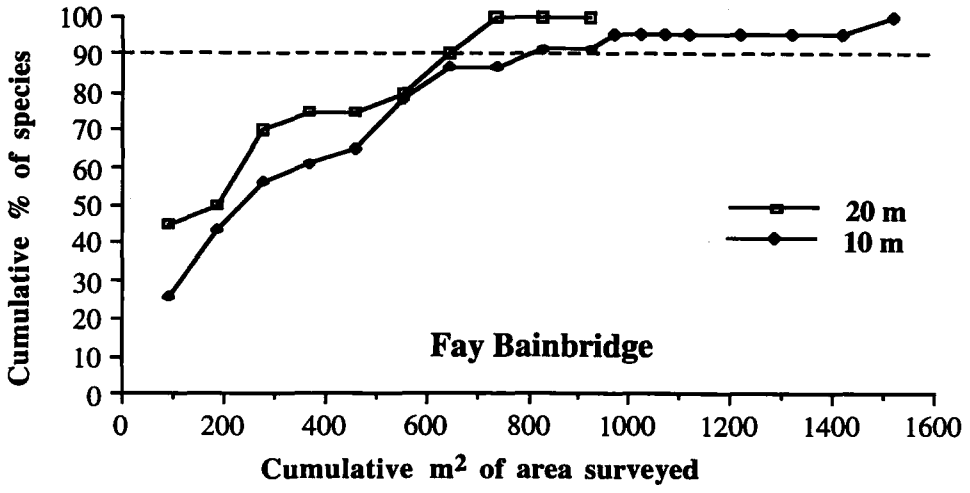

Figure 1. Cumulative number of species for Fay Bainbridge State Park, 10 m depth and 20 m depth. Dashed line indicates 90 percent of the total number of species seen per site.

Calculated average abundances were as high as 798.6 per 100 m^2. Relative diversity measures for all the reference stations and sites were significantly different for all between-depth and between-site comparisons (Table 1). Significant differences in the mean number of species observed per 5 m^2 segment could be found only between the 20 m vs. 30 m and the 10 m vs. 30 m transects at Alki Point, and between Alki Point (10 m) and Fay Bainbridge State Park (10 m). The mean number of individuals seen per 5 m^2 segment was not significantly different in any of the between-depth comparisons, except Alki Point (10 m vs. 30 m). All of the between-site comparisons of mean number of individuals per 5 m^2 segment indicated significant differences.

Of the 47 species seen at the reference stations, significant differences for between-depth abundances were found for eight different species; for between-site abundances, significant differences were found for six different species (Table 1).

Table 1. Summary of the results of between-depth and between-site comparisons of relative species diversity, number of species, and number of individuals for all reference sites. BB = Fay Bainbridge State Park, PP = Picnic Point.

	Rel. species diversity	Mean no. 5 m^{-2}		Species with significantly different abundances
		Species	Individuals	
Between-depth comparison				
Alki - 10 m vs. 20 m	$J' \neq J'$	$\mu = \mu$	$\mu = \mu$	Bivalves, *Metridium* sp.
Alki - 20 m vs. 30 m	$J' \neq J'$	$\mu \neq \mu$	$\mu = \mu$	*Eupentacta, H. crassicornis*
Alki - 10 m vs. 30 m	$J' \neq J'$	$\mu \neq \mu$	$\mu \neq \mu$	Bivalves, *Eupentacta, H. crassicornis, M. aequalis, P. fimbriatus*
BB - 10 m vs. 20 m	$J' \neq J'$	$\mu = \mu$	$\mu = \mu$	*A. californica, H. crassicornis, M. aequalis, P. gurneyi, U. columbiana*
Between-site comparison				
10 m Alki vs. BB	$J' \neq J'$	$\mu \neq \mu$	$\mu \neq \mu$	Bivalves, *P. armatus*
20 m Alki vs. BB	$J' \neq J'$	$\mu = \mu$	$\mu \neq \mu$	*H. crassicornis, M. aequalis, Metridium* sp., *P. armatus*
20 m Alki vs. PP	$J' \neq J'$	$\mu = \mu$	$\mu \neq \mu$	Bivalves, *H. crassicornis, M. aequalis, S. coccinea*
20 m BB vs. PP	$J' \neq J'$	$\mu = \mu$	$\mu \neq \mu$	Bivalves, *Metridium sp., P. armatus, S. coccinea*

Use of the Protocol at Two Salmon Net-Pen Test Sites

A total of 20 species representing 17 families were seen at the two field test sites; of these, five species were seen only at Port Townsend, and five were seen only at Global Aquaculture. Of the 20 species, 40% were observed in less than 10% of all transects, 35% were observed in 10%-24% of all transects, 15% were observed in 25%–50% of all transects, and 10% were observed in more than 50% of all transects. The most common species were *Metridium* sp. and *Cancer gracilis*; both were observed in 60% of all transects at the net-pen sites. This compares with 85% (*Metridium* sp. and 10% (*C. gracilis*) of the transects at the reference sites.

A comparison of the number of species falling into each of five large taxa groups for each of the two net-pen sites (all stations) and a mean for the three reference stations (all 20 m transects) was made (Fig. 2). With the exception of the crustaceans and "other" group, the reference site mean showed a higher number of species present than either of the two net-pen sites, the largest difference being in the number of echinoderm species seen (4 to 5 at the net pens compared with an average of > 9 at the reference stations).

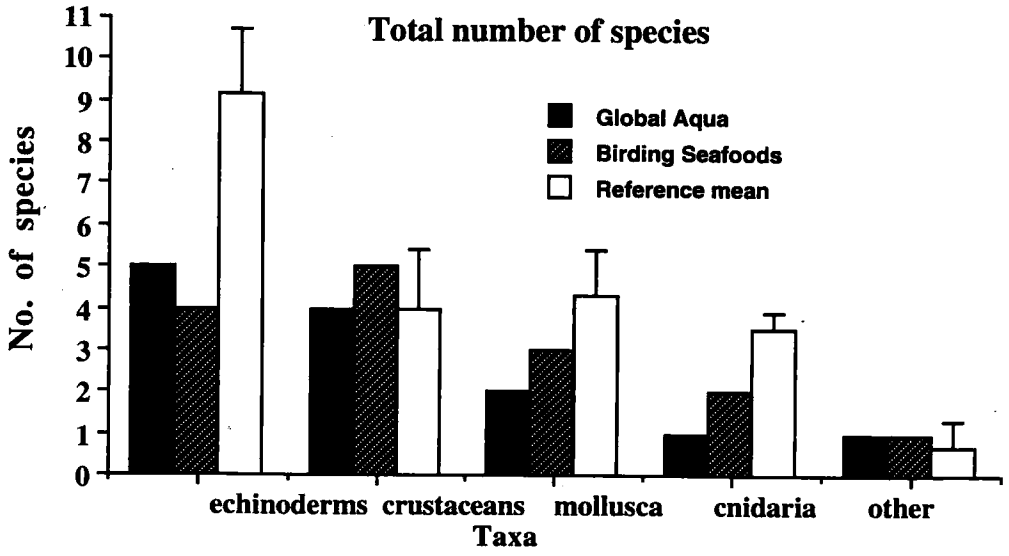

Figure 2. Total number of species seen in each of five large taxa groups at net-pen sites (all distances combined) with mean number of species seen at all reference sites. Bars show the 95 percent confidence interval for the reference site means.

A comparison of the number of seastar species at each site surveyed shows a large difference between the reference sites and the net-pen sites. At both net-pen sites, less than 2 seastars species were observed at any distance compared with 6-8 at each of the reference stations (Fig. 3).

When comparing the percentage of species in each of five large taxa groups for each net-pen site, a decrease in the relative percentage of echinoderms and mollusc species at the net-pen sites and an increase in the number of crustaceans was noted (Fig. 4A, B).

Average abundance per 5 m^2 segment was calculated for every species seen at the net-pen test stations. For all but one species (*Parastichopus californicus*), there were statistically no differences in average abundance between stations at the 0 m and 50 m distances at either Global Aquaculture or Birding Seafoods. Presence of food pellets and the average number of species per segment were both statistically different, while the average number of individuals was not.

Significant differences in relative diversity calculations and the number of individuals per 5 m^2 segment were not found between the 0 m and 50 m distances at Global Aquaculture; however, the average number of species per 5 m^2 segment was found to be significantly different (Table 2). Of the comparisons made between two adjacent distance stations (0 vs. 50 m, or 50 vs. 100 m), the number of species that were observed at both distance stations ranged from 65% to 56% of the total number of species seen at only one of the distance stations. The largest difference observed was the comparison of the 0 vs. 100 m stations at Port Townsend, where 27% of the species seen at either station were seen both stations.

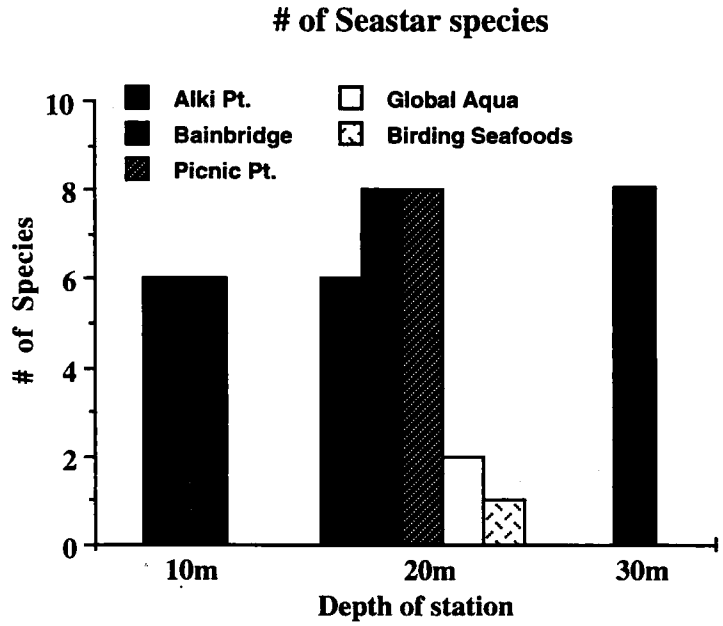

Figure 3. Total number of seastar species for both the reference sites and the net-pen sites (all distances combined)

For most species (95%), there were no abundance differences between stations at the 0 m, 50 m, or 100 m distances at Port Townsend. *Cancer gracilis* was significantly different between the 0 m and 50 m stations, and the 0 m and 100 m stations; no differences could be shown between the 50 m and 100 m stations for this species. The presence of *Beggiatoa* was significantly different between the 0 m, 50 m, and 100 m stations. Presence of food pellets, relative diversity, and the average number of species per 5 m^2 segment were all statistically different between 0 m and 50 m and between 0 m and 100 m, with no difference between 50 m and 100 m. While the total number of species seen at each distance was essentially the same, the average number of species per segment was found to be statistically different between all stations (Table 2).

Table 2. Summary of the results of between-distance comparisons and t-tests of all net-pen sites for all distances. J' indicates the Shannon-Wiener relative diversity index used in Hutcheson's t-test for equal diversities.

Between-distance comparisons	Relative diversity	Species per 5 m^2	No. Ind. per 5 m^2	# of species at		% seen at one only
				both	one only	
GA 0 vs. 50 m	$0.10<p<0.20$	$\mu \neq \mu$	$\mu = \mu$	11	6	35%
PT 0 vs. 50 m	$J' \neq J'$	$\mu \neq \mu$	$\mu \neq \mu$	6	9	64%
PT 50 vs. 100 m	$p > 0.50$	$\mu \neq \mu$	$\mu \neq \mu$	7	6	46%
PT 0 vs. 100 m	$J' \neq J'$	$\mu \neq \mu$	$\mu \neq \mu$	4	11	73%

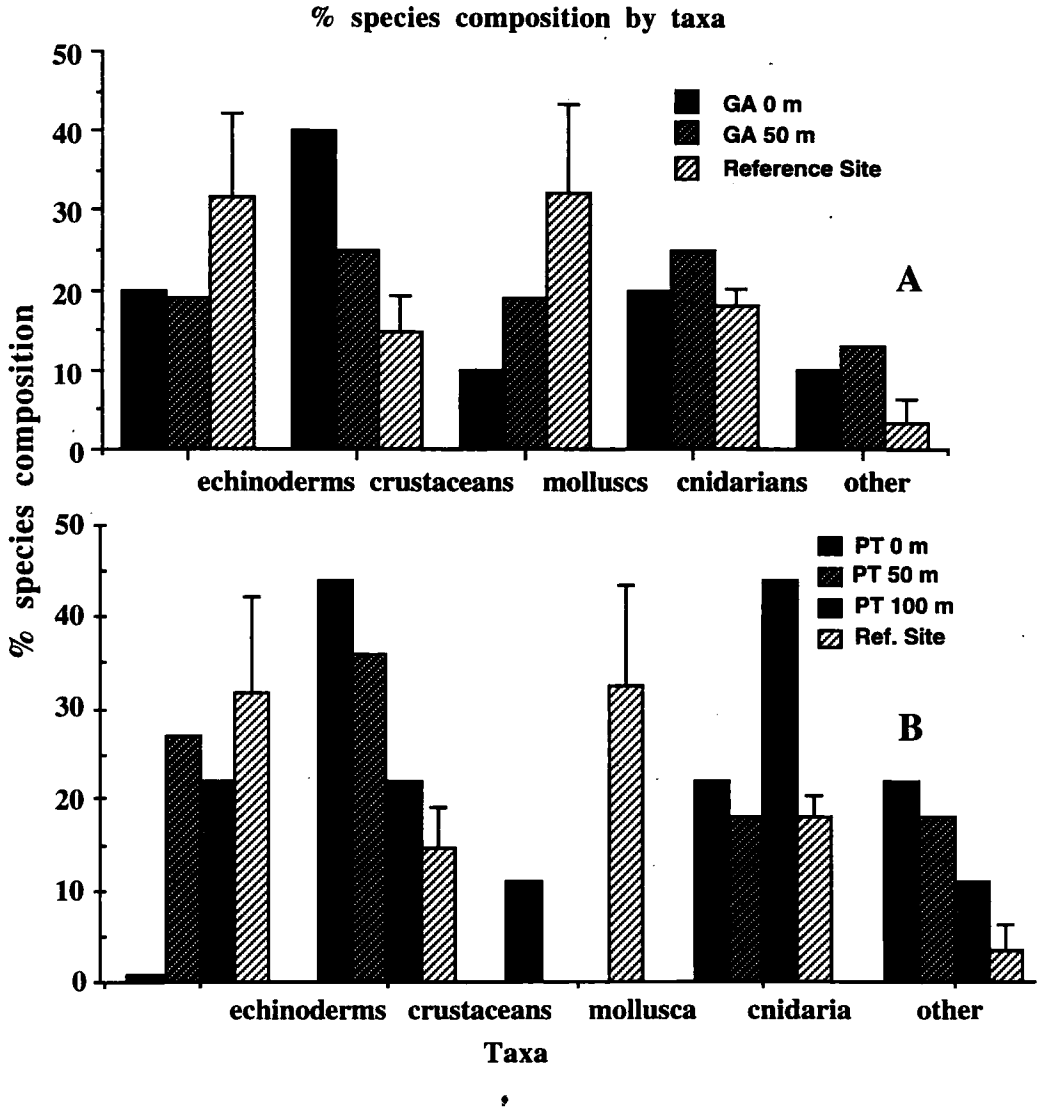

Figure 4. Percentage species composition in each of five large taxa for (A) Global Aquaculture, Clam Bay and (B) Birding Seafoods, Pt. Townsend. Reference site means (10 and 20 m depth stations combined) are shown with 95% confidence intervals. GA = Global Aquaculture, PT = Port Townsend.

DISCUSSION

Potential Indicator Metrics

While the total number of species seen at each of the reference stations was high (47), the percentage of those species that were consistently seen at every site and depth was small. Only 15% of the species sighted at any of the three reference sites were observed on 50% or more of all transects. Three of the four species that were seen with the greatest frequency (75% of all transects) have other characteristics that may affect their usefulness as direct measures. For example, the presence of *A. californica* and *P. gurneyi* are correlated since *A. californica* feeds solely on *P. gurneyi* (Kozloff, 1987). *Metridium* sp. were observed on nearly every transect, but were usually associated with debris or other structures that allow it to avoid direct contact with the benthos. Bivalves were also found in nearly every transect, but the visibility of

bivalves using the developed method may vary as much as 50% (Washington Department Fish., pers. comm) between surveys. It should also be noted that under current state guidelines any significant concentration of commercially important sessile species such as geoducks (*Panope abrupta*) would prohibit the siting of any net-pen operation (Weston, 1986). The use of bivalves as indicator species is seriously complicated as the siting of net pens are specifically chosen to avoid these species, so low abundances may not be related to organic deposition.

This project has provided considerable insight into the species and species groups that are either inappropriate or have potential usefulness in the creation of a marine benthic IBI. Table 3 gives an overview of (1) those metrics that are hypothesized to have value in a marine benthic macroinvertebrate IBI for evaluating areas affected by organic deposition, and (2) associated qualities of those metrics that make them attractive. The process for developing a functioning IBI will involve careful evaluation of each of these metrics to determine their potential for accurate assessments of community changes associated with increased impact. Many of these metrics measure the same species or trophic group, but at different scales.

Table 3. Overview of potential metrics found in this study, including an evaluation of these metrics in four categories: ease of identification, ease of qantification, an estimate of variance and the trend that was observed at the two-pen sites

Potential metric species, trohpic groups, and measures	Easy to identify	Easy to quantify	Variance*	Trend with deposition
1. Total no. of species	X	X	High	Decrease
2. No. species/segment	X	X	Moderate	Increase
3. Total no. of individuals	X	X	High	Increase
4. No. of individuals per segment			Moderate	Increase
5. % of individuals as the most abundant taxa	X	X	High	No trend
6. No. of echinoderm species	X	X	Moderate	Decrease
7. No. of mollusc species	X	X	Moderate	Decrease
8. No. of cnidaria species	X	X	Moderate	Decrease
9. No. of crustacean species	X	X	Low	No trend
10. No. of seastar species	X	X	Low	Decrease
11. % segments with bivalves present	X	X	Low	Decrease
12. % of segments w/*Beggiatoa* spp.	X		Low	Increase
13. % of segments w/food pellets	X		High	Increase
14. % of segments w/rare species†		X	Low	No trend
15. % of segments with sea cucumbers	X	X	High	No trend
16. % of species as *Cancer sp.*	X	X	Low	Increase
17. % of species as Cnidarians	X	X	Low	Decrease
18. % of species as Crustaceans	X	X	Moderate	Increase
19. % of species as Echinoderms	X	X	High	No trend
20. % of species as mobile	X	X	Moderate	Increase
21. % of species as predators	X	X	Moderate	Increase

* Estimates of variation are based on coefficients of variation (CV) of all measures for each metric; CVs <30% = low, ≥30% and <70% = moderate, and >70% = high.

† Any species observed in <10% of all transects at the reference sites in this study was considered rare.

The development of the Metrics Underwater Transect Tool proved to be most instrumental to the success of this project. In the past, visual scuba surveys have been hampered by visibility estimations and sampling width calculations. The MUTT provided both a non-permanent transect length marker (that did not require any setup time before surveys) and a clear boundary for the survey width such as can be found in quadrat sampling.

All three reference sites and Global Aquaculture were similar in sediment composition, consisting of mainly medium to very fine sand. No change in sediment composition with depth was apparent for the reference sites. However, grain size analysis showed that sediments at Birding Seafoods were distinctly different from sediments at the other sites. The sediments taken at Birding were 100% silt and clay fraction, compared with less than 5% at all other sites. This distinction should be kept in mind when comparing the data from Birding Seafoods with data from other sites.

Reference stations

The differences between measures at the three reference sites used in this project, despite controlled depth, grain size, and general geographical area, suggest that location of the reference sites be considered very important for future surveys. While the depths of the surveys should be held consistent within a net-pen site, the location of the reference site should be as adjacent to the net-pen site as possible. Ideally, transects could be run parallel to the pens at increasing distances until no difference exists between adjacent transects, with the resulting distance being the control station. While the use of a few generalized regional reference sites is appealing for the sake of time and financial concerns, this study demonstrated that the high variability of the limited sites used warrants the use of a wider range of reference sites that are as close to the ecotype of the study site as possible without being affected by the organic enrichment.

Use of the Protocol at Two Salmon Net-Pen Test Sites

The two field test sites showed a marked decrease in the number of species observed (20 compared with 47 at the reference sites), and of these, only 13% were in 50% or more of the transects at all distances from the pens (the highest being 60%). In comparing the number of species in each of five taxa (echinoderms, crustaceans, mollusca, cnidaria, and other) for each of the two net-pen sites and an average from all the reference sites, a generally equal decline in all taxa groups was found, with the exception of crustaceans. The number of crustacean species was the same or greater at the net-pen facilities than the reference mean, suggesting that crustaceans as a group would be attracted to the organic deposition from the pens. This was obvious to the divers as large numbers of *Cancer* sp. individuals and *Pandalus danae* shrimp were observed at both net-pen sites.

Cancer gracilis has also been observed in high abundances at other net-pen sites with relatively soft bottoms. Pease (1977) found large numbers of *C. gracilis* under a net pen in Henderson Inlet, Washington, adjacent to a log-rafting yard. The apparent association of this species with net-pens may also be affected by the sediment type. The use of crustaceans as a positive indicator of organic degradation should be considered, along with any correlations with sediment type.

Echinoderms and specifically seastars showed the largest change between sites (two to three species at the net pens and an average of nine at the reference sites), suggesting that echinoderms as a group are less tolerant of deposition and should be examined more thoroughly as indicator species.

Very little *Beggiatoa* or food pellets were observed at Global Aquaculture; however, they were both widespread at the Birding Seafoods site. The presence of both was significantly more pronounced as the stations neared the edge of the pens. *Beggiatoa* spp. is commonly found in the transition layer between oxic and anoxic sediments, where O_2 and H_2S are supplied from opposite sides of the transition layer. *Beggiatoa* patches have been noted under net pens in many studies (Rosenberg and Diaz, 1993; Pease, 1977) and can be a distinct indicator of anaerobic decomposition and a good measure of the effects of deposition. However, *Beggiatoa* spp. is often absent from areas with extremely heavy organic impact. This factor may limit the usefulness of *Beggiatoa* spp. as an indicator in areas affected by heavy organic enrichment or areas with strong flushing.

CONCLUSIONS

This project has found that this scuba-based survey method worked well at reference sites with no debris and at the net-pen sites with considerable underwater obstructions. A relatively large area could be covered in the time limits available with scuba, and the auto-correlation associated with this specific pattern of transacting was a factor for only a few species.

The development of the MUTT as well as the investigation of the survey technique has led to the identification of a broad list of hypothesized metrics that have potential as indicators of the biotic integrity of the epibenthic community. Each of these metrics will need to be further evaluated as the next step in the development of a functioning Marine Benthic IBI. This Marine Benthic IBI can then be used as a rapid evaluation tool for these areas, giving regulatory agencies the ability to assess the effects of organic material deposition quickly, accurately, and inexpensively.

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FIDALGO BAY: LONG-TERM MONITORING OF AN OILED SALT MARSH

Rebecca Z. Hoff[1]

INTRODUCTION

On February 22, 1991, a pump failed during off-loading at a Texaco refinery near Anacortes, Wash. As a result, approximately 30,000 gallons of North Slope crude oil entered Fidalgo Bay, a shallow bay characterized by broad mud flats and large subtidal eelgrass beds. In an effort to keep oil away from the eelgrass beds and the herring spawn that was occurring at the time of the spill, oil was contained with booms along the southern shoreline of the bay. This containment, concurrent with a high tide cycle and northerly winds, resulted in heavy oiling of the fringing salt marsh.

This fringing marsh, dominated by *Salicornia virginica* and *Distichlis spicata* (pickleweed and saltgrass) is not pristine—it lies adjacent to roadbed fill of a state highway. Nonetheless, the marsh provides increasingly scarce wetland habitat for aquatic organisms and shorebirds. During the cleanup, efforts were made to control access and detrimental impact to the marsh by cleanup workers. Several low-impact cleanup techniques were used to remove oil without causing further damage to the marsh or adjacent mudflats. A simple qualitative monitoring program was established to document the effectiveness of these response techniques and the subsequent recovery of marsh vegetation.

STUDY DESIGN/METHODS

The study consists of two phases: Phase I documented vegetative recovery from April 1991-September 1994 in areas treated with different cleanup methods; Phase II (ongoing) investigated the effect of surface tilling and sediment removal in a heavily oiled portion of the marsh. Parameters measured included percent cover of surface vegetation, below-ground plant biomass and chemical analysis of residual oil in sediments.

Phase I

In April 1991, four transects were established in the marsh along the south end of Fidalgo Bay (Figure 1). These transects represented areas affected by the spill and cleanup in different ways: Transect 1 was a control, located in an unoiled area; transect 2 was located in an area that was lightly oiled but subjected to trampling from extensive foot traffic; transects 3 and 4 were heavily oiled, protected from trampling by the placement of boards over the surface of the marsh, and cleaned in two different ways. Transect 3 was vacuumed with an industrial vacuum to remove surface oil, and transect 4 was flushed with low-pressure, ambient-temperature sea water, and vacuumed like transect 3. A fifth transect, labeled 2.5 because it was located between transects 2 and 3, was established in August 1992 to track a heavily oiled patch noticeably devoid of vegetation.

Tidal elevations for each transect were measured using standard survey methods, and all sample quadrats were within 0.15 meters (m) of one another (elevations ranged from 2.60m to 2.76m). Because of its relatively high elevation, the marsh is flooded infrequently, during exceptionally high tide cycles.

The narrow width of the marsh limited the area available for sampling, and monitoring sites were selected where we were certain that particular treatments took place. As a result of these limitations, the study design does not include replicate samples, nor were sample transects or quadrats selected randomly. Our results are therefore qualitative, rather than quantitative, and quadrat samples should be interpreted as indicator locations that are monitored over time, rather than as statistical representatives of the entire marsh.

[1] National Oceanic and Atmospheric Administration, Hazardous Materials Response and Assessment Division, 7600 Sand Point Way N.E., Seattle, WA 98115

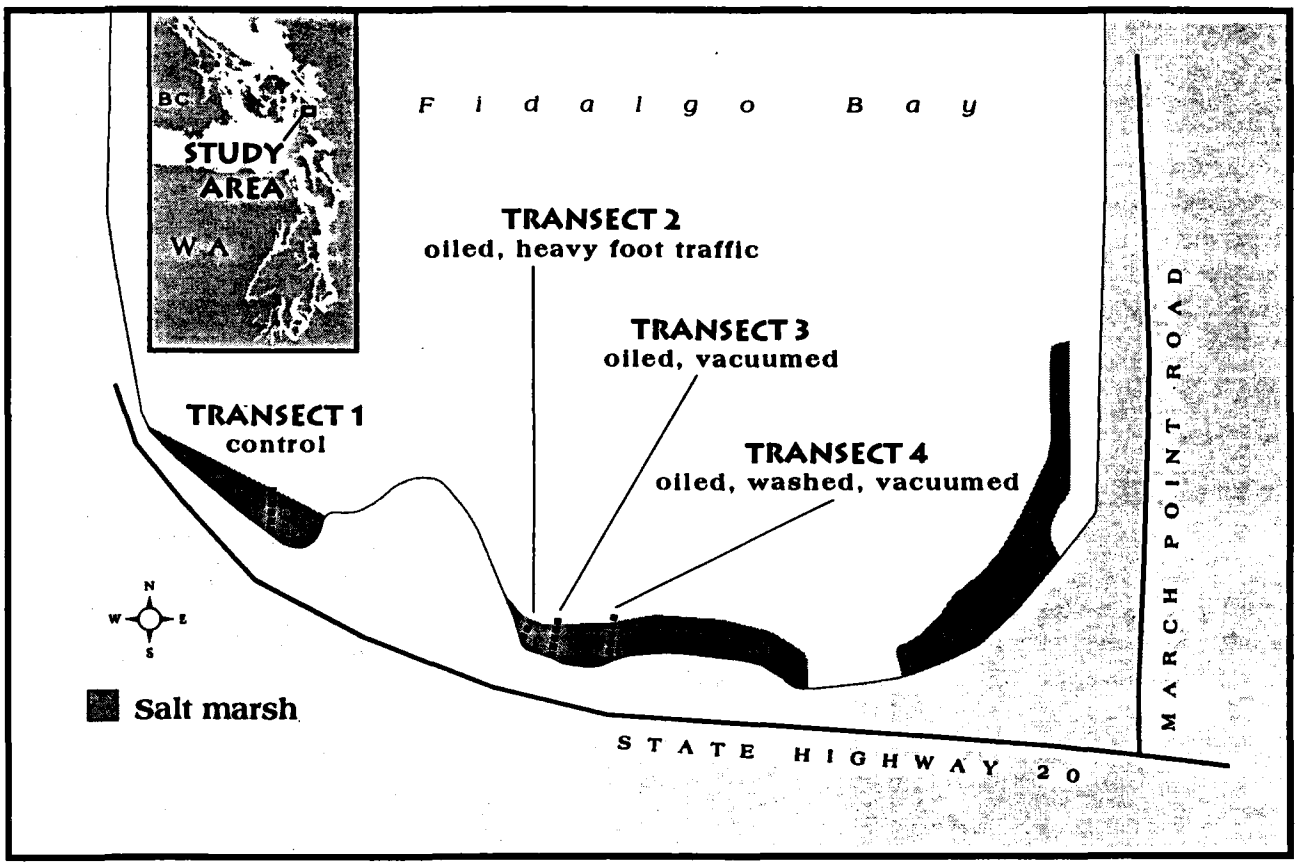

Figure 1.

Photo quadrats ($0.25m^2$) were established at fixed locations along each transect. Each quadrat was photographed monthly during the growing season, and a surface sediment sample was collected for chemical analysis of oil weathering. Biological core samples were collected in April each year for analysis of below-ground plant biomass. Chemistry core samples (diameter 7 cm and length greater than or equal to 10 cm) were collected at all transects in April and October to measure depth of oil penetration. Quadrat photo slides were converted to numerical estimates of percent cover by projecting them over a standard-sized grid and counting the squares containing green plant material.

Below-ground biomass was measured from biological core samples collected with a hand-held aluminum coring device, (10.7 cm diameter) sampling a sediment volume of approximately 1.1 liter. Biological core samples were analyzed by rinsing the contents through a 2.0 mm sieve, separating the vegetative material and sorting live and dead material. Live and dead material was dried separately at 60°C until repeated weighing resulted in the same weight (drying time was approximately 48 hours).

For chemical analysis, oil was extracted from sediment samples and characterized using gas chromatography/mass spectroscopy (GC/MS) following methods detailed in Michel et al. (1990) and Michel et al. (1991).

Oil weathering was tracked using indicator compounds (C18/phytane) and compared to fresh Prudhoe Bay crude oil.

Phase II

In fall 1993, the oiled patch around transect 2.5 was the focus of Phase II studies. Since no plants had colonized this area in the three growing seasons since the spill, we postulated that surface tilling of the oiled sediments or removal of contaminated surface sediments would speed recolonization by adjacent plants.

Eight rectangular quadrats (0.25m by 0.5m) were established along a transect running the length of the oiled area and parallel to the shoreline. Three quadrats were tilled using a hand trowel, with two quadrats left as controls. The top 3 cm of sediment was removed from two additional quadrats, with one quadrat as control. Surface sediment samples were collected (as a composite from three spots inside each quadrat) before and after treatment, and periodically thereafter. Photos were taken to determine percent cover of vegetation as with Phase I. These plots were monitored through September 1994.

RESULTS

Phase I

Vegetative cover

Differences in the percent cover of vegetation were most marked in the first growing season after the spill in 1991, when transects 2 and 3 lagged behind transects 1 and 4 in percent cover (Figure 2). By the 1992 growing season, all transects showed similar patterns and had essentially 100 percent vegetative cover in July. This similarity continued through 1993 and 1994. Data from transect 2.5 is available only for 1993-94, but this quadrat remained essentially bare through July 1994.

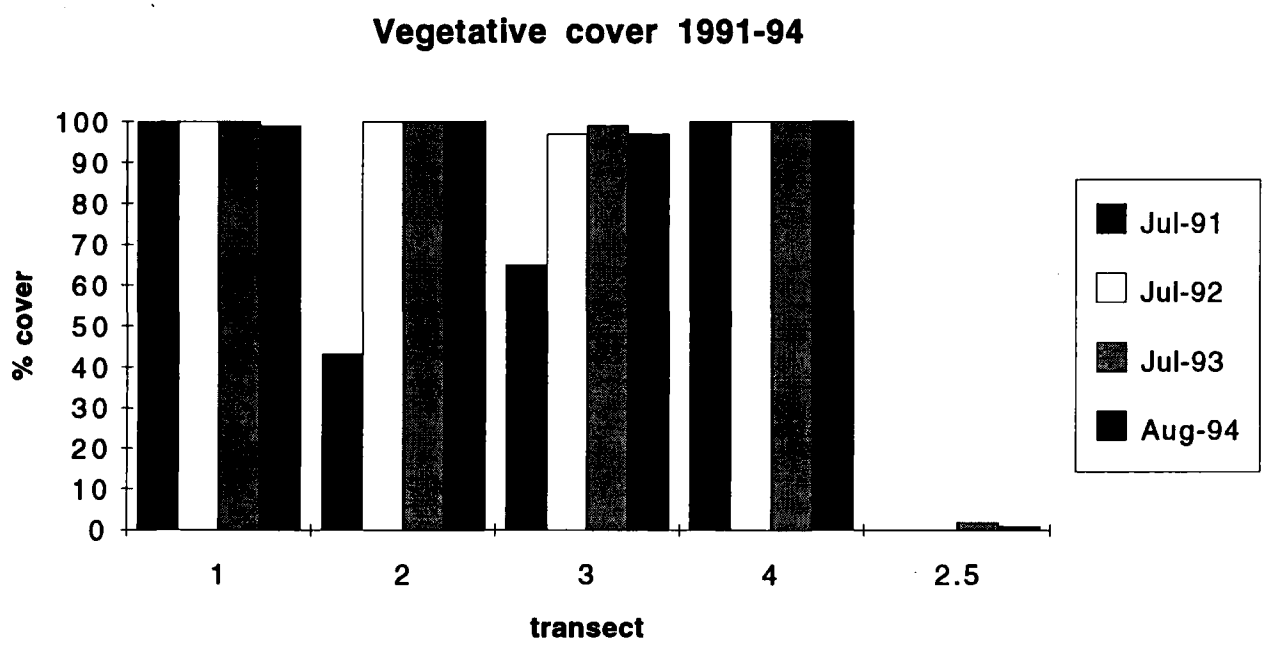

Figure 2. Percent cover of surface vegetation at transects 1-4 from 1991-94

Below-ground biomass

Live below-ground biomass is presented as a percent of the total biomass in the core (Figure 3). Patterns in below-ground biomass were different from those of surface vegetation and varied considerably

from year to year. In 1991, percent live biomass varied between transects, but oiled transects (2-4) did not appear to have substantially less biomass than the control transect (transect 1). In 1992, however, all oiled transects had less biomass than the control.

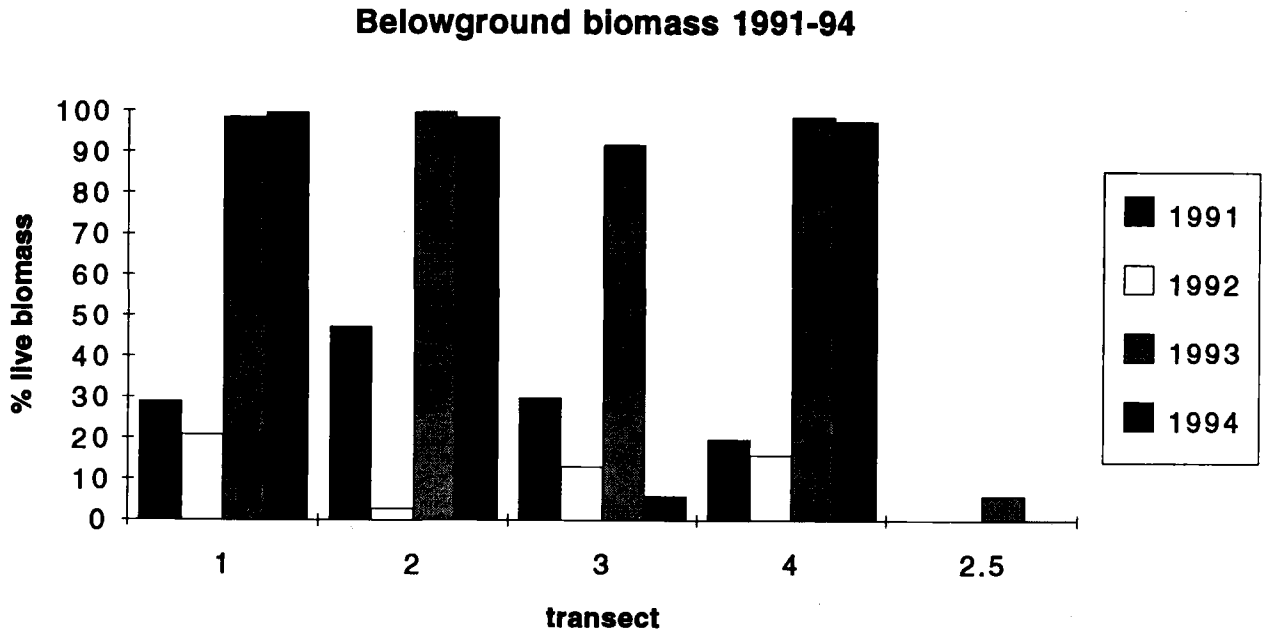

Figure 3. Belowground biomass from core samples collected in April 1991-94 shown as percent live biomass

Overall, below-ground biomass varied considerably from year to year even at the control site. Because of the lack of replication, it is impossible to distinguish natural spatial variability from possible oil effects. Greatest year-to-year variability is found at oiled sites, indicating that below-ground biomass may have been damaged during the spill and subsequent cleanup.

Sediment chemistry/oil weathering

From April-October 1991, substantial weathering took place in oiled surface sediments at transects 2, 3, and 4 as evidenced by the virtual disappearance of phytane in the oil (Figure 4; Kennicutt, 1988). These degradation rates are comparable to rates from other studies conducted in marshes (Hershner and Lake, 1980). Transect 2.5, however, weathered much more slowly than the other transects, probably due to the thickness of the oil layer at that site.

Chemistry cores showed that oil did not penetrate deeply at most sites, likely because of the dense clay sediments of the marsh. At all transects, most of the oil was found in the top 2.5 cm. Sediment cores collected in April 1993 showed some oil at depths to approximately 10 cm at transects 2, 3 and 2.5. The highest quantity of oil below 2.5 cm was found at transect 2.5, consistent with the lack of surface vegetation or below-ground biomass at that site.

Phase II

Quadrats in Phase II remained bare through 1993. Some plants appeared in the tilled quadrats late in the 1994 growing season (Figure 5). Both tilled quadrats and controls had some new plant growth at this time, with most tilled quadrats having greater percent cover than controls. Removal quadrats showed less

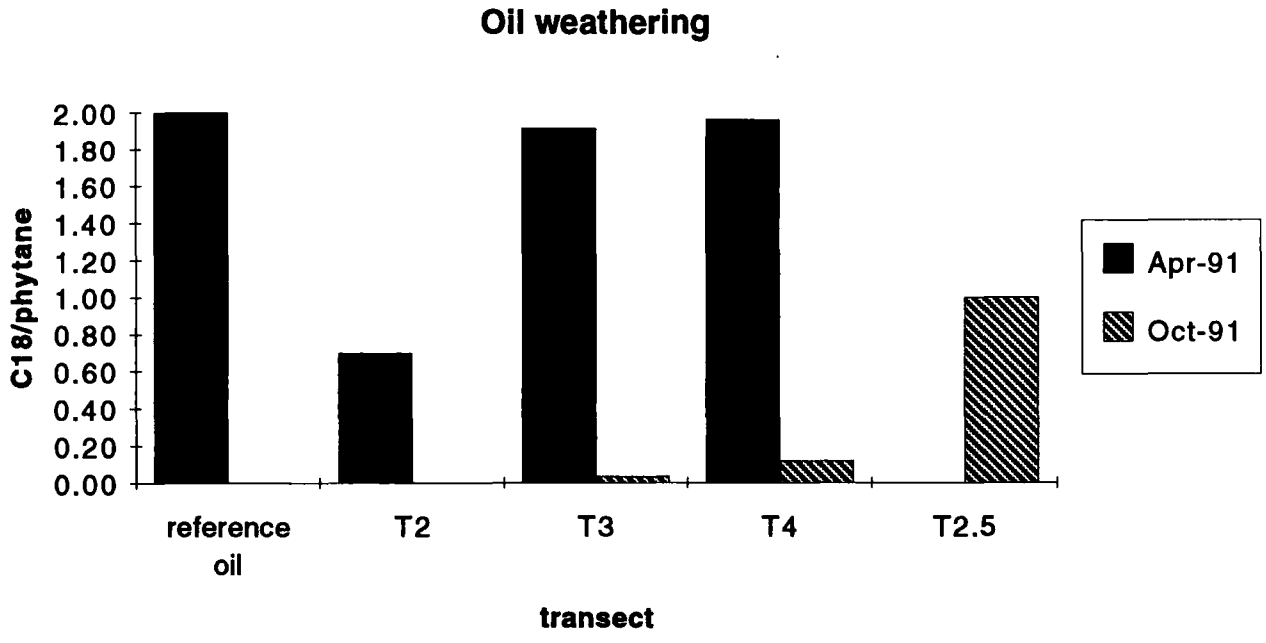

Figure 4. Oil weathering measued by the ratio of C18:ohytane at sample transects compared with reference Prudhoe Bay crude oil

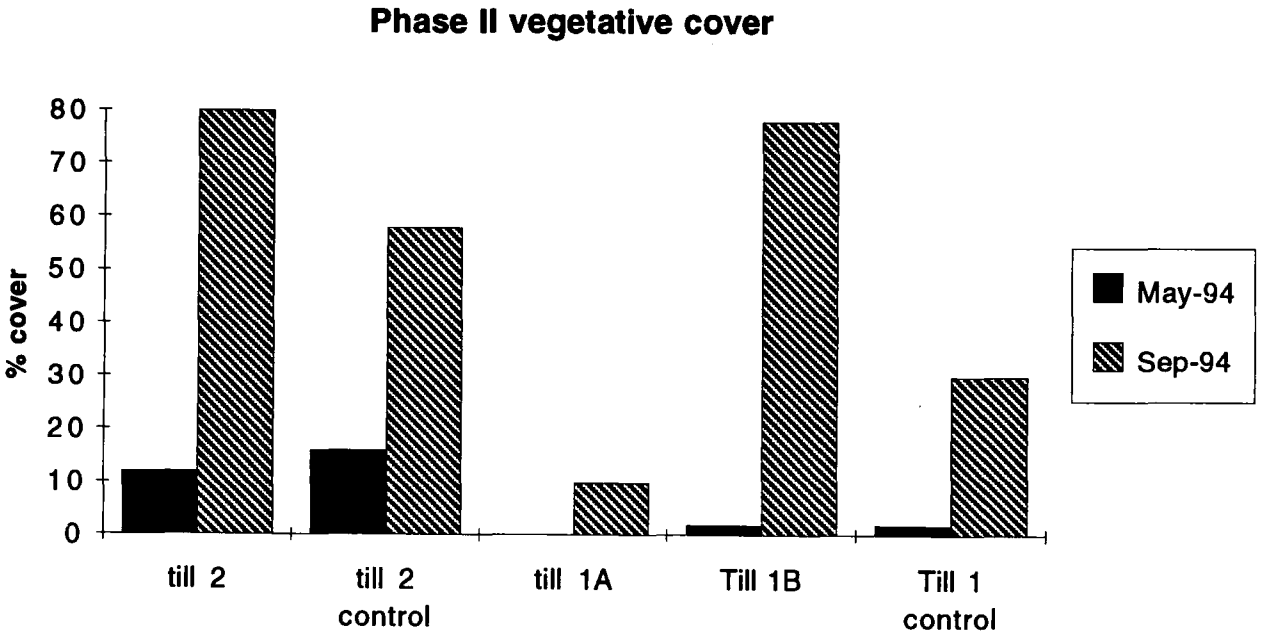

Figure 5. Percent cover of surface vegetation for phase II quadrats in May and September 1994

change. One removal quadrat showed some vegetative growth by September 1994, while the second removal and control remained essentially bare. Plants appear to be growing into the experimental quadrats from adjacent areas. The small size of the plots and their proximity to nearby vegetation may obscure any effects from tilling or sediment removal. Results from sediment chemistry are not yet available for Phase II samples.

DISCUSSION

Apart from any response activities, oil itself is toxic to marsh plants to varying degrees. The specific effect depends on factors such as oil type, thickness of oil on the marsh surface, season in which the spill occurred, species of plants involved, and the percentage of the individual plant that is covered with oil (Hershner and Moore, 1977; Alexander and Webb, 1985; Alexander and Webb, 1987; Mendelssohn et al., 1990). Most studies on this topic have been conducted in *Spartina* marshes, so we were unsure whether the *Salicornia/Distichlis* marsh would follow similar patterns.

The regrowth of vegetation at transects 2, 3 and 4 in the first growing season after the spill shows that *Salicornia/Distichlis* affected during their dormant period can survive short-term oiling, provided physical impacts (trampling) are avoided. However, the markedly slower recovery of transect 2.5 demonstrates the toxic effects of heavy oil layers not removed from the marsh surface. Since this spill caused initial heavy oiling over the *Salicornia/Distichlis* marsh, the option to leave the marsh to recover without attempting to remove oil would likely have resulted in many more bare areas and much slower vegetative recovery.

Given that it was desirable to remove the heavy layer of oil from the Fidalgo Bay marsh, the ideal response technique would have been one that maximized oil removal and minimized disturbance to vegetation and marsh sediment. The use of low-pressure, ambient-temperature washing with vacuuming proved to be the optimal response technique in this situation. This technique appears to have been effective because it removed the most oil (oil was lifted off the surface of the marsh with the water and removed with the vacuum) without uprooting plants or trampling sediment.

This study also confirms what many other researchers have documented: that physical disturbance of salt marshes, especially of surface sediment, has detrimental and long-lasting effects on the marsh ecosystem and on marsh vegetation in particular (Vandermeulen et al., 1981; Vandermeulen and Jotcham, 1986; Mendelssohn et al., 1990). The fact that transect 2 (the trampled area) exhibited slower vegetative recovery in 1991 and deeper oil penetration than other sites provides evidence of the detrimental impacts of trampling.

Several studies have documented the importance of the below-ground root and rhizome system to the above-ground productivity in marsh plants (Alexander and Webb, 1987; Gross et al., 1991). Though the vegetative cover at transects 2, 3 and 4 is fairly consistent throughout 1992-94, the below-ground biomass indicates that much of this above-ground growth may originate from only a few plants, and that the surface vegetation is not always supported by a dense below-ground root mass, especially at transects 2 and 3. This may indicate less complete recovery than might be estimated from the surface vegetation alone. This provides a caution for the use of surface vegetation alone as an indicator of general marsh recovery.

Results from the Phase II studies are still preliminary, though it appears that tilling may be helping to speed recolonization of bare areas.

Response to oil spills in marshes is always problematic, because of the great risk of causing more harm to the environment from the response itself. In the case of Fidalgo Bay, careful response using low-intensity methods to remove oil was clearly beneficial to the eventual recovery of the marsh. Though vegetative recovery has been under way since 1992, measurable impacts from the spill are still evident (seen in patchy, below-ground biomass and some remaining oil patches) four years after the initial event.

ACKNOWLEDGMENTS

Many thanks to Charlie Henry and Pauline Robertson of Louisiana State University, who conducted all chemical analyses and interpretations. Gary Shigenaka of NOAA Hazmat was instrumental in setting up the study and participating in field work throughout.

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PUGET SOUND WATERBIRDS AS CONTAMINANT MONITORS

Mary S. Mahaffy[1], Camille R. Bennett[2] and Wendy Parson[3].

INTRODUCTION

Monitoring contaminant concentrations in select Puget Sound waterbirds has been identified as an important component of the Puget Sound Ambient Monitoring Program (PSAMP). The PSAMP is an interagency, long-term monitoring program for measuring background conditions in Puget Sound and is described in the PSAMP design report (PSWQA, 1988). As an implementing agency for the PSAMP, the U.S. Fish and Wildlife Service (USFWS) is responsible for measuring contaminants in waterbirds in Puget Sound. Data on contaminants in waterbirds will help evaluate bioaccumulation of contaminants and their movement through the food web in Puget Sound. When this information is combined with data collected from other programs within the PSAMP, a more thorough assessment of environmental conditions in Puget Sound will be possible.

Pigeon guillemots (*Cepphus columbia*), surf scoters (*Melanitta perspicillata*) and double-crested cormorants (*Phalacrocorax auritus*) were selected by the PSAMP as potential contaminant monitoring species. These species are common in Puget Sound and feed exclusively in marine areas. Our efforts to evaluate the use of surf scoters and pigeon guillemots as monitoring species are discussed in this paper. Cormorants have not been evaluated as a potential monitoring species.

SURF SCOTERS

Introduction

Migrating and winter resident surf scoters appear in September in the Strait of Juan de Fuca, the San Juan Islands, Puget Sound, and Hood Canal, with numbers increasing during the winter. Surf Scoters dive for mollusks and crustaceans on rock, sand, and mud substrates of bays and channels (Angell and Balcomb, 1984). Surf scoters wintering in the Pacific Northwest accumulate selenium, cadmium, mercury, copper, manganese, zinc, aluminum, lead, PCBs and DDE (Vermeer and Peakall, 1979; Henny et al., 1991). If surf scoters were found to remain in the same general location throughout the winter, it would be possible to assume that contaminant exposure was occurring at that site. In November 1992, a telemetry study on winter movements of surf scoters was initiated to determine whether collection of scoters in fall and spring was appropriate to measure contaminant exposure at sites in Puget Sound.

Methods

In an attempt to capture surf scoters, we tried several techniques that had been used successfully elsewhere for capturing waterbirds. These techniques included a mist net, a net gun, and a baited-wire trap. All capture efforts were conducted in the Commencement Bay and Quartermaster Harbor area, near Tacoma, Wash. In November and December 1993, attempts were made to trap surf scoters using a baited wire-mesh trap and a net gun. The mesh trap was similar to that used by Haramis et al. (1982), but modified by adding floats made with capped ABS pipe. It was used on six days. The net gun, equipped with a net with weighted floats on the corners, was used on 10 days. A mist net was used for a total of three days in January and February 1993 (hereafter referred to as Year One) and on 30 days between November 1993 and January 1994 (hereafter referred to as Year Two).

[1] U.S. Fish and Wildlife Service, 3704 Griffin Ln. SE, Suite 102, Olympia, WA 98501

[2] Washington Wildlife Heritage Foundation, PO Box 5015, Redondo, WA 98054

[3] 6551 NE Windermere Rd., Seattle, WA 98105

The set-up design and capture techniques for the mist net followed those recommended by J. Foster (1992, pers. comm.). Two black nylon Avinet Inc. mist nets (18.3 x 3 m, 100 mm mesh, 210 denier, 4-ply) were sewn together to make a net 36.6 m long. One end of the net was attached to an aluminum pipe. The pipe then was attached with straps to the side of a piling in the water. The other end of the net was attached to a steel pipe which was then strapped to an anchored Topper No-Wake buoy. Once the net was set, small groups of scoters (usually 20 or less) were slowly herded toward the net with a motor boat. When the birds were less than 10 m from the net and ready to take flight, the boat was accelerated rapidly in the direction of the net, causing the birds to fly into the net.

Radio transmitters were surgically implanted at a veterinary facility. Internal transmitters were used since external transmitters may be lost when scoters dive. The radio transmitters, manufactured by Telonics, weighed approximately 20 grams, or approximately two percent of the bird's weight, and were equipped with thermistors to detect bird mortality. Procedures for surgically implanting transmitters followed those specified by Olsen et al. (1992). The birds were held for a minimum of six hours following surgery to ensure that the effects of anesthesia had worn off.

The study area for regular radio telemetry monitoring extended from south of Point Defiance up to Dumas Bay, near Federal Way and up to Paradise Cove on the southwest side of Vashon Island (Figure 1). The scoters' movements were monitored by boat for a minimum of three days per week through February both years. From the beginning of March until the birds departed in late March and early April, scoters were monitored two days per week in Year One and three days per week in Year Two. In Year Two, daylight hours were divided into three time periods, and scoters were monitored at least once weekly in each of the time periods.

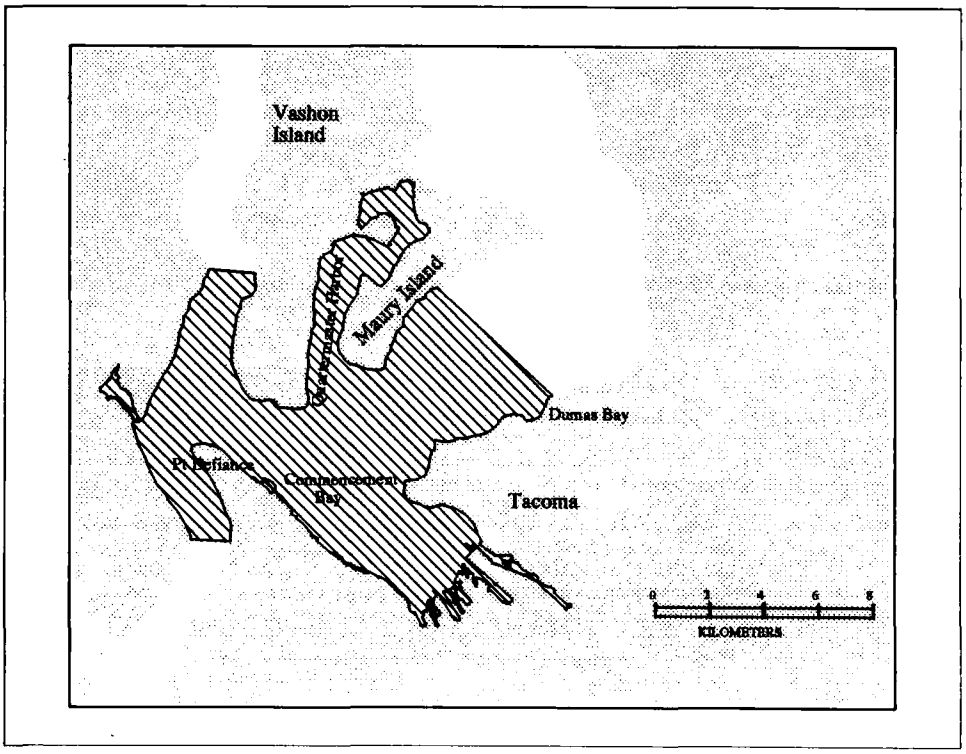

Figure 1. Study area for the surf scoter telemetry project, Puget Sound near Tacoma, Wash.

Radio-tracking after dark, between 1730 h and 2130 h, was conducted on four occasions in Year Two. When contact was lost with individual scoters, radio-tracking by boat was conducted outside the study area on a limited basis. One aerial survey was conducted in Year Two in an attempt to locate three missing birds.

RESULTS AND DISCUSSION

Attempts to capture scoters with the wire-mesh trap and net gun were unsuccessful. Eight surf scoters were mist-netted in Year One and 23 in Year Two, resulting in 2.66 and 0.77 birds/capture day in Years One and Two, respectively. Scoters were caught on 67 percent and 30 percent of the days that mist-netting was attempted in Years One and Two, respectively. One to five birds were caught each time. An average of 3.5 birds were caught per successful flush attempt in Year One and an average of 1.9 birds per successful flush attempt in Year Two. Only one successful flush attempt per day was possible, with the exception of two days in Year Two. The mist net was up between 45 minutes and four hours per day, averaging 2.3 hours per day. The length of time the net was up depended on weather conditions and tides.

In Year One, two of the scoters died within two weeks of release. Telemetry observations of each of the remaining six scoters were obtained on 81 percent to 100 percent (mean 92 percent) of the days that radio-tracking was attempted. Only two birds were located less than 95 percent of the time, because they could not be located during the first three days of tracking. The birds were very predictable in their movements. All radio telemetry locations of scoters occurred within 9 km of the capture location. They were found from 57 percent to 85 percent (mean 76 percent) of the time at one location specific to that bird. One location is defined as a 1-kilometer diameter area. Each bird used either two or three different locations (mean 2.5) throughout the tracking period.

In Year Two, four of the 23 scoters caught weighed less than 1000 g and so were released without implanting transmitters. Two scoters with transmitters died within one day of release. A third scoter was found dead in a tree near shore, apparently killed or scavenged by a raptor three weeks following release. In Year Two, two of the 17 scoters with transmitters, both adult males, left the study area. One bird left 11 days after release and was located on three separate occasions in the Seattle area. The second bird left the study area three weeks after release and was found in the Seattle area. Approximately one month after the bird left the study area, he was again located in the study area at Dumas Bay. During the first week of March, he made at least four trips between Dumas Bay and Seattle. He was then located in Dumas Bay until the beginning of April.

A third scoter was observed in the study area during the first 12 days after release in Year Two, but was observed only once during the next 45 days. After 45 days, he was found two miles up one of the Commencement Bay waterways. Only a short distance up the waterways had been previously checked. He was found in this location 89 percent of the time during the next 40 days until surf scoters began leaving the area in March.

Each of the 14 remaining surf scoters tracked in Year Two were present in the study area for 79 percent to 100 percent (mean 90 percent) of the days that the radio telemetry monitoring was conducted. All of their locations were within 11 km of their capture sites. Each bird used from two to seven different locations (mean 3.9) throughout the tracking period. Based on the site fidelity of most (87 percent) of the radio-tagged scoters in their wintering area, surf scoters would be considered an appropriate contaminant monitoring species.

PIGEON GUILLEMOTS

Introduction

Pigeon guillemots are year-round residents in Washington, nesting along the Strait of Juan de Fuca, Hood Canal, the San Juan Islands, and Puget Sound. Pigeon guillemots are cavity or burrow nesters that require a site where eggs, chicks and brooding adults are protected from both terrestrial and avian predators. They are the most versatile of the alcid species and typically nest in natural cavities in a variety of habitats, including talus slopes, crevices, driftwood and hollows in bluffs of sand or clay (Drent et al.,

1964; Campbell, 1975). They also use cavities on the undersides of piers and wharfs (Speich and Wahl, 1989). Pigeon guillemots usually forage close to their colonies on benthic fish in nearshore areas (Nelson, 1987; Emms and Verbeek, 1989).

Productivity and chick growth rates may be affected by environmental contaminants, as well as by other factors such as inadequate food supplies or disturbance. Limited data are available on contaminant concentrations in pigeon guillemot eggs and tissues from Puget Sound (Oakley, 1976; Riley et al., 1983), Oregon (Henny et al., 1982), Alaska and British Columbia (Ohlendorf et al., 1978, 1982). Eggshell thickness data for pigeon guillemots are also discussed by Speich et al. (1992).

Artificial nesting burrows have been used in a number of different alcid studies to enhance population growth. Pigeon guillemots successfully fledged young from wooden nest boxes set out on Southeast Farallon Island, California (Nelson, 1987). Wilson (1986) and Ainley et al. (1981) successfully used burrows built of wood for rhinoceros auklets (*Cerorhinca monocerata*) and Cassin's auklets (*Ptychoramphus aleuticus*), respectively. Between 1992 and 1994, we placed artificial nest boxes at four locations in Puget Sound (Olympia, Seattle, Port Townsend, and Protection Island) and at Westport on the outer coast. Nest boxes allow easy access for recording nest productivity, for measuring chick growth rates, for banding chicks, and potentially for contaminant monitoring.

Methods

Wooden nest boxes approximately 20 cm x 45 cm were constructed with a hinged roof (Figure 2). A tunnel (approximately 15 cm long, 10 cm wide and 16 cm high) was attached to the front of the majority of the boxes. Boxes with no tunnels and with tunnels 30 cm, 38 cm, and 50 cm long also were tried. The base of the box extended 10 cm from the entrance to the tunnel, providing a perch for the birds to land on before entering the box.

In 1992, nine boxes were attached under the pier at Fort Worden State Park in Port Townsend. An additional box was added in 1993 for a total of 10. In 1992, four boxes without tunnels were placed under the Department of Natural Resources (DNR) dock in Olympia. They were replaced with boxes with 50 cm tunnels in 1993 in an attempt to deter use by rock doves (*Columba livia*). Because of the use of the boxes by other bird species, they were removed before the start of the 1994 nesting season. In 1993, seven boxes were placed under piers both at the Port of Olympia and at the Port of Seattle. At Westport, on Washington's coast, six boxes were attached to the side of a breakwater. In 1994, 21 boxes were placed on the ground in driftwood on Protection Island National Wildlife Refuge.

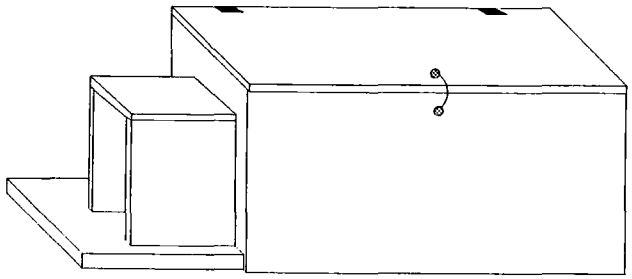

Figure 2. Pigeon guillemot nest box

Nest box use was monitored several times during the 1992-1994 nesting seasons. We also searched for additional nests in the same colonies, which were monitored as well. When possible, chick weight and wing measurements were recorded at least three times during the nesting season. Chicks and adults were banded with a numbered U.S. Fish and Wildlife Service (USFWS) band and a color band on one leg and with two color bands on the other leg so they could be individually recognized. During the first year at Fort Worden State Park, however, chicks were banded only with a white band on one leg and a numbered band on the other leg.

Adult birds were captured for banding to document nest site fidelity. During the 1993 and 1994 nesting seasons, entrances to three nest boxes at different colonies were covered so the incubating adult

could be lifted out through the roof door and banded. After the nesting season in 1993, adult guillemots were captured for banding using a black nylon Avinet Inc. mist net (18.3 x 3 m, 100 mm mesh, 210 denier, 4-ply) attached on the outer edge of the pier at Fort Worden State Park. In 1994, before nest initiation at Fort Worden, observations to look for the banded birds were made on three days for a total of approximately eight hours. After nest initiation, observations were made on four days for a total of approximately five hours.

Results and Discussion

At Fort Worden State Park, guillemots successfully fledged young from the same two boxes in 1992, 1993 and 1994. Although guillemot chicks hatched in two additional boxes in 1994, young fledged from only one of the boxes. The same two openings on the outer edge of the pier were occupied by guillemots all three years of monitoring, and young fledged each year. The one adult that was captured and banded while incubating in a nest box successfully fledged one young, which was subsequently banded. A total of 21 chicks from the nest boxes and pier openings at the Fort Worden State Park colony have been banded. Only one of the boxes at the Port of Olympia was occupied by guillemots in 1993 and 1994. The incubating adult bird was captured in the nest box and banded in 1993. Three weeks after the egg was observed pipping, the box was rechecked and the chick was absent. Since the pier was connected to land on one end, the box may have been accessible to predators such as rats or cats. Before the nesting season in 1994, the box was moved to a section of the pier that was not accessible from land and the banded adult successfully fledged one young. None of the boxes at the DNR docks in Olympia were used by guillemots.

None of the nest boxes in Seattle were used by guillemots in either 1993 or 1994; however, two other locations near the boxes were used both years. None of the boxes at Westport were used by guillemots the first year (1993), but two of the six were used the second year. Two of the 21 boxes on Protection Island were used the first year (1994), one successfully. One adult was captured while incubating in a nest box on Protection Island. The next time the box was checked it was found tipped over, which possibly caused the nest to be unsuccessful.

Pigeon guillemots used boxes lacking tunnels and all the different tunnel lengths, except for the 50 cm tunnels. The length of the tunnel did not seem to affect use of the boxes by rock doves. Rock doves used boxes under all the pier locations except in Seattle. Unidentified birds that used a large quantity of grass as nesting material utilized boxes at the DNR dock in Olympia and one box at Westport.

Use of the mist net at Fort Worden State Park was successful in the fall after the nesting season in 1993, but not in the following year before the nesting season. Eight adult guillemots were captured and banded in 1993. In 1994, three or possibly four adults that had been banded in 1993 were observed. At least one chick banded in 1992 and one in 1993 also were observed. The chicks could not be individually recognized because only one leg was visible for color band identification. Observations of banded birds at Fort Worden State Park were difficult because of the distance between the birds and the observers, rapid flights past the observers, and poor light conditions.

Pigeon guillemots have not used the nest boxes enough at this time to be considered as an appropriate contaminant monitoring species. In 1995, boxes will be placed at several new locations within the same colonies. The effect of box orientation relative to the shoreline or edge of the pier will be examined to determine the effects, if any, on use by pigeon guillemots. At least one to two more years are needed to evaluate the use of guillemots as a monitoring species for the PSAMP.

ACKNOWLEDGMENTS

We wish to thank the following people and organizations for their assistance with the surf scoter project: J. Foster, Dr. B. Hall, Dr. K. Lawson, D. Frederick, R. Carlson, Asarco Incorporated, Tacoma Parks Department, Progressive Animal Welfare Society, and many volunteers. We wish to thank the following people and organizations for their assistance with the pigeon guillemot project: G. Divoky, D. Jenkins, R. Reisley, C. Madrona, L. Robinson, Port of Seattle, Port of Olympia, Fort Worden State Park,

and the Port Townsend Marine Science Center. J. Grettenberger and G. Stagner provided review of the paper, and C. Langston prepared the graphics.

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PUGET SOUND RESEARCH '95

SESSION 9B

ESTABLISHING LINKS: THE HUMAN FACTOR

Session Chair:

Kathy Fletcher

People for Puget Sound

PUGET SOUND WATERSHED PERCEPTIONS OF WATER QUALITY AND QUANTITY PROBLEMS

Gene E. Patterson[1]

INTRODUCTION

During August and September of 1994, a mail survey was conducted of 1,307 residents of watersheds draining into Puget Sound. A little more than one-third of the questionnaires were completed by residents of the Eld and Totten/Little Skookum watersheds in southern Puget Sound. The remainder came from northern Puget Sound residents of Whatcom and Skagit counties and the Stillaguamish watershed in northern Snohomish County.

A main purpose of the study was to help staff from the Washington Department of Ecology understand how watershed residents perceived their connection to enhancing and preserving water quality. For the northern watersheds, a related purpose was to establish a baseline from which to evaluate the effectiveness of upcoming educational programs. The study in the southern areas sought to evaluate existing programs for the Eld and Totten/Little Skookum watersheds, which have been the focus of a concentrated, local government-sponsored water quality education campaign. In essence, surveying both the northern and southern watershed areas allowed for comparisons between residents in watersheds that had undergone intensive educational efforts and residents of areas just beginning intensified educational efforts.

Since the study design divided the respondents into 467 southern Puget Sound and 840 northern Puget Sound residents, the results are reported separately for these two groups, with comparisons summarized at the end.

Southern Puget Sound Residents (Eld and Totten/Little Skookum watersheds)

Water Resource Priorities

When asked what were the most important environmental issues facing their local area, 44% wrote down something related to water pollution.

Out of a list of 17 water resource problems, Eld and Totten/Little Skookum watershed residents seemed most concerned about Puget Sound pollution in general, and fish and shellfish habitat destruction in particular. Pollution from industries and septic tanks, pollution of rivers and streams, increased amounts of runoff, and stormwater pollution were secondary concerns. Pollution from agriculture or home gardening was a minor problem, as were water rights, drinking water availability and purity, sewage treatment plant pollution, and flooding.

Most residents seemed to think that water quality had stayed about the same over the previous five years (56%), although more people were likely to say water quality had worsened (21%) than said it had improved (6%).

Information Sources

Almost everyone had heard about how to save water and how to prevent water pollution through the mass media (90%), and a majority through word of mouth (70%) and brochures received in the mail (64%). Out of a printed list of eight local water-enhancement programs, residents were most familiar with Adopt-A-Stream (73%), Adopt-a-Beach (62%), and Common Sense Gardening (60%). Residents with graduate school experience were more likely to be aware of local programs.

Overall, 40% had participated in at least one water-related program. Residents were most likely to have actually participated in Country Living (31%) and Common Sense Gardening (30%). People 65 or older and those with a high school education were more likely than the rest to have been participants in these two programs.

[1] Elway Research, Inc., 2125 Fifth Ave., Seattle, WA 98121

People who were knew about fewer than five of the eight programs were less likely to consider themselves environmentalists, less likely to have changed their household habits to conserve or protect water, and less interested in finding out more about water-related topics. They were also more likely to be on a community water system.

Household Habits and Government Involvement

Almost all residents were on septic systems (90%). Among these people, 70% had had maintenance work done on them within the previous five years.

A majority indicated that they practiced each item on a list of five water conservation/protection measures. Most common were reduced use of yard chemicals (67%) and use of low- or no-phosphate detergents (66%). More than a third of surveyed residents (37%) saw themselves as already doing a lot to conserve and/or protect water.

In an open-ended question, residents indicated that information and educational programs would do the most to influence them to do more to conserve and/or protect water (20% mention). On the other hand, almost two-thirds (65%) thought they knew enough about water conservation and protection. Changes in water quantity (8%) and monetary incentives (7%) were considered secondary influences on their behavior.

Enforcement of existing water pollution control regulations (50%) was what these residents considered important, not creation of new laws (13%). Overall, 61% would pay at least $1 per month to help reduce water pollution.

Residents were most interested in finding out more about natural landscaping (40%), protecting their wells from contamination (36%), and home practices for protecting water quality (36%).

Northern Puget Sound Residents (Whatcom, Skagit, and northern Snohomish counties)

Water Resource Priorities

When asked what were the most important environmental issues facing their local area, 36% wrote down something related to water pollution. Issues connected to land use and development came in second (23%), followed by timber-related concerns (21%).

Out of a list of 17 water resource problems, Northern Puget Sound watershed residents seemed most concerned about Puget Sound pollution in general (88% noted it as a "major" or "minor" problem), and fish and shellfish habitat destruction in particular (84%, including 63% "major problem"). Pollution of local streams and rivers was also a top priority (86%, but only 40% "major problem"). Most of the listed issues, however, were concerns for a majority of respondents. The exceptions were water availability (46%) and sewage treatment plant pollution (45%). Overall, it appears as though residents were most worried about aquatic habitat degradation, and least concerned about drinking water supplies.

Half thought that local water quality had stayed about the same during the previous five years (50%), although more people were likely to say water quality had worsened (24%) than to say it had improved (8%).

Information Sources

Most everyone had heard about how to save water and how to prevent water pollution through the mass media (88%), and a majority through word of mouth (69%) and brochures received in the mail (59%).

Out of a printed list of eight local water-enhancement programs, the 362 Whatcom County residents were most familiar with Friends of Lake Whatcom (65%) and the North Cascades Audubon Society (61%). Skagit County residents (364 surveyed) were most familiar with Adopt-a-Stream (71%) and Master Gardeners (55%). The 114 surveyed residents of the Stillaguamish watershed in north Snohomish County were most familiar with Adopt-a-Stream (78%) and the Stillaguamish Festival of the River (63%).

People who knew about fewer than four of the eight programs were less likely to consider themselves environmentalists, less likely to have changed their household habits to conserve or protect water, and less interested in finding out more about water-related topics.

Overall, 18% had participated in at least one water-related program.

Household Habits and Government Involvement

Two out of five northern Puget Sound residents were on septic systems (39%). Among these people, 67% had had maintenance work done on them within the previous five years.

A majority indicated that they practiced each item on a list of five water conservation/protection measures. Most common were use of low- or no-phosphate detergents (61%) and reduced outdoor watering (61%). Three out of 10 residents (31%) saw themselves as already doing a lot to conserve and/or protect water.

In an open-ended question, residents indicated that information and educational programs would do the most to influence them to do more to conserve and/or protect water (21% mention). On the other hand, almost two-thirds (63%) thought they knew enough about water conservation and protection. Changes in water quantity (9%) and monetary incentives (9%) were considered secondary influences on their behavior.

Enforcement of existing water pollution control regulations (50%) was what these residents considered important, not creation of new laws (12%). Overall, 57% would pay at least $1 per month to help reduce water pollution.

Residents were most interested in finding out about protecting home water quality (39%), natural landscaping (34%), and non-toxic household products (36%).

Comparisons between southern and northern watershed residents

Respondent Characteristics

The northern watershed study participants were more likely than those in the southern area to be 65 years or older (28% compared to 18%). Most southern area residents lived in places they considered to be rural (79%, compared to 34% of those in the northern areas). Northern area residents were less likely to have a college degree (35%, compared to 49% among southern area residents).

Southern area residents were much more likely than those in the northern study area to use private water wells (52% compared to 15%). Septic system use was much more prevalent among the southern area respondents (90% compared to 39%), although similar proportions of septic system owners had inspected or pumped out their tanks recently.

Due to the small size and location of the southern watersheds, residents there were much more likely to live on the water (33%compared to 8%). About 9% of each sample kept farm animals on their property.

Southern area residents were more apt to consider themselves environmentalists (60% to 49%).

Water Resource Priorities

Residents from the southern and northern watersheds named very similar topics as the most important environmental issues, namely, water-related pollution problems.

Compared to northern area residents, southern residents were much more likely to name septic system pollution as a local problem (81% compared to 62%). Flooding was a major concern for northern area residents (74%) and hardly a problem for southern residents (43%). Runoff from farms was also more problematic for northern residents (73%) than for southern residents (62%). Neither sample was very worried about drinking water availability or purity.

About half of those surveyed in both areas thought water quality had not changed much recently.

Information Sources

For both the northern and southern Puget Sound study areas, mass media and word of mouth were the primary sources of information on how to conserve water and reduce water pollution at home.

Findings suggest that, compared to those in the northern watersheds, southern area residents were more aware of their local water quality enhancement programs. Caution must be used, however, in interpreting these results, since the number and type of programs vary by location.

Compared to northern area residents, southern watershed residents were much more apt to have participated in at least one of the listed programs (40% to 18%).

Household Habits and Government Involvement

Majorities of both northern and southern area residents practiced water conservation and protection measures at home. Northern area respondents were a little less likely to say that their household is already doing a lot to save and protect water (31% to 37%).

Both groups thought "additional information" would be the best way to get them to do more to conserve and protect water resources (20%-21% mention).

The two groups were nearly identical in their priorities for water pollution control: Half of each group preferred enforcement over new laws. Majorities of both groups were willing to pay at least a dollar a month to help reduce water pollution (61% of southern and 57% of northern area residents).

Compared to northern area respondents, those in the southern study area were much more interested in protecting their water wells (36% compared to 12%), and somewhat more interested in natural landscaping and gardening (40% compared to 34%) and composting (30% compared to 24%). This is to be expected, since southern area residents were more apt to have private wells.

CONCLUSIONS

Overall, surveyed residents of various watersheds around Puget Sound showed serious concern about issues related to local water quality. In both surveyed watershed areas, residents were most worried about Puget Sound pollution in general, and fish and shellfish habitat destruction in particular. In contrast, few residents seemed worried about the purity or availability of drinking water.

Majorities of residents in all areas said that they practiced each of five listed water conservation/protection measures. In fact, more than three out of 10 indicated that their household was already "doing a lot" to save water and prevent water pollution. This points out that most residents perceive themselves as being involved in water issues at the household level.

Similarly, almost two-thirds of residents thought they knew enough about water conservation and protection. People under 35, however, showed greater interest in almost all suggested topics. This age cohort also generally expressed greater concern about water quality issues.

Comparisons between the watersheds suggest that focused educational efforts in the southern watershed are paying off: Southern area residents were much more likely than northern area residents to be aware of and participating in local programs. Another interesting point is that two of the southern area programs—Country Living and Common Sense Gardening—appealed to types of people who were not normally attracted to water quality educational programs, namely, people 65 years or older and those whose education ended in high school. This may be because these two programs provided practical suggestions for efficient gardening and watering, with less of an emphasis on environmental effects.

Overall findings suggest that reaching "unaware" or "uninvolved" residents poses some challenges. Many did not practice water conservation measures, and many did not consider themselves environmentalists. A number of them appeared to lead busy lives, and, compared to "aware" or "involved" residents, fewer of them had graduate school experience. On the other hand, almost two out of five said they lacked information on water conservation and protection. This suggests a desire for more information, but perhaps with less of an "environmentalist" perspective.

ACKNOWLEDGMENTS

The author wishes to acknowledge the contributions of all those who took part in this study, particularly Annie Phillips of the Washington Department of Ecology. Thanks also go to the representatives of local governments in Mason, Skagit, Snohomish, Thurston and Whatcom counties who suggested topics for inclusion in the survey instrument.

THE SUCCESS OF WATER WATCHER ADULT EDUCATION PROGRAMS: HOW PEOPLE FORM RELATIONSHIPS WITH CONTROVERSIAL PUBLIC POLICY CONCERNS AND MOVE TO LOCAL STEWARDSHIP ACTION

L. Katherine Baril[1] and Lyn Pinkerton[2]

ABSTRACT

Previous research has shown that efforts to protect Puget Sound, particularly watershed planning, are a political, not a scientific, process. However, very little research or documentation has been done on efforts to change the attitudes and behaviors of adult public policy and decision-makers. A very successful model of adult education and involvement has been the Watcher community education programs that operate in counties around Puget Sound, in states as diverse as Alaska, Idaho, Ohio, Delaware and Texas, and in three foreign countries. Starting as a 1988 Public Involvement and Education project with Puget Sound Water Quality Authority contract funds, this program has been very successful in building local citizen awareness, action, and political constituencies for water quality protection.

Our objectives are to document for researchers, public policy professionals, and water quality managers a successful model of community involvement and action in water quality issues, and to increase the awareness of common property ownership models that may be applicable to today's water and salmon controversies. Eight years of empirical and anecdotal research and evaluation exist on the Water Watcher programs in Puget Sound. This data, as well as participant references, will be analyzed and compared to current public policy and sociology research. The data from the Watcher programs will be compared to the principles currently being identified by Kettering (1992), Harwood (1994) and Yankelvitch (1992), and key indicators of success will be defined and substantiated for evaluation and replication.

Awareness and support of this successful public policy education strategy will increase understanding of the elements necessary to help the public "work through" difficult issues and come to a new stewardship public judgment. We conclude that:

- Initiatives to engage citizens on public policy issues must recognize and work with the idea of "meaningful chaos" and tap into the possibilities of building new, stronger relationships among diverse adversaries and interests.
- There are documented and established techniques and approaches that can significantly increase a community's ability to identify with and take action on public policy issues. These approaches are rarely used in today's traditional watershed planning in Puget Sound.
- There is a significant body of national research expertise and a knowledge base that documents the basic tenets that lead to the success of the Watcher model. By understanding these principles, Puget Sound planners and agency representatives could be more successful in bringing about the changes in attitude, behavior and lifestyle that are necessary to protect Puget Sound.

The Water Watcher, Bay Watcher and related programs offer a critical model for local planning efforts to involve the public in complex, controversial issues in a successful manner—a manner that results in an educated and supportive constituency and action rather than aversion to water issues.

[1] Washington State University Cooperative Extension, P.O. Box 572, Port Townsend, WA 98368

[2] University of British Columbia

CONNECTIONS BETWEEN BELIEFS AND VALUES AND ENVIRONMENTAL POLICIES: THE MANAGEMENT OF CONTAMINATED SEDIMENTS IN PUGET SOUND

Thomas M. Leschine[1] and Kent A. Lind[2]

INTRODUCTION

Sediment contamination in the Puget Sound basin is a problem of long-standing concern. Even though the release of toxic chemicals via industrial and municipal sources appears to have peaked during the 1950s and 1960s, contamination persists in many areas. In urban bays concentrations of some contaminants are 100 or more times greater than the levels found in sediments in rural areas (PSWQA, 1992). Although much of this contamination is historical, point source discharges, non-point runoff, accidental spills and atmospheric deposition continue to add contaminants to the system.

Extensive studies have documented numerous adverse effects from sediment contamination. These include impaired growth in marine invertebrates, decreased reproductive success, tumors, fin erosion and other abnormalities in bottom fish, and compromised immune systems in Chinook salmon (Casillas, 1993; Casillas et al., 1992; Johns et al., 1989; Malins et al., 1984; Varanasi et al,. 1992, 1993). Some contaminants bioaccumulate in marine organisms, thus generating pathways by which they may be passed on through the food chain to humans as well (PSWQA, 1992; Varanasi et al., 1993).

In 1991 Washington became the first, and to date only, state to adopt specific standards for the assessment and management of contaminated marine sediments (EPA, 1992). With roots in the referendum-generated Model Toxics Control Act, Washington's sediment management initiative has to date engendered relatively little public controversy. Nevertheless, the cost and difficulty of dealing with contaminated sediments is potentially quite high. The Department of Ecology has estimated that costs associated with meeting current sediment-based source control regulations could exceed $400 million. In Elliott Bay alone, remediation of sediment contamination could require the capping or removal of more than 7,500,000 cubic yards of sediments (Ecology, 1990). Moreover, potential liability for contaminated sites has raised concern among both public and private submerged lands owners, who fear they could be forced to bear the costs of cleanup actions (Boren, 1994).

With the contaminated-site rankings required by Ecology's regulations yet to be published and only voluntary or federally mandated site cleanups having so far taken place, many of the elements of Ecology's sediment management initiative that are capable of engendering significant conflict have yet to emerge. It is appropriate therefore to examine in more detail the nature of the consensus over the direction of the sediment management program that has emerged to date, and to probe for areas where consensus could weaken as current program development efforts give way to program implementation. We pursue these questions in this article using the results of a mail survey we conducted during the first half of 1994. The survey focused on the beliefs, values and attitudes of knowledgeable individuals affected by or directly involved with the state's emerging sediment management program. It was developed to reflect a number of research hypotheses about the nature of the interaction among opposing forces in policy debates, embodied in the so-called "Advocacy Coalition Framework" (Sabatier, 1988).

THE CONTAMINATED SEDIMENT POLICY SURVEY

During the spring of 1994 we conducted a mail survey of a broad spectrum of individuals connected to Puget Sound's sediment management arena. We were seeking information on their beliefs and values with respect to environmental management in the region generally and in connection with the emerging sediment management program more specifically. We also sought information on policy preferences with respect to

[1] School of Marine Affairs, University of Washington, Seattle, WA 98195

[2] Plans and Regulations Division, National Marine Fisheries Service, Silver Spring, MD 20910

a number of specific issues that we felt, based on our background research, were important to Ecology's current sediment management program. Our survey sample included agency personnel, environmental group members, tribal representatives, landowners potentially affected by the sediment management initiative, and university scientists and environmental consultants who had been involved with aspects of the contaminated sediment problem. The agency personnel surveyed represented both regulatory and resource agencies like Ecology, EPA and NOAA, as well as regulated or potentially liable public agencies such as the Department of Natural Resources (DNR), King County Metro, and the region's public ports. Sixty of the 92 surveys mailed were returned, for a response rate of 65 percent.

The Advocacy Coalition Framework

The survey was constructed and analyzed using the Advocacy Coalition Framework (ACF) developed by Paul Sabatier and his colleagues (Sabatier, 1988, 1993). The ACF model posits that many important policy debates take place largely outside the public eye, involving relatively small but fluid groups from legislative committees, public agencies and affected interests that interact over fairly long periods of time. These interactions serve to shape the policies that ultimately emerge, and the policies that are adopted reflect the belief systems of those having a dominant influence on their development. Policies thus embody not only a set of priorities over values, but also specific assumptions about the underlying causes and significance of the conditions being addressed. Beliefs about the ability of the policy approaches adopted to achieve desired policy ends are also important. Surveys and content analysis of public documents are among the primary research tools used by ACF researchers.

An "advocacy coalition" consists of interest-group leaders, legislators, agency officials, researchers, journalists and others who share a set of normative and causal beliefs, and who seek to realize these beliefs by influencing the behavior of government institutions over time (Sabatier and Zafonte, 1994). When policy debates involve significant components of scientific and technical information, such information may enter the policy arena through the process of "analytical debate." Opposing advocacy coalitions develop or defend their positions by introducing evidence to demonstrate (or dispute) the seriousness of perceived policy problems, the workability or cost of proposed solutions, or the extent to which the problems under discussion can really be identified with particular causes (Sabatier, 1988). Policy development in such domains as offshore oil and gas leasing, water allocation policy, and watershed-based environmental management has been usefully analyzed via the ACF model (Sabatier and Jenkins-Smith, 1993).

Attitude and opinion surveys typically emphasize preferences and attitudes regarding current issues or events of broad societal concern or regarding present or proposed government policies or programs. While similarly focused, ACF-based survey research depends also on the ability to identify the beliefs and values that participants in a particular policy domain hold at deeper levels. ACF researchers argue that policy-relevant beliefs include such fundamental or "deep core" beliefs as attitudes concerning the nature of the relationship between humans and their environment or the balance that society should strive for between individual freedom and government control (Sabatier, 1993). More obviously policy-relevant beliefs and values can be further subdivided into "policy core" beliefs (regarding preferences with respect to the basic strategies that might be employed to achieve desired ends) and other "secondary" aspects of belief systems. The latter category includes the beliefs about the efficacy of specific approaches for resolving contemporary problems that are often the focus of public opinion surveys.

Well-defined advocacy coalitions exist in a policy domain when members of the groups seeking either to change or to maintain government policies show similar values and causal beliefs. Opposing coalitions, while defined by the ways in which their belief systems differ, may nevertheless share beliefs and values in a number of areas important to particular policy debates. ACF researchers argue that it is this sharing of beliefs and values across otherwise opposing interests that makes relatively painless policy change possible. The institutions associated with the policy-making process in a particular policy arena can play significant roles in promoting greater cross-coalition sharing of beliefs, a process Sabatier calls "policy learning," through their information production and dissemination efforts. A basic tenet of ACF research, however, is that when deep divisions exist in beliefs in "deep core" areas, the corresponding policy problems are

unlikely to find easy resolution. Moreover, the ability of scientific and technical information injected into the policy arena to promote consensus-building appears to depend on a number of institutional and situational factors whose influence is poorly understood (Sabatier, 1988).

CONTAMINATED SEDIMENT MANAGEMENT FOR PUGET SOUND: COOPERATION IN A POLICY ARENA MORE OFTEN MARKED BY CONFLICT?

The widespread presence of contaminated sediments in the urban bays of Puget Sound, together with evidence that this contamination is having detrimental effects on bottom-dwelling marine organisms in regular contact with contaminated sediments, has been documented in studies going back to the 1970s. By the mid-1980s, several Puget Sound-based programs had emerged to deal with the problems of assessing and managing sediment contamination. These include the Commencement Bay "Superfund" investigation, the Puget Sound Dredge Disposal Analysis (PSDDA), EPA's Puget Sound Estuary Program (PSEP), the Department of Ecology's Urban Bays Action Teams (UBATS) and the Puget Sound Water Quality Management Plan. The 1991 Washington State sediment management standards (WAC 173-204), which make use of approaches developed in some of these other initiatives, can thus be seen as the culmination of a variety of interagency and intergovernmental cooperative research, development and planning efforts spanning a time period of more than a decade.

PSDDA, an interagency group of state, federal and local agencies now entering its second decade, has met with success in developing guidelines for evaluating dredged materials for disposal and in locating disposal sites within Puget Sound. The high degree of consensus achieved over these initiatives seemingly stands in sharp contrast to the experience of many other regions of the country, where a process Kagan (1991) terms "adversarial legalism" has stymied efforts to deal with issues involving the dredging and disposal of contaminated sediments. For example the Port of Oakland's attempt to deepen navigation channels to accommodate modern container ships has until very recently led only to ever more stringent environmental stipulations and continued costly delay, a consequence, Kagan argues, of overly fragmented decision-making authority and the politics of self-interest.

Ecology's sediment management program appears to build on the earlier success of PSDDA and other local efforts to address the problems associated with sediment contamination, using the same management guidelines and technical assessment approaches (e.g., the Acceptable Effects Threshold [AET] approach to assessing contamination developed in the Commencement Bay Superfund study, and the "no" and "minor" adverse effects categorizations of contamination levels developed by PSDDA). In the view of Bish (1982), the kind of advance that is signified by the adoption of the sediment management standards is possible because Washington has a long and fairly unusual history of openness in state government. The degree of citizen access is relatively high, and a multiplicity of single-purpose resource management agencies use a well-developed informal communications network to sustain a highly collaborative decision-making environment. In contrast to the situation with Oakland Harbor, Kagan (1991) argues, authority relationships among agencies in the Puget Sound region are clearer, and disposal is more easily accommodated in the deeper, better-mixed waters of the Sound, particularly for the relatively uncontaminated materials whose disposal is permitted at the current PSDDA sites.

FINDINGS: ADVOCACY COALITIONS IN THE PUGET SOUND SEDIMENT MANAGEMENT ARENA

The Advocacy Coalition Framework predicts that we should be able to separate the individuals we surveyed into distinct coalitions on the basis of differences in their responses to survey questions concerning fundamental "deep core," but policy-relevant, beliefs. We would expect, however, to find more accord across otherwise opposing coalitions at the levels where beliefs and attitudes are more directly connected to the substance of current policies than at the level of their core beliefs.

Moreover, if environmental management in the region continues to operate as characterized by Bish (1982) and Kagan (1991), we would expect to find a fairly high level of connectedness of the individuals we surveyed to current efforts to develop policy responses to Puget Sound's sediment contamination

problems. If individuals from a wide spectrum of the interests affected by this problem have been fairly actively involved with it over a long period of time, and if there is indeed a basic accord on the policy direction, then we can infer that institutional efforts like PSDDA have contributed to the consensus-building that has occurred to date.

In order to address such questions, we chose respondents from a cross-section of groups with an interest in the sediment management problem and designed our survey with a comprehensive view of the problem's relevant dimensions. We aimed to identify respondents' beliefs in a variety of areas, including:

- Factors affecting the quality of life in the Puget Sound region
- Factors affecting the ecological health of Puget Sound and the health of residents in the region
- Causes, effects and present status of sediment contamination in Puget Sound
- Factors important to consider in establishing source control or sediment remediation priorities
- Quality of scientific information supporting sediment management decisions, and the role scientific information should play in decision making
- Desirability of a number of specific contaminated sediment policy proposals
- Beliefs about the effectiveness and influence exerted by organizations connected to sediment management policy making, and views on the relative desirability of having various levels of government in charge of the problem.

We also asked respondents to describe their connections and length of involvement with sediment management issues. Nearly half of those surveyed (29 of 60 surveys returned), represented government agencies, including public ports, and across the whole sample those responding had spent on average 9.1 years dealing with problems related to sediment contamination in some capacity.

To facilitate statistical analysis, most survey questions were framed using 100-point thermometer scales (typically representing the relative seriousness or importance of each of a series of named items with respect to a particular issue or problem), or seven-point Likert scales (representing the strength of agreement or disagreement with a particular proposition). The multivariate technique of factor analysis was used to construct scales capable of separating individuals into clusters on the basis of their responses to selected survey items. Scale reliability was tested via Cronbach's alpha statistic (see Lind, 1994, for additional details). Additional statistical correlations were developed (via Pearson's R) to test the strength of association between underlying beliefs and views on specific policy proposals.

Advocacy Coalitions

Factor analysis permitted us to identify two distinct advocacy coalitions which, on the basis of the views expressed, we labeled the environmental protection and economic development coalitions. This was done by means of paired attitudinal scales developed from survey information in three general areas of inquiry: quality of life in the region, ecological health of Puget Sound, and health of the region's residents. Respondents associated with various interests separated largely in the ways one would expect on the basis of the beliefs they expressed about the relative seriousness of:

- marine ecosystem problems, as compared to social and economic problems, as threats to the quality of life in the region;
- pollution, as compared to habitat loss and regional development, as threats to the ecological health of Puget Sound; and
- marine pollution, as compared to terrestrial and air pollution, as threats to the health of the region's residents (see Figure 1; the specific questions used to define each scale and details on how the scales were produced are described in Lind, 1994).

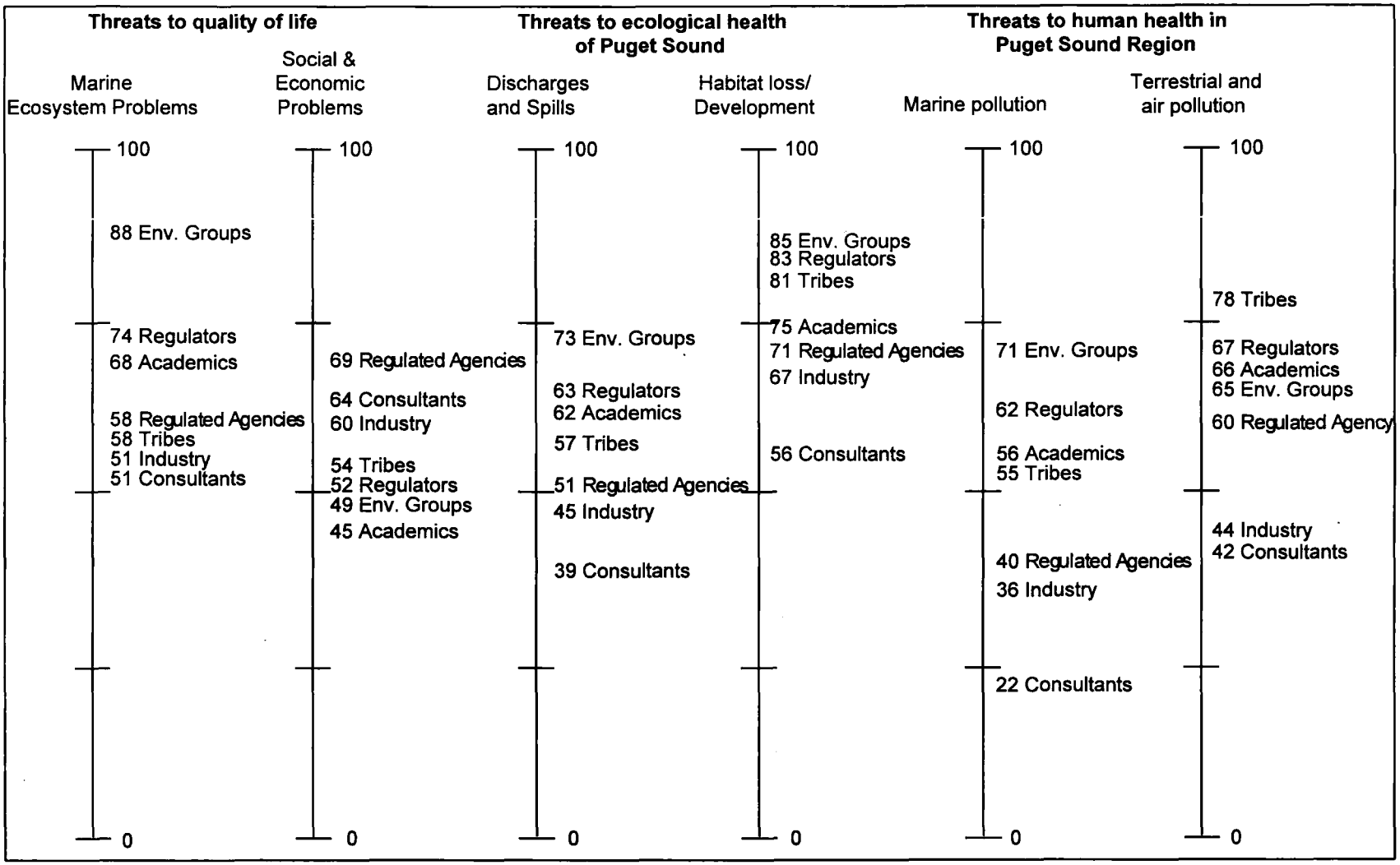

Figure 1. Placement of contaminated sediment policy advocacy groups on attitudinal scales to identify underlying coalition structure

Environmental groups, government regulators, and university researchers, who made up the bulk of those we identified with the environmental protection coalition, rated marine ecosystem problems as posing much more serious threats to quality of life in the region than did representatives of regulated agencies, tribes, industry and consultants, whom (except for tribal representatives) we identified with the economic development coalition. But on the question of connections between social and economic problems and quality of life in the region, these groups largely reversed positions (see Fig. 1). The associated environmental protection and economic development scales were highly reliable (alpha = .74 and .83, respectively).

Regulated vs. Regulator Agencies

The agency personnel surveyed also separated fairly consistently into the two opposing coalitions on the basis of their stated beliefs and values, depending on whether they represented land owner (regulated) or pollution control (regulator) agencies. As shown in Figure 1, the mean difference between these groups was more than 10 points on five of the six scales we used to place groups into advocacy coalitions. This suggests that the apparent success these agencies have enjoyed in collaborative efforts in the sediment management arena stems neither from shared bureaucratic neutrality nor from shared beliefs regarding the relative importance of sediment contamination and related problems in comparison with other problems facing the region.

We speculate that DNR's participation in PSDDA may have been instrumental in assuring that the belief structure of the economic development coalition was represented at the table as the basic direction later embodied in the sediment management standards was taking shape. The subsequent participation of DNR and public port representatives in Ecology's sediment management rule-making effort may then have helped assure that these beliefs continued to be represented as the region's sediment management program matured. If so, then the basic dynamic described by Bish appears to be at work in the region's sediment management arena: The continuing involvement of multiple agencies representing a broad spectrum of beliefs and values on the environmental protection-economic development continuum has assured sufficient consistency with the dominant (though conflicting) value systems to permit acceptance by a range of interests of the policies, standards and evaluation procedures that ultimately emerged.

Policy Level vs. Deep Core Beliefs

In contrast to the questions of fundamental beliefs that we used to separate survey respondents into the basic coalitions described above, other survey questions dealt with beliefs in areas that were more directly related to sediment policy (policy-level beliefs). These included several questions concerning the economic impacts of sediment regulations (which permitted construction of an "economic impacts of sediment regulation" scale), and other questions concerning the scope and thresholds for required sediment remediation actions (which permitted construction of a "scope of sediment remediation" scale). Respondents' beliefs in these areas separated in fairly predictable ways as well, but with somewhat less coherence than was shown by the deep core beliefs that produced the results shown in Figure 1.

Unlike with deep core beliefs, however, where individuals stood on these policy-level beliefs correlated fairly well with their views on the desirability of specific policy proposals in several areas—specifically, the strengthening of regulatory programs to control runoff and industrial discharges, and requiring property owners to remediate sites identified as "high priority" sites by Ecology. These policy-level beliefs correlated less well with beliefs about the desirability of policy proposals in three other areas, however (increasing public infrastructure investments in source control, limiting liability when sites have historic contamination not caused by current owners, and limiting DNR's liability for contaminated public trust lands).

The weakening of contrasts in belief structures across coalitions in those areas where basic policy approaches are at issue, illustrated here by the lower reliability of the scaling for policy-relevant beliefs, by the relative lack of correlation between policy-relevant beliefs and specific policy proposals, and by the virtual absence of correlation between deep core beliefs and specific policy proposals, is consistent with a view of the sediment management arena as one where progress is possible in spite of considerable

disagreement at fairly fundamental levels. People identifying with environmental values don't necessarily believe that property owners should be held strictly liable for contamination, and people who value highly economic development don't necessarily believe that contaminated sites shouldn't be cleaned up, even at private expense.

The associations that do appear to connect deep core beliefs with views on specific policy approaches can suggest areas to address in order to increase the acceptability of those policies, or to build more strongly the case for their necessity. For example, a fairly strong association exists between the acceptability of a policy proposal to strengthen source control regulations and beliefs about the impacts of sediment contamination on human health (R = .55). This association is stronger than any relating to beliefs about ecological impacts, suggesting that arguments for stronger source control regulation based upon evidence of human health impacts would be more compelling than the same arguments made on the basis of evidence of purely ecological harm. On the other hand, belief in the desirability of this same policy proposal is also negatively correlated with beliefs concerning the economic impact of sediment regulation (R = -.62). Strong arguments on behalf of such a proposal may well be necessary, coupled perhaps with fairly specific strategies for lessening its economic impact.

Sediment Contamination Assessment Tools and Their Role in Sediment Management

Ecology's basic strategy under the sediment management regulations is to separate the process of site assessment (for all intents and purposes a risk-assessment activity) from decisions on actual cleanup or other remedial actions (the process of risk management). Ecology's SEDRANK model can be used to develop scores representing the relative hazard that areas of contamination pose to human or ecological health. But decisions about actual cleanup priorities among sites are expected to take into account a broad array of social, economic and legal considerations included neither in SEDRANK nor in any of the other technically based site classification procedures developed by Ecology (WAC 173-204-550).

Ecology's assessment tools appear to be based on factors that, if not directly quantifiable, are at least amenable to resolution through empirical data or the application of theories rooted in the natural sciences. Those questions more likely to touch upon areas of core beliefs are reserved for resolution in the management arena, where process plays a prominent role in bringing disputed matters to resolution. While the process of defining technical tools can also bog down, the ACF model predicts that impasses are less likely to occur at the level where technical tools are being developed than when they are later applied to the decisions they are designed to support.

In order to test the strength of agreement regarding the technical approach to assessing risks embodied in the contaminated sediments rule, we developed a series of eight questions about factors that are or could be taken into account when Ecology's SEDRANK model is used to rank contaminated sites. We then used the responses to these questions in an attempt to generate, via factor analysis, paired scales like those displayed in Figure 1. Paired scales (i.e., multiple factors capable of differentiating clusters of respondents) could not be generated, however, indicating that respondents basically agreed about the relative importance of scoring factors similar to those used in SEDRANK. At least as far as these respondents are concerned, SEDRANK appears to incorporate about the right factors and to ask about the right questions concerning the relationship between the presence of contaminants in sediments and possible effects on natural resources or human health. If such accord is indicative of the success of the decision process that produced SEDRANK, then that process appears to have been successful.

SUMMARY AND CONCLUSIONS

The stakes in Puget Sound's contaminated sediments issue are considerable. The region's ports and waterfront industries and the state's Department of Natural Resources could face expensive site cleanups, and the region's environmental community and an array of marine natural resource users would like to see both the discharges that contaminate marine waters and sediments and the threats posed by existing areas of sediment contamination eliminated. The dimensions of the policy disputes involving these groups have been made fairly explicit as Ecology's sediment management standards have been developed. Less clear is

the extent to which policy participants are also separated by fairly distinctive sets of "deep" beliefs regarding, for example, the importance of a healthy economy relative to the importance of a healthy marine environment in the overall quality of life in the Puget Sound region.

That such differences in core beliefs need not lead to a policy impasse is evident in the progress made to date in dealing with contaminated marine sediment issues in the region. While we have no basis for comparing the intensity or extent of such beliefs to beliefs held by policy participants in regions (such as Oakland, Calif.) where similar questions have led to protracted conflict, the differences in the degree to which underlying issues have proved to be resolvable through regional consensus-building are considerable. When, some 10 years ago, a local dispute over the continued use of the so-called "Four Mile Rock" dredged material disposal site near Seattle led to the creation of PSDDA as a forum for developing a regional approach to dredged material disposal (Leschine, 1990), a process of consensus-building through technical dialogue was begun that continues today. Then as now, the emphasis appears to be on the resolution of technical questions in a forum that insulates the consideration of technical issues from the need to confront also the ramifications of applying technical tools in regulatory decisions. Perhaps as a result, there appears to be a high degree of accord that the tools that have been developed for Ecology's contaminated sediments program take into account the right factors in about the right ways.

Beyond this lies the more difficult question of whether consensus will dissolve as assessment turns to management. Expectations on both sides that sound technical tools, once applied, will yield the "right" answers cannot likely be met to the equal satisfaction of both sides. The fact that important players like the ports and maritime industries were not directly represented in PSDDA may explain in part PSDDA's ability to achieve consensus (Kagan, 1991). But the strong participation of DNR officials sympathetic to the plight of ports and maritime industries despite their basic resource protection mission may mean that the system Ecology will use to target future remediation activities will have the adaptability to avoid major conflict. If so, then the ability of the region's resource agencies to maintain a long-running, albeit predominantly technical, dialogue in a collegial, multi-agency forum may be a primary reason.

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UNDERWATER PARKS FOR PRESERVATION AND RESTORATION

Bruce Higgins[1]

INTRODUCTION

Demand for park resources has grown along with the urbanization of Puget Sound. One resource that has scarcely been tapped has been the subtidal lands adjoining waterfront parks. These subtidal lands can become year-round underwater parks for recreational scuba divers.

In 1970 the City of Edmonds established an underwater park at Bracketts Landing. The park has proved to be not only an attraction for divers but also a useful preservation tool, as demonstrated by the site's gradual improvement.

After the area was first designated as an underwater park and protected as a no-harvest area, local support was raised for planning and implementation. General uplands improvements have been matched with underwater improvements at little cost.

The park has applied general preservation and restoration techniques adapted for the marine environment to provide a recreation resource enjoyed by the region. Features have been added to improve diver safety. A perimeter buoy system to exclude boat traffic and an internal buoy system to mark specific sites have been installed. Underwater trails have been built to connect sites of interest and to guide divers back to the beach; this system of lines is now more than 2,000 feet long. Some wooden ships—features that are in great demand by divers—have also been installed.

The underwater park has been supported by a management system based on safety, security, and maintenance. Marine life in the area has returned and flourished; in fact, the park now contains some of central Puget Sound's largest specimens of lingcod and cabezon. Of course, it is always a challenge to meet the recreational needs of a diverse population without overloading the resource, and underwater parks are no exception.

RECREATIONAL DIVING IN THE NORTH PACIFIC

Planning an underwater park is difficult for people who are unfamiliar with diving. What follows, then, is a brief description of recreational diving in the Northwest.

The North Pacific is not blessed with great visibility or warm temperatures. It is, however, blessed with abundant plankton, which provide a wide base for the food web. This allows animals to live long and grow to massive size. And because many of the animals are to some extent camouflaged, they allow close observation by divers. The majority of divers are not harvesters for the same reason most hikers aren't hunters: The scarcity of game has forced seasons and management practices. So most divers venture into the water for the same reason people like to hike; just seeing the various marine creatures in their natural setting is reward enough.

Because of the cold, divers in the North Pacific need more equipment than those in the tropics. The typical diver carries a cylinder, weight belt, suit, and other equipment totaling about 60 pounds. It takes a diver about an hour to unload, assemble and put on all this equipment. The in-water segment of a diving excursion lasts about an hour and a half. The divers actually spend between 30 minutes and one hour underwater since they are limited by the amount of air they carry and the depth-time limits for recreational divers. The rest of their in-water time is spent snorkeling about. Often another limiting factor for dive duration is staying warm. Even for divers wearing the better equipment, cold is a frequent problem. After returning to the beach, divers remove and pack their equipment, a process that takes another hour or so. So, for a diver using a waterfront park, the minimum visit lasts about three hours.

[1] Battelle Marine Sciences Laboratory, 1529 W. Sequim Bay Road, Sequim, WA 98382

An Example Park

The establishment in 1970 of an underwater park by the City of Edmonds at Brackett's Landing has proved to be a useful preservation tool as well as recreational outlet. Edmonds has a number of special-purpose parks that focus on baseball, soccer, bird watching, and the like. It was natural, then, to turn a segment of the beach into an underwater park. The site holds historical significance to the City of Edmonds because it is where the city's founder, George Brackett, established his home and shingle mill. The site now adjoins a ferry terminal on the south and so is seen by people traveling to and from Kingston.

This site has historic underwater features as well. The remains of the shingle mill can be found scattered about the area. In 1935, a dry dock more than 300 feet long was sunk as a current barrier for the docking ferries. This is a historic dry dock because it serviced sailing ships for 25 years at Dockton on Vashon Island at the turn of the century.

The uplands portion of the park is slightly more than two acres. Around the 1960s the city started uplands improvements with the construction of a bath house and parking to allow better access to the sandy beach. In 1970, the city established the park as a no-harvest area by city ordinance and secured a lease for the subtidal lands for recreational diving from Washington's Department of Natural Resources. This lease extended offshore to the outer harbor line, since this had been a commercial site. The lease was later extended north to include 25 acres total of subtidal lands for diving and conservation. The no-harvest area was included in the state fishing regulations.

With the start of the 1980s the Parks Department in conjunction with Shoreline Community College's Marine Science Program developed a Beach Ranger Program for spring and summer beach interpretation and tours for school groups. This has expanded and is now a joint educational effort of the cities of Edmonds, Lynnwood, and Mountlake Terrace. The program is administered by the Edmonds Parks and Recreation Department.

The park's subsequent gradual improvement has shown how preservation combined with recreation and education can be a useful development tool. Volunteer divers have formed a network that allows for routine maintenance of the park's features. Features have been added to improve diver safety. A perimeter buoy system to exclude boat traffic and an internal buoy system to mark specific sites have been installed. Underwater trails connect sites of interest and guide divers back toward the beach. This system of lines, held to the bottom by cinder blocks and culvert, is now more than 2,500 feet long. Two wooden ships have been brought in to provide features in great demand by divers. Uplands interpretive information gives the diver and beach user details about the site and about marine life. The park has become a regional recreational resource because of its beautiful views and the near-shore access to varied marine life.

For years the park had been out of sight, so it was forgotten. But now because of the site's popularity with divers, the upkeep of the park is receiving more attention. The restoration effort includes removal of litter and the removal of ghost nets—nets that continue to fish after being lost by fishermen. Re-exposure of lost anchors, chains, ship parts, and industrial remains found on the area can help the site tell its story. Intertidal debris can be put to other uses as well. At the Edmonds park, for instance, abandoned railroad track has been used as intersection markers for the trail system.

The marine life, especially lingcod and cabezon, has returned and has flourished in the park. The simple oasis strategy of placing isolated features about 100 foot apart, away from critical eelgrass habitat, has been very effective. These features have been made of on-site material displayed to the divers' benefit. The marine life has needed havens from predators, which include occasional harbor seals, sea lions, and bald eagles, which feed in the park and put on quite a show. Besides providing havens for marine life, the diver-placed features are also useful for directing divers into less visited portions.

ELEMENTS OF AN UNDERWATER PARK

Following are the key elements of an underwater park.

Designation as a No-harvest Area

Designation as a no-harvest are is a most important first step. This sets a tone for the development plan and the park's future. This way, come planning and decision time, conservation strategies for the site will prevail over harvest management strategies. A no-harvest designation also puts bounds on the level of development to meet conservation and educational needs. This makes a strong statement to the Department of Natural Resources during the lease application as to the intended purpose of the lease. The general rule of thumb is to use the same land-use policy for the subtidal area as for the adjacent uplands. If there is no harvest in the uplands, there should be no harvest in the subtidal as well.

Access

Access controls how divers view the site. If access is difficult, divers may choose not to invest their effort there. Upland parks have shown that access does not have to be immediate and curbside but that some access needs to be provided. Furthermore, underwater park access must allow for the bulk and weight of diving equipment as well as emergency equipment. Access conflicts should be anticipated and dealt with ahead of time. Conflicts often arise with multiple use (divers leaving sand on a roller-skating path, for example).

Safety

The first safety issue is water quality suitable for swimming contact. This often means dogs and horses must be kept off the beach to preserve water quality. Divers don't typically dig in the sediment to the extent that sediment quality becomes an issue, but they can suspend surface material with their fin kicks much as a storm would.

The diving community has supported a "responsible diver program" to make divers aware that they are responsible for their own safety. Diving safety is enhanced by a perimeter buoy system to keep boats and divers separate. Other safety features include markers for key underwater features and underwater trails to provide guidance. A shoreside site chart and tidal information are important as well.

Security

Underwater parks carry special security concerns. The intertidal resources are not sheltered during storms as the subtidal ones are. Buoys, stairs for access, and near-shore structures are at risk every year. Too often park designs are proposed based on a visit to the beach during a calm, sunny summer low tide. The reality of 4-foot waves during a winter storm at high tide sends the plan back for a redesign. The careless use of boats in or near the park can play havoc with buoys, which are struck and sunk by boats operating after dark. Theft of park resources is a possible problem, complicated by the difficulty of discovering losses (with varied diving conditions it may be some time before an inspection can be made). Designs that address these issues are more successful.

A Long-term Plan

A clear long-term plan is an important part of a successful underwater park. As with any park, purpose, objectives, audience, evaluation criteria, and budget timing are all factors that need careful consideration. Every parks department or board has its own planning and budget cycles.

The idea of underwater parks has been slow in taking root. The underwater environment is nearby but has for years been viewed as unfathomable. And for many people underwater recreation is associated with exotic locations, not Puget Sound. But during the past year, a method has been suggested for local groups wishing to get involved in underwater park planning. The method involves five simple steps that provide a reasonable base for turning the dream of an underwater park into reality. The steps are:

1) Research and study the site. During this step divers map the area and identify key habitat, features, and items of interest. This includes starting baseline observations that would be required for future permits. Underwater sites require more research than upland park areas because, being out of sight to all but divers, they are unlikely to have received a detailed review.

2) Synthesize and analyze the information that's been gathered. During this stage the information is documented and presented in a form that can be used for the present and future activities.

3) Develop a plan. The plan should be based on the information collected during the previous steps. While the plan is being developed all the concerned agencies and groups can provide information and see what is planned for the site.

4) Implement the plan. During this phase the plan is put into action.

5) File progress reports. Everyone wants to know how the plan is progressing. Sometimes the steps are months apart; progress reports can remind everyone how the steps fit together in the overall plan.

SUMMARY

Underwater parks can be a valuable recreational resource and could be considered in conservation and restoration efforts. Underwater parks can be used year-round by a community with aquatic recreational interests.

COMMUNITY-BASED ENVIRONMENTAL MONITORING IN PORT TOWNSEND BAY, WASHINGTON

James G. Norris[1] and Judy D'Amore[2]

INTRODUCTION

Research alone will not preserve a healthy Puget Sound ecosystem. What really matters are the countless day-to-day activities of individual citizens and businesses throughout the Puget Sound region. Government regulations may influence those activities, but in a democratic society regulations themselves are simply expressions of the public's current opinion about what is, and is not, acceptable or appropriate behavior. In the end, it is an educated and motivated citizenry that will make the difference. Thus, the links between sound research, public education, strategic planning, and government regulation are critical to preserving a healthy Puget Sound ecosystem. This paper summarizes programs at the Port Townsend Marine Science Center (PTMSC) designed to strengthen these critical links.

The PTMSC was founded in 1982 as a non-profit, membership organization dedicated to helping educate local citizens and visitors about the Puget Sound marine environment. Its aquarium, classroom, and offices are located on the public pier in Fort Worden State Park. Exhibits are open about 140 days and attract more than 20,000 visitors each year. The center is staffed by five part-time hourly employees augmented by more than 2,000 volunteer hours annually. During 1994, the PTMSC conducted 293 separate education programs, each involving five to 30 students. Funding for the center comes from grants, the state legislature, entry fees, book and gift sales, donations, and dues from society members. The total annual budget for 1994 was about $110,000.

Since 1988, the PTMSC has conducted a community-based environmental monitoring and education program through funding from the Centennial Clean Water Fund administered by the Washington Department of Ecology. Other participants in this program are the Jefferson County Planning Department, the City of Port Townsend, the Port Townsend School District, and a local consulting firm (Marine Resources Consultants). The goals of the program are threefold: (1) to make significant contributions to the scientific knowledge of the ecology of nearshore marine habitats; (2) to increase public awareness of the ecological importance of nearshore marine habitats and their sensitivity to water quality degradation; and (3) to strengthen the environmental consciousness and commitment of citizens by providing opportunities to participate in monitoring nearshore habitat utilization and water quality in Port Townsend Bay.

COMPONENTS OF THE PROGRAM

The overall program has six components: (1) beach observations; (2) conventional water quality monitoring; (3) weather observations; (4) beach seine observations; (5) annual bottom trawl surveys; and (6) semi-annual underwater video surveys to map and estimate basal area coverage of eelgrass along the Port Townsend waterfront. Data are collected following Puget Sound Protocols and are stored in ASCII format for easy exporting to other databases. The following sections describe each of these components in more detail.

Beach Observations

Beach observations are conducted by volunteers at five beach sites in the study area. Beaches are monitored each week for beach composition, weather, animals and plants sighted, debris of any kind, and oil. Volunteers are trained in observation and water collection procedures and provided with equipment and data sheets. Meetings are held twice a year to inform volunteers about trends observed in the data.

[1] Marine Resources Consultants, P.O. Box 816, Port Townsend, WA 98368

[2] Port Townsend Marine Science Center, Fort Worden State Park, 532 Battery Way, Port Townsend, WA 98368

Weather

The weather station is located at the PTMSC pier and is monitored daily by volunteers. The following data are collected: water and air temperature, barometric pressure, cloud cover, rainfall, and wind speed and direction.

Conventional Water Quality Monitoring

Baseline water quality profile data (temperature, salinity, dissolved oxygen, secchi disk depth) are collected each month from 15 stations in Port Townsend Bay. Data are collected at the surface, every meter for the first five meters, and every five meters to a depth of 35 meters. Four of the stations are located along the Port Townsend waterfront and have data dating to 1988. The *R/V Monte Python*, a 26-foot open vessel operated by the PTMSC, is used to collect this data. All eighth-grade students in the Port Townsend School District participate in this nearshore component of the program, which is integrated with the eighth-grade science and computer curriculum. While participating on field data collection trips, students receive information on sources of contamination to Puget Sound and are informed about what they can do as citizens to help prevent water quality degradation.

Eleven offshore stations were added to the program in 1993 to provide a more complete description of the bay. These data are collected using the *R/V Brendan D II*, a 36-foot research vessel operated by Marine Resources Consultants. Senior high-school marine biology students help monitor these offshore stations.

Beach Seines

Beach seines are an important component of many of the PTMSC educational programs. They are conducted at various times throughout the year in an eelgrass meadow near the PTMSC. Students and volunteers help haul the net, and PTMSC staff provide information about the natural history of the species captured. A species checklist is used to record presence/absence and relative abundance (greater or less than 25).

Demersal Fish Abundance Surveys

Annual demersal fish abundance surveys have been conducted since 1991. Fifteen stations are sampled during the last week of June each year using a modified 7.6-m otter trawl and following Puget Sound protocols. All vertebrates and commercially important invertebrates are counted. Length samples are taken from all gadids, flatfish, and herring on each haul. Data are recorded on field data forms and entered into an onboard computer. The computer database follows the format used by the National Marine Fisheries Service, including species codes. Volunteers help with sorting, counting, measuring, and entering data. Each survey takes two days and is divided into morning and afternoon shifts to accommodate volunteer time schedules. Data from these surveys have been used to estimate population abundances of demersal fish species (Norris 1992a, 1992b).

Underwater Video Eelgrass Surveys

In 1994, semi-annual seagrass surveys using underwater video techniques (see Mumford et al., this volume) were initiated. Surveys are conducted at times of maximum (July) and minimum (February) eelgrass biomass to create maps of eelgrass distributions and estimate the basal area coverage of eelgrass (i.e., area of bottom covered with eelgrass) in the nearshore habitat between Point Hudson and the Port Townsend Boat Haven (1.0 nm of shoreline). Students and local citizens assist with the surveys.

Each survey consists of a series of straight line transects perpendicular to the shoreline. The underwater video camera and light are mounted in a down-looking orientation on a towfish deployed directly off the stern of the vessel using the cargo boom and boom winch. Global Positioning System (GPS) data and video signals are input into a laptop computer equipped with a video overlay controller and data logger software. GPS data (date, time, latitude, and longitude) along with transect identification numbers are stored directly onto the video tape using a four-head VCR. Data and survey notes are stored

automatically on a floppy disk at two-second intervals. Each transect provides data on the fraction of the seabed that is covered by eelgrass, as measured by time or distance. Standard statistical procedures are used to estimate the basal area coverage over the entire study area. Data also can be exported to a Geographic Information System for creating thematic maps of seabed attributes.

DISCUSSION

At the regional level, the data collected during the PTMSC community-based environmental monitoring project will complement ongoing data collection and research activities by other agencies, such as the Washington Department of Fisheries, Habitat Investigations Division, the Washington Department of Natural Resources, Division of Aquatic Lands, and the Puget Sound Ambient Monitoring Program. But more important is the project's impact on creating the critical links at the local level. Taking an active role in monitoring can create a greater personal stake in protecting the environment. This project strives first to give people experiences that build that commitment, and second to provide them with the knowledge to turn that commitment into constructive behaviors. All educational components of the program strive to provide young people and adults with the tools they need to make informed decisions about water quality issues both as voters and through personal action. Thus, by integrating research and public education, this program supports efforts to act proactively in the protection of rapidly disappearing habitats as is recommended in the Puget Sound Water Quality Management Plan.

While it is difficult to measure the program's success, we cite four instances where this project is contributing both data and educational opportunities to the shoreline management decision-making process for Port Townsend Bay. Nearshore marine habitats in Jefferson County are increasingly threatened by economic growth, especially shoreline development. Three proposed development projects are (1) renovation of the Union Wharf, a historic pier that has been condemned since 1981 when a truck crashed through the loading dock; (2) installation of a waste-water outfall at a local fish processing plant; and (3) construction of a new downtown marina. In each of these examples, video tapes from the July 1994 underwater video survey have been used to examine eelgrass distributions in the vicinity of each project. Local officials and other interested parties will participate in the February 1995 survey to get a firsthand look at the subtidal habitat near their project of interest. A fourth proposed development project is the expansion of the Port Townsend Boat Haven to accommodate a heavy haulout facility. Conventional water quality and demersal trawl survey data were used to prepare the draft EIS for that project (Bonar, in press). For local students, each of these cases offers a real-life example of a difficult public policy decision involving water quality issues.

One major obstacle for the program has been securing liability insurance to allow school children on the research vessels. In the fall of 1993, the Port Townsend School District required that it be named as Additional Assured on research vessel liability insurance policies. It was difficult to find an underwriter willing to accept liability for school children on the vessels, and then only at considerable extra expense.

In summary, this project provides Jefferson County with a means of working closely with community organizations and public schools to enhance public involvement and awareness of water quality issues relating to shoreline habitats, while collecting baseline data on marine water quality conditions. Information obtained from this project may directly assist city and county planners in issuing determinations of significance/non-significance for shoreline development. For schools, this project offers exciting, socially relevant experiences for students. For the community, it offers an opportunity to become directly involved in monitoring procedures that can be used to help detect water quality problems in the area. The project also assists residents in becoming better informed about water quality issues affecting the area in which they live. Finally, this project can serve as an example to other agencies and communities of how to use local resources to obtain scientifically useful information, while at the same time providing public information.

ACKNOWLEDGMENTS

First and foremost, we thank the many volunteers who have committed their time and energy to making this monitoring project a success. Science teachers Tedd Davis and Lois Sherwood also deserve special recognition for integrating this monitoring project into their classroom curriculum. Charles Simenstad of the University of Washington provided technical guidance during project development. Janie Civille, Toni Canova, and Brad Caldwell of the Washington Department of Ecology helped with the financial and administrative details. We also thank the Jefferson County Planning Department, the City of Port Townsend, the Port of Port Townsend, Port Townsend Paper Company, and the Port Townsend School Board for their support and cooperation. This project was funded by Centennial Clean Water Fund Grant Numbers 91018 and G9200331 and was administered by the Washington Department of Ecology.

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PUGET SOUND RESEARCH '95

SESSION 9C

OCEANOGRAPHIC AND ENVIRONMENTAL MEASUREMENTS

Session Chair:

Tim Ransom
Puget Sound Water Quality Authority Staff

COMBINING FIELDWORK WITH MODELING TO OPTIMIZE INFORMATION YIELD

Donald O. Hodgins and Anthony J. Webb[1]

THE ISSUE

Public awareness and concern over municipal wastewater and industrial effluent disposal in the marine environment has increased over the past few years, and this is a trend that is likely to continue in the future. It is reasonable to expect that, as marine scientists and engineers, we will be in a position to provide a scientifically credible explanation of the dispersion processes and ultimate fate of a discharge. Traditionally, this problem has been approached using simple models for initial dilution and secondary dispersion based on similarity laws, or a localized oceanographic study using drogues, current meters, or, perhaps, dye tracing. Until recently the combination of both approaches, extended to give far-field predictions, has seldom been attempted, especially for smaller outfalls. Cost is often cited as the justification for not providing a more thorough examination of wastewater fate.

Two new technological developments have helped to change this situation. The first is the introduction of relatively inexpensive yet versatile *in situ* dispersion surveying instruments like the TRACER system. The second is the development, and now routine application, of three-dimensional (3D) models for circulation and dispersion in stratified coastal waters. It is widely appreciated that two-dimensional, depth-averaged models are not applicable in Puget Sound, Juan de Fuca Strait and the Strait of Georgia because they do not resolve the depth variations in density and current necessary for accurate dispersion modeling.

The synthesis of site-specific field observations with a 3D dispersion model is discussed in this paper. A brief outline of the TRACER system is given first, followed by a discussion of the GF-series of 3D models. Their use in a study of optimal wastewater dispersion for a small town in British Columbia is then described.

OBSERVATIONS VERSUS MODELING: PROS AND CONS

It might be argued that a dispersion study for an outfall needs field observations, or modeling, but not both. Each approach has advantages and disadvantages, and both are now quite feasible. Some pros and cons of each method are summarized in Table 1.

It is apparent that neither method is sufficient to answer all the questions that arise, and it is apparent that the two approaches are intimately linked and highly complementary.

DISPERSION SURVEYING USING TRACER

The objective of dispersion surveying is to accurately delineate the wastewater plume as it spreads out from the outfall or diffuser, and to quantify the rate of dilution along the transport path. This is usually done by introducing a readily detected, stable tracing substance such as Rhodamine WT Intracid dye into the wastewater stream and measuring its concentration in the receiving water. Because tidal currents carry the dye cloud rapidly away from the outfall location, and because the cloud often traps below surface, towed, high-sampling rate *in situ* instruments are required to measure concentrations. Only such instruments can achieve the spatial resolution and sampling density needed to define dilution accurately.

In 1988 Seaconsult introduced the TRACER system (Hodgins, 1989), which was modified in the early '90s into a lightweight, portable sensor package, called the Dragonfly, suitable for small-boat use in shallow coastal waters (shown in Figure 1). It consists of an accurate underwater VARIOSENS fluorometer providing a log-linear concentration range spanning four orders of magnitude (0.1-1000 µg/L), a Sea Bird conductivity-temperature-depth (CTD) instrument, and a motor to control the attitude of the lift foils.

[1] Seaconsult Marine Research Ltd., 8805 Osler Street, Vancouver, Canada V6P 4G1

Table 1. Comparison of field observations and modeling

SITE-SPECIFIC FIELD OBSERVATIONS	
Advantages	**Disadvantages**
accurate measurement of localized currents, tides and density	limited spatial resolution of the flow field
detailed, high-resolution measurements of trapping, initial dilution and local transport [dilution ≈ 1000:1, transport over ≈ 5 km]	valid only for period of observations; must be repeated for other conditions
necessary for validation of any model or description of actual conditions	usually limited to a single outfall for each survey
THREE-DIMENSIONAL MODELING	
Advantages	**Disadvantages**
valid for all conditions once calibrated and verified [assuming baseline data are available]	lower spatial resolution and lower accuracy than observations
far-field capability [dilution > 10^7:1, range > 50 km]	high data demands [density field, river runoff]
multiple-outfall combined effects; pre-built and as-built conditions	
excellent data visualization for technical and lay audiences	

These devices are mounted in a stabilized frame, connected to the computer data logger in the boat by an electro-mechanical wire (power down-signal up). The in-water sensors are sampled at 2 Hz. Positioning information is obtained using GPS or a microwave network, updated every second.

The instrument package is towed behind a 20-to 25-foot boat at 3-5 knots, over a depth range of 1-80 m. The depth and stability of the package is controlled by hydrofoils, which can be adjusted from the surface using a joystick. The spatial resolution of the dye concentration measurements is about 10 cm. Using differential correction on the GPS, or the microwave positioning system, the spatial location of each measurement is known to within 5 m. By towing the sensors back and forth through the dye cloud, the effluent plume can be quickly and accurately positioned in all three dimensions (x,y,z), and the dilution at any point can be quantified.

Surveying with this instrument is effective at the surface, and at subsurface trapping depths. By oscillating the tow, both top and bottom edges of the wastewater plume can be mapped. When combined with current data from one or two strategic locations in a given area, the dye concentrations and the definition of the vertical and horizontal stratification fields provide a complete physical description and explanation for the observed dispersion patterns. Such data also provide solid verification for numerical dispersion models.

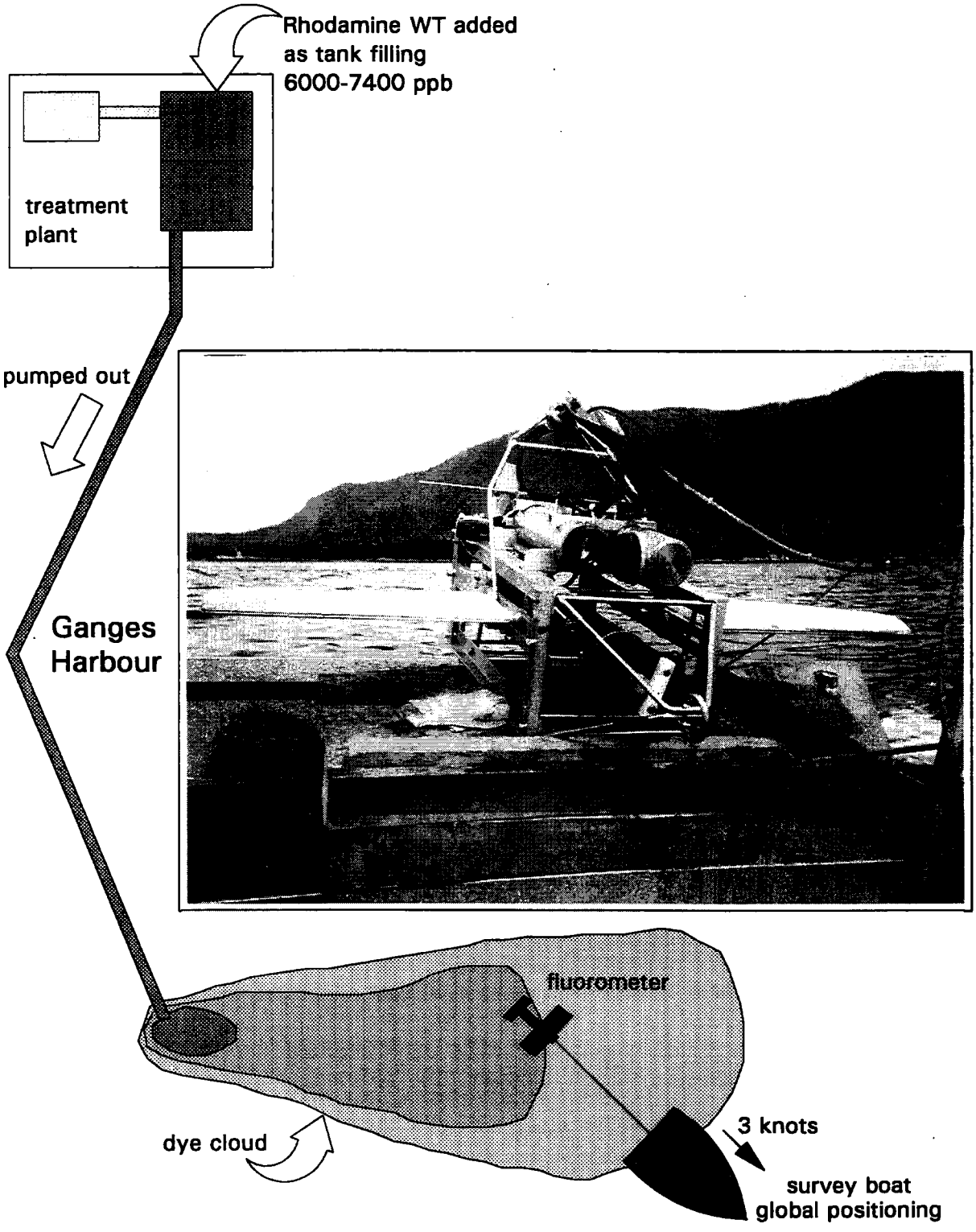

Figure 1. Photograph of the TRACER Dragonfly underwater fluorometer and CTD instrument used for plume delineation. The schematic diagram shows the Ganges case study dye injection scheme and surveying principle.

THREE-DIMENSIONAL MODELING

The Puget Sound-Juan de Fuca waterway is an estuarine system, driven mainly by the Fraser River but with obvious local contributions from smaller tributaries in Washington state. The currents and density stratification are governed by the river runoff, by the tides, by wind, by the intrusion of oceanic water from the Pacific Ocean, and by the shape of the basins. In order to model wastewater dispersion, the vertical and horizontal variations in density and currents resulting from the mixing of river runoff and oceanic water must be taken into account. This is not a simple task because of the strong currents and intense mixing that occurs in the passes through the San Juan and Gulf Islands. A fully three-dimensional model is required to simulate these oceanographic processes.

Beginning in 1988 the Canadian federal department of Fisheries and Oceans embarked on development of the 3D Georgia-Fuca (GF) series of models through a series of contracts to Seaconsult. In 1992 the models were calibrated and verified (Stronach et al., 1993) and have been used subsequently for a number of dispersion studies (see for example, Hodgins, et al. (1993) and Hodgins and Stronach (1993) for a discussion of far-field pulp mill effluent dispersion assessment). The models are based on conservation laws for momentum, mass, density (through salinity and temperature variations), and mass of solute in the wastewater. The governing equations (Hodgins, 1993; Stronach et al., 1993) are solved on Cartesian grids, with variable vertical spacing, using finite difference methods. The GF8 version resolves vertical variations in a series of fixed layers; the GF9 version features a dynamic upper layer suitable for simulating thin, dynamic river plumes such as the Fraser River. Input data consist of the bathymetry and shoreline geography, a starting density field, and boundary data on tide, wind, density, and runoff. One or more wastewater sources can be specified in terms of discharge rate and contaminant concentration. The output consists of 3D fields of current, mixing coefficients, water levels, density and contaminant concentration every few minutes through the tidal cycle. The model can be run for a few tidal cycles to examine localized dilution, or for several months in order to estimate far-field fate. The spatial resolution depends on the grid size and layer thicknesses. These parameters are selected to meet site-specific requirements.

The GF series of models accounts for all of the governing physical processes, and is limited only by the resolution provided by the grid, and by boundary data. Information on ocean water density and wind are the most serious deficiencies for Juan de Fuca Strait and Puget Sound.

CASE STUDY: WASTEWATER DISPERSION IN GANGES HARBOR

The town of Ganges is located on Salt Spring Island, British Columbia. It has a sewage collection system, with secondary treatment and wastewater disinfection using ultraviolet light. Flows in the system currently range from about 250 m^3/day to 525 m^3/day, and wastewater is discharged daily from 183 m^3 storage tanks on ebb tide. The discharge is pumped through a 4,800-m outfall and diffuser. The ebb-only discharge practice was instituted to prevent dispersion of fecal coliforms into the enclosed harbor basin; however, this method suffers from the disadvantage that significant bacterial regrowth takes place in the holding tanks after the disinfection stage. A study of the dispersion characteristics was carried out in 1993 to examine continuous discharge at the present flow levels, and at increased flows reflecting population growth and expansion of the sewage system in the future. The study area and bathymetry are shown in Figure 2.

This study was planned with a short, site-specific observing program to characterize the near-field plume behavior, and a detailed modeling phase using the dispersion measurements to validate model performance.

Field Observations

A five-day field program was carried out in November 1993 concentrating on dye dispersion measurements using the TRACER instrument package. Over the five days, each holding tank was injected with 6 L of 20% Rhodamine WT dye, and the subsequent dispersion was measured on both ebb and flood flows (Figure 1). In total 42 L of dye was added to 1,270 m^3 of wastewater giving an overall average dye

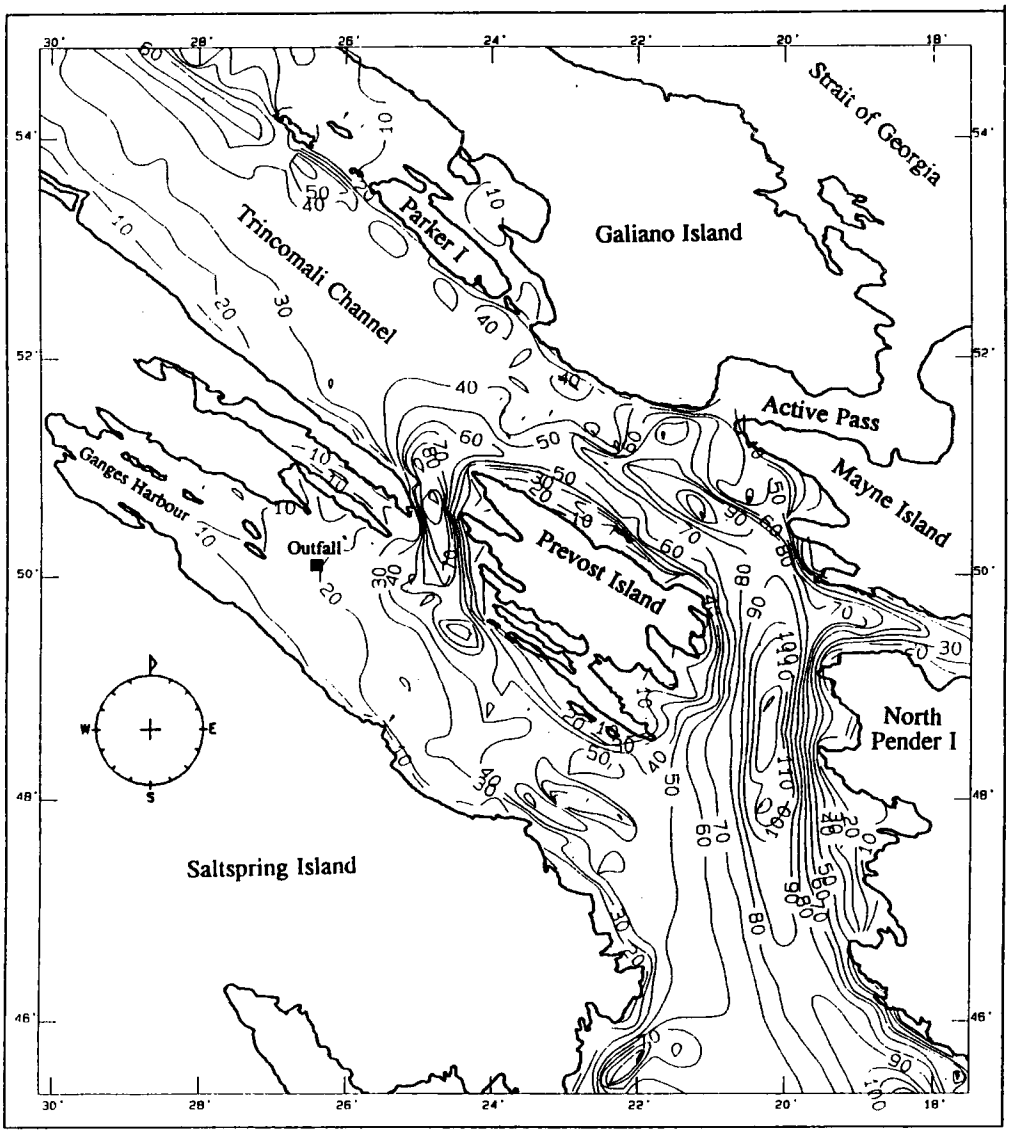

Figure 2. Map of Ganges Harbor in the Gulf Island of British Columbia, showing the outfall location

concentration of 6,700 µg/L in the outfall prior to initial dilution. The *in situ* detection limit was 0.1 µg/L; thus, the total measured dilution was 67,000:1.

The other data collected were:

1) currents in the dyed cloud using drogued drifters, positioned by the survey boat;
2) currents at 9 and 10 m using moored self-recording current meters adjacent to the diffuser;
3) local overwater winds near the diffuser location; and
4) water density using the Sea Bird CTD, in both towed and vertical profiling modes.

Data on tides, water density in the Strait of Georgia, and winds around the Strait were available from government sources.

Dispersion Modeling

The GF8 model was used to simulate the wastewater dispersion. Thirteen layers were used in the vertical dimension, with layer thicknesses of 5 m near the surface. The model was applied at two grid scales: 2 km to resolve the Juan de Fuca-Strait of Georgia waterway, and a high-resolution nested model with a grid spacing of 167 m for which boundary data were supplied from the 2-km strait-wide model. The 2-km grid model had been previously verified (Stronach, 1991). The current meter observations were used to confirm that the nested-grid model correctly predicted the main flow features (Figure 3). The agreement between the measurements and model output is generally good: the model successfully reproduces the persistent north-northeastward flow and its tidal modulation. The amplitude of modeled and measured currents is in good agreement.

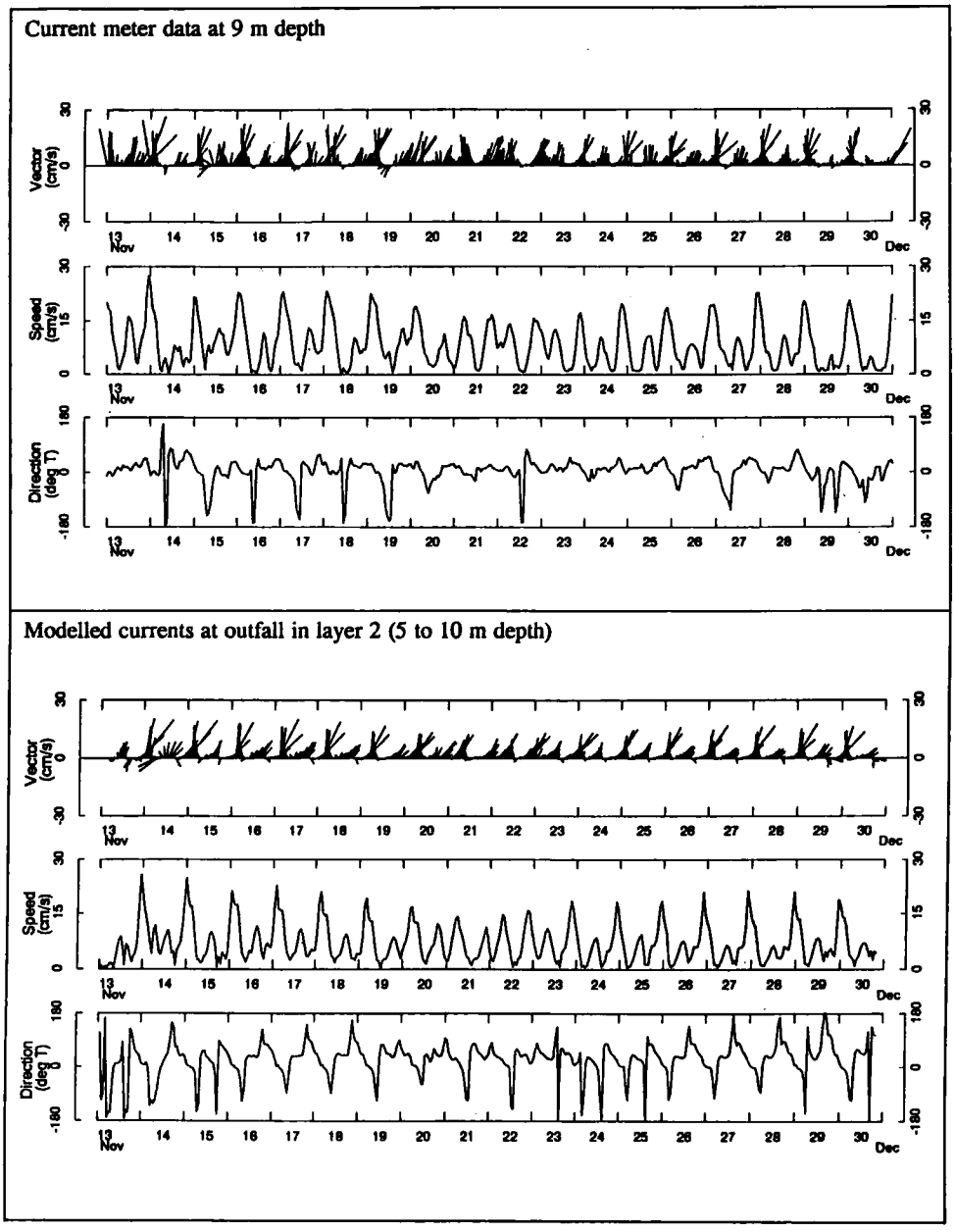

Figure 3. Comparison of current measurements at 9 m with the GF8 3D model simulation

Next, the model was used to hindcast actual conditions during the dye dispersion survey. A typical observed concentration field is shown in Figure 4, derived from towed measurements at 2.5-3.5 m (trapping depth) over a period of 1.5 hours. The dye was pumped out of the outfall during the rising limb of the tide (flood), and measurements spanned the high-water slack flow and small ebb of the day. The spatial detail resolved in the towed survey is evident in the high-concentration lenses and the elongated tongue extending northward from the diffuser, and the shore contact, albeit at very low concentrations, is clearly mapped. Peak concentrations were approximately 0.40 μg/L, showing that initial and secondary dilution were effective under these oceanographic conditions (dilution of 16,750:1). The corresponding modeled dye cloud is shown in Figure 5; although the spatial patchiness is not reproduced by the model on the 167-m grid, the general transport direction and effective dilution are correctly predicted.

The field observations provided unambiguous data on the trapping characteristics of the wastewater plume and the near-field concentrations of the wastewater along the dominant transport directions. They showed the patchiness in the dispersion pattern, which is quite typical of turbulent tidal flows over complex bathymetry, and the data were conclusive in proving that the numerical model would provide reliable simulations. The field data were, however, insufficient to establish the concentration of contaminants in the harbor since these concentrations were below the detection limit. Thus, the observations in themselves did not address one of the key issues of public concern and, of course, could not be extrapolated to other tidal conditions and discharge practices.

The model was then run for a number of scenarios, including continuous discharge of 410 m^3/day. To illustrate the differences between the ebb-only discharge and continuous release, the peak contaminant concentration throughout the study area over a 15-day simulation period in winter was plotted. The contour maps for each condition are shown in Figure 6; the contour value of 1 is equivalent to a dilution of 10^6:1. The effect of continuous discharge is to slightly lower the area around the diffuser for concentrations greater than 20,000:1, and to roughly double concentrations at the head of the harbor, although dilution at these locations exceeded 200,000:1. These maps correspond to a conservative contaminant, and represent the worst case.

These examples illustrate how the model greatly extends the power of the observations by increasing the area over which effects can be predicted, and by treating various scenarios for wastewater disposal. In this study the local newspaper editor observed the dye tracing survey from a small boat, and by subsequently reporting the activities (Richards, 1993) raised public awareness of the nature of the study and the importance of field data. In addition to providing engineering data, the computer simulations were used to prepare animations of the wastewater dispersion for presentation to the trustees of the local sewer committee. From the computer data visualization techniques, they quickly grasped the essential findings of the study and came to appreciate how the field data together with the modeling solved a very complex oceanographic problem with confidence in the outcome.

CONCLUSIONS

Combining dye tracing field observations with 3D modeling of wastewater dispersion for a small municipal outfall proved to be highly effective. The field data clearly defined the localized diffuser performance, and provided confidence in model predictions by demonstrating the validity of simulated currents and contaminant concentrations. The model greatly extended the range of prediction of the wastewater's fate from what could be obtained directly from the observations, and allowed simulation of different operating conditions. The engineering output data were used to decide on the approach to be taken for future outfall upgrades and permits, and the computer visualization of the modeled concentrations provided a dramatic and readily comprehended explanation of the results to non-technical committee members making these decisions. Studies of this nature can generally be carried out for less than $50,000 and yield significant benefits in terms of the information obtained.

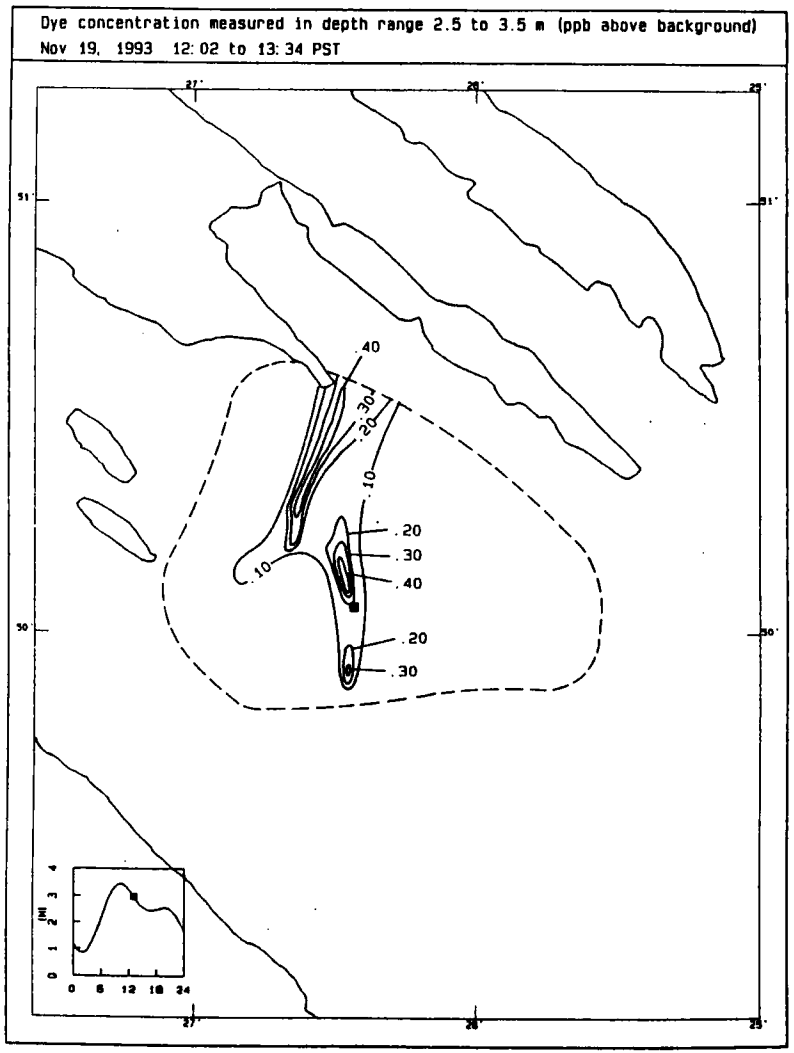

Figure 4. A map of dye concentration in µg/L at the trapping depth (2-5 m) during ebb tide. The dashed line marks the limit of the towed survey. The peak concentration was 0.48 µg/L.

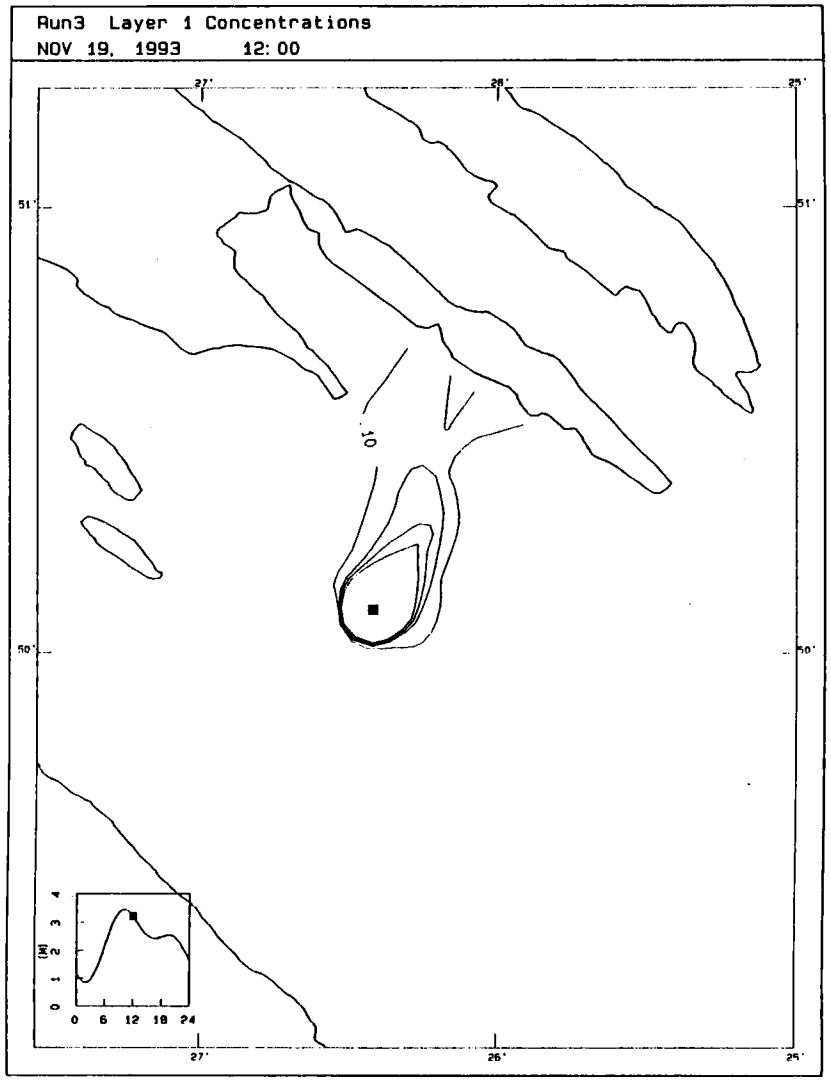

Figure 5. A map of dye concentration in the surface layer (0-5 m) predicted by the 3D GF8 model corresponding in time with Figure 4. The contour interval is 0.1 µg/L.

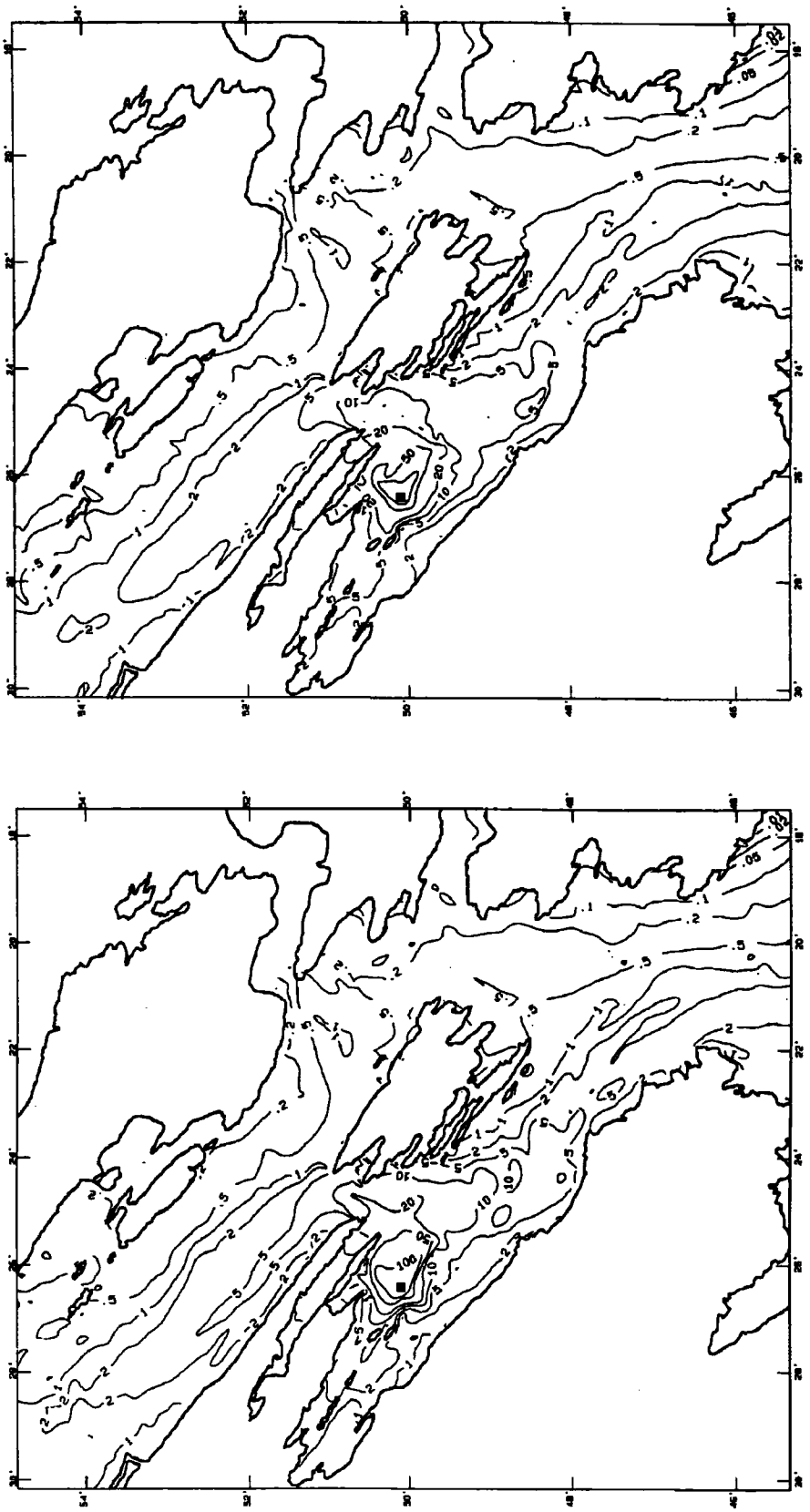

Figure 6a. Contour map of minimum effluent dilution (maximum concentration) in the study area for (a) ebb-only and (b) continuous discharges. A contour value of 1 represents 10^6:1 dilution.

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WINTER DISPERSION AND INTRUSION OF FLOATING WOODEN CARDS RELEASED ALONG JUAN DE FUCA STRAIT

Curtis C. Ebbesmeyer, Carol A. Coomes and Eric C. Noah[1]

INTRODUCTION

The fate of oil spilled along oil tanker routes in Juan de Fuca Strait continues to be of concern. To investigate the lateral dispersion of oil associated with surface currents intruding inland from the Pacific Coast, 13,800 floatable wooden, non-toxic drift cards were released during January-March 1992 near major tanker routes in Juan de Fuca Strait (Figure 1). Recoveries of 2,934 cards along the Strait's shores and the Pacific Ocean coast indicate possible destinations of spilled oil associated with currents flowing both into and out of the Strait.

Recoveries of near-surface drifting objects (drift cards, bottles, shipwreck debris) on the shores of the study area during the past century have been summarized by Ebbesmeyer and Coomes (1993). Earlier recoveries, widely scattered over space and time, were difficult to interpret because: 1) releases along the routes were not made synoptically; 2) recoveries varied according to day of the week, season, and shoreline accessibility.

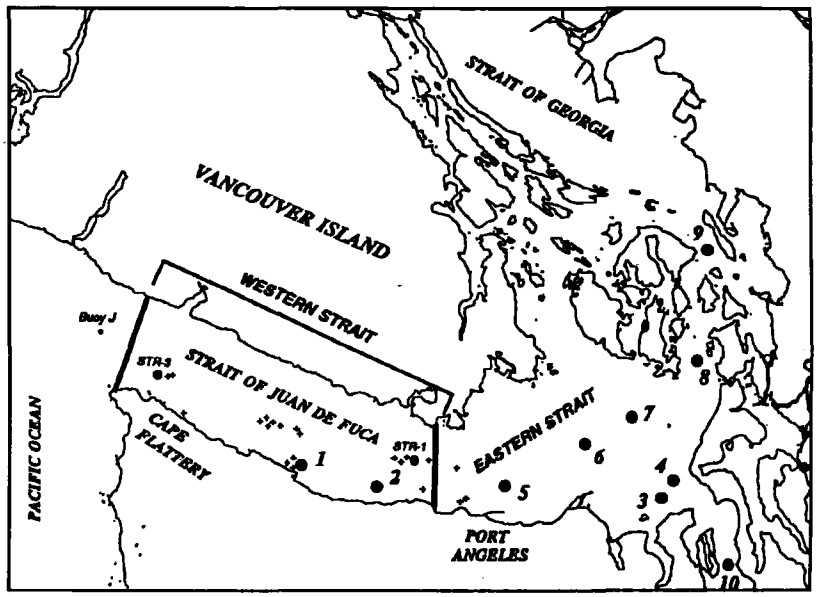

Figure 1. Locations of drift card releases. Approximately 30 batches of 50 drift cards were released at two-day intervals during 7 January through 11 March 1992 at 10 locations: dots, 1-10; +, sites of historical current meter records; and STR1, STR3, current records used to compute residence time in the western Strait.

The present study attempts to overcome these difficulties through the release of many cards at a number of sites at nearly identical times. Because of the simultaneity of the releases, a given beachcomber could have found a drift card from any of the release locations. In previous field work, approximately 20,000 drifters were released and 5,235 were observed during a number of years, whereas in the present single, intensive experiment, 13,800 drifters were released and 2,934 reported in 100 days (Ebbesmeyer et al., 1991b; Ebbesmeyer and Coomes, 1993). When viewed in historical context, the large sample deployed in a short time interval gives this study's results substantial weight.

METHODS

Intrusions

The drift card experiment was conducted during winter to document the effects of coastal oceanic water intruding into Juan de Fuca Strait. Storm winds along the coast of Washington state and Vancouver Island

[1] Evans-Hamilton, Inc., 731 N. Northlake Way, Seattle, WA 98103

frequently drive near-surface oceanic water to varying distances eastward along the southern shores of Juan de Fuca Strait (Holbrook et al., 1983). Some storms are capable of transporting debris from miles off the coast as far inland as Bellingham Bay, located at the head of the Strait (p. 31, Waldichuk, 1963; Ebbesmeyer et al., 1991a).

Physical characteristics of historical intrusions were examined to determine the time interval at which drift cards should be deployed. A total of 57 intrusion events were detected in current meter records previously obtained in the upper 20 meters of the water column in U.S. waters of the western Strait during October through April, 1973-1991. An intrusion event was defined as a time interval when the mean currents were directed inland and parallel to the Strait's axis (tides were removed with a numerical filter). In this sample, intrusions accounted for 25 percent of the total duration of the current meter records (1.9 years), and 68 percent of the intrusions lasted 1.5 days or longer (Figure 2). With a two-day release interval, we were reasonably certain that drift cards would be released in most of the intrusions noted during our field observations.

Drift Cards

Each wooden card measured 0.5 x 9.8 x 14.9 centimeters. To aid beachcombers in finding them, the cards were coated with red, non-toxic paint. Each batch of 50 cards carried a distinct serial number. Stenciled on each card were: the batch number; a request for beachcombers to report the date and location of recovery, and an address and 800-telephone number enabling beachcombers to report recoveries with minimal effort.

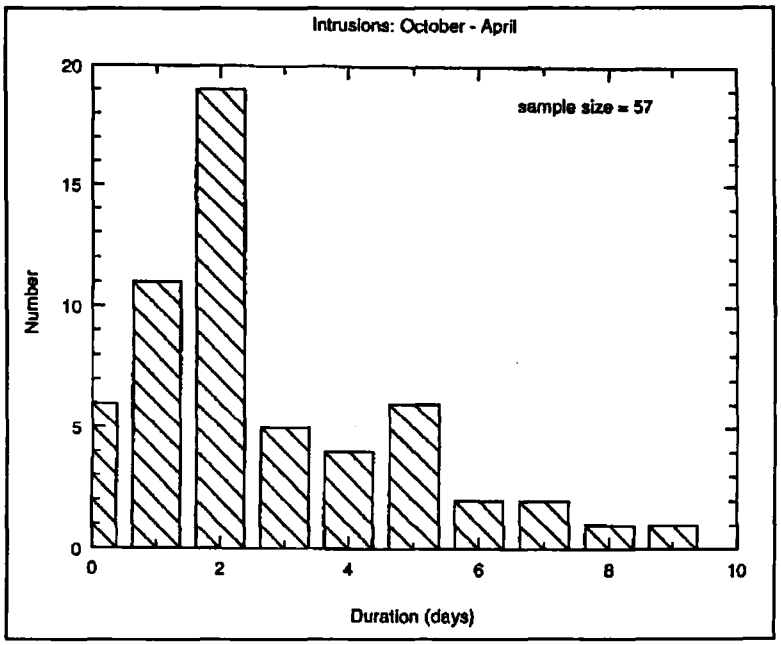

Figure 2. Intrusion duration. Histogram of the durations of 57 intrusions in historic current meter observations during October through April, 1973-1991.

Several hundred batches of 50 cards were dropped at 10 locations (sites 1-10; Figure 1) by a small aircraft (Cessna model 172) that flew over the sites at low altitude (approximately 100 m) at two-day intervals. Each flight lasted approximately two hours. Because poor weather prevented some flights from reaching certain sites on given dates, an average of 93 percent (1,494) of the desired 1,600 cards were released at nine sites. A few drops made at site 10 in Admiralty Inlet also have been included for comparison with those in Rosario Strait.

Between 7 January and 11 March, a total of 13,800 drift cards were released during 32 flights. Within 36 days (16 April) after termination of the releases and 100 days after initiation of the flights, 21.3 percent of the released cards were reported by beachcombers (Table 1).

Table 1. Summary of drift card releases and recoveries. Numbers of drift cards released between 7 January and 11 March 1992 at 10 sites in Juan de Fuca Strait and approaches (see Figure 1 for locations), and numbers of drift cards recovered within 100 days of the first release (as of 16 April 1992).

Release site (see Fig. 1)	Number released	Number recovered	Percentage recovered
1	1400	126	9.0
2	1450	217	15.0
3	1550	365	23.6
4	1500	370	24.7
5	1450	220	15.2
6	1500	304	20.3
7	1500	298	19.9
8	1550	415	26.8
9	1550	494	31.9
10	350	125	35.7
Total	13,800	2,934	21.3

RESULTS

Drift card recoveries

To tabulate the drift card recoveries efficiently, the shoreline of the Strait and portions of its approaches were segmented into 1,102 intervals, each approximately 1 nautical mile long. Then the 2,934 recoveries listed in Table 1 were apportioned into the shoreline segments. For this paper, the recoveries have been grouped into three regions (Figure 1): (1) eastern Strait, the shoreline inland of the north-south line connecting Beechy Head on Vancouver Island and Observation Point, Washington; (2) Pacific Coast, shorelines westward of the line connecting Vancouver Island and Cape Flattery, Washington; and (3) western Strait, the area of the Strait between (1) and (2) (Figure 1).

The percentages of all recoveries for a given site in the eastern Strait and Pacific Coast regions are shown in Figures 3 and 4, respectively. Western Strait percentages have not been shown because they were small, varying between 3 percent and 11 percent of total recoveries; they may be derived by subtracting from 100 percent the total of Figures 3 and 4. For example, of 1,400 releases at site 1, a total of 126 cards were recovered (Table 1). Of the 126 recoveries, 30 percent were found in the eastern Strait (Fig. 3), 59 percent on the Pacific Coast (Fig. 4), and 11 percent in the western Strait. The following paragraphs describe recoveries in the three general areas.

As an observer travels eastward along the tanker route from the western Strait into Georgia Strait and Puget Sound, the percentage of recoveries in the eastern Strait increases threefold, rising from 30 percent at site 1 off Pillar Point, Washington, to 94 percent at Site 9 in the northern end of Rosario Strait, and to 89 percent at site 10 in Admiralty Inlet. For example, of the 1,400 cards released at site 1, 30 percent of the 126 cards recovered, or 38 (2.7 percent of the total cards released), were found in the eastern Strait.

Within the overall threefold increase, the percentages vary in steps. At sites 2 and 5, the percentages are nearly identical (56 percent and 54 percent, respectively), and close to twice the percentage at site 1. Farther inland at sites 6 and 7, the percentages increase to nearly identical values at 78 percent and 76 percent, respectively. Within constricted Rosario Strait and Admiralty Inlet, the percentages are high, varying between 89 percent and 94 percent (sites 8, 9 and 10).

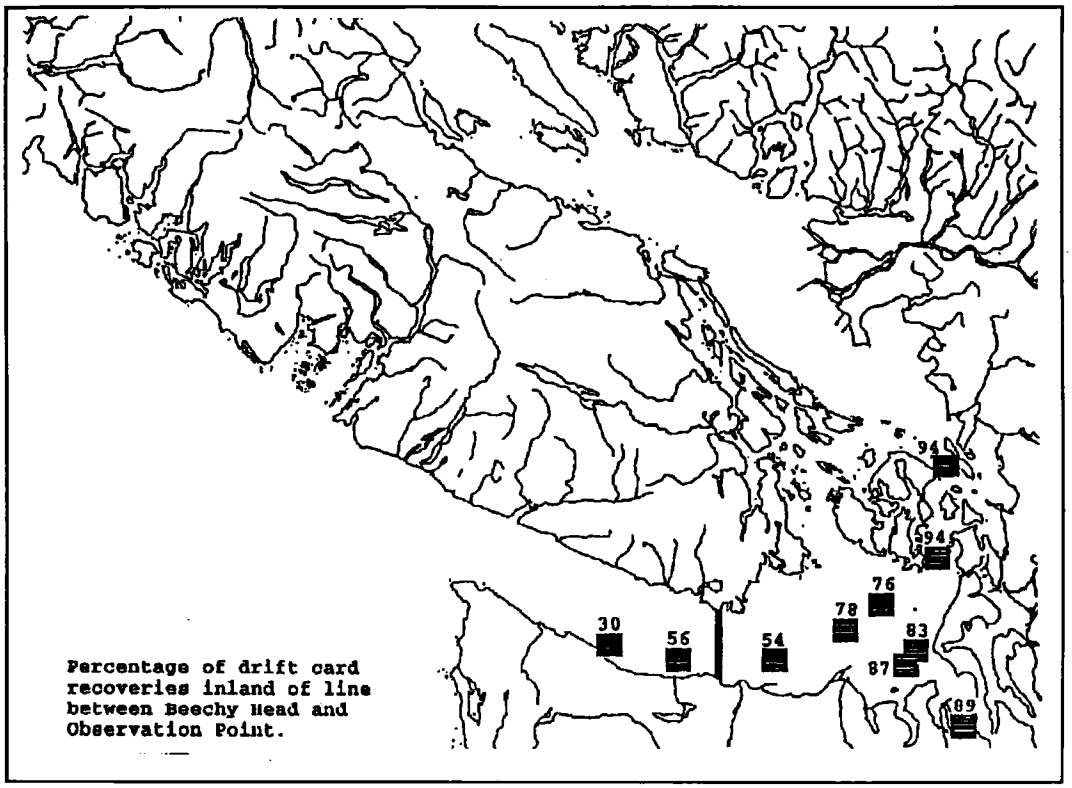

Figure 3. Eastern Strait drift card recoveries. Numbers at the release sites (squares) indicate percentages of drift card recoveries inland of the line between Beechy Head on Vancouver Island and Observation Point, Washington (see Figure 1 for site number designations). For example, at site 1 off Pillar Point, Washington, 30 percent of all cards recovered from releases at that site were found inland of the Beechy Head-Observation Point line.

Percentage recoveries in the western Strait varied between 9 percent and 11 percent at sites 1, 2, 5, 6, and 7, and between 2 percent and 7 percent at sites 3, 4, 8, 9, and 10. The low percentages were surprising, since the length of the western Strait's shoreline is comparable to that of the eastern Strait.

As the observer travels westward along the tanker route, the recoveries on the Pacific Coast increase (Figure 4). Inland of site 6, the percentage is less than 15 percent. Between sites 5 and 6, the percentage increases threefold over a distance of 20 kilometers, and between sites 2 and 3 a nearly twofold increase occurs, also over a 20-kilometer distance. Since the Strait is approximately 150 kilometers long, the doubling and trebling occurred over 15 percent of the Strait's length.

Comparison with current meter records

Two aspects of the drift card recoveries—inland transport and the scarcity of western Strait recoveries—were compared with statistics of the historical current meter records.

To investigate inland movement of the drift cards, the current vectors measured during each of the 57 intrusions were added, yielding the distance that a hypothetical water parcel would have traveled during a given intrusion (progressive vector length; PVL). The probability of exceeding a given PVL is presented in Figure 5. Since site 1 lies 35 kilometers from the western Strait boundary, the current meter records indicate that approximately 30 percent of the intrusions would produce PVLs exceeding this length. Since

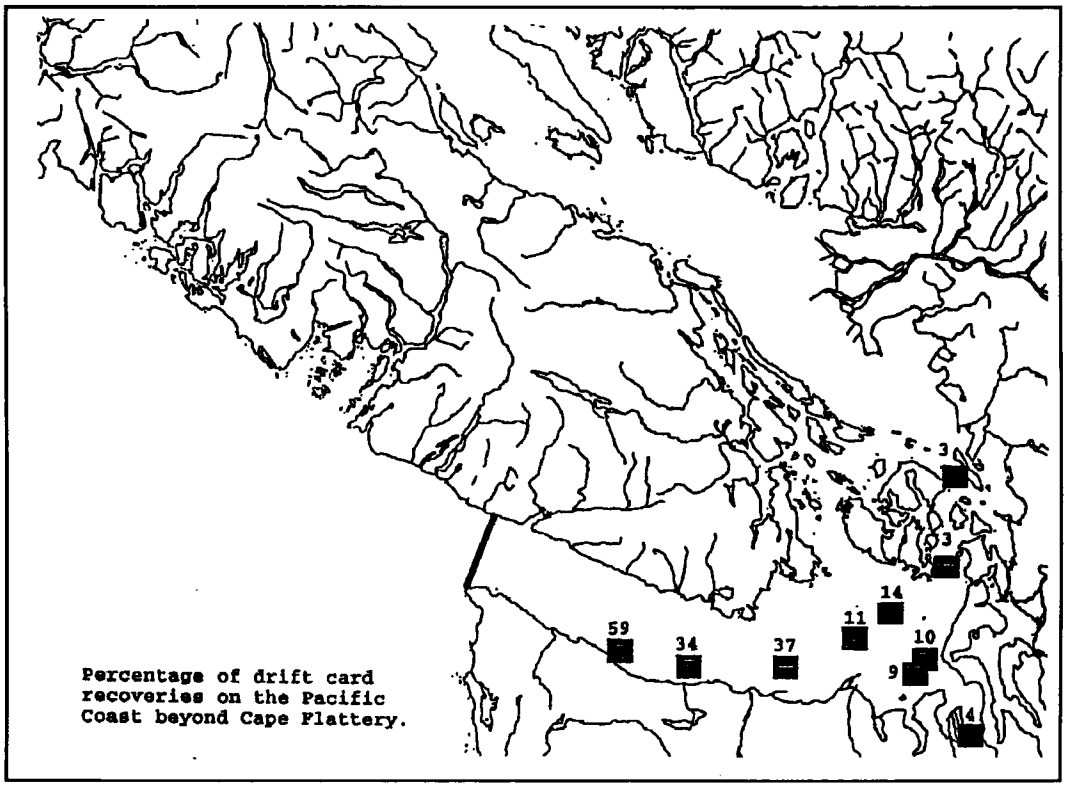

Figure 4. Pacific Coast drift card recoveries. Numbers at the release sites (squares) indicate the percentage of drift card recoveries from that location (center of square) that were found west of the line between Vancouver Island and Cape Flattery, Washington. For example, at site 1 off Pillar Point, Washington, 59 percent of the cards recovered from releases at that site were found west of the Vancouver Island/Cape Flattery line.

intrusions account for 25 percent of the current meter records, intrusions producing PVLs sufficient to transport cards from site 1 to the western Strait would be expected to occur 7.5 percent of the time.

Of the cards released at site 1, 2.7 percent were reported in the eastern Strait compared with 7.5 percent estimated from current meter records. For site 2, 8.3 percent of the cards released were reported in the western Strait compared with 15.0 percent estimated from current meter records. The estimates from the current meters exceed the drift card results for a number of reasons, including: (1) some drift cards remain for a time in the eastern Strait without beaching, but eventually are flushed to the western Strait; (2) the current meter statistics assume that hypothetical drifters from each intrusion are reported by beachcombers.

To assess the apparent rapid flushing in the western Strait, progressive vector lengths (PVLs) were computed from current meter records obtained near the western Strait's eastern and western boundaries (sites STR1 and STR3, Figure 1). PVLs were computed beginning at each time in the current meter records and noting the duration over which the PVL equaled the length of the western Strait. These computations yielded the durations that hypothetical water parcels would remain in the western Strait (residence time), assuming that once a parcel reached either end of the western Strait it would not reenter the strait, and that the beginning and ends of the records were connected, forming continuous loops with which to compute PVLs.

The residence times computed from the current meter records are shown in Figure 6. For hypothetical drifters released at both ends of the western Strait the most frequent residence time is two days. Apparently, a few days' residence does not allow the drift cards enough time on the shore for beachcombers to recover more than a small fraction of them.

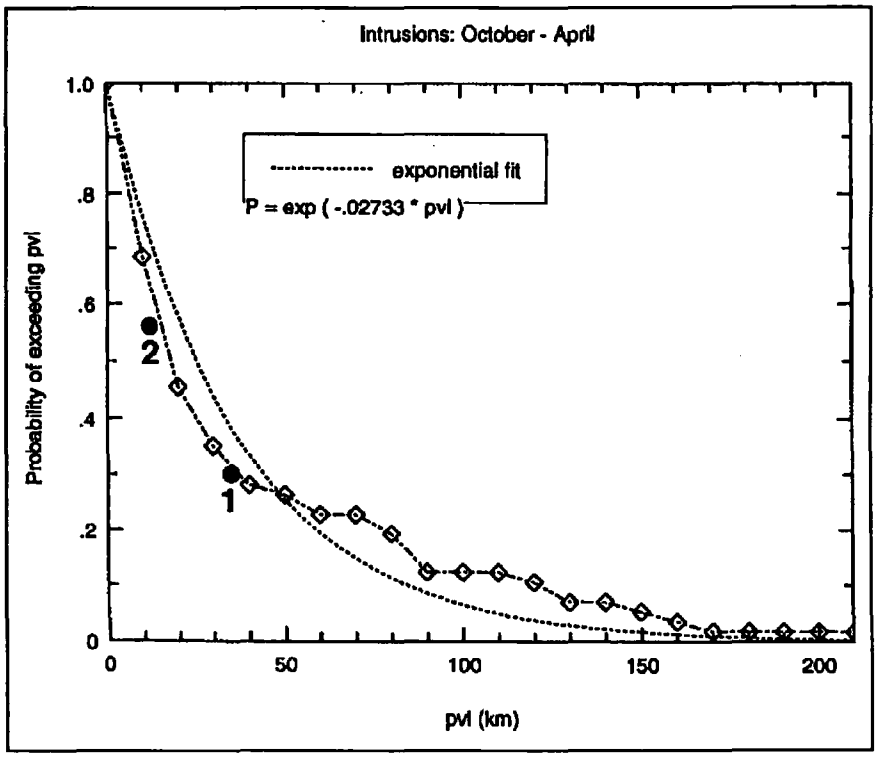

Figure 5. Intrusion penetration distance into Juan De Fuca Strait. Diamonds represent the probability of exceeding a given intrusion distance computed from the current meter records as progressive vector length (PVL). Dashed line represents the least-squares-best exponential fit to the observations. For purposes of comparison, the two dots indicate the drift card recovery percentages in the eastern Strait from Figure 2.

DISCUSSION AND CONCLUSIONS

Maps of the drift card recoveries demonstrate several new results important in formulating marine policy (Figures 3 and 4):

(1) Small changes in the horizontal distance along the tanker route significantly affected the drift card recovery patterns. Perhaps most striking is the twofold difference in recovery percentages between sites 1 and 2 in the western Strait. These results point to substantial differences in dispersal processes occurring between sites separated by relatively short distances. For example, for oil spilled from a site located off Port Angeles, the drift card recoveries suggest that most of the oil would be recovered in the eastern Strait, but some would be recovered on the Pacific Coast. Conversely, for a spill midway along the western Strait, much of the oil would reach the outer coast, but some would be transported into the eastern Strait. Moving the site westward along the western Strait, although shifting the bulk of the recoveries from the eastern Strait to the Pacific Coast, does not eliminate recoveries from the eastern Strait.

(2) For more than a century, it has been known that floating objects drifted on occasion from the Pacific Coast to the head of Juan de Fuca Strait (Ebbesmeyer and Coomes, 1993). Why they drifted inland became clear by the early 1980s when wind and current records revealed that coastal storms frequently drove surface waters far inland. It is now firmly established that intrusions of coastal water are a major and recurring feature of the Strait's general circulation throughout the year (Holbrook et al., 1983).

The present results allow us to obtain clearer historical perspectives. The current meter records indicate that intrusions occur during approximately 25 percent of the winter along the western Strait's southern shores. In Canadian waters, north of the international boundary, the percentage is expected to be much smaller because of the influence of outflowing water from the Fraser River. Unfortunately, the international boundary divides not only politics, but also the frequency of occurrence of intrusions. Canadian and U.S. oceanographers, by focusing on national waters, can be expected to obtain differing intrusion frequen-

cies. International cooperation is necessary for an objective determination of the fate of spilled oil.

During November 1875, wreckage from the collision of the SS Pacific and clipper ship Orpheus was driven inland from the coast by severe storms during an entire month. Some of the current meters showed intrusions, accounting for 58 percent of the total record. That the wreckage in 1875 was driven inland through the Strait to Victoria for a month suggests that on rare occasions storms may reverse the western Strait's surface currents nearly continuously for an entire month, or 100 percent of a typical current meter record.

After the Nestucca spill in December, 1989, most of the oil was transported northward along the coasts of Washington and British Columbia. Winds measured during the oil transport suggested that intrusions should have occurred, and some oil was observed at the head of Juan de Fuca Strait (Harding and Englar, 1989; Ebbesmeyer et al., 1991a). Some of the oil in the eastern Strait was chemically fingerprinted to that spilled from the Nestucca barge. Therefore, intrusions did occur, diverting a fraction of the oil being transported northward along the Pacific Coast. Since intrusions capable of transporting oil a hundred kilometers inland account for only 10 percent of the historical intrusions, and intrusions account for only 25 percent of the current meter records, we estimate that on the order of 1 percent of the oil transported along the coast may have been transported to the eastern Strait.

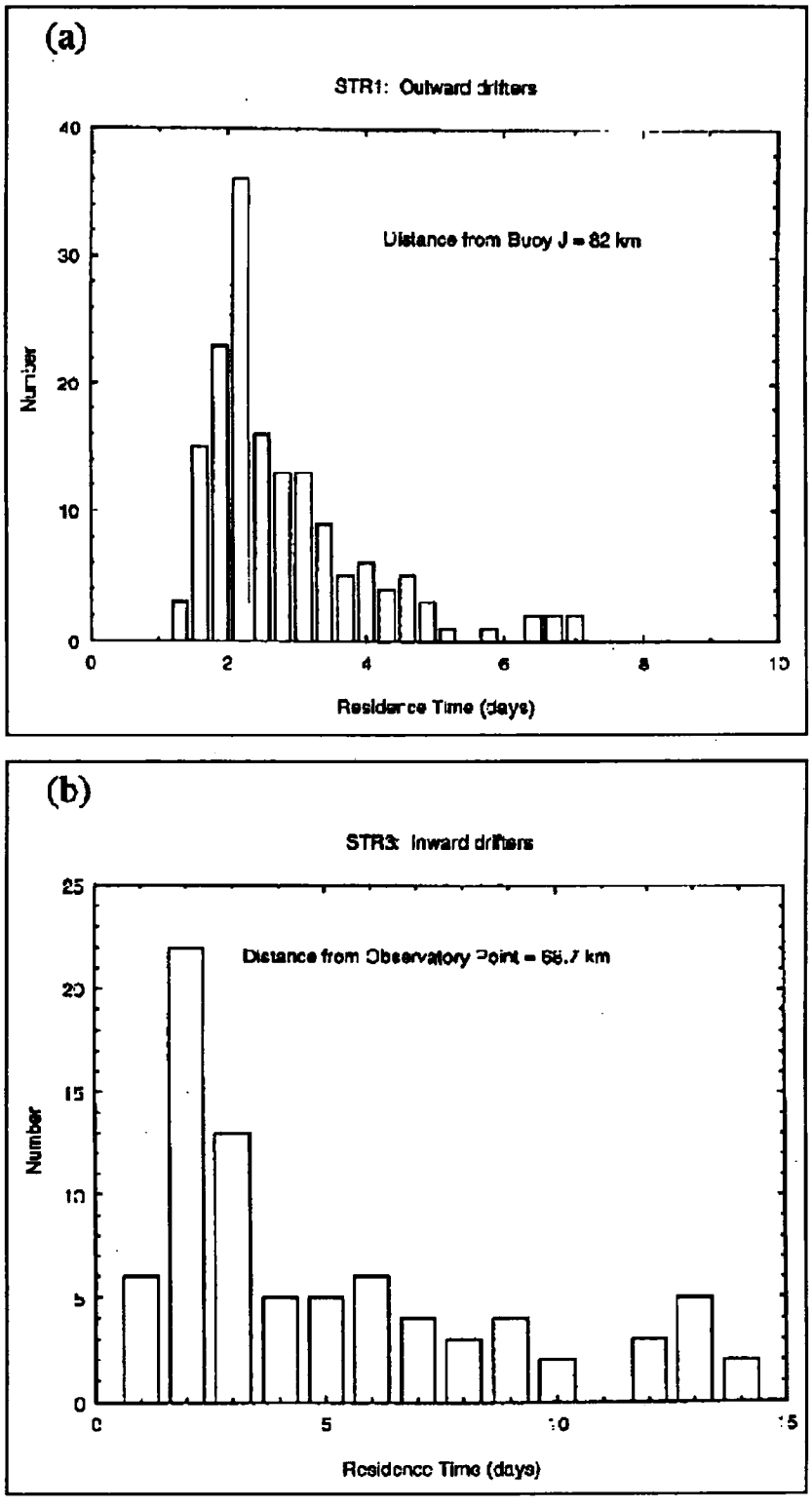

Figure 6. Residence time in the western Strait. (a) Duration for a drifter to travel westward from site STR1 (outward) through the western Strait; (b) duration for a drifter to travel eastward through the western Strait from site STR3 (Fig. 1).

ACKNOWLEDGMENTS

We thank Gary R. Miller, Trans Mountain Oil PipeLine Corporation, for permission to publish these results, Prof. Dora P. Henry, University of Washington, for editing, Dr. Richard D. Romea, STI Optronics, Inc., for assistance in analyzing the current meter records, and Dr. Andrea Copping, Washington Sea Grant Program, for encouragement.

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EL NIÑO WEATHER CONDITIONS REFLECTED IN PUGET SOUND TEMPERATURES AND SALINITIES

J.A. Newton[1]

INTRODUCTION

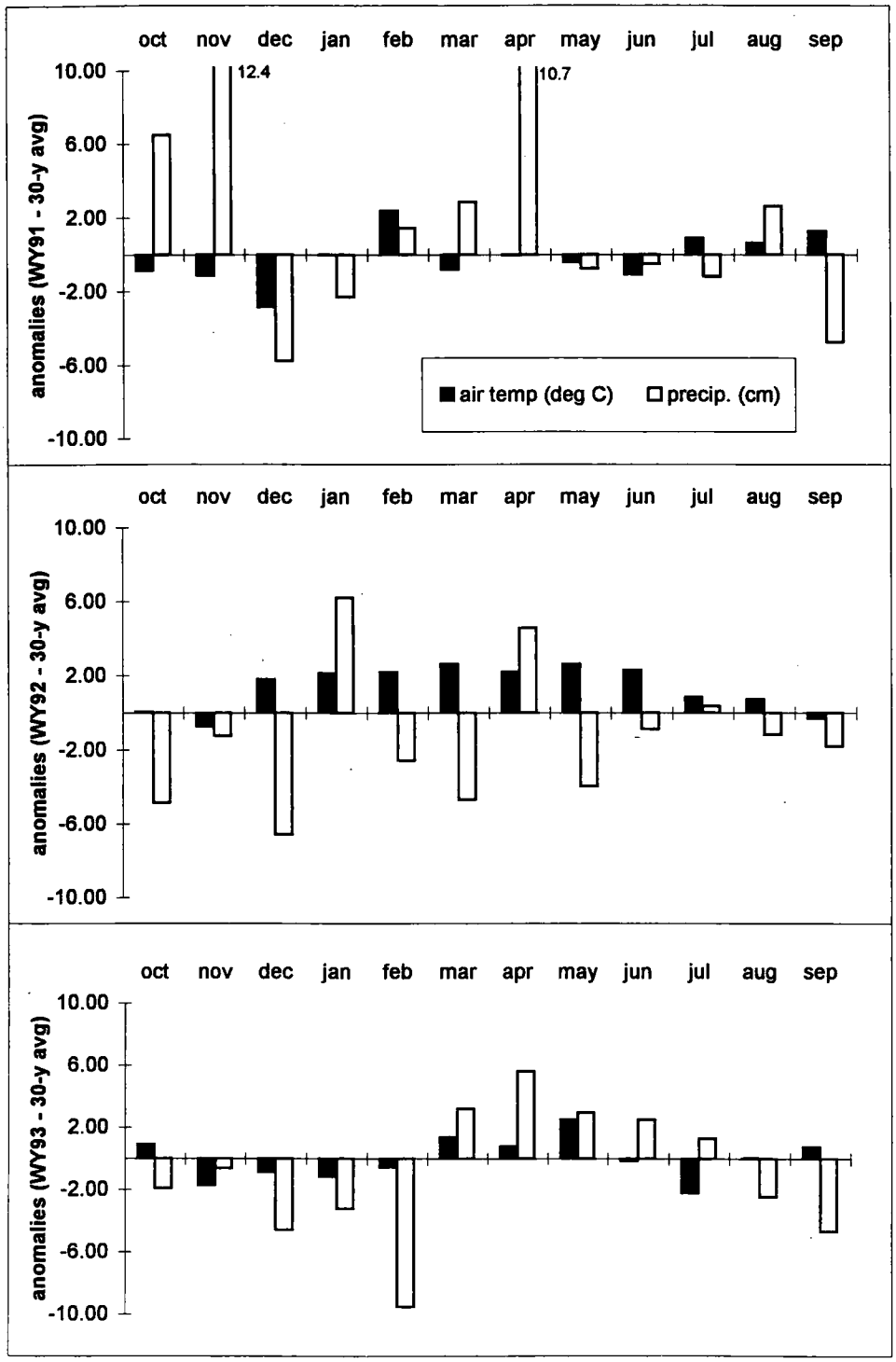
The central question of this analysis is: What role does climatic forcing play in determining the temperature and salinity of Puget Sound surface waters? There are many influences on both of these parameters, including solar radiation, river flow, precipitation, evaporation, air temperature, and mixing (wind and tidal). Many of these influences are related to weather conditions. El Niño-Southern Oscillation (ENSO) events result in anomalous local weather conditions and provide an excellent opportunity to assess the effects of climatic forcing on Puget Sound waters.

The occurrence of El Niño in the equatorial Pacific can remotely force anomalous weather conditions in areas throughout the globe (Rasmusson and Wallace, 1983; Philander, 1990). During ENSO conditions, there is a locational shifting of high and low atmospheric pressure cells and the path of the jet stream (Horel and Wallace, 1981). This can result in anomalous air temperature and precipitation patterns (e.g., droughts in Australia and floods in Texas). Air temperatures over the Pacific Northwest, western Canada and southern Alaska are warmer (Ropelewski and Halpert, 1986; 1987). An effect of ENSO on the North American Pacific coast waters is warmer sea-surface temperatures (SSTs) due to coastally trapped Kelvin waves that originated at the equator. There is also a reduction in the duration and intensity of wind-driven upwelling off the North American west coast during summer that translates to warmer coastal waters, some of which enter Puget Sound (Thomson, 1994). Local Puget Sound weather during ENSO events is characterized by warmer air temperatures, particularly in winter-spring; the precipitation signal, however, is not consistent (Ropelewski and Halpert, 1986; 1987). Of the last five major ENSO events, three were dry (76-77, 86-87, 91-92) but two were wet (82-83, 94-95).

Three recent years, 1991, 1992, and 1993, each had different degrees of ENSO forcing and also substantially different local weather conditions. Analysis of both weather and sea-surface data from these three wateryears (WY = October through September of named year) affords an opportunity to investigate the impact of local weather on Puget Sound waters. A moderate ENSO event was evident in WY92 (Oct 91-Apr 92) and a weak event was observed in WY93 (Feb 93-Jun 93) (Kessler and McPhaden, 1995a,b). WY91, however, did not have ENSO conditions. While WY92 and WY93 were drier than climatology (30-y average for 1961-1990), WY91 was wetter. Patterns of anomalies (WY - 30-y average) in air temperatures and precipitation recorded at Sea-Tac Airport for each of the three wateryears (Figure 1) show the annual differences in local weather. In summary, WY91 was cool and very wet, WY92 was warm and very dry, and WY93 had average (but mixed) temperatures and was dry. In addition, river flow, as typified by the Skykomish River, is noted on Figure 1. This river has been used as a representative index of western Washington flow (e.g., USGS, 1991). River flow was substantially above normal in WY91 and well below normal in both WY92 and WY93.

The Washington Department of Ecology conducts long-term monitoring of Puget Sound waters. The program is described in Newton et al. (1995). Numerous stations are monitored monthly for conventional water quality parameters, including temperature and salinity. In order to investigate the effect of the local weather conditions described above on Puget Sound temperatures and salinities, water column data from the above-mentioned three wateryears were analyzed.

[1] Environmental Investigations and Laboratory Services, Washington Department of Ecology, 300 Desmond Dr., Olympia, WA 98504-7710



1991

	air temp.	precip.
mean:	-0.19	1.75
sd:	1.37	5.67

Flow = 132% of mean

1992

	air temp.	precip.
mean:	1.35	-1.42
sd:	1.20	3.75

Flow = 73% of mean

1993

	air temp.	precip.
mean:	-0.06	-0.98
sd:	1.38	4.30

Flow = 77% of mean

Figure 1. Climate anomalies versus month for air temperature and precipitation during wateryears 1991, 1992, and 1993, with WY means and standard deviations (sd). Data are for Sea-Tac Airport, obtained from National Climate Data Center (NOAA, 1991; 1992; 1993). Also shown are river flow data for the Skykomish River, as a percentage of mean according to USGS (1991; 1992; 1993).

METHODS

Sea temperature and salinity data were obtained using a Sea-Bird Electronics, Inc. Seacat® model SBE- 19 conductivity-temperature-depth profiler. Relevant methods and quality assurance procedures are described in Newton et al. (1994). Analysis of ENSO forcing on Puget Sound temperatures and salinities was conducted as follows.

1) The three wateryears were ranked in order of ENS0 forcing strength :

moderate → WY92 → WY93 → WY91 → *weak*

2) Temperature and salinity data from 0.5-m, 10.0-m and 30.0-m depths at five Puget Sound stations were selected from Ecology's database. Stations were: GRG002, in the Strait of Georgia; ADM001, in Admiralty Inlet; PSB003, off West Point in the Main Basin; DNA001, in Dana Passage; and BUD005, in Budd Inlet (Figure 2; see Newton et al., 1994, for station coordinates). The stations were selected to represent a variety of conditions (e.g., stratification, mixing, river proximity) within the Puget Sound environs.

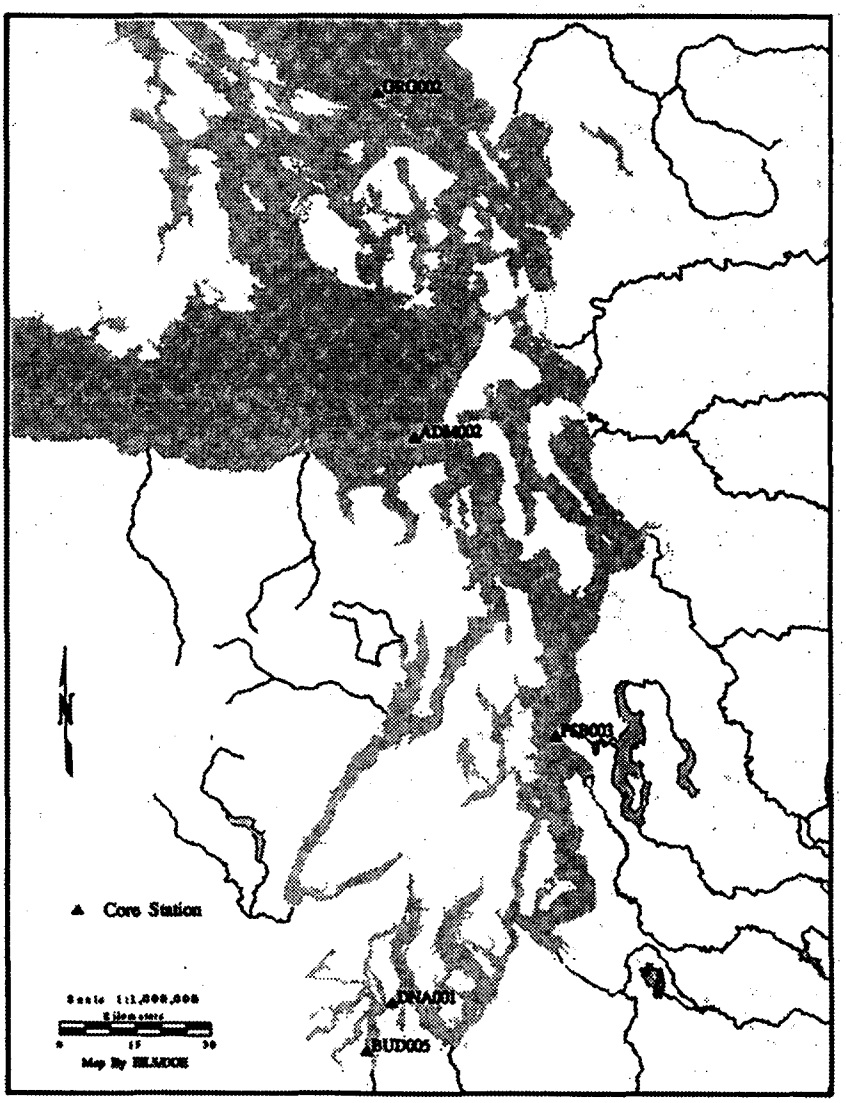


Figure 2. Location of Ecology long-term monitoring stations used in this analysis. Station coordinates are in Newton et al. (1994).

3) Annual sea temperature and salinity data were paired into three combinations such that years with weaker/no ENSO forcing were subtracted from wateryears with stronger ENSO forcing:

WY92-WY91
stronger {WY92-WY93} *weaker*
WY93-WY91

The magnitude of the differences, referred to hereafter as delta values, should indicate the relative effect of ENSO forcing on temperatures and salinities between the two paired years. It should be noted however, that the variation in local climate may not have been driven primarily by ENSO. In order to properly evaluate ENSO forcing, an analysis conducted on a longer data record with multiple ENSO occurrences is necessary. The results of the present analysis actually yield the relative effect of warmer-drier weather between the two given paired years. Whether the warmer-drier weather was ENSO-driven is only implied by association. Another procedural note is that the preferred method for this analysis would

be to calculate anomalies, rather than delta values, for the sea temperature and salinity data. Anomalies were not calculated due to lack of a 30-y data record of consistent, annual data. Marine water monitoring by Ecology began in WY73, although winter months were not sampled until WY89. Major station and method changes in WY89 also obscure this effort. Given the results of the present analysis, a more rigorous analysis over a longer data record is currently being investigated. The utility of continuous, long-term data records for evaluating climate effects cannot be overemphasized.

Because the WY92 and WY93 ENSO events were associated with warmer and drier than normal local weather (Figure 1), it would be expected that the subtractions (step 3) would result in **positive** delta values if these weather conditions indeed resulted in warmer and saltier marine waters. As shown in Figure 1, the stronger ENSO year had even warmer and drier weather than did the weak ENSO event. Because of these differences in local weather associated with the two ENSO events, the magnitude of the positive delta values could be expected to follow:

WY92-WY91 > WY93-WY91 > WY92-WY93
or, moderate-none > weak-none > moderate-weak

RESULTS AND DISCUSSION

Sea Temperature

For the paired subtractions, the monthly sea temperature delta values, with WY means and standard deviations, for each of the five stations are presented in Figures 3, 4, and 5. As predicted, the overwhelming majority of the delta values are positive. Although most pronounced at 0.5 m, the positive delta values are evident even down to 30 m.

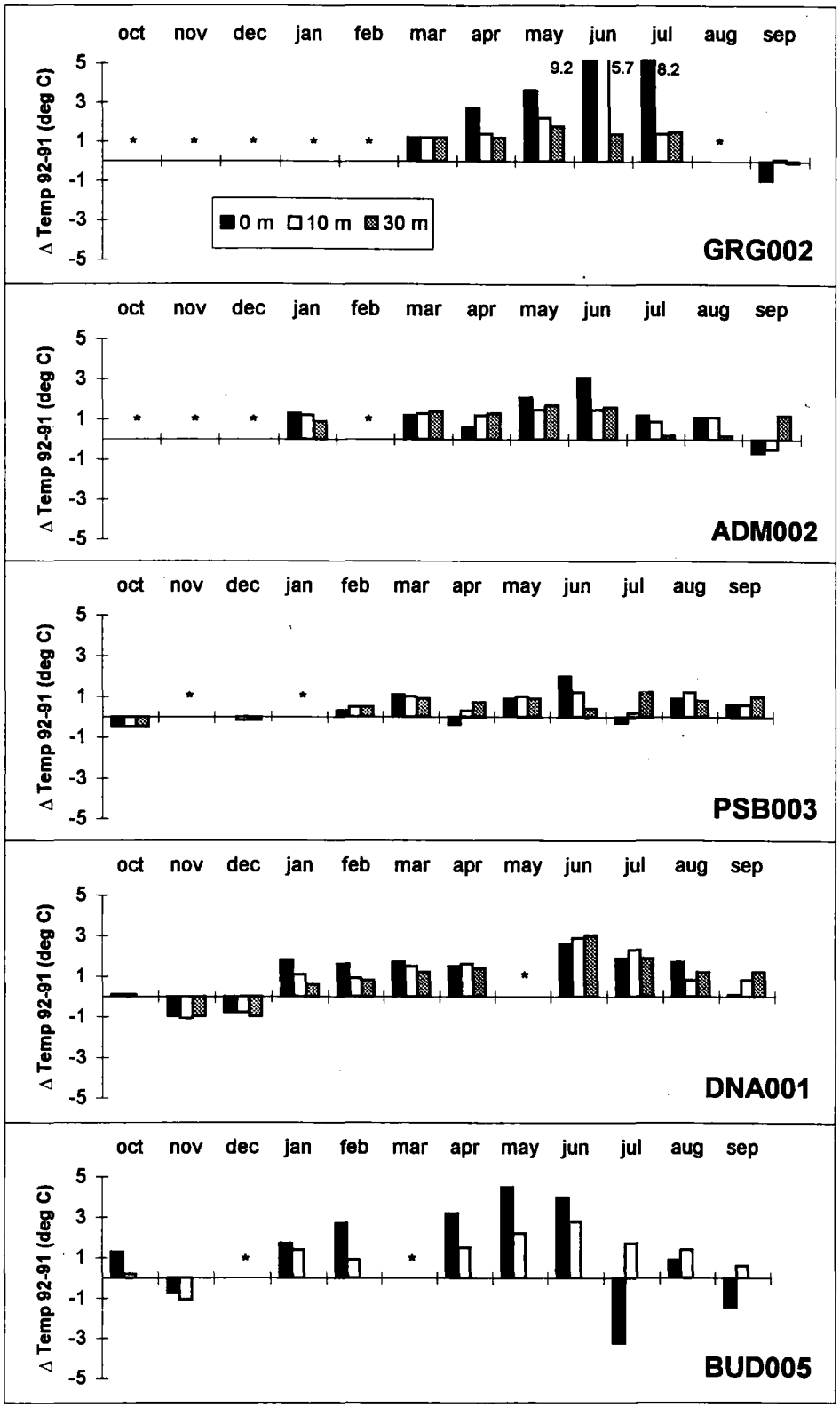
To summarize the data, the sea-surface (0.5-m) temperature (SST) data from all stations and months were averaged (Table 1). The 0.5-m data were selected since, in general, the temperature effect was most profound at 0.5 m and all three depths showed the same trend (though exceptions exist for both). Based on these data, the magnitude of the positive delta values does not follow the predicted pattern, but instead:

WY92-WY91 >> WY93-WY91 < WY92-WY93

This pattern and the SST delta values (Table 1) show that relative to WY91, a strong temperature difference is evident in WY92, during a moderate-strength ENSO, and a much weaker temperature difference (by a factor of 3) is evident in WY93, the weak ENSO year. The predicted delta value pattern was not seen because the WY93 ENSO did not have a strong effect on air temperature for the entire wateryear (Figure 1). The observed SST data are commensurate with the air temperature anomalies; delta values calculated for air temperature anomalies show the same pattern as those for SST (Table 1) and suggest a reasonable correlation between SST and air temperature.

Table 1. Mean delta values. For temperature (SST) and salinity (SSS), values are means of all sea-surface (0.5-m) data from all stations (n=5), except for SSS, where first value is from Puget Sound stations (n=4), second from Strait of Georgia station (n=1). Values for air temperature, precipitation and flow reflect means of values shown in Figure 1. Predicted ENSO-driven effects are indicated by positive delta values for SST, SSS, and air temp., negative delta values for precip. and flow, see text.

Relative ENSO forcing	Years	SST (°C)	SSS (PSU)	Air temp. (°C)	Precip. (cm)	Flow (% norm)
moderate-none	WY92-WY91	1.6	0.7, -5.1	1.54	-3.17	-59%
weak-none	WY93-WY91	0.5	0.6, -0.5	0.13	-2.73	-55%
moderate-weak	WY92-WY93	0.9	-0.04, -3.3	1.41	-0.44	-4%



	0 m	10 m	30 m
mean:	3.98	2.00	1.17
sd:	3.98	1.93	0.66

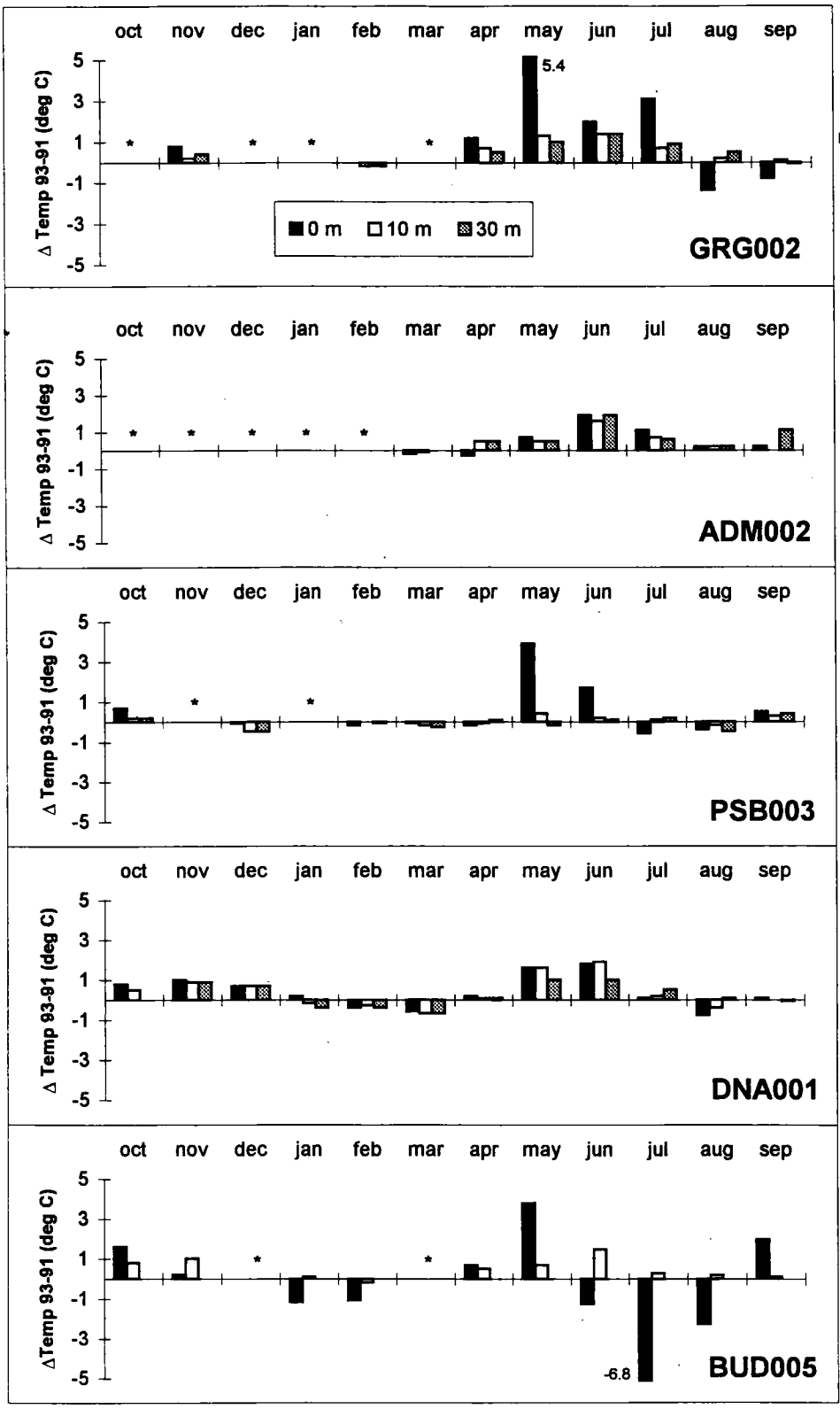
	0 m	10 m	30 m
mean:	1.24	1.03	1.06
sd:	1.10	0.65	0.59

	0 m	10 m	30 m
mean:	0.46	0.53	0.57
sd:	0.79	0.59	0.54

	0 m	10 m	30 m
mean:	1.02	0.92	0.85
sd:	1.20	1.20	1.18

	0 m	10 m	30 m
mean:	1.27	1.16	
sd:	2.51	1.09	

*Figure 3. Sea-temperature delta values at three depths for WY92-WY91 comparison at each station versus month. The * indicates missing monthly data. Also shown are WY mean and standard deviation (sd) for each depth.*



	0 m	10 m	30 m
mean:	1.29	0.55	0.55
sd:	2.21	0.58	0.54

	0 m	10 m	30 m
mean:	0.51	0.49	0.69
sd:	0.78	0.57	0.64

	0 m	10 m	30 m
mean:	0.52	0.02	-0.06
sd:	1.36	0.27	0.31

	0 m	10 m	30 m
mean:	0.39	0.36	0.23
sd:	0.82	0.80	0.59

	0 m	10 m	30 m
mean:	-0.44	0.50	
sd:	2.90	0.51	

*Figure 4. Sea-temperature delta values at three depths for WY93-WY91 comparison at each station versus month. The * indicates missing monthly data. Also shown are WY mean and standard deviation (sd) for each depth.*

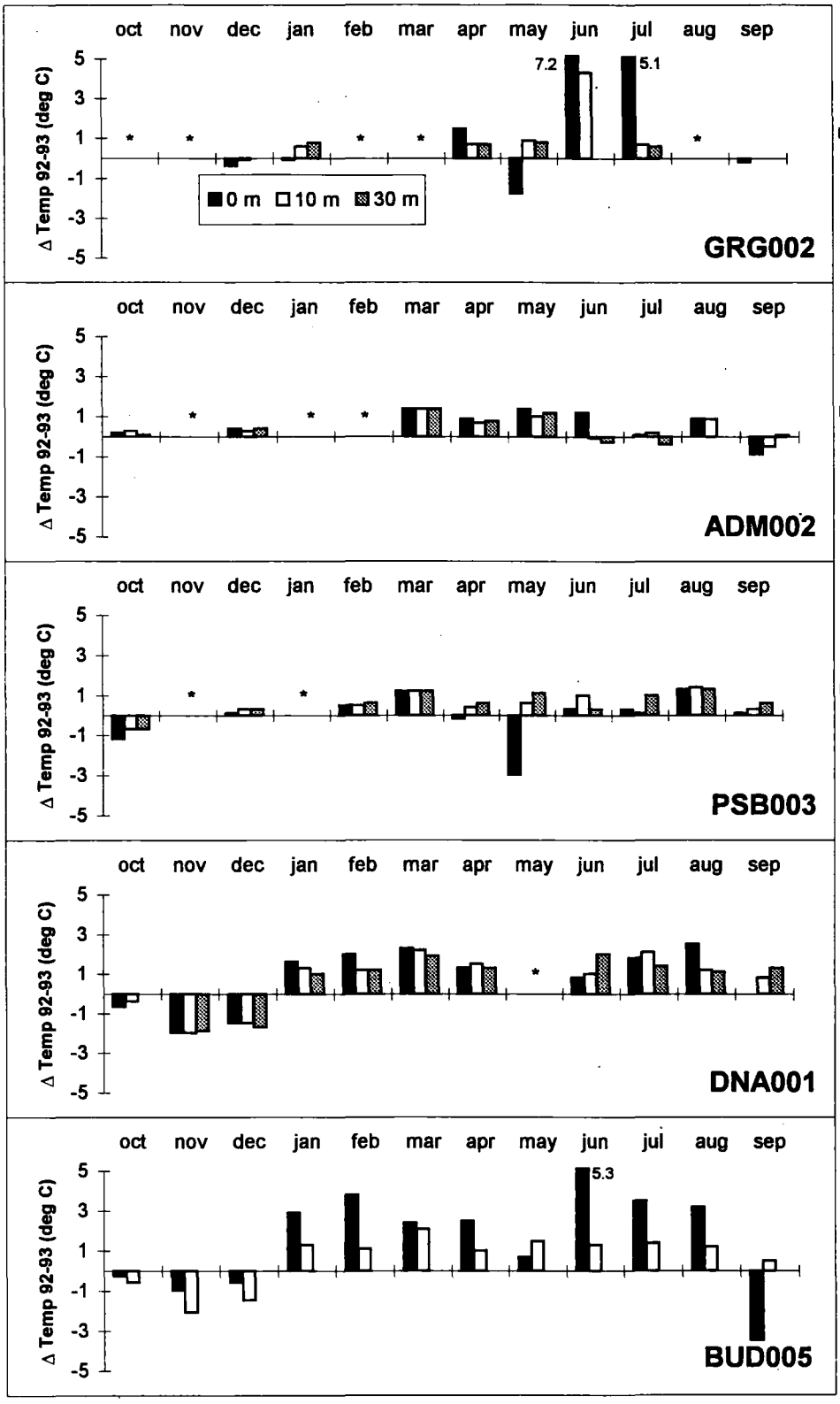


*Figure 5. Sea-temperature delta values at three depths for WY92-WY93 comparison at each station versus month. The * indicates missing monthly data. Also shown are WY mean and standard deviation (sd) for each depth.*

For both ENSO years, local air temperatures were warmer than normal during those months that the ENSO was also evident in the equatorial Pacific: for WY92, the ENSO was evident Oct-Apr and the air was warmer Dec-Aug; for WY93, the ENSO was evident Feb-Jun and the air warmer Mar-May (Figure 1). This result confirms ENSO forcing of local air temperatures, as has been noted by Ropelewski and Halpert (1986, 1987). Thus, ENSO occurrence, warmer than normal local air temperatures, and warm Puget Sound SSTs appear to co-vary.

Sea Salinity

For the paired subtractions, the monthly sea salinity delta values with WY means and standard deviations for each of the five stations are presented in Figures 6, 7, and 8. As with sea temperature, the majority of the delta values are positive; however, there are many more occurrences of negative delta values, most notably in the WY92 data from the Strait of Georgia (Figs. 6 and 8) and in the WY92-WY93 comparison (Figure 8).

Although positive salinity delta values are evident down to 30 m, there is a high frequency of cases where the 0.5-m delta value is substantially greater than the 10-m and 30-m values. This result follows the salinity structure in Puget Sound where salinity-driven stratification is quite evident (cf. Newton et al., 1994), with low-salinity waters confined to a shallow layer. Lower river flow, increased evaporation, and decreased precipitation all would be expected to affect surface waters most.

Sea-surface (0.5-m) salinity (SSS) delta value means from all stations and months averaged (Table 1) show profound differences between the Strait of Georgia and Puget Sound. In Puget Sound, SSS was higher during both ENSO wateryears (= positive delta values, Table 1). Relative to WY91, both ENSO wateryears have about the same impact. The magnitude of the positive delta values for SSS is :

WY92-WY91 = WY93-WY91 >>> WY92-WY93

The Strait of Georgia station exhibits markedly different dynamics. SSS was highest in WY91, and much lower during ENSO wateryears (= negative delta values, Table 1), particularly WY92. WY92 showed substantially fresher SSSs at 0.5 m during Apr-Jul (Figures 6 and 8). All three SSS delta value means are negative; two are profoundly so (Table 1). The magnitude of the least-negative delta values for SSS at station GRG002 is:

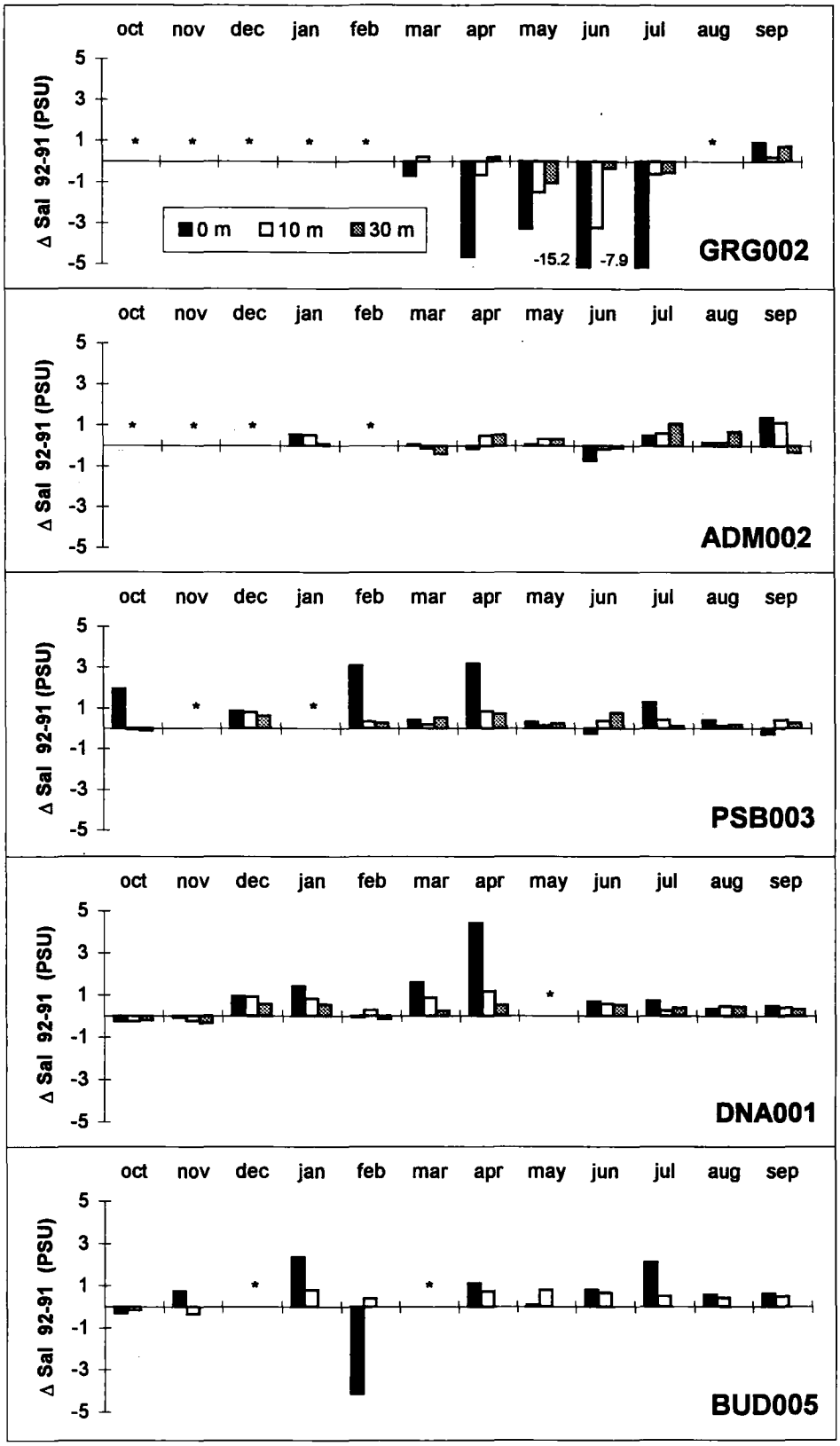
WY92-WY91 <<<< WY93-WY91 >>> WY92-WY93

Such a large influence in SSS (5-15 PSU) is undoubtedly related to the absence versus presence of the Fraser River plume. Plume dynamics are influenced by local winds that possibly were affected by the moderate ENSO conditions, advecting the plume southward during WY92.

The Puget Sound SSS data show similarities with river flow data and to a lesser extent with the precipitation data. Delta values calculated for precipitation and flow data would be expected to be negative if ENSO results in less precipitation and flow. Negative delta values were observed (Table 1), and the absolute values of both parameters showed the expected delta value pattern, but with little difference between the two ENSO years:

WY92-WY91 > WY93-WY91 >>>> WY92-WY93

Although WY92 had more precipitation, both ENSO years showed quite similar flow (Figure 1). The Puget Sound SSS data are also not substantially different between the two ENSO years, suggesting a stronger influence on SSS from flow than precipitation. This would be expected considering the magnitude of these two sources of freshwater input to Puget Sound and that factors, such as diversions, de-couple precipitation from river flow. The near zero, but slightly negative Puget Sound SSS delta value for WY93-WY92 (Table 1) is indicative of the numerous negative values in Figure 8. Negative SSS delta values are a curious result considering that both precipitation and flow ranged from roughly equal to slightly higher in WY93 compared to WY92 (Figure 1). The higher SSSs in WY93 (Figure 8) may reflect the impact of two consecutive dry years.



GRG002	0 m	10 m	30 m
mean:	-5.14	-0.94	-0.18
sd:	5.80	1.30	0.63

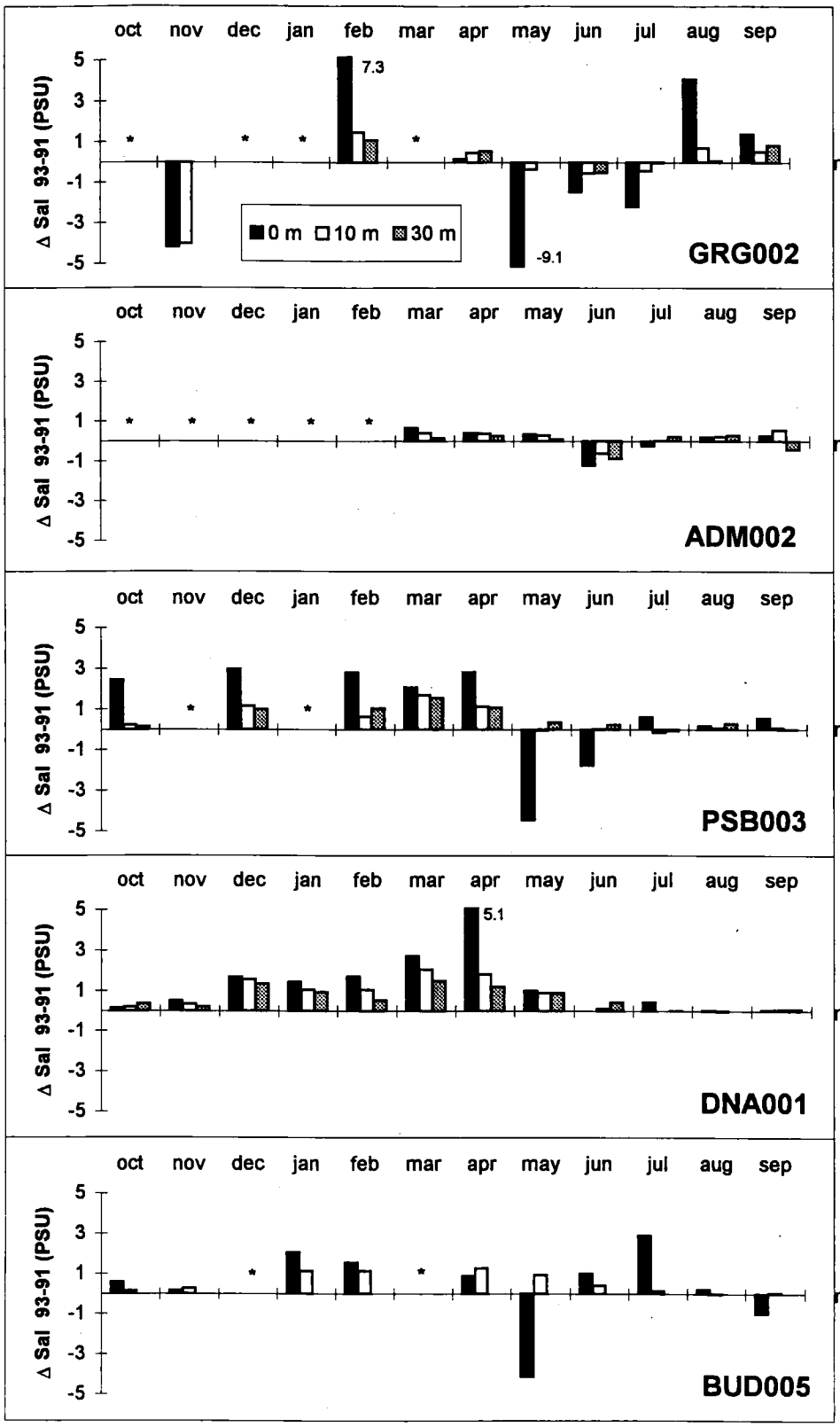
ADM002	0 m	10 m	30 m
mean:	0.23	0.36	0.23
sd:	0.62	0.43	0.53

PSB003	0 m	10 m	30 m
mean:	1.08	0.35	0.36
sd:	1.27	0.28	0.29

DNA001	0 m	10 m	30 m
mean:	0.92	0.47	0.25
sd:	1.30	0.46	0.34

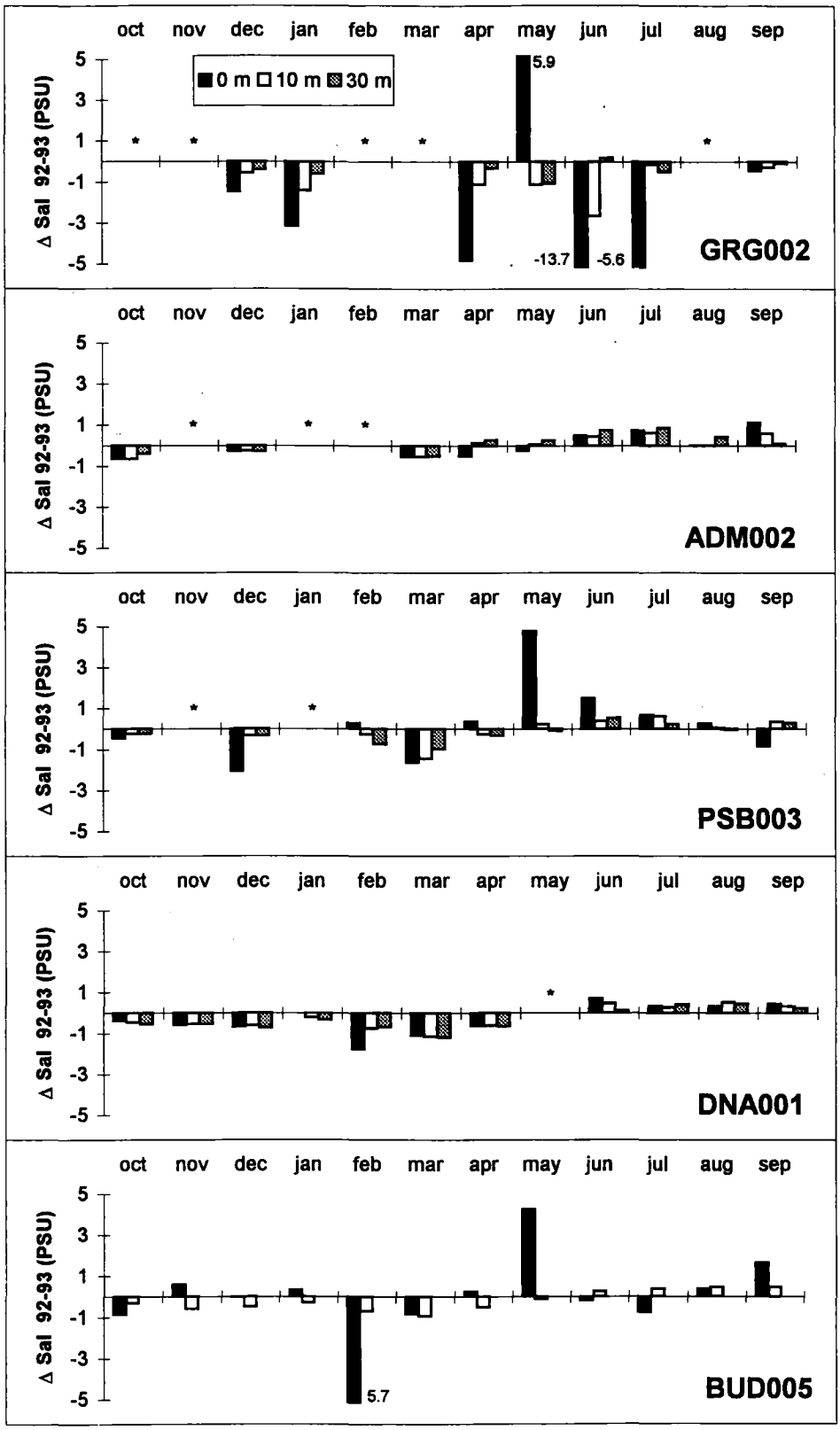
BUD005	0 m	10 m	30 m
mean:	0.39	0.42	
sd:	1.80	0.40	

*Figure 6. Sea-salinity delta values at three depths for WY92-WY91 comparison at each station versus month. The * indicates missing monthly data. Also shown are WY mean and standard deviation (sd) for each depth.*



	0 m	10 m	30 m
GRG002 mean:	-0.53	-0.3	0.27
GRG002 sd:	5.04	1.67	0.56
ADM002 mean:	0.04	0.16	-0.06
ADM002 sd:	0.63	0.39	0.45
PSB003 mean:	0.81	0.46	0.54
PSB003 sd:	2.41	0.64	0.56
DNA001 mean:	1.21	0.75	0.61
DNA001 sd:	1.49	0.75	0.53
BUD005 mean:	0.4	0.53	
BUD005 sd:	1.94	0.51	

*Figure 7. Sea-salinity delta values at three depths for WY93-WY91 comparison at each station versus month. The * indicates missing monthly data. Also shown are WY mean and standard deviation (sd) for each depth.*



	0 m	10 m	30 m
mean:	-3.35	-1.06	-0.42
sd:	5.92	0.85	0.40

	0 m	10 m	30 m
mean:	0.00	0.03	0.16
sd:	0.64	0.48	0.50

	0 m	10 m	30 m
mean:	0.27	-0.11	-0.19
sd:	1.92	0.59	0.47

	0 m	10 m	30 m
mean:	-0.32	-0.27	-0.33
sd:	0.75	0.57	0.55

	0 m	10 m	30 m
mean:	-0.09	-0.21	
sd:	2.26	0.50	

*Figure 8. Sea-salinity delta values at three depths for WY92-WY93 comparison at each station versus month. The * indicates missing monthly data. Also shown are WY mean and standard deviation (sd) for each depth.*

River influence on SSS is further shown by comparing the five stations. The salinity delta values for Admiralty Inlet showed the smallest negative or positive magnitude (Figures 6, 7, and 8). The ADM001 station is the farthest from river influence of the five stations. The very small salinity delta values imply a constancy of the salinity at this station that could be the result of a relative lack of river influence or more effective mixing processes than the other stations. However, temperature delta values at this station were significant and were sometimes greater than these seen at other stations (e.g., Figure 3). This indicates the salinity constancy is primarily due to the lack of river influence at this station, relative to the other stations studied here.

Weather

For the three years in this analysis, greater ENSO forcing was associated with warmer (positive air temperature delta values; Table 1) and drier weather and less river flow (negative precipitation and flow delta values; Table 1). Less precipitation and less river flow in the Pacific Northwest are not characteristic of all ENSO events; however, the occurrence of warmer local air temperatures during ENSO events has been demonstrated (Ropelewski and Halpert, 1986; 1987). In this analysis, the degree of ENSO forcing was not reflected by the relative magnitude of the air temperature anomalies (Table 1). This is because the anomalies were averaged over the wateryear, whereas ENSO forcing was evident only part of the year (Kessler and McPhaden, 1995a,b). The positive air temperature anomalies also were seen only part of the year, primarily late winter through spring (Figure 1). An improved method of analysis would use monthly ENSO indices (Climate Analysis Center, 1991) to quantify the degree of ENSO forcing rather than the year-long distinctions used here.

SUMMARY AND CONCLUSIONS

Although this analysis was elementary, some salient results were obtained and conclusions indicated. Of the three years analyzed, SST was noticeably warmest during the moderate ENSO year, when air temperatures also were clearly warmer (by 1.4°C, Figure 1). In terms of annual averages, SST was increased over the non-ENSO year's value by 1.6°C during the moderate ENSO and by only one-third as much (0.5°C) during the weak ENSO. In Puget Sound, SSS was saltiest during ENSO events, although SSS changes averaged less than 1 PSU. In spite of weaker ENSO conditions and slightly more precipitation (0.5 cm) in WY93 than in WY92, the two wateryears exhibited similar SSSs and flow. In the Strait of Georgia, SSS conditions were the opposite of those in Puget Sound, with saltiest values during the non-ENSO year and freshest in the strongest ENSO year. The difference is probably due to advection of the Fraser River plume. Although the sea-surface differences in this analysis may not all be directly related to ENSO, the analysis does demonstrate the importance of local weather on Puget Sound.

Conclusions from this analysis are:

1) Climatic conditions (i.e., ENSO) noticeably impact sea-surface temperature and salinity.

2) Puget Sound SST appears to co-vary with air temperature.

3) Puget Sound SSS appears to co-vary with river flow and less strongly with precipitation.

4) The Strait of Georgia station GRG002, north of Patos Island, shows variable influence from the Fraser River plume that is possibly affected by ENSO events.

ACKNOWLEDGMENTS

The author would like to thank Nick Bond (PMEL, NOAA) and Mike McPhaden (PMEL, NOAA) for their reviews of the manuscript and insights. Discussions with William Kessler (PMEL, NOAA) regarding ENSO dynamics are also acknowledged. This work benefited from graphical and editing assistance by Angie Thomson (Ecology), whose contribution is greatly appreciated.

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PRINCIPLE COMPONENT ANALYSIS OF HYDROGRAPHIC DATA IN SINCLAIR AND BUDD INLETS; OR, HOW TO SAMPLE THE GREATEST AMOUNTS OF VARIABILITY (WITH THE LEAST EFFORT)

Skip Albertson[1]

ABSTRACT

Temperature, salinity, dissolved oxygen and nutrient distributions in Sinclair and Budd Inlets are examined with the intent of identifying the minimum underlying data set necessary to describe seasonal variability, and to identify the dominant physical characteristics in each estuary to a set level of significance. Principle component analysis (a.k.a. eigenvector or factor analysis, empirical orthogonal functions) is used with data from Ecology's marine water-column ambient monitoring database to explore interrelationships between these data.

In both inlets, two depth layers account for more than 90 percent of the variability seen in the entire vertical water column. Density (sigma-T) is most closely associated with salinity (S), although in Sinclair Inlet temperature (T) is also significant. Among the measured variables, temperature is most closely associated with date, reflecting seasonality, and dissolved-oxygen (DO) with depth. Ammonium-N and nitrate-N are independent of the physical parameters in Budd Inlet; thus independent monitoring of nutrients is justified. Based on hydrographic (T, S and DO) data, the most redundant stations in Budd Inlet are near the mouth and along the west side of the inlet. Four of the 20 stations in Budd Inlet and three of the six Sinclair slack tide stations could have been omitted without much loss of the total information attained in those locations.

INTRODUCTION

In 1967, two years before the Department of Ecology was founded, its predecessor, the Water Pollution Control Commission, began taking long-term hydrographic data in Puget Sound. Between 1967 and 1989, data were taken monthly from spring until fall at stations from the Canadian border, in the north, to Olympia in the south. Data taken after 1973 are available in a computer database. Beginning in 1989, subsequent to the formation of the Puget Sound Ambient Monitoring Program (PSAMP), data were taken monthly throughout the year with a modern conductivity, temperature and depth probe (CTD). Data from 0.5-m, 10-m and 30-m depths were culled from these vertical profiles for inclusion in the EPA *STORET* and Ecology databases, in keeping with the historical precedent.

In 1992, additional funding within PSAMP allowed the initiation of Ecology's seasonal monitoring component for the purpose of sampling with greater spatial and temporal resolution than was previously possible with the long-term monitoring component (Janzen, 1992). Seasonal monitoring is conducted to further investigate areas that may have or are known to have poor water quality. However, since sampling resolution is subsequently increased over long-term monitoring, seasonal monitoring also addresses the adequacy of one station to represent an estuary. The first two seasonal projects were Budd Inlet in south Puget Sound, and Sinclair and Dyes Inlets in the central Sound. It is these data that are analyzed using principle component analysis (PCA).

PCA is an attempt to quantify the variability in field measurements, whatever the physical and biological causes, to a known level of significance. The technique is a general one and could be applied to the entire Puget Sound database as well as to specific inlets. PCA is a quantitative tool that can be used either to reduce the number of variables being measured (e.g., station locations) or to detect structure in relationships between variables. PCA can be used to explore whether economizing could be made in either: 1) time, by increasing future intervals between seasonal surveys; 2) location, by decreasing the

[1] Washington State Dept. of Ecology, P.O. Box 47710, Olympia, WA 98504

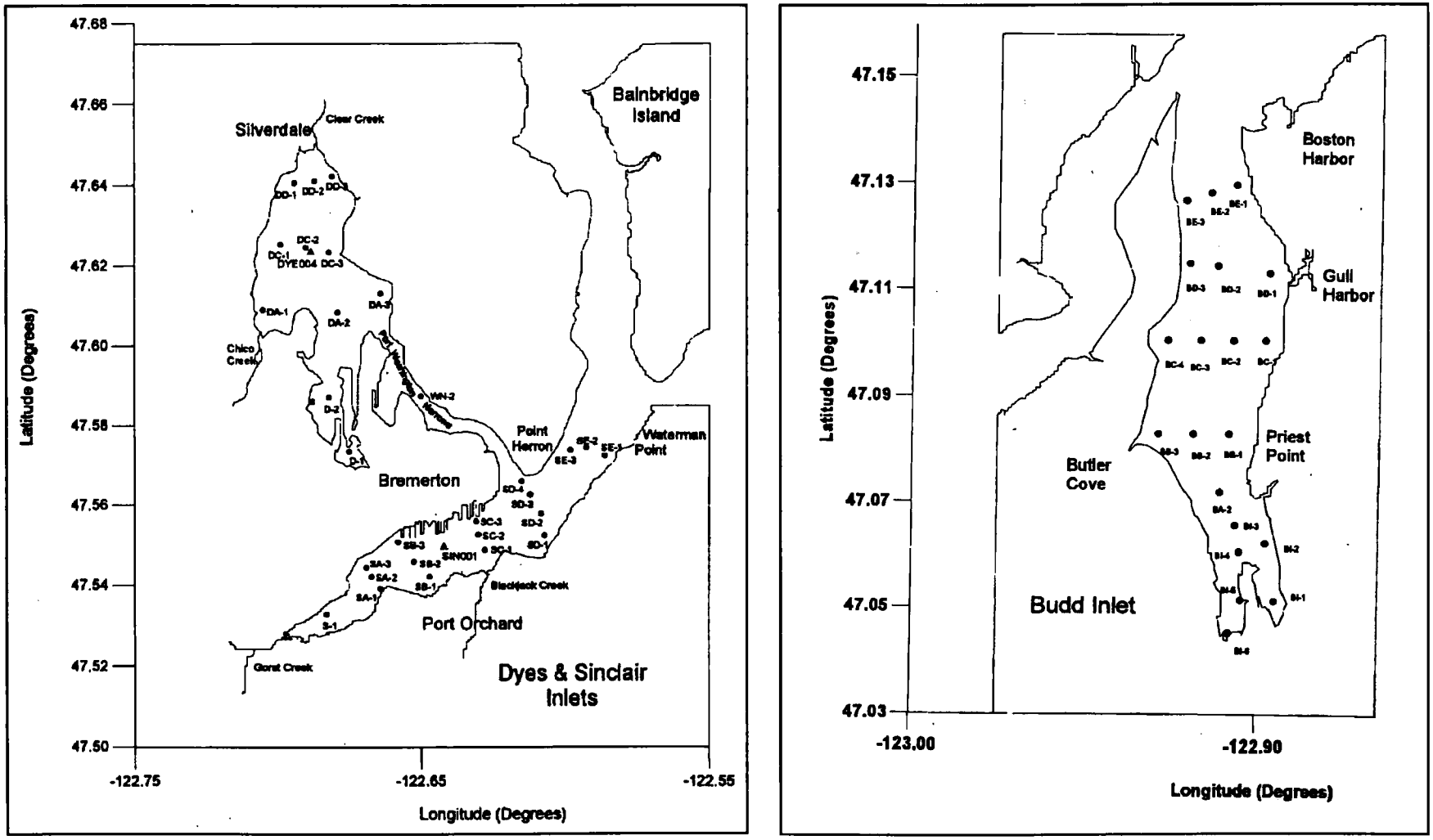

Figure 1. Seasonal and long-term monitoring station locations from Sinclair and Dyes Inlets (left) and Budd Inlet (right)

number of stations visited on a given survey; 3) number of parameters measured, by decreasing the number of parameters measured in a survey to the truly independent ones; or 4) depth, by decreasing the amount of data permanently stored in databases from the high-resolution 0.5 bin-averaged vertical profiles collected, without significant loss of vertical modes.

The hydrodynamic conditions in Puget Sound are complex, and the amount of precision desired in data will depend on the question being asked. For instance, an engineer at a wastewater treatment plant concerned about the corrosiveness of seawater on a discharge pipe would likely need to know salinity to fewer significant digits than a physical oceanographer studying circulation patterns in the same area. After a period of initial sampling, the question of how much variability is being measured at each sampling point should be answered based on the data gathered to date. This report addresses that question using seasonal monitoring data and PCA. A "datapoint" in this multidimensional space is defined by several independent variables (location, depth and time) as well as the dependent ones (parameters: temperature, salinity, etc.).

METHODS

Sampling

Field surveys were planned every two weeks between March and October 1992 in both inlets, though logistical constraints occasionally prevented this regular sampling interval from being accomplished. Approximately 20 to 30 stations were monitored in each study area (Figure 1). The biweekly sampling interval used during the seasonal surveys was insufficient, relative to the period of the tides or the solar day, in order to calculate their effect on variability. Only data from equivalent (e.g., midday, neap exchange, low tide) tidal states are compared here, thus minimizing variability on these smaller time scales.

A Sea-Bird Electronics Sealogger SBE-25® CTD profiler was used as the primary CTD for collecting continuous water column profile data. Parameters including temperature, salinity, and dissolved oxygen (DO) were accessible directly from the CTD. The CTD was calibrated monthly at Ecology and annually by a National Bureau of Standards certified lab, per the manufacturer's suggestion (Sea-Bird Electronics, 1990). A 1.2 liter (L) Niskin® bottle was manually deployed to collect discrete water samples for nutrient analyses (e.g., ammonium-N, etc.). Sample collection methods followed the Recommended Protocols and Guidelines for Measuring Conventional Water Column Variables in Puget Sound (PSEP, 1990). Ecology's seasonal monitoring sampling plan is described further in Eisner et al. (1994).

Analytical Methods

PCA can best be explained with reference to the following contrived estuary (Figure 2):

For each analysis a matrix of input data (e.g., by station and survey date) is analyzed to determine redundancies for a particular water quality parameter. An "input" matrix is constructed by entering data (e.g., surface temperatures) into columns (by station) and rows (by survey date).

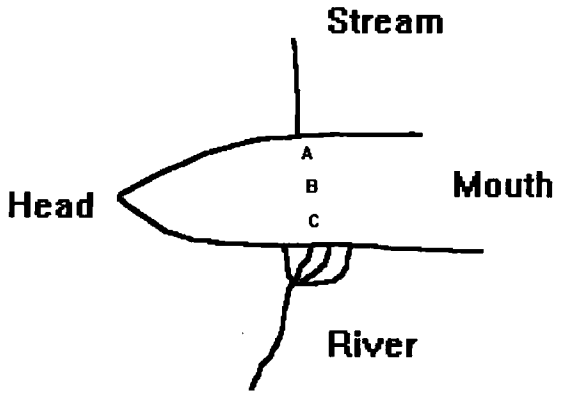

Figure 2. A fictictious estuary with 3 stations on a cross-bay transect

date / station	A	B	C
date 1	5	5	5
date 2	10	2	10
date 3	5	4	5
date 4	0	-3	0

The relevant correlation matrix is created by the following steps:

1) Subtracting the mean of each column from each entry in that column to mean-center the data:

date / station	A	B	C
date 1	0	3	0
date 2	5	0	5
date 3	0	2	0
date 4	-5	-5	-5

2) Dividing each entry in each column by the unbiased (n-1) standard deviation of all the entries in that column, thus standardizing the "input" matrix (creating $\underline{S}$). Columns (original variables) of different parameters can now be compared with each other:

date / station	A	B	C
date 1	0	0.84	0
date 2	1.22	0	1.22
date 3	0	0.56	0
date 4	-1.22	-1.4	-1.22

3) Pre-multiplying this matrix by its transpose, resulting in the desired correlation matrix ($\underline{A} = \underline{S}^T * \underline{S}$). The eigenvalue analysis of the correlation matrix will show whether there is redundancy (a determinant close to zero), where $\underline{I}$ is the Identity matrix and λ, the unknown eigenvalue(s):

$$\det(\lambda\underline{I}-\underline{A}) = \begin{vmatrix} \lambda-1.71 & -1.71 & -3 \\ -1.71 & \lambda-3 & -1.71 \\ -3 & -1.71 & \lambda-3 \end{vmatrix} = 0$$

The solution of this contrived problem is a cubic in λ. The solutions [$\lambda_1 = 7.303$ (81.8%); $\lambda_2 = 1.6298$ (18.2%); $\lambda_3 = 0$ (0%)] show that one of the stations (either A or C, determined by inspection of the corresponding eigenvectors) is a linear combination of the other two (an exact duplicate, in fact).

In the more complex analyses of actual data, the significance of each eigenvalue was usually selected by the Kaiser criterion: that is, unless a new component accounted for more variance than an original variable ($\lambda > 1.0$), it was dropped.

RESULTS AND INTERPRETATIONS

Time

In order to use PCA effectively to evaluate the redundancy of data by locale, depth and parameter, it must first be shown that the input data have been sampled over a sufficiently relevant timescale. Evidence to support the argument that the frequency of sampling was insufficient to resolve tidal or diel variability is presented in Figure 3. Some parameters, like DO, can change substantially over several hours at a fixed point. The Nyquist criterion from sampling theory states that the sampling frequency must be at least twice

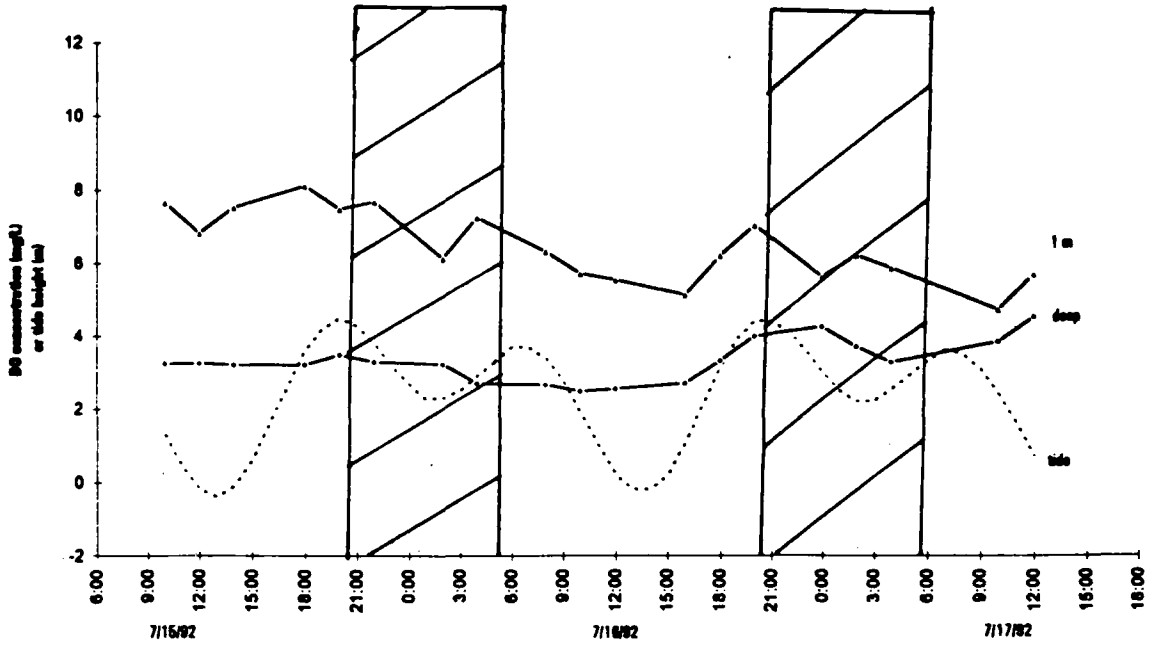

Figure 3. Dissolved oxygen (DO) concentrations versus time over a 52-h tidal cycle survey on 15 to 17 July 1992 in Budd inlet for 1 m (triangles) and deep (1 m above seabed; diamonds) samples at station BI-5. Shading represents night.

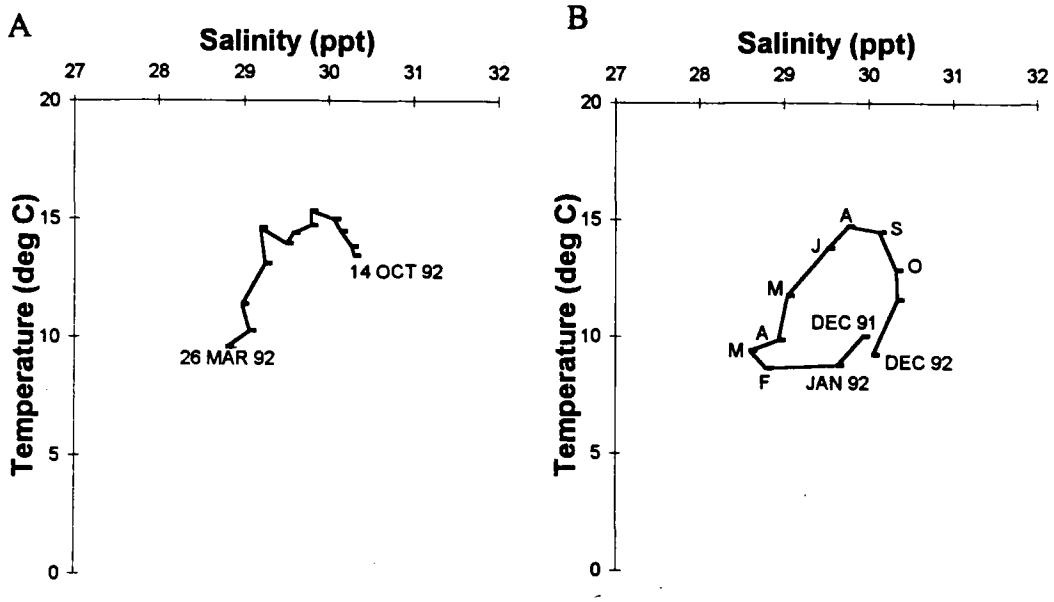

Figure 4. Progressive T/S (temperature/salinity) endpoint diagrams from 1992 a) seasonal surveys and b) long-term monitoring station SIN001

the lowest frequency of interest in order to avoid the problems associated with aliasing (e.g., Ramirez, 1985). In a practical sense, hourly data would be sufficient to resolve the effects of the semi-diurnal tide.

Evidence to support the hypothesis that the biweekly sampling period will suffice for measuring seasonal variability is presented in Figure 4. Progressive plots of temperature/salinity (T/S) endpoint from both the seasonal (biweekly) and corresponding long-term (monthly) data trace a near-perfect ellipse in T, S space—note that temperature decreases before salinity in the autumn. Sampling less often than monthly would sacrifice detail in these annual cycles. These plots provide some justification for using the biweekly seasonal data in the rows (cases) of these PCA analyses.

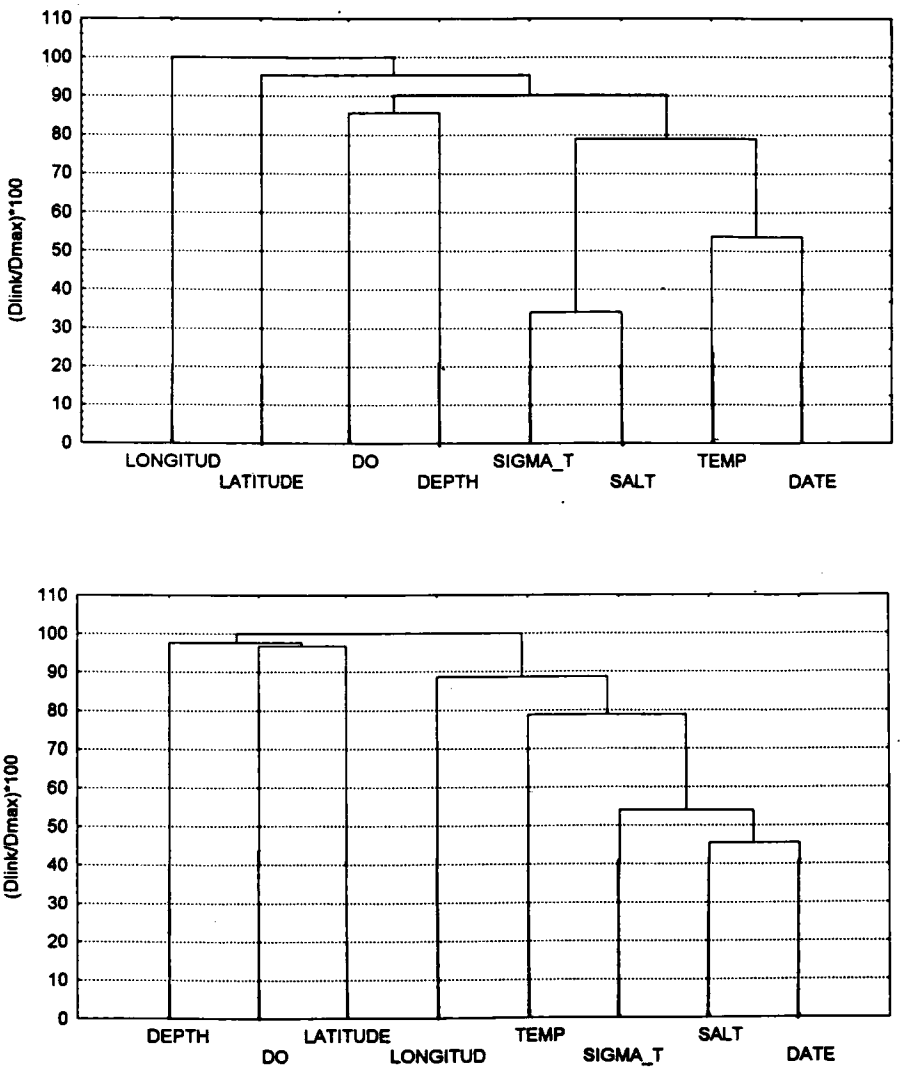

Figure 5. Tree diagram of Euclidean distances between variables from all 1992 seasonal data in a) Budd Inlet and b) Sinclair and Dyes Inlet

Parameter

By creating an "input" matrix from all 1992 data with columns of latitude, longitude, depth, temperature, salinity, density and DO, it can be shown that density was most closely related to salinity in Budd Inlet (Figure 5a). The same was true to a lesser extent in Sinclair Inlet (Figure 5b), where the Euclidean distance (i.e., the square-root of the sum of the squared correlation differences for each variable) between density and temperature was also relatively small (this is more clearly apparent in a separate analysis of just density, salinity and temperature, not included here). Strong freshwater-induced stratification in Budd Inlet may also account for this result. Other parameters were more independent of each other, but DO was more related to depth in Budd Inlet than in Sinclair and Dyes Inlets.

Depth

In order to evaluate station independence, the assumption that the water column could be split into two layers was made. Although the CTD samples continuously and inexpensively at every depth, it may be costly to maintain all these data in a database. By creating an "input" matrix of data with depth-bins as columns (0.5m, 1m 1.5m, etc.) and entering all the casts made during 1992 as rows (cases), a PCA analysis shows that two components (the near-surface [< 2m] and near-bottom) typically account for more than 90 percent of the vertical variability in the water column for T, S and DO (Figure 6). The occurrence of subsurface algae blooms affecting DO are likely the largest defeating factor to this scheme. Similar results were obtained in Sinclair Inlet, although the depth and degree of separation were slightly different.

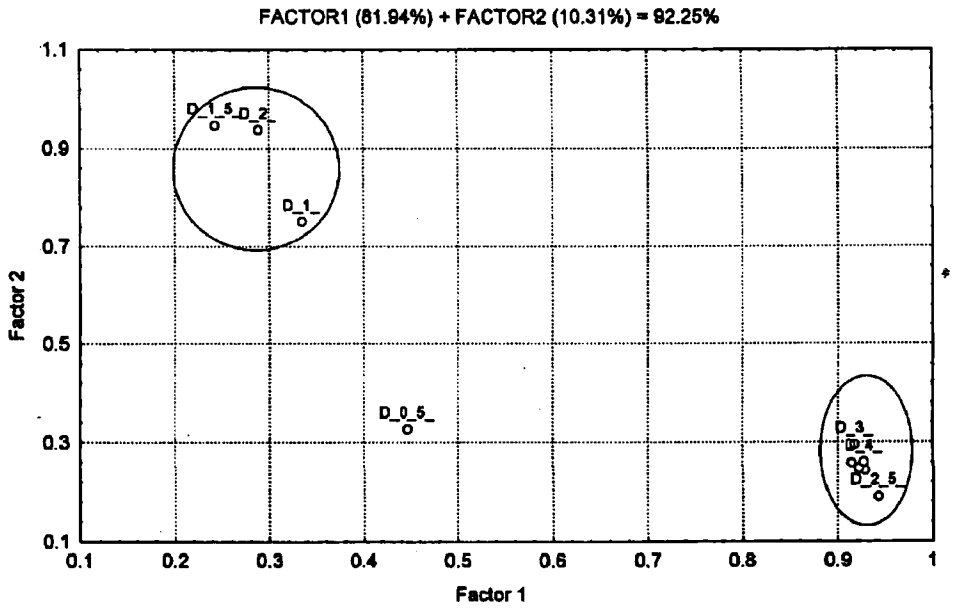

Figure 6. Two-factor PCA plot with varimax rotation. Justification for two depth layer assumption from 1992 seasonal Budd Inlet data (D_1_5=depth of 1.5m etc.) based on station BI-5. All depths, other than 0.5 m, align with two factors (surface mixed layer, bottom layer). The ellipses (l → r) enclose depths between 1 & 2 m and greater than 2 m.

Location (Station)

This is where PCA can be used to greatest advantage. By making the assumption that the water column can be split into 2 layers and that the 14 survey dates (cases) reasonably represent the seasonal variability, a workable "input" matrix can be constructed. The columns (original variables) in the matrix were composed of near-surface and near-bottom temperatures, salinities, DO, nitrate-N and ammonium-N at each station. Each survey date constituted a different case and was entered as a separate row in the matrix.

Sinclair Inlet

Slack tide data—surface temperature

In Sinclair Inlet, the most independent stations of the slack tide transect for surface temperature were SE-2 and S-1, and the most alike were SB-2 and SC-2 (Figure 7). The first PCA component, accounting for more than 90 percent of the total seasonal variability in surface temperature, was the "free body" mode, where all parameters change together at all locations (Table 1). Extrapolating to the future, if 90 percent of the variability in surface-temperature will suffice, then only one station (e.g., long-term monitoring station SIN001) needs to be monitored. The second component (Table 1) has one sign reversal in its component loadings. This component accounts for an additional 5 percent of the observed variability and seems to be related to the influence of outer Puget Sound (i.e., stations toward the mouth of the estuary have a negative thermal anomaly in summer). If so, this component is likely to reverse itself twice a year (i.e., Sinclair Inlet is cooled by the outer Sound in the summer but warmed by it in the winter). A test of this hypothesis

could be made by collecting winter data and making a similar analysis. If correct, a second station at SE-2 would extract an additional 5 percent of the total variability from Sinclair Inlet. The third component, with two sign reversals, might be related to freshwater inputs from Gorst and Blackjack Creeks. Caveats, pertaining to tidal variability and how representative 1992 was, apply.

Table 1. PCA results of seasonal near-surface temperature at slack tide from Sinclair Inlet

Variable	Component 1	Component 2	Component 3
SE-2	.907	-.415	-.021
SD-2	.967	-.036	.142
SC-2	.989	.076	.090
SB-2	.982	.132	.041
SA-2	.989	.139	.042
S-1	.948	.072	-.304
Eigenvalue	5.577	0.221	0.124
% Variance	92.94	3.69	2.07

Budd Inlet

Slack tide data—independence of location and parameters

To evaluate the independence of each slack tide station by parameter (based on T, S, DO, ammonium-N and nitrate-N data), an "input" matrix was constructed by making columns at each slack tide station, of each parameter, at two depths (near-surface and near-bottom). Thus each station gave rise to 10 separate columns (e.g., BI-5SA = station BI-5, near-surface, ammonium-N). The resulting correlation matrix showed that only about 2/3 of the total variance could be expressed by two components. Correlation with two factors (Figure 8) was much less satisfactory than in Figure 5. Although they do imply a fair amount of redundancy in the data, nutrient values are more independent of the physical parameters (e.g., temperature, salinity) and thus warrant separate monitoring (Figure 8).

Cross-bay transects—location independence

To evaluate the total independence of all the stations (based on T, S & DO, since nutrient data were not taken everywhere), a new "input" matrix was constructed. Columns were formed from data at each cross-bay and slack tide station, of each parameter, at two depths (near-surface and near-bottom). The matrix

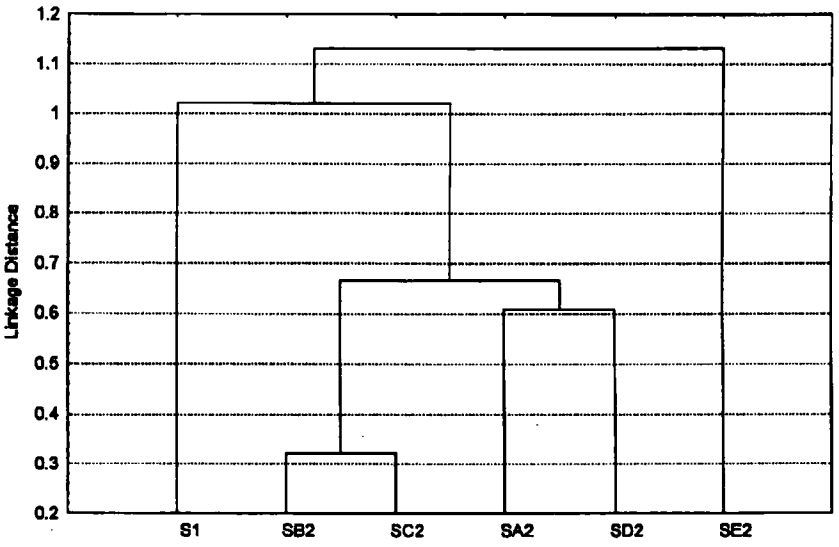

Figure 7. Tree diagram of Euclidean distances between slack tide stations' temperature, salinity and DO data from all 1992 seasonal data in Sinclair Inlet

was standardized and the columns of different parameters and depths were re-combined so that the order of parameters and depths were preserved from one station to the next. The new columns correspond to the total variability of the chosen three parameters, at two depths, at each station. Unique rows (cases), again, represent each survey. The resultant cluster analysis from all components is shown in Figure 9. In general, outer bay stations at the BE transect are the most alike. At the BB transect, the station on the east side (i.e., BB-1) is the most unique. Based on this analysis, stations BE-1, BE-3, BC-3 and BB-3 could be dropped with the least loss of unique information.

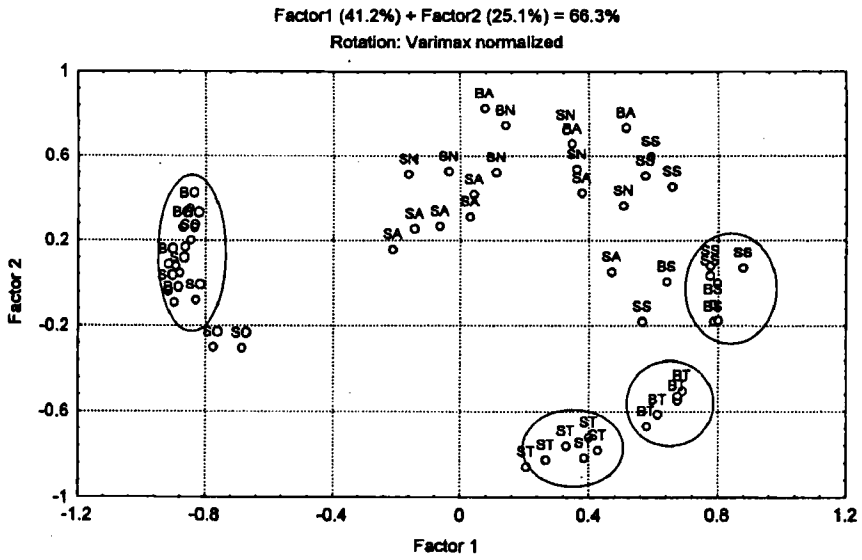

Figure 8. Two-factor PCA plot of parameters from various stations (e.g., BA = Bottom Ammonium-N) from 1992 slack-tide, seasonal Budd Inlet data. Parameters include temperature (T), salinity (S), DO (O), ammonium-N (A) and nitrate-N (N). Circles (l → r) enclose DO data, ST, BT & salinity data. None of the nutrient data cluster well or with the physical parameters.

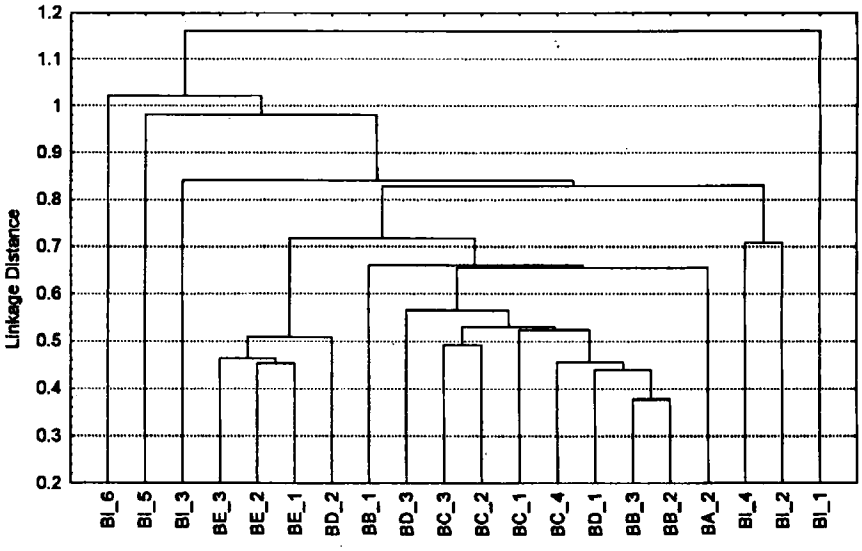

Figure 9. Tree diagram of Euclidean distances between all stations' temperature, salinity and DO data from 1992 seasonal data in Budd Inlet. Stations BE-1, BE-3, BC-3 and BB-3 are the most redundant.

SUMMARY

In both inlets, two depth layers account for more than 90 percent of the variability seen in the entire vertical water column. Density (sigma-T) is most closely associated with salinity (S), although in Sinclair Inlet temperature (T) is also significant. This reflects higher importance of freshwater input in Budd than in Sinclair Inlet. Among the measured variables, temperature is most closely associated with date, reflecting seasonality, and dissolved oxygen (DO) with depth, reflecting a number of processes that vary with depth (e.g., stratification, atmospheric coupling, biological production). Ammonium-N and nitrate-N are independent of the physical parameters in Budd Inlet; thus independent monitoring of nutrients is justified. Based on hydrographic (T, S and DO) data, the most redundant stations in Budd Inlet are

near the mouth (BE transect) and along the west side of the inlet. Four of the 20 stations (i.e., BE-1, BE-3, BB-3 and BC-3) in Budd Inlet and three of the six Sinclair slack tide stations could have been omitted without much loss of the total information attained in those locations.

Finally, PCA would be a useful technique to help re-evaluate the importance of long-term monitoring stations, as well. By dropping redundant stations, additional locations closer to unique sources could be monitored in their place.

ACKNOWLEDGMENTS

Support for collection and analysis of water quality data was provided by PSAMP and the Washington Department of Ecology. The author wishes to thank Jan Newton, Lisa Eisner and Angie Thomson for their support in this work.

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DISSOLVED OXYGEN CONCENTRATIONS IN HOOD CANAL: ARE CURRENT CONDITIONS DIFFERENT FROM THOSE OF 40 YEARS AGO?

J.A. Newton[1], A.L. Thomson[1], L.B. Eisner[1], G. Hannach[2], and S.L. Albertson[1]

INTRODUCTION

The following is a summary of work in progress by the Washington Department of Ecology to investigate the severity of low dissolved oxygen (DO) conditions in Hood Canal. Hood Canal is a biologically productive system exhibiting persistent density stratification during summer months, a condition prime for the development of low DO concentrations. It is important to assess whether Hood Canal, although naturally prone to low DO concentratrions, is undergoing changes with respect to the frequency or intensity of low DO conditions, and whether this may be related to anthropogenic influence. Development and other human impacts that could influence parameters affecting DO in Hood Canal have changed since the 1950s and 1960s, a period for which comprehensive water column data exist (Collias et al., 1974). Ecology is evaluating whether the present-day magnitude and/or areal extent of low DO concentrations in Hood Canal is significantly different from those recorded in the historical Collias et al. (1974) database.

The study in Hood Canal represents a focused project of Ecology's Marine Water Monitoring within the Puget Sound Ambient Monitoring Program (PSAMP). Ecology's Marine Water Monitoring Unit monitors numerous stations within Puget Sound to establish baseline water quality data and to identify emerging problems as a component of PSAMP (see Newton et al., 1995). Ecology's approach includes both long-term monthly monitoring throughout Puget Sound and short-lived (six months to three years) focused projects on water quality-sensitive areas. Focused projects are conducted with increased spatial and/or temporal resolution to assess the existence or extent of water quality problems and to detect whether conditions reflect long-term changes. A focused project in Hood Canal to investigate the occurrence and severity of low DO concentrations was begun in April 1994 and will continue through 1995.

Hood Canal is a large subregion of Puget Sound that has physical characteristics distinct from the Puget Sound main basin. Much of our understanding of biological-physical dynamics in Puget Sound has come from studies conducted in the main basin that cannot be directly applied to Hood Canal (e.g., Metro, 1977, off West Point; Metro, 1984, off Seahurst). The circulation in Hood Canal is much slower than that in the main basin (Barnes and Ebbesmeyer, 1978). Although Hood Canal receives less freshwater input in comparison with the main basin (Curl and Paulson, 1991), this input, largely from the Skokomish River, produces a significant amount of salinity-driven density stratification. Because the tidal exchange in Hood Canal is weaker than in the main basin (Barnes and Ebbesmeyer, 1978), the strong salinity-driven stratification persists. This is particularly true in southern Hood Canal, where low DO concentrations primarily have been observed. In addition to weak currents, the entrance sill to Hood Canal, located north of Bangor, impedes inflow and flushing. Model formulations by Cokelet et al. (1988) show that in the Puget Sound system the mean age of salt particles is greatest in Hood Canal. Also, the residence time for a particle injected into Hood Canal locations ranges from 72-121 d, whereas in the main basin it is only 59-90 d (Cokelet et al., 1988).

The physical attributes of Hood Canal—persistent salinity-driven stratification, slow circulation and long residence time—can result in the development of low DO concentrations. The physically stable environment enables seasonally high biological productivity in the surface layer. Settling and oxidation of

[1] Environmental Investigations and Laboratory Services, Washington Department of Ecology, 300 Desmond Drive, Olympia, WA 98504-7710

[2] U.S. Environmental Protection Agency, Pacific Ecosystems Branch, 2111 S.E. Marine Science Dr., Newport, OR 97365-5260

the organic material coupled with persistent stratification result in low DO concentrations in the underlying water. In addition, the deep waters in Hood Canal exhibit a high apparent oxygen utilization (Barnes and Ebbesmeyer, 1978), due to slow circulation coupled with high organic carbon content. This condition also favors the development of low DO concentrations.

Human impacts can cause or exacerbate low DO concentrations. Human impact to Hood Canal includes substantial development of the shoreline and in the watershed. Development has resulted in habitat alteration and possible nutrient enrichment. Nutrient enrichment is likely because of failing septic tanks, agricultural runoff, and logging, yet this effect has not been quantitatively assessed in Hood Canal. Fecal contamination is prevalent in southern Hood Canal (Health, 1993) and has been primarily affected by failing on-site sewage systems (Health, in prep.). Another human impact has been the diversion of the Skokomish River through Cushman Dam, built in 1930, altering the freshwater delivery. This is potentially important since the salinity-driven circulation of estuaries could be affected by freshwater diversions (Ebbesmeyer and Tangborn, 1995). Whether the alteration in freshwater delivery magnitude and timing is large enough to affect the salinity and circulation of Hood Canal has not been evaluated.

Both nutrient enrichment and decreased circulation could result in lower DO concentrations and thus poorer water quality in Hood Canal. A set of DO profiles collected during August 1986 led Curl and Paulson (1991) to conclude "the volume of hypoxic water is much greater than any seen in the previous three decades." Numerous fish kills (seven events from 1989-1992; Oberlander, 1992) have been observed that could have been caused by low DO concentrations. The events were recorded in late summer to early fall; many were observed after rains that had followed a dry period. In consideration of these observations and the sensitivity of the system, it is important to assess whether low DO conditions in Hood Canal have worsened. Substantial historical data exist for Hood Canal (Collias et al., 1974; unpublished data of T.G. Thompson from the 1930s). Ecology's Hood Canal-focused project was designed to evaluate whether low DO conditions have worsened, potentially affected by human impacts or other processes, by comparing present-day values with the historical data.

The following hypotheses were developed in order to assess long-term changes in DO and evaluate causative factors in Hood Canal:

H_o: The low DO concentrations in Hood Canal are of the same magnitude and areal extent as 40 y ago.

H_a: There has been a decrease in the DO concentrations and/or an increase in the areal extent of low DO waters:

1) that is driven by an increase in primary production stimulated by nutrient enrichment; or

2) that is driven by a change in the circulation or flushing characteristics of Hood Canal.

The strategies being employed to evaluate each hypothesis are as follows:

H_o:

Collect data during 1994-95 to compare with those from 1952-1966 in the Collias et al. (1974) database along the same transect of stations.

H_a-1:

- Measure primary production (^{14}C uptake experiments) with and without added nutrient spikes to assess whether nutrient enrichment would result in increased production.
- Assess nutrient loading to Hood Canal.

H_a-2:

- Measure temperature, salinity, and density and compare to historical data.
- Measure a conservative tracer to track water mass movement (Warner, UW).

We have conducted five transect cruises measuring DO concentrations and other hydrographic parameters along a transect (Figure 1), incorporating Collias et al. (1974) stations and long-term Ecology stations. Three stations (#1 in the main basin, #10 in central Hood Canal, and #14 in southern Hood Canal; Figure 1) were selected for the primary productivity experiments. At each station the integrated primary production was determined by incubating sea water from six depths with ^{14}C-labeled sodium bicarbonate, with and without an added nutrient spike (N+P). The physical attributes and circulation of Hood Canal have been addressed by contouring hydrographic data from the transects and also by the independent research of Mark Warner (School of Oceanography, University of Washington), who measured the chlorofluoromethanes F-11 and F-12 on several of our cruises. These dissolved gases are conservative tracers that can be used to track water mass movement. Collaboration with Roberto Llansó of Ecology's Marine Benthic Monitoring Unit was begun in 1994 to assess the abundance and diversity of benthic infauna as an indicator of the persistence of low DO concentrations.

Initial results of the project are:

1) The DO concentrations measured during the transect cruises in 1994 (Fig. 1) were not obviously different in magnitude from the historical Collias et al. (1974) values; however, the areal pattern was different:

a) Hypoxia (DO concentration < 0.15 mg-at/L) was not observed in Lynch Cove during the 1994 cruises, yet was frequently seen in the Collias et al. (1974) database.

b) Deep-water hypoxia was observed centered at the Great Bend region during 1994, whereas in the historical data the locus for low DO was in Lynch Cove, emanating seaward into the Great Bend region but not centered there.

2) The F-11 data (Warner, UW) indicated the least amount of flushing (stable F-11 concentrations) at the same Great Bend location (station #12) where the DO concentration was minimum.

3) For each of the three months that experiments were conducted (July, August, September), nutrient additions in-

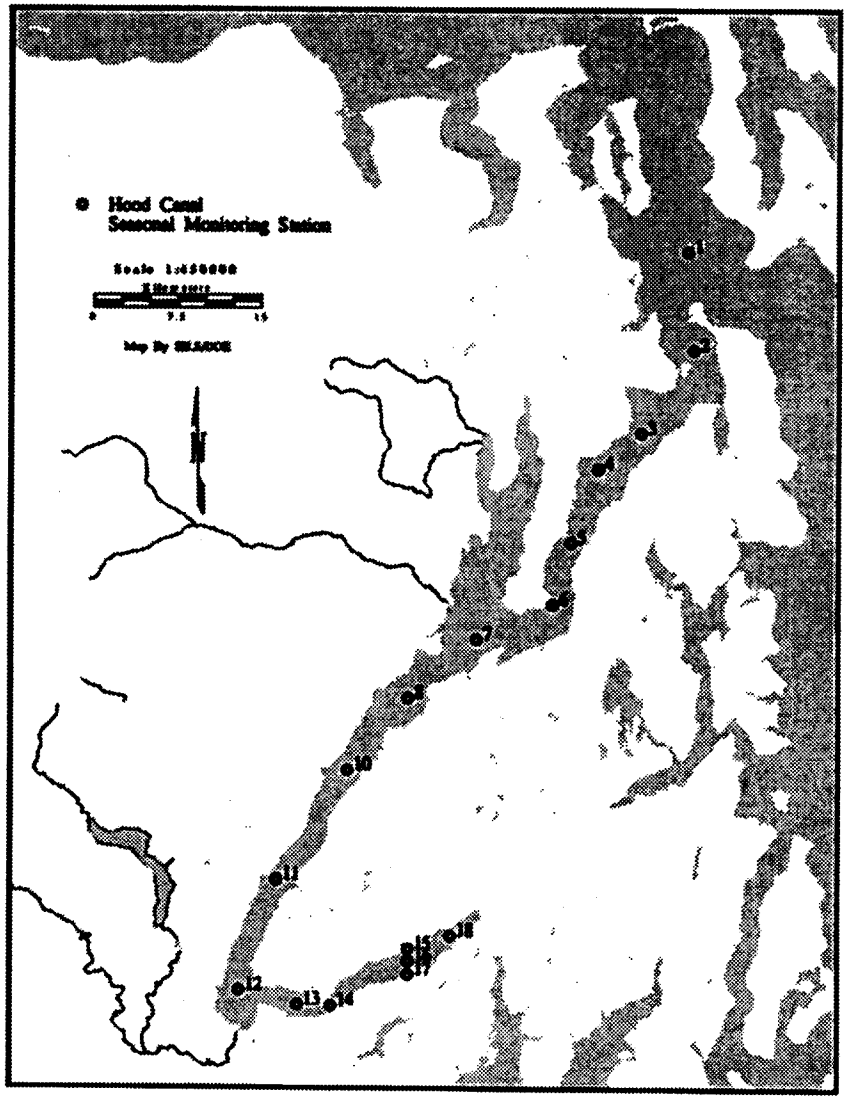

Figure 1. Transect of stations for Ecology's focused project in Hood Canal. Stations 2, 3, 4, 6, 7, 8, 10, 12, 13, 14, and 16 are Collias et al. (1974) stations. Stations 5 and 14 are Ecology long-term stations; 10 and 16 are Ecology rotating stations (see Newton et al., 1994).

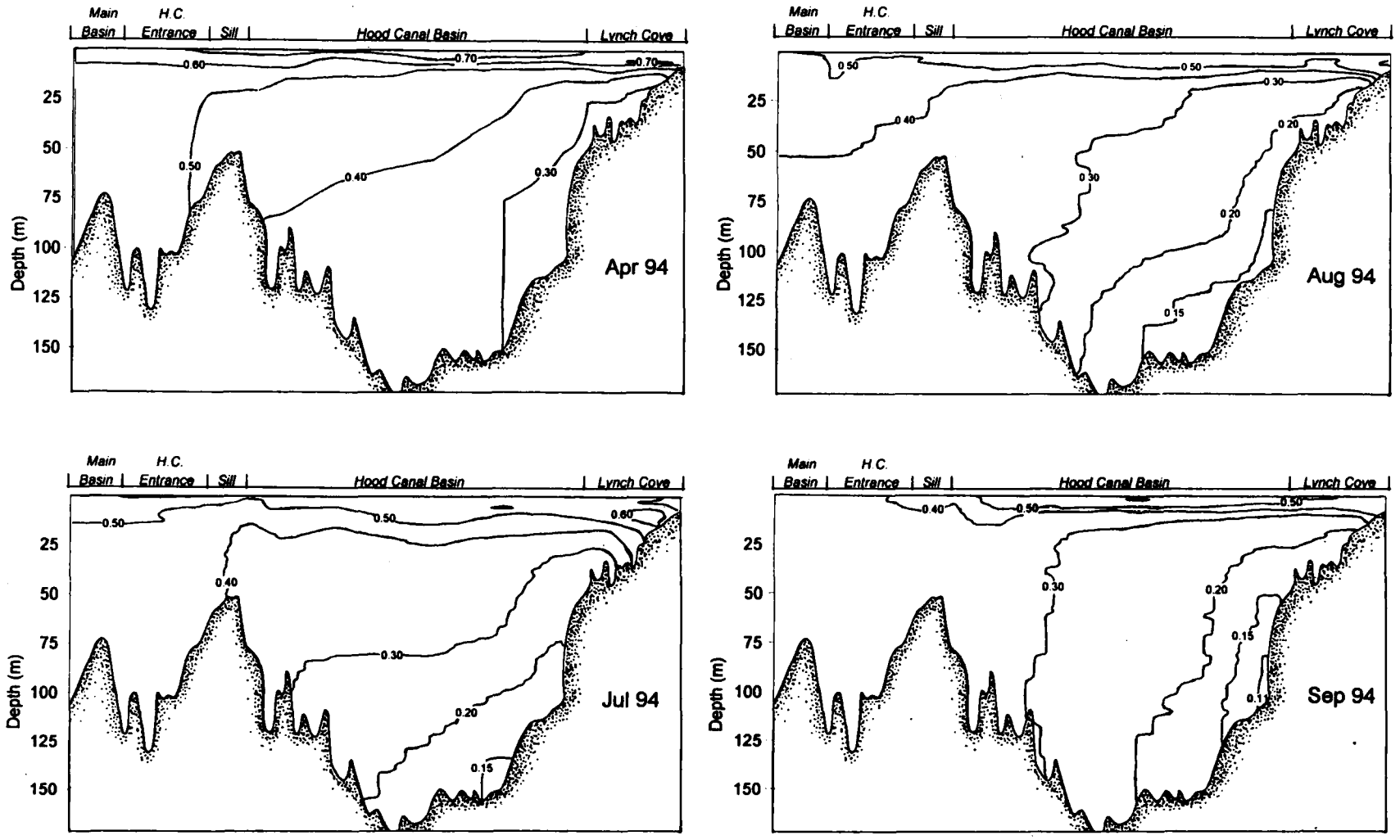

Figure 2. Contour plots of dissolved oxygen (mg-at/L) from Ecology's focused project in Hood Canal during 1994. Data collected continuously with depth at all stations in Fig. 1; see Newton et al. (1994) for sampling methodology. The Great Bend is located between Hood Canal Basin and Lynch Cove

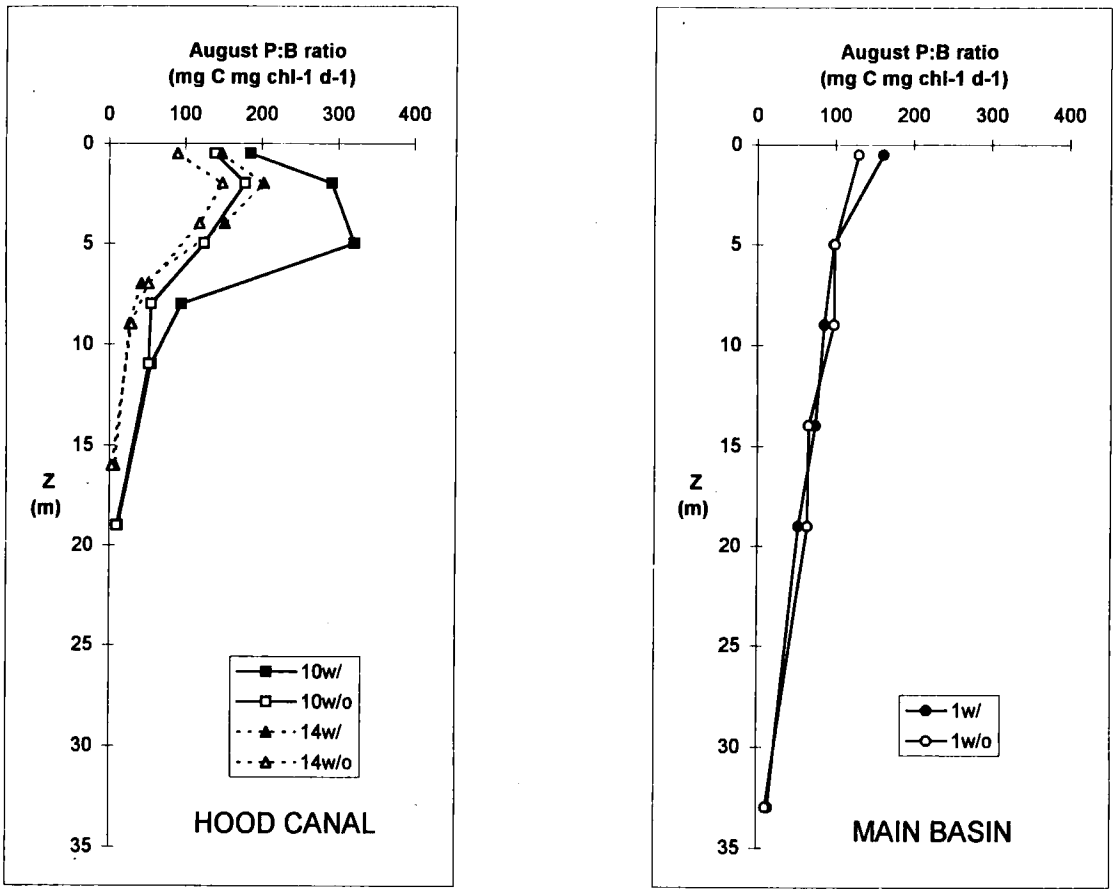

Figure 3. Profiles of chlorophyll a-normalized primary productivity (P:B ratio) versus depth for 24-h ^{14}C-uptake incubations, with and without nutrient spikes (N+P), during August 1994 in Hood Canal (stations 10 and 14) and Puget Sound main basin (station 1). Integrated production at station 10 without nutrients added was 1151 mg C m^{-2} d^{-1}; with nutrients it was 2096 mg C m^{-2} d^{-1}.

creased the integrated primary production in Hood Canal by as much as 80 percent, representing an additional 1000 mg C m^{-2} d^{-1} (Fig. 3). The primary productivity rate was stimulated by as much as 300 percent. The effect was confined to the upper 5-10 m of the water column. In contrast, primary production was not stimulated by nutrient addition to sea water from the main basin of Puget Sound, south of Admiralty Inlet (Figure 3), as was determined previously for the main basin (Metro, 1977). These results indicate that primary production in Hood Canal is nutrient-limited during the growth season. Thus, significant near-surface anthropogenic nutrient enrichment to Hood Canal would cause an increase in the organic loading and potentially affect DO concentrations.

Based on the first two results, a possible change in the water column dynamics is indicated. Although not seen during our 1994 cruises, hypoxia has been recorded in Lynch Cove during recent years, according to Ecology long-term monitoring data (e.g., 1992 in Janzen and Eisner, 1993; 1993 in Newton et al., 1994). This observation, therefore, does not imply long-term change for the Lynch Cove area. However, an observation of hypoxia centered in the Great Bend region, as seen in 1994, was not recorded in the Collias et al. (1974) database in 60 months of data spanning 1952-1966, despite the use of the same Great Bend station and depth coverage by both Collias et al. and Ecology. Nor was this pattern observed in additional

historical data from 1965-1966 (Collias and Loehr, 1986). When low DO was observed at the Great Bend historically, it was primarily apparent in Lynch Cove, emanating seaward into the Great Bend region. The observation of low DO in the Great Bend but not in Lynch Cove appears unique to the 1994 data, but its significance is not known.

The station where the lowest DO concentrations were observed in 1994 coincided with the station where Warner observed the least variation in F-11 concentrations from April to August. This result indicates the least amount of ventilation or flushing at this site. The co-occurrence of these two results makes intuitive sense. However, what is not known is whether the unique DO distribution observed in 1994 (Figure 2) indicates long-term change (e.g., in circulation), or whether it simply reflects anomalous conditions (perhaps due to low rainfall years). Additional monitoring during 1995 will facilitate a better conclusion to this project.

Objectives for 1995 are to: 1) gain additional measurements of the seasonally low DO signature in the waters of Hood Canal; 2) evaluate whether long-term change is indicated and if so, to identify causative factors; and 3) to assess nutrient inputs to Hood Canal.

Results of this project will be externally reviewed and published following the 1995 field year. Interested parties are advised to contact the senior author.

ACKNOWLEDGMENTS

The senior author thanks Parker MacCready (University of Washington) for review of the manuscript and Curt Ebbesmeyer (Evans-Hamilton, Inc.) for several insightful discussions regarding Hood Canal. We thank Mark Warner and Richard Peters (University of Washington) for their collaboration and access to unpublished data. We also thank Charles Eaton of the *R/V Kittiwake* for assistance at sea.

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VICTORIA'S WASTEWATER DISCHARGES: EFFECTS ON THE MARINE ENVIRONMENT

L.A. Taylor[1], P.M. Chapman[2], R.A. Miller[1], and R.V. Pym[1]

INTRODUCTION

The issue of the Victoria area's lack of sewage treatment has been debated locally, nationally and internationally. With the exception of the discussion at the local level, the relevant scientific information has not been considered in the sewage treatment debate. This omission must be corrected if a responsible decision about the expenditure of public funds is to be made. The scientific issue most central to this debate is the effect of the discharge on the marine environment, as the majority of municipal wastewater discharge in the Victoria area is to the ocean.

In the Victoria region the Capital Regional District (CRD) operates 10 marine outfalls, eight of which discharge primary- or secondary-treated sewage effluent. The eight outfalls are located in the Gulf Islands and along the east coast of the Saanich Peninsula where the marine waters are generally shallow and confined. The remaining two outfalls discharge to Juan de Fuca Strait into deep, rapidly moving water. These two outfalls receive preliminary treatment, which consists of screening to 6 mm. It is the treatment and disposal practices at these outfalls that are the topic of contention.

The two outfalls of concern are located at Clover and Macaulay Point (Figure 1). In 1993 the combined discharge from both outfalls was approximately 98,000 m^3 per day, and they served a population of 210,000. Discharge at both locations was initially to the shoreline. However, to alleviate shoreline pollution the outfalls were extended, Macaulay Point outfall in 1971 and Clover Point in 1981. The resulting outfalls are 1.8 km long and 1.1 km long, respectively. Both outfalls discharge at approximately 60 m through diffuser sections.

Sewage effluent is primarily fresh water, so upon discharge into salt water it initially rises. However, neutral buoyancy of the effluent plume is quickly reached because of rapid entrainment of salt water. At Clover and Macaulay Point this mixing process ensures that the plumes rarely reach the surface.

OFFSHORE WATER QUALITY

The initial water quality monitoring program at the Macaulay Point outfall began in May 1970, 15 months before the outfall was extended, and continued until 1979. Thirteen water quality parameters were measured (silicate, dissolved oxygen, coliforms, turbidity, forel color, floatables and slicks, nitrite, nitrate, phosphate, chlorophyll-a, temperature, salinity and UV absorbance). The 1970-79 data indicated that levels of the measured parameters were not affected by the extension of the Macaulay Point outfall, with the exception of concentrations of coliform bacteria (Balch et al., 1973; Vassos, 1982a). Coliforms were elevated above the outfall but remained far below levels considered unsafe for primary contact recreation (Balch et al., 1973; Vassos, 1982a). Further, there was no evidence of a buildup over time of any of the water quality parameters including coliform bacteria (Vassos, 1982a).

A less extensive monitoring program was carried out at the Clover Point outfall in 1981-82. The results of this study showed that the effluent was being well dispersed, and coliform concentrations were well below the primary contact recreation standard (Vassos, 1982b).

Of particular interest is the finding that the Macaulay Point outfall was not affecting receiving water nitrogen concentrations or causing plankton blooms. This appears to be a result of the natural nitrogen dynamics in Juan de Fuca Strait. Deep oceanic water, drawn into the strait by estuarine circulation, brings approximately 2,000 tons of nitrogen per day into Juan de Fuca, while the Fraser River contributes about

[1] Capital Regional District, P.O. Box 1000, Victoria, B.C., V8W 2S6

[2] EVS Consultants, 195 Pemberton Ave., N. Vancouver, B.C., V7P 2R4

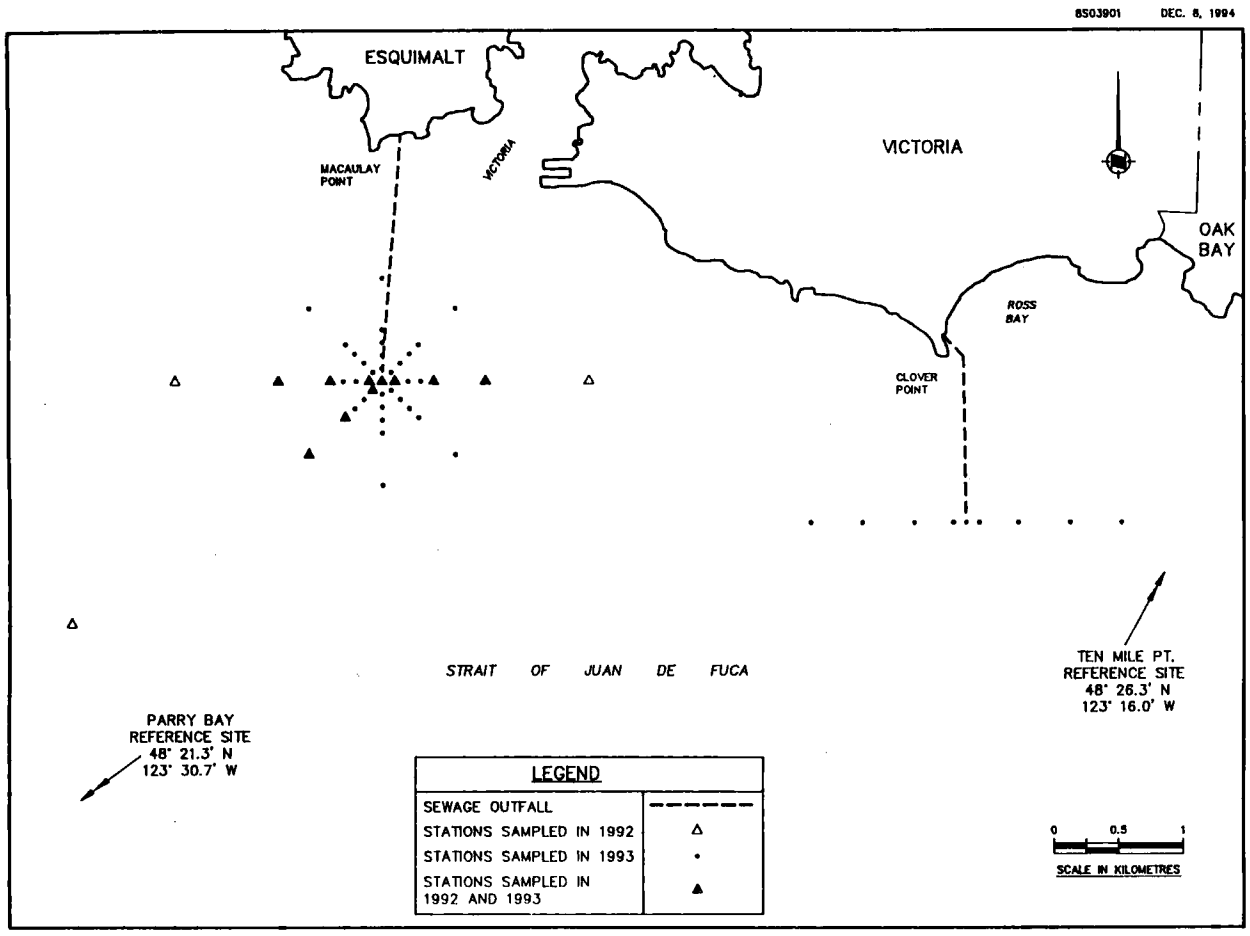

Figure 1. Study area with location of 1992 and 1993 sediment sampling stations

50 tons per day (Harrison et al., 1994). This creates a situation where nitrogen concentrations remain high throughout the year and do not limit primary productivity. Consequently, the relatively low input of 3-3.5 tons of nitrogen per day—0.2 percent of the daily deep ocean water input—from the Clover and Macaulay Point outfalls (Harrison et al., 1994) does not affect primary productivity and is difficult to detect.

After 1979 the monitoring of most water quality parameters was discontinued because the majority of the parameters measured appeared to be unaffected by the Macaulay Point outfall extension. At both Clover and Macaulay Point, surface fecal coliform sampling was retained and monitored quarterly from 1984 to 1987, and monthly since that time. The monthly data have shown no buildup in fecal coliforms over time, and generally fecal coliform levels in the vicinity of the two outfalls have remained well below the standard for primary contact recreation, i.e., geometric mean of 200 fecal coliforms per 100 mL (Figure 2 shows annual data).

SHORELINE WATER QUALITY

Before 1993 a large number of recreational beaches in the Victoria area were posted as being unsafe for swimming by the CRD Health Department. The beaches were posted based on high fecal coliform counts in the foreshore waters. The cause of these high fecal coliform counts was commonly thought to be the two long sewage outfalls. To investigate the origin of the beach contamination, the CRD carried out a series of surveys of fecal coliform concentrations at affected beaches. These surveys clearly demonstrated

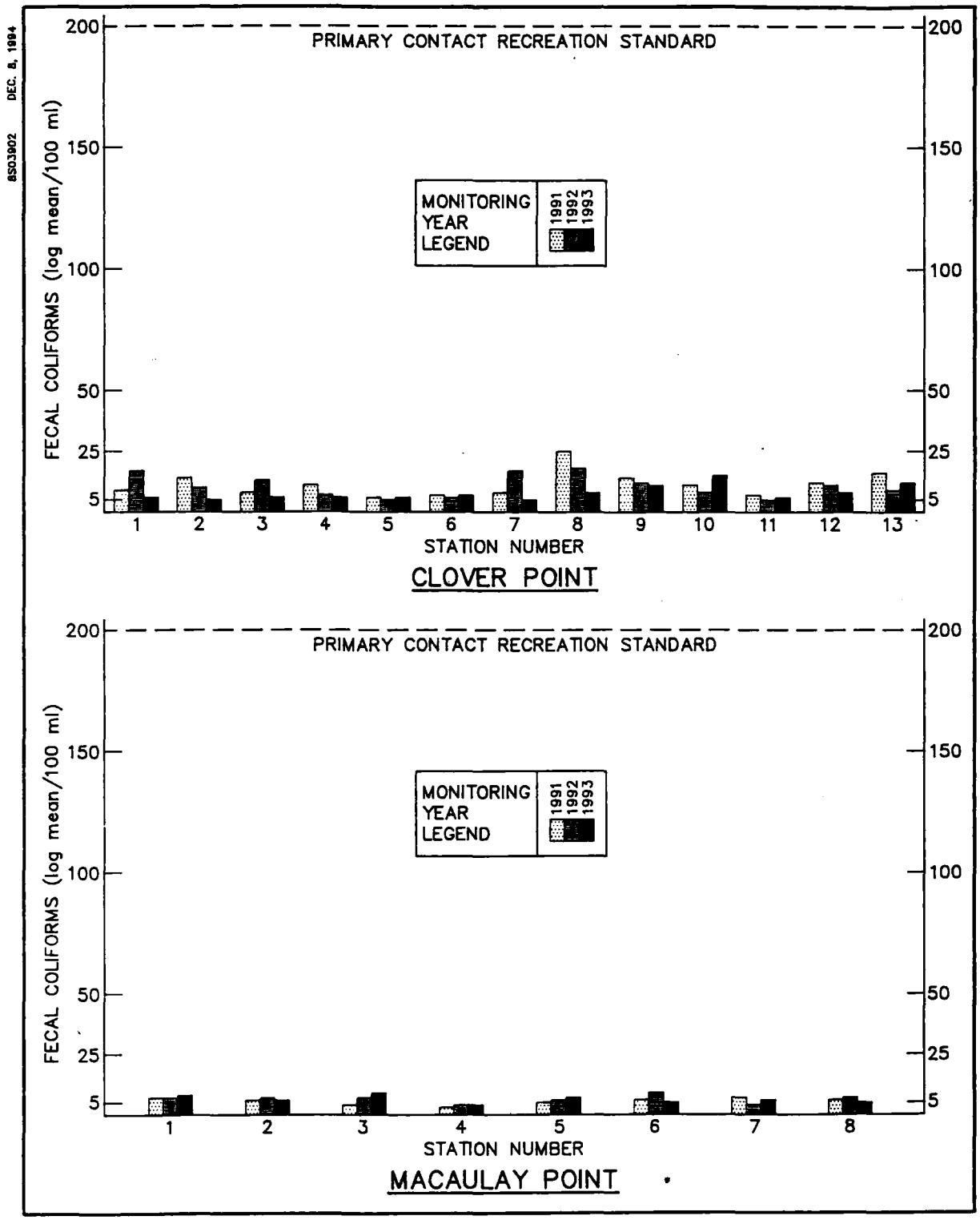

Figure 2. Surface fecal coliform data (n = 11)

that the source of beach contamination was the storm drains that emptied onto the beach's foreshores (Crawford and Warman, 1989; Miller, 1993). With this information, the municipalities responsible for the contaminated storm drains carried out work to reduce the input of contaminated stormwater to the beaches. As a result, since 1993, there have been no marine beaches posted as unsafe for swimming in the CRD.

SEDIMENT QUALITY

Recently the focus of the CRD's investigations into the effects of the Macaulay and Clover Point outfalls has shifted to examining effects on the sediment environment. This shift in focus occurred because, unlike the receiving water environment, the sediment environment and the animals that inhabit it are relatively stationary, so they are constantly exposed to the discharges and integrate effects over time. Consequently, effects will usually be detectable in sediments before they can be found in the water column.

Macaulay Point

Intensive investigations into the Macaulay Point sediment environment were carried out in 1992 and 1993. The 1992 investigation consisted of a sediment triad study (Chapman, 1990). This was followed in 1993 by an extensive survey of sediment chemistry. Seventeen stations were sampled in 1992 and 42 in 1993 (Figure 1). Results from both years were compared to the Washington Department of Ecology Sediment Standards (WDOE, 1991). Exceedance of these standards indicates that the sediment has the potential to cause adverse biological effects.

The majority of chemicals measured in both years (40 chemicals were measured in 1992 and 22 in 1993) did not exceed WDOE standards. Standard exceedances were detected in sediment mercury, 1,4-dichlorobenzene and some PAH concentrations in a limited area around the outfall (Figure 3). 1,4-dichlorobenzene levels were above the standards in both years at the 0 m stations and some of the 100 m stations (with the exception of a 1993 400 m station, which had a high concentration in one of three replicates). Mercury exceedances occurred only in 1992 at the station 0 m from the outfall. Sources of mercury to Macaulay Point sewage effluent are mainly dental offices and hospitals. 1,4-dichlorobenzene appears to be coming primarily from the white deodorant disks used in men's urinals.

Sediment PAH concentrations were measured only in 1992. The 1992 data indicate that the highest PAH concentrations occurred 400 m to the east of the outfall. Also, exceedances of WDOE standards for PAHs occurred only at this 400 m east station (Figure 3). PAH values at 0 m from the outfall were lower and did not exceed the WDOE standards. Detailed chemical investigations of the Macaulay Point sediments revealed the presence of coal and coke in samples, particularly those to the east of the outfall (EVS, 1992). Coal and coke contain high levels of PAH.

In 1891 a collier ran aground near the Macaulay Point outfall and was subsequently blown up because it was a navigational hazard (Guss, 1992). These events deposited coal on to the seafloor, where it remains to this day. Apparently it was this coal/coke that was causing the WDOE standards exceedances for PAH at the 400 m east station. The lack of standard exceedances at stations closer to the outfall (Figure 3), despite the presence of coal/coke in these samples, indicate that outfall contributions of PAH to sediment were not at levels of concern. Because of the confounding effects of the presence of coal in sediments off the outfall, PAHs have not been sampled since 1992. In summary, the sediment chemistry results indicated that WDOE standards exceedances caused by the outfall were restricted to a 200 m radius of the outfall.

In 1992, three sediment toxicity tests were run on Macaulay Point sediments: amphipod survival, juvenile *Neanthes* growth and survival, and oyster larvae development. This set of tests was chosen so that both acute and chronic toxicity could be measured. The amphipod sediment toxicity test showed no evidence of toxicity related to the outfall (Figure 4). *Neanthes* growth was significantly affected at 0 m and 100 m from the outfall (Figure 4), and bivalve normality showed significant effects out to the 400 m stations (Figure 4). This indicates that the sediments around the Macaulay Point outfall were not causing acute toxicity, and chronic toxicity was evident to 400 m, a pattern of effects similar to that shown by the sediment chemistry data.

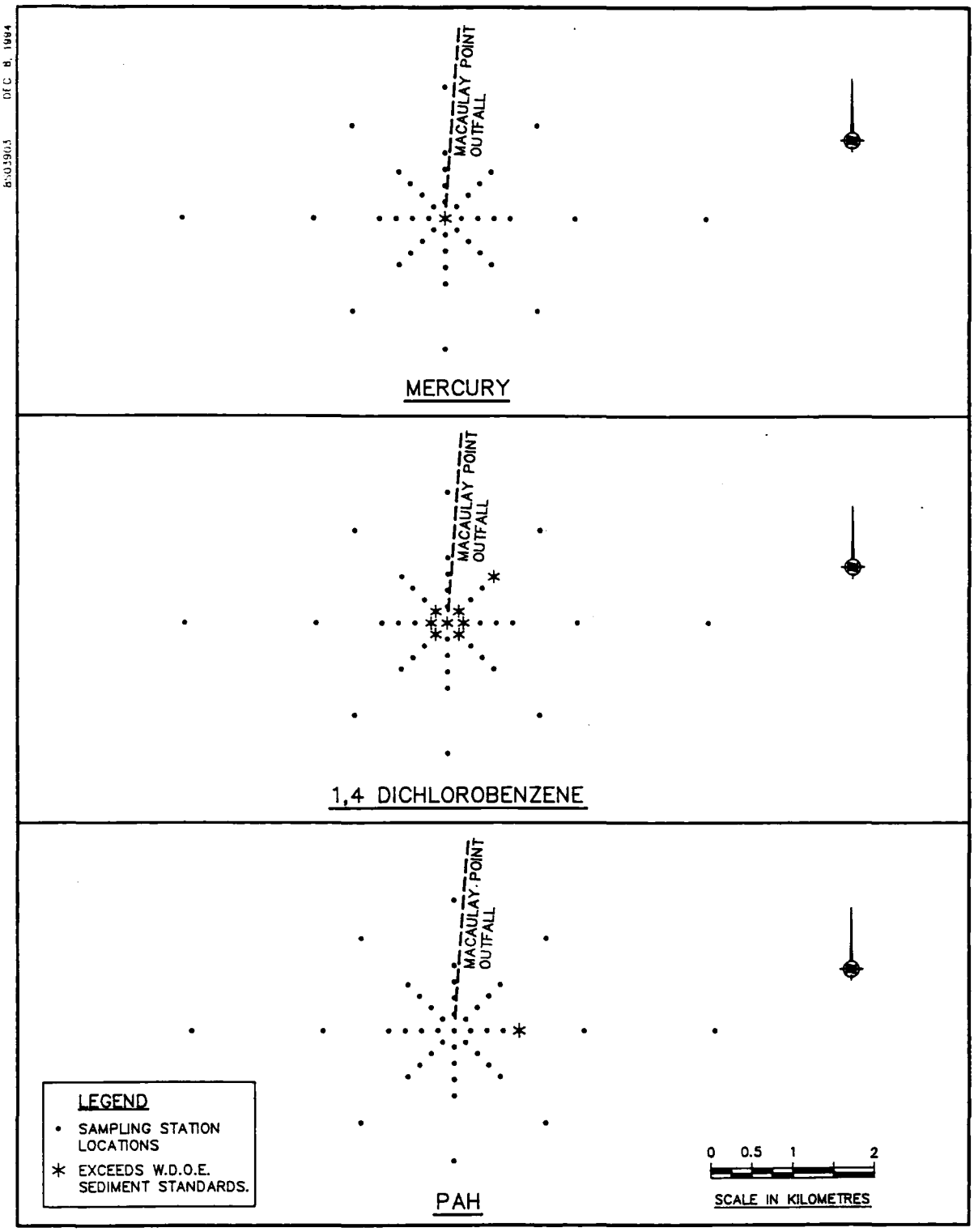

Figure 3. Macaulay Point sediment chemistry

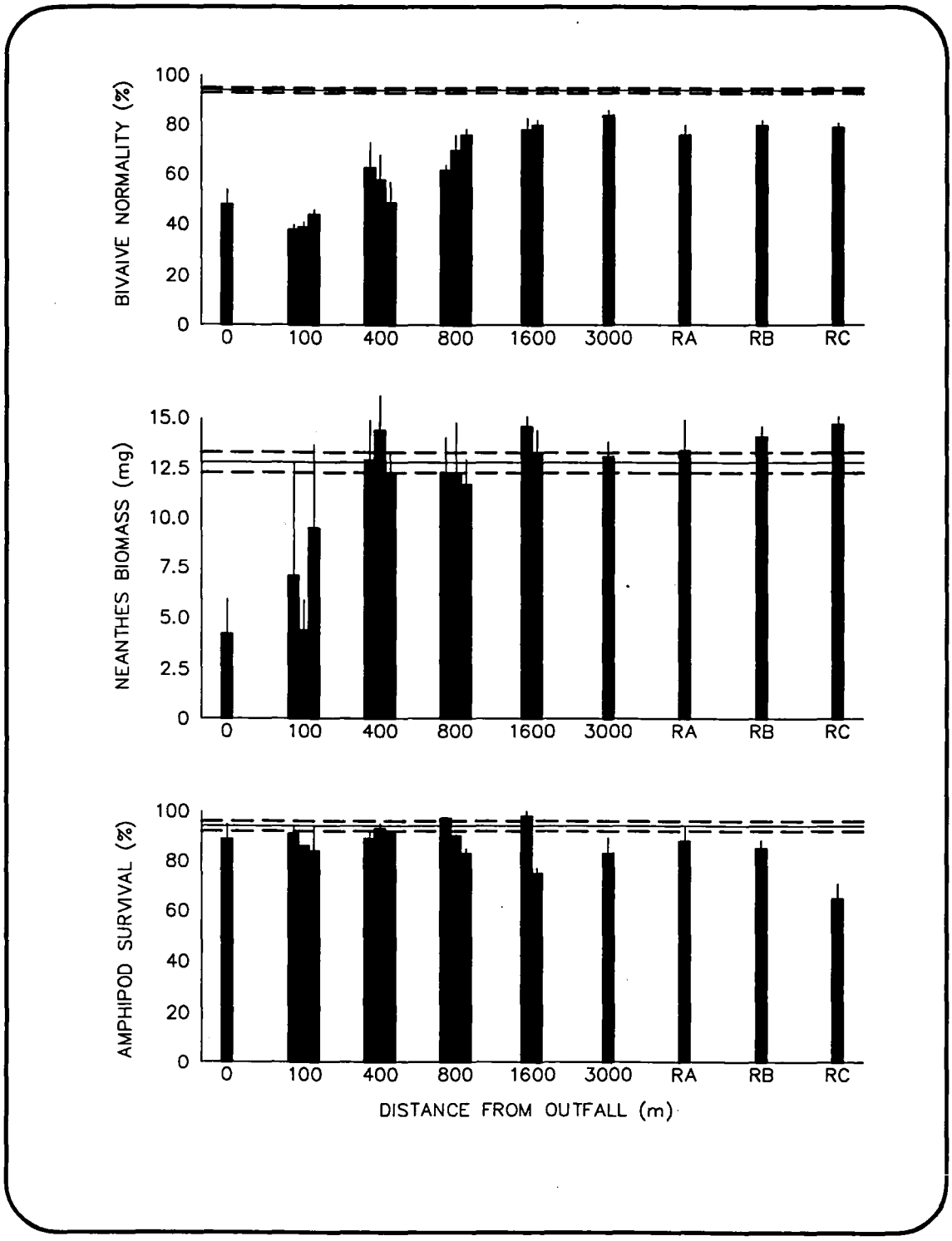

Figure 4. Sediment toxicity test results for Macaulay Point Stations - 1992

Benthic community data from the Macaulay Point outfall exhibited a classic response to organic enrichment as described by Pearson and Rosenberg (1978) (Figure 5). In the Pearson and Rosenberg (1978) model, as organic enrichment increases, abundance first increases and then decreases after a critical level of enrichment is reached (Figure 5). At Macaulay Point benthic richness (number of taxa) increased with distance from the outfall while abundance decreased (Figure 5). However, this effect was not evident beyond the 100 m stations. The observed trends in richness and abundance suggest that chemical toxicity of Macaulay Point sediments is moderate at worst and localized in extent (EVS, 1992). A decrease in number of taxa and abundance would be expected if highly toxic conditions existed close to the outfall. A similar pattern would be expected if organic loading to the sediments was severe. The sediment chemistry, sediment toxicity and benthic community data all indicate that effects to the sediment environment around the Macaulay Point outfall are generally contained within a 100-400 m radius around the diffuser.

Clover Point

The seafloor off the Clover Point outfall—cobbles covered with epifauna—made the collection of samples for a triad study impractical. As a result, a tissue chemistry study was carried out on the resident mussel *Modiolus* (see Figure 1 for sampling station locations). Levels of tissue chemicals near the outfall were similar to concentrations at the reference station, i.e., within a factor of 2 (EVS, 1992). No clear pattern of elevated tissue chemical levels at the outfall was apparent. Some chemicals were higher at the reference station than near the outfall, while others showed the reverse pattern. Further studies on the hard substrate environment at Clover Point to detect and define outfall effects are ongoing.

EFFLUENT TOXICITY

Wastewater discharged through the Clover and Macaulay Point outfalls is acutely toxic to rainbow trout, primarily due to low oxygen levels and high ammonia (EVS, 1992). However, these parameters are rapidly diluted once effluent is released. Dilution predictions from the CRD's effluent dispersion model (Seaconsult, 1992) were coupled with toxicity tests on rainbow trout, *Ceriodaphnia* and bivalve larvae to estimate the zone of water column effects above the two outfalls (EVS, 1992). Figure 6 schematically shows the extent of toxicity in the water column around the outfalls. The effluent must rise 1.4 m to pass LC50 tests for rainbow trout, 1.5 m to pass LC50 tests for *Ceriodaphnia* and 4.3 m for EC50 tests for bivalve larvae (Figure 6). These results clearly indicate that toxicity effects in the water column are extremely localized.

CONCLUSIONS

Present impacts from the discharge of wastewater through the Clover and Macaulay Point outfall appear to be minimal. Receiving water quality off the outfalls is good and provides little cause for concern for human health. Water quality at beaches in the vicinity of the outfalls is not adversely affected by the two outfalls. Effects to the sediment environment at Macaulay Point are generally contained within a 100-400 m area around the diffuser. At Clover Point the pattern and levels of bioaccumulation of outfall-related chemicals in resident biota are at present not a cause for concern. These results must be taken into account by all levels of government and the public if a responsible decision is to be made about the appropriate sewage treatment for the Clover and Macaulay Point outfalls.

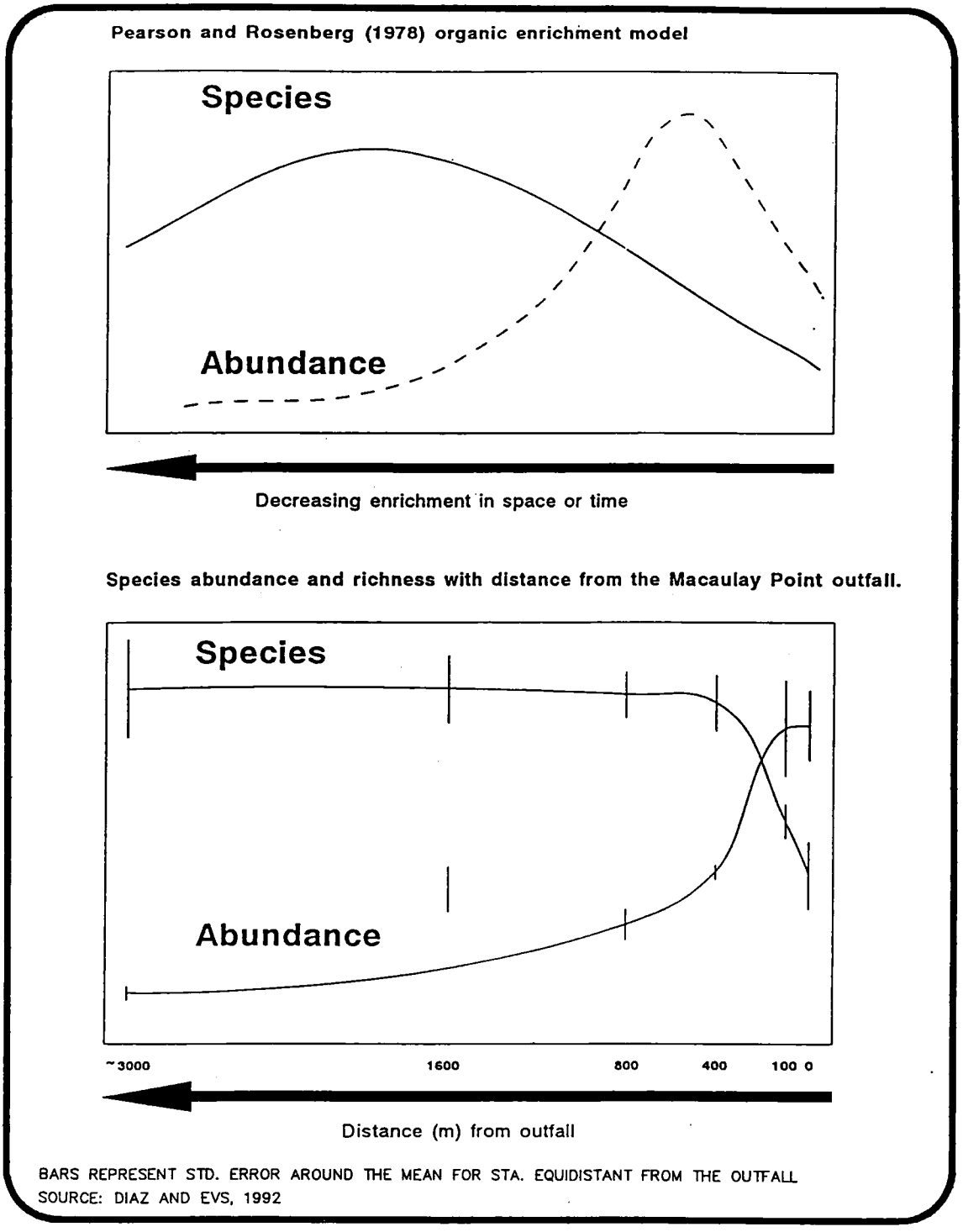

Figure 5. Comparison of species abundance and richness with distance from the Macaulay Point outfall to the Pearson and Rosenberg (1978) organic enrichment model

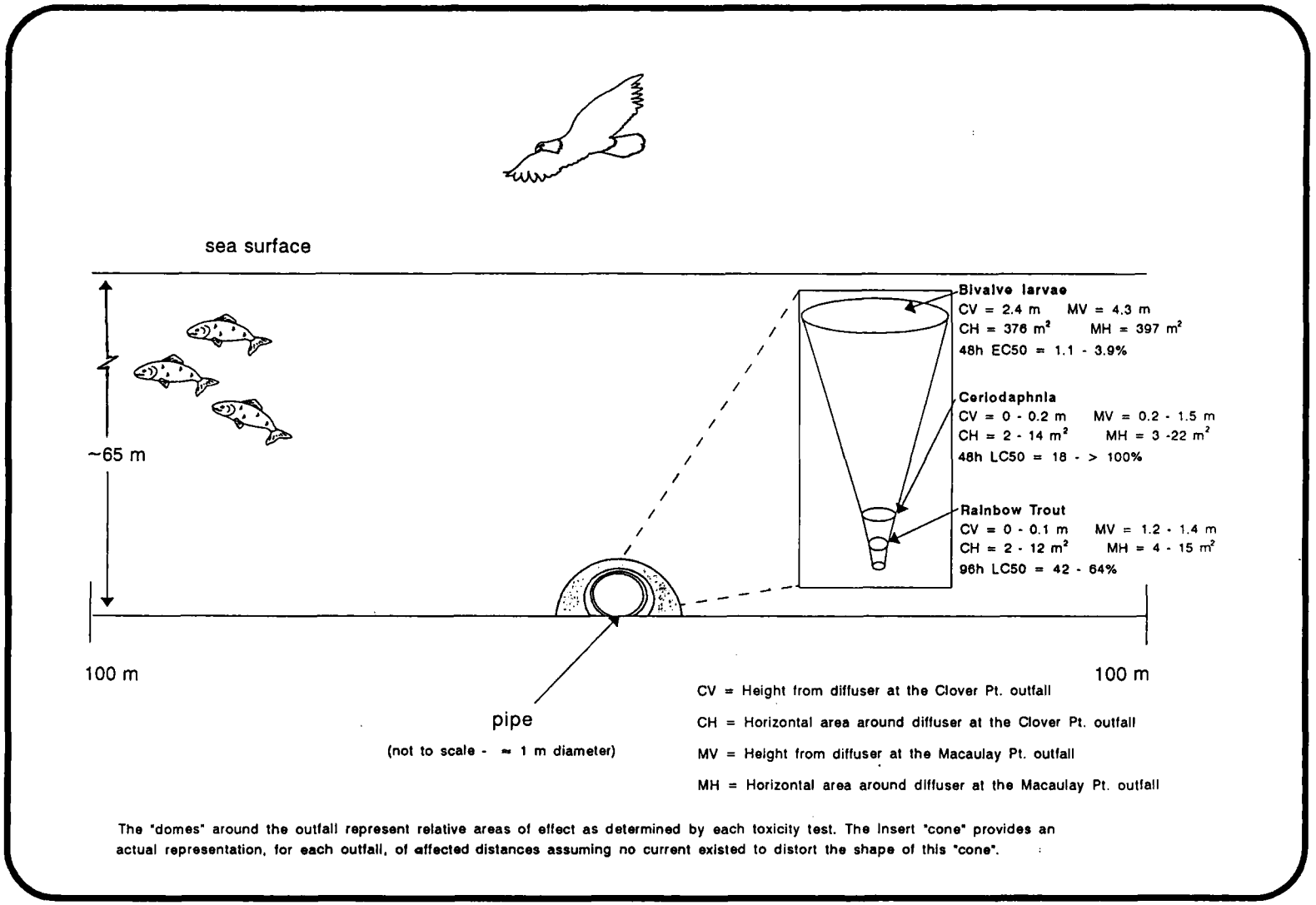

Figure 6. Effluent toxicity in the receiving waters of the clover and Macauley Point outfalls

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PUGET SOUND RESEARCH '95

POSTER ABSTRACTS

PHYTOPLANKTON SPECIES COMPOSITION IN RELATION TO DISSOLVED NUTRIENTS, CHLOROPHYLL *A*, LIGHT PENETRATION AND STRATIFICATION AT THREE PUGET SOUND STATIONS LOCATED IN NORTH, CENTRAL AND SOUTH SOUND: MONTHLY DATA FROM MAY 1992 TO OCTOBER 1994

Lisa Eisner[1]

Monitoring of phytoplankton species composition, as well as nutrients and physical parameters, is important in understanding the factors involved in phytoplankton species occurrence in Puget Sound. A long-term database of phytoplankton species composition does not exist at present; therefore, the data presented here also provides baseline information for stations in three diverse Puget Sound locations. Monthly data were collected from May 1992 through October 1994 at one station in Georgia Strait north of Patos Island, one in the central main basin at West Point, and one in central Budd Inlet in the south Sound. Discrete water samples were collected at 0.5 m and analyzed for phytoplankton species composition, chlorophyll *a* and dissolved nutrients (nitrite+nitrate-N, ammonium-N and orthophosphate-P). Vertical profiles of conductivity-temperature-depth (CTD) and Secchi depth measurements were also conducted. Comparisons of phytoplankton species composition with dissolved nutrients, chlorophyll *a*, light penetration (determined from Secchi depth), and stratification (determined from CTD measurements) are presented.

Phytoplankton abundances overall were highest at the Budd Inlet station, followed by the central main basin station and then by the Georgia Strait station, according to chlorophyll *a* and cell count data. In Budd Inlet from July to August or September during 1992 and 1993, dinoflagellate species had high concentrations (10^5 to $>10^6$ cells/L) and were more abundant than diatom species, whereas, in the central main basin and in Georgia Strait dinoflagellate species had low concentrations ($< 10^4$ cells/L) and were less abundant than diatom species throughout the year. Potentially toxic *Pseudonitzschia* spp. tended to be observed more frequently at the central main basin and Georgia Strait stations than at the Budd Inlet station.

[1] Washington Department of Ecology, P.O. Box 47710, Olympia, WA 98504-7701

BIOACCUMULATION OF OXYTETRACYCLINE IN SHELLFISH

Stephanie Harris[1], George J. Vasconcelos[2] and Kelly M. Williams[3]

A study was undertaken to determine the bioaccumulative abilities of oxytetracycline in several economically important species of shellfish. This antibiotic is frequently used by commercial net pen operations for the control of bacterial disease. Recent concern regarding the potential for development of antibiotic-resistant marine bacteria, the accumulation of antibiotic at toxic levels in shellfish harvested near commercial net pens, and the potential for using shellfish to monitor the antibiotic discharge on-site prompted this study. In two studies performed, shellfish were exposed to oxytetracycline in uncirculated tanks containing seawater for 48 and 168 hours, respectively. Two forms of oxytetracycline were used, bound and unbound. A rapid microbial bioassay was utilized to determine shellfish antibiotic concentrations. Following the exposure period, shellfish were placed in tanks containing free-flowing seawater to determine the depuration time. The limit of detection was 2.5 ppm. *Crassotrea gigas* (Pacific oyster) proved to be the only shellfish capable of concentrating the antibiotic above background levels and then only when exposed to the bound form of the antibiotic. The results indicate that oysters are capable of concentrating oxytetracycline and may be a useful bioindicator organism to monitor the amount of antibiotic discharged into the environment in the vicinity of net pens.

WATER QUALITY STUDY OF SEQUIM BAY

Gabriela Hannach[4]

The water quality of Sequim Bay was investigated in response to concerns expressed by the local community. In the summer of 1993 four monthly bay-wide surveys were carried out in order to characterize physical and biological conditions and to detect anomalies indicative of water quality deterioration. On each survey, 15 stations were sampled intensively during a full tidal cycle. A conductivity-temperature-depth (CTD) profiler equipped with additional sensors was used to collect continuous water column profile data. Vertical profiles thus recorded include key physical parameters, dissolved oxygen and fluorescence emitted by algal photosynthetic pigments.

Depth profiles show density stratification characteristic of Puget Sound embayments in summer. Phytoplankton blooms occurred throughout the season, but were not associated with significant dissolved oxygen (DO) depletion. DO distributions indicate decreasing concentrations eastward and towards the inner bay, consistent with tidal current patterns; near bottom concentrations generally stayed above 5 mg/L. Analysis of water samples indicates levels of ammonium and nitrate nitrogen representative of Puget Sound embayments, with surface minima occurring during July and August. The significance of these and other results will be discussed in relation to the water quality of other Puget Sound embayments.

[1] Environmental Protection Agency, Region 10, Manchester Lab, 7411 Beach Drive NE, Port Orchard, WA 98366

[2] U.S. Public Health Service detailed to the Environmental Protection Agency, Region 10 Laboratory, Port Orchard, WA 98366

[3] Veterinary Medical Program, Tuskegee University

[4] Washington Department of Ecology, P.O. Box 47600, Olympia, WA 98504-7600

MONITORING WATER QUALITY EFFECTS DURING SEDIMENT REMEDIATION

Carol M. Sanders and J. Patrick Moore[1]

The effects on water quality from dredging and capping of contaminated sediments is a key concern as remediation of contaminated aquatic sites continues into the twenty-first century. To minimize as well as quantify the possible impacts, various methods of water quality monitoring have been employed over the past decade. These methods ranged from crude field measurements to sophisticated data collection and management. The methods used on a variety of projects throughout Puget Sound region and the United States will be reviewed. The results from various monitoring efforts and their impact on future projects will be discussed.

The methods used to monitor these effects are becoming more sophisticated as our knowledge of the environmental impacts increases. The "leading edge" of water-quality monitoring techniques will be discussed giving insight into the most sophisticated means of instantaneous data recovery. The ability to monitor data in real time for determining the impacts of aquatic remediation is an invaluable tool. From tracking the dredge plume, to noting the impacts on dissolved oxygen from dredge material disposal, these techniques have been field tested and have proven to be effective during one of the most aggressive remediation projects in Puget Sound—the Sitcum Waterway Remediation. The Sitcum project, as well as ongoing projects in Puget Sound and around the country, will be highlighted to show the evolution of water quality monitoring.

MAPPING PUGET SOUND NEARSHORE HABITATS

Thomas F. Mumford, Jr., Allison R. Bailey, Rebecca Ritter, Elizabeth Lanzer and Betty Bookheim[2]

The nearshore marine and estuarine habitats of Puget Sound are a critical part of the Puget Sound ecosystem, forming the edge or interface between the uplands and the deep-water ecosystems and serving as habitat for many fish and wildlife. The type, location and amounts of these habitats are poorly known. We are classifying and mapping these habitats, using remote sensing multispectral scanner imagery plus ancillary data. We will show the results of this effort, especially as applied in urban embayments. The results will be compare to previous efforts in the Coastal Zone Atlas and the National Wetland Inventory. Results will also be compared to national and oil spill response mapping efforts. The products fulfill a task of the Puget Sound Ambient Monitoring Program and will be used for better management of aquatic resources by the Department of Natural Resources.

[1] Sanders & Associates, Inc., 12204 N.E. 64th St., Kirkland, WA 98033

[2] Department of Natural Resources, Division of Aquatic Resources, P.O. Box 47027, Olympia, WA 98504-7027

PADILLA BAY RESERVE: RESEARCH FOR COASTAL ZONE MANAGEMENT

Douglas A. Bulthuis and Terence C. Stevens[1]

Padilla Bay National Estuarine Research Reserve was designated in 1980 by the National Oceanic and Atmospheric Administration (NOAA) and Washington State under the Coastal Zone Management Act. Padilla Bay has a four-fold mission of resource protection, public information, education, and research on the Padilla Bay estuary.

Research in Padilla Bay is carried out by investigators from several universities in Washington and by state and federal agencies. Research projects carried out since designation of Padilla Bay as a National Estuarine Research Reserve have increased our understanding of the important habitats and components of the estuary and have contributed to policy and protection of estuarine environments throughout the state. There is both a need for further research and the opportunity to do so in Padilla Bay. Padilla Bay is a good site to conduct certain types of research because of its protected status, the availability of other studies for comparative purposes, and the institutional and infrastructural support provided by the Reserve.

Padilla Bay is a shallow protected estuary with an extensive intertidal area predominately covered by the eelgrasses, *Zostera marina* and *Zostera japonica*. The eelgrass habitat is important for many marine and estuarine animals including juvenile salmon, Pacific herring, Dungeness crabs, and waterfowl such as Brant, Widgeon, Pintail, Scaup, Bufflehead and Scoter.

The poster illustrates some of the research conducted in Padilla Bay and major findings.

ESTUARINE HABITAT RESTORATION IN AN URBAN ENVIRONMENT: MIMICING MORPHOLOGY TO IMPROVE FUNCTION

Justine Barton[2], Curtis D. Tanner[3] and Patrick Cagney[4]

Estuaries are the gateways to watersheds for humans as well as fish and wildlife. Their importance to maritime commerce has resulted in significant loss of habitat area and function, nearly 100 percent in some Puget Sound estuaries. Despite these impacts, fish and wildlife continue to depend on these areas for vital portions of their life history. This project identifies and evaluates approaches to habitat restoration that address the unique challenges of highly urbanized estuaries. Three pilot projects are being constructed and monitored in Seattle's Duwamish River estuary. Projects were designed to take advantage of site characteristics by mimicing historic morphology to restore habitat function. Preliminary monitoring and evaluation suggests that these construction techniques have changed site morphology and resulted in improved fish and wildlife use. Innovative techniques can be used to restore functions for fish and wildlife in a relatively cost-effective manner. These techniques maximize site specific opportunities and need not preclude economic development and use. Watershed-scale restoration cannot simply "write off" highly urbanized portions of our systems. This project documents new restoration options for consideration when managing degraded estuarine environments.

[1] U.S. Environmental Protection Agency, Region 10, 1200 Sixth Avenue, Seattle, WA 98101

[2] U.S. Environmental Protection Agency, Region 10, 1200 Sixth Avenue, Seattle, WA 98101

[3] U.S. Fish & Wildlife Service, 3704 Griffen Lane S.E., Suite 102, Olympia, WA 98501

[4] U. S. Army Corps of Engineers, Seattle District, P.O. Box 3755, Seattle, WA 98124

WATER QUALITY, SUSTAINABLE AGRICULTURE AND WILDLIFE ENHANCEMENT

Lorna Ellestad[1]

Agriculture has been implicated as a source of nitrate pollution in surface and ground water. Studies suggest that different cultivation practices can influence the concentration of nitrogen available for nitrate leaching. Cover crops can improve water quality by removing nitrates from the soil, and can improve soil quality by reducing erosion, thereby increasing water infiltration and nutrient retention, and by adding organic matter.

For the past two years, the Ducks Unlimited "Barley for Birds" project has been implemented in the Skagit Valley, in cooperation with the U.S. Fish & Wildlife Service, the Puget Sound Water Quality Authority, Washington State Department of Fish & Wildlife, and local farmers. The planting of fall cover crops of barley in 1993 reduced the levels of nitrogen in surface and subsurface soils by an average of 130 lbs per acre, while providing over 450 tons of grain for over-wintering waterfowl.

The purpose of my research is to identify factors which relate to the accumulation and transportation of nitrates in the soil column. Soil samples were taken in tiers to delineate vertical movements, and at different times to establish sequential changes in ion type and concentration. The fields were further analyzed for biomass and yield, soil type, organic matter, and weed suppression.

On-farm research using real field conditions and farming methods is the best way to persuade farmers to adjust fertilizer applications for better nutrient management. Providing farmers with a practical way to monitor available nitrogen and creating an awareness that both money and resources are being lost can help accomplish a significant reduction in nitrate pollution.

Farmers have found that the "Barley for Birds" project has been a positive way of building partnerships within the community and with regulatory agencies. One Field Day was attended by over 30 people, representing 15 agencies and groups. We have been successful in presenting a favorable environmental image at a time when the public has focussed attention on water quality problems associated with agriculture.

[1] Huxley College of Environmental Science, Bellingham, WA

REAL-TIME TRACKING OF DREDGE MATERIAL PLUMES DURING DEEP WATER DISPOSAL OPERATIONS OFF SAN FRANCISCO, AND THE APPLICABILITY OF THIS TECHNOLOGY TO DISPOSAL OPERATIONS WITHIN PUGET SOUND

Jeff Cox[1]

Puget Sound dredge-material disposal locations were selected a number of years ago partially on the basis of model predictions of the quantity of dredged material which would reach the bottom within the disposal site, and estimates of where and how local currents would transport and dilute any material remaining in the water column. Monitoring studies since that time have focused on the location, and chemical and biological condition of the dredged material located on the bottom within or adjacent to the disposal areas. Studies of the movement and dispersion of the dredged material stripped off in the water column have not been performed to confirm the initial estimates made during the siting studies, due to the technical difficulty and cost in performing such efforts.

In September 1993, a coordinated monitoring effort was conducted at the Navy's deep water disposal site off San Francisco to track the vertical and horizontal movement, and dilution rate, of eleven barge loads of disposed dredge material. The barges contained sediments dredged from two Navy facilities within San Francisco Bay: the Alameda Air Station and the Naval Supply Center in Oakland. Water depth at the disposal site averaged approximately 2,900 meters. The purpose of the monitoring effort was to determine if actual sediment movement and dispersion agreed with previous predictions made within an Environmental Impact Statement (EIS) which were based on a number of field measurements and numerical model calculations. Identifying any sediment movement into two nearby marine sanctuaries was also of primary interest.

Plume movement was tracked using several instruments: a towed 600 kHz, modified Acoustic Doppler Current Profiler (ADCP), a ship-mounted 75 kHz ADCP, a 200 kHz fathometer, a transmissometer, and discrete water samples. Water stratification was measured with a Seabird CTD; currents were obtained from both ADCP units combined with DGPS navigation data. Grain size characteristics of the sediments in the barges prior to disposal were also measured. The sediment plume which formed at the disposal site was successfully tracked down to approximately 700 meters, and over five to six hours while the plume moved approximately one to three nautical miles. The plume movement and dispersion rate appeared in general agreement with predictions presented in the project EIS; specific results are presented herein. The technology used successfully off San Francisco can be used to investigate similar questions within Puget Sound where natural sediment loads are not excessive. Such investigations can include not only confirmation of actual versus estimated movement of dredged material plumes, but also tracking of some industrial and municipal effluent, river-generated sediment plumes, and plankton layers.

[1] Evans-Hamilton, Inc., 731 N. Northlake Way, Suite 201, Seattle, WA 98103

WATER QUALITY APPLICATIONS FOR A GEOGRAPHICAL INFORMATION SYSTEM

Kathy Thornburgh, Michael McGuiness and Susan Grigsby[1]

Snohomish County's Surface Water Management Division and Department of Information Services have cooperated to improve the ability of watershed managers and elected officials to make informed water quality management decisions. Snohomish County utilizes a geographic information system (GIS) which can spatially analyze, query, and graphically display water quality and hydrologic data for decision making.

Within the Surface Water Management Division, the GIS is used for water-quality data analysis, hydrologic modeling, planning, and tracking detention pond maintenance and drainage investigations. Some of the county-wide information in the GIS includes hydrology, watersheds, roads, land cover, future land use, soils, geology, wildlife habitat areas, drainage complaints, and water quality monitoring and gauging sites. The database includes information about the type and frequency of data which is collected at each site and the actual water quality and flow data. The GIS application was developed to graphically show time series plots of water quality data.

Some goals for using the GIS in Surface Water Management are:

- to make the existing water quality database available to local governments, tribes, and agencies;
- to identify data monitoring gaps in local government, tribal, and agency monitoring programs;
- to promote inter-governmental and inter-agency cooperation in water-quality monitoring programs and identification of water quality problems;
- to promote education of watershed managers, elected officials, the public and educators by spatially and graphically displaying existing water quality and hydrologic conditions in their watersheds;
- to provide a model for other counties and local governments to follow in dealing with water quality data from a variety of monitoring programs; and
- to increase accessibility to water quality data so that managers can focus their pollution reduction and prevention efforts where they are most needed.

[1] Snohomish County Department of Public Works, Surface Water Management Division, 2930 Wetmore Avenue, Suite 101, Everett, WA 98201

THE SURF SMELT, *Hypomesus pretiosus*, IN PUGET SOUND: A REVIEW

Daniel E. Penttila[1]

The surf smelt is a common and widespread local nearshore schooling forage fish, important to marine food webs and supporting localized sport and commercial fisheries. Ongoing Washington Department of Fish & Wildlife (WDFW; formerly the Department of Fisheries) investigations have greatly expanded the known distribution of its upper intertidal spawning beaches in the Puget Sound region.The life history and spawning habits of the surf smelt involve this species in many aspects of current management activities in the Puget Sound basin, from habitat inventory to land-use regulation. Its spawning habitats support forage stocks, provide harvest opportunity, and yet are vulnerable to adverse human impacts and changes in the characteristics of upper intertidal beach sediments.

The author has led WDF/WDFW surf smelt investigations in the Puget Sound region since 1972. Currently, the WDFW "Intertidal Baitfish spawning Beach Survey Project" (IBSBSP) emphasizes mapping of heretofore unknown spawning sites around Puget Sound through the detection of the demersal eggs in upper intertidal beach materials. Other recent surf smelt investigations have included spawning ecology studies, biological studies of spawning fish, and sport fishery monitoring.

The Puget Sound region is now known to support nearly 150 lineal statute miles of surf smelt spawning beach, and it is very likely that much more spawning habitat will be found as the IBSBSP continues its survey efforts in the coming years. Spawning tidal elevations, spawn densities, spawn deposition frequencies, *in situ* mortalities, and spawn substrate grain sizes can be characterized. Spawning populations can generally be divided into "fall-winter" spawners or "summer" spawners,although some beaches are now known to support virtually year-round spawning activity.

Despite its widespread occurrence in the Puget Sound region, the species is relatively poorly known to many local residents. Much spawning habitat has been destroyed in the past by urbanization and shoreline armoring, for lack of protective policies and/or lack of knowledge the local existence of the resource. The surf smelt is currently listed in the WAC Hydraulic Code Rules as a marine species with particular habitat concerns. In harvest management terms, the surf smelt resource Sound-wide may be considered "under-utilized," with some opportunity for increased harvest. Both sport and commercial harvest opportunities are curtailed by lack of sufficient public beach access to the increasing-privatized shorelines of Puget Sound.

[1] Washington Department of Fish & Wildlife, Puget Sound Baitfish Unit, 1702-Bay 4, Anderson Road, Mt. Vernon, WA 98273

THE DISTRIBUTION, ABUNDANCE AND HABITAT REQUIREMENTS OF TWO ENDANGERED FISHES FROM THE NOOKSACK RIVER DRAINAGE IN CANADA

Susan D. Inglis[1] and Dr. Marvin L. Rosenau[2]

An expanding urban environment has had major impacts on the habitat quality of the many small rural and urban streams in the Fraser Valley and Lower Mainland of British Columbia. This has affected endangered fish species (the Salish sucker, *Catostomus* sp., and Nooksack dace, *Rhinichthys* sp.) inhabiting some of these streams. These small, demersal fish are post-glacial relics of the Chehalis fauna and are restricted to the Fraser Valley in British Columbia and the Chehalis River and Puget Sound drainages in Washington state. Because of declining numbers, two studies were conducted to determine the current status and habitat requirements of these fish. In 1992, we found that the Salish sucker's range was considerably diminished compared to previous reports and it is now extirpated from most of its former range. Likewise, although Nooksack dace are relatively abundant in streams within the Nooksack River drainage, a 1993 survey indicates that their already restricted distribution is also shrinking. The streams that these two species inhabit are small (< 6 m in average width) and Salish suckers utilize a variety of hydraulic types including pools, glides and riffles. Compared to adults, young-of-the-year suckers prefer micro-habitats with a higher percentage of over-stream cover. Habitat suitability curves were developed for Nooksack dace, and riffles with water velocities of approximately 0.28 $m.s^{-1}$ and substrate comprised of loose gravel and cobbles are the preferred habitat for adults. Young-of-the-year dace were found in the slower water of pools and glides adjacent to riffles containing adults. The results of these studies provide a framework for land use planning, including the development of protected habitat areas. Without government and public action to preserve their habitat, the Salish sucker and Nooksack dace will likely become extinct from Canadian streams.

[1] #103 - 1265 Beach Ave., Vancouver, B.C. V6E 1V4

[2] British Columbia Ministry of Environment Fish & Wildlife Management

LOCAL MARINE RESERVES: A PROPOSAL TO PROTECT PUGET SOUND BEACHES FROM OVERHARVEST

Mark D. Plunkett[1]

The Puget Sound region has experienced a major increase in human population over the past several decades, and this trend is projected to continue. This has placed unprecedented pressure on the harvest of the area's marine resources, for both personal and commercial purposes. In addition, health concerns exist regarding consumption of plants and animals from local beaches. In response to these issues, the city of Seattle and the King County Department of Metropolitan Services (Metro) have embarked upon a shellfish harvest study. Pre-study clam surveys were field tested in 1993 and 1994. The methodology found to be most appropriate involves weighing/measuring selected bivalves dug from one-cubic foot sites on a systematic sampling grid.

In 1995 or 1996, the beach will be equally divided into adjacent harvest and non-harvest areas. Semi-annual clam surveys will commence for at least three years after partitioning. Populations estimates will be compared between the harvest and non-harvest sections. The objective of the study is to determine what future level of human collection is appropriate, if any, on Seattle beaches. Ultimately, conclusions from this work may be utilized in guiding the study and management of local marine resources to augment county, state and federal programs.

OCTOPUSES AND CLAMS: THE PACKAGING PROBLEM

Roland C. Anderson[1]

When an octopus finds a clam its problems with getting food are not over, as it still has to get between the hard shells. Large octupi (*Octopus dofleini*) of the Pacific Northwest were offered the mussel *Mytilus trossulus* and the clams *Tapes philippinarum* and *Protothaca staminea* for food at the Seattle Aquarium. They solved the penetration problem differently for each species of bivalve. They usually pulled apart the valves of *Tapes*. Thinner *Mytilus* shells were equally often broken apart, chipped at the edge, or pulled apart. The thicker *Protothaca* shells were chipped or had a hole drilled in them with the radula and salivary papilla. Nearly all chips and drills into Tapes were successful, but only half into *Protothaca* resulted in clam opening. Tests of clam strength showed that *Mytilus* needed less pulling force than *Tapes*, which in turn needed less than *Protothaca*. If *Tapes* shells were wired shut, the octopus equally often resorted to chipping, drilling, or breaking in attempts to penetrate the clams. Thus the octopus has four ways of getting into a clam, and appeared to use the easiest possible, resorting to drilling only when the other methods were unsuccessful.

[1] The Seattle Aquarium, Pier 59, Seattle, WA 98101

A VIDEO-ACOUSTIC TECHNIQUE FOR ASSESSING ROCKY REEF FISHES IN PUGET SOUND

Wayne Palsson, N. Lemberg, R. Pacunski, R. Mueller and S. Burton[1]

A new technique was developed for assessing populations of lingcod, rockfishes, and other fishes living on rocky reefs in Puget Sound. The Video-Acoustic Technique (VAT) incorporates a scientific echosounder and remotely operated camera to assess fish densities on reefs where direct assessment methods are otherwise limited. During the fall of 1993 and summer of 1994, VAT surveys were conducted in the San Juan Archipelago and Strait of Juan de Fuca. Fine scale nautical charts and local knowledge were used to identify and quantify likely reef areas in depths of 40 m or less. These locations provided the sampling frame for systematic surveys of the nearshore environment. During 1993, over 100 stations were surveyed in the San Juans and in 1994, almost 600 stations were surveyed in northern Puget Sound.

The acoustic component of the VAT collected fish density observations along a strip transect over surveyed portions of reefs. Acoustic observations were limited to the water column 2 m above the bottom. To assess the near bottom species, a video camera mounted on a tripod was placed on the reef to survey the fishes living within 2 m of the bottom. Remote operation from a surface support vessel allowed the camera to sweep a circle and observe fishes within a range of 1 m to 3 m. The camera was also used for acoustic target identification and for bottom type characterization. The abundance estimates from the 1993 survey of the San Juans were 2.1 million copper rockfish (*Sebastes caurinus*), 0.7 million quillback rockfish (*S. maliger*), 25 million Puget Sound rockfish (*S. emphaeus*), and 0.3 million lingcod (*Ophiodon elongatus*). Coefficients of variations ranged from 30 percent for the more abundant species greater than 100 percent for the rarer species. The results from the ongoing 1994 survey are not yet available, but no rockfish were detected west of Port Angeles despite a sampling of 50 nearshore stations.

[1] Washington Department of Fish & Wildlife, 600 Capitol Way N., Olympia, WA 98501-1091

OUTMIGRANT GREEN RIVER CHINOOK SALMON (*Oncorhynchus tshawytscha*) DISTRIBUTION AND GROWTH IN THE DUWAMISH RIVER AS A FUNCTION OF WATER QUALITY PARAMETERS AND SUBSTRATE TYPE

Eric Warner and Rob Frit[1]

The Green River and its two hatcheries produce several million juvenile salmon every year, primarily chinook. All of these fish must migrate through the Duwamish estuary, a highly modified and heavily industrialized section of the river flowing through the port city of Seattle, Washington. During the 1994 chinook outmigration from the Green/Duwamish River, beach seining was conducted at nine stations over the entire salinity range (10 km) of the estuary. Lengths and weights were collected for over 5,000 salmonids, primarily chinook and chum, including over 60 coded wire tagged fish. The distribution and growth of outmigrating juveniles was tracked as they entered and passed through this degraded estuary. Water quality data were gathered concurrently at tidal extremes in order to determine spatial and temporal trends in dissolved oxygen,salinity, temperature, pH and turbidity. Water quality information correlated with tides and river discharge allowed us to determine the location of the salt water wedge. The degree to which the observed fish distribution is influenced by this wedge or by other factors was calculated. The information gathered will assist in both locating and designing future restoration sites in the Duwamish estuary and elsewhere.

NONPOINT SOURCE POLLUTION CONTROLS: PACIFIC NORTHWEST EMERGING TECHNOLOGIES IN REVIEW

Joseph B. H. Smith[2], John Macpherson[3] and John Beal[4]

Over the last several years, federal and state environmental regulatory agencies have placed an increasing emphasis on stormwater runoff as a major source of surface water pollution. In November 1990, the Environmental Protection Agency (EPA) published their final regulations concerning stormwater discharges from industrial and construction sites. Since that time, the EPA and state and local regulatory agencies have developed numerous additional permits, regulations, design standards, and Best Management Practices (BMPs) that address a wide range of stormwater management issues. This poster presentation will review two of the new technologies (catch basin filters and bio-check booms) developed in the Pacific Northwest to meet the demands of the new stormwater regulations.

[1] Muckleshoot Indian Tribe, 705 N. 92nd St., Seattle, WA 98103

[2] Foss Environmental Services Co., 7440 W. Marginal Way S., Seattle, WA 98108

[3] Stormwater Services Corp.

[4] I'm a Pal Foundation, 742 South Southern St., Seattle, WA 98108

PARALYTIC SHELLFISH POISONING: TOXIN ACCUMULATION IN THE MARINE FOOD WEB, WITH EMPHASIS ON PREDATORY SNAILS

A.L. Matter[1]

The vectors of paralytic shellfish poisoning (PSP) toxin transmission through the marine food web are more complex than originally thought. While the classical vector of PSP toxin transmission from phytoplankton to humans has been filter-feeding molluscan bivalves, these toxins also accumulate in zooplankton, non-bivalve invertebrates, fish, birds and mammals.

The accumulation of PSP toxins by non-bivalve marine invertebrates is best documented in predatory snails, which obtain these toxins from their filter-feeding prey, such as clams. Many field-collected samples of predatory snails, including whelks (*Buccinum undatum*), moon snails (*Euspira heros* and *Polinices lewisii*), dogwinkles (*Nucella lamellosa*) and other marine snails (*Oliva vidua fulminans* and *Zidona angulata*) have exceeded the advisory beach closure level of 80 µg saxitoxin equivalent per 100 g shellfish tissue. Documented PSP illnesses and/or deaths have resulted from the consumption of recreationally harvested marine snails in Massachusetts, Argentina, Canada and Malaysia.

Species of intertidal marine snails that have tested positive for PSP toxins, and moon snails and dogwinkles in particular, are consumed by recreational and subsistence harvesters in the Puget Sound area. Washington State Department of Health (DOH) has primary responsibility for monitoring PSP toxin levels in shellfish. While PSP toxin levels are determined for many types of shellfish, marine snails are not directly monitored. However, when the DOH issues advisory beach closures for shellfish, they now include "other marine invertebrates, such as moon snails" (as of spring 1994). Efforts are under way to quantify levels of PSP toxins in Puget Sound moon snails.

[1] University of Washington, School of Fisheries, HF-15, Seattle, WA 98195

BIVALVE TRANSPLANTS: MANIPULATIVE EXPERIMENTS AND DEPLOYMENT METHODS

Sandra M. Salazar[1] and Michael H. Salazar[2]

Transplant studies and *in situ* bioassays combine the experimental control of laboratory testing and the environmental realism of field testing with measurements over space and time. Bivalve populations have been used extensively as indicators of exposure by measuring bioaccumulation because they can accumulate contaminants at concentrations that are orders of magnitude above those found in surrounding media. Bivalves are also well suited to measuring bioeffects when held in cages. Confinement facilitates monitoring individuals during a defined exposure period. There is tremendous flexibility in the transplant methodology, with various options for cage type, deployment configuration, degree of replication, and species used. Many species of bivalves have been used successfully in freshwater and marine systems for ecological risk assessments.

We believe it is important to measure both exposure and response, *and* in the same test animals, because of the link between environment and organism that is necessary to predict effects in ecological risk assessments. Bivalves are particularly well suited to the transplant methodology because they are sedentary; their hard shells make them easy to collect, handle, cage and measure; and they survive well under most environmental conditions. Various deployment configurations and some examples of results are presented for San Diego Bay, CA, Harbor Island, WA, Sinclair Inlet, WA, Delaware Bay, DE, Tampa Bay, FL, and Sudbury River, MA, where we have successfully transplanted marine and freshwater mussels and oysters to evaluate chemical exposure and biological effects.

[1] EVS Consultants, 2517 Eastlake E., Seattle, WA

[2] National Oceanic & Atmospheric Administration, Bioeffects Branch, 7600 Sand Point Way, Seattle, WA 98115

SEAWATER CHALLENGE OF COHO SALMON SMOLTS EXPOSED TO ENDOTHALL

Dave Serdar and Art Johnson[1]

Since 1980, the Washington State Department of Ecology (Ecology) has permitted the use of some herbicides containing endothall (chemical name 7-oxabicyclo [2,2,1]heptane-2,3-dicarboxylic acid). While endothall has relatively low acute toxicity to a variety of fish species, there are concerns that exposure to endothall or its formulated products may reduce the ability of salmon smolts to physiologically adapt for marine survival. To address these concerns, smolting coho salmon (*Oncorhynchus kisutch*) were challenged with seawater following exposure to endothall.

Thirty healthy smolts were first exposed to 5 mg/L technical-grade endothall in fresh water for 96 hours. Fish in a control group were exposed to dechlorinated municipal water (Manchester, WA). Smolts were then challenged by seawater for 24 hours (Clam Bay in Puget Sound). Blood plasma sodium was measured as an indicator of the smolts' ability to osmoregulate.

No mortality was observed among the exposed or control smolts. There was essentially no difference in plasma sodium concentrations of exposed fish (mean = 171 meq/L) compared to control fish (mean = 170 meq/L). These concentrations are consistent with normal levels in fully smolted coho following a 24-hour seawater challenge, and are well below the 200 meq/L level where high mortality has been observed shortly after transfer to seawater. Analysis of endothall in the exposure tanks showed no degradation during the 96-hour exposure period.

Results of this investigation indicate that coho smolts do not suffer a decreased ability to regulate their blood sodium concentrations when exposed to maximum endothall levels recommended for herbicide application. We recommend other herbicides be tested if they are used in the vicinity of smolting salmon.

TECHNIQUES FOR USING MULTIPLE REFERENCE STATIONS IN SEDIMENT BIOASSAY EVALUATIONS

Bruce W. Rummel[2]

Regulatory interpretation of sediment bioassays requires comparing results at test stations with those obtained at reference stations. Sediment investigations may sample multiple reference stations for a variety of reasons, including wide distribution of grain sizes at test stations, use in the investigation of two species of test organisms in one class of bioassay (e.g., *Rhepoxyius abronius* and *Ampelisca abdita* in the amphipod bioassay), and reliability of reference station performance, among others. This presentation explores techniques to select, pool or otherwise use data from multiple reference stations for sediment bioassay evaluations. Two test cases with three reference data sets are used to illustrate and compare the approaches.

[1] Washington Department of Ecology, Washington Department of Ecology Environmental Investigations and Laboratory Services Program, Toxics Investigations Section, Olympia, WA 98504-7710

[2] URS Consultants, 1100 Olive Way, Suite 200, Seattle, WA 98101

MONITORING PUGET SOUND EELGRASS IN A TRANSPLANT AND ADJACENT BEDS

Allison Reak[1]

Eelgrass (*Zostera marina L.*) is a nearshore aquatic plant that provides important habitat for many marine species, including crabs and juvenile salmon. Along North Beach, near a sewage treatment plant at West Point in Seattle, eelgrass forms a series of beds covering about 50 acres. In March 1992, an eelgrass transplant was conducted at North Beach, as part of a mitigation effort to restore lost habitat and biological function to an area affected by the construction of a temporary barging facility.

The eelgrass transplant was designed to replace eelgrass beds that were excavated during construction. The transplant was also intended to mitigate for potential operational impacts that may have been caused by subsequent barging activity. This first large-scale eelgrass transplant attempt in Puget Sound covered 11,500 ft^2 and provided mitigation area for the displaced eelgrass habitat at a greater than 4:1 ratio.

Turion densities were monitored quarterly along permanent transects in the transplant bed and in natural beds both adjacent to the transplant and at a reference site. Using aerial photographs, the areas of the transplant and selected adjacent beds were calculated annually. During two years of monitoring, eelgrass density and area showed great variability in both the transplant and natural beds. Transplant turion densities had increased significantly after one year, but decreased after two years. Transplant area declined steadily during the two years. Natural eelgrass beds along North Beach showed similar, but less severe trends. Crab bioturbation appeared to exert continual disruptive pressure on the transplant area, but not on the natural beds. Other specific causes of eelgrass decline were not apparent.

VERTICAL DISTRIBUTION OF THE MARINE PHYTOPLANKTON *Heterosigma* sp.

P. K. Hershberger, J. E. Rensel, A. L. Matter and F. B. Taub[2]

Heterosigma blooms have occurred in Puget Sound as well as coastal waters of Japan, Singapore, New Zealand, Spain, Chile, Belgium, Bermuda and Korea. High concentrations of the *Raphidophyceae* species in surface waters have been associated with mortalities of chinook salmon (*Onchorhynchus tschawaytscha*), Atlantic salmon (*Salmo salar*), rainbow trout (*Onchorhynchus mykiss*), yellowtail (*Seriola quinqueradiata*), red sea bream (*Pagrus major*), and sea bass (*Dicentratus labrax*), at mariculture facilities. Our work is focused on determining the environmental conditions that contribute to rapid bloom formations of this species.

Past researchers have suggested that high concentrations of *Heterosigma* may occur due to increased growth rates which occur as a result of elevated nutrient levels and/or diurnal migration of this flagellated species. Data from our lab provides evidence for rapid formation of elevated surface concentrations of *Heterosigma* when a distinct halocline is present in the water column. Elevated surface concentrations are maintained 24 hours per day until the salinity gradient is removed. The questions being asked include: 1) Can salinity gradients in the water column be responsible for sudden blooms of *Heterosigma*? 2) Is anichthyotoxin produced by the cells (via osmotic stress, low nutrients, or low salinity) when the cells are at the surface? 3) Are surface concentrations the result of active migration or passive flotation by the cells? and 4) How do the cells detect that a halocline is present above them and what actually triggers their upward movement?

[1] Parametrix, Inc., 5808 Lake Washington Boulevard NE, Kirkland, WA 98033

[2] University of Washington, School of Fisheries, HF-15, Seattle, WA 98195

PUGET SOUND COOPERATIVE RIVER BASIN TEAM

The Puget Sound Cooperative River Basin Team (PSCRBT) is an interdisciplinary, interagency team providing technical assistance to identify nonpoint pollution sources and impacts to beneficial uses of water in the Puget Sound watersheds. The team's primary activity is developing watershed characterizations for Watershed Management Committees who are working to develop a Watershed Action Plan for their watershed through the process defined in Local Planning and Management of Nonpoint Source Pollution (WAC 400-12).

The Team's poster for the conference includes a map showing the 20-plus watersheds the team has worked in since 1987. This includes 16 full watershed characterizations (including geographic information system [GIS] databases and maps), five partial watershed characterizations, three watershed ranking reports, and five database and map sets for watersheds for which we were not able to provide full characterizations. In addition, depending on the availability of space, the poster may include examples of display GIS maps produced for individual watersheds, display copies of watershed characterizations, and a fact sheet "hand-out" of information about the team and list of the watersheds the team has worked in.

NEEDED: A PUGET/GEORGIA BASIN FORUM

Dick Nelson[1]

A new regional Puget/Georgia Basin forum for the identification and discussion of long-range growth issues is proposed. The forum would focus on forecasted population growth and development and their effects on the ecosystems defined by the Puget Sound, the Strait of Georgia and the Strait of Juan de Fuca, including surrounding watersheds and airsheds. Forum participants would include representatives of local, sub-regional, and state and provincial governments, tribal governments, environmental groups, and economic interests from British Columbia and Washington state. The forum would provide a needed comprehensive approach to the major growth problems facing the Puget/ Georgia Basin. It would complement, not compete with, efforts to manage growth and address environmental impacts currently under way on both sides of the international boundary, and between the state and provincial governments.

[1] Institute for Transportation and the Environment, 122 NW 50th, Seattle, WA 98107

NISQUALLY RIVER MANAGEMENT PROGRAM

Peter Moulton[1]

The Nisqually River is unique in Washington state, if not the nation, in having its headwaters in a national park and its estuary within a national wildlife refuge. The intervening 78 miles of river flow through forested mountainous terrain and rolling farmlands in three counties, past small towns, and through the Fort Lewis Military Reservation and Nisqually Indian Reservation, before entering Puget Sound near the site of the first European settlement in the region.

These unique qualities were recognized under Washington's 1972 Shorelands Management Act, which declared the Nisqually to be a river of "statewide significance." In 1985 the state Legislature directed the Department of Ecology to develop a Nisqually River Management Plan providing for a balanced stewardship of the basin's economic, cultural and environmental resources.

Ecology established the Nisqually River Task Force, comprised of timber, agriculture, and hydropower interests, conservation and environmental organizations, private landowners, resource management agencies, and the Nisqually Indian Tribe. The key issues the Task Force had to address included public access, flood control, fish and wildlife protection and enhancement, public desires to maintain existing rural landscapes and economies, and the balancing of private property rights with statewide public interests.

In 1987, the Legislature adopted the findings of the Task Force, established the Nisqually River Management Plan, and created the Nisqually River Council as an interagency body committed to the protection and enhancement of the Nisqually River basin through education, advocacy and coordination. Funding to implement the objectives of the plan is provided by the Legislature through Ecology.

The Council represents state and federal resource agencies, local and tribal governments, and public utilities. A Citizens Advisory Committee represents citizen interests throughout the basin, expressing their opinions and concerns, and assisting in the development of recommended policies for the management plan.

[1] Washington Department of Ecology, Southwest Regional Office, P.O. Box 47775, Olympia, WA 98504