1994 Puget Sound Update

Fifth Annual Report of the Puget Sound Ambient Monitoring Program

February 1995, revised December 1995

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SUMMARY

Assessing the health of Puget Sound can be likened to working on a jigsaw puzzle. Each year of monitoring adds more pieces and takes us one step closer to being able to see the whole picture. Adding to the complexity of the puzzle is the fact that the picture is constantly changing, due both to natural conditions such as weather patterns and human-related conditions such as population growth.

After five years of monitoring through the Puget Sound Ambient Monitoring Program (PSAMP), the picture of the Sound's long-term health is beginning to take shape. Although we cannot yet draw conclusions about long-term environmental trends, data collected indicates that the health of Puget Sound is generally good, although serious problems exist. Widespread destruction and degradation of natural shoreline areas has greatly decreased the quality and quantity of fish and wildlife habitat. Sediments in many urban bays and along shorelines close to pollutant sources exceed sediment quality standards. In several urban bays, bottomfish exhibit high percentages of liver tumors. Fecal contamination has resulted in the closure of large areas of the Sound to commercial and recreational shellfish harvest. Populations of many species of marine fish and salmonids are decreasing dramatically.

At the same time, the PSAMP has shown that many contamination problems are restricted to fairly small areas near the shorelines and urban bays. Sediment contaminants are generally found in low concentrations in areas distant from shorelines or pollutant sources. While fecal contamination is evident in fresh waters and in nearshore marine waters throughout the Sound where shellfish resources are harvested, the open marine waters of the Sound exhibit lower levels of fecal coliform bacteria.

Designed in 1988 and initiated in 1989, the PSAMP expands on existing monitoring programs and coordinates the collection of information to address the environmental quality of Puget Sound in a comprehensive fashion. The program measures ambient, or background, conditions. In doing so, it complements existing monitoring near direct (point) sources of pollution and in problem areas, and evaluates the degree to which contamination disperses to affect broader areas of the Sound. In addition, the PSAMP is a long-term program designed to address changes in Soundwide conditions over time. PSAMP uses information collected by the program as well as information gathered by other monitoring programs to provide a comprehensive evaluation of environmental conditions in Puget Sound.

Continued monitoring will let us know whether the extent and severity of water quality problems in Puget Sound are increasing over time.

Reporting results of the Puget Sound Ambient Monitoring Program

The *1994 Puget Sound Update* is the fifth annual report of the Puget Sound Ambient Monitoring Program (PSAMP). It reports the results of sampling undertaken in 1993, the most current year for which the data have undergone analysis and quality assurance tests.

The program is a coordinated effort among five state and two federal agencies to measure sediment and water quality; population levels and contaminant concentrations in fish, shellfish, marine mammals, and birds; and the amount and types of nearshore habitats within Puget Sound. PSAMP monitors ambient, or background, conditions. Monitoring is conducted away from the immediate proximity of pollution sources to evaluate the extent to which these pollution sources affect wider areas of the Sound.

MEASURING THE HEALTH OF PUGET SOUND

The PSAMP determines Puget Sound's health by examining five key indicators that measure the extent to which human activities adversely affect different parts of Puget Sound's ecosystem. The indicators are chemical contamination of sediments and biological organisms; fecal contamination of marine waters, fresh waters and shellfish; types and amounts of nearshore habitat; abundance of biological resources; and the quality of marine waters as measured by conventional parameters such as dissolved oxygen levels.

The program is performing a valuable function by filling data gaps and collecting information in areas not sampled by other monitoring programs. While many programs collect data in urban bays, few other than the PSAMP monitor the rural bays and open waters of Puget Sound. The collection of this data is expanding and refining our understanding of the status of environmental conditions throughout Puget Sound. As more years of data are collected, the program will increasingly address how these conditions are changing over time.

1993 monitoring results for these indicators point to the following conclusions about the overall condition of Puget Sound:

CHEMICAL CONTAMINATION

Sediments, fish, shellfish and birds were used by the PSAMP to assess chemical contamination from heavy metals and organic contaminants, such as lead, mercury, petroleum hydrocarbons and synthetic pesticides.

1993 PSAMP data on sediment chemistry results were consistent with past findings of the program. At ambient sites, many contaminants are found at low levels near analytical detection limits. Contaminants are generally more concentrated in urban bays, although levels at ambient monitoring sites in urban bays are considerably lower than in nearshore sediments close to sources. Ambient monitoring refers to sampling conducted away from the immediate proximity of pollution sources. As in past years, only a few PSAMP stations exceeded standards for sediment quality. Sinclair and Dyes inlets had levels of mercury above sediment standards for the fifth straight year. For the second consecutive year, Elliott Bay exceeded standards for HPAHs (high molecular weight polycyclic aromatic hydrocarbons, which result primarily from combustion of petroleum products and organic materials).

Building on previous years of sampling, which established levels of contaminants in fish, in 1993 the PSAMP focused on determining the nature of this contamination. How, for example, do chemical concentrations vary with the age of fish, among sites where the fish are found, and among tissues within the fish's body? Monitoring results showed that some contaminant levels increased with the age of the fish, suggesting that fish accumulate toxicants throughout their lives. The PSAMP found some significant variations in chemical concentrations among sites; higher levels did not always correlate with a higher degree of urbanization. Levels of PCBs—chlorinated organic contaminants—in English sole were higher in urbanized areas, but

the same correlation was not found for metal contaminants. It could not be determined, however, if the correlation between the degree of urbanization and contamination concentrations is applicable to other organic chemicals. Concentrations of chemical contaminants (with the exception of arsenic) were much higher in liver tissue of fish than in muscle tissue.

PSAMP monitoring generally revealed low levels of chemical contamination in the tissue of native littleneck clams collected over the last several years—a somewhat surprising result considering that a number of sampling sites were in urban bays near potential pollution sources, and that these organisms live within sediments, where contaminants may accumulate. Tissue concentrations varied little among sites, with the exception of lead and mercury. Clam tissue from Eagle Harbor had lead concentrations three times higher than all other sites. When compared to other sites, mercury concentrations were twice as high at Eagle Harbor. Organic contaminants were detected infrequently. The threat to human health associated with consuming fish and shellfish from sites sampled by the PSAMP is considered to be low for all chemicals other than lead, mercury and PCBs. (The Environmental Protection Agency is currently reviewing human health-related criteria for lead, mercury and PCBs. Therefore, health-related conclusions for these contaminants are not available at this time.)

Although the number of bald eagles has been increasing throughout Washington state in recent years, reproductive success has remained low for the past 13 years in bald eagles nesting near Hood Canal. Preliminary results of an interagency investigation (not part of the PSAMP) into the causes of this reproductive failure indicate that bald eagle eggs in the Hood Canal area contain high levels of PCBs; these levels have been associated with reproductive failures in other studies.

FECAL CONTAMINATION

Fecal waste from humans and animals enters Puget Sound through a number of sources, including runoff of surface water and failing on-site sewage (septic) systems. Concern over fecal contamination stems from the fact that the pathogens (bacteria, viruses and protozoa) associated with human and animal waste have the potential to make people who swim in or eat shellfish from contaminated waters sick. The PSAMP monitors fecal coliform bacteria in marine waters, fresh waters and shellfish as an indicator of the presence of fecal waste and associated pathogens.

Monitoring from several programs outside of the PSAMP has shown high levels of fecal coliform bacteria at nearshore areas around the Sound, suggesting that large amounts of fecal waste are entering the basin. Bacteria levels at ambient sites located away from shorelines were much lower, probably due to the fact that fecal coliform bacteria do not survive well in marine waters.

Fecal coliform bacteria levels in almost half the rivers and streams monitored in the Puget Sound basin (15 of the 34 sites sampled in wateryear 1993) had annual geometric means above levels allowed by state water quality standards. Five of the 10 major rivers in the basin exceeded standards.

Many of these rivers have had high bacterial levels for several years, suggesting chronic contamination that is not improving.

Fecal contamination found in shellfish tissue revealed patterns similar to results from past years. Some of the most contaminated sites are in rural areas exposed to a variety of pollution sources, indicating that fecal contamination is not limited to urban areas.

In 1993, the Washington State Department of Health (DOH) began classifying recreational shellfish beaches to improve the safety of recreational shellfish harvesting. Twenty-nine recreational beaches are classified as open to harvest, four are conditionally closed to harvest (i.e., closed after heavy rainfalls), and 37 are closed to harvest. Seventy-two recreational beaches remain unclassified because these areas have not been monitored sufficiently to assess the risk of exposure to fecal contamination. Although harvest restriction continued in large portions of commercial shellfish growing areas, results from 1993 were promising. 1993 marked the first year in with the DOH upgraded more commercial growing areas than it downgraded. Four commercial growing areas, totaling 2,690 acres, were upgraded, compared with 1,070 acres downgraded in two growing areas.

NEARSHORE HABITAT

PSAMP monitoring of nearshore habitat continues to focus on determining the composition and coverage of these important intertidal and subtidal areas. Progress is necessarily slow, as the technology used to inventory nearshore habitat is new and complex.

Using remote sensing, the Washington Department of Natural Resources (DNR) mapped five nearshore habitat areas in 1993 and 1994—Cherry Point in Whatcom County, a portion of central Hood Canal, and three areas in Elliott Bay. Aquatic vegetation at Cherry Point is dominated by eelgrass, whereas vegetative coverage within Elliott Bay is dominated by various types of algae, with small eelgrass beds present.

The Department of Ecology and Thurston County conducted a study analyzing shoreline hardening or armoring (the construction of structures to prevent shoreline erosion) in Thurston County from 1977 to 1993. The analysis indicates that the amount of shoreline with armoring structures more than doubled during that time. Over the 16-year-period, the length of armored shoreline increased an average of approximately one percent, or slightly more than one mile, per year. Currently, one-third of the county's shoreline is armored. If the rate of armoring documented by the study continues, the entire shoreline in Thurston County will be armored within 50 years.

BIOLOGICAL RESOURCE ABUNDANCE

Determining the effects of human activities on the abundance of natural populations is a difficult task and the PSAMP is still in the beginning stages of monitoring. Because of this the program tracks numerous outside studies to assess biological resource abundance.

PSAMP monitoring thus far has focused mainly on bird populations. The results provide some preliminary indications of distribution patterns. The data indicate that bird populations in Puget Sound are more than twice as abundant in winter as in summer, and that gulls are the dominant populations during summer, while ducks and geese are the most numerous groups in winter. Intensive shorebird surveys indicate that the most common shorebird in Puget Sound during the winter is the dunlin, and that species richness (total number of species) of shorebirds has been highest in the Strait of Juan de Fuca and Admiralty Inlet over the last three surveys. The greatest total numbers of shorebirds, however, occur in north Puget Sound, particularly in Port Susan, Skagit Bay, Padilla Bay and Samish Bay.

A study conducted by the Washington Department of Fish and Wildlife (WDFW) on marbled murrelet populations suggests that the proportion of juveniles in the Puget Sound region may be higher than in Oregon and California. The WDFW also assessed gillnet mortality among marine birds. Their sampling indicates that common murres were captured in gillnets more frequently than other species and provides a preliminary entanglement rate for the fisheries observed in 1993.

A review of information on marine fish in Puget Sound indicates that marine fish populations are declining dramatically. WDFW data indicate that harvest rates of many Puget Sound fish are at their lowest level in 55 years, due to decreasing populations and increasing harvest restrictions.

Of the 14 sites monitored for shellfish abundance, Dosewallips State Park has the highest concentrations of manila clams, two sites in Sequim Bay have the highest concentrations of Native littleneck clams, and Shine Tidelands and Camano Island have the highest concentrations of butter clams. Although the three years of data gathered to date are insufficient to draw conclusions about population trends, no dramatic increases or decreases in the abundance of shellfish are evident.

Nine different gray whales were sighted in Puget Sound in 1993, compared to six in 1992 and 17 in 1991. Five of the whales sighted in 1993 were located in the Port Susan/Whidbey Island area; four were sighted in the Strait of Juan de Fuca. As in 1992, there were no strandings of dead gray whales in 1993 in Puget Sound, whereas three were stranded in 1991.

CONVENTIONAL WATER QUALITY

"Conventional" water quality problems are generally caused by contaminants other than toxic compounds. Examples of conventional water quality problems include oxygen depletion, sedimentation, excessive acidity or alkalinity, and high water temperatures.

1993 PSAMP monitoring reveals some degree of water column stratification at many stations sampled throughout the Sound. Stratification refers to the horizontal layering of the water column, in which density increases with depth so that surface waters tend not to mix with denser, deeper waters. Stratification can have an important influence on many water quality parameters, such as dissolved oxygen and nutrient concentrations.

Blooms of phytoplankton (single-celled plants that live suspended in the water) occurred at many stations where stratification was observed. Phytoplankton blooms were infrequent in the winter, when lower light levels limit photosynthesis and stronger winds reduce stratification. At some stations, blooms occurred more frequently in spring and fall, with lower levels in the summer, possibly reflecting limited nutrients. Other stations showed elevated chlorophyll *a* concentrations (a measure of phytoplankton abundance) even in summer months, suggesting that nutrient depletion did not limit phytoplankton growth.

The Department of Ecology found low concentrations of dissolved oxygen at six stations in Puget Sound. These stations exhibited low oxygen levels in past years as well, suggesting chronic low levels resulting from various natural causes and, in some cases, possible human influences. Low oxygen levels can stress or, in severe cases, kill aquatic organisms.

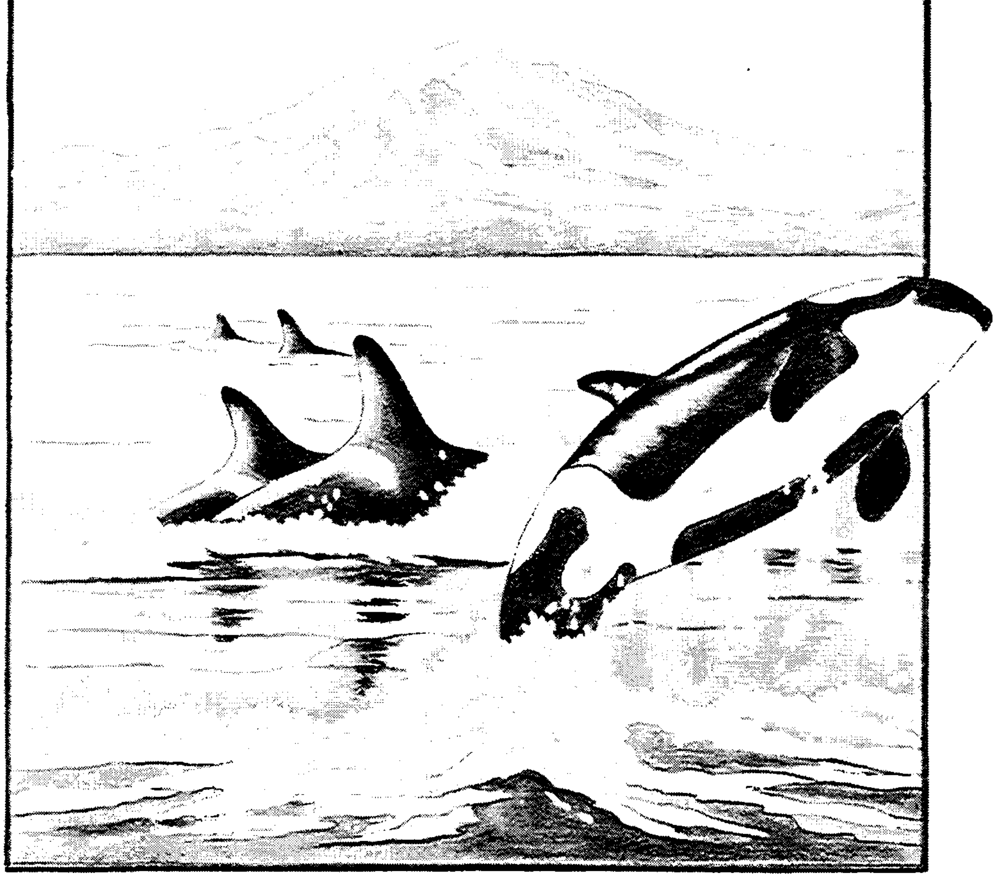
Ecology conducted intensive seasonal monitoring of Budd Inlet in 1992. Budd Inlet can be separated into three portions, with somewhat different physical and biological processes occurring in each. Central and outer Budd Inlet, north of Priest Point, flush well, with characteristics representative of ambient conditions in greater Puget Sound. Inner Budd Inlet, south of Priest Point, flushes poorly, with water quality conditions influenced by outflow from the Deschutes River and Capitol Lake, as well as discharges from LOTT (Lacey, Olympia, Tumwater, Thurston County)—the regional sewage treatment plant—and nonpoint pollution sources.

Stratification of Budd Inlet was strongest in the inner bay, and decreased from the head to the mouth of the inlet. Water column stratification was strongest during March and July in the inner bay, although some degree of stratification was present throughout the inlet during the entire study. Phytoplankton blooms occurred throughout the bay during the survey. Highest chlorophyll *a* concentrations consistently occurred in the central bay, between July and September. Analyses of phytoplankton species composition revealed that diatom species were dominant in spring and fall, while dinoflagellates were dominant in summer.

Many parts of the bay had low dissolved oxygen concentrations. In late summer and early fall, Ecology consistently found dissolved oxygen concentrations below 5.0 mg/l in the central and inner bay. Values below 5.0 mg/l occurred most frequently in West Bay's near-bottom waters, and to a lesser extent in the central bay near the eastern shore. The lowest dissolved oxygen concentrations were in the near-bottom depths of the inner bay within East Bay and West Bay. In these areas, values below 3.0 mg/l were observed during late August and early October.

Tidal and daily cycles affected many water quality parameters, including dissolved oxygen and the location of phytoplankton blooms. Understanding how these cycles affect water quality can help in the interpretation of monitoring data.

INTRODUCTION



HOW HEALTHY IS PUGET SOUND?

The first question people usually ask when they learn about the Puget Sound Ambient Monitoring Program (PSAMP) is "how healthy is Puget Sound?" Five years ago the PSAMP took on the challenging task of answering that question by assessing the overall condition of Puget Sound's water, sediments and biological resources, and by identifying and characterizing environmental problems. The information collected for the program since then begins to tell us what types of problems are most serious, where those problems are most evident, and what changes occur over seasons and among years.

Today, in many ways, the PSAMP is reaching a critical point—we are increasingly seeing the benefits of ongoing monitoring. As the body of data grows, our knowledge of environmental quality problems and their dynamics becomes more definitive. At the same time, the growing body of information on the Sound's water quality suggests there is no simple answer to the question, "how healthy is Puget Sound?" No area is entirely free from the effects of human activities, but the degree to which these activities affect different parts of the Puget Sound ecosystem varies widely. Some resources, such as shellfish and nearshore habitats, exhibit serious and widespread degradation. Others, such as the marine water column, do not appear to be seriously contaminated.

Table 1. Description of full PSAMP sampling design and implementation.

Task	Agency*	FULL IMPLEMENTATION Number of Stations/Surveys	Frequency of Sampling	1989 - 1994 IMPLEMENTATION Number of Stations/Surveys	Sampling dates/ frequency
Sediment quality Sediment chemistry Bioassays Benthic invertebrates	Ecology	75 throughout PS	Annually - spring	48 throughout PS	March-April, 1989-94
Marine water column	Ecology				
Baseline monitoring		10-12 throughout PS	Monthly	21-27 throughout PS	Monthly, 1990-94
Intensive seasonal monitoring		Not specified	Annually, spring - fall	2 sites	Spring - fall '92, '93, '94
Solstice-cycle monitoring		Not specified	Summer/winter solstices	Not funded	Not funded
Fish	WDFW				
Tissue chemistry (bottomfish)		21 stations	Annually - early summer	12-18 stations	May '89, '91, '92, '93, '94
Liver histopathology (bottomfish)		21 stations	Annually - early summer	12-18 stations	May '89, '91, '92, '93, '94
Tissue chemistry (cod, rockfish, salmon)		5-10 stations	Annually, depending on species	3-5 stations	Pacific cod - Feb. '90, '92, '93 Rockfish - Oct. '89, '91, '92, '93 Salmon - April '90, Fall '92 & '93
Shellfish	DOH &				
Abundance	WDFW	35 beaches	Annually	10 beaches	Summer 1991-93
Bacterial contamination		35 beaches	Quarterly	20 beaches	Quarterly, 1990-94
Tissue chemistry		35 beaches	Annually	10 - 20 beaches	Annually, 1990-93
Paralytic shellfish poisoning		35 beaches	Monthly (or more often)	16 beaches	Monthly (or more), 1990-94
Birds	WDFW &				Summer 1993, Winter 1993-94
Abundance	USFWS	Surveys throughout PS	Semi-annually	Surveys throughout PS	Summer 1992, Winter 1992-93
Tissue chemistry		3-5 stations	Annually	Not funded	Not funded
Marine mammals	WDFW	Surveys throughout PS	Semi-annually	Surveys throughout PS	Summer 1993, Winter 1993-94 Summer 1992, Winter 1992-93
Nearshore habitat Area and type	DNR	One-third of PS	Annually	Surveys throughout PS	Summer 1991, 1992
Fresh Water	Ecology	75 throughout watersheds	Monthly	10 major rivers within the PS basin	Monthly, 1990-94

* Ecology = Washington Department of Ecology; WDFW = Washington Department of Fish and Wildlife;
DOH = Washington Department of Health; USFWS = U.S. Fish and Wildlife Service; DNR = Washington Department of Natural Resources

The *1994 Puget Sound Update*—the fifth annual summary report of this program—evaluates the data collected by the PSAMP in 1993 (the most recent year for which the data have undergone quality assurance review and interpretation) and compares these data to past information on Puget Sound. Data available from other programs are included to provide a more complete assessment of conditions within the Sound.

PSAMP is a long-term, multi-agency monitoring program designed to assess the health of Puget Sound and its resources. PSAMP coordinates the activities of five agencies in conducting ambient monitoring of eight major components of the Puget Sound ecosystem (Table 1). Each year, the program evaluates the monitoring data collected from the previous year and describes the results of these analyses in the *Puget Sound Update*.

The five implementing agencies are responsible for collecting data and producing technical reports on monitoring results (Table 1). The Puget Sound Water Quality Authority is responsible for program coordination and data management, as well as annual publication of the *Puget Sound Update*. The agency technical reports contain more detailed information about specific findings from each monitoring task, and are available from the implementing agencies (please see the contact list provided at the end of each chapter). More extensive background information about the PSAMP and the Puget Sound ecosystem is provided in the first two *Puget Sound Updates* (PSWQA, 1990, 1991). The policies and status of environmental programs designed to protect Puget Sound are described in the *1992 State of the Sound* (PSWQA, 1992) and the *1994 Puget Sound Water Quality Management Plan.*

EVALUATING THE PUGET SOUND AMBIENT MONITORING PROGRAM

Thanks to monitoring conducted under the PSAMP, the amount of environmental data available to resource managers continues to grow, providing baseline and long-term information on Puget Sound's water, sediments, biological populations and habitat. But does this information provide the answers necessary to protect the Sound?

To ensure that the PSAMP remains an effective and efficient program that generates data useful to scientists and water quality managers, the *Puget Sound Water Quality Management Plan* calls for an evaluation of the program after its first five years of operation. In 1995, the PSAMP Steering Committee will identify an independent organization to evaluate the program. Among other things, the evaluation will consider:

- The effectiveness of PSAMP sampling, analyses and data management in meeting program goals.

- The degree to which quality assurance requirements are met and are effective in generating high-quality data.

- The degree to which PSAMP reports are effective and appropriate in meeting the program goals.

- The degree to which PSAMP results are used in making decisions about water quality management.

DETERMINING THE HEALTH OF PUGET SOUND

We measure the condition of Puget Sound by looking at five key indicators of estuarine health. These indicators, described below, are a measure of the extent to which natural processes and human activities affect different parts of the Puget Sound ecosystem.

Chemical contamination. Many toxic chemicals introduced into estuaries adhere to suspended particles within the water and settle to the bottom. Areas close to pollution sources may become severely contaminated because contaminant-laden sediments settle out close to their sources and accumulate over time.

Monitoring Puget Sound's health

Three types of monitoring are available to evaluate the effect of human activities on environmental quality: compliance monitoring, intensive surveys and ambient monitoring.

Compliance monitoring involves monitoring discharges from industrial, sewage treatment and stormwater facilities to determine whether they comply with regulations. Samples are generally taken from the outfalls of these facilities, although some monitoring may be conducted within the receiving waters to evaluate the effects of the discharge on receiving waters.

Intensive surveys are short-term, focused assessments designed to characterize the extent, nature and dynamics of an identified environmental problem, and to provide information that can be used to determine potential sources of the problem. Intensive surveys are generally concentrated on a specific area. A large number of samples may be taken throughout the waterbody and at several different times to provide data on the specific locations and times when the problem is most severe.

Ambient monitoring is conducted away from the immediate proximity of pollution sources and evaluates the extent to which these sources affect wider areas of the Sound. To be useful, ambient monitoring must be conducted over long periods at regular intervals (usually monthly or annually). Sampling is generally conducted in the middle of urban and rural bays to evaluate the cumulative effects of contamination from the numerous sources within the bay. Sampling is also conducted at reference stations far removed from pollution sources to provide valuable information about natural background levels of chemicals.

Ambient monitoring does not identify sources of pollution. It is used to evaluate the overall health of a body of water, and to identify emerging problems at an early stage. When problems become evident, these findings may trigger intensive surveys to evaluate the extent and likely sources of a problem. If a likely point source is identified, compliance monitoring results from that facility may be reviewed as supporting evidence. Thus all three types of monitoring are complementary and essential for a comprehensive understanding of the nature, dynamics and causes of water quality problems.

When contaminant levels exceed state standards

The *Puget Sound Update* compares monitoring results to a set of state environmental quality standards to determine whether contaminants found in sediments, surface waters, fresh waters and marine waters are high enough to cause problems. These standards provide a convenient benchmark against which to compare monitoring results to provide a relative measure of environmental quality and the severity of environmental quality problems.

The terminology associated with the comparisons can be confusing, however. Does the commonly used phrase "exceeds standards" mean that a particular measurement meets standards, or that the observed concentration is above allowable limits?

Within the *Puget Sound Update*, the phrases "exceeds standards" and "above standards" mean that the concentration of a particular parameter are above levels allowed in state standards, and that the measurement does not meet standards. Phrases such as "below standards" and "meets standards" mean that the measured concentration is within allowable limits specified in standards.

Plants and animals that are exposed to toxic contaminants present in the water and within sediments may accumulate contaminants to levels that affect their health. Contaminants accumulated in the tissues of these organisms may in turn harm other organisms as the contaminants pass up the food web. In species harvested for human consumption, contaminated tissues may present a threat to human health.

Fecal contamination. Failing on-site sewage systems (septic systems), improperly treated sewage, untreated waste discharged from boats, stormwater runoff, and runoff containing waste from marine birds and mammals, pets, and wild and farm animals may introduce pathogens contained within fecal matter into estuarine waters. Shellfish, which filter estuarine waters for food, can accumulate these pathogens and become contaminated.

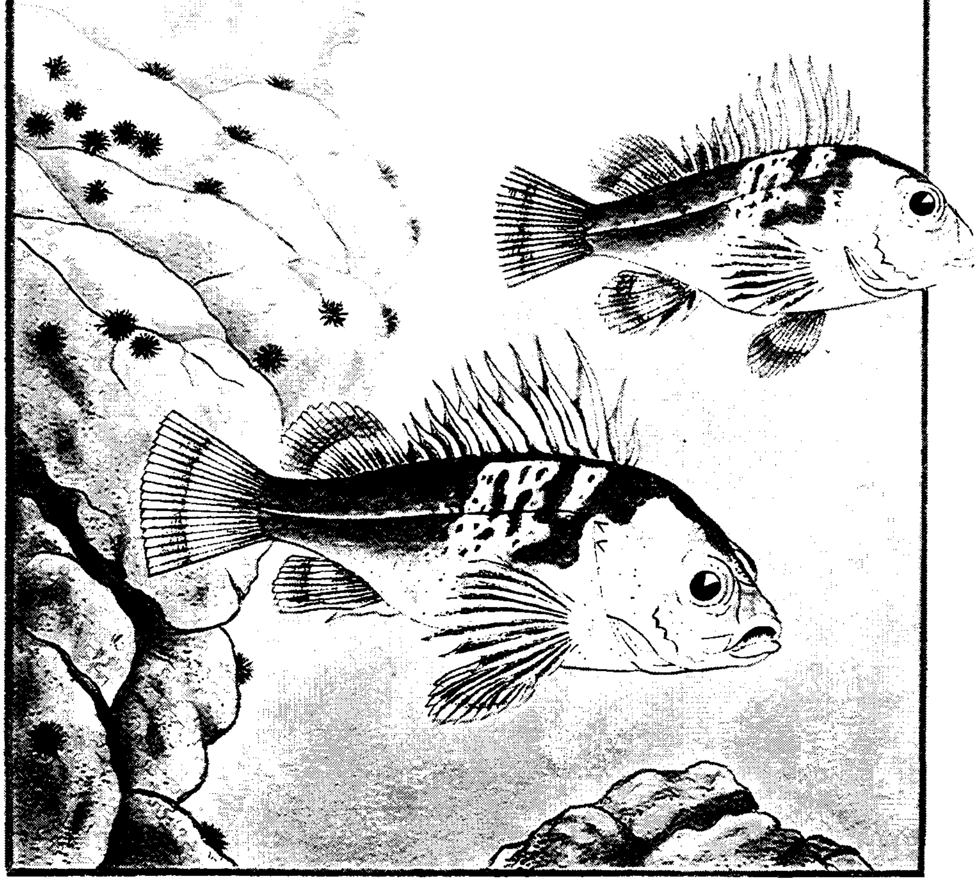
Types and amounts of nearshore habitat. Construction, dredging and other human activities that occur along the shoreline and adjacent shallow areas destroy and degrade kelp and eelgrass beds, salt marshes, mud flats, and other forms of nearshore habitats. This destruction harms the plants and animals that depend on these habitats for food, protection and spawning.

Abundance of biological resources. Habitat destruction, overharvesting and chemical contamination can affect the abundance of biological resources and wildlife populations. The effect of human activities is difficult to assess, since population abundance is controlled by complex natural and human factors that may vary widely from year to year. Nevertheless, it is clear that many human activities have the potential to adversely affect biological population abundance.

Conventional water quality. Problems related to conventional water quality can result from changes in water quality parameters such as temperature, salinity, nutrients and dissolved oxygen. These parameters affect biological processes in the water column. Examples of problems include eutrophication (an increase in nutrients or organic matter that stimulates large phytoplankton blooms and leads to oxygen depletion, foul odors and fish kills); increases in the amount of suspended solids that reduces light penetration for photosynthesis; or changes in freshwater input that can affect estuarine circulation.

Editor's Note: The 1994 Puget Sound Update *reports monitoring results in a more concise manner than previous reports. Each chapter contains an introduction of the indicator monitored by the PSAMP, a brief summary of the most recent findings and how they improve or expand our understanding of Puget Sound, and an in-depth section detailing the 1993 results of the PSAMP. Each chapter ends with a detailed resources section, which lists the technical reports used to compile our information and the PSAMP contact for the implementing agency or agencies. Our intention is to make it easier for the reader to access monitoring results and determine how they fit into the overall patterns of Puget Sound's water quality.*

CHEMICAL CONTAMINATION



WHAT DO WE KNOW ABOUT CHEMICAL CONTAMINATION?

The Puget Sound Water Quality Management Plan (PSWQA, 1994) defines a contaminant as "a substance that is not naturally present in the environment or is present in amounts that can, in sufficient concentration, adversely affect the environment." While many chemical contaminants occur naturally (e.g., all metals, petroleum hydrocarbons), others occur solely as a result of human production (e.g., synthetic organic chemicals such as chlorinated pesticides). In either case, if discharged in concentrations that exceed the marine environment's ability to readily assimilate them, these substances can harm Puget Sound and its resources.

What happens to chemical contaminants introduced into the Sound? Most end up in the surface sediment layer that forms the floor of Puget Sound because they naturally adhere to particles suspended in the water, such as silts and clays. As these particles settle out, the associated contaminants are transported downward and accumulate within the sediment layer. When measuring contaminants within Puget Sound, scientists generally find very low or undetectable levels of contaminants in the water (except very close to pollution sources), and much higher levels within the sediments.

A wide variety of animals, including crabs, clams, oysters, bottomfish, gray whales and bottom-feeding birds, rely on sediments for food or habitat.

When sediments become contaminated, species that rely on sediments may become contaminated as well, with potentially adverse effects on their health and populations. In addition, when humans eat those species directly, or consume organisms that feed on contaminated sediment dwellers, they may be exposed to contaminants.

The Puget Sound Ambient Monitoring Program (PSAMP) evaluates the effect of chemical contaminants on the Sound by measuring contaminant concentrations in sediments and the possible consequences on exposed biological populations (e.g., bottomfish, shellfish, benthic communities). This evaluation also provides an assessment of the potential risk to humans consuming these resources. Because contaminant levels are generally low or undetectable in the water column—particularly at the ambient sites sampled—the PSAMP does not monitor toxic chemicals in the water column.

SUMMARY OF 1993 FINDINGS ON CHEMICAL CONTAMINATION

1993 Sediment Chemistry Monitoring Results

The Department of Ecology (Ecology) conducted a limited set of analyses on the 1993 PSAMP data on sediment chemistry. The results were consistent with past findings of the program. At ambient sites, many contaminants are found at low levels near analytical detection limits. Contaminants are generally more concentrated in urban bays, although levels at ambient monitoring sites in urban bays are considerably lower than in nearshore sediments close to sources (see sidebar on page 9 for a description of ambient monitoring). As in past years, only a few PSAMP stations exceeded standards for sediment quality. Sinclair and Dyes inlets had levels of mercury above sediment standards for the fifth straight year. For the second consecutive year, Elliott Bay exceeded standards for HPAHs (high molecular weight polycyclic aromatic hydrocarbons, which result primarily from combustion of petroleum products and organic materials).

1993 Fish Monitoring Results

The Washington Department of Fish and Wildlife (WDFW) detected several patterns of tissue contamination in English sole, rockfish and Pacific cod. Concentrations of several contaminants in English sole and rockfish tissue varied significantly among sites. For some contaminants, concentrations increased significantly with the age of fish, suggesting that these contaminants accumulate throughout their lives. With the exception of arsenic, contaminants in English sole tended to be much more concentrated in liver tissue than in muscle tissue.

1993 Shellfish Monitoring Results

The Washington Department of Health (DOH) reviewed data on tissue chemistry in native littleneck clams collected over the last several years. In 1993, as in past years, the DOH found low levels (concentrations close to analytical detection limits) of metal and organic contaminants. Metals varied little among sites, with the exception of lead and mercury. Clam tissue from Eagle Harbor had lead concentrations three times higher than all other sites. When compared to other sites, mercury concentrations were twice as high at Eagle Harbor. Organic contaminants were detected infrequently.

The threat to human health associated with consuming fish and shellfish from sites sampled by the PSAMP is considered to be low for all chemicals other than lead, mercury and PCBs. (The U.S. Environmental Protection Agency is currently reviewing human health-related criteria for lead, mercury and PCBs. Therefore, health-related conclusions for these contaminants are not available at this time.)

1993 Bird Monitoring Results

Although the number of bald eagles has been increasing throughout Washington state in recent years, reproductive success has remained low for the past 13 years in bald eagles nesting near Hood Canal. A number of federal and state agencies have been cooperating in an investigation to determine potential reasons for this low reproductive success. Preliminary results indicate that bald eagle eggs collected from this area contain high levels of PCBs (polychlorinated biphenyls; industrial compounds used to cool and lubricate electrical equipment until the 1970s), which are associated with reproductive failures.

DETAILS OF 1993 FINDINGS ON CHEMICAL CONTAMINATION

Chemical Contamination of Sediments

The Washington Department of Ecology (Ecology) collects and analyzes sediment quality data for the Puget Sound Ambient Monitoring Program. Although, the PSAMP did not receive a technical report on the sediment data collected in 1993, Ecology did prepare a brief memo describing the more prominent results of its 1993 sediment chemistry data. The findings were consistent with results reported in past *Puget Sound Updates* (Table 2). Ecology recently initiated a review of the last five years of sediment data. This review is scheduled for completion in 1995, and will be reported in the next *Puget Sound Update.*

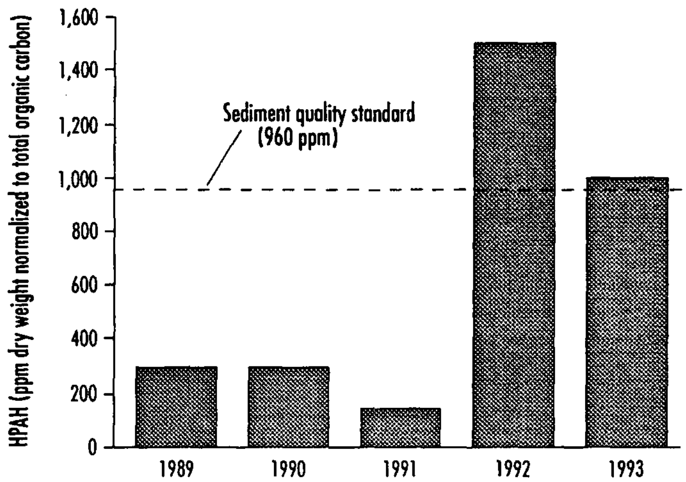
Table 2. Select results in 1993 PSAMP sediment data.

Parameter	Past Findings	1993 Results
Mercury (standard = 0.41 ppm)	Stations at Sinclair and Dyes inlets exceeded sediment quality standards from 1989 - 1993 (PSWQA, 1990; 1991; 1992; 1993).	Stations at Sinclair (0.43 ppm) and Dyes (average = 0.41 ppm) inlets were at or barely exceeding standards.
Lead, silver, zinc	Stations met sediment quality standards. Highest concentrations at Sinclair and Dyes inlets (PSWQA, 1993).	Stations met sediment quality standards. Highest concentrations at Sinclair and Dyes inlets. Copper levels were also high at these two stations.
PAHs (polycyclic aromatic hydrocarbons)	Concentrations have been highest at stations in Commencement Bay, Elliott Bay, Eagle Harbor and Dyes Inlet. Some sites have exceeded standards for one or more PAH compounds (PSWQA, 1990; 1991; 1993).	HPAHs (high molecular weight PAHs) exhibited elevated concentrations in Commencement Bay, Elliott Bay, Eagle Harbor and Dyes Inlet. Total HPAHs—and several HPAH compounds—exceeded sediment standards at Elliott Bay.

As in past years, few sites had levels of chemical contaminants above standards for sediment quality. The two exceptions were mercury at Sinclair and Dyes inlets, where mercury levels exceeded state standards for the fifth consecutive year, and total HPAHs at Elliott Bay (Figure 1). Total HPAHs, and several individual HPAH compounds, were above sediment quality standards at Elliott Bay for the second consecutive year (Figure 2).

Figure 1. Total HPAH levels in Elliott Bay, 1989 - 1993.

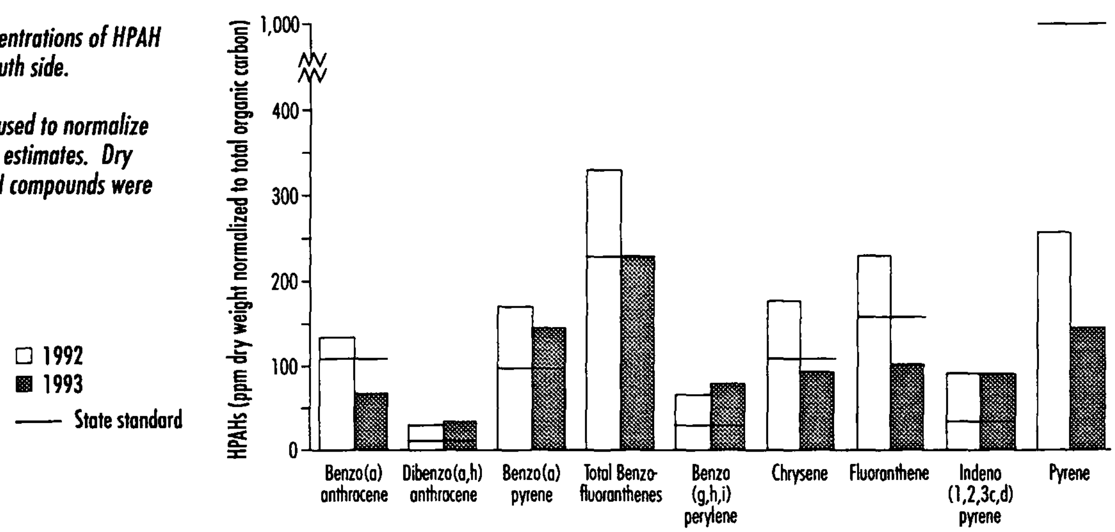
Total organic carbon values used to normalize 1991 and 1993 data were qualified as estimates. Dry weight values of several PAH compounds were qualified as estimates.



Reference: PSAMP central database

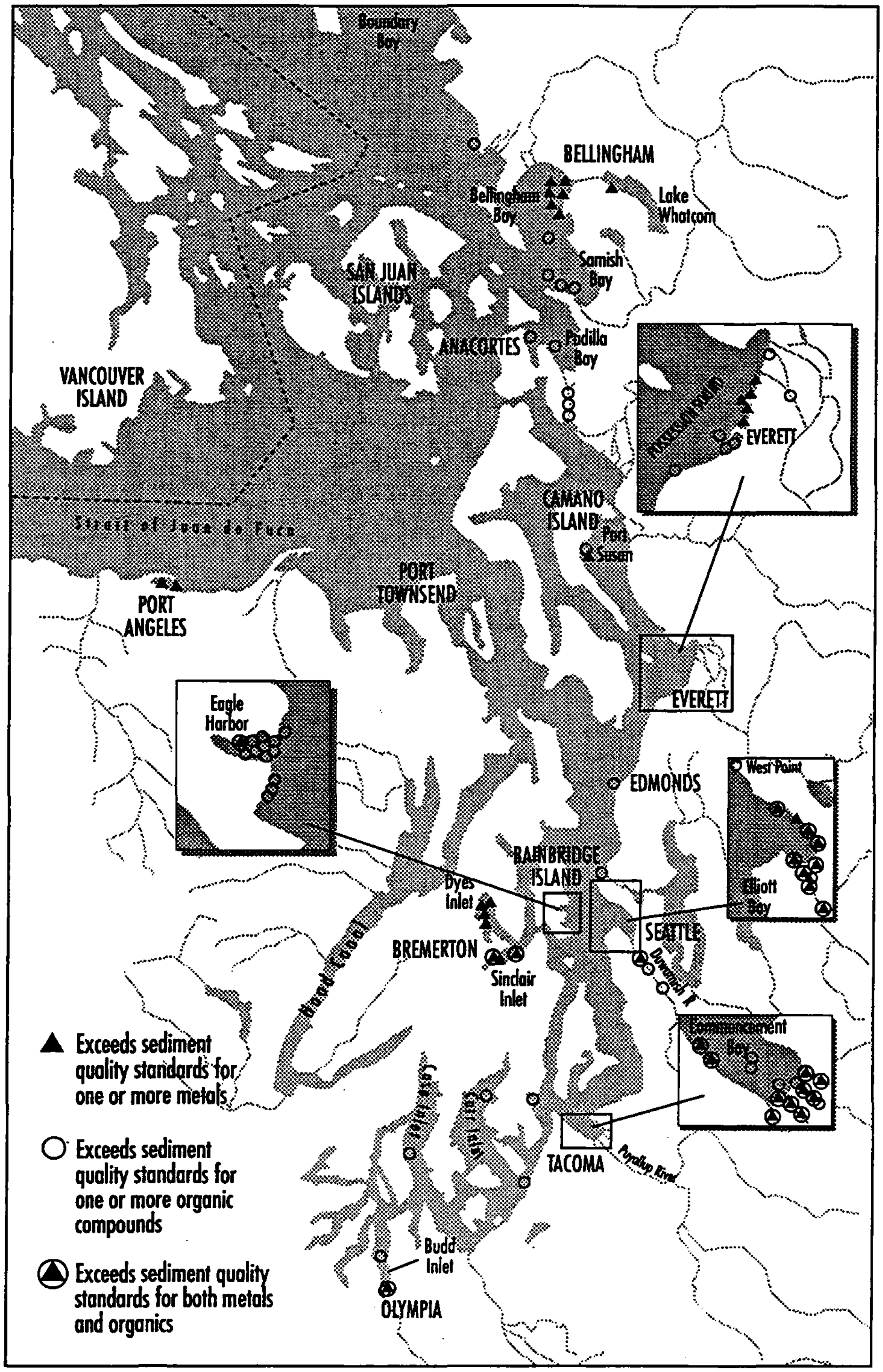
Figure 2. 1992 - 1993 concentrations of HPAH compounds at Elliott Bay, south side.

Total organic carbon values used to normalize 1993 data were qualified as estimates. Dry weight values of several PAH compounds were qualified as estimates.



Reference: PSAMP central database

Despite the limited analysis of PSAMP sediment data in 1993, the information on sediment quality provided to date by the PSAMP and other efforts provides an increasingly clear assessment of sediment conditions throughout the Sound. A few municipal and industrial dischargers, stormwater utilities, and environmental programs, such as Superfund, collect sediment data in nearshore areas to evaluate the effect of contaminant sources on nearby sediment quality. The collective data acquired by these efforts indicate that extensive portions of the shoreline in urban embayments, and several isolated areas of shoreline throughout the rest of Puget Sound, exceed sediment quality standards for metal and/or organic contaminants (Figure 3).



Reference: SEDQUAL database

Figure 3. Organic and metal contamination of sediments in nearshore areas and urban bays monitored by programs other than the PSAMP.

The PSAMP complements the information provided by these nearshore efforts by collecting data in ambient areas removed from sources of contamination and not typically sampled by other programs. This provides an expanded view of sediment quality throughout the Sound, and supplies information on whether contamination in nearshore areas has dispersed to affect broader areas of the Sound. Available PSAMP data suggest that the widespread contamination in urban nearshore areas does not disperse in high concentrations beyond the nearshore environment (PSWQA, 1992). In

general, the five years of sampling indicate that contaminant concentrations at most PSAMP sites are well below sediment quality standards, and often near analytical detection limits. The few PSAMP sites with contaminant levels above standards (Table 2) are generally in urban bays, many of which contain Superfund sites (see page 22 for a description of Superfund sites in Puget Sound). This suggests that chemical contaminants discharged into the Sound settle out and accumulate near their sources. This accumulation tends to result in toxic hot spots of pollution that do not disperse readily, and can only be removed or covered up by uncontaminated sediments (through natural processes or by "capping" with clean sediments).

While most chemical contaminants introduced into the Sound remain close to their sources, there is evidence that low levels of some contaminants disperse to sites removed from their sources. For example, PCBs—human-made contaminants not found in nature—have been found in the water (Romberg et al., 1984) and sediments (Romberg et al., 1984; Macdonald and Crecelius, 1994) of the Puget Sound central basin. Since the areas sampled in these studies are some distance from likely contaminant sources, these results suggest that transport of low levels of contaminants does occur. In addition, some contaminants bind poorly to sediments, so that larger proportions of these toxic chemicals remain dissolved in the water column. These contaminants, including arsenic, cadmium, LPAHs (low molecular weight PAHs) and some volatile organochlorines, do not rapidly or completely settle out with sediments and tend to disperse farther (Macdonald and Crecelius, 1994).

The PSAMP has not yet evaluated statistical trends over time in the data on sediment chemistry. The five years of sampling provide important baseline information, but do not establish a data record of sufficient length to assess statistical trends. Longer data records are generally required to assess trends (Shelly, 1994).

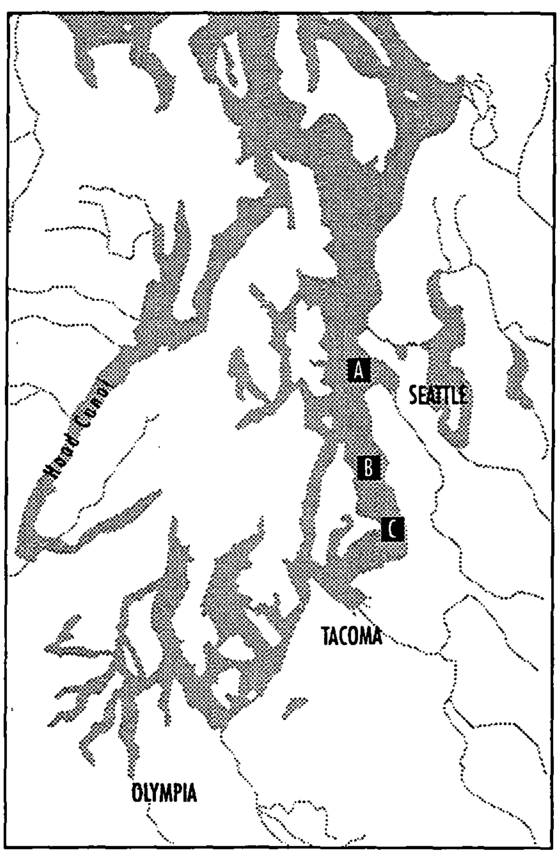


Figure 4. Sediment-core stations sampled for long-term patterns in contaminant concentrations.

Reference: Lefkovitz et al., in prep.

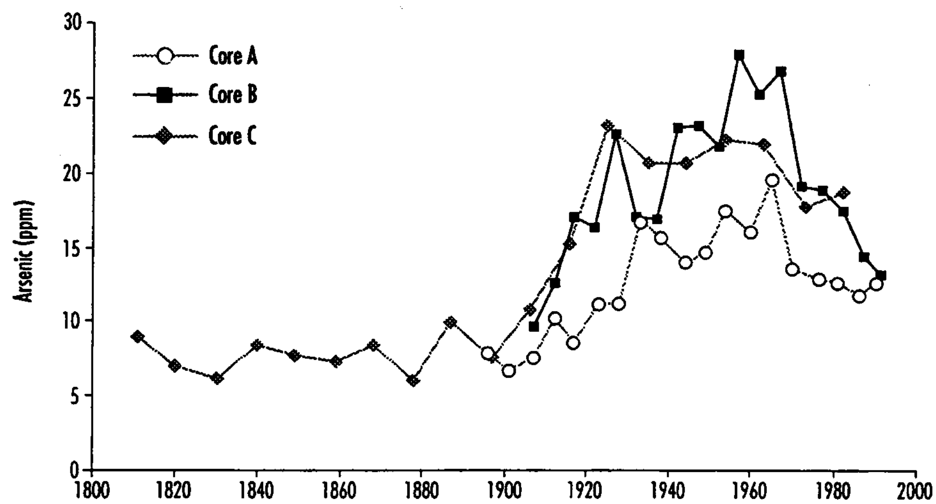
Other Studies on Chemical Contamination of Sediments

Sources of information other than the PSAMP can help evaluate trends in sediment contaminants. Sediment chemists evaluate present and historical sediment contamination by taking samples of the sediment core. Chemists then analyze different sediment

layers for contaminant concentrations. By aging the different layers of sediment analyzed within the core, sediment chemists determine when each layer was deposited and, coupled with the results of the chemical analyses, how sediment contamination varied over time.

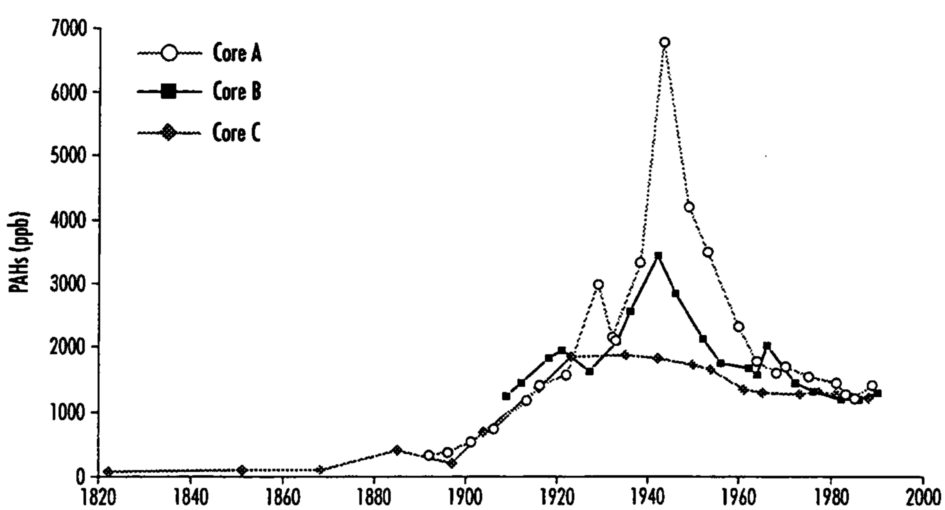
Sediment-Core Studies

Researchers recently reviewed studies of sediment-core data collected in Puget Sound (Macdonald and Crecelius, 1994) (Figure 4). Although the concentrations of different contaminants over time varied widely, several patterns were evident. Many contaminants increased steadily from 1850 until the early 1970s, at which point concentrations began to decrease. This pattern was evident in contaminants such as lead, arsenic, PCBs and DDT (an insecticide widely used until it was banned in the 1970s) (Figure 5). Numerous environmental controls, product bans and industry closures around 1970 may underlie these patterns. These included decreasing the use of leaded gasoline (lead), decreasing production at and eventually closing the ASARCO plant (arsenic), phasing out and eventually banning PCB use, and banning DDT. Other contaminants showed variations on this pattern. PAHs appeared to peak between 1945 and 1960, after which they gradually decreased (Figure 6). This is probably due to patterns in coal burning,



Reference: Macdonald and Crecelius, 1994; Lefkovitz et al., in prep.

Figure 5. Arsenic in Puget Sound sediments.



Reference: Macdonald and Crecelius, 1994; Lefkovitz et al., in prep.

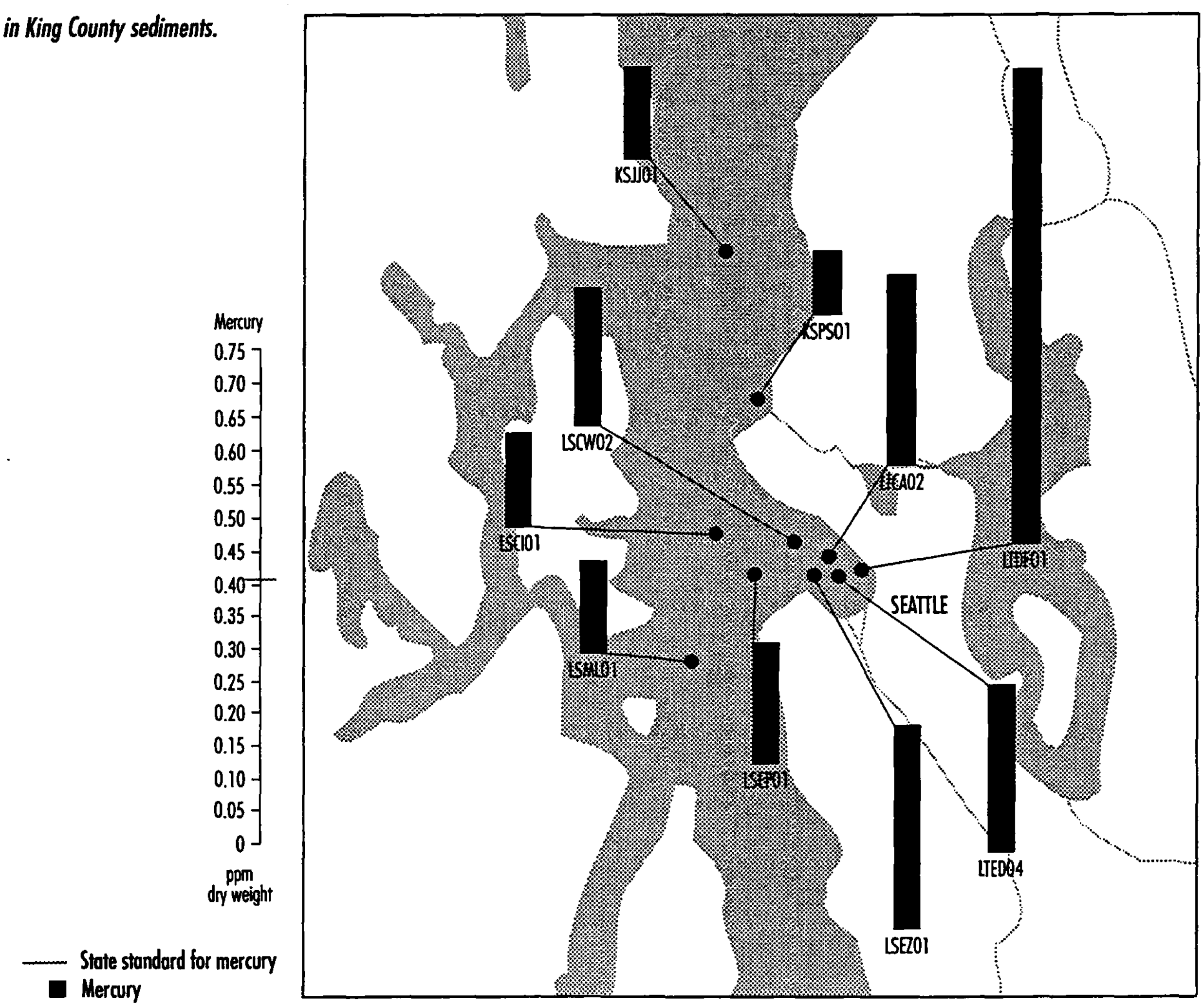
Figure 6. Total PAHs in Puget Sound sediments.

which produces high levels of PAHs (Macdonald and Crecelius, 1994). Coal burning increased until about 1950, after which it was gradually replaced by other fuels. Mercury also reached a peak in 1950, and appears to have decreased since then. Other contaminants, such as copper and tin, did not show signs of decreasing.

King County sediment monitoring

The King County Department of Metropolitan Services (Metro) monitors marine waters throughout King County to assess baseline conditions and the effects of sewage treatment plant discharges on marine water and sediment quality. Metro sampled sediments at 10 ambient stations in 1993 for chemical contaminants and analyzed them for approximately 130 toxicants listed as Environmental Protection Agency (EPA) priority pollutants. The findings in 1993, as in past years, indicate that a majority of the pollutants occur below detection limits at these ambient sites (Metro, 1994). Metro typically detected metals, which occur naturally in sediments, and PAHs, which are associated with a wide range of oil, gas and other hydrocarbons and their combustion products. Most of the chemicals were at low concentrations below sediment quality standards, with the exception of mercury at one site (Figure 7) and select HPAH compounds (Metro, 1994).

Figure 7. Mercury in King County sediments.



Reference: Metro, 1994

Puget Sound Dredged Disposal Analysis Program monitoring

The Puget Sound Dredged Disposal Analysis Program (PSDDA) provides a cooperative interagency framework for managing the disposal of clean or mildly contaminated sediments that have been dredged to develop and maintain navigation and commerce activities. The PSDDA program identified eight acceptable open-water disposal sites. Participating state and federal agencies developed evaluation procedures to characterize the suitability of sediments for disposal at these sites. A key goal of the PSDDA process is to provide objective standards for management of the disposal sites.

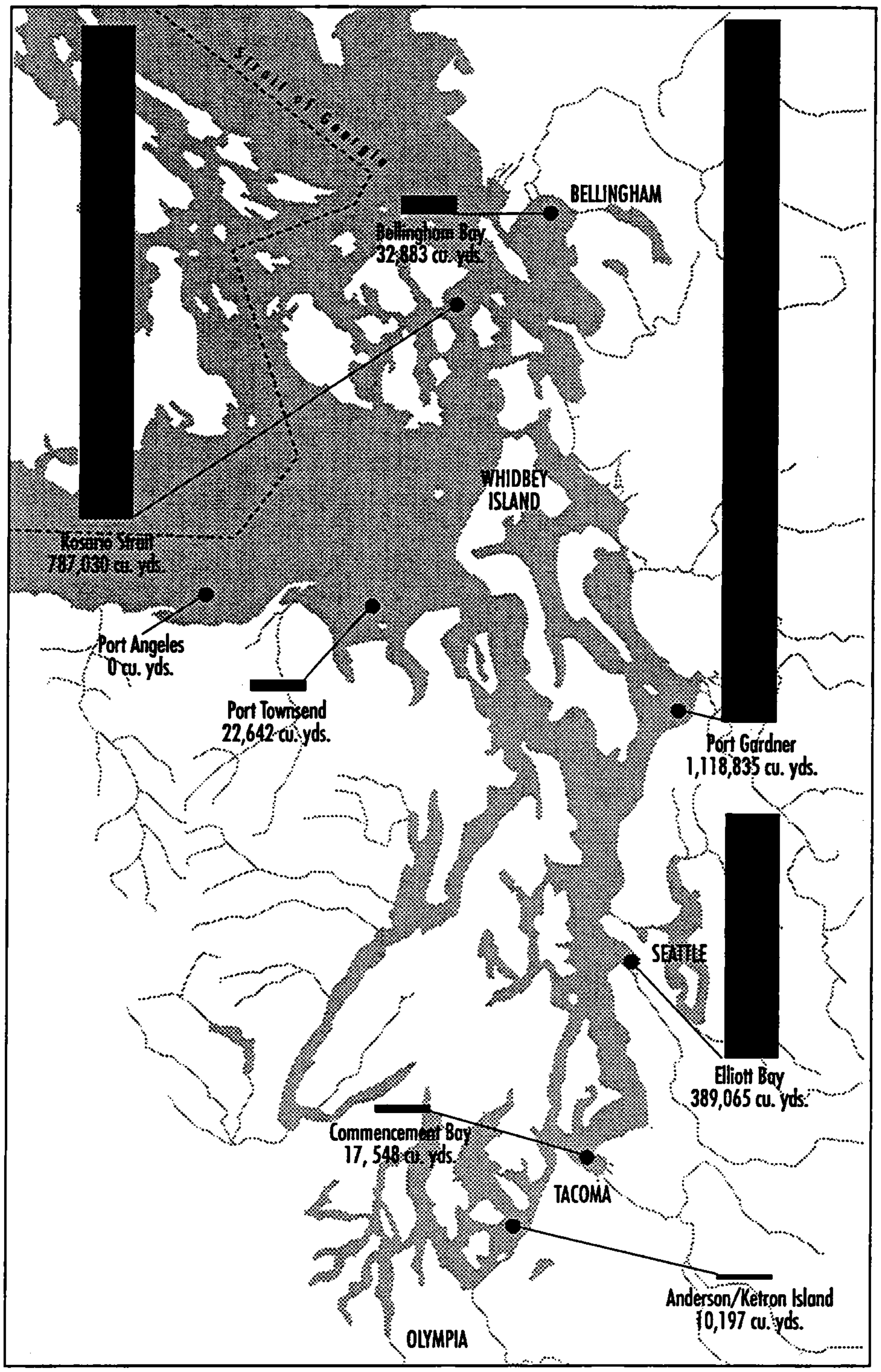


Figure 8. Cumulative disposal volumes (dredging years 1989 - 1993).

Reference: PSDDA, 1994

The PSDDA disposal sites are in Port Gardner, Rosario Strait, Elliott Bay, Bellingham Bay, Port Townsend, Commencement Bay, Anderson/Ketron islands, and Port Angeles (Figure 8). Of the eight sites, Port Angeles is the only site that has not been used yet. Most disposal activity has occurred at three sites: Port Gardner (1,118,835 cu. yd.), Rosario Strait (787,030 cu. yd.) and Elliott Bay (389,065 cu. yd.).

The PSDDA agencies have conducted post-disposal monitoring at five of the sites. The most recently monitored sites were Elliott Bay in 1992, Bellingham Bay in 1993 and Port Gardner in 1994. A sixth monitoring survey is scheduled for Commencement Bay in 1995. Due to infrequent use of the Anderson/Ketron islands site, the PSDDA agencies do not plan to monitor this location in the near future. Site monitoring includes physically mapping disposed material; characterizing on- and off-site sediment chemistry, sediment toxicity and off-site infaunal bioaccumulation; and analyzing off-site benthic community structure.

The results of the 1993 monitoring at Elliott Bay and Bellingham Bay indicate that dredged disposal material is staying on-site and is not adversely affecting non-dispersive sites or adjacent areas (PSDDA, 1994). Chemical data collected along the perimeter of the Elliott Bay site, however, indicate some elevation of metal concentrations relative to baseline (pre-disposal) data. Further investigation of metal concentrations at benchmark stations (in Elliott Bay, but away from the potential influence of dredged material that has been disposed) revealed levels similar to those observed at the site perimeter. For example, copper levels were 79 ppm (parts per million) at the site perimeter and 91 ppm at the benchmark station. Similarly, lead levels were 62 ppm at the site perimeter and 80 ppm at the benchmark station. The levels at the benchmark site are higher than those recorded in 1988, and a similar pattern was observed for other metals. This suggests that sediment quality for metals outside of the disposal zone varies greatly throughout Elliott Bay, and is not related to PSDDA disposal activity.

At the PSDDA disposal site in Elliott Bay, on-site sediment quality was measured at the primary station within the disposal zone (station EBZ01) in 1988, 1990 and 1992. Apparent decreases in comparative levels of metals and organic compounds at the disposal site since 1988 suggest that continued disposal of relatively clean dredged material may be improving sediment quality as the site is used (PSDDA, 1994).

The Bellingham Bay PSDDA disposal site was partially monitored in 1993. Concentrations of organic chemicals of concern at stations along the site's perimeter were either much lower or comparable in 1993 relative to the 1989 baseline (pre-dredged disposal) survey. For example, the concentration of phenol at a perimeter station (BBP04) was 680 µg/kg in 1993 compared to 4,800 µg/kg in 1989. Four organic compounds, however, exceeded trigger values (PSDDA screening levels that trigger further investigation; equal to 1.47 times the baseline concentration) for perimeter stations, but these values still did not exceed state levels for sediment quality. A similar pattern was observed for metals. Relative to 1989, some analytes, such as mercury, were measured at lower concentrations in 1993, while others, such as arsenic, were slightly elevated.

Superfund Program

The EPA's Superfund program identifies, monitors and restores some of Puget Sound's most contaminated areas. The U.S. Congress created the Superfund program in 1980 through passage of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). Under the Superfund Program, the EPA evaluates contamination at prospective sites, and takes long-term cleanup actions to stop or substantially reduce releases of hazardous substances.

Several Superfund sites may directly affect Puget Sound water or sediments, or actually include contaminated Puget Sound sediments (Figure 9).

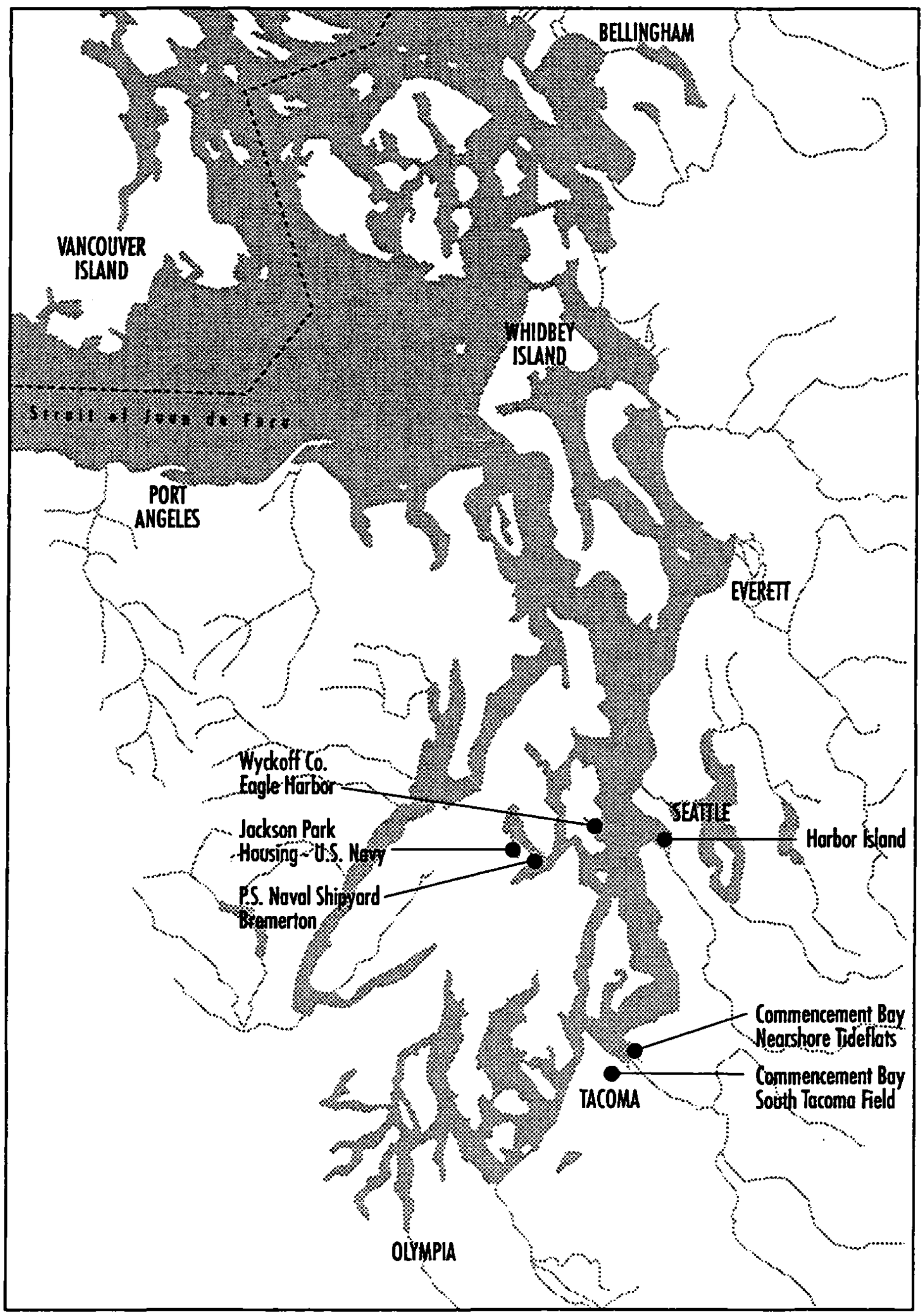


Figure 9. Superfund sites within Puget Sound.

Reference: EPA, 1993a; 1993b

The following Superfund sites occur within Puget Sound:

Commencement Bay
- Commencement Bay Nearshore Tide Flats
- Commencement Bay South Tacoma Channel

Elliott Bay
- Harbor Island

Eagle Harbor
- Wyckoff Company–Eagle Harbor

Sinclair Inlet
- Puget Sound Naval Shipyard

Dyes Inlet
- Jackson Park Housing (U.S. Navy)

The Superfund program does not include sites contaminated by petroleum products. Contamination by petroleum products is addressed by Washington's Model Toxics Control Act, which lists additional contaminated sites within Puget Sound. These sites will be described in a future *Puget Sound Update*.

Puget Sound Superfund site descriptions (source: EPA, 1993a; 1993b)

Commencement Bay

• Commencement Bay contains five waterways with extensive industrial activities. For nearly 100 years, various industries (including metal smelting, chemical and wood products manufacturing, shipbuilding, shipping, oil refining, and food processing) released hazardous substances and waste materials into the soil, ground water and marine environment. Several studies have revealed a variety of contaminants in the sediments, water, fish and shellfish of Commencement Bay's waterways and shorelines (EPA, 1993). The pollutants of most concern to humans and marine life are toxic metals, PCBs, PAHs (polycyclic aromatic hydrocarbons, by-products from combusted and uncombusted fossil fuels), and a variety of chemicals used to make plastics. In many cases, pollution sources could be readily identified, increasing the chance they could be controlled or reduced.

• Ecology's Urban Bay Action Team is directing activities to control pollution sources in Commencement Bay, and has confirmed 64 ongoing sources of problem chemicals that drain to the Thea Foss, Wheeler-Osgood, Middle, Sitcum and Hylebos waterways.

> *Hylebos Waterway:* At the mouth of the Hylebos, the major problem chemicals found in sediments are chlorinated organic compounds, including PCBs. A broad range of sources contribute to contamination in sediments at the head of the Hylebos including chemical companies, log sorting yards, landfills in the vicinity of Hylebos Creek, and storm drains. Three chemicals were selected as indicators of contamination: arsenic, PAHs and PCBs. Chemical concentrations in approximately 381,000 cubic yards of sediment in this problem area do not meet cleanup goals.
>
> *Thea Foss Waterway:* Contamination in the sediments at the head of the Thea Foss Waterway is attributed to storm drains, maritime industries and electroplating facilities. PAHs, cadmium, lead and mercury were selected as chemicals most likely to result in adverse biological effects.

Approximately 575,000 cubic yards of sediments in this problem area were initially identified as needing cleanup. At the mouth of the Thea Foss Waterway, contamination in sediments is attributed to petroleum storage facilities and unknown sources.

Sitcum Waterway: Pollution from ore unloading facilities and storm drains are responsible for sediment contamination in the Sitcum Waterway. Copper and arsenic were chosen as chemicals with adverse biological effects.

- In the Commencement Bay South Tacoma Channel area, the source of contaminants appears to be stormwater runoff from the city of Tacoma storm sewers. At the Tacoma Landfill, the city of Tacoma operates a groundwater extraction system that has removed and treated more than 645 million gallons of water since December 1992. The extraction system also captures vinyl chloride contaminants at this site.

Eagle Harbor: Wyckoff Company

- The Wyckoff facility, which operated between 1903 and 1988, was a wood treatment facility located at the mouth of Eagle Harbor that used a creosote pressure-treatment process. Creosote is made up of PAHs such as naphthalene and benzo(a)pyrene. These operations contaminated the site with PAHs. Contamination is present in sediments, on beaches and in the soil. To date, the EPA has removed approximately 20,000 tons of contaminated material from the site.

- Bottom sediments in other parts of Eagle Harbor are also contaminated with chemicals from wood treatment and shipyard operations, including PAHs and mercury. PAHs are predominant in east harbor sediments, while mercury is the contaminant of primary concern in the west harbor. The U.S. Army Corps of Engineers, under supervision of the EPA, has capped (placed clean sandy materials on top of) the central harbor hot spot and other heavily contaminated sediments in the east harbor. For the west harbor site, the EPA is negotiating an agreement for focused sampling, and design and planning of the cleanup.

Elliott Bay: Harbor Island

- Petroleum products and tributyltin are the primary contaminants of concern at Harbor Island. The federal Superfund statute does not address petroleum, but it is included under Washington's Model Toxics Control Act. For this reason, the EPA placed Ecology in charge of cleaning up contamination associated with the three petroleum tank farms on Harbor Island.

Sinclair Inlet: Puget Sound Naval Shipyard and Jackson Park Housing sites

- Site investigation studies are under way at these newly listed sites. In addition, the Puget Sound Naval Shipyard has collected data that is being evaluated to determine contamination levels and possible remedies.

Collectively, the ongoing and planned cleanup activities conducted under the Superfund program will address highly contaminated sediment hot spots presently identified in Puget Sound's urban bays.

Additional Superfund sites within the Puget Sound basin (final and proposed)

The following sites are within the Puget Sound basin and may directly affect marine water and the quality of waters draining into Puget Sound, as well as the health of populations (e.g., salmon, birds) within the Puget Sound basin.

Whatcom County

Northwest Transformer - Everson
Northwest Transformer (S. Harkness) - Everson
Snohomish County
Tulalip Landfill

King County

Pacific Car & Foundry Co. - Renton
Pacific Sound Resources - Seattle
Queen City Farms - Maple Valley
Seattle Municipal Landfill (Kent Highlands) - Kent
Western Processing Co., Inc. - Kent
Midway Landfill - Kent

Island County

Naval Air Station (Ault) - Whidbey Island*
Naval Air Station (Seaplane) - Whidbey Island*

Kitsap County

Bangor Naval Submarine Base - Silverdale*
Bangor Ordnance Disposal - Bremerton*
Naval Undersea Warfare Station (four areas) - Keyport*
Port Hadlock Detachment (USN) - Kitsap*

Pierce County

American Lake Gardens - Tacoma*
Fort Lewis Landfill No. 5 - Tacoma*
Fort Lewis Logistics Center - Tillicum*
Hidden Valley Landfill - Pierce County
Lakewood Site - Lakewood
McChord AFB Wash Rack - Tacoma*

**Denotes a federal facility*

Chemical Contamination of Fish

The Puget Sound Ambient Monitoring Program measures tissue contaminant levels in fish to evaluate the accumulation of contaminants in the marine food web (PSWQA, 1988). Monitoring tissue contaminants also helps determine the threat to human health from eating fish. The Washington Department of Fish and Wildlife (WDFW) monitors contaminants in six species with differing habitats and diets to assess contamination in fish: English sole (*Pleuronectes vetulus*), copper rockfish (*Sebastes caurinus*), quillback rockfish (*S. maliger*), chinook salmon (*Oncorhynchus tshwawytscha*),

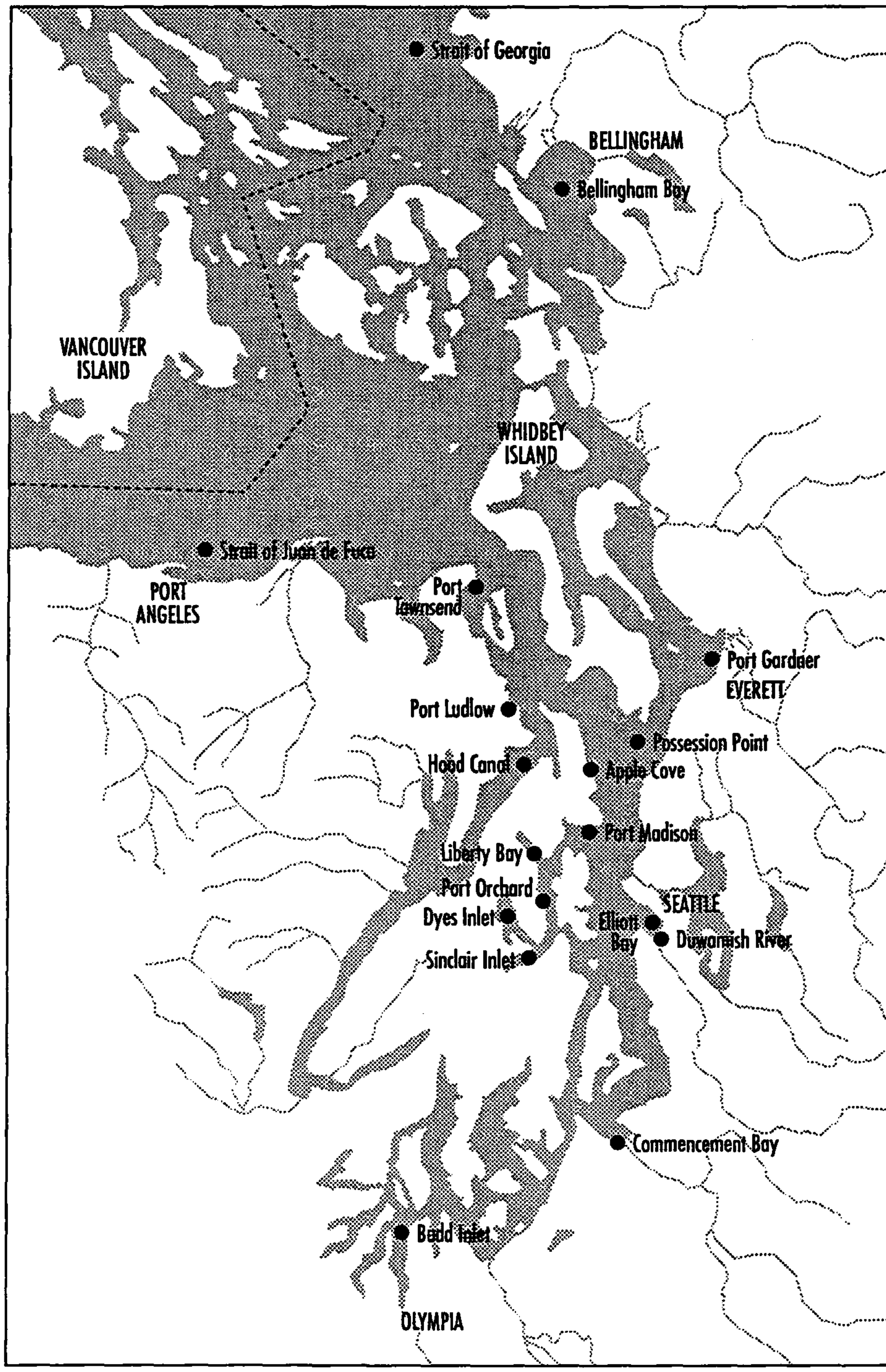


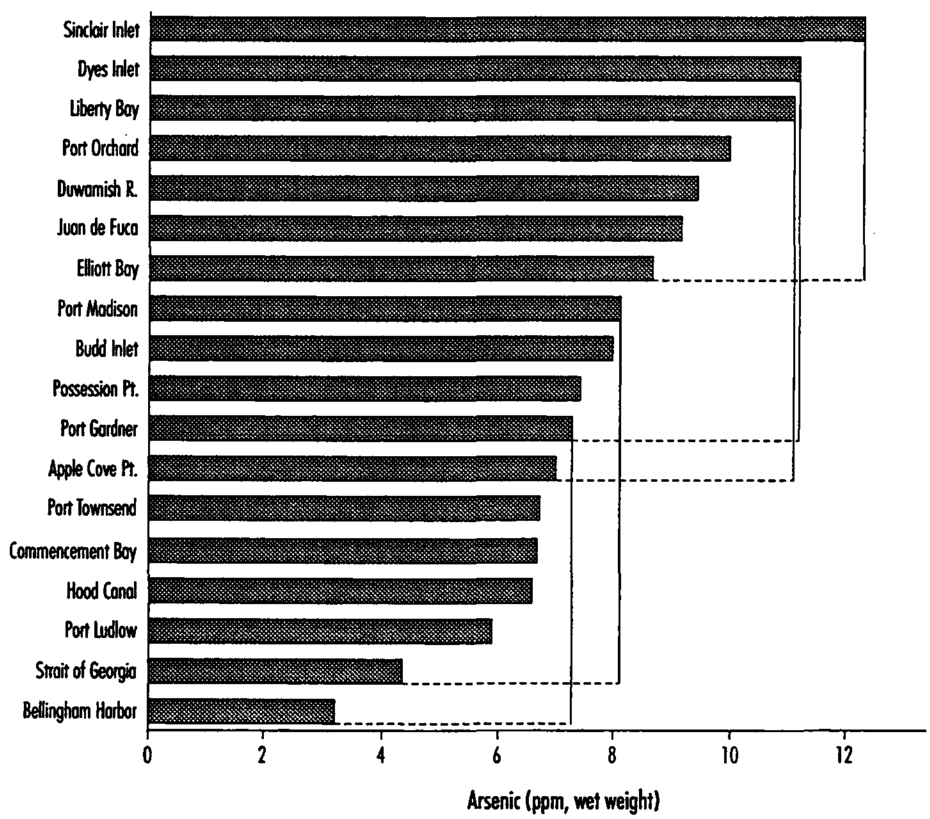
Figure 10. 1992 PSAMP English sole monitoring sites.

Reference: WDFW, in prep. a

coho salmon (*O. kisutch*) and Pacific cod (*Gadus macrocephalus*).

English Sole

The WDFW sampled 18 sites throughout Puget Sound in 1992 (the most recent data that have undergone quality assurance review and interpretation) (Figure 10). Analyses of the 1992 tissue contaminant data indicate that statistically significant differences exist in the levels of all metals in liver and muscle tissue at the different sites sampled (WDFW, in prep. a). However, patterns of contamination were complex, and did not always reflect the degree of urbanization. For example, arsenic, copper and mercury concentrations were significantly higher in muscle tissue of fish from Sinclair Inlet, which is an urban embayment, than in tissue from the Strait of Georgia, which is removed from urban areas. However, arsenic concentrations found in fish from other urban embayments, such as Bellingham Harbor and Commencement Bay, were significantly lower than in tissue from the Strait of Juan de Fuca (Figure 11).

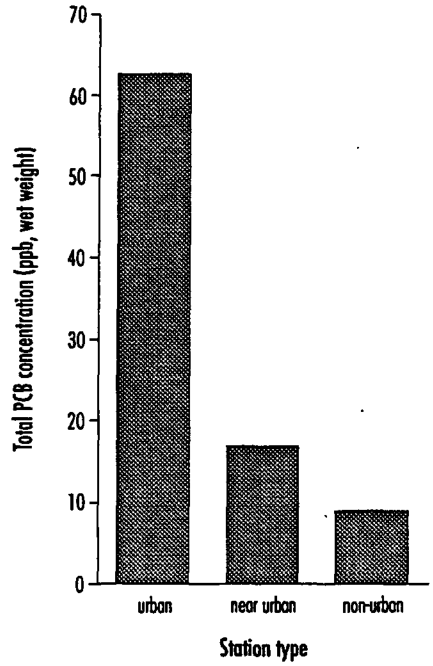


Reference: WDFW, in prep. a

Figure 11. Arsenic in English sole muscle tissue, 1992. (Mean arsenic concentrations at sites connected by lines are not significantly different.)

The concentration of metals in muscle and liver tissue of fish generally did not seem to correlate with concentrations of metals found in sediments. A relationship between concentrations of tissue contaminants and sediment contaminants at a particular site might be expected in bottomfish and fish that feed on benthic organisms. Metabolic activities within fish may remove contaminants in areas with high levels of sediment contaminants, which may explain the absence of a significant relationship. Fish are known to regulate levels of copper, lead and other metals (Phillips and Rainbow,

Figure 12. Average PCB levels in muscle tissue from English sole of similar age (mean age = 5.1 - 8.3 years). Average concentrations at urban sites are significantly different than averages at near- and non-urban sites.



Urban Sites	Near-Urban Sites	Non-Urban Sites
Elliott Bay	Possession Point	Hood Canal
Commencement Bay	Port Gardner	Port Ludlow
Sinclair Inlet	Port Orchard	Apple Cove Point
Duwamish River		Port Madison
Dyes Inlet		

Reference: WDFW, in prep. a

1989), and only accumulate these metals in the musculature when contaminant levels are very high (Prosi and Lierde, 1979). The WDFW is investigating the hypothesis that concentrations of metals in sediments at Sinclair and Dyes inlets may exceed the ability of English sole to regulate them. The highest concentrations of metals in sediments and English sole muscle tissue tend to occur in Sinclair and Dyes inlets. Analyses suggest significant correlations between sediment and muscle tissue concentrations at these sites (WDFW, in prep. a).

In contrast to patterns observed with metals, concentrations of organic contaminants appeared to correlate with the degree of urbanization. PCBs were detected in muscle tissue at all sites sampled in 1992 except Bellingham Bay, Hood Canal and the Strait of Georgia. Concentrations in the muscle tissue of English sole were significantly higher in urban areas, such as Sinclair Inlet, Commencement Bay, Elliott Bay and the mouth of the Duwamish River, than in non-urban areas, such as Hood Canal and the straits of Georgia and Juan de Fuca (WDFW, in prep. a). After grouping sites with similar-aged fish (since age can affect contaminant concentrations) into urban, near-urban and non-urban categories, the WDFW found significantly higher PCB concentrations in tissue from the urban group than in tissue from the near- or non-urban groups (Figure 12) (WDFW, in prep. a; b). DDE and DDD (breakdown products of the pesticide DDT) were detected at only a few sites so that it was not possible to correlate concentrations with the degree of urbanization. However, the sites with detectable levels of these products were all urban sites—Commencement Bay, Elliott Bay and the mouth of the Duwamish River.

The WDFW found that a few contaminants—notably mercury and PCBs—varied significantly with the age of fish. Older fish tended to have higher levels of mercury and PCBs in their tissues. In addition, most contaminant concentrations were much higher in liver tissue than in muscle tissue. Cop-

per concentrations in the liver were eight to 72 times higher than in muscle tissue, lead levels were 18 to 54 times higher, and total PCB concentrations were six to 49 times higher. Overall, copper levels averaged over an order of magnitude higher in the liver than in the muscle tissue, while mercury was 1.2 to 2.8 times higher. Only arsenic concentrations were comparable between liver and muscle tissue, with liver concentrations at each station ranging from 0.42 to 2.4 times the concentration in muscle tissue (Table 3).

Because the vertebrate liver removes and detoxifies contaminants in the body, higher contaminant concentrations are expected in this organ. Since human health assessments are based on contaminants in muscle tissue,

Table 3. Trace metals in English sole muscle and liver tissue.

Muscle Tissue

Contaminant	Detection Frequency*	Range** ppm, wet weight	Liver/Muscle Concentration	Muscle Tissue/ Sediment Concentration	Spatial Variability
Arsenic	18/18	3.23 - 12.3	0.42 - 2.4 times; not significantly correlated.	Not significantly correlated with sediment concentrations.	Varied significantly among stations.
Copper	18/18	0.20 - 0.34	8 - 72 times; not significantly correlated.	Significant correlation with sediment concentrations.	Varied significantly among stations. Concentrations at Sinclair and Dyes inlets significantly higher than at Strait of Georgia.
Lead	3/18	0.033 - 0.040	18 - 54 times; correlation not applicable due to infrequent detection.	Not applicable due to infrequent detection.	Not applicable due to infrequent detection.
Mercury	18/18	0.03 - 0.07	1.2 - 2.8 times; significantly correlated.	Significant correlation with sediment concentrations.	Varied significantly among stations.

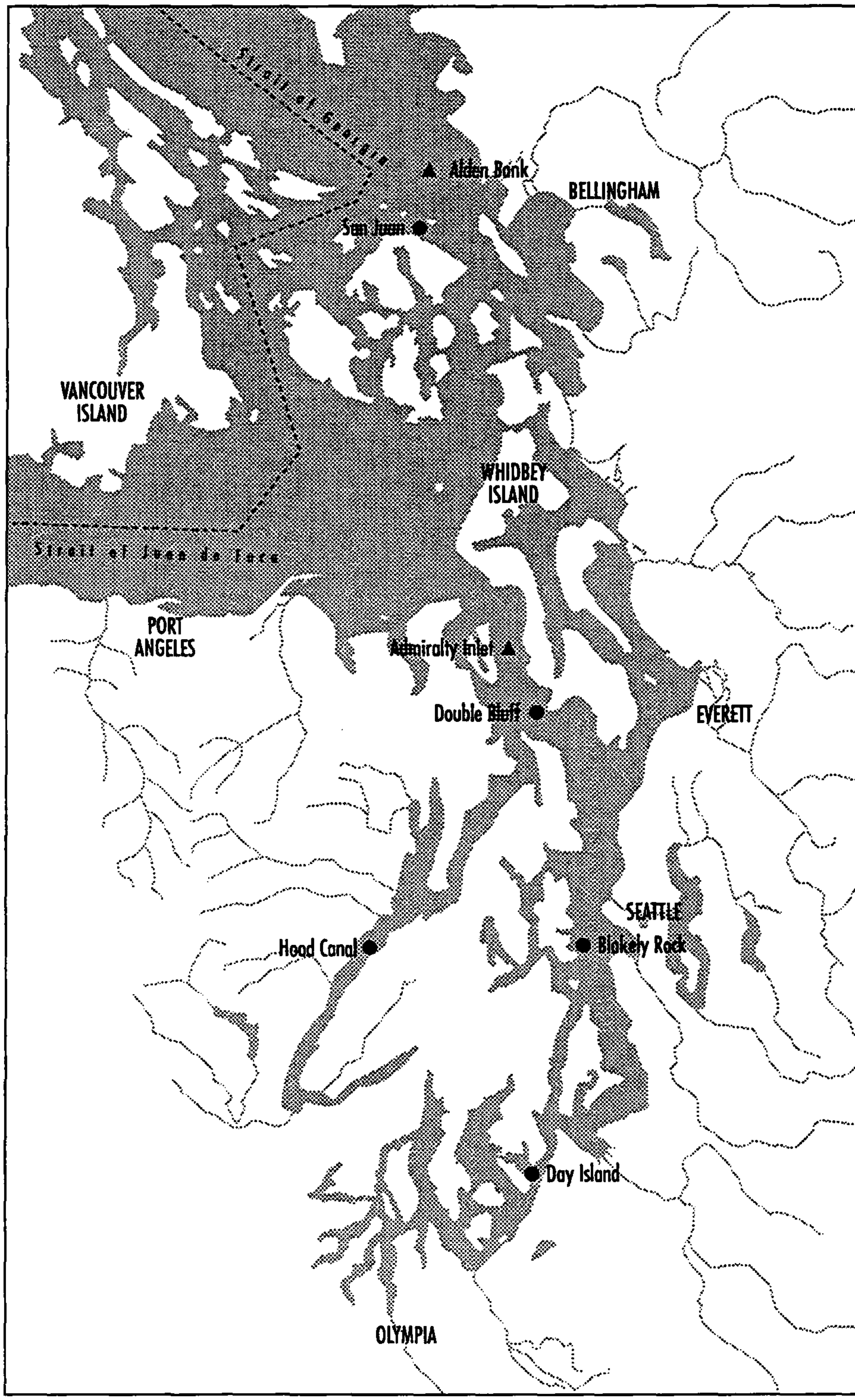
Liver Tissue

Contaminant	Detection Frequency*	Range** ppm, wet weight	Muscle Tissue/ Sediment Concentration	Spatial Variability
Arsenic	18/18	2.3 - 20.7	Not significantly correlated with sediment concentrations.	Varied significantly among stations.
Copper	18/18	2.83 - 11.0	Not significantly correlated with sediment concentrations.	Varied significantly among stations.
Lead	14/18	0.10 - 2.0	Not significantly correlated with sediment concentrations.	Varied significantly among stations. Concentrations at Sinclair Inlet were significantly higher than at Dyes Inlet or Liberty Bay.
Mercury	18/18	0.041 - 0.157	Significantly correlated.	Varied significantly among stations.

** Number of stations at which the contaminant was detected.*
*** Mean station value*

which people consume more frequently than liver tissue, contaminant levels in English sole are generally below levels associated with adverse effects to human health (Kalman et al., 1994). However, concentrations are sufficiently high to adversely affect the health of English sole, as documented by higher levels of liver disease in fish from urban areas than in fish from rural areas (McCain et al, 1988; PTI, 1991; WDFW, in prep. b).

Figure 13. 1993 PSAMP rockfish and Pacific cod monitoring sites.



▲ Pacific cod sampling sites
● Rockfish sampling sites

Reference: WDFW, in prep. a

The WDFW also monitored tissue chemistry in English sole in 1989 and 1991. The range of concentrations for most tissue contaminants appear similar among the three years. In general, the WDFW found little evidence that concentrations of tissue contaminants increased or decreased over that time.

Rockfish

The WDFW collected copper and quillback rockfish at five sites throughout Puget Sound in October 1992 (Figure 13). Insufficient sample sizes prevented the WDFW from conducting statistical analyses on copper rockfish at Day Island and Hood Canal. The WDFW thus compared results from quillback rockfish at San Juan Island, Double Bluff and Blakely Rock.

The average and range of metal concentrations in rockfish tissue corresponded with findings from previous years at all sites (including Day Island and Hood Canal) (Table 4). As in 1989 and 1991, the WDFW did not detect lead at any of the sites. Copper was generally present at low levels, and no significant differences existed in concentrations among the three sites that the WDFW compared statistically. In contrast, arsenic concentrations varied significantly among the three sites, with significantly higher concentrations at Double Bluff and Blakely Rock than at San Juan Island. In 1992, mercury concentrations did not differ significantly among the three stations sampled. Mercury varied significantly with fish age, as concentrations tended to be higher in older fish. Mercury concentrations were above 0.40 ppm in several individual composites at the three stations, approaching the EPA's screening level of 0.6 ppm (WDFW, in prep. a).

Table 4. Trace metals in rockfish muscle tissue.

Station	Species	Lead ppm, wet wt.	Copper ppm, wet weight		Arsenic ppm, wet weight		Mercury ppm, wet weight	
		Mean	Mean	Range	Mean	Range	Mean	Range
San Juan Island	Quillback Rockfish	Not detected	0.267	0.20 - 0.32	1.68	1.0 - 2.1	0.243	0.10 - 0.51
Double Bluff	Quillback Rockfish	Not detected	0.248	0.21 - 0.30	2.35	2.0 - 2.8	0.257	0.17 - 0.41
Blakely Rock	Quillback Rockfish	Not detected	0.303	0.21 - 0.43	2.02	1.7 - 2.4	0.285	0.16 - 0.47
Hood Canal	Quillback Rockfish	Not detected	0.280	0.20 - 0.32	4.50	3.1 - 5.9	0.230	0.21 - 0.25
Hood Canal	Copper Rockfish	Not detected	0.200	0.20 - 0.20	4.80	4.8 - 4.8	0.170	0.17 - 0.13

Among organic contaminants, PCB 1260 was the most frequently detected compound. PCB levels did not differ significantly among the three sites sampled. Concentrations of PCB 1260 also correlated positively with fish age, suggesting that this contaminant may accumulate with age. PP-DDE (a breakdown product of the pesticide DDT) and Dieldrin (a pesticide) were the only other organic compounds detected, although detection was infrequent and generally at low levels.

Pacific Cod

WDFW sampling of Pacific cod at two stations in 1993 (Figure 13) revealed findings similar to previous years. Lead was detected in only one of the six samples at Admiralty Inlet, and was at low levels close to the chemical detection limit. The WDFW found copper and mercury in all 1993 samples, with no significant differences in concentrations between the two sites. Arsenic was also detected in all samples, with concentrations at Admiralty Inlet significantly higher than concentrations at Alden Bank.

Organic contaminants were detected infrequently in Pacific cod, and were invariably at low levels close to analytical detection limits. PCB 1260 was detected in two of the six samples at Admiralty Inlet, while diethyl phthalate (a plasticizer) was detected in only one of six samples at Admiralty Inlet. Butyl benzyl phthalate was detected in one sample from Alden Bank and in two samples at Admiralty Inlet.

Other Sources of Information on Chemical Contamination of Fish

Larval Surf Smelt

The Environmental Conservation Division (ECD) of the National Marine Fisheries Service recently evaluated the effects of contaminated sediments on the health of larval surf smelt (*Hypomesus pretiosus*) (Misitano et al., 1994). The ECD exposed larval smelt to sediments from three urban bays—Eagle Harbor, Elliott Bay and Commencement Bay—and to control (comparatively uncontaminated) sediments from East Passage near Vashon Island. The ECD researchers also mixed urban sediments with varying concentrations of control sediments to look at effects from a range of contaminant concentrations.

Many researchers believe that marine organisms—particularly organisms which do not live within or upon the sediments—may not uptake (absorb) contaminants bound to sediments. To investigate this, the ECD exposed larvae to sediments with radioactively-labeled contaminants, and found that the free-swimming larval surf smelt incorporated contaminants contained within sediments after only a few days of exposure.

In exposing smelt to sediments from urban bays, the ECD found that contaminant levels in the three urban bays caused adverse biological effects. Surf smelt exposed to sediments from the urban bays had significantly lower survival rates than smelt exposed to control sediments. Even when the Elliott Bay sediments were diluted 90 percent by mixing with control sediments, smelt exposed to the sediments had significantly lower survival rates. Smelt exposed to Eagle Harbor sediments had lower survival rates when exposed to sediments diluted 99 percent.

The results from these experiments provide further confirmation that sublethal effects, such as lowered DNA and protein content (which are more precise measures of growth than length for small-bodied organisms), are more sensitive indicators of exposure to contaminated sediments than mortality rates. Survival rates of smelt exposed to sediments from Commencement Bay were not significantly lower than of smelt exposed to control sediments. However, exposure to a concentration as low as 10 percent of Com-

mencement Bay sediments significantly lowered DNA content when compared to control sediments. Similarly, low concentrations of Eagle Harbor and Elliott Bay sediments resulted in reduced larval DNA content.

These findings show that contaminant levels in the sediments of Puget Sound's urban bays are sufficient to produce adverse biological effects. Perhaps more importantly, the results contribute to a growing body of literature that suggests these effects are not limited to organisms that live or feed within sediments, but may also affect a broader portion of Puget Sound's marine life that lives and feeds within the water column.

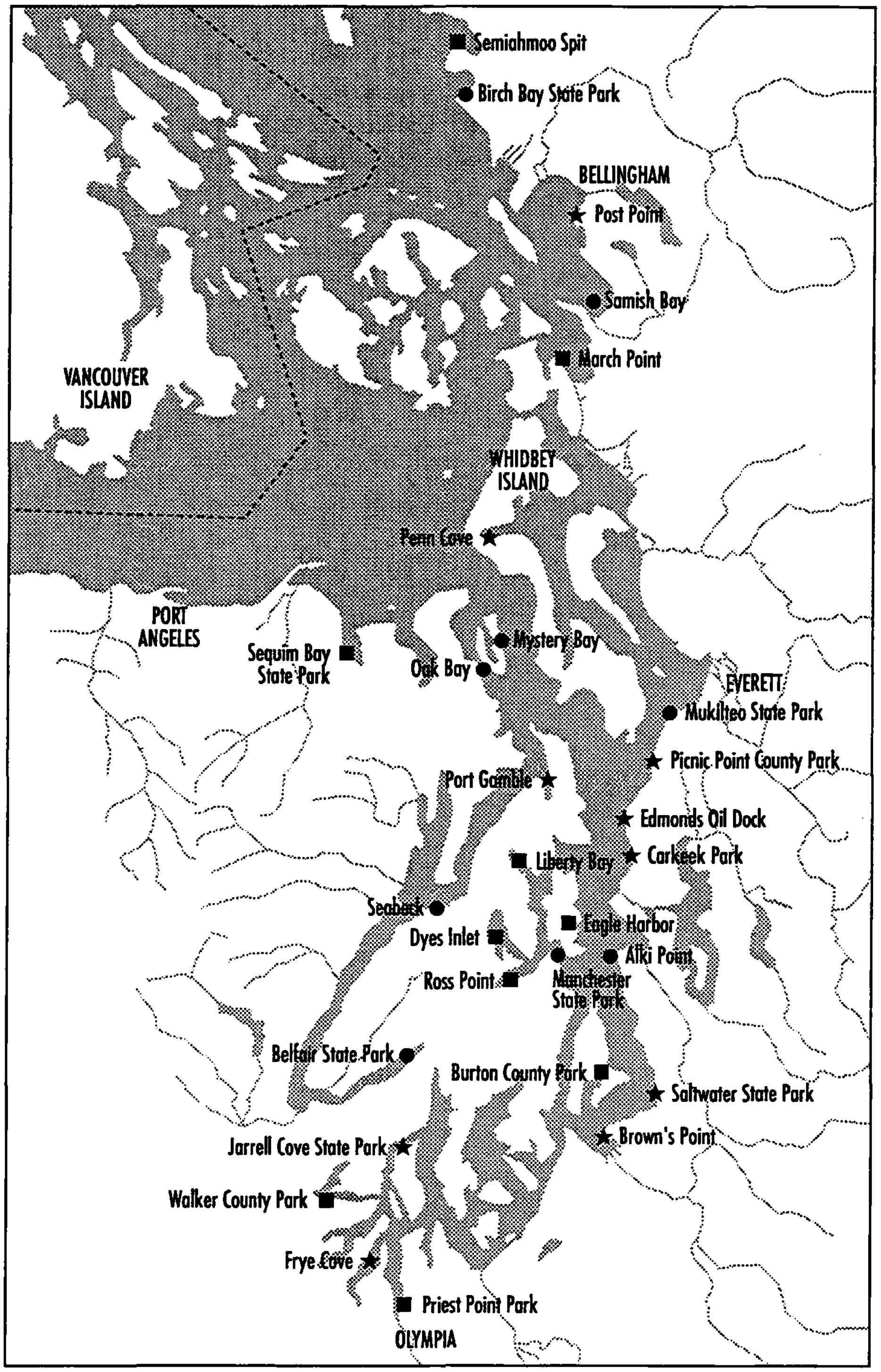


Figure 14. 1992 - 1993 PSAMP collection sites for shellfish tissue chemistry.

Reference: DOH, in prep.

Chemical Contamination of Shellfish

The Washington Department of Health (DOH) annually collects native littleneck clams (*Protothaca staminea*) at several beaches throughout Puget Sound for analyses of tissue chemistry (Figure 14). The DOH reviewed the levels of chemical contaminants found in samples from 1992 to 1993 (DOH, in prep.). Clam tissue was analyzed for six metals (arsenic, cadmium, copper, lead, mercury and zinc) and nearly 100 organic contaminants, including pesticides, PCBs and PAHs.

The DOH detected low levels of metals in all samples from each site. With the exception of lead and mercury, most metals varied little in concentration among the different sites. The two-year average concentration of lead was over three times higher in shellfish from Eagle Harbor than from all other sites sampled. The average mercury concentration in Eagle Harbor shellfish was over twice as high as in all other sites sampled. This pattern is similar to results found in previous years (PSWQA, 1993)

1992 and 1993 monitoring revealed only nine organic compounds in shellfish (Table 5). The DOH generally detected organic compounds at low levels near analytical detection limits. Analytical results become highly variable near detection limits. For this reason, it is difficult to draw conclusions from results in which all measurements are near detection limits, as patterns of variability are more likely due to analytical variability than to differences between sites or years.

Table 5. Organic chemicals detected in shellfish.

Organic Chemicals Detected in Shellfish
2-methylphenol
benzoic acid
benzyl alcohol
bis(2-ethylhexyl)phthalate
butylbenzyl phthalate
di-n-butyl phthalate
fluoranthene
phenanthrene
pyrene

Results of a preliminary human health assessment based on mean sample concentrations indicated that the threat to human health posed by tissue chemical concentrations in native littleneck clams at sites sampled by the PSAMP is low. The one possible exception may be lead concentrations in shellfish from Eagle Harbor. Lead concentrations in Eagle Harbor shellfish were significantly higher than tissue concentrations from other locations (DOH, in prep.) The EPA is currently reviewing the human health criteria for lead, so that the health-related conclusions for elevated lead concentrations are not available at this time. The PSAMP will reevaluate the lead data from Eagle Harbor when the EPA review is complete.

The four years of results available on shellfish tissue chemistry indicate that tissue contaminants are generally at low levels near analytical detection limits. For several sites these results are unexpected. A number of the sites sampled for shellfish tissue chemistry are near potential pollutant sources, including a Superfund site with heavily contaminated sediments (Eagle Harbor) and several sites near urban areas and industrial activities such as petroleum facilities (e.g., Edmonds Oil Dock and March Point).

The consistently low levels of contaminants documented in four years of sampling native littleneck clams suggest that tissue contaminants in this species may not reflect nearby contamination—particularly in Eagle Harbor,

where high levels of sediment contamination have been documented (EPA, 1993a; 1993b). For this reason, native littlenecks may not be as effective a sentinel (early warning) species as other shellfish. The PSAMP will evaluate the need to revise future sampling, although at present funds for future shellfish tissue sampling have been eliminated.

Chemical Contamination of Birds

Hood Canal bald eagles

Bald eagles are listed as a federally threatened species in Washington state. The population declines that led to this listing resulted partially from contamination by DDT and associated compounds, which can cause eggshell thinning and reproductive failure. Since the DDT ban in 1972, bald eagle populations have increased throughout most of the United States and in most areas of Washington state. Since 1982, the number of young produced in the Puget Sound region has increased by 400 percent (PSWQA, 1993; WDFW, unpublished data). Bald eagles in Hood Canal, however, do not reflect this increase in nesting success—their reproductive success has remained low over the last 13 years. In 1990, bald eagles in Hood Canal produced 0.82 young per nest, compared to 1.02 per nest throughout the Puget Sound Region. In 1991, Hood Canal nests averaged 0.38 young, compared to a statewide average of 0.97 young per nest, and 15 of the 21 Hood Canal nesting eagles did not produce young. Low reproductive success continued in Hood Canal through 1992 (0.48 young per nest), 1993 (12 nest failures) and 1994 (0.24 young per nest) (WDFW, unpublished data).

The U.S. Fish & Wildlife Service initiated a cooperative study with the Washington departments of Ecology and Natural Resources, the U.S Navy, and the U.S. National Biological Survey to investigate possible causes of the low reproductive success among Hood Canal bald eagles. The study initially focused on evaluating levels of contaminants in bald eagles eggs. The results from the first year of the study (1992) indicate that total PCB concentrations range from 7.9 ppm to 24.8 ppm. Total PCBs levels of less than 4.0 ppm are considered necessary for normal reproduction (Wiemeyer et al., 1984). In addition, levels of dioxins (2,3,7,8-TCDD: 9.7-22 ppt; 1,2,3,7,8-PeCDD: 12-34 ppt) and furans (2,3,7,8-TCDF: 13-36 ppt; 1,3,4,7,8-PeCDF: 6.5-20 ppt) were elevated compared to values obtained at other sites (Anthony et al., 1993). Concentrations of metals appeared to be below levels associated with adverse effects.

The cooperating agencies followed up these results with further sampling of eggs, and sampling of sediment and potential prey species to evaluate the pathways of the observed contamination. The results of these analyses will be reported in a future *Puget Sound Update* as they become available.

The Puget Sound Protocols and Guidelines

The usefulness of environmental data collected within a region is greatly increased if data from different monitoring efforts are directly comparable. Combining comparable data can provide a more comprehensive evaluation of environmental conditions.

Within the Puget Sound region, environmental agencies are attempting to improve the quality and consistency of environmental information collected through development and use of the Puget Sound Protocols and Guidelines. These protocols and guidelines consist of procedural descriptions that encourage, where possible, use of well-defined and consistent methods for sampling and analyzing environmental data.

The current protocols and guidelines address quality assurance and control; sediment chemistry; sediment bioassays; station positioning; measurement of metals in water, sediment and tissues; microbial studies; organic compounds in sediment and tissues; subtidal benthic macroinvertebrate assemblages; fish pathology; conventional water quality variables for fresh water; soft-bottom demersal fishes; conventional water quality variables for marine water; and analysis of marine mammal tissue.

The protocols play an important role in the Puget Sound Ambient Monitoring Program (PSAMP). Agencies responsible for collecting data used in the PSAMP or added to the PSAMP database follow the protocols and guidelines. Additional studies and data from other investigations or outside agencies is sometimes used to supplement the PSAMP data to get a better picture of long-term trends. Such data is more readily compared to the PSAMP data if the protocols are followed.

The Puget Sound Water Quality Authority makes available electronic copies (3.5" floppy disk in WordPerfect format) of the Puget Sound Protocols and Guidelines. To obtain copies, call the Authority at (360) 407-7329. The Authority is revising several chapters, including those dealing with quality assurance and quality control; metals and organic compounds in sediment, water and tissues; sediment bioassays; and conventional marine water-column variables. If you have expertise in any of the topic areas and would like to be involved in current or future revisions, contact the Authority at 1-800-54-SOUND.

AVAILABLE RESOURCES FOR ASSESSING CHEMICAL CONTAMINATION

PSAMP Reports

Sediments

Dutch, M., H. Dietrich, and P.L. Striplin. 1993. Puget Sound Ambient Monitoring Program 1992: Marine Sediment Monitoring Task - Annual Report 1992. Washington State Department of Ecology, Environmental Investigations and Laboratory Services Program. Olympia, WA. Publication #93-87. 50 pp.

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Recent Reports from Other Monitoring Efforts and Additional Literature Cited

Puget Sound Water Quality Authority (PSWQA). 1994. Puget Sound water quality management plan. Puget Sound Water Quality Authority. Olympia, WA. 272 pages.

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Environmental Protection Agency (EPA). 1993a. A Region 10 Superfund update. EPA. Seattle, WA. EPA Publication 910-F-93-002.

Environmental Protection Agency (EPA). 1993b. The Superfund remedial program. EPA. Washington D.C. EPA Publication 9230.0-09SF

King County Department of Metropolitan Services (Metro). 1994. Water quality status report for marine waters: King County area 1990-1992. Publication 171.

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Macdonald, R.W. and E.A. Crecelius. 1994. Marine sediments in the Strait of Georgia, Juan de Fuca Strait and Puget Sound: What can they tell us about contamination? In: Wilson, R., R. Beamish, F. Aitkins, and J. Bell [eds.]. 1994. Review of the marine environment and biota of Strait of Geor-

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Wiemeyer, S.N., T.G. Lamont, C.M. Bunck, C.R. Sindelar, F.J. Gramlich, J.D. Fraser, and M.A. Byrd. 1984. Organochloride pesticide, polychlorobiphenyl, and mercury residues in bald eagle eggs - 1969-79 - and their rela-

tionship to eggshell thinning and reproduction. Arch. Environ. Contam. Toxicol. 13:529-549.

PSAMP CONTACTS

Data on chemical contamination is also available from the PSAMP central database. Contact the Puget Sound Water Quality Authority, (360) 407-7300.

Sediments

Washington Department of Ecology
Roberto Llanso, Ph.D.
(360) 407-6992

Data Available: Annual sampling of sediment chemistry, benthic community structure, and sediment toxicity at 48 sites throughout Puget Sound; 1989-present.

Sediment data also available from the SEDQUAL database. Contact Tuan Vu at the Department of Ecology, (360) 407-7449.

Marine Fish

Washington Department of Fish and Wildlife
Sandra O'Neill
(360) 902-2843

Data Available: Tissue contaminants in: English sole liver and muscle tissue (1989, 1991-present; approx. 15 sites per year); English sole liver histopathology (1989, 1991-present; approx. 15 sites per year); rockfish muscle tissue contaminants (1989; 1991-93; approx. five sites per year); Pacific cod tissue contaminants (1990, 1992, 1993; two sites per year); Salmon tissue contaminants (1990, 1992, 1993; three to five sites per year).

Shellfish

Washington Department of Health
Glen Patrick
(360) 753-1930

Data Available: Tissue contaminants in native littleneck clams (1989-1993; collected annually at 4-20 sites annually)

Publications containing more information about the Superfund program can be obtained from EPA's Public Information Center by calling toll free 1-800-424-4EPA.

FECAL CONTAMINATION

WHAT DO WE KNOW ABOUT FECAL CONTAMINATION?

Water is easily contaminated by human and animal fecal wastes and their associated pathogens. Fecal wastes in surface waters and shellfish pose a serious threat to human health because these wastes may contain bacteria, protozoa and viruses associated with typhoid, cholera, salmonella, hepatitis and other diseases. In fresh waters, humans may be exposed to fecal contamination by drinking or swimming in polluted waters. In marine waters, exposure to fecal contamination occurs primarily through consumption of contaminated shellfish, although swimming in contaminated marine waters is also a possible route of exposure.

Fecal contamination enters surface waters from many urban, rural and natural sources. The most significant source at a particular site depends on the activities in the surrounding watershed. Failing on-site sewage systems, improperly managed farm animal waste and combined sewer overflows are potential sources of contamination. Scientists have shown that many other sources also contribute fecal contaminants. Examples from past monitoring include fecal matter from marine mammals at Dosewallips State Park (DOH, 1994), untreated waste discharges from boats at Penrose Point State Park (Determan et al., 1992), and pet wastes in Seattle's Pipers Creek watershed (Herrera Environmental Consultants, 1993).

Past monitoring of fecal contaminants suggests that the open marine waters of Puget Sound have low levels of fecal contaminants. The flow of contamination into the Sound primarily affects shallow areas near stream and riverine inflows, or other passageways of fecal coliform bacteria along the shore, such as improperly managed stormwater runoff, sewage treatment plant discharges and failing on-site sewage systems. Ironically, shellfish resources are most concentrated in shallow waters, and it is within these resources that the effects of fecal contamination are most strongly reflected.

SUMMARY OF 1993 FINDINGS ON FECAL CONTAMINATION

What is a geometric mean?

A "geometric mean" is another way to average a set of values. It is commonly used with parameters such as fecal coliform bacteria, which show a great deal of variability, in order to reduce the effect that occasional high values have on the average.

1993 Marine Water Monitoring Results

• The open waters of Puget Sound sampled by the Puget Sound Ambient Monitoring Program (PSAMP) do not exhibit high levels of fecal contamination. In wateryear 1993 (October 1992- September 1993), only one ambient site—in Possession Sound—had an annual geometric mean level of fecal coliform bacteria above those allowed by Washington's marine water quality standards (Newton et al., 1994). Other sites did, however, show bacterial levels above natural background concentrations. Ambient stations in Commencement Bay, the Main Basin near West Point, Budd Inlet, and Oakland Bay periodically exhibited bacterial concentrations above background levels. This suggests that significant amounts of fecal bacteria enter Puget Sound at these sites, and that higher levels of contamination may be present in the nearshore areas closer to sources.

> These findings are consistent with past findings of the program (Janzen, 1992; Janzen and Eisner, 1993a; b; PSWQA, 1993a). Fecal coliform bacteria are thought to survive poorly in marine waters (Lessard and Sieburth, 1983). The open marine waters sampled by the program are generally distant from any direct sources of fecal contamination; therefore fecal coliform bacterial levels should not be high or even detectable at most sites.

• Extensive monitoring of the marine waters in King County shows low or undetectable levels of fecal coliform bacteria in most ambient sites located away from the shoreline. Fecal contamination is severe in the nearshore areas, however, as few stations meet either portion of the marine bacterial standards (Metro, 1993) (see sidebar on page 43 for an explanation of the marine standards).

> Although fecal coliform bacteria survive poorly in marine waters, nearshore areas tend to have consistently high levels of fecal contamination because they are close to upland sources and passageways of fecal bacteria (e.g., stormwater outfalls, urban runoff, contaminated stream and riverine inflow). The concentrated and continuous flow of fecal contaminants does not allow the reduction of bacterial populations that normally occurs through natural die-off and dilution. While the PSAMP does not monitor nearshore marine areas for fecal contamination, other monitoring efforts have shown high levels of fecal contamination in nearshore areas (e.g., DOH, unpublished data; PSWQA, 1993b).

- Monitoring in Budd Inlet over the last several years reveals fecal contamination in the inner part of the inlet (Davis et al., 1993; LOTT, unpublished data). Although concentrations are high when compared to marine waters throughout Puget Sound, several inner-inlet sites do not exceed water quality standards because these waters are designated Class B, with less-restrictive bacterial standards.

    Past monitoring of Budd Inlet indicates that concentrations of fecal coliform bacteria are consistently above background levels. Although the inner inlet is monitored infrequently by the PSAMP, geometric mean bacterial levels are above those allowed by state standards (Janzen, 1992).

1993 Shellfish Monitoring Results

Fecal contamination found in shellfish tissue reveals patterns similar to results from past years. Some of the most contaminated sites are in rural areas exposed to a variety of nonpoint pollution sources, indicating that fecal contamination is not limited to urban areas.

- In 1993, the Washington State Department of Health (DOH) began classifying recreational shellfish beaches to improve the safety of recreational shellfish harvest. Twenty-nine recreational beaches are classified as open to harvest, four are conditionally open to harvest (i.e., closed after heavy rainfalls), and 37 are closed to harvest. Seventy-two recreational beaches remain unclassified because these areas have not been monitored sufficiently to assess the risk of exposure to fecal contamination.

- Harvest restrictions continued in vast portions of commercial shellfish growing areas. Results from 1993 are promising, however. 1993 marks the first year in which the DOH upgraded more commercial growing areas—and more total acreage—than it downgraded. Four commercial growing areas, totalling 2,690 acres, were upgraded, compared with 1,070 acres downgraded in two growing areas (DOH, 1993).

    The first commercial upgrade in the history of Puget Sound occurred in 1989, and the number of acres upgraded has increased each year since 1991. In addition, new harvest restrictions since 1989 have been minimal compared to previous years (PSWQA, 1993a). This is a promising indication of improvement, yet it is not reflected in long-term data on Soundwide bacterial levels in shellfish or nearshore marine waters. Shellfish tissue from several Puget Sound sites monitored since 1986 do not show significant decreases in bacterial levels (PSWQA, 1993a), nor do bacterial levels in marine waters Soundwide appear to be improving. These results suggest that the improvements in commercial shellfish bed classifications are the result of intensive local efforts to clean up contamination.

1993 Freshwater Monitoring Results

- Fecal coliform bacteria levels in almost half the rivers and streams monitored in the Puget Sound basin (15 of the 34 sites sampled in wateryear 1993) were above levels allowed by state water quality standards. Five of the 10 major rivers in the basin exceeded standards (Hallock and Hopkins, 1994).

Wateryear sampling

The Department of Ecology bases its sampling schedule on "wateryears", which run from October - September. Wateryear 1993 ran from October 1992 - September 1993.

Many of these major rivers had high bacterial levels for several years, suggesting chronic contamination that is not improving.

> These findings are in keeping with past results from the ambient monitoring program (Hopkins, 1993; PSWQA 1993a), and add to the growing body of data indicating widespread and chronic fecal contamination in the waters entering Puget Sound.

- Recent watershed studies reveal fecal contamination throughout the lower stretches of several Puget Sound rivers. The Skagit River at Mount Vernon has a long record of low concentrations of fecal coliform bacteria and consistently meets bacterial standards. However, a 1993 study indicates that the lower main stem of the river below Mount Vernon, and all the tributaries along the lower river, had geometric mean bacterial levels above those allowed by state standards (Entranco, 1993). The Deschutes River near Olympia exhibits a similar pattern—the upper watershed has low concentrations of fecal coliform bacteria, while bacteria in the lower watershed, which drains the urban, residential and outlying areas, exceeded state standards (Davis et al., 1993). Fecal contamination is evident throughout the streams and rivers of western King County (Metro, 1994).

STANDARDS FOR FECAL COLIFORM BACTERIA

Data on concentrations of fecal coliform bacteria in marine waters may be measured against two guidelines: standards outlined in the *National Shellfish Sanitation Program Manual of Operations* (1993) (NSSP manual), and WAC 173-201A: *Water Quality Standards for Surface Waters of the State of Washington.* Both guidelines state that: 1) geometric mean concentrations of fecal coliform bacteria in Class A and AA marine waters shall not exceed 14 organisms per 100 ml, and 2) not more than 10 percent of the samples shall exceed 43 organisms per 100 ml. However, the two standards differ in their requirements for comparing data to these criteria. The NSSP manual states that a minimum of 15 values, collected over a period of three years or less, should be used in calculating the geometric means of fecal coliform bacteria data. WAC 173-201A does not provide any guidelines on the minimum number of samples required, but states that fecal coliform bacteria data cannot be averaged beyond a 30-day period where such averaging would mask non-compliance. Obviously, unless samples are collected every other day (which would be very expensive), both of these requirements cannot be met.

The two guidelines are designed for different purposes, and there are advantages and disadvantages to both approaches. For the purposes of the *Puget Sound Update*, annual geometric means, generally based on ten to 12 monthly samples collected over a year, are compared to the numeric criteria in the water quality standards. This approach is used for several reasons:

> 1) It provides a discrete measure of fecal contamination for each year that can be readily compared between years.
>
> 2) As with many monitoring programs throughout the Sound, the PSAMP collects only one sample at each site per month. Since WAC 173-201A states that samples cannot be averaged beyond 30 days, this

would require comparison of only one sample result to the standard. Because individual measurements of fecal coliform bacteria are highly variable, single values that are high due to measurement variability would result in misleading "violations" of the standard.

3) The use of ten to 12 samples provides a sensitive measure of fecal contamination (since two or more months with values greater than 43 organisms per 100 ml will be above levels allowed in the second part of the standards), yet is based on enough samples to have greater confidence in the geometric mean value than could be provided by comparing one value to the standard.

The comparisons to standards in this report are meant to provide an indicator of fecal contamination at sites throughout the Sound, and should not be interpreted as evaluations of regulatory compliance with water quality standards.

DETAILS OF 1993 FINDINGS ON FECAL CONTAMINATION

Fecal Contamination of Marine Waters

Most open marine waters have low levels of fecal coliform bacteria. Although monitoring of freshwater inflow and shellfish growing areas suggests that there are areas where high levels of fecal contaminants discharge into the Sound, monitoring of open marine waters indicates these sources have minimal effects in areas removed from shorelines, river mouths and other sources or passageways of fecal contamination. This is probably due, in large part, to dilution of these sources as they mix with marine waters, and to poor survival of fecal coliform bacteria in marine waters (Lessard and Sieburth, 1983). In marine environments, fecal coliform bacteria may die off rapidly enough that they rarely occur in high concentrations, except near sources or in areas receiving extremely high contributions of fecal wastes.

PSAMP results during the last several years indicate that few of the ambient marine sites monitored had annual geometric mean levels of fecal coliform bacteria above averages allowed by state standards, despite the fact that standards for marine water quality are much lower (more restrictive) than freshwater standards. In wateryear 1993, the ambient site in Possession Sound was the only PSAMP station with bacterial levels exceeding water quality standards (Newton et al., 1994). Bacterial levels at PSAMP sites have been low the last two wateryears. While four sites had annual geometric means above 14 organisms/100 ml in wateryears 1990 and 1991, there has been only one site per year for the last two wateryears with annual geometric means above this level (Table 6). This may be due, in large part, to the fact that these two wateryears were drier than average, whereas wateryear 1991 had higher than average precipitation.

Annual geometric mean values at ambient marine sites are rarely above the 14 organisms/100 ml guideline stated in the first part of the standards relating to geometric means (see sidebar). However, ambient sites occasionally have peak values of fecal coliform bacteria that cross the 10 percent threshold stated in the second part of the standard. This suggests that even at ambient sites that exceed standards, contamination is not severe.

Marine water quality standards for fecal coliform bacteria

The state standard for fecal coliform bacteria in marine waters is composed of two parts.

First, the geometric mean cannot be higher than 14 organisms/100 ml for Class A and AA marine waters.

Second, no more than 10 percent of the samples can be above 43 organisms/100 ml for Class A marine waters.

The second part of the standard is the one marine waters exceed most frequently, as bacterial measurements are highly variable and may contain several high values.

A high geometric mean exceeding the first part of the standard, however, means that bacterial levels are consistently high and fecal contamination is likely a chronic problem.

Table 6. Ambient sites with annual geometric means greater than 14 organisms/100 ml, or with more than ten percent of their values greater than 43 organisms/100 ml.

Nisqually Reach and one of the Budd Inlet sites were only monitored in 1990; all other sites were monitored all four years.

1990	1991	1992	1993
Budd Inlet (two sites)	Admiralty Inlet	Sinclair Inlet	Possession Sound
Commencement Bay	Commencement Bay		
Nisqually Reach	Main Basin/West Point		
Oakland Bay			
Possession Sound			

Because fecal coliform bacteria survive poorly in marine waters, areas of Puget Sound located away from sources of fecal contamination should have concentrations of bacteria at or below detection limits at ambient sites. In addition to comparing annual geometric means to water quality standards, Ecology scientists also look at sites that consistently have hits (high individual readings above 14 organisms/100 ml, but with annual geometric means still below standards). At these sites, sources of fecal wastes probably exist, and nearshore areas closer to sources may have bacteria levels that exceed standards. Ecology found that during wateryears 1991-1993, fecal coliform concentrations at ambient stations within Budd Inlet, Commencement Bay, Oakland Bay and Possession Sound were consistently above detection levels, and often above 14 organisms/100 ml (Newton et al., 1994). In wateryear 1993, stations at Bellingham Bay, Budd Inlet, Commencement Bay, Elliott Bay, Oakland Bay, Possession Sound and Sinclair Inlet had one or more samples above 14 organisms/100 ml. Information from other studies and indicators of fecal contamination, such as beta-coprostanol, also suggests problematic fecal contamination in many of these areas (Davis et al., 1993; PSWQA, 1993a; 1993b).

Disadvantages of fecal coliform bacteria as indicators of fecal wastes

While there are rare forms of fecal coliform bacteria that threaten human health, generally the presence of these bacteria is used as an indicator that other harmful pathogens associated with fecal wastes may be present. However, there is no consistent quantitative relationship between the concentrations of fecal coliform bacteria present and the concentrations of pathogens. Surface waters with high concentrations of fecal coliform may in fact have low concentrations of bacteria and viruses harmful to humans. In contrast, enteric (intestinal) viruses have been found at significant levels in waters with low fecal coliform bacteria concentrations. For these and other reasons, fecal coliform bacteria are not ideal indicators of the risk of exposure to fecal pathogens.

An extensive national effort—the National Indicator Study—is under way to improve methods for assessing fecal contamination in shellfish growing waters. Until this effort develops improved indicators, fecal coliform bacteria—in spite of its disadvantages—remain one of the better means of assessing fecal contamination.

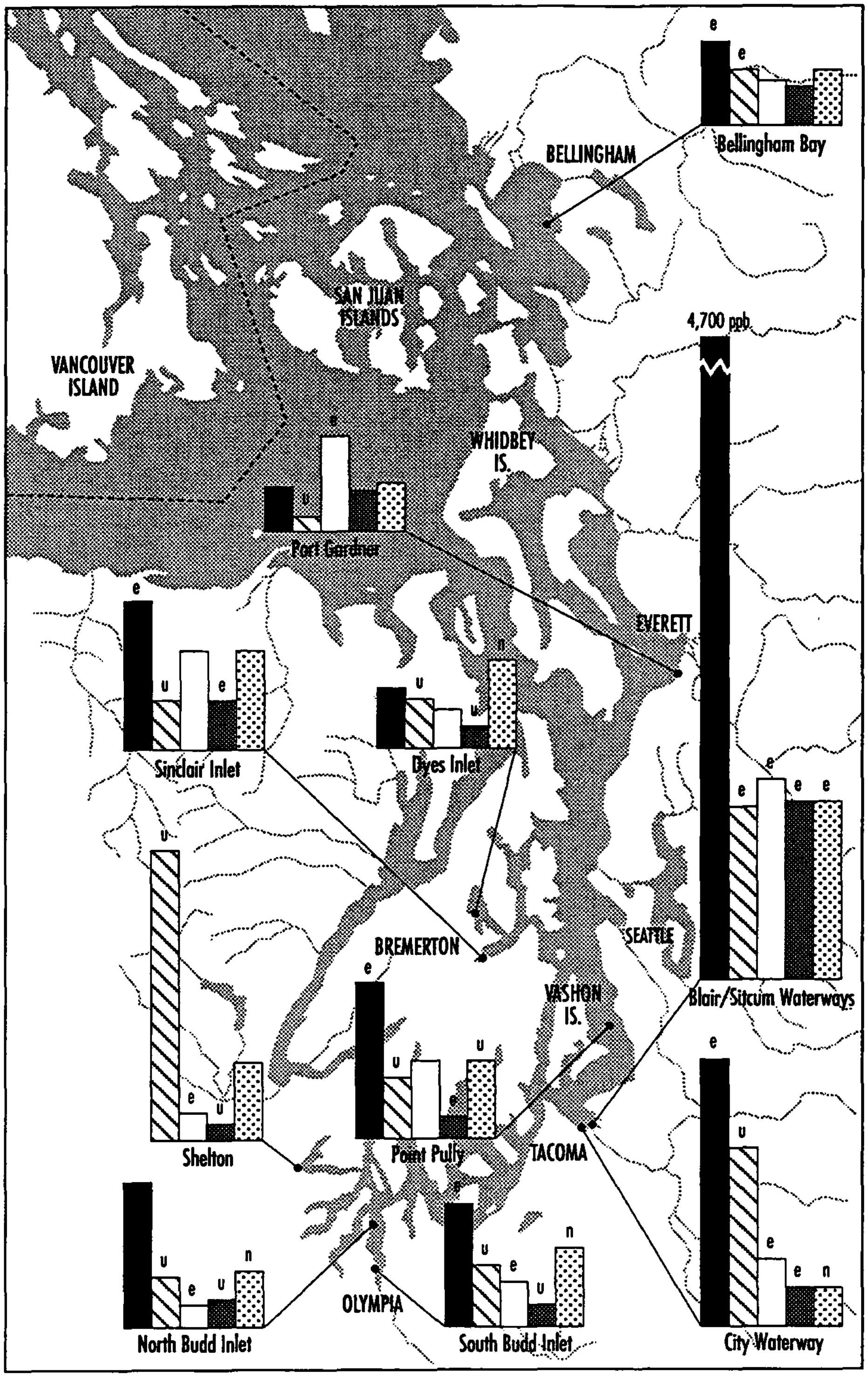
Other Indicators of Fecal Contamination

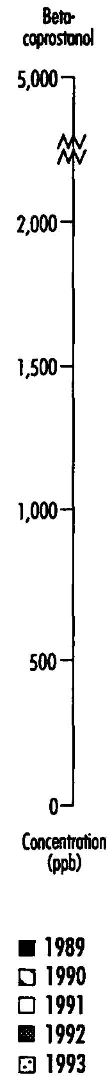
The reliance on fecal coliform bacteria to assess the presence of fecal wastes and their associated pathogens has several disadvantages (see sidebar). Because of this, a great deal of research is directed toward improving methods of detecting fecal wastes in surface waters. An alternative indicator of fecal wastes is beta-coprostanol (Venkatesan and Kaplan, 1990), a sterol formed by the enteric (intestinal) bacterial breakdown of cholesterol in mammals. While this chemical is not generally harmful by itself, it is frequently associated with sewage effluent and nonpoint pollution sources such as failing on-site sewage systems or animal waste runoff from dairy farms. It has a few important advantages over the use of fecal coliform bacteria. For example, it is not affected by bacterial growth and die-off, two factors which make fecal coliform bacteria less reliable indicators. However, beta-coprostanol is not without disadvantages. Like fecal coliform bacteria, its concentration cannot be quantitatively linked to concentrations of pathogens. In addition, it is not specific to human sources of sewage, but is also found in marine mammal and other mammalian wastes.

Since 1989, several PSAMP sites have consistently displayed elevated concentrations of beta-coprostanol in their sediments when compared to other sites monitored by the program. In particular, the two sites in Commencement Bay had the highest average concentrations over the last five years (Figure 15). Other sites that ranked highly during that time include Shelton

Figure 15. Beta-coprostanol levels at the 10 Puget Sound sites with the highest concentrations, 1989 - 1993.

Data qualifiers: e = values qualified as estimates; u = values below detection limit shown; n = results based on presumptive evidence.





Reference: PSAMP central database

(primarily due to high detection limits in 1989), Sinclair and Dyes inlets, Point Pully, Budd Inlet, Port Gardner, and Bellingham Bay (Figure 15). These sites are all near sewage treatment plant outfalls, and most are in semi-enclosed bays with urban development.

The spatial patterns evident in these results suggest that beta-coprostanol accurately indicates sewage discharged into a given area, as adjacent sites tend to have similar concentrations. Embayments containing two monitor-

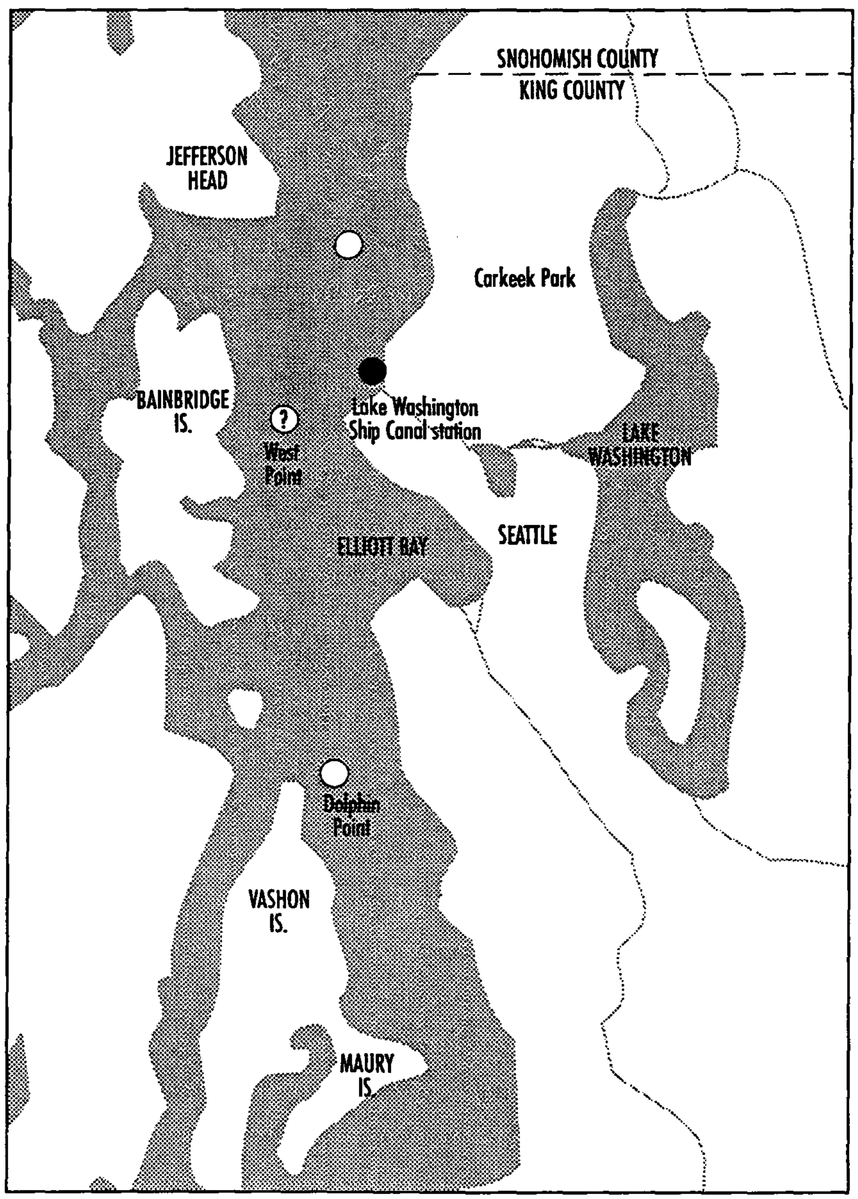
ing stations—such as Commencement Bay and Budd Inlet—tended to have similar five-year geometric mean concentrations, with the sites closest to sewage treatment plant outfalls having higher values. In addition, Sinclair and Dyes inlets, which are in close proximity, had similar average concentrations of beta-coprostanol over the five years of sampling.

Other Studies on Fecal Contamination of Marine Waters

King County

The King County Department of Metropolitan Services (Metro) monitors marine waters throughout King County to assess baseline conditions and the effects of sewage treatment plant discharges on marine water quality. Metro samples an extensive network of offshore and nearshore stations located away from discharges to evaluate background water quality, and a network of stations near discharges to evaluate the effects of these discharges on marine waters.

Figure 16. Comparison of fecal coliform bacteria at Metro offshore sampling stations to surface-water standards, 1990 - 1992.



○ Meets standards

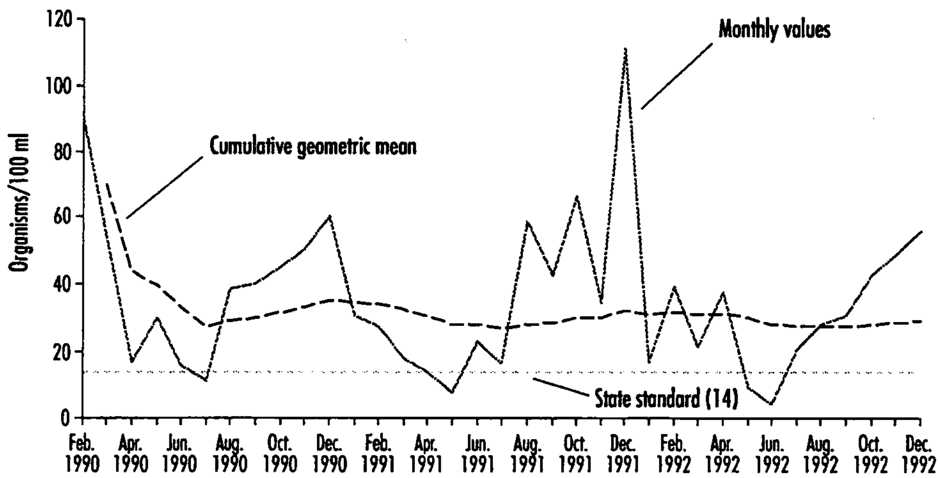
● Exceeds standards

? At or barely above bacterial standards, depending on the number of sampling dates and depth used to calculate compliance.

Reference: Metro, 1993

In a recent evaluation of data collected between 1990 and 1992 (Metro, 1993), Metro found that fecal contamination of offshore waters did not appear to be a problem, perhaps due to the depth and large volume of tidal exchange in these waters. In the nearshore areas, however, fecal contamination was more prevalent, and many nearshore stations had high levels of fecal coliform bacteria. This was true even of nearshore stations located some distance from Metro sewage outfalls, suggesting that urban runoff may play a major role in nearshore fecal contamination.

Offshore Water Quality: Most of the offshore stations—whether located near Metro outfalls or in open waters some distance from outfalls—had low levels of fecal contamination (Figure 16). Two offshore areas did show some evidence of fecal contamination. The first—at a station near the mouth of the Lake Washington Ship Canal—is probably influenced by contaminated fresh water flowing from the canal. It is also the offshore station located closest to shore (and therefore closest to sources of fecal contamination), which may in part explain the higher levels of fecal coliform bacteria at this station. This station exceeded both parts of the fecal coliform standard during the study period (Figure 17).



Reference: Metro, 1993

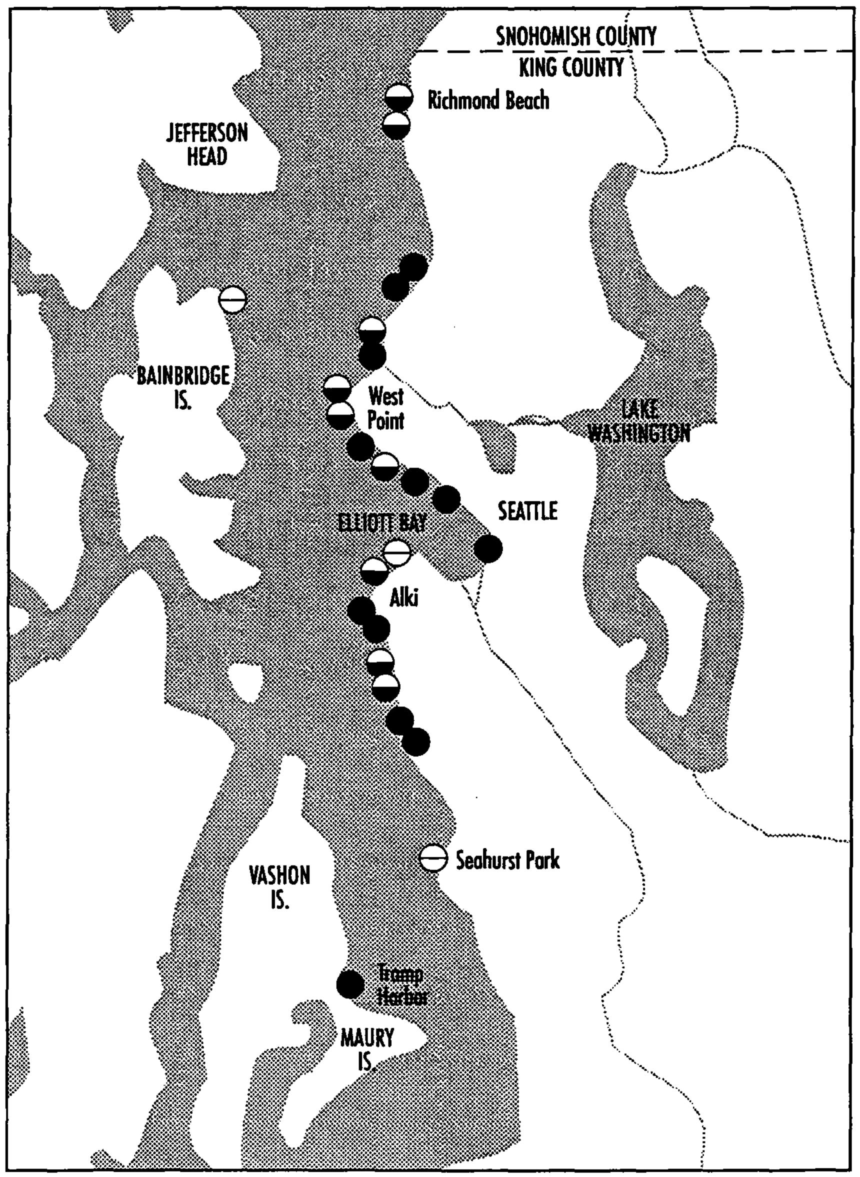
Figure 17. Long-term record of concentrations of fecal coliform bacteria at the ambient site near the Lake Washington Ship Canal in Seattle.

The cumulative geometric mean is compared to the state water quality standard (14 organisms/100 ml for Class A and AA waters).

The second area exhibiting signs of fecal contamination was in the vicinity of West Point. The stations near this outfall tended to have elevated coliform concentrations during the winters of 1990-91 and 1991-92. On one date in particular—December 5, 1990—Metro observed surface concentrations as high as 6,000 organisms/100 ml. Metro noted that effluent sampling at the West Point Treatment Plant the previous day revealed high effluent flows with elevated concentrations of fecal coliform bacteria. A few stations close to this outfall may have exceeded the second part of the fecal coliform standard in 1990 and 1991, depending on how compliance is calculated. Metro samples offshore stations at several depths. Depending on how the resulting numbers were used to calculate the geometric mean, and how many sampling dates were used, the stations either met or barely exceeded fecal coliform standards. Because state standards do not specify the exact method for comparing data to the standards, it is not possible to determine whether these stations met standards.

Nearshore Water Quality: In contrast to the offshore monitoring stations, intertidal, nearshore stations throughout King County had high levels of fecal coliform bacteria. All but three of the 24 nearshore stations had more than 10 percent of their measured values above 43 organisms/100 ml, and half of the stations had geometric means above 14 organisms/100 ml, suggesting chronic fecal contamination at these sites (Figure 18). The sources of this contamination are not known. Since the offshore stations had low bacterial concentrations (despite the fact that Metro's outfalls are generally located some distance from shore) and the compliance stations near the outfalls also generally exhibited low concentrations, it is unlikely that sewage treatment plant discharges caused the nearshore contamination. It is more likely that runoff from urban areas and inflow from contaminated urban streams were responsible.

Figure 18. Fecal contamination at King County nearshore (intertidal) stations, 1990 - 1992.



⊖ Met both geometric mean and >10% provisions

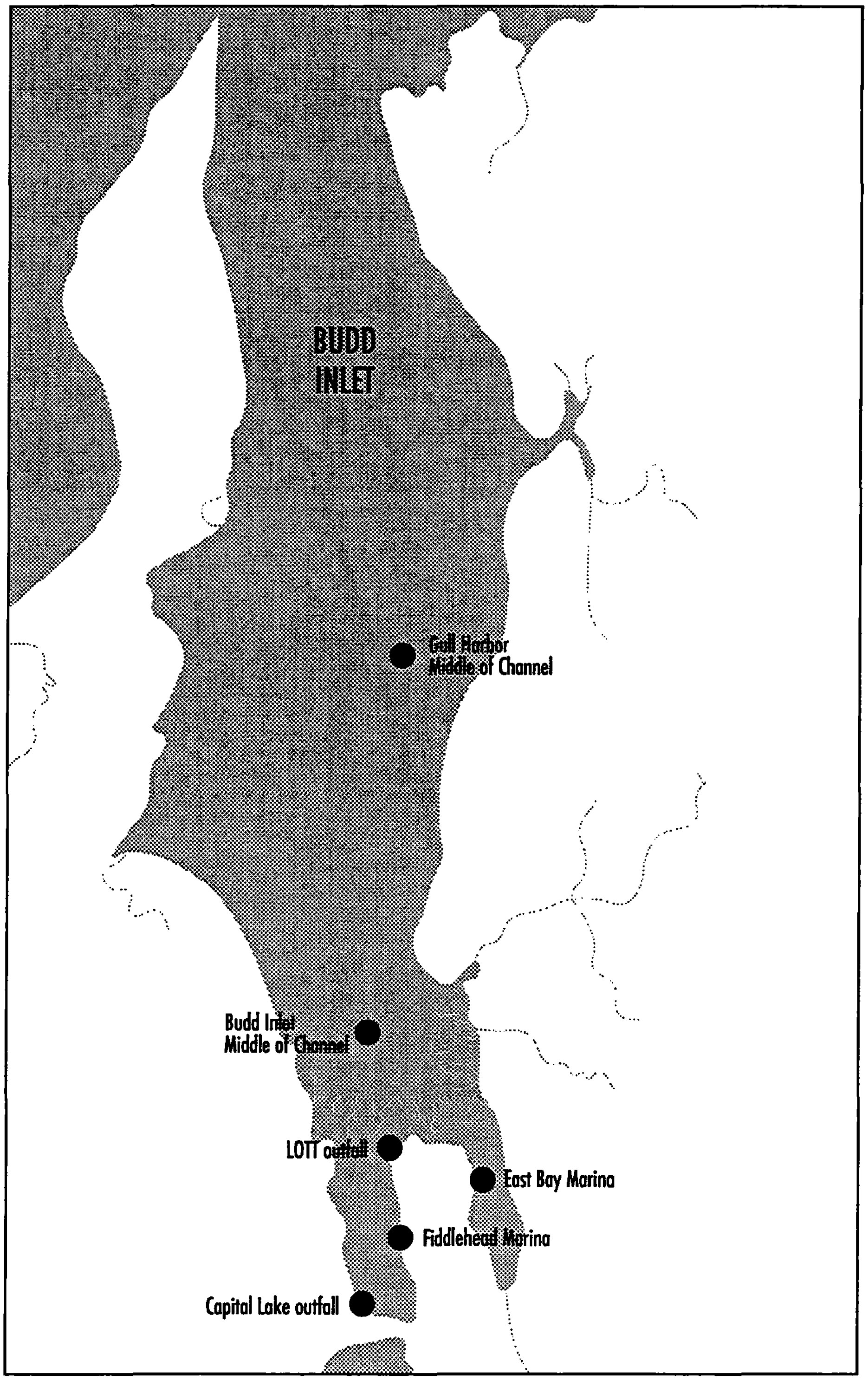
◒ Met geometric mean provision, but exceeded >10% provision

● Exceeded both geometric mean and >10% provisions

Reference: Metro, 1993

Budd Inlet

Thurston County recently completed a comprehensive, two-year study of water quality in the Budd/Deschutes watershed (Davis et al., 1993). The study, conducted between December 1990 and March 1992, characterizes water quality throughout the watershed. Monitoring stations were located in the Deschutes River and its tributaries, Capitol Lake (into which the Deschutes River flows before discharging to Budd Inlet), Budd Inlet, and some tributaries flowing directly into Budd Inlet.



Reference: Davis et al., 1993

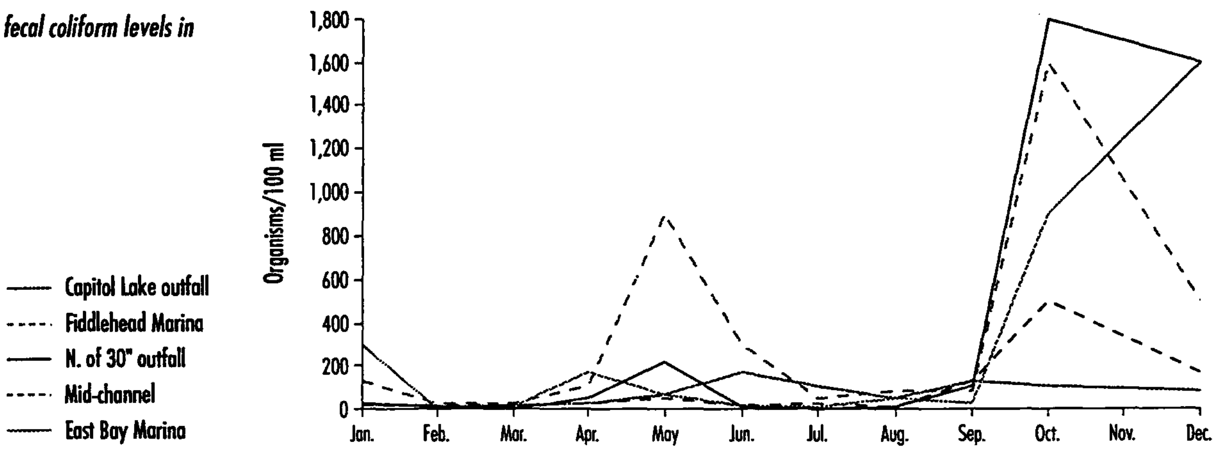
Figure 19. Sites sampled within Budd Inlet.

Thurston County sampled six stations in Budd Inlet during this study (Figure 19). The resulting annual geometric means are high when compared to marine waters throughout Puget Sound, but are nevertheless below the Class B fecal coliform standard, where geometric means cannot exceed 100 organisms/100 ml (Class B waters comprise most of inner Budd Inlet). The one station in Class A waters—near Gull Harbor—had a annual geometric mean below 14 organisms/100 ml.

Several stations, however, exceeded the second part of the Class B fecal coliform standard (more than 10 percent of the samples cannot exceed 200 organisms/100 ml). The station at the LOTT (Lacey, Olympia, Tumwater, Thurston County) sewage treatment plant outfall and the station near East Bay Marina had more than 10 percent of their samples above 200 organisms/100 ml. More than 10 percent of the Gull Harbor station samples were above the Class A standard of 100 organisms/100 ml.

LOTT (Lacey, Olympia, Tumwater, Thurston County) sewage treatment plant officials also monitor several of the Budd Inlet stations sampled in the Budd/Deschutes study. Results from their 1993 monitoring were similar to Thurston County's results. LOTT's monitoring indicated that stations at the Capitol Lake outfall and in the middle of Budd Inlet's main channel met water quality standards, while stations at the East Bay Marina and the LOTT outfall exceeded the second part of the Class B standards. The primary difference in results between the two studies was that LOTT's sampling indicated that the station at Fiddlehead Marina exceeded both portions of the Class B standard in 1993 (Figure 20).

Figure 20. Budd Inlet fecal coliform levels in 1993.



Reference: Unpublished LOTT data

Results from the four years of sampling conducted in these two monitoring efforts do not show any apparent increasing or decreasing trends over time. However, with a parameter as variable as concentrations of fecal coliform bacteria, much longer data records are generally required to detect changes over time that are a result of improvements or declines in environmental conditions.

Fecal Contamination of Shellfish

In marine nearshore areas close to freshwater discharges, upland runoff and other direct pollution sources to the Sound, fecal coliform bacteria counts are often high (Metro, 1993; unpublished DOH data). Because shellfish are most concentrated in these nearshore areas, it is in the contamination of Puget Sound's shellfish resources that fecal contamination takes the most notable environmental and economic toll. Rough estimates of the economic effect of fecal contamination suggest that every acre of high-quality, commercial shellfish beds closed to harvest represents a potential annual gross revenue loss of as much as $100,000 (D. Fagergren, pers. comm.).

The Washington State Department of Health (DOH) has extensive programs that evaluate fecal contamination of commercial and recreational shellfish resources. The DOH has monitored fecal contamination in commercial shellfish growing waters since the 1950s to ensure the safety of commercial shellfish. With the initiation of the PSAMP, the DOH began monitoring fecal coliform bacteria in shellfish tissue at public beaches to assess fecal contamination in shellfish collected recreationally.

Fecal Contamination of Recreational Beaches

The DOH collects shellfish quarterly at numerous recreational beaches throughout Puget Sound to evaluate fecal contamination of shellfish tissue. In a recent evaluation of data collected since 1989 (DOH, in prep.), the DOH found that most sites exhibited a large degree of variability in tissue bacterial levels, with values ranging one to two orders of magnitude over this time period.

Despite this variability, many sites exhibited consistent contamination patterns. To assess patterns of contamination, the DOH divided concentrations of fecal coliform bacteria into three categories:

1) Less than 30 organisms/100 g of shellfish tissue (corresponding to low or undetectable levels of contamination).

2) Concentrations between 30-230 organisms/100 g of shellfish tissue (moderate levels of contamination).

3) Concentrations greater than 230 organisms/100 g of shellfish tissue (unhealthy levels of contamination).

The Department of Health found three highly contaminated sites, with over 50 percent of their measurements above 230 organisms/100 g tissue (Table 7). These sites were reported as highly contaminated in past *Puget Sound Updates* (PSWQA, 1991; 1992). The DOH also identified sites with consistently low levels of bacteria over the four years of sampling, with more than 50 percent of the measurements below 30 organisms/100 g (Table 7). Most of these sites lie in sparsely populated rural areas away from point sources of pollution, although Penn Cove, Ross Point and Sequim Bay receive discharges from sewage treatment plants. The consistently low contamination levels at these three sites suggest that the treatment plants effectively reduce fecal coliform bacteria, that currents from these embayments do not carry contaminants toward the sampled areas, or that fecal coliform bacteria die off before reaching sampling areas.

The DOH also identified a number of sites with intermediate levels of contamination that did not fall into either consistently clean or contaminated categories (Table 7). Although the moderate levels of tissue bacteria present at these sites do not necessarily indicate unhealthy conditions, they do suggest that contaminants are consistently present at measurable—and sometimes even high—levels. The sites in this category vary widely in characteristics and possible sources. They include sparsely populated, rural areas (such as Glen Cove, Penrose Point, Port Gamble and Vaughn Spit) as well as urban sites (such as Carkeek, Post Point, Priest Point and Saltwater state parks).

Surveys conducted by the DOH and others indicate that a range of contaminant sources affect these sites, including sewage treatment plant discharges, urban runoff, failing on-site sewage systems (e.g., Glen Cove), animal wastes and boat wastes (e.g., Penrose Point State Park).

Table 7. Fecal contamination at recreational shellfish beds (based on quarterly geometric means from 1989 to 1993).

Highly Contaminated (majority of values greater than 230 organisms/100 g)	**Moderately Contaminated** (less than 50 percent of values in highest or lowest categories)	**Uncontaminated** (majority of values less than 30 organisms/100 g)
Belfair State Park	Carkeek Park	Burton County Park
Dosewallips State Park	Glen Cove	Camano Island State Park
Walker County Park	Penrose Point	Frye Cove Tidelands
	Port Gamble	Jarrell Cove State Park
	Post Point	Penn Cove Tidelands
	Priest Point	Ross Point
	Saltwater State Park	Sequim Bay State Park
	Semiahmoo Spit	
	Vaughn Spit	

Recreational Shellfish Bed Classifications

The Department of Health recently completed its first classification of recreational shellfish beaches throughout Puget Sound. The classifications advise recreational harvesters on the safety of harvesting shellfish from public beaches throughout the Sound (Figure 21). Under WAC 246-280, the DOH classifies recreational shellfish beaches as open, closed, conditionally open or unclassified. The DOH's first listing of recreational beaches includes 142 high-use beaches. Additional recreational beaches will be phased into the classification system in the future. The first listing classifies 29 recreational beaches as open to harvest, four as conditionally open to harvest (i.e., closed after heavy rainfalls or during boating season), and 37 as closed to harvest. Seventy-two recreational beaches remain unclassified because these areas have not been monitored sufficiently to assess the risk of exposure to fecal contamination. The PSAMP will track future changes in recreational classifications as a measure of environmental conditions and to determine how successfully sources of fecal contamination are being managed.

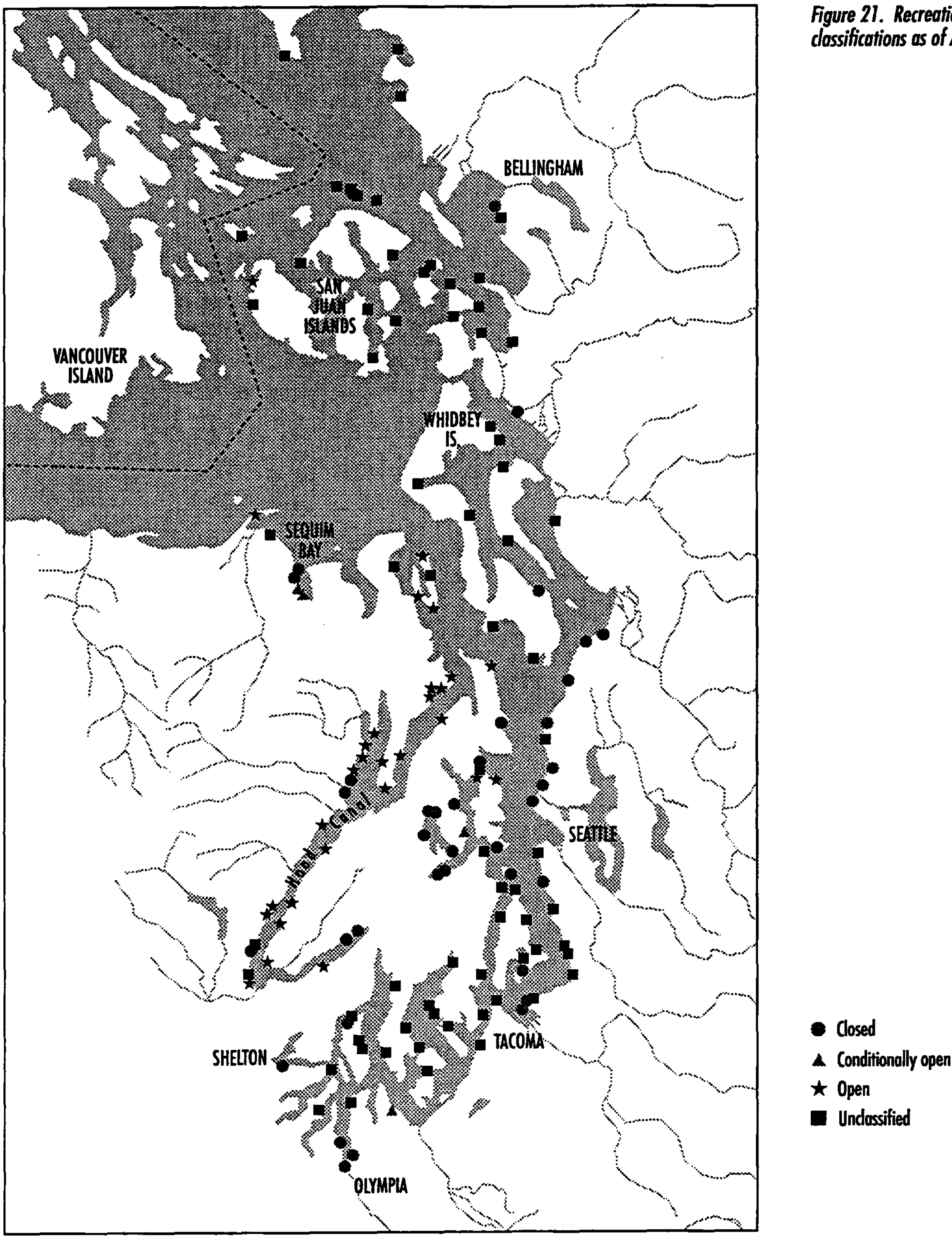


Figure 21. Recreational shellfish beach classifications as of August 1994.

Reference: DOH, in prep.

Fecal Contamination of Commercial Shellfish Beaches

The DOH monitors commercial shellfish beaches for fecal contamination to ensure the safety of shellfish sold commercially. As reported in past *Puget Sound Updates*, fecal contamination of commercial shellfish beds is a widespread problem that has serious environmental, economic and cultural consequences (PSWQA, 1991; 1992).

Fecal contamination has already claimed approximately 40 percent of Puget Sound's commercial shellfish acreage. Recent trends in the classification of commercial shellfish acreage have been promising, however. In 1989, the DOH upgraded 1,380 acres in Oakland Bay from restricted to conditionally approved because of improvements in water quality and in the Shelton sewage treatment plant. By 1992 an additional 2,490 acres had received upgrades. 1993 was consistent with this pattern. 1993 marks the first year in which the DOH upgraded more commercial growing areas—and more total acreage—than it downgraded. In 1993, the DOH upgraded 2,690 acres in four commercial growing areas, compared with 1,070 acres downgraded in two growing areas. Since 1989, the DOH has upgraded a total of 6,560 acres (DOH, 1993). While fecal contamination of shellfish beds remains a serious problem that merits priority attention, these numbers suggest that education, monitoring, enforcement and financial support are beginning to pay off.

Other Studies on Fecal Contamination of Shellfish

Sequim Bay

Battelle Marine Sciences Laboratory conducted long-term monitoring of fecal coliform bacteria in shellfish tissue in Sequim Bay to evaluate the effects of the John Wayne Marina on shellfish resources within the bay. Battelle has monitored six sites around the bay biweekly since 1978 (Figure 22), and recently evaluated the results from 1978-1991 (Cullinan et al., 1994).

Battelle divided concentrations of fecal coliform bacteria in shellfish tissue into three categories: less than 20 organisms/100 g, 20-230 organisms/100 g, and more than 230 organisms/100 g. These categories are similar to those used by the DOH, with the exception that Battelle used a lower value for the lowest category (20 organisms/100 g) than the DOH (which uses 30 organisms/100 g). Battelle found that most sites had a low percentage of results in the highest category—more than 230 organisms/100 g—which is the level at which fecal contamination of shellfish tissue is considered a human health threat. Battelle Beach—located at the entrance to Sequim Bay—had the highest percentage of values above 230 organisms/100 g, with 10 percent of the samples collected having bacterial levels that might pose human health threats. All other sites had less than five percent of their values within the highest category over the 14 years of sampling (Figure 22).

Five of the six sites also had a majority of their values below detection, which is consistent with Health's results from Sequim Bay (Table 7). The site with the highest levels—Battelle Beach—still had slightly less than 50 percent of its values below detection.

Battelle also looked for temporal patterns in the data. They found that few sites exhibited increases or decreases in tissue bacterial levels over time. The one exception may be Battelle Beach, which had peak coliform values in 1980, when 33 percent of its values fell in the highest category. This gradually decreased to four percent in 1991. Battelle did not perform a statistical analysis of this temporal pattern, however, so it is not known whether this is a significant trend. Their results also indicate that the three sites closest to the entrance of Sequim Bay—Battelle Beach, Travis Spit and Middle Ground—had much higher values in 1980 than in other years. These sites

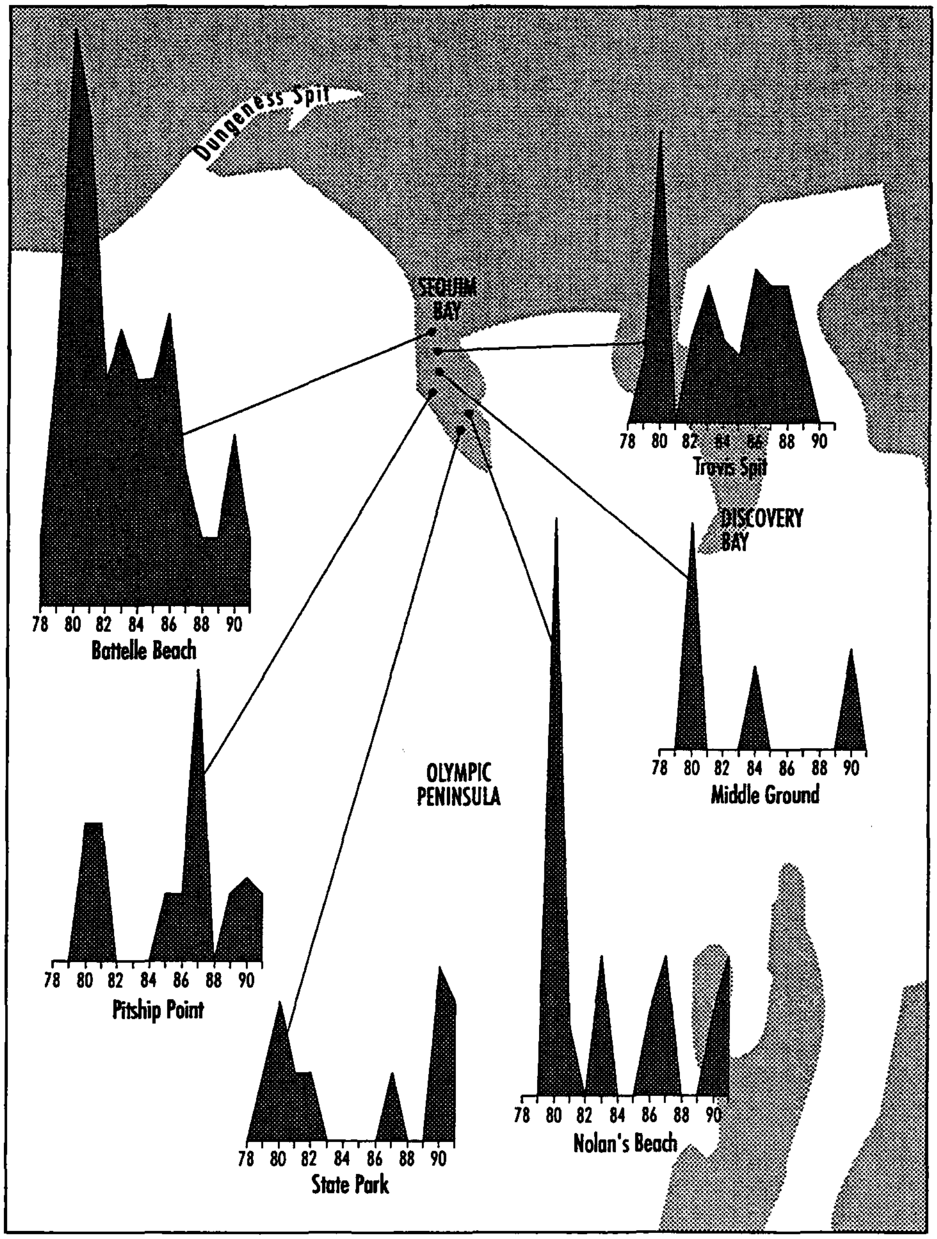
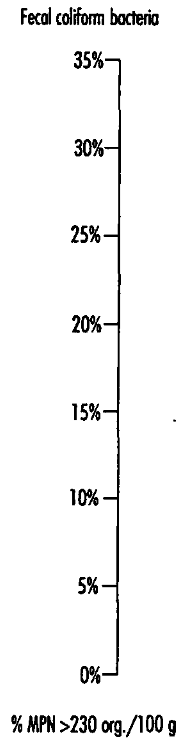


Figure 22. Percentage of samples from each site with most probable number (MPN) scores greater than 230 organisms/100 g clam tissue.

Monitored by Battelle Marine Science Laboratory, 1978 - 1992.



Reference: Cullinan et al., 1994

are closest to two major sources of fecal coliform bacteria in the bay: Bell Creek, which receives runoff from several cattle farms, and the Sequim municipal sewage treatment plant, which actually discharges outside of the bay in shallow nearshore waters but may contribute fecal coliform bacteria on incoming tides. Data are not available to determine whether these sources contributed particularly high concentrations of fecal coliform bacteria in 1980.

Fecal Contamination of Freshwater Inflow to Puget Sound

The growing body of data on fecal contamination increasingly suggests that fecal contaminants are most concentrated within the fresh waters of the basin. Half of the major rivers in the basin exceed standards for fecal coliform bacteria (PSWQA, 1993a), and data presented in the following paragraph suggest that streams and tributaries throughout the basin exhibit sim-

Freshwater standards for fecal coliform bacteria

Class AA - Fecal coliform bacteria shall not have a geometric mean of more than 50 organisms/100 ml; not more than 10 percent of all samples shall have a value higher than 100 organisms/100 ml.

Class A - Fecal coliform bacteria shall not have a geometric mean of more than 100 organisms/100 ml; not more than 10 percent of all samples shall have a value higher than 200 organisms/100 ml.

Class B - Fecal coliform bacteria shall not have a geometric mean of more than 200 organisms/100 ml; not more than 10 percent of all samples shall have a value higher than 400 organisms/100 ml.

ilar percentages of non-compliance. These results indicate that a large amount of fecal contamination enters Puget Sound through the 39 million acre-feet of water that flows annually from the basin's rivers and streams.

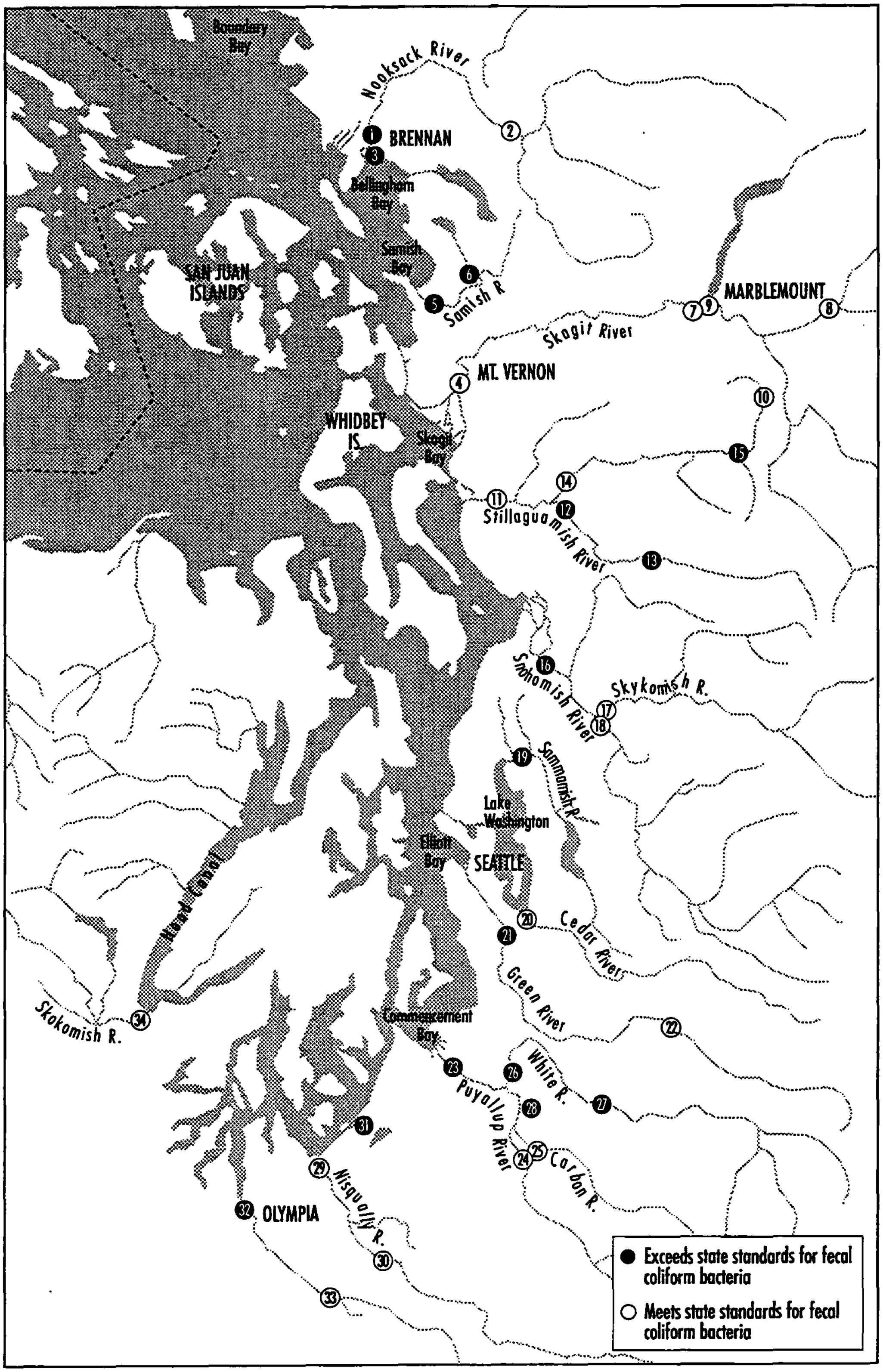
It would be very difficult to compare the amount of fecal contamination carried to the Sound by rivers and streams to that contributed by sources draining directly to the Sound (such as sewage treatment plants and stormwater runoff that discharge directly to marine waters). It is, however, reasonable to suggest that freshwater inflow is a significant source of fecal contaminants in Puget Sound. For this reason, an appraisal of fecal contamination in Puget Sound would be incomplete without assessing the waters draining into the Sound. Substantial data exist on freshwater contamination in the basin during 1993, due in part to the increasing emphasis on watershed studies for local planning and resource management needs.

The Washington State Department of Ecology (Ecology) monitors streams and rivers within the Puget Sound basin. Ecology monitored 34 stations within the basin in 1993, including 12 core stations (larger rivers, which are monitored monthly every year), 18 rotating stations (monitored monthly for one year out of every three), and four floating stations (which are monitored for only one year to address site-specific concerns about water quality). Ecology samples fecal coliform bacteria at these stations, as well as other conventional variables.

During wateryear 1993, Ecology found that 15 of the 34 stations monitored within the basin exceeded state standards for fecal coliform bacteria (Figure 23). Five of the 10 major rivers within the Puget Sound basin exceeded the standards: the Nooksack, Snohomish, Sammamish, Green and Puyallup rivers. Several of these rivers exhibit chronic problems with fecal contamination, and do not show signs of improving. The Sammamish and Puyallup rivers exceeded both parts of the standard for fecal coliform bacteria for the last three wateryears, indicating severe and chronic fecal contamination. The Nooksack River also had fecal coliform bacteria levels above those allowed in state standards for the last three wateryears, and the Green River exceeded standards for the last two wateryears.

In 1993, Ecology determined that several rivers—the Snohomish, Sammamish and Nisqually—exhibited significant decreasing trends over the past 10 years in concentrations of fecal coliform bacteria (Hopkins, 1993). These trend analyses were particularly encouraging for the Sammamish River, since it is one of the rivers with the most severe fecal contamination in the Puget Sound basin (the Sammamish River has exceeded both parts of the bacterial standard since 1977). Results from wateryears 1992 and 1993 did not follow that trend, however. Geometric means for wateryears 1992 and 1993 were over twice the geometric mean for 1991, and were the highest geometric means since wateryear 1983. Because concentrations of fecal coliform bacteria vary greatly, it is not known whether the high values over the last two years indicate a reversal of the decreasing trend identified in 1991, or are a result of annual variability.

Ecology's freshwater monitoring results make it clear that fecal contamination is a widespread problem throughout the fresh waters of the Puget Sound basin, and that several major rivers entering Puget Sound are highly



Reference: Hallock and Hopkins, 1994

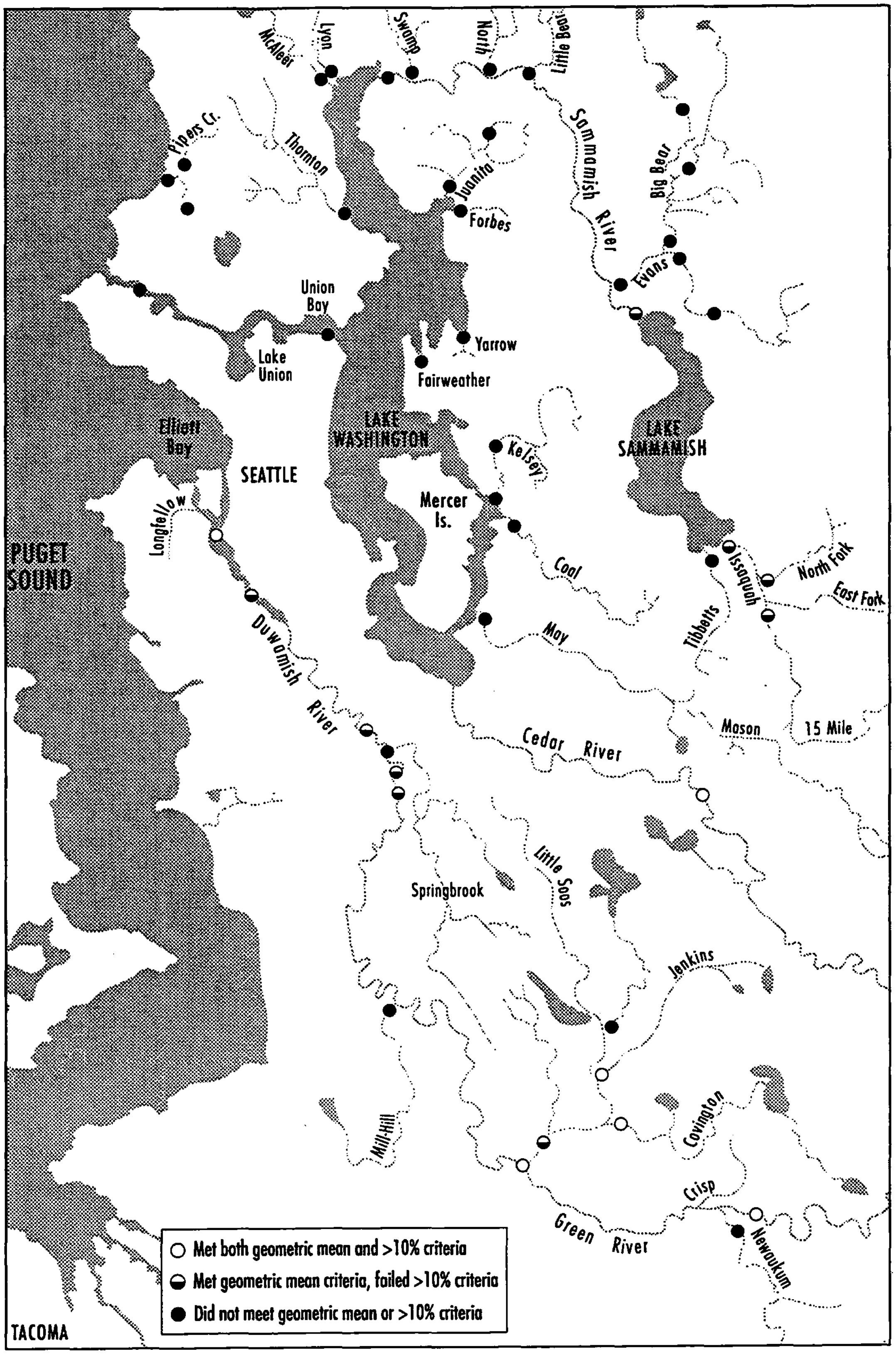
Figure 23. Fecal contamination at freshwater stations monitored during wateryear 1993.

STATION DESCRIPTIONS

1 Nooksack River at Brennan
2 Nooksack River at No. Cedarville
3 Silver Creek near Brennan
4 Skagit River near Mt. Vernon
5 Samish River near Burlington
6 Friday Creek below Hatchery
7 Skagit River at Concrete
8 Skagit River at Marblemount
9 Baker River at Concrete
10 Sauk River near Rockport
11 Stillaguamish R. near Silvana
12 South Fork Stillaguamish R. at Arlington
13 South Fork Stillaguamish R. near Granite Falls
14 North Fork Stillaguamish R. at Cicero
15 North Fork Stillaguamish R. near Darrington
16 Snohomish River at Snohomish
17 Skykomish River at Monroe
18 Snoqualmie River near Monroe
19 Sammamish River at Bothell
20 Cedar River at Logan St./Renton
21 Green River at Tukwila
22 Green River at Kanaskat
23 Puyallup River at Meridian Street
24 Puyallup River at Orting
25 Carbon River near Orting
26 White River at Sumner
27 White River at Buckley
28 South Prairie Creek near S. Prairie
29 Nisqually River at Nisqually
30 Nisqually River at McKenna
31 Chambers Creek near Steilacoom
32 Deschutes River at E. Street Bridge
33 Deschutes River near Rainier
34 Skokomish River near Potlatch

contaminated. It also shows that fecal contamination is far more prevalent in the Puget Sound basin than in other parts of Washington state. Of the 18 stations around the state that exceeded fecal coliform standards in wateryear 1993, 15 were in the Puget Sound basin (Hallock and Hopkins, 1994).

Figure 24. Fecal contamination in King County rivers and streams, 1990 - 1993.



Reference: Metro, 1994

Other Studies on Fecal Contamination in Fresh Waters

Perhaps due to widespread contamination in rivers, streams and creeks, studies on fecal contamination in fresh waters by monitoring programs other than the Puget Sound Ambient Monitoring Program are much more prevalent than studies in shellfish growing or marine waters. Summarized below are results from other monitoring programs on fecal contamination in fresh waters.

Western King County

The King County Department of Metropolitan Services (Metro) maintains long-term ambient monitoring stations in streams and rivers throughout western King County. Metro's evaluation of data collected between 1990 and 1993 (Metro, 1994) revealed that fecal coliform bacteria were the most widespread water contaminant in the study area. Approximately two-thirds of the monitored stations exceeded standards for fecal coliform bacteria. Many of the streams and rivers met standards only because their waterbody classifications were less restrictive and allowed higher bacteria levels. All three Class B stations along the Duwamish River, four of the 14 Class A streams (the Lower Green River and Big Soos, Covington and Jenkins creeks), and only one of the 30 Class AA stream stations (the Cedar River) met standards (Figure 24).

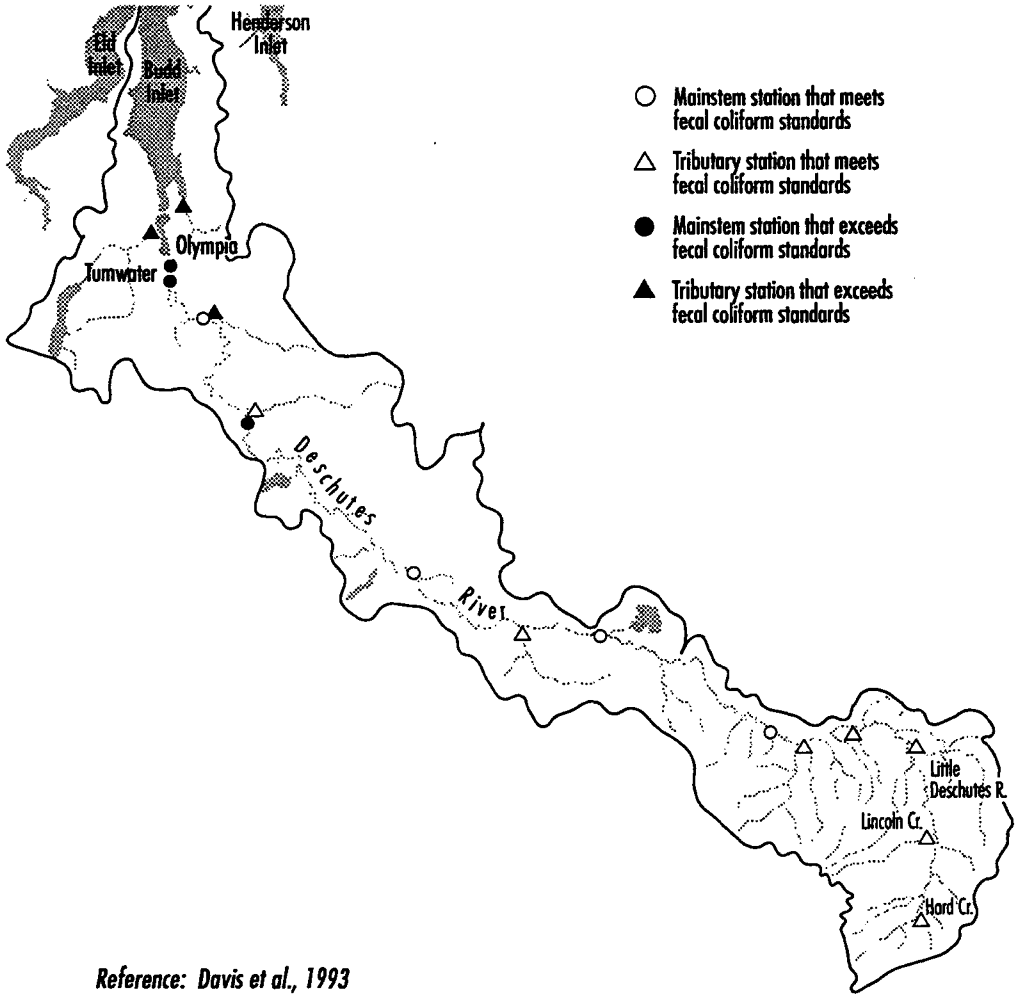
Metro did not conduct source-tracing studies, and so did not have information to determine the sources of fecal contaminants. Metro's study recommended RNA (ribonucleic acid)-tracking studies, similar to those performed by Herrera Environmental Consultants (1993), to determine whether contamination originated from human, livestock, wildlife or pet wastes. This information would help identify ways to reduce fecal contamination in streams which exceed bacterial standards.

Deschutes River

A recent Thurston County study characterizing water quality in the Budd/Deschutes watershed revealed that fecal contamination is limited to the lower portion of the watershed (Davis et al., 1993). The study involved monitoring the Deschutes River and its tributaries, and intensive surveys of water quality to address seasonal variations in water conditions, particularly in response to storm events.

In the main stem of the Deschutes River, all but one monitoring station at or below river mile 10.5 exceeded standards for fecal coliform bacteria. The station at river mile 5.0 barely met standards (Figure 25). These results support Ecology's long-term monitoring at river mile 0.6, which shows levels of bacteria above accepted standards for two of the last three wateryears. Three of the tributaries to the lower watershed—Percival, Moxlie and Chambers creeks—also exceeded bacterial standards. Fecal contamination problems in the lower watershed may be caused by the accumulation of bacteria contributed along the length of the river, and by differing land uses along the watershed. The upper watershed drains primarily forested lands, with some low-density agricultural and residential use, whereas the lower watershed drains urban and high-density agricultural and residential areas (Davis et al., 1993).

Figure 25. Fecal contamination in the Budd/Deschutes watershed, December 1990 - March 1992.



Reference: Davis et al., 1993

Thurston County found seasonal patterns in bacterial concentrations and loadings. The concentrations of fecal coliform bacteria at all the tributary and main stem stations were actually higher during the dry summer months, when stream flows were lower, than during wet winter months, when runoff and stream flow were higher. While Thurston County's dry-month results are based on limited sampling and should be interpreted with caution, this pattern has emerged in other studies on bacterial concentrations in streams and rivers (e.g., Determan et al., 1992; Entranco, 1993).

Higher bacterial concentrations during dry months may be due to several factors, including:

- The rate of bacterial contribution is relatively constant and not affected by runoff rates. In this case, bacteria are diluted less during periods of low flow, so that concentrations are higher. This pattern might be caused by pollution sources that do not rely on runoff for transport, such as farm animals with direct access to streams, municipal and industrial waste water, or other sources that discharge directly to surface waters.

- More fecal coliform bacteria enter the water during summer months. This could be caused by sewage treatment plants and on-site

sewage systems, which may treat more waste during tourist seasons, or by wildlife that congregate or immigrate during summer months.

It is not known which factor or combination of factors, if any, is responsible for the observed patterns. Higher dry-month concentrations of fecal coliform bacteria appear to occur mainly in streams and smaller rivers. Long-term monitoring of the 10 major rivers in the Puget Sound basin has not revealed similar patterns (see, for example, Hopkins, 1993), although this has not been evaluated statistically.

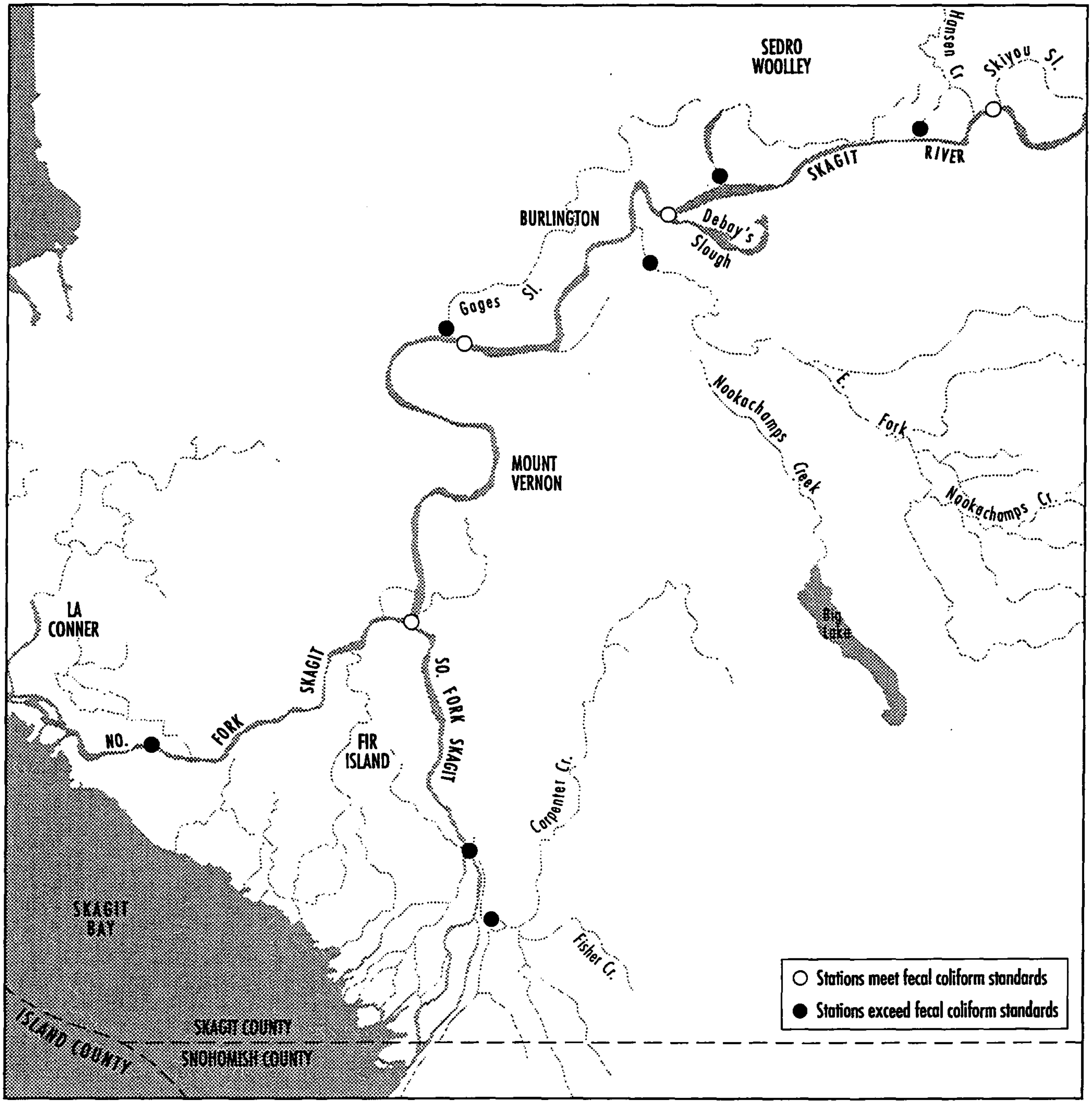
The Deschutes River flows into Capitol Lake before discharging into Budd Inlet. Thurston County monitored two stations in the lake—at the inflow to the lake and in the middle of the lake basin. Bacterial concentrations at the point where the Deschutes River empties into the lake exceeded fecal coliform standards and were much higher than concentrations in the middle of the lake, which met standards. This may be due to the fact that bacteria tend to adhere to sediments, which settle out upon reaching the slower-moving waters of Capitol Lake (Davis et al., 1993). If this pattern is consistent, it suggests that Capitol Lake retains fecal coliform bacteria contained in the Deschutes River, and may reduce the concentration of fecal contaminants flowing into the Sound.

Lower Skagit River

The Skagit County Department of Planning and Community Development and the Washington State Department of Ecology recently sponsored a comprehensive evaluation of water quality in the lower Skagit River basin (Entranco, 1993). Results from Ecology's long-term monitoring at Mount Vernon indicate that the Skagit River generally has excellent water quality (Hopkins, 1993). However, data are sparse or unavailable for the river below Mount Vernon, and for the extensive network of streams and sloughs that drain into the lower Skagit River. Some early studies and extensive harvest restrictions on commercial shellfish beds in Skagit Bay suggest that water quality problems exist in the portions of the basin below Mount Vernon (Entranco, 1993). Skagit County conducted surveys between 1991 and 1992 to evaluate water quality conditions in the lower river and its tributaries.

The lower Skagit River study did not collect the large numbers of samples or involve the long period of sampling required to provide an accurate picture of a parameter as variable as concentrations of fecal coliform bacteria. It did, however, provide important information that helps to fill data gaps on this portion of the river. The results of the lower Skagit River study are consistent with Ecology's long-term monitoring results, and indicate that fecal contamination is not a problem between the main stem of the river and river mile 10 below Mount Vernon—the point at which the river diverges into the north and south forks of the Skagit River (Figure 26). The two monitoring stations located on the north and south forks below the divergence were the only mainstem stations that exceeded fecal coliform bacteria standards.

Figure 26. Fecal contamination in the lower Skagit River basin.



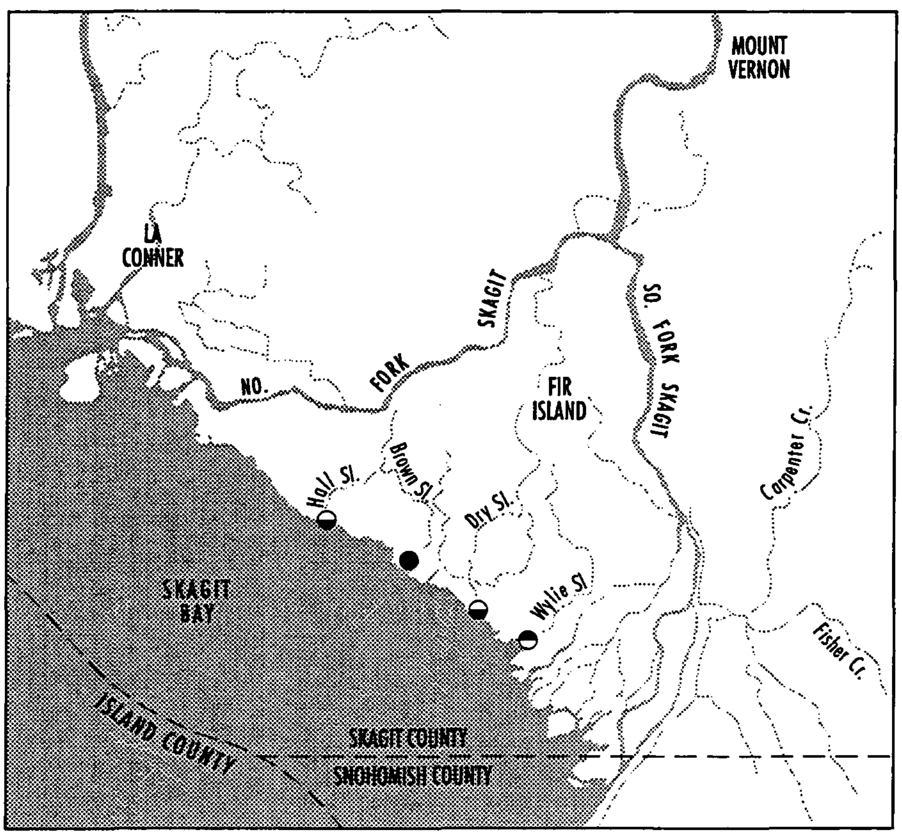
Reference: Entranco, 1993

The tributaries to the lower Skagit River, however, exhibited widespread fecal contamination. All tributaries leading into the main stem of the river had levels above standards for fecal coliform bacteria (Entranco, 1993) (Figure 26). In addition, Skagit County conducted intensive sampling throughout the Nookachamps watershed, which is the largest tributary of the lower Skagit River. They found that all but one station exceeded fecal coliform bacteria standards. The only station to meet state standards was located furthest upstream in the watershed.

Skagit County also sampled four sloughs draining directly into Skagit Bay between the two forks of the Skagit River (Figure 27). The sloughs are divided into upstream (fresh water) and downstream (marine) sections by flood control dikes and tide gates. The upstream portions of Brown and Wylie sloughs exceeded freshwater standards, and the downstream sections of Hall, Brown and Dry sloughs had levels above marine standards.

Skagit County did not conduct source-tracing studies to identify the origin of contamination in the tributaries, sloughs and lower main stem of the Skagit River, so it is difficult to definitively evaluate the sources and effects of fecal contamination in this area. It may be that the numerous tributaries with high bacterial levels contribute an accumulating load of bacteria along the length of the lower river, so that dilution cannot maintain bacterial levels below standards by the time the river discharges into Skagit Bay and Puget Sound. Numerous potential sources below the divergence of the main stem may also contribute fecal contaminants. These include:

- Dairy farms present below the divergence.
- Natural sources of fecal wastes—the area is a rearing and feeding ground for large populations of waterfowl (Kraege, 1990) and home to harbor seals.
- Skagit Bay (and the sources that discharge into the bay), as this area of the lower River Basin is inundated by tidal inflow.



Reference: Entranco, 1993

Figure 27. Fecal contamination in the lower delta of the Skagit River.

- Upstream portion exceeds freshwater standards
- Downstream portion exceeds marine standards
- Upstream and downstream portions exceed standards

The lower Skagit River study reveals important limitations that need to be considered in the interpretation of monitoring data. As mentioned, long-term data records indicate that the Skagit River at Mount Vernon has excellent water quality, and has met water quality standards over the last 10 years (Hopkins, 1993). Ecology chose this sampling location based on sound sampling protocol—namely, to evaluate water quality above tidal inflow so that results reflect freshwater conditions and are not influenced by marine water quality. The additional spatial coverage provided by the study shows that the picture provided by the long-term data record is accurate for the main stem of the Skagit River above and just below Mount Vernon. However, it also shows that the long-term record is not representative of conditions in the tributaries, or in the sloughs and lowest portion of the river draining into Puget Sound.

The latter two points are of primary interest in assessing Puget Sound's water quality. While the long-term data record might suggest that the Skagit River contributes minimal fecal contaminants to Puget Sound, this study shows that the sloughs and the lowest portion of the river draining directly into Puget Sound exceed standards. Because the Skagit River is the largest river within the Puget Sound basin, the contamination flowing into Skagit Bay and Puget Sound may be considerable.

A monitoring program is always limited by available resources, and can only sample a limited portion of the area it is designed to evaluate. This is particularly true of an area as large as the Puget Sound basin. However, the lower Skagit River study illustrates the importance of supplementing long-term monitoring with special studies that evaluate how representative the long-term monitoring network is.

AVAILABLE RESOURCES FOR ASSESSING FECAL CONTAMINATION

PSAMP Reports

Marine Waters

Janzen, C.D. 1992. Marine water column monitoring program, annual data report for wateryear 1990. Washington State Department of Ecology, Environmental Investigations and Laboratory Services Program. Olympia, WA. Publication #92-77. 38 pp.

Janzen, C.D. and L.B. Eisner. 1993a. Marine water column ambient monitoring program: annual report for wateryear 1991. Washington State Department of Ecology, Environmental Investigations and Laboratory Services Program, Olympia, WA. Publication #93-13. 86 pp.

Janzen, C.D. and L.B. Eisner. 1993b. Marine water column ambient monitoring program: wateryear 1992 data report. Washington State Department of Ecology, Environmental Investigations and Laboratory Services Program. Olympia, WA. Publication #93-41. 22 pp.

Newton, J.A., S.A. Bell, and M.A. Golliet. 1994. Marine water column ambient monitoring report: wateryear 1993 data report. Washington State Department of Ecology, Environmental Investigations and Laboratory Services Program. Olympia, WA. Publication #94-210. 57 pp.

Puget Sound Water Quality Authority (PSWQA). 1993a. 1993 Puget Sound update: fourth annual report of the Puget Sound Ambient Monitoring Program. Puget Sound Water Quality Authority. Olympia, WA. 89 pp.

Puget Sound Water Quality Authority (PSWQA). 1993b. Oakland Bay measuring results report. Puget Sound Water Quality Authority. Olympia, WA.

Shellfish

Department of Health. 1990. Department of Health 1990 technical report, shellfish tasks for Puget Sound ambient monitoring programs. Office of Shellfish Programs. Olympia, WA. 57 pp.

Department of Health. 1994. Puget Sound ambient monitoring program: shellfish monitoring task annual report 1991. Office of Shellfish Programs. Olympia, WA. 53 pp.

Department of Health. In preparation. Puget Sound ambient monitoring program: shellfish monitoring task annual report 1992-1993. Office of Shellfish Programs. Olympia, WA.

Fresh Water

Hallock, D. and B. Hopkins. 1994. River and stream ambient monitoring report for wateryear 1993. Washington State Department of Ecology, Environmental Investigations and Laboratory Services Program, Olympia, WA, 24 pp. Publication #94-158.

Hopkins, B., D. Hallock, and B. James. 1991. Freshwater ambient monitoring report for wateryear 1990. Washington State Department of Ecology, Environmental Investigations and Laboratory Services Program, Olympia, WA, 60 pp.

Hopkins, B. 1993. Freshwater ambient monitoring report for wateryear 1991. Washington State Department of Ecology, Environmental Investigations and Laboratory Services Program, Olympia, WA, 101 pp. Publication #93-75.

Recent Reports from Other Monitoring Efforts and Additional Literature Cited

Marine Waters

Davis, S., S. Berg, and J. Michaud. 1993. Budd Inlet/Deschutes River watershed characterization. Part II: water quality study. Thurston County Public Health and Social Services Dept., Environmental Health Division. Olympia, WA. 161 pp.

King County Department of Metropolitan Services (Metro). 1993. Water quality status report for marine waters: King County area 1990-1992. Publication 171.

Lessard, E.J. and J.M. Sieburth. 1983. Survival of natural sewage populations of enteric bacteria in diffusion and batch chambers in the marine environment. Appl. Environ. Microbiol. 45:950-959.

Venkatesan, M.I. and I.R. Kaplan. 1990. Sedimentary coprostanol as an index of sewage addition in Santa Monica Basin, Southern California. Environ. Sci. Technol. 24:208-213.

Shellfish

Cullinan, V.I., E.A. Crecelius, C.W. Apts, and J. Freudenthal. 1994. The influence of a marina on fecal coliform bacteria levels in clams. Battelle Marine Sciences Laboratory, Sequim, WA. 19 pp.

Department of Health. 1993. Annual inventory of commercial and recreational shellfish areas in Puget Sound. Office of Shellfish Programs. Olympia, WA. 37 pp.

Fagergren, D. Personal communication. Puget Sound Water Quality Authority. August 1994.

Fresh Water

Davis, S., S. Berg, and J. Michaud. 1993. Budd Inlet/Deschutes River watershed characterization. Part II: water quality study. Thurston County Public Health and Social Services Dept., Environmental Health Division. Olympia, WA. 161 pp.

Determan, T.A., J.A. Hoyle, and M.C. McCormick. 1992. Penrose Point/Mayo Cove water quality protection report. Prepared for U.S. Environmental Protection Agency, National Estuary Program, 65 pp. + appendices.

Entranco. 1993. Lower Skagit River basin water quality study. Prepared for Skagit County Department of Planning and Community Development and Washington State Department of Ecology. 74 pp.

Herrera Environmental Consultants, Inc. 1993. Pipers Creek: bacteriological source tracking investigation. Prepared for Seattle Engineering Department, Drainage and Wastewater Utility. Seattle, WA.

King County Department of Metropolitan Services (Metro). 1994. Water quality of small lakes and streams: western King County 1990-1993. Water Resources Section, Water Pollution Control Dept., King County Department of Metropolitan Services. Publication 946.

Kraege, D. 1990. Cooperative management of Puget Sound waterfowl resources. pp 155-170. In: Armstrong, J.W., and A.E. Copping, eds. Status and management of Puget Sound's biological resources. EPA 910/9-90-001. U.S. Environmental Protection Agency. Seattle, WA.

PSAMP CONTACTS

Data on fecal contamination is also available from the PSAMP central database. Contact Chris Prescott at the Puget Sound Water Quality Authority, (360) 407-7300.

Marine Waters

Washington Department of Ecology
Jan Newton, Ph.D.
(360) 407-6675

Data Available: Monthly fecal coliform bacteria concentrations in marine waters. Five to ten year data records for core sites monitored every year. Less frequent for rotational sites.

Shellfish

Washington Department of Health
Bob Woolrich
(360) 753-5957

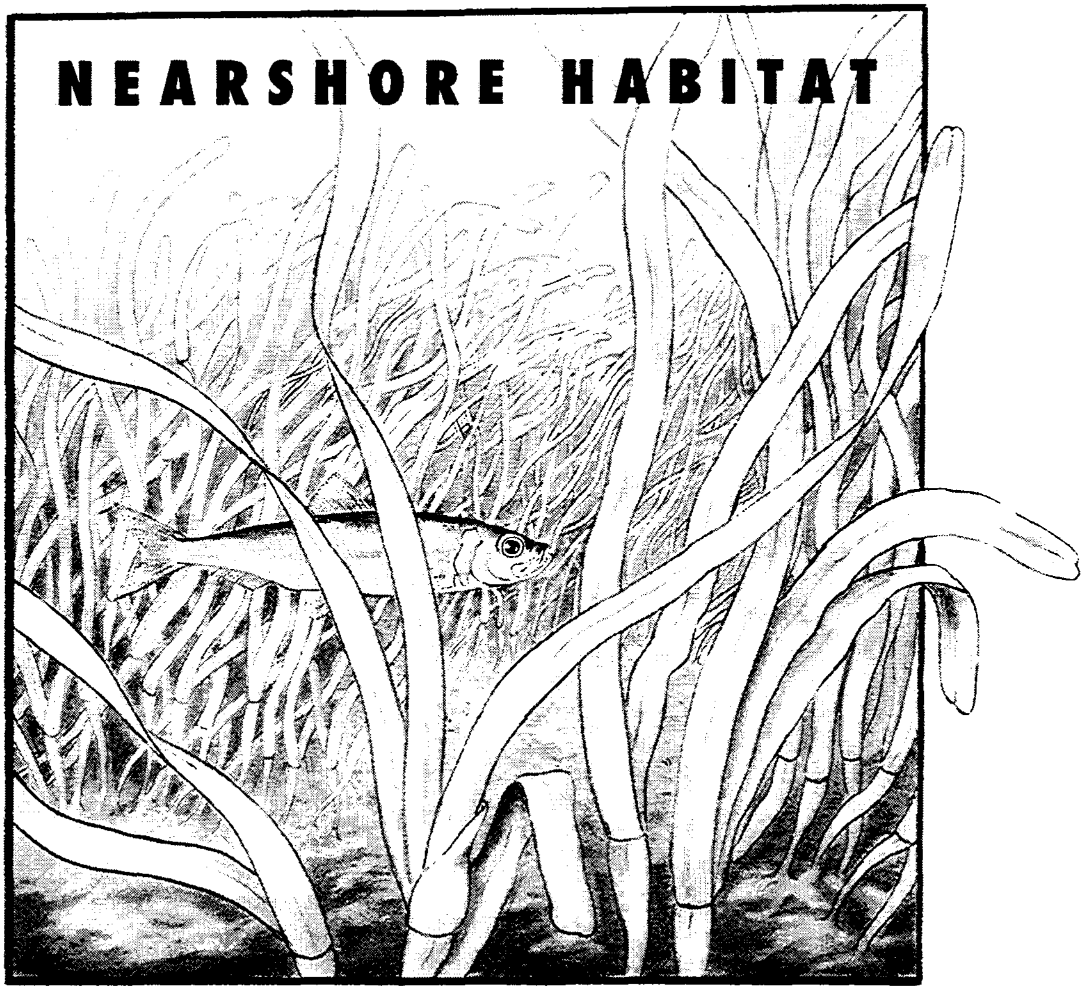
Data Available: Quarterly fecal coliform bacteria in shellfish, 1989-1993.

Fresh Water

Washington Department of Ecology
Brad Hopkins
(360) 407-6686

Data Available: Monthly fecal coliform bacteria concentrations in freshwater streams and rivers. Generally 10+ year data records for major rivers, depending on location. Streams and tributaries are usually monitored on a rotational cycle (monthly for one year out of every three).

NEARSHORE HABITAT



WHAT DO WE KNOW ABOUT THE COMPOSITION AND COVERAGE OF NEARSHORE HABITAT?

The kelp and eelgrass beds, salt marshes, sand and mud flats, and beaches that make up Puget Sound's intertidal and subtidal areas are essential to the health of Puget Sound. Most of the region's marine animal life use these nearshore habitats at one time or another as they spawn, rear their young, feed, or take refuge from predators. In addition, nearshore habitats protect the shoreline from erosion, filter pollutants from the water, and, in the case of salt marshes, reduce flooding by retaining storm water during high flow periods. Vegetated habitats are also highly productive, forming an important base of the Sound's food web.

Commercial and residential developments along Puget Sound's shorelines have already degraded and destroyed many of these habitats. In October 1994, the British Columbia/Washington State Marine Science Panel—a technical advisory panel to the Governor of Washington and the Premier of British Columbia—ranked the loss of nearshore habitats as the greatest threat to the Puget Sound and Strait of Georgia ecosystems (Marine Science Panel, 1994; Levings and Thom, 1994). Despite the urgency of this problem, lack of data on nearshore habitats represents one of the largest information gaps in evaluating the health of Puget Sound. Habitat managers know that historical losses of nearshore habitat have been very large and essentially

irreversible (Marine Science Panel, 1994). For example, 73 percent of the area covered by salt marshes in Puget Sound (Thom and Hallum, 1990), and nearly all salt marsh habitats in river deltas within the major urban areas (Bortleson et al., 1980; Hutchinson, 1988) have been destroyed. Estimated rates of total wetland and nearshore habitat losses exist (e.g., Canning and Stevens, 1989; Rylko and Storm, 1991), but are based either on indirect evidence, or are very rough approximations because accurate and complete data are not available to verify the estimates.

Given the importance of these habitats and the essentially irreversible nature of their loss (Marine Science Panel, 1994), it is reasonable to assume that the alteration and destruction of nearshore habitats in the past continues to adversely affect Puget Sound. However, the need for more recent, accurate and complete data on the amount of each habitat type present and its rate of loss is becoming critical, as is the need for information on the functions associated with each habitat type. Without these data, evaluating whether current management methods sufficiently protect the remaining nearshore habitats is impossible. Because of the extensive and irreversible nature of these losses, further delays in evaluating the adequacy of protection could be very costly to the health of Puget Sound and its resources.

SUMMARY OF 1993 FINDINGS ON NEARSHORE HABITAT COMPOSITION AND COVERAGE

- Using remote sensing, the Washington Department of Natural Resources (DNR) mapped five nearshore habitat areas in 1993 and 1994—Cherry Point in Whatcom County, a portion of central Hood Canal, and three areas in Elliott Bay. Aquatic vegetation at Cherry Point and Hood Canal is dominated by eelgrass, whereas vegetative coverage within Elliott Bay is dominated by various types of algae, with small eelgrass beds present.

  A comparison of DNR habitat maps with previously published habitat maps (from the Coastal Zone Atlas and National Wetlands Inventory) suggests that the DNR maps provide finer delineation among vegetation types, and greater resolution, enabling better detection of small habitat patches.

- Analysis of shoreline hardening or armoring (the construction of structures to prevent shoreline erosion) in Thurston County from 1977 to 1993 indicates that the amount of shoreline with armoring structures more than doubled over that time. During the 16-year-period, the length of shoreline armored increased an average of approximately one percent, or slightly more than one mile, per year. Currently, one-third of the county's shoreline is armored. Based on the rate of armoring documented by the study, the entire shoreline in Thurston County will be armored within 50 years.

  Literature reviews of studies evaluating the effects of shoreline hardening indicate a wide range of repercussions on the physical and biological characteristics of Puget Sound. These include erosion of substrates, changes in habitat structure, shifts in biological community composition, elimination of suitable fish spawning areas, adverse effects on the populations of fish-prey species, and various other effects.

DETAILS OF 1993 FINDINGS ON NEARSHORE HABITAT COMPOSITION AND COVERAGE

The Washington Department of Natural Resources (DNR) has collected two years of remote-sensing data on nearshore habitat coverage over approximately two-thirds of the Sound. The DNR processed information from six flight lines over the past year, classifying and tabulating the amount of vegetated habitat occurring in each flight line. (Flight line refers to the area over which the plane flies as it collects remote-sensing data.) The DNR also compared the habitat maps produced from its remote-sensing data with two previously published nearshore vegetation maps: the Coastal Zone Atlas and the National Wetlands Inventory. The atlas and inventory contain the most comprehensive nearshore vegetation maps in the Puget Sound basin. The Coastal Zone Atlas, produced in the late 1970s, and the National Wetlands Inventory, produced in the early 1980s, are based on aerial photography and field verification. Comparing the DNR's results with these earlier maps helped habitat managers evaluate the quality and resolution of the Puget Sound Ambient Monitoring Program (PSAMP) data, which were collected and processed with more sophisticated methods.

In general, the DNR found that the PSAMP data provide two major advantages over the earlier maps. The PSAMP data contain much more detailed information on the specific types of vegetation at each site. For example, whereas the PSAMP maps differentiate between seagrass, kelp and four different types of algal communities, the Coastal Zone Atlas maps grouped all algal communities into one type, and the National Wetlands Inventory maps grouped all six PSAMP map classes into one group (Table 8). The second difference is that the PSAMP data have higher resolution, which means they depict smaller beds of aquatic vegetation that were not represented by the other two mapping efforts.

Over the last year, the DNR analyzed six flight lines to determine the coverage of each vegetation type listed in Table 8, and then compared the results to the Coastal Zone Atlas and National Wetlands Inventory maps.

Table 8. Correspondence between vegetation categories for existing maps in Puget Sound basin.

PSAMP Class	Coastal Zone Atlas Class	National Wetlands Inventory Class
Eelgrass	Seagrass	Aquatic bed
Kelp	Kelp community	Aquatic bed
Green algae	Other algal community	Aquatic bed
Brown algae	Other algal community	Aquatic bed
Red algae	Other algal community	Aquatic bed
Mixed algae	Other algal community	Aquatic bed
Salt marsh	Salt meadow, salt marsh brackish marsh	Emergent
Spit/berm vegetation	Vegetated spit	No corresponding wetland class

Cherry Point
Whatcom County (Flight Line No. 6)

The Cherry Point flight line extends from the eastern border of Birch Bay State Park to Sandy Point, and includes the north end of Lummi Bay (Figure 28). The DNR found extensive eelgrass beds, covering 486.6 hectares. The eelgrass beds are located along the northwest shore between Birch Bay State Park and Point Whitehorn, and just north of the lagoon at Sandy Point and within Lummi Bay. A large kelp bed is present at Point Whitehorn, and smaller kelp beds are present all along the shoreline from Point Whitehorn south to Sandy Point. In total, kelp beds comprise 18.3 hectares of the flight line. (The DNR only analyzed the Cherry Point data for eelgrass and kelp beds. Other types of vegetation may have been present.

The National Wetlands Inventory map categorizes the entire area as aquatic bed and unconsolidated shore habitat. This is consistent with DNR's findings. The Inventory's data indicate that both vegetated and unvegetated areas are present, but the maps do not differentiate vegetated areas from unvegetated areas. In addition, the National Wetlands Inventory maps do not specify which types of vegetation (e.g., eelgrass, kelp, algae) are present. The Coastal Zone Atlas maps show less extensive eelgrass beds between Birch Bay and Point Whitehorn (which could be due to growth or annual variability in eelgrass coverage between the two mapping periods) (DNR, 1994).

Figure 28. The Cherry Point flight line. This map does not include the nearshore habitat inventoried by the DNR. For an accurate map, call the DNR contact listed at the end of this chapter.

Central Hood Canal County (Flight Line No. 69)

This flight line runs along the eastern shore of central Hood Canal, from Seabeck Bay to Little Beef Harbor (Figure 29). In analyzing the remote-sensing data, the DNR found a continuous band of various types of vegetated habitat along the entire flight line. A thin strip of eelgrass exists between Seabeck Bay and Little Beef Harbor, with small patches of green and mixed algae inshore of the eelgrass. The band of eelgrass becomes wider and denser at Little Beef Harbor and continuing north. At Big Beef Harbor, the DNR found a salt marsh at the south end, with eelgrass at the mouth of the harbor and mixed algae and green algae inshore toward the salt marsh. The analysis also revealed patches of green algae north of Big Beef Harbor, and another salt marsh in an embayment north of Big Beef Harbor. Overall, eelgrass was by far the dominant vegetation along this flight line.

The National Wetlands Inventory and Coastal Zone Atlas maps do not contain many of the aquatic beds indicated within the PSAMP data. The National Wetlands Inventory data set does not show any of the eelgrass beds from Seabeck Bay to just south of Big Beef Harbor, but does indicate a wide strip of eelgrass within the harbor and north of the harbor to the northern embayment. It indicates the salt marsh present within Big Beef Harbor, but does not indicate the other forms of vegetation there, or the salt marsh within the northern embayment. The Coastal Zone Atlas map shows

Figure 29. The central Hood Canal flight line. This map does not show the nearshore habitat inventoried by the DNR. For an accurate map, call the DNR contact listed at the end of this chapter.

the eelgrass beds south of Big Beef Harbor, but does not indicate the patches of algae south of the harbor or within the harbor. The Atlas' map also does not indicate the salt marsh within the northern embayment.

Growth of aquatic vegetation between the PSAMP mapping efforts and the two previous efforts may explain some of the differences observed. Nevertheless, the PSAMP maps clearly provide a more detailed definition of vegetation types in the nearshore zone. In addition, these comparisons suggest that PSAMP mapping detects aquatic beds of smaller size than the two previous efforts, as the National Wetlands Inventory and Coastal Zone Atlas maps do not show any beds as small as those detected by the PSAMP. As additional years of data are collected, these characteristics will improve the ability to detect changes over time in the PSAMP data.

North Elliott Bay
King County (Flight Line No. 48)

Flight line no. 48 includes the southern portion of Shilshole Bay to West Point, and extends southward from West Point to Fourmile Rock (Figure 30). The flight line is covered predominantly by green algae (25.2 hectares), with small patches of eelgrass (4.0 hectares), brown algae (0.6 hectare), and spit or berm vegetation (0.7 hectare; this category includes plants such as dune grass (*Elymus mollis*) and sedges (*Carex macrocephala*)). From southern Shilshole Bay to the south side of West Point, the DNR found patches of eelgrass with green algae inshore. Along the south shore of West Point, a small amount of spit or berm vegetation is present. Further south, a large continuous patch of green algae, with patchy eelgrass beds, runs along the shoreline.

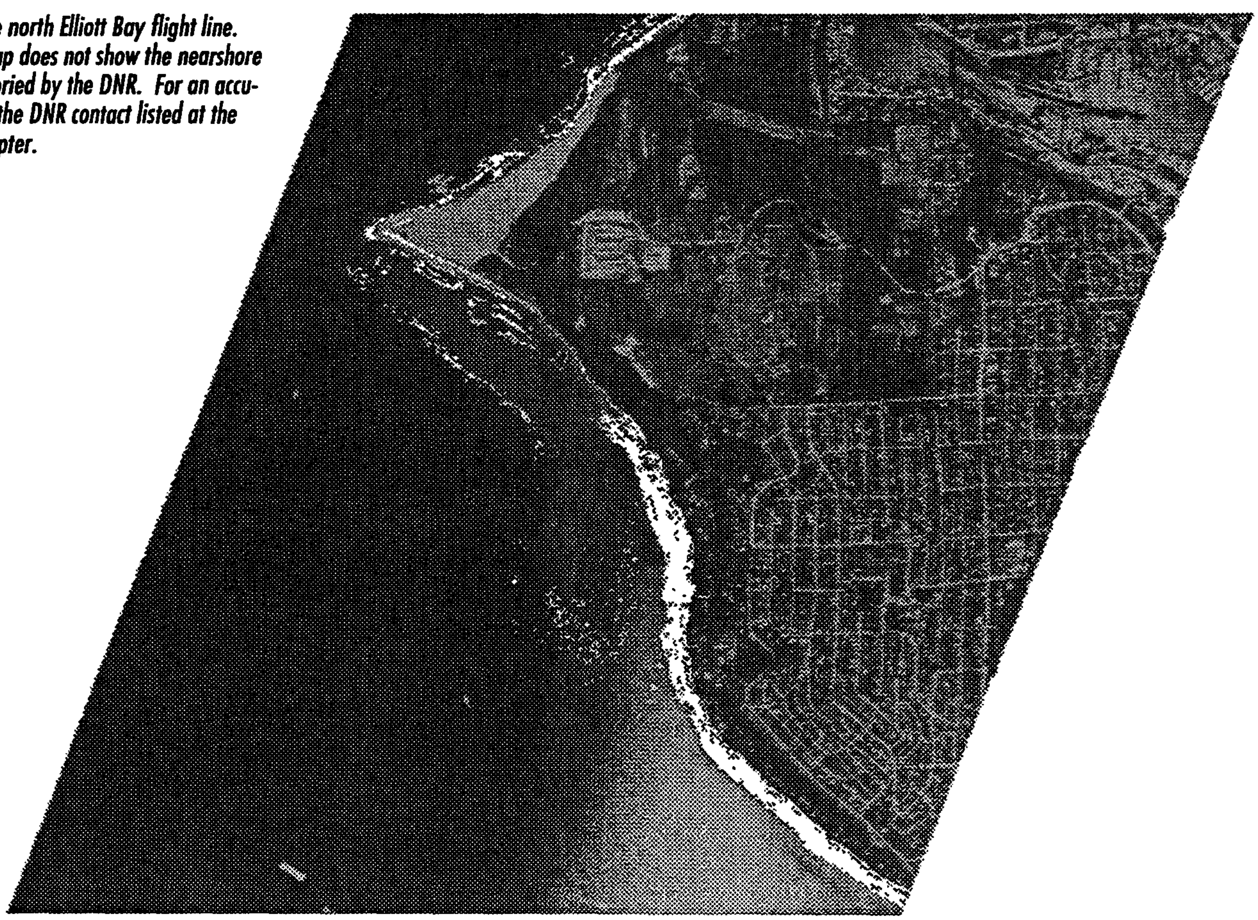


Figure 30. The north Elliott Bay flight line. (Note: This map does not show the nearshore habitat inventoried by the DNR. For an accurate map, call the DNR contact listed at the end of this chapter.

Central Elliott Bay
King County (Flight Line No. 49)

This flight line continues south from Fourmile Rock and includes Elliott Bay through to East Waterway by Harbor Island (Figure 31). Similar to the southern portion of the previous flight line, a continuous patch of green algae is present along the shoreline, with patchy eelgrass beds seaward. Two small, isolated kelp beds are apparent to the west and east of the Elliott Bay Marina. Mixed algae runs all along the riprap for the marina breakwater. Similarly, mixed algae is present all along the riprap for Pier 90. From Smith Cove southeast, a continuous band of green algae extends along the shoreline, with mixed algae growing seaward. The band of green algae diminishes right before the downtown Seattle piers, grading into mixed algae in the upper intertidal with brown algae below. A narrow band of kelp extends seaward. In the vicinity of East Waterway, mixed algae is present, with green algae south of the Spokane Street Bridge.

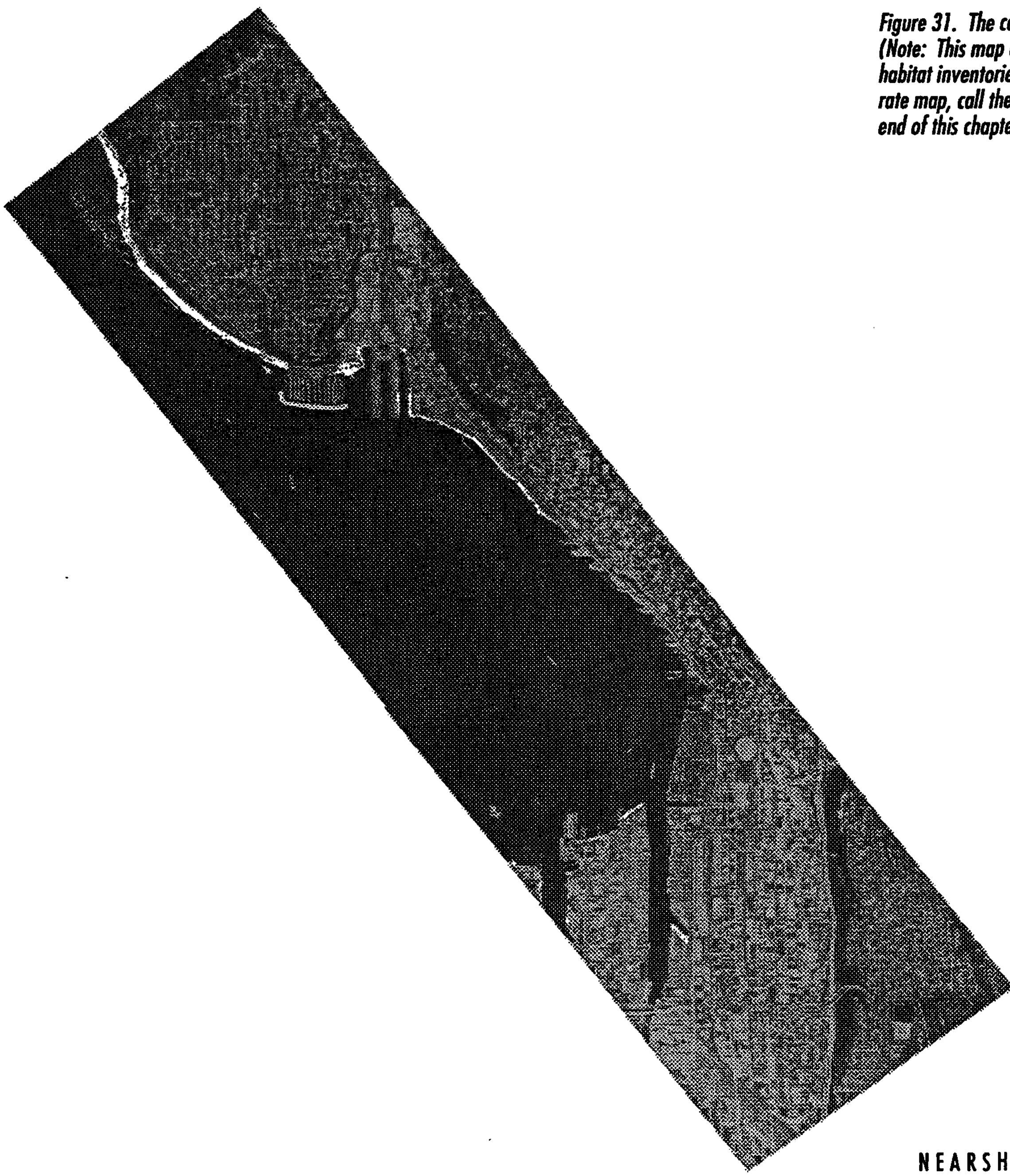


Figure 31. The central Elliott Bay flight line. (Note: This map does not show the nearshore habitat inventoried by the DNR. For an accurate map, call the DNR contact listed at the end of this chapter.

South Elliott Bay, Harbor Island and the Duwamish River King County (Flight Line No. 50)

Harbor Island, Alki Point and the estuarine tidal portion of the Duwamish River are included in flight line no. 50. Brown, green and mixed algae dominate the vegetation types along the marine tidal portions of the Duwamish River (Figure 32). Green algae extends furthest upstream into the river. Brown algae appears just south of the turning basin, with large patches of brown and green algae present within the basin itself. Mixed algae is the prevalent vegetation around Harbor Island, along the shoreline of the Duwamish adjacent to Harbor Island, and along the northern shore of Alki Point. Small patches of salt marsh are also present along the shore of the river toward the harbor. Along the southern shore of Alki Point, two long, thin and parallel strips of eelgrass appear; one close to shore and one further seaward. Brown algae is further inshore from the shallower strip.

Figure 32. Tthe south Elliott Bay flight line. (Note: This map does not show the nearshore habitat inventoried by the DNR. For an accurate map, call the DNR contact listed at the end of this chapter.

Other Studies on Nearshore Habitat

Inventory and Characterization of Shoreline Armoring in Thurston County

The Department of Ecology has been carrying out the Coastal Erosion Management Strategy project, a study on techniques of shoreline armoring (the construction of structures such as walls and ripraps to protect shorelines from erosion) and its physical and biological effects in Puget Sound. One component of the project involved inventorying and characterizing armoring in a representative suburban area: Thurston County. Using shoreline armoring permit information, aerial photography and field inspections, the Thurston Regional Planning Council assessed the changes in shoreline hardening between 1977 and 1993.

The study indicated that, at present, approximately one-third of the county's marine shoreline is hardened. Between 1977 and 1993, the amount of armored shoreline more than doubled from 76,049 to 159,453 feet (Table 9). During the 16 years evaluated, the length of shoreline armored increased an average of approximately one percent, or slightly more than one mile, per year. At this rate, the entire shoreline in Thurston County will be armored within 50 years.

Table 9. Shoreline armoring in Puget Sound.

	Budd Inlet	Dana Passage	Eld Inlet	Henderson Inlet	Nisqually Reach	Totten Inlet	Total
Shoreline length (feet)	73,051	25,879	181,779	101,511	92,531	71,465	546,236
Feet of shoreline armored in 1977	20,735	2,767	29,977	9,996	5,970	6,604	76,049
Feet of shoreline armored in 1993	34,108	8,485	63,701	19,177	19,594	14,388	159,453
% of shoreline armored in 1993	47%	33%	35%	19%	21%	20%	29%
% change in armoring between 1977-1993	65%	207%	113%	92%	228%	118%	110%

Reference: Morrison et al., 1993

The study also indicated that the percentage of armored shoreline varied throughout the county. Budd Inlet had the highest percentage, with close to half its shoreline armored (47 percent). The least-armored shorelines included Henderson Inlet (19 percent), Totten Inlet (20 percent) and Nisqually Reach (21 percent). The percentage change in armored shoreline from 1977 to 1993 varied throughout the county, and appeared to correlate with the nature and type of water body. Nisqually Reach and Dana Passage are north-facing, non-inlet water bodies that have the highest level of exposure to Puget Sound and experience the greatest direct impact from winter storms (Morrison et al., 1993). Armoring in these two areas also increased dramatically over the study period, with a 228 percent increase in hardened shoreline at Nisqually Reach and a 207 percent increase at Dana Passage. These values are far above percentage increases for the rest of the county (Table 9).

Shoreline Armoring Effects on Coastal Ecology and Biological Resources

What are the effects of shoreline armoring on Puget Sound? The Department of Ecology hired contractors to review literature and interview relevant experts to answer this question (Thom and Shreffler, 1994). The study concluded that:

1) The elevation at which the armoring structure is constructed within the tidal zone is critical, as structures extending further out into the intertidal may have larger impacts.

2) The consequences of similar shoreline armoring can vary at different locations, depending on factors such as sediment supply and wave and current energy. For example:

- When extensive armoring is present along the shoreline, beaches composed of fine sediments erode down to gravel, cobble or hardpan beaches within a few decades (Thom and Hallum, 1990; Macdonald et al., 1993).

- Armoring effects are most pronounced along gravel-cobble beaches, where wave and current energies are typically high, as opposed to highly depositional sites such as mudflats or salt marshes, where wave and current energies are typically low. Along gravel-cobble beaches, armoring may result in changes that alter the substrate from one that favors the growth of hardshell clams to one dominated by surface-dwelling seaweed, kelp and barnacles (Ellifrit et al., 1973; Antrim et al., 1993).

3) Most armoring structures provide poorer habitats than natural shoreline for the marine life that provide food for many benthic feeding fish, including salmon. In addition, spawning areas for surf smelt, sand lance, herring and rock sole may be lost due to removal of fine sediments and woody debris from the intertidal zone and replacement by impervious structures (Macdonald et al., 1993).

4) Construction of shoreline armoring often results in the loss of overhanging shade trees. This may cause increased siltation (Beschta et al., 1987), reduced addition of organic matter, and changes in beach habitat structure.

AVAILABLE RESOURCES FOR ASSESSING NEARSHORE HABITAT COMPOSITION AND COVERAGE

PSAMP Reports

Department of Natural Resources. 1994. Puget Sound Ambient Monitoring Program (PSAMP): Nearshore Habitat 1993-1994 Annual Technical Report. Division of Aquatic Resources, Department of Natural Resources. Olympia, WA. 15 pp.

Recent Reports from Other Monitoring Efforts

Antrim, L.D., R.M. Thom, and W. W. Gardiner. 1993. Lincoln Park shoreline erosion control project: monitoring for surface substrate, infaunal bivalves and eelgrass, 1993. Final Report prepared for U.S. Army Corps of Engineers, Seattle District. Battelle Pacific Northwest Laboratory. Richland, WA.

Beschta, R.L., R.E. Bilby, G.W. Brown, L.B. Holtby, and T.D. Hofstra. 1987. "Stream temperature and aquatic habitat: fisheries and forestry interaction." pp. 191-232 In: Salo and T.W. Cundy (eds.). Streamside management: forestry and fishery interactions. University of Washington, Institute of Forest Resources Contribution 57. Seattle, WA.

Bortleson, G.C., M.J. Chrzastowski, and A.K. Helgerson. 1980. Historical changes of shoreline and wetland at eleven major deltas in the Puget Sound region, Washington. U.S. Geological Survey, Hydrologic Investigations Atlas HA-617.

Canning, D.J. and M. Stevens. 1989. Wetlands of Washington: a resource characterization. Environment 2010 Project. Washington Department of Ecology. Olympia, WA. 45 pp.

Ellifrit, N.J., M.S. Yoshinaka, and D.W. Coon. 1973. Some observations of clam distribution at four sites on Hood Canal, Washington. Proc. Nat. Shellfish. Assoc. 63:7.

Hutchinson, I. 1988. Estuarine marsh dynamics in the Puget Trough--implications for habitat management. pp. 455-462 In: Proceedings of the first annual meeting on Puget Sound research. Puget Sound Water Quality Authority. Seattle, WA.

Levings, C.D. and R.M. Thom. 1994. Habitat changes in Georgia Basin: implications for resource management and restoration. In: Wilson, R., R. Beamish, F. Aitkins, and J. Bell (eds.). 1994. Review of the marine environment and biota of Strait of Georgia, Puget Sound, and Juan de Fuca Strait: proceedings of the B.C./Washington Symposium of the Marine Environment. Can. Tech. Rep. Fish. Aquat. Sci. 398 pp.

Macdonald, K., D. Simpson, B. Paulson, J. Cox, and J. Gendron. 1993. Shoreline armoring effects on physical coastal processes in Puget Sound. Preliminary Report prepared by CH2M Hill for Washington State Department of Ecology. Olympia, WA.

Marine Science Panel. 1994. The shared marine waters of British Columbia and Washington. Report to the British Columbia/Washington Environmental Cooperation Council. 119 pp.

Morrison, S., J. Keltman, and D. Haug. 1993. Inventory and characterization of shoreline armoring, Thurston County, Washington. 1977-1993. Prepared by Thurston Regional Planning Council for the Washington Department of Ecology. Olympia, WA.

Rylko, M. and L. Storm. 1991. How much wetland mitigation are we requiring? Or is no net loss a reality? In: Proceedings, Puget Sound Research '91. Puget Sound Water Quality Authority. Olympia, WA. Vol. 1, pp. 314-327.

Thom, R. and D. Shreffler. 1994. Shoreline armoring effects on coastal ecology and biological resources in Puget Sound, Washington. Prepared by Battelle Marine Sciences Laboratory and CH2M Hill for the Washington Department of Ecology. Olympia, WA.

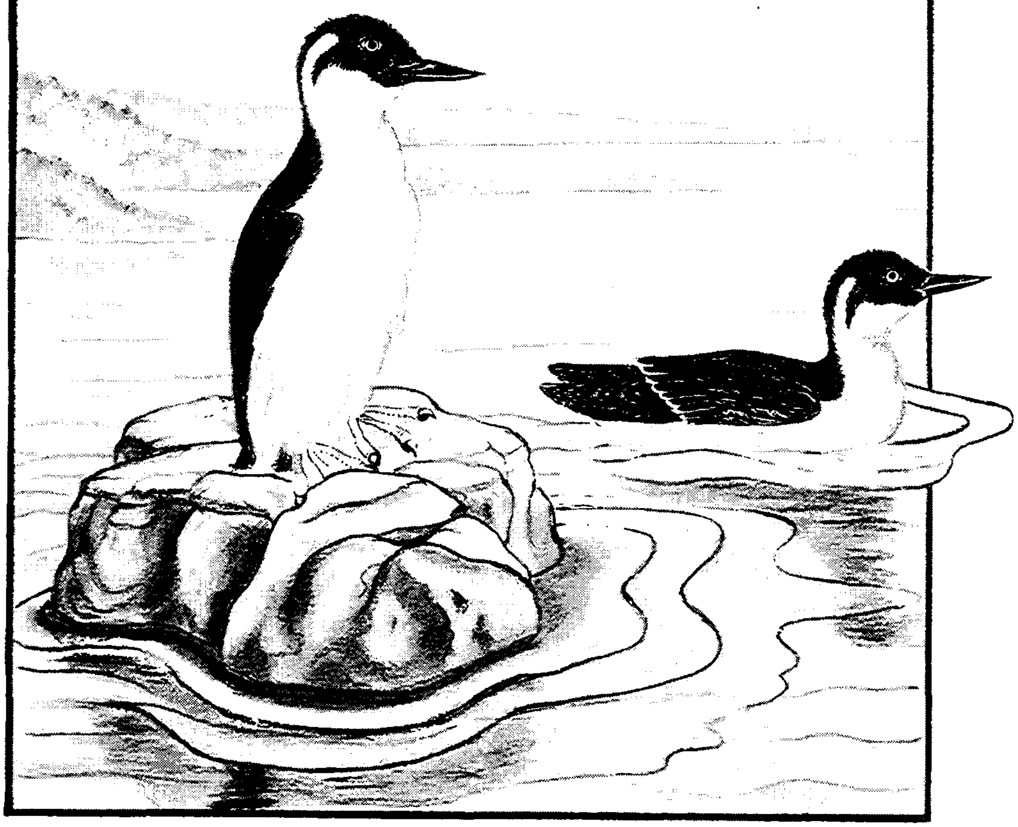
Thom, R. and L. Hallum. 1990. Compilation and characterization of Puget Sound nearshore and estuarine wetland habitat. EPA 910/9-91-005. Prepared for U.S. Environmental Protection Agency. Seattle, WA. 52 pp. + appendices.

PSAMP CONTACTS

Washington Department of Natural Resources
Tom Mumford, Ph.D.
(360) 902-1079

Data Available: Digital remote-sensing data on nearshore habitat composition and coverage over approximately two-thirds of Puget Sound, collected in 1991-1992.

BIOLOGICAL RESOURCE ABUNDANCE



WHAT DO WE KNOW ABOUT BIOLOGICAL RESOURCE ABUNDANCE?

Evaluating the effects of human activities on the abundance of natural populations is extremely difficult. Most marine populations naturally increase or decrease from year to year in response to factors such as temperature, storms, food supply, reproductive success and predation. In the midst of such natural variation, it is often difficult to distinguish changes in abundance caused by human activities from those that are a result of natural factors. It takes several years of data merely to assess the degree of natural variation among years. Even longer data records are necessary to evaluate whether a population is increasing or decreasing in response to human activities. For many populations in Puget Sound, sufficient data records do not exist.

Despite the difficulty in evaluating patterns of biological resource abundance, developing and maintaining long-term data records on marine populations is crucial, as they provide a key indicator of Puget Sound's health. In addition to numerous natural factors that affect population abundance, marine life is also affected by the results of human activities such as habitat loss or degradation, overharvesting, and chemical contamination. The decline of a population may be the first indication that human activities may

be inflicting more widespread damage. The decline of bald eagle and other raptor populations, for example, provided one of the first indicators that DDT (dichlorodiphenyl trichloroethane, a pesticide used during the 1970s) was causing widespread damage to biological populations. Similarly, the current decline of salmon populations is alerting us to the importance of maintaining the integrity of stream habitats and watersheds. While the science of monitoring the chemical, physical and biological integrity of the environment is constantly improving, there will always be effects of human activities that escape detection. Monitoring population abundance is another tool that helps ensure that human activities do not result in irreversible harm before they are recognized.

The value of Puget Sound's biological populations extends far beyond their utility as indicators of the Sound's health. Marine fish, birds, shellfish and mammals play an important role in the region's economy, ecology and culture. To many people, it is important to protect these populations because they are part of an ecosystem whose integrity and function we hope to maintain. To others, Puget Sound's marine populations represent an irreplaceable source of food and income. In either case, maintaining sufficient information about these populations is necessary to properly manage and protect them.

The data available on the abundance of biological resources suggest wide variation in the health of Puget Sound's populations. Some species, such as the spotted owl and the marbled murrelet, are on the Federal Endangered Species List. Others, including threatened salmon stocks, are being considered for inclusion on the list. At the same time, some populations are improving dramatically in response to protection and management programs. Harbor seal populations have recovered since cessation of the bounty program and implementation of the Marine Mammal Protection Act of 1972 (Calambokidis et al., 1988; PSWQA, 1991). The number of young bald eagles produced each year in the Puget Sound basin has increased by over 400 percent since 1980 (PSWQA, 1993; unpublished WDFW data).

As one would expect from an indicator as complex and poorly understood as biological resource abundance, no unifying themes or patterns exist that capture the status or trends in populations throughout the Sound. It is clear, however, that much more information is needed on the population abundance of Puget Sound's marine life. For example, we do not have consistent monitoring programs for many marine fish populations, but several indirect indicators suggest that many of these populations are seriously threatened (Schmitt and Schweigert, 1994). Monitoring programs for several populations, such as marine birds and shellfish, are in place, but it will take several more years to collect sufficient data to evaluate the health of these populations.

SUMMARY OF 1993 FINDINGS ON BIOLOGICAL RESOURCE ABUNDANCE

Monitoring population abundance in several Puget Sound species is just beginning—a stage at which it is both difficult and misleading to draw solid conclusions. However, early results are providing important preliminary findings about the status of these populations. In addition, some results from longer-term monitoring programs are available.

1993 Marine Fish Monitoring Results

Recent Washington Department of Fish and Wildlife (WDFW) data summaries indicate that many of our most prized marine fish populations are in a serious state of decline. Harvest rates of many Puget Sound fish are at their lowest level in 55 years, due to decreasing populations and increasing harvest restrictions.

1993 Marine Bird Monitoring Results

The two years of PSAMP data available on marine bird abundance provide some preliminary indications of distribution patterns:

- Bird populations in Puget Sound are more than twice as abundant in the winter as in the summer.

- Gulls are the dominant populations during summer; ducks and geese are the most numerous groups in winter. The composition of bird groups within the two seasons has been fairly consistent in the two survey years.

- Distributional patterns differ between the two seasons. During the winter, bird populations concentrate more in protected areas and along shorelines than during the summer.

The PSAMP co-sponsored intensive shorebird surveys indicate that:

- The most common shorebird species in Puget Sound during the winter is the dunlin (*Calidris alpina*), comprising over 90 percent of the shorebirds soundwide.

- Species richness (total number of species) of shorebirds has been highest in the Strait of Juan de Fuca and Admiralty Inlet over the last three surveys. The greatest numbers of shorebirds, however, occur in north Puget Sound, particularly in Port Susan, Skagit Bay, Padilla Bay and Samish Bay.

The WDFW conducted a special study on marbled murrelet populations in Puget Sound to assess population productivity by estimating the proportion of juveniles present in the population. The study suggests that the proportion of juveniles in the Puget Sound region may be higher than in Oregon and California.

The WDFW also assessed gillnet mortality among marine birds. Their sampling indicates that common murres were captured in gillnets more fre-

quently than other species, and provides a preliminary entanglement rate for the fisheries observed in 1993.

1993 Shellfish Monitoring Results

Three years of sampling indicate that of the 14 sites monitored, Dosewallips State Park has the highest concentrations of manila clams (*Tapes phillippinarum*); two sites in Sequim Bay have the highest concentrations of Native littleneck clams (*Protothaca staminea*), and Shine Tidelands and Camano Island have the highest concentrations of butter clams (*Saxidomus giganteus*). Although the three-year data record is insufficient to draw conclusions about trends in population abundance, no dramatic increases or decreases are evident.

1993 Marine Mammal Monitoring Results

Nine different gray whales were sighted in Puget Sound in 1993, compared to six in 1992 and 17 in 1991. Five of the whales sighted in 1993 were located in the Port Susan/Whidbey Island area; four were sighted in the Strait of Juan de Fuca. As in 1992, there were no strandings of dead gray whales in 1993 in Puget Sound, whereas three were stranded in 1991.

DETAILS OF 1993 FINDINGS ON BIOLOGICAL RESOURCE ABUNDANCE

Marine Fish Populations

PSAMP does not monitor the abundance of fish populations. When the program was created, harvest information and stock assessments on many fish populations existed. PSAMP chose to rely on these sources of information, and put limited funds toward monitoring other aspects of ecosystem health for which little or no information existed. Since that time however, many Puget Sound fish populations have declined, in some cases dramatically. To protect these populations, Washington state has restricted or closed the harvest of many species. While this is an effective management method for stopping and reversing those declines, it also means that information on these populations, which was derived from annual harvest rates and catch-per-unit effort statistics, is no longer available. This information is critical in assessing management success and the need for additional management actions.

The information available on marine fish abundance in Puget Sound suggests that populations are in a serious state of decline. Fish harvesting in the Sound is at its lowest level in 55 years (Schmitt and Schweigert, 1994), although this is influenced by the fact that the harvest of many species has been restricted or closed in recent years. Nevertheless, the status of nearly all populations caught commercially and recreationally is judged to be poor (Table 10).

Most marine fish populations in Puget Sound have exhibited patterns of decline in populations or in total catches (Table 10). The reasons for these declines are poorly understood, and probably vary among species. Commercial and recreational harvest pressures increased through the 1980s as the human population and interest in fishing grew, and for many popula-

Table 10. The health of Puget Sound marine fish populations.

Summarized from Schmitt and Schweigert (1994). Status designations based on best professional judgement of authors.

Species	Status	Description	Harvest Limitations
Pacific Herring	low	Commercial catches peaked at approximately 6,000 metric tons per year in 1975, but has declined to less than 500 tons in 1984. Catches have remained stable since reaching low.	Reduction (for fish meal) and sac roe fisheries closed in early 1980s.
Pacific Hake	very low	Stock biomass peaked in 1983 at approx. 15,000 metric tons; declined to a low of 4,000 metric tons in 1992. Current estimates lower than 4,000 tons.	Closed since 1987-88 due to low stock levels. Fishery is closed when total adult abundance is below 12 million pounds.
Pacific Cod	very low	Severe decline in abundance throughout the 1980s.	Commercial set net fishery closed in 1987 due to low abundance. In 1991 the recreational fishery in Agate Passage was closed; daily bag limit for recreational catch was reduced from 15 to two fish in central and southern Sound; bottom trawl was prohibited at Protection Island and Port Townsend.
Pollock	low	Although abundance estimates are not available, abundance of southern stocks considered very low based on harvest and catch per unit effort data. Severe decline in 1980s thought to be due to poor recruitment and harvest pressures. At one time was one of the most numerous marine fish in recreational fishery; is now one of the least common.	Daily recreational bag limits reduced from 15 to five fish in 1990.
Dogfish	average to high	Populations appear healthy and possibly expected to increase, partly due to low harvest rates relative to population size.	No closures or restrictions. Harvested commercially in trawl, longline, and set net fisheries. Currently accounts for half of total groundfish catch in Puget Sound.
Lingcod	very low	Severe decrease in total catch and catch rate suggest that populations underwent dramatic decline during the 1980s. Total catch presently less than 50 metric tons.	Commercial handline jig and bottomfish troll fisheries closed in 1992, other commercial and recreational fisheries severely restricted to promote rebuilding of lingcod resources.
Rockfish	low	Recreational catch rates and sizes of rockfish have declined consistently for several years, particularly around San Juan Islands and southern Puget Sound. Rockfish susceptible to overharvest because of slow growth and maturation, and ease of harvest.	Commercial limits increasingly reduced (pounds reduced). Recreational limits adopted in 1994.
English Sole	low to average	Populations relatively healthy and stable, with the exception of Discovery Bay and Bellingham Bay.	Bottom trawling south of Port Townsend closed in 1989, preventing harvest of English sole.

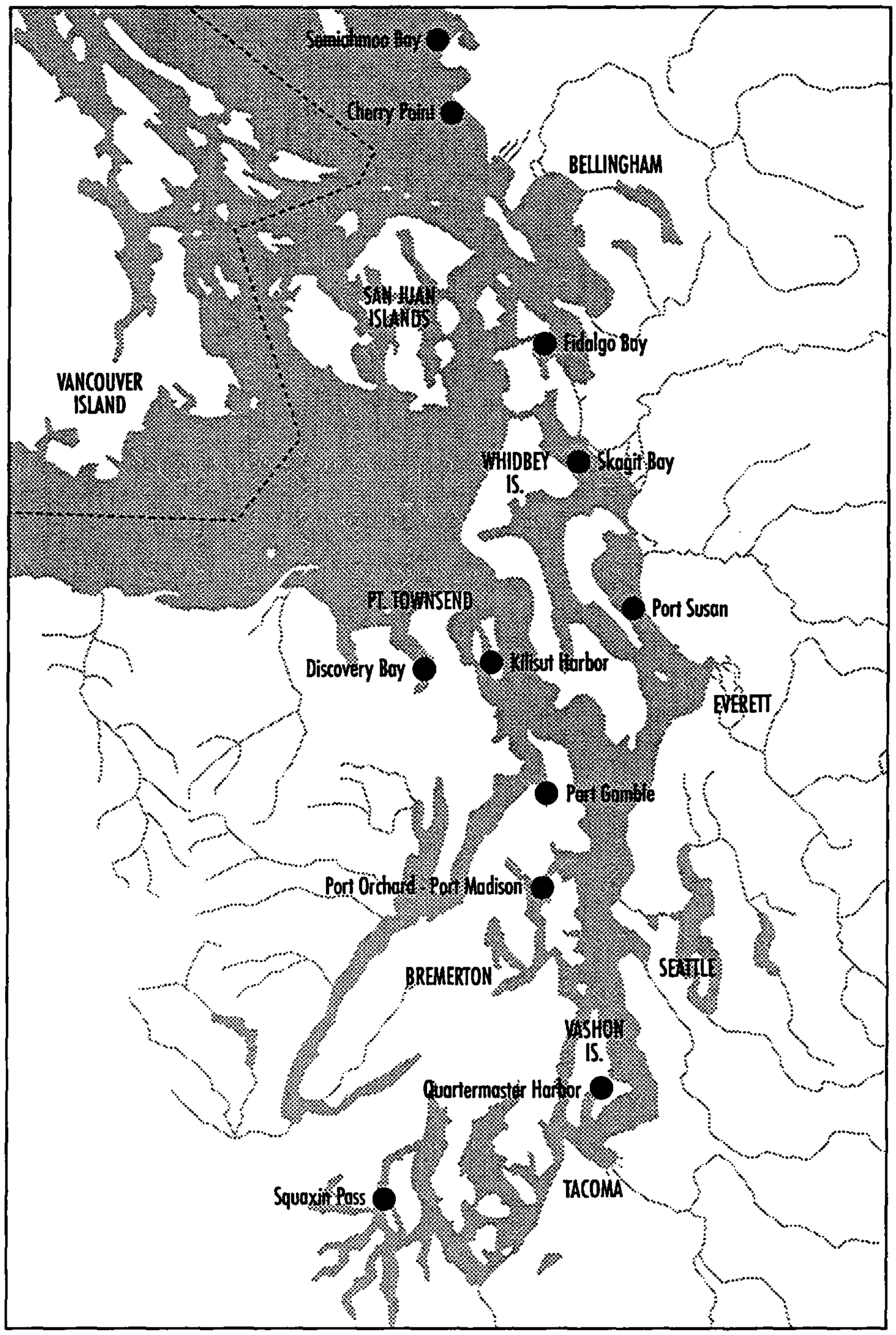
tions this was probably the primary factor driving the declines in the early 1980s (Schmitt and Schweigert, 1994). Harvest restrictions and closures have greatly reduced harvest pressures on many populations since then, yet most of these populations remain at low levels. Additional factors have probably kept these populations from recovering, as populations at low levels are particularly susceptible to stresses that in healthy populations might be inconsequential. Additional factors that may have contributed to population and

fisheries declines and that may be preventing recoveries include loss and degradation of eelgrass beds and other critical nearshore habitats, predation pressures from increasing marine mammal populations, and unfavorable environmental conditions such as warmer winter temperatures.

Pacific Herring

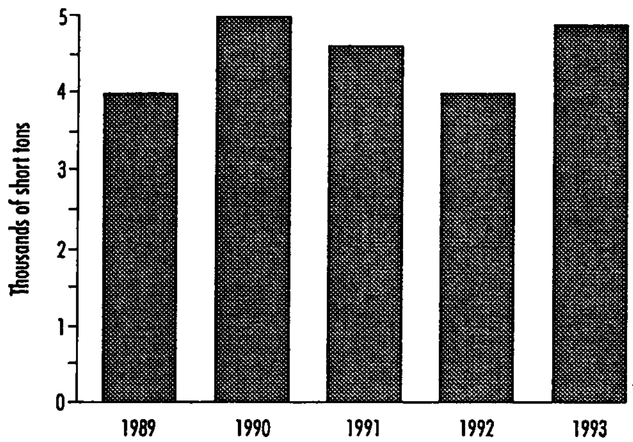
Pacific herring (*Clupea pallasi*) are an integral component of the Puget Sound ecosystem. They are an important food source for birds, marine mammals, salmon, and other fishes. Herring generally return to the same spawning area each year and, as with salmon, each spawning ground is thought to

Figure 33. Major Puget Sound herring spawning stocks.



Reference: WDFW, unpublished data

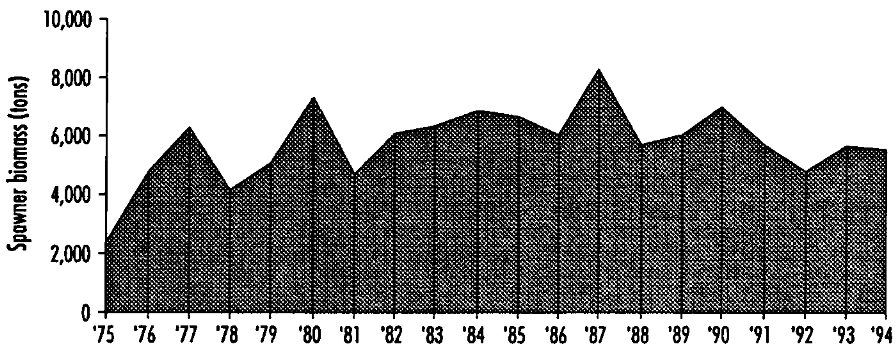
represent a distinct stock (O'Toole, 1989).



Reference: *Stick, 1993*

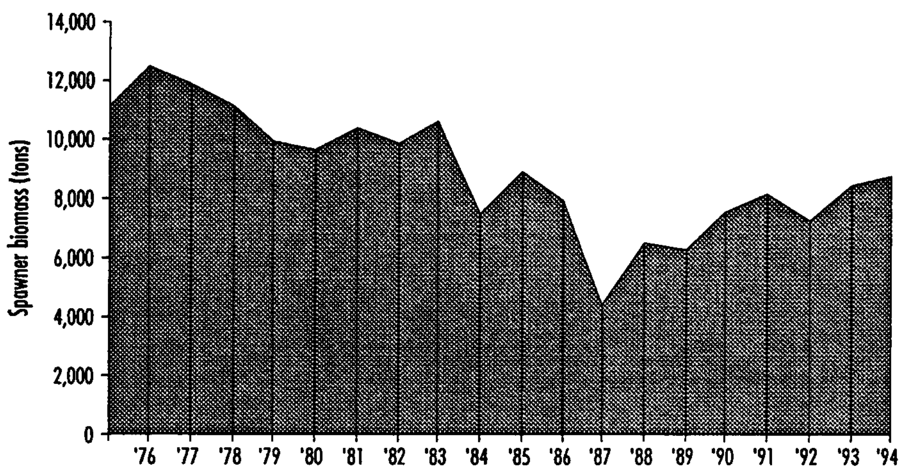
Figure 34. Total spawner herring biomass at Cherry Point, 1989 - 1993.

The Baitfish Unit of the WDFW estimates herring spawning stock abundance through spawn deposition surveys and hydroacoustic trawl surveys. The WDFW has identified 11 major herring stocks in Puget Sound (Figure 33), and several smaller ones. Cherry Point in Whatcom County contains Puget Sound's largest herring stock (Stick, 1992), which has averaged a total spawner biomass of approximately 4,000 tons since 1989 (Figure 34). Long-term monitoring of adult populations in Puget Sound indicates stability among herring populations in southern and central Puget Sound since 1975 (Figure 35). Populations in north Puget Sound, however, appear to be recovering from low numbers in 1987 (M. O'Toole, WDFW, pers. comm.) (Figure 36).



Reference: WDFW, unpublished data

Figure 35. Adult herring population estimates for south and central Puget Sound, 1975 - 1993.



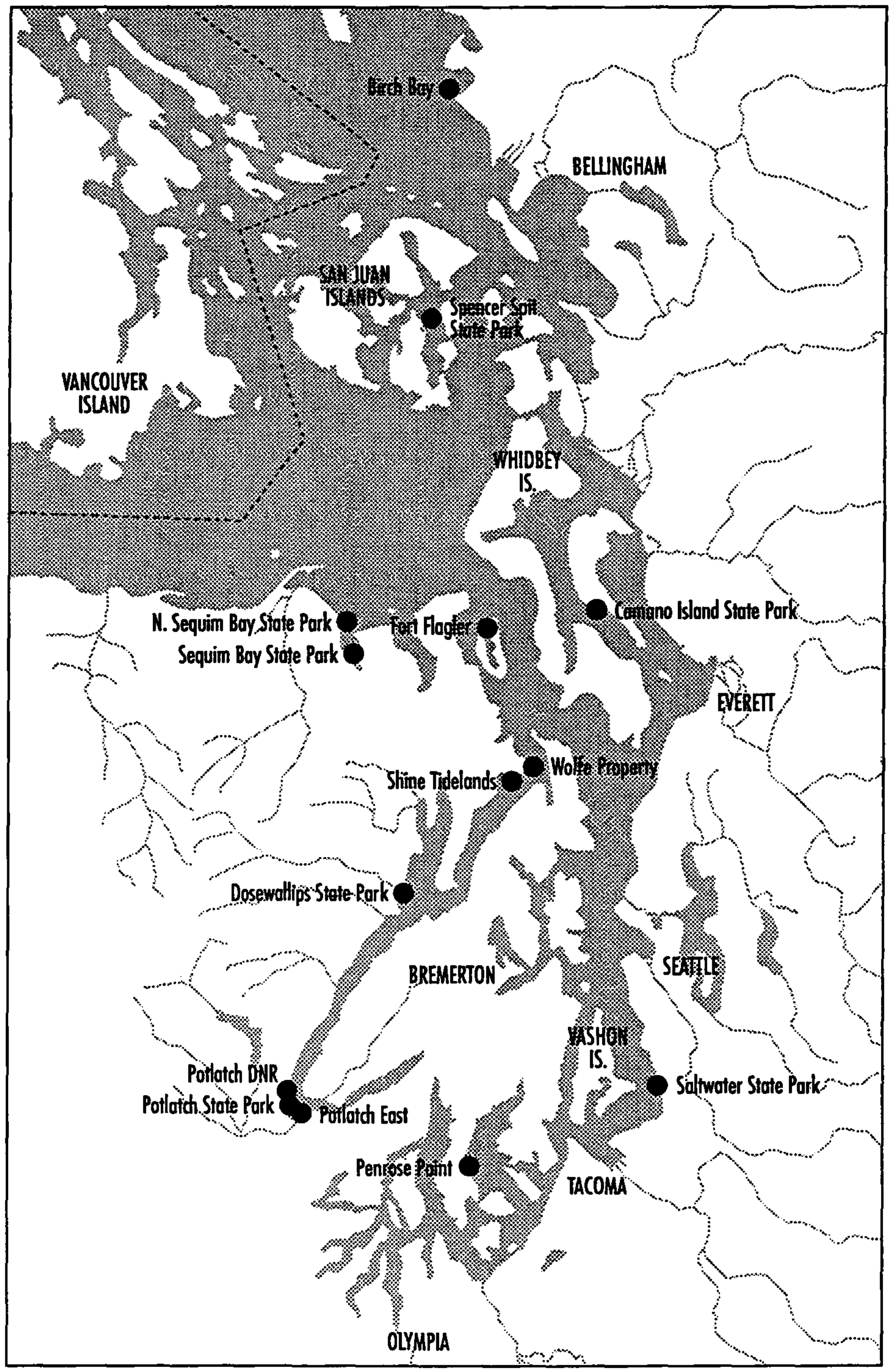
Reference: WDFW, unpublished data

Figure 36. Adult herring population estimates for north Puget Sound, 1975 - 1993.

Shellfish Populations

The Washington Department of Fish and Wildlife annually surveys clam and oyster populations on public beaches to estimate their abundance. The WDFW uses these surveys for setting harvest levels which prevent overharvesting and ensure that sufficient adult shellfish remain to maintain the population. The PSAMP tracks the results of abundance surveys from 14 of the beaches sampled by the WDFW as one measure of shellfish resource abundance. These beaches are located around the Sound at popular recreational harvest locations in state parks (Figure 37).

Figure 37. State parks monitored for shellfish resource abundance.



Reference: WDFW, unpublished data

The WDFW has collected three years of data on clam (Figure 38) and oyster (Figure 39) abundance. The three years of sampling indicate that, of the sites monitored, Dosewallips State Park has by far the highest concentration of Manila clams (*Tapes philippinarum*). Dosewallips State Park was closed to harvest over the three sampling periods, which may account for the higher numbers. The Department of Health (DOH) has since re-opened part of the park to harvest, so that the three years of data will provide a valuable baseline for evaluating the effects of harvest on shellfish abundance. The two sites monitored in Sequim Bay had the highest concentrations of Native littleneck clams (*Protothaca staminea*) over the three years, and the Shine Tidelands and Camano Island had the highest concentrations of butter clams (*Saxidomus giganteus*).

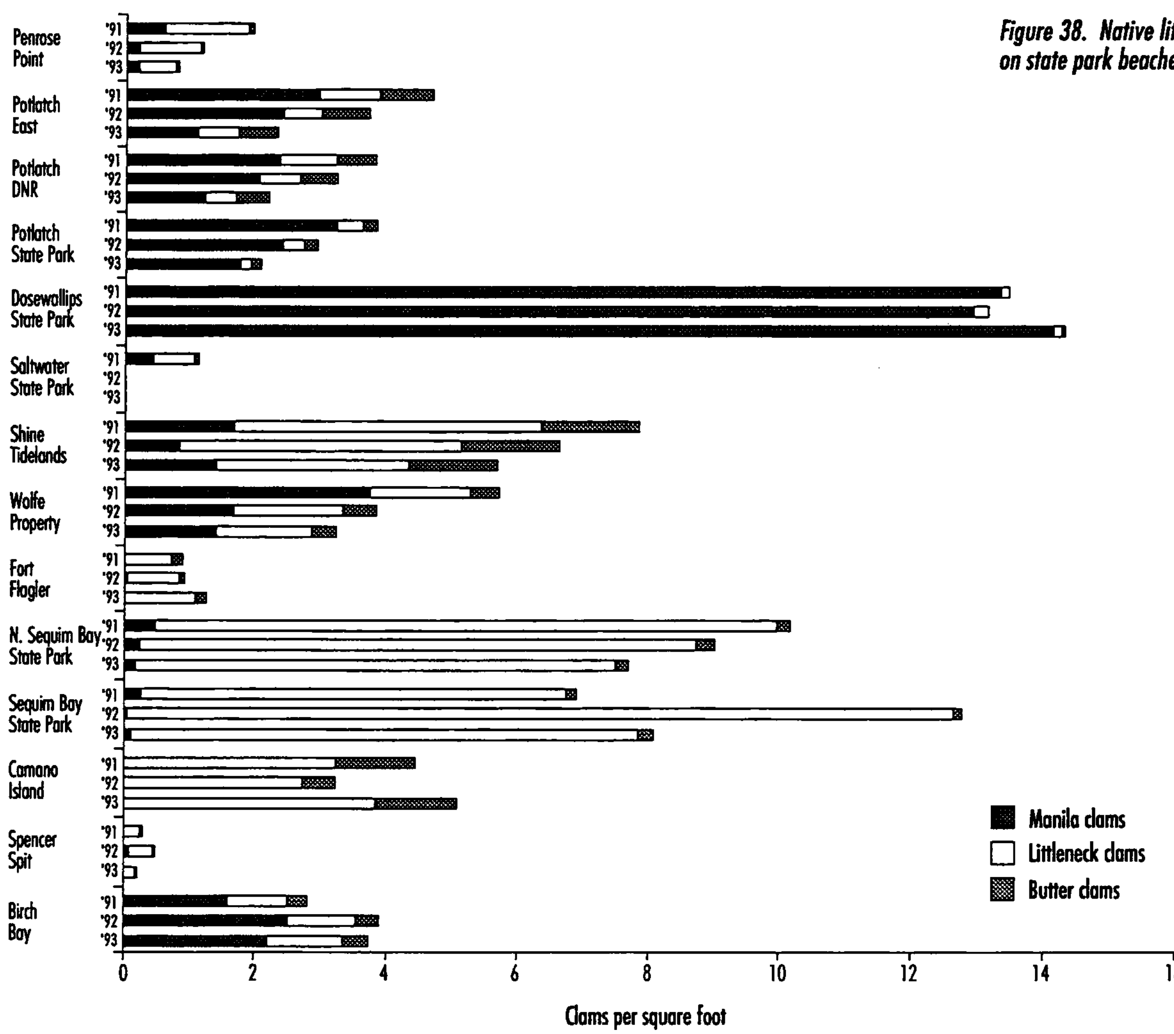
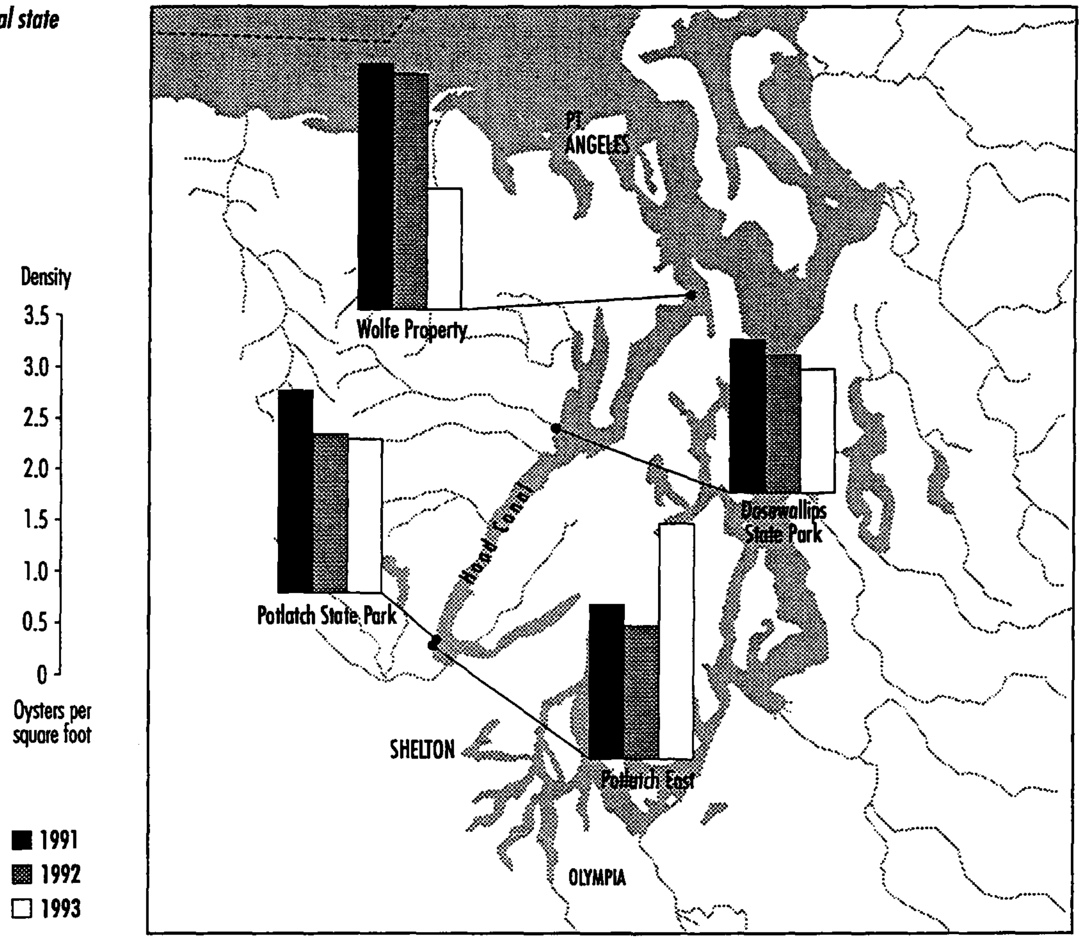


Figure 38. Native littleneck clam densities on state park beaches.

Reference: DOH, in prep.; WDFW, unpublished data

The data generally show a good deal of variability in shellfish abundances between years. Although a three-year data record is not sufficient to draw conclusions about trends in the abundance of natural populations, no dramatic increases or decreases are evident. The number of shellfish, as with most biological populations, varies among years in response to environmental factors. Thus what appear to be short-term increases or decreases result-

Figure 39. Oyster densities at several state park beaches, 1991 - 1993.



Reference: DOH, in prep.; WDFW, unpublished data

ing from changes in harvest pressures may in fact be responses to cyclical patterns in weather, food supply, recruitment success and other factors unrelated to human activities. For this reason, the first few years of population abundance data are best used for establishing baseline conditions and assessing spatial variability. Although it differs greatly among populations, ten years is often considered a minimum data record for conducting trend analyses to determine population changes over time.

Marine Bird Populations

Since 1992 the Washington Department of Fish and Wildlife has been surveying marine birds in Puget Sound. The WDFW flies transects throughout Puget Sound and counts and identifies all birds seen along these transects. WDFW scientists use these numbers to estimate the total number of each species found in the Sound, and to determine how population densities vary throughout the Sound.

The WDFW surveys birds in summer (July-August) and winter (December-February) to determine seasonal variations in population abundances, and to census migratory species that may be present in the Sound for only part of the year. Data from four WDFW surveys have been completed and processed: summer 1992, winter 1992-93, summer 1993 and winter 1993-94.

In the data analyzed so far, the WDFW has documented the following patterns (Nysewander et al., in prep.):

General

- Puget Sound's bird population is much more numerous in the winter than in the summer. Winter populations ranged from 2.5 to five times the abundance of summer populations during the two years of study. Distributional patterns and species composition also differed dramatically for certain migratory species during the two seasons.

Summer

- Gulls (*Larus* spp.) and terns are by far the most numerous bird group, accounting for over 70 percent of the bird species observed (Figure 40). The most numerous species within this group were Glaucous-winged gulls (*Larus glaucescens*), Bonaparte's gull (*L. philadelphia*), Heermann's gull (*L. heermanni*) and California gull (*L. californicus*). Gull and tern flocks were generally distributed along shorelines, with feeding flocks of certain species (e.g., Heermann's gull) concentrating in central and northern Puget Sound.

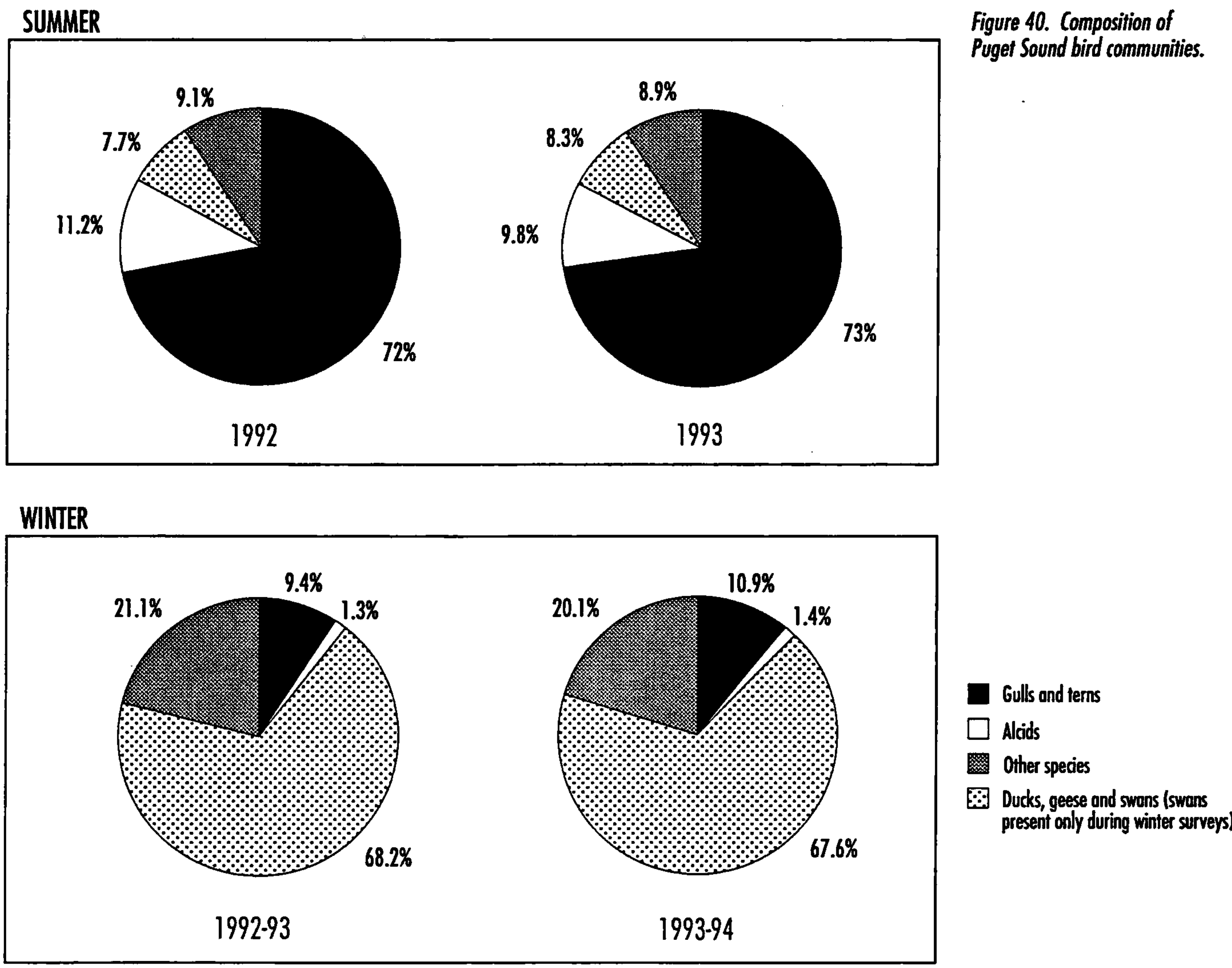


Figure 40. Composition of Puget Sound bird communities.

Reference: Nysewander et al., in prep.

- Alcids were the second most numerous bird group in the summer, accounting for approximately 10 percent of all birds observed. Common murres (*Uria aalge*), rhinoceros auklets (*Cerorhinca monocerata*) and pigeon guillemots (*Cepphus columba*) were the most commonly observed species in both summer surveys. Feeding flocks of larger species of alcids, such as murres and auklets, were generally seen in the deeper waters of central and north Puget Sound, while the smaller species, such as pigeon guillemots and marbled murrelets, associated more closely with nearshore areas.

- Ducks and geese comprised approximately eight percent of all birds observed in both summer surveys. Molting and feeding flocks of ducks tended to be found along shorelines and river deltas.

Winter

- Larger numbers of birds were found in south Puget Sound during the winter than in the summer.

- Ducks, geese and swans increased dramatically in the winter, comprising approximately 68 percent of all birds observed. Waterfowl density increased along shorelines and river deltas. The Skagit River Delta and Padilla Bay had particularly large numbers of waterfowl and geese.

- Grebes and loons migrated into the Sound. They tended to be found in protected areas with deeper waters and low currents. Common locations included south Puget Sound, Bainbridge Island, Whidbey and Camano islands, Bellingham, Padilla Bay, and portions of the San Juan Islands.

As with most biological populations, the two years of PSAMP data provide important baseline information but cannot be used to draw conclusions about changes in population size over time—establishing trends will require far longer data records. The two years of data do show some temporal patterns of interest, however. The overall percent composition of the major bird groups appears remarkably consistent between years (Figure 40), with little variation evident in the two years of study. There were notable differences, however, in patterns of distribution during the two years of surveys. These differences generally related to varying weather patterns and differences in the timing of annual migrations (Nysewander et al., in prep.).

The WDFW also performed important quality assurance work during the 1993-94 surveys. Aerial surveys are a cost-effective method of counting bird populations over large areas, such as Puget Sound. As with almost any form of environmental sampling, however, this method contains some biases and inaccuracies. As such, it is important to evaluate and correct for any biases, and to be able to evaluate the accuracy of the results. Biases in aerial surveys of birds may result from:

- Cryptic coloration in some species that may make them harder to spot than more brightly colored species.

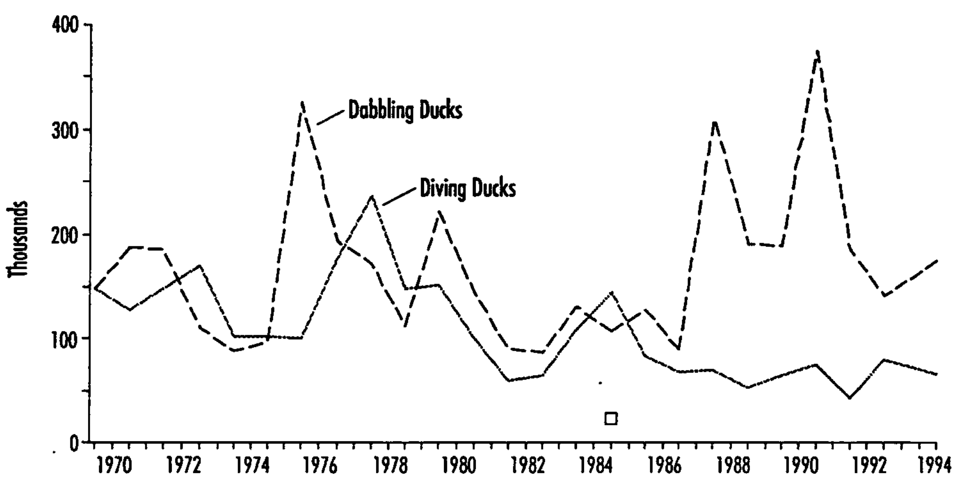
- Behavioral avoidance in species that may be frightened by overfly-

ing planes (particularly true of some diving species).

- High variability in censuses of highly aggregated species, which may be over- or underestimated because of the percentage of flocks that happen to be located along transect lines.

The WDFW conducted some quantitative evaluations of these biases in its aerial surveys by performing simultaneous boat surveys. This enabled the agency to derive correction factors from extensive comparisons of the results from the two methods. These correction factors will help the WDFW make its estimates of total Puget Sound population sizes more accurate, and will help in comparing PSAMP data to other surveys. The WDFW will continue to develop and refine these correction factors in the future.

The WDFW conducts more intensive surveys of waterfowl populations to support harvest management of these species. Long-term data records since 1970 indicate considerable variability among years in waterfowl populations. There are some indications of increases and decreases over time, although these should be interpreted with caution as they have not been evaluated statistically for trends. Since the late 1980s, there is some indication that dabbling ducks may be increasing (Kraege, 1990). In contrast, numbers of diving ducks have appeared to decrease since 1978, although methodology changes in 1986 limit comparison of data before and after this time (Figure 41). Trumpeter Swans (*Cygnus buccinator*) appear to be increasing over the last 15 years, with numbers doubling in some areas. Brant (*Branta bernicla*) populations were as low as 3,000 when hunting was closed in 1981. When hunting reopened in 1987, the population had risen to 16,000. Since then, the population has ranged between 10,000 and 14,000 (Nysewander et al., in prep.).



Reference: Nysewander et al., in prep.

Figure 41. Abundance of ducks in Puget Sound.

□ ***Note: Survey methods for diving ducks changed from plots to overall census after 1985.***

Mahaffy et al. (1994) also evaluated some apparent changes over time in several Puget Sound bird populations (Table 11). These changes should be interpreted with caution, since the population size of birds may vary considerably, and because many of these observations compare populations between two censuses, rather than over a continuous time series as is required to support trend analysis.

*Table 11. Temporal patterns in several Puget Sound bird populations.**

Population	Temporal Pattern	Source
Pigeon guillemots, rhinoceros auklets, Pelagic cormorants, and black oystercatchers at the San Juan Islands and Protection Island National Wildlife refuges.	Appear to have stable populations. Rhinoceros auklets have only been sampled three times since 1976, so that temporal patterns are not well-defined.	Unpublished USFWS data, Nisqually Wildlife Refuge
Double-crested cormorants at the San Juan Islands and Protection Island National Wildlife refuges.	Increased slightly.	Unpublished USFWS data
Glaucous-winged gulls on Protection Island	Increased approximately four percent per year during the early 1980s; populations stable since then.	Galusha et al., 1987; J. Galusha, unpublished data
Glaucous-winged gulls in urban areas	Increased in recent years.	Eddy, 1982; Wahl, pers. obs.
Tufted Puffins nesting on Protection, Smith, and San Juan islands	Declined from historical levels of 1,066 to 74 in 1989. Only 13 nesting pairs on Protection Island in 1993. Numbers consistently low for the last 20 years in most sites in eastern Strait of Juan de Fuca and San Juan Islands.	U. Wilson, unpublished report; Speich and Wahl, 1989
Bald Eagles in Puget Sound	Occupied nesting territories have increased from 57 in the 1980s to 216 in 1992.	PSWQA, 1993
Peregrine Falcons in San Juan Islands	Increased from one territory in 1980s to nine in 1992.	Watson and McAllister, 1992
Ospreys	Statewide territories have increased 220 percent from 1984 to 1989. "Much of this increase took place in the greater Puget Sound area."	Watson and McAllister, 1992

** From Mahaffy et al. (1994). Descriptions should not be used to imply statistically significant trends, as the appropriate statistical analyses have not been performed.*

Shorebird Populations

The WDFW aerial surveys typically underestimate the number of shorebirds because these species are concentrated in a thin strip along the shoreline (Nysewander et al., in prep.). In order to provide more accurate assessments of shorebird populations in Puget Sound, the WDFW contracted the Cascadia Research Collective to conduct land-based winter counts of shorebird abundance, and to perform focused aerial flights in areas difficult to reach by land. Combined with Cascadia surveys conducted in the winter of 1990-91, three years of information on shorebird abundances are now available.

Cascadia Research observed a total of 19 species over the three years in which shorebird surveys occurred (Table 12). The most abundant species by far was the dunlin (*Calidris alpina*), comprising an average of approximately 94 percent of all the individuals sighted over the three years. This proportion showed little variation over the three winters, and is consistent with eight years of observations in Totten Inlet (Buchanan, 1988). The dunlin is clearly the predominant shorebird species in Puget Sound. Wintering populations regularly exceed 50,000 birds (Evenson and Buchanan, 1994).

Cascadia Research divided Puget Sound into four regions to assess spatial patterns of abundance (Figure 42). Over three years of sampling, Cascadia's researchers found the highest species richness (the average number of species found at a site) in the Strait of Juan de Fuca and Admiralty Inlet

region, and lowest in the Hood Canal region. Seventeen of the 19 species observed throughout Puget Sound were found in the Strait of Juan de Fuca and Admiralty Inlet region. The northern Puget Sound region had the highest total number of birds. This was due to high numbers of shorebirds at Port Susan, Skagit Bay, Padilla Bay and Samish Bay. In the three winters studied, all counts of more than 10,000 birds occurred at these sites. The high numbers of birds in these areas may reflect extensive foraging and roosting habitat at those sites (Evenson and Buchanan, 1994).

Table 12. Shorebird species observed during 1990-94 winter counts.

Shorebird species

Spotted Sandpiper	*Actitis macularia*
Surfbird	*Aphriza virgata*
Ruddy Turnstone	*Arenaria interpres*
Black Turnstone	*Arenaria melanocephala*
Sanderling	*Calidris alba*
Dunlin	*C. alpina*
Western Sandpiper	*C. mauri*
Least Sandpiper	*C. minutilla*
Least/Western/Dunlin	*C. minutilla, C. mauri & C. alpina*
Rock Sandpiper	*C. ptilocnemis*
Willet	*Catoptrophorus semipalmatus*
Semipalmated Plover	*Charadrius semipalmatus*
Killdeer	*Charadrius vociferus*
Black Oystercatcher	*Haematopus bachmani*
Long-billed Dowitcher	*Limnodromus scolopaceus*
Dowitcher spp.	*L. scolopaceus or L. griseus*
Whimbrel	*Numenius phaeopus*
Black-bellied Plover	*Pluvialis squatarola*
Lesser Yellowlegs	*Tringa flavipes*
Greater Yellowlegs	*T. melanoleuca*

Reference: Evenson and Buchanan, 1994

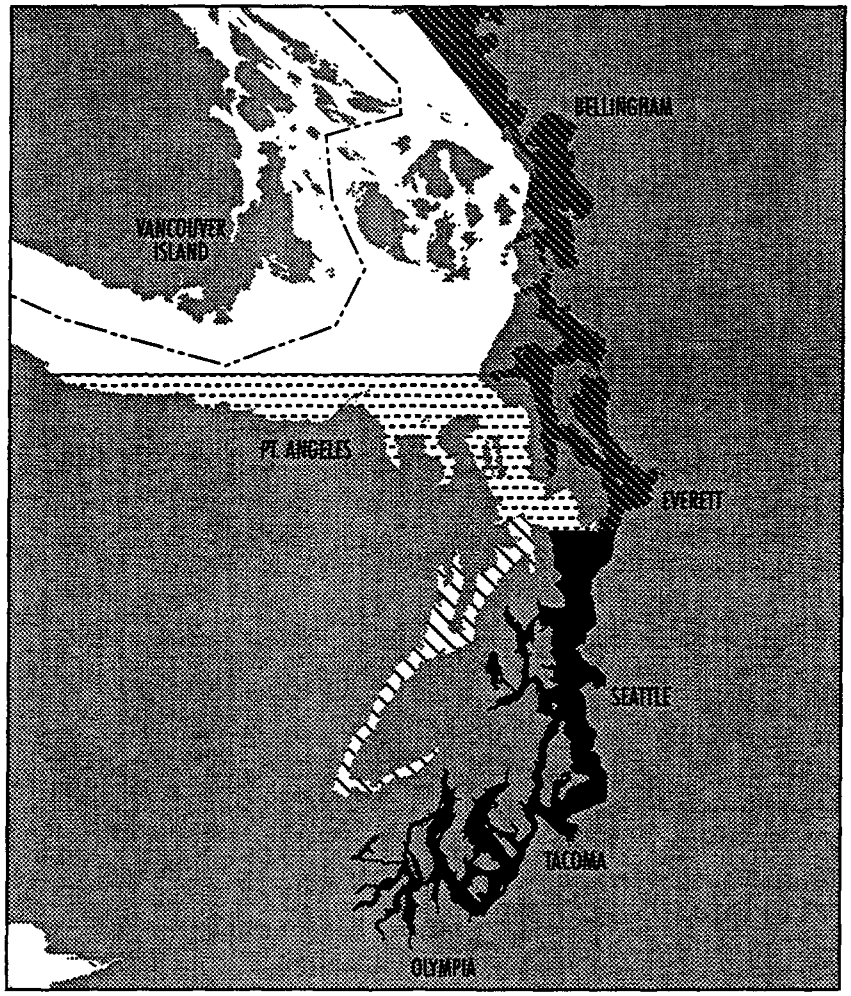
The numbers obtained from this study cannot be used to provide an accurate estimate of the total number of shorebirds in Puget Sound. Surveys of each site took place over several weeks, and movements of shorebirds among sites would make such an estimate inaccurate (Evenson and Buchanan, 1994). However, the numbers do provide a rough indicator of spatial patterns of shorebird abundance throughout the Sound, and a general indicator of how this changes over time. The patterns of abundance at the sites with the most shorebirds over the last three years (Figure 43) make it evident that there is considerable variation over time at any particular site. Some of this variability is probably due to differing use of sites by birds among the years, annual variability in the total number of shorebirds present in Puget Sound, effects of adverse weather, and movement among sites.

Other Studies on Bird Populations in Puget Sound

Marbled Murrelets

In 1992, the federal government listed the marbled murrelet (*Brachyramphus marmoratus*) as a threatened species in Washington, Oregon, and California due to low numbers and a decline in nesting habitat (Mahaffy et al., 1994). Marbled murrelets nest in old growth forests. The dramatic reductions in these habitats are considered one of the primary reasons for declines in marbled murrelet populations. Accurate population counts and quantitative evaluations of factors causing declines in this species are lacking, however. Better protection may be forthcoming, thanks to current monitoring efforts that will provide much-needed information on marbled murrelets and the threats to their population.

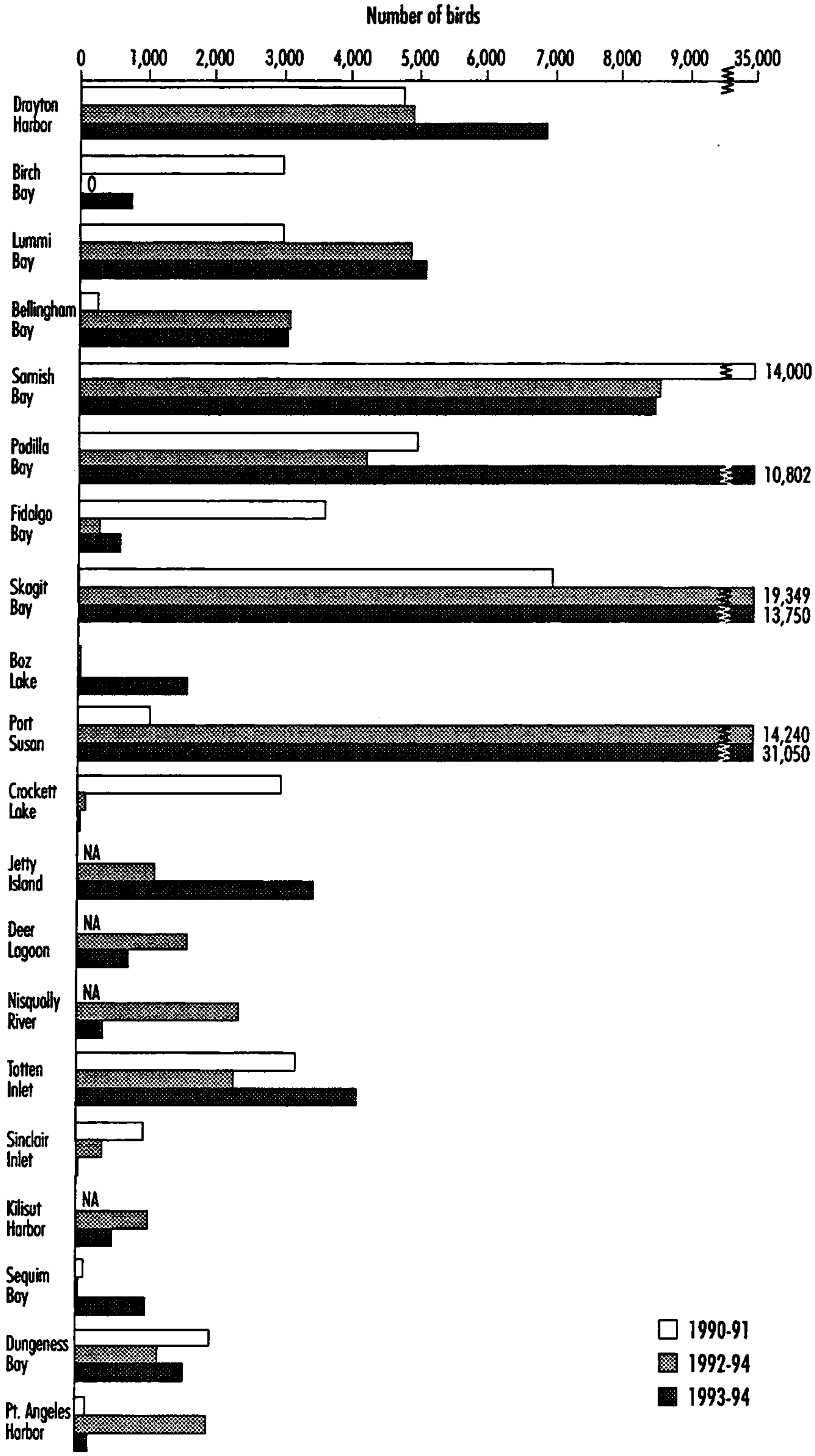
Figure 42. Puget Sound study area where shorebird counts were conducted during winter 1993-94.



- Northern Puget Sound
- Strait of Juan de Fuca & Admiralty Inlet
- Central and Southern Puget Sound
- Hood Canal

Reference: Evenson and Buchanan, 1994

The WDFW recently completed a study evaluating the proportion of juvenile marbled murrelets present within Puget Sound populations (Stein, 1994). Recent studies suggest that marbled murrelets are experiencing very low recruitment rates (Strong et al., 1992). Measuring the proportion of juveniles within the population provides an indirect indicator of breeding success, as low percentages of juveniles suggests that few young are produced or survive. The WDFW conducted boat surveys in several areas throughout Puget Sound. They found that juveniles composed from 8.2 to 11.9 percent of the populations surveyed. This estimate was considerably higher than the proportion observed in studies from Oregon (2.5 to three percent; Strong et al., 1993) and California (less than three percent; Ralph and Long, unpublished data), and in keeping with estimates of 10 percent from Clayoquot Sound in British Columbia (Manley and Kelson, unpublished data). This estimate suggests that breeding success may be higher within Puget Sound than in some of the other areas studied. However, the WDFW also noted several differences in the studies that may in part explain the higher proportions observed in this study. If funding is available, the WDFW will continue these surveys in the future to improve the accuracy of its estimates and provide an indicator of year-to-year fluctuations in the productivity of this threatened population.



Reference: Evenson and Buchanan, 1994

Figure 43. Puget Sound sites with ≥1,000 shorebirds during winter shorebird counts, 1990 - 1994.

Gillnet Mortality in Seabirds

While the destruction of nesting habitat is considered the primary factor causing population declines in marbled murrelets, other factors, such as oil spills and mortality caused when the birds become tangled in fishing nets, may further affect the population. Diving birds in particular are susceptible

to capture and entanglement in fishing nets. This source of mortality has been documented in other areas, but quantitative estimates of the incidental capture of marine birds in Washington state are lacking.

The WDFW recently completed a preliminary study of seabird mortality resulting from capture in non-treaty salmon gillnets (Ritchie et al., 1994). The agency initiated the study to provide information on marbled murrelet mortalities caused by net fisheries, but also collected data on capture and mortality of other marine birds and marine mammals. The WDFW placed trained observers on several commercial gillnet fisheries boats using various gillnetting methods and gear, and catching different salmon species.

The WDFW emphasized that the results of this preliminary study should be interpreted with caution. Observer coverage of the fishery was extremely low, as the WDFW observers were present for an average of 1.5 percent of the total fishing effort. This is particularly problematic in trying to estimate mortality in a species as rare as the marbled murrelet—the chances of capturing rare birds with a low sampling percentage are small. Nevertheless, the study provides some preliminary indications of gillnet mortality in marine birds, and the WDFW may use the results to refine further studies.

Within the small percentage of the gillnet fishery observed, the WDFW observed no marbled murrelets captured within gillnets. However, the WDFW did observe entanglement of other marine bird species. A total of 91 dead and 18 live birds were captured in gillnets over the observation period. In addition, two dead harbor seals were captured in gillnets. Of the marine birds captured in gillnets, common murres had the highest percentage of entanglement (89 captured; 82 percent of total number of birds caught). Western grebes (*Aechmophorus occidentalis*) (11 captured; 10 percent), rhinoceros auklets (four captured; four percent), loons (*Gavia* spp.) (two captured; two percent), and other species (three captured, three percent) were also entangled over the study period.

The WDFW derived a preliminary entanglement-rate estimate of 0.17 birds captured per gillnet set. The WDFW also analyzed additional factors affecting entanglement rates (e.g., target fishery, time of day, net type), but the sample sizes were small for these analyses, and will require further sampling for reasonable confidence in any patterns observed.

While the preliminary nature of this study probably yields as many caveats as it does conclusions, it is important because it is a beginning effort to provide some quantitative estimates of gillnet mortality on marine birds in Puget Sound. In particular, the high percentage of common murres captured in gillnets during this study warrants further investigation, as populations of this species are thought to be in a state of decline (Mahaffy et al., 1994). The WDFW provided several recommendations for improving the accuracy of these estimates, and for improving estimates of entanglement rates of rare birds such as marbled murrelets.

Marine Mammal Populations

Gray Whales

The PSAMP funded the Cascadia Research Collective to track gray whales (*Eschrichtius robustus*) within Puget Sound in 1993. Cascadia tracks movement patterns of individual gray whales using unique markings on their skin. Biologists need this information to estimate how many whales visit Puget Sound, their movement patterns, their length of stay in the Sound, and the mortality rate of whales that visit the Sound. Information on movement patterns also supplements the data on contaminants in gray whale tissues collected by the National Marine Fisheries Service. By tracking each individual's movement patterns within Puget Sound, scientists can determine whether whales that died spent prolonged periods feeding in areas of potential contamination.

Cascadia found nine different gray whales in Puget Sound in 1993, as compared to six in 1992 and 17 in 1991. Five of the whales sighted in 1993 were located within the Port Susan/Whidbey Island area and four were located in the Strait of Juan de Fuca. As in 1992, there were no gray whale strandings in Puget Sound during 1993, whereas three gray whales were stranded in 1991.

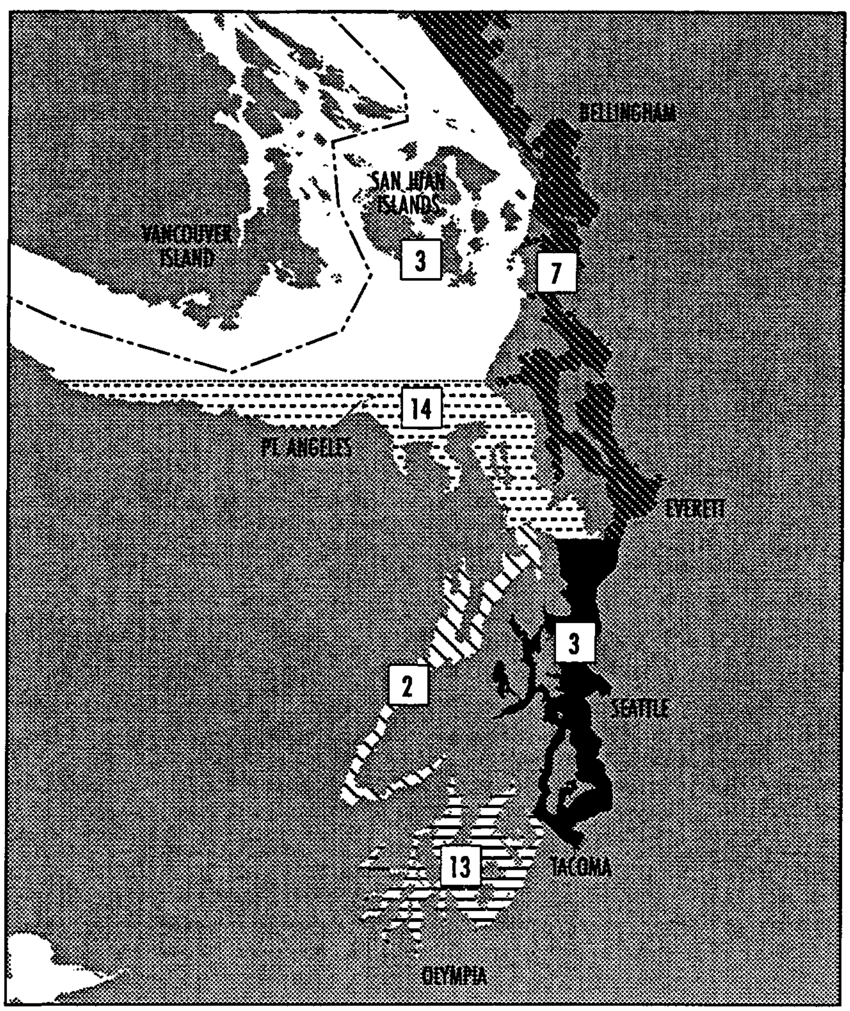


Figure 44. Total number of individual gray whales sighted in different regions of Puget Sound, 1984 - 1993.

- Northern Puget Sound
- Strait of Juan de Fuca & Admiralty Inlet
- Central Puget Sound
- Southern Puget Sound
- Hood Canal

Reference: Calambokidis et al., 1994

Between 1984 and 1993, Cascadia Research identified 41 different individual gray whales in Puget Sound (Calambokidis et al., 1994). The highest number of individuals was found in the Strait of Juan de Fuca and in south Puget Sound (Figure 44). However, gray whales appear to use north Puget Sound most extensively, particularly the Port Susan and Whidbey Island area, where the same individuals often return over several years and stay for extended periods.

As the Cascadia Research Collective continues to accumulate data on gray whale abundance and movement patterns, it is finding out more about the whales and the role that Puget Sound plays in the ecology of these migratory animals. Cascadia Research has found that many individuals are sighted on more than one occasion, and that the time between sightings may be considerable (i.e., several months). This suggests that gray whales visiting Puget Sound stay for extended periods, and do not enter merely in the process of migrating to other areas.

Two different patterns of use are apparent for gray whales that enter Puget Sound. Gray whales found in the Port Susan and Whidbey Island area tend to be individuals previously sighted in this area. Individuals that are found dead in this area tend to be transients that have not been previously sighted within Puget Sound. In contrast, gray whales sighted in south Puget Sound are generally transients that were not seen in previous years. They seem to have a higher rate of mortality than whales sighted in the Port Susan and Whidbey Island area (Calambokidis et al., 1993). There is not enough evidence at present to determine whether gray whales in poor health tend to migrate towards south Puget Sound, or whether conditions in the south Sound induce higher mortality rates.

RESOURCES AVAILABLE FOR ASSESSING THE ABUNDANCE OF BIOLOGICAL RESOURCES

PSAMP Reports

Marine Birds

Evenson, J. 1993. Census results of 1992 winter shorebird counts from Puget Sound, Strait of Juan de Fuca, and Willapa Bay. Cascadia Research Collective. Olympia, WA. 20 pp.

Evenson, J. and J. Buchanan. 1994. Shorebird abundance at greater Puget Sound estuaries: results from winter 1993-1994 aerial and ground-based counts. Cascadia Research Collective. Olympia, WA. 22 pp.

Nysewander, D., M. Nixon, and J. Stein. In preparation. Puget Sound ambient monitoring program: progress report of the marine bird, waterfowl, and marine mammal monitoring project, covering July 1992 to March 1994. Wildlife Management Division, Washington State Department of Fish and Wildlife. Olympia, WA. 84 pp.

Puget Sound Water Quality Authority (PSWQA). 1993. Puget Sound update: fourth annual report of the Puget Sound ambient monitoring program. Puget Sound Water Quality Authority. Olympia, WA. 89 pp.

Marine Mammals

Calambokidis, J., J.R. Evenson, and S.J. Jeffries. 1993. Monitoring of gray whales in Puget Sound and surrounding waters, 1992. Prepared for Washington Department of Wildlife, Olympia, WA. Cascadia Research Collective. Olympia, WA. 31 pp.

Calambokidis, J., J. Evenson, G. Steiger, and S.J. Jeffries. 1994. Gray whales of Washington state: natural history and photographic catalog. Prepared for Washington Department of Wildlife, Olympia, WA. Cascadia Research Collective. Olympia, WA. 28 pp.

Puget Sound Water Quality Authority (PSWQA). 1991. Puget Sound update: second annual report of the Puget Sound ambient monitoring program. Puget Sound Water Quality Authority. Olympia, WA. 99 pp.

Recent Reports from Other Monitoring Efforts and Additional Literature Cited

Marine Fish

Beamish, F. Aitkins, and J. Bell [eds.]. 1994. Review of the marine environment and biota of Strait of Georgia, Puget Sound, and Juan de Fuca Strait: proceedings of the B.C./Washington Symposium of the Marine Environment. Can. Tech. Rep. Fish. Aquat. Sci. 398 pp.

O'Toole, M. 1989. Summary of January - April 1988 Pacific herring spawning ground surveys in Washington state waters. Washington Department of Fisheries Briefing Report No. MF80-006. 22 pp. Washington Department of Fisheries. Olympia, WA.

O'Toole, M. Personal communication. Washington Department of Fish and Wildlife.

Schmitt, C. and J. Schweigert. 1994. Anthropogenic influences on fish populations in the Georgia Basin, part II: marine fishes. In: Wilson, R., R. Beamish, F. Aitkins, and J. Bell [eds.]. 1994. Review of the marine environment and biota of Strait of Georgia, Puget Sound, and Juan de Fuca Strait: proceedings of the B.C./Washington Symposium of the Marine Environment. Can. Tech. Rep. Fish. Aquat. Sci. 398 pp. (contains PSAMP data)

Stick, K.C. 1992. Summary of 1992 Pacific herring spawn deposition surveys in Washington state waters. Washington Department of Fisheries Progress Report No. 302. 46 pp. Washington Department of Fisheries. Olympia, WA.

Marine Birds

Buchanan, J.B. 1988. The abundance and migration of shorebirds at two Puget Sound estuaries. Western Birds: 69-78.

Kraege, D. 1990. Cooperative management of Puget Sound waterfowl resources. pp. 150-170. In: Armstrong, J.W., and A.E. Copping, eds. Status and management of Puget Sound's biological resources. EPA 910/9-90-001. U.S. Environmental Protection Agency. Seattle, WA.

Mahaffy, M., D. Nysewander, K. Vermeer, T. Wahl, and P. Whitehead. 1994. Status, trends and potential threats related to birds in the Strait of Georgia, Puget Sound and Juan de Fuca Strait. In: Wilson, R., R. Beamish, F. Aitkins, and J. Bell [eds.]. 1994. Review of the marine environment and biota of Strait of Georgia, Puget Sound, and Juan de Fuca Strait: proceedings of the B.C./Washington Symposium of the Marine Environment. Can. Tech. Rep. Fish. Aquat. Sci. 398 pp. (contains PSAMP data)

Ritchie, W., D.J. Pierce, and R. Krueziger. 1994. Preliminary findings of seabird interactions with the non-treaty salmon gillnet fishery: Puget Sound and Hood Canal Washington. Washington Department of Fish and Wildlife, Olympia, WA. 14 pp. (contains PSAMP data)

Stein, J. 1994. A feasibility study for determining the proportion of juvenile marbled murrelets, *Brachyramphus marmoratus*, in the inland marine waters of Washington state during the 1993 post-breeding season. Washington Department of Fish and Wildlife, Olympia, WA. 19 pp.

Strong, C.S., J.R. Gilard, I. Gaffney, and J.M. Cruz. 1992. Distribution and abundance of marbled murrelets at sea on the Oregon coast. Unpublished report. Cresent Coastal Research. Cresent City, OR.

Marine Mammals

Calambokidis, J., G.H. Steiger, J.C. Cubbage, S. Kort, S. Belcher, and M. Meehan. 1988. Status of Puget Sound harbor seals: trends in population size and contaminant concentrations. pp. 589-597. In: Proceedings of the first annual meeting on Puget Sound research. Puget Sound Water Quality Authority. Seattle, WA.

PSAMP CONTACTS

Marine Fish

Washington Department of Fish and Wildlife
Sandra O'Neill
(360) 902-2843

Data Available: Because PSAMP does not collect data on marine fish abundance (see pg. 60), the only data available to the program is species composition of fish collected during English sole trawls from 1989-present. However, other programs within WDFW have information on the abundance of various species.

Shellfish

Washington Department of Health
Bob Woolrich
(360) 753-5957

Data Available: Clam and oyster abundance, 1991-92. More recent data is available from Anita Cook, (360) 796-4601.

Marine Birds

Washington Department of Fish and Wildlife
Dave Nysewander
(360) 664-9348

Data Available: Winter and summer estimates of Puget Sound marine bird populations, July 1992-present.

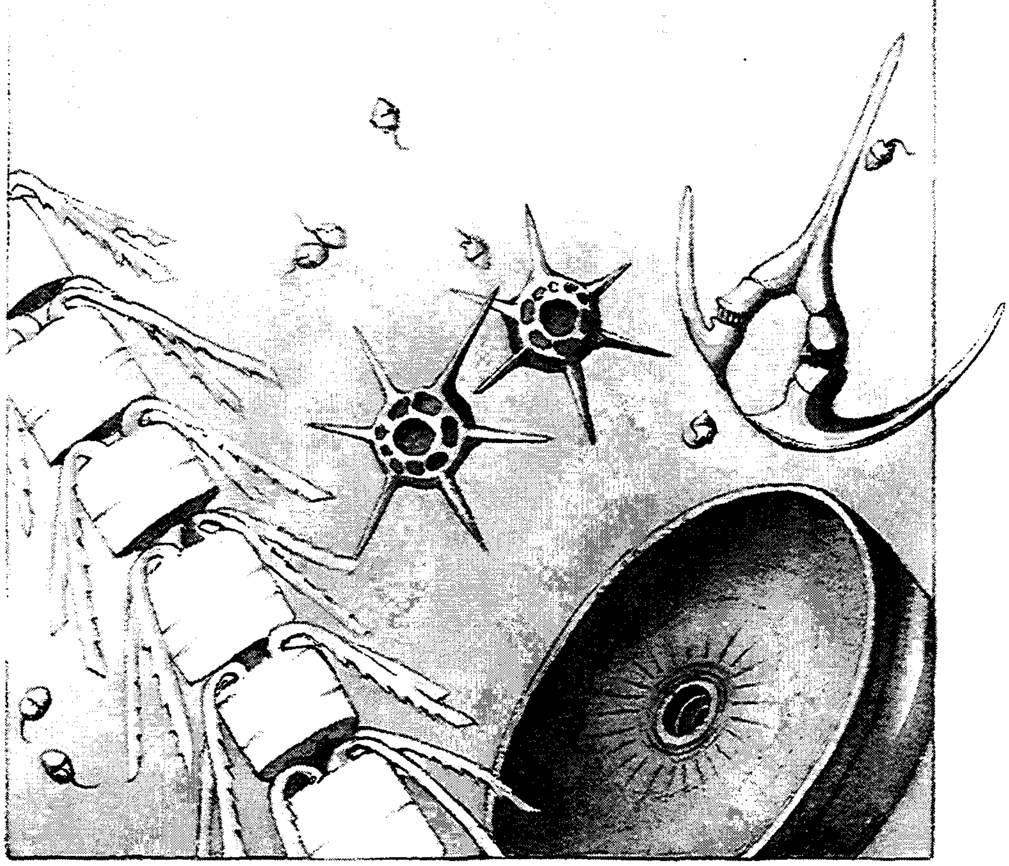
Marine Mammals

Washington Department of Fish and Wildlife
Dave Nysewander
(360) 664-9348

Cascadia Research Collective
John Calambokidis
(360) 943-7325

Data Available: Location and numbers of gray whale sightings, 1984-present. 1992 estimates of harbor porpoise abundance.

CONVENTIONAL WATER QUALITY



WHAT DO WE KNOW ABOUT CONVENTIONAL WATER QUALITY?

One of the most prevalent problems related to conventional water quality in estuaries across the nation is eutrophication—the excessive nutrient enrichment, or overfertilization, of a water body. It is caused by excessive amounts of nutrients and organic matter, which stimulate the growth of phytoplankton (single-celled plants that live suspended in the water column). When phytoplankton populations become very dense and die off, they may create water quality problems such as depleted oxygen, fish kills and foul odors.

While eutrophication is a very serious water quality problem in many East Coast estuaries, it is not one of the more significant problems affecting Puget Sound's water quality. This is largely due to the mixing and dilution that occurs in the Sound's waters. In the open embayments and basins of Puget Sound, waters tend to be well-mixed and exchange freely with the Pacific Ocean via the Strait of Juan de Fuca. Large tidal currents and the presence of sills (which enhance vertical mixing by forcing deeper waters to the surface) usually deter open waters from stratifying. Stratification can strongly influence conventional water quality. Stratification refers to horizontal layering of the water column, in which density increases with depth so that surface waters tend not to mix with denser, deeper waters. The lack of vertical mixing may:

1) Prevent deeper waters from becoming replenished with oxygen because mixing with oxygen-rich surface waters is restricted.

2) Promote phytoplankton blooms (since phytoplankton remain at the surface where sunlight is abundant).

3) Result in nutrient depletion of surface waters (since nutrients removed by phytoplankton are not replenished by mixing with nutrient-rich deeper waters).

Within Puget Sound, eutrophication is evident primarily in poorly mixed or stratified embayments (e.g., Budd Inlet, Hood Canal) (Janzen and Eisner, 1992; 1993) and in some shallow nearshore areas (Thom et al., 1988). Human sources of nutrients and organic matter may create problems in these areas because the water bodies are naturally susceptible to eutrophication, and additional nutrients and organic matter only worsen existing problems.

Monitoring Conventional Water Quality in Marine Waters

Understanding the dynamics of problems related to conventional water quality in marine waters requires measurement of a broad spectrum of water quality parameters, as many factors interact to determine conventional water quality. PSAMP scientists measure the following variables to determine the quality of the water column and its susceptibility to potential problems:

Temperature and salinity: these provide information about stratification and mixing of the water column.

Dissolved nutrients: these are essential for phytoplankton growth.

Chlorophyll *a* and phaeopigment: these are measures of phytoplankton biomass and chlorophyll degradation, respectively.

Light transmission: this is used to assess turbidity caused by suspended sediment or phytoplankton blooms.

Secchi disk depth: this relates to how deeply light penetrates the water column.

SUMMARY OF 1993 FINDINGS ON CONVENTIONAL WATER QUALITY

The Washington Department of Ecology's analysis of data collected around Puget Sound in wateryear 1993 (October 1992 - September 1993) documented several patterns in conventional water quality.

- Some degree of water column stratification was evident at many stations sampled within the Sound. Persistent stratification (stratification throughout the year) and seasonal stratification (stratification primarily in the summer months) were present at many of the same stations where these patterns were seen in previous years.

- Phytoplankton blooms—as indicated by chlorophyll *a* concentrations—occurred at many stations where stratification was observed. Phytoplankton blooms were infrequent in the winter, when lower light levels limit photosynthesis and stronger winds reduce stratification. Spring, summer and fall phytoplankton blooms exhibited three typical patterns. At some stations, blooms occurred more frequently in spring and fall, with lower levels in the summer, possibly reflecting limited nutrients. Other stations showed elevated chlorophyll *a* concentrations even in summer months, suggesting that nutrient depletion did not limit phytoplankton growth. Low chlorophyll *a* levels throughout the year were evident at well-mixed stations where stratification did not develop.

- Ecology found low concentrations of dissolved oxygen (less than 5.0 mg/l) at six stations in Puget Sound. These stations exhibited low oxygen levels in past years as well, suggesting chronic low levels resulting from various natural causes and, in some cases, possible human influences.

- Climatic conditions throughout the wateryear showed some correlation with patterns of water temperature and salinity at several stations in Puget Sound. Compared to past years, temperature and salinity patterns in wateryear 1993 characterized some effects on water quality that resulted from the drier, warmer conditions thought to be linked to El Niño influenced conditions. Effects included warmer water temperatures and, after two consecutive years of below-average precipitation, higher salinities in wateryear 1993.

1992 Budd Inlet Monitoring Results

Ecology's intensive seasonal monitoring of Budd Inlet in 1992 revealed the following:

- Budd Inlet can be separated into three portions, with somewhat different physical and biological processes occurring in each. Central and outer Budd Inlet, north of Priest Point, flush well, with characteristics representative of ambient conditions in greater Puget Sound. Inner Budd Inlet, south of Priest Point, flushes poorly, with water quality conditions influenced by outflow from the Deschutes River and Capitol Lake, as well as discharges from LOTT (Lacey, Olympia, Tumwater, Thurston County), the regional sewage treatment plant, and nonpoint pollution sources.

- Stratification of Budd Inlet was strongest in the inner bay, and decreased from the head to the mouth of the inlet. Water column stratification was strongest during March and July in the inner bay, although some degree of stratification was present throughout the inlet during the entire study (from March to October).

- Phytoplankton blooms occurred throughout the bay during the survey. Highest chlorophyll *a* concentrations consistently occurred in the central bay, between July and September. During these blooms, nitrogen concentrations in surface waters were typically below reporting

limits, with the exception of the inner bay, where concentrations were rarely below reporting limits.

• Analyses of phytoplankton species composition revealed that diatom species were dominant in spring and fall, while dinoflagellates were dominant in summer. Two species of potentially harmful phytoplankton were present within the inlet, although it is not known whether the observed concentrations were high enough to adversely affect water quality.

• Low dissolved oxygen concentrations were also present in many parts of the bay. In late summer and early fall, Ecology consistently found dissolved oxygen concentrations below 5.0 mg/l in the central and inner bay. Values below 5.0 mg/l occurred most frequently in West Bay's near-bottom waters, and to a lesser extent in the central bay near the eastern shore. The lowest dissolved oxygen concentrations were in the near-bottom depths of the inner bay within East Bay and West Bay. In these areas, values below 3.0 mg/l were observed during late August and early October.

• Tidal and daily cycles affected many water quality parameters, including dissolved oxygen and the location of phytoplankton blooms.

DETAILS OF 1993 FINDINGS ON CONVENTIONAL WATER QUALITY

Marine Water Column Stratification

In assessing stations throughout Puget Sound, the Department of Ecology found that most stations sampled in wateryear 1993 exhibited some degree of stratification. Ecology categorized four patterns of stratification:

1) Persistent stratification, in which waters at a station were strongly stratified throughout the sampling year.

2) Seasonal stratification, in which strong stratification was only observed for part of the year (typically between April and September).

3) Episodic stratification, which involves isolated events of stratification.

4) Weak stratification, meaning that the water column was relatively well-mixed during all observations (Table 13).

Wateryear 1993 stratification patterns throughout Puget Sound were similar to patterns exhibited in wateryears 1991 and 1992 (Newton et al., 1994; Janzen and Eisner, 1993a; b).

When natural conditions cause a waterbody to fail water or sediment quality standards

In some instances, natural conditions in Puget Sound may not meet water or sediment quality criteria for specific parameters. For example, areas with poor circulation and naturally high levels of phytoplankton production may have low dissolved oxygen levels, and areas with a naturally abundant source of a metal, such as copper, might have high levels in the water or sediment. Evaluating environmental conditions in such areas poses difficulties. Sediment and water quality standards typically allow for high values of a parameter due to natural conditions, but do not state how to differentiate between high values resulting from natural conditions, and those stemming from human activities.

When investigators evaluate the effect of a particular source or discharge in an area with background conditions that do not comply with water quality standards, they typically sample locations upgradient or outside the area of influence of the discharge, and compare them to values within the area of influence of the discharge. However, ambient programs such as the Puget Sound Ambient Monitoring Program (PSAMP) are designed to collect data away from the immediate influence of any particular human activities that may affect water or sediment quality so that such an approach does not apply. At ambient locations, the contaminants introduced by the suite of sources along a particular shoreline mix with Puget Sound waters and disperse, making it difficult—if not impossible—to distinguish how much of a parameter's value at an ambient site is due to natural conditions, and how much is the result of human activities. The only way to determine with certainty that ambient values reflect natural or human influences would be to compare present conditions to those existing prior to the addition of human pollutants, and such data are rarely available.

In reviewing and analyzing PSAMP data, investigators try to consider the potential for natural causes as contributing factors in poor sediment or water quality conditions. Often they can only accomplish this by using their best professional judgement, and by considering factors such as circulation patterns, geochemistry and proximity to human sources of contaminants.

Persistently Stratified	Seasonally Stratified	Episodically Stratified	Weak Stratification
Bellingham Bay	Admiralty Inlet near Protection Island	Henderson Inlet	Dana Passage
Budd Inlet	Admiralty Inlet at south end of Whidbey Island	Oakland Bay	Lopez Island
Commencement Bay	Carr Inlet		Port Townsend
Elliott Bay	Case Inlet		Totten Inlet
Hood Canal at Sisters Point	East Sound		
Hood Canal near King Spit	Eld Inlet		
Possession Sound	Strait of Georgia		
Saratoga Passage	Main Basin off West Point		
Sinclair Inlet			

Reference: Newton et al., 1994

Table 13. Water column stratification* at Puget Sound stations in wateryear 1993.

**** Stratification was defined here as a change in sigma-t (a measurement of density) >2 through the water column.***

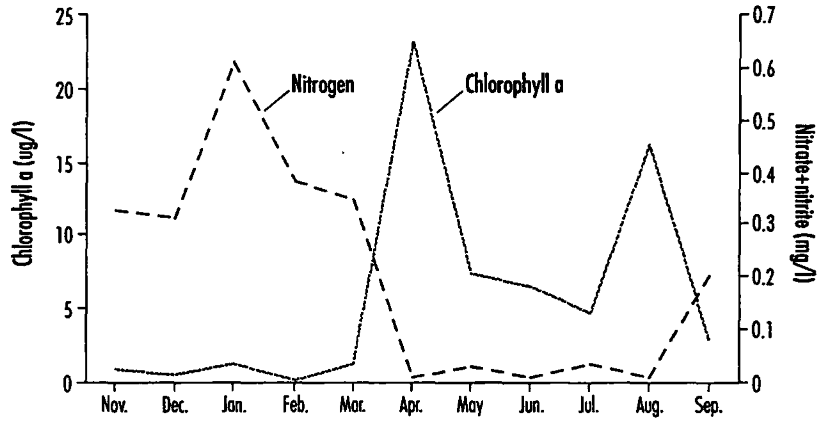
Nutrients and Phytoplankton in Marine Waters

Phytoplankton growth in Puget Sound, as in most temperate water bodies, is seasonal. In winter, when sunlight levels are low, phytoplankton population growth rates slow and population levels decrease. Winter storms can also mix phytoplankton below depths where light penetrates. Nutrient levels are high during these months because the phytoplankton population consumes fewer nutrients and storms mix nutrients-rich deep waters to the surface. As light and temperature increase in spring and into summer, phytoplankton populations grow, driving down nutrient levels in the process. Blooms—high accumulations of phytoplankton—occur when phytoplankton population growth exceeds the rate of loss due to processes such as mixing and grazing by zooplankton. Low phytoplankton abundance indicates that either high rates of loss are occurring or populations are growing slowly.

The seasonal pattern of phytoplankton blooms during wateryear 1993 varied greatly among the stations monitored. At several Puget Sound stations, phytoplankton blooms occurred in spring and fall, with lower summertime levels of chlorophyll *a*. The low summertime levels may have resulted from nutrient limitation in stratified waters during the summer. Ecology found that stations with persistent or seasonal stratification exhibited this seasonal pattern of phytoplankton growth at 0.5 and 10 meters in wateryear 1993, including stations at Bellingham Bay, Carr Inlet and Saratoga Passage (Figure 45).

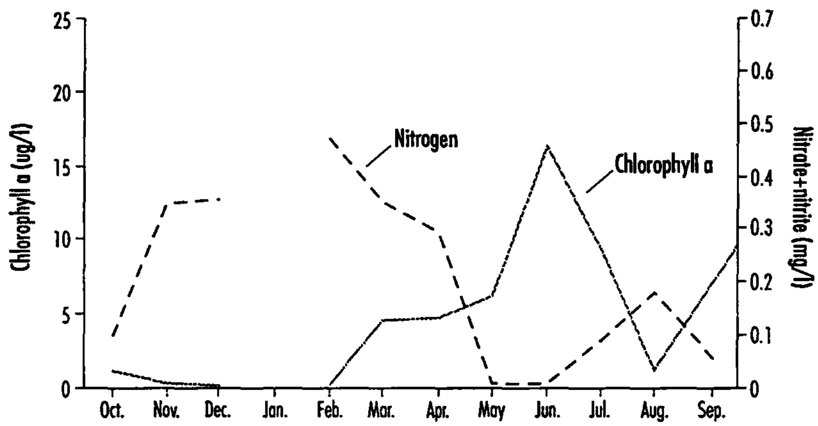
In contrast, some stations had elevated chlorophyll *a* during the summer months, suggesting that the amount of nutrients did not limit growth at these stations. Stations exhibiting this pattern in wateryear 1993 included Budd Inlet, Commencement Bay, Case Inlet, Hood Canal at Sister's Point, Oakland Bay, the Main Basin, and Port Townsend Harbor (Figure 46). Some of these stations were not persistently or seasonally stratified (e.g., Port Townsend and Oakland Bay), or were shallow, allowing nutrient-rich bot-

Figure 45. Chlorophyll a and nitrogen at Bellingham Bay (at 0.5 m): wateryear 1993.



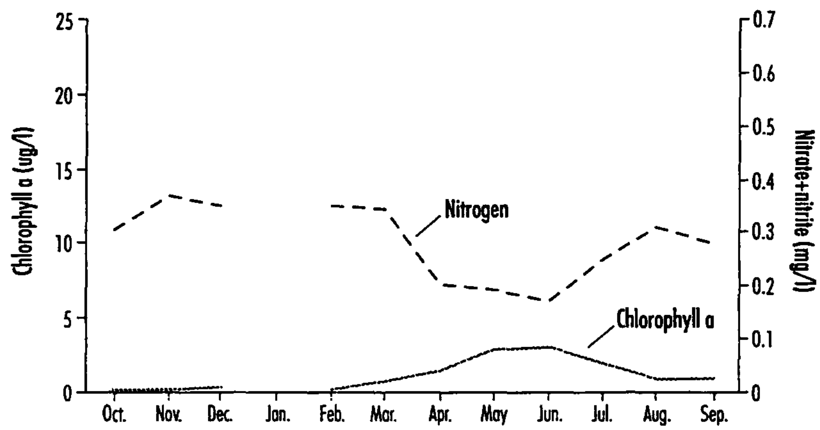
Reference: PSAMP central database

Figure 46. Chlorophyll a and nitrogen at Commencement Bay (at 0.5 m): wateryear 1993. Station not sampled in January.



Reference: PSAMP central database

Figure 47. Chlorophyll a and nitrogen at Admiralty Inlet, near Protection Island (at 0.5 m): wateryear 1993. Station not sampled in January.



Reference: PSAMP central database

tom waters to circulate to the surface where phytoplankton populations thrive. However, many of these stations exhibited persistent or seasonal stratification. These stations may have received additional nutrients from sources such as failing on-site sewage systems and agricultural or urban runoff (e.g., Budd Inlet and Commencement Bay).

Stations with strong physical mixing and weak stratification typically had low chlorophyll *a* levels throughout the wateryear. Because of mixing and low phytoplankton abundance, nutrients at these stations rarely fell to levels below the reporting limit. Stations exhibiting this pattern in wateryear 1993 included the Strait of Georgia, Admiralty Inlet and Dana Passage (Figure 47).

Toxic Phytoplankton Blooms

Some types of phytoplankton are toxic to animals. A wide range of phytoplankton species within Puget Sound are harmful to fish, shellfish, birds, marine mammals and humans when present in sufficient concentrations in marine waters or in the marine organisms consumed by these species. Paralytic shellfish poisoning (PSP) and amnesic shellfish poisoning (also known as domoic acid poisoning) are two serious threats to human health arising from the consumption of shellfish contaminated by toxic phytoplankton.

Resource managers can do little to reduce or eliminate PSP or domoic acid outbreaks. The conditions that lead to these outbreaks are not known. They do not appear to be caused or made worse by human activities, although there is some evidence that excessive nutrients may promote or prolong outbreaks (see PTI, 1991 for review).

Paralytic Shellfish Poisoning

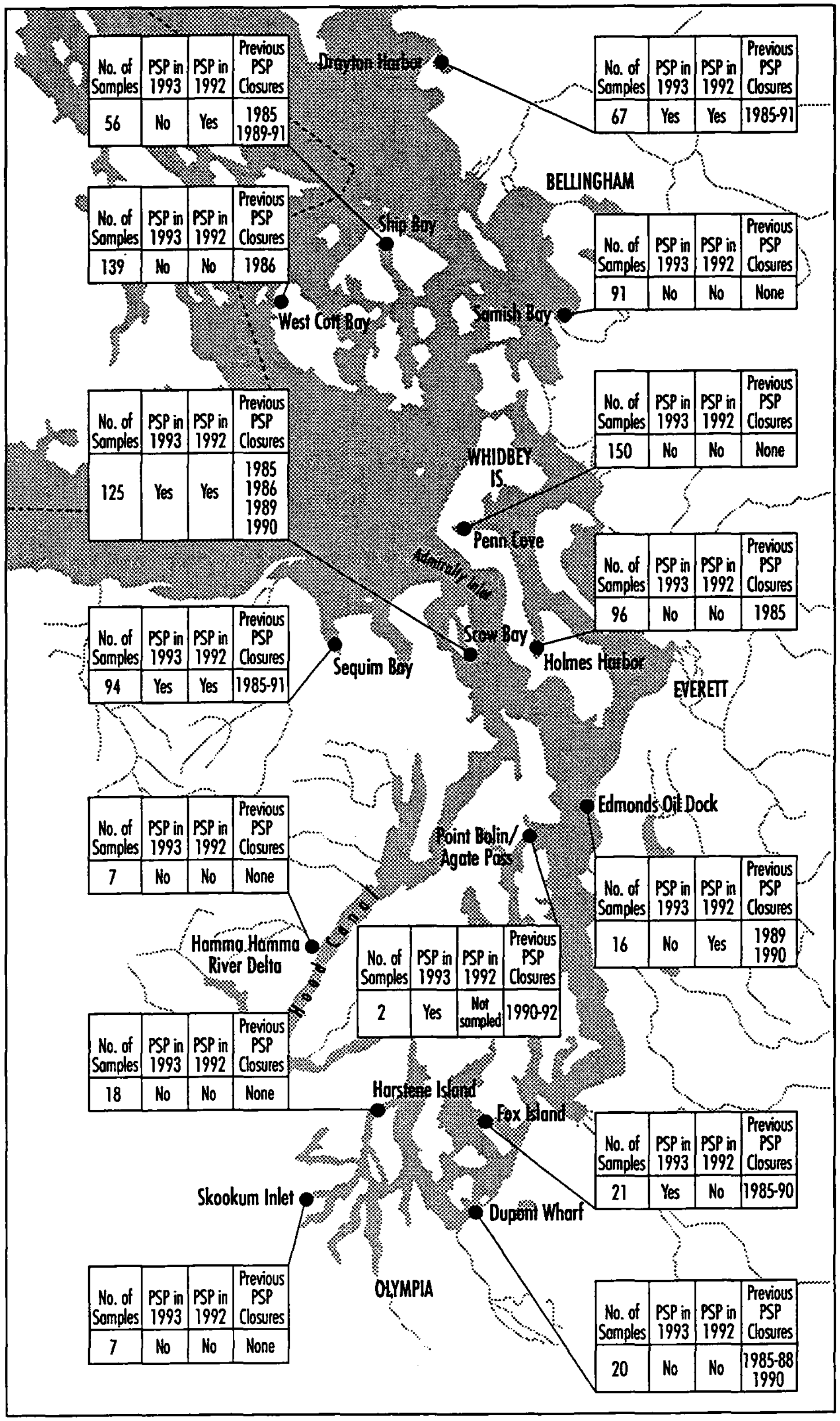
Paralytic shellfish poisoning (PSP) is caused by a type of phytoplankton (the dinoflagellate *Alexandrium catenella*) that produces a naturally occurring nerve toxin. This species grows in Puget Sound waters on a frequent but unpredictable basis. When the phytoplankton population reaches a high density, shellfish can concentrate enough of the biotoxin to make their meat dangerous, if not fatal, to humans. Because of the potential life-threatening nature of PSP, the Washington Department of Health (DOH) routinely monitors shellfish from commercial and recreational shellfish areas for PSP, and numerous beaches are closed for shellfish harvesting every year when the PSP toxin is detected.

The PSAMP tracks the results of PSP monitoring at 15 beaches throughout Puget Sound. Over the last four years, the PSP toxin in shellfish at six sites has not exceeded the Food and Drug Administration (FDA) standard of 80 µg/100 g shellfish tissue—the level at which the DOH restricts shellfish harvesting. In contrast, a number of sites have had toxin levels that regularly require closure (Figure 48). In 1993, five sites had levels of toxin exceeding 80 µg/100 g shellfish tissue, compared to five sites in 1992, two sites in 1991 and nine in 1990.

Dissolved Oxygen in Marine Waters

Nearly all marine animals require dissolved oxygen. State standards for dissolved oxygen in marine waters require 7.0 mg/l or more for Class AA

Figure 48. PSP closures at PSAMP sites.



Reference: DOH, in prep.

waters and 6.0 mg/l or more for Class A waters, unless natural conditions, such as water welling up from the bottom, cause oxygen concentrations to drop below those levels. Levels below 5.0 mg/l can physiologically stress many organisms, particularly fish (Whitmore et al., 1960; Kramer, 1987).

Lower levels—particularly levels below 3.0 mg/l—may have more severe effects, such as mortality, and may affect organisms less sensitive to low dissolved oxygen levels than fish.

Because many natural factors can lower oxygen levels, and because no data exist on oxygen concentrations prior to human settlement, it is difficult to determine whether present oxygen concentrations below the numeric standard are due to natural or human causes (see sidebar on page 108). For this reason, Ecology tracks stations with oxygen levels below 5.0 mg/l, rather than levels below numeric standards. Regardless of the cause, these depressed oxygen levels may have biological consequences. In addition, such areas may be particularly sensitive to any additional nutrients or organic matter from human sources.

In wateryear 1993, Ecology found six stations with dissolved oxygen levels of less than 5.0 mg/l—four in northern Puget Sound and two within Hood Canal (Table 14). Consistently low dissolved oxygen at these sites in past wateryears suggests that this may be a chronic condition. Past monitoring has shown low oxygen levels at three additional sites: two within Hood Canal and one near Port Angeles (Janzen and Eisner, 1992; 1993a; 1993b). These stations are monitored every three years and so were not monitored in wateryear 1993.

Table 14. Stations exhibiting low dissolved oxygen concentrations during wateryear 1993.

	Dissolved Oxygen <5 mg/l			Dissolved Oxygen <3 mg/l		
Station	Wateryear 1993	Wateryear 1992	Wateryear 1991	Wateryear 1993	Wateryear 1992	Wateryear 1991
Strait of Juan de Fuca near Admiralty Inlet	●		●			
East Sound	●	●		●	●	●
Hood Canal at Sister's Point	●	●	●	●	●	●
No. Hood Canal near Bangor	●	●				
Possession Sound near Gedney Island	●	●	●			
Saratoga Passage	●	●	●			

Reference: Newton et al., 1994

The lowest oxygen levels occurred mainly in deeper waters, and usually between the summer months of June and September, although some stations (e.g., Hood Canal) had low levels during other seasons. In addition, two of these stations exhibited dissolved oxygen concentrations less than 3.0 mg/l: East Sound and Hood Canal at Sister's Point. All stations with low dissolved oxygen were either persistently or seasonally stratified (Table 15).

Weather Patterns in Wateryear 1993

When evaluating conventional water quality and its changes over time, determining the effects of natural factors such as weather is important. Weather patterns can have a strong effect on conventional marine water quality. Rainfall patterns can affect salinity, nutrient concentrations, turbidi-

Table 15. Characteristics of stations exhibiting chronic low dissolved oxygen concentrations.

Station	Station Characteristics	Low Dissolved Oxygen (D.O.) Characteristics	Possible Causes
Strait of Juan de Fuca near Admiralty Inlet	Deep (almost 100 m) station; moderate seasonal stratification May-Sept.	D.O. just below 5 mg/L in July and Sept. '93, at depths below 50 m	Inflow of deep oceanic waters with naturally low D.O.
East Sound	Shallow (~30 m); moderate seasonal stratification May-Sept.	D.O. < 5 mg/l below 25 m in June; < 3 mg/l at bottom	More data needed; inflow at deep waters with naturally low D.O. and decomposition of spring phytoplankton bloom possible causes.
Hood Canal at Sister's Point	~ 50 m deep; persistently stratified	Persistent low D.O., below 5 mg/l for seven out of 10 sampled months; similar patterns in previous two years. In Oct., D.O. < 3mg/l throughout most of water column	Area with high natural productivity because of strong and persistent stratification and abundant nutrient supply; area susceptible to human sources of nutrients
North Hood Canal near Bangor	Deep station (100 m) with moderate stratification	D.O. < 5 mg/l below 12 m in Oct. '92.	Characteristics similar to other Hood Canal station, although less severe. Inflow of low D.O. water from further in Hood Canal.
Possession Sound near Gedney Island	Deep station (100 m) with strong and persistent stratification, partly due to proximity to riverine inputs	D.O. < 5 mg/l in Nov '92 and July and Sept. '93.	Strong stratification favors phytoplankton blooms; inputs of nutrients and organic matter from river; inflow of low D.O. water from the Port Susan area.
Saratoga Passage	Deep station (>100 m) with strong and persistent stratification, partly due to proximity to riverine inputs	D.O. < 5 mg/l below 35 m in Sept. '93.	Strong stratification favors phytoplankton bloom; inputs of nutrients and organic matter from river.

***Reference:** Newton et al., 1994*

ty and other factors by increasing or decreasing upland runoff and riverine discharges. Air temperature can affect water temperature, which influences factors such as dissolved oxygen concentrations, water column stratification, and phytoplankton population dynamics. Ecology is tracking several measurements of weather patterns to better understand connections between these patterns and parameters related to conventional water quality, and as one of many factors that may explain differences in conventional water quality among years.

In comparing wateryear 1993 weather patterns to 30-year monthly averages, Ecology found that wateryear 1993 was characterized by warmer and drier fall conditions (October - November 1992), cooler and drier winter conditions (December 1992 - February 1993), warmer and wetter spring conditions (March - June 1993), and warmer and drier summer conditions (July - September 1993). These patterns appeared to correlate with some patterns in marine water temperature and salinity at several representative stations

throughout the Sound. For example, the higher than average precipitation and air temperatures in April and May coincided with higher water temperatures and lower salinities (when compared to five-year averages) in several stations near rivers (Newton et al., 1994).

Compared to previous wateryears, Ecology found that the effects of the drier, warmer local weather (which were thought to be linked to El Niño conditions) were reflected in marine water quality. El Niño conditions were strong in the early part of 1992 and weaker (but observed) in the first part of 1993. Water temperatures in wateryear 1992 were warmer at the representative stations analyzed from January to August 1992. Ecology also found that below-average precipitation in wateryears 1991 and 1992 were reflected in higher salinities in wateryear 1993. Ecology will conduct more thorough analyses of El Niño effects on conventional water quality, the results of which will be reported in the next *Puget Sound Update.*

Seasonal Monitoring in Budd Inlet

Ecology conducted its first seasonal monitoring study (see sidebar on page 116 for a description of seasonal monitoring) on Budd Inlet in 1992 (Eisner et al., 1994). Budd Inlet is a semi-enclosed embayment at the extreme southern end of Puget Sound (Figure 49). It extends from the outfall of Capitol Lake in Olympia north to a line connecting Dover and Cooper points. It is a shallow inlet (average depth is nine meters), with moderately steep shorelines and muddy substrates (PTI, 1991). There is no sill at the entrance to the inlet.

Budd Inlet is a partially mixed, weakly stratified estuary with a two-layer circulation pattern. Puget Sound waters enter the inlet from the Tacoma Narrows via Dana Passage and mix with fresh water from the Deschutes River via Capitol Lake, the inlet's major source of fresh water. This results

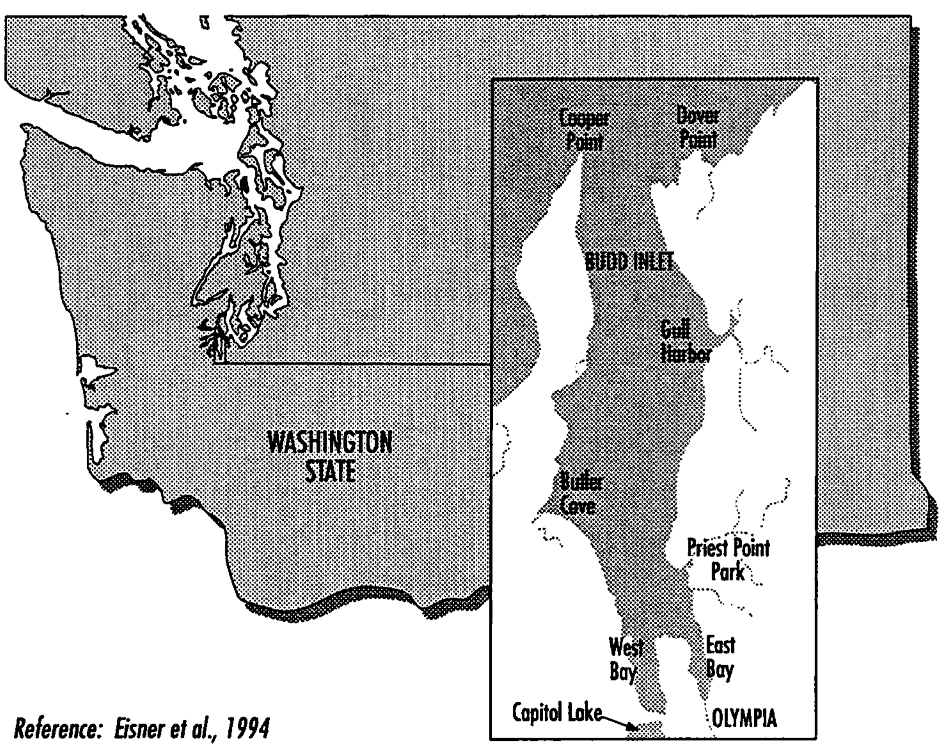


Figure 49. Budd Inlet seasonal monitoring study area.

Reference: Eisner et al., 1994

Sampling schedules

The Puget Sound Ambient Monitoring Program (PSAMP) uses two different sampling schedules to provide a more complete characterization of conventional water quality in Puget Sound's marine waters.

Long-term baseline monitoring

The first part of the design for PSAMP monitoring of the water column involves sampling a limited number of open-water stations once a month to evaluate long-term trends in water quality. The open-basin stations are intended to represent background water quality conditions in Puget Sound, so they are located away from the shoreline, often in mid-channel, and away from the influence of individual sources.

Intensive seasonal monitoring

Many water quality problems occur on shorter time scales in localized areas. Phytoplankton blooms may develop and subside in less than a month. Water quality conditions may also vary dramatically within one area. Therefore, when water quality problems are suspected, it is important to sample an adequate number of stations on a frequent basis to understand the severity and extent of the problem. Intensive sampling is expensive, so it is focused on a few select embayments each year, and during times when problems are most likely to develop.

in a layer of low-salinity surface water—comprised largely of fresh water from the Deschutes River—that flows northward to the mouth of the inlet, and a deeper, high-salinity water layer—comprised of cold Puget Sound waters—that flows south toward the head of the inlet.

Budd Inlet can be separated into three portions, the inner, central and outer inlet, with somewhat different physical and biological processes occurring in each (URS, 1986; Eisner et al., 1994). Water in outer Budd Inlet, north of Priest Point, flushes well, with characteristics representative of ambient conditions seen in greater Puget Sound. Inner Budd Inlet waters, south of Priest Point, flush poorly, with water quality conditions influenced by outflow from the Deschutes River and Capitol Lake, as well as discharges from LOTT (Lacey, Olympia, Tumwater, Thurston County), the regional sewage treatment plant, and nonpoint pollution sources. Flushing in the central inlet, near Priest Point, is influenced by flow conditions that are dependent upon the volume of freshwater inputs and seasonal runoff (URS, 1986). The estimated mean residence time in Budd Inlet (the average amount of time a parcel of water remains in Budd Inlet) is eight days, with a maximum residence time of 14 days (PTI, 1991). Because the inner inlet does not flush well, it is susceptible to problems that affect conventional water quality, including oxygen depletion, excessive phytoplankton blooms, and—on rare occasions—fish kills. Ecology initiated seasonal monitoring in Budd Inlet to better understand the dynamics of conventional water quality in the inlet, and the extent and nature of conventional water quality problems.

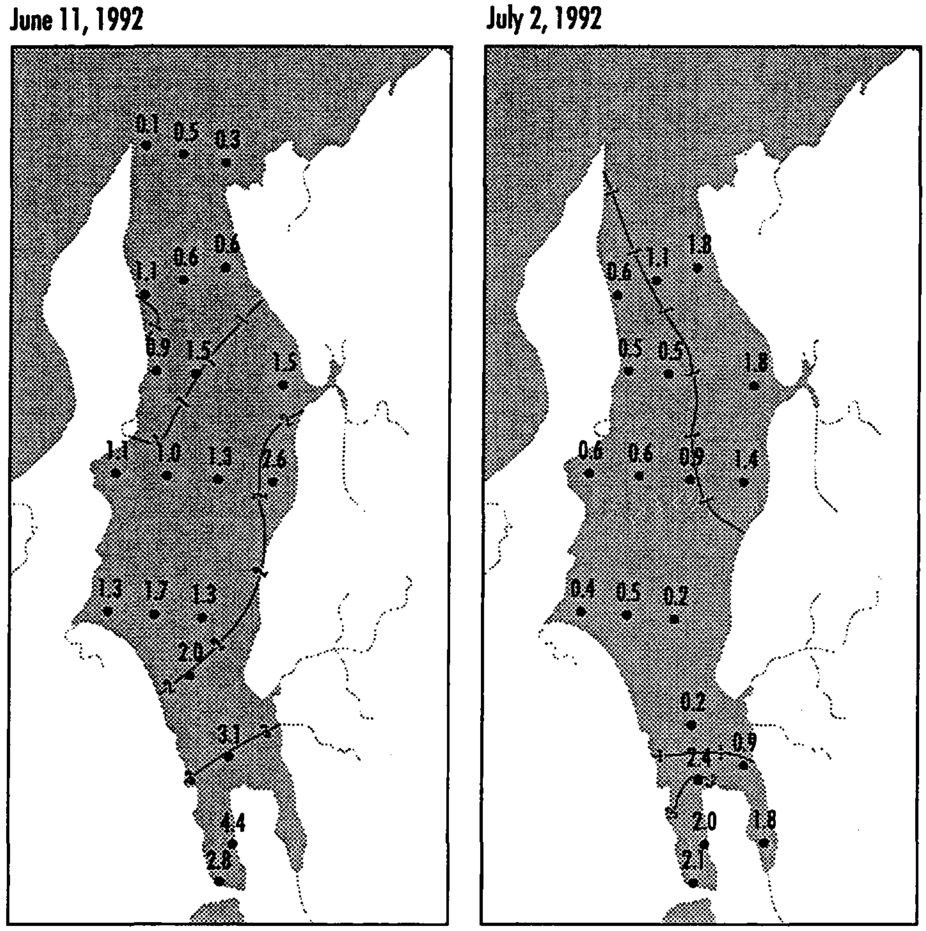
Ecology's seasonal monitoring study (Eisner et al., 1994) entailed sampling numerous stations to assess spatial patterns of conventional water quality throughout the inlet, and sampling more frequently to better capture the highly dynamic nature of conventional water quality. Ecology sampled up to 25 stations within the inlet—most biweekly. In addition, Ecology conducted an intensive, 52-hour tidal-cycle survey (sampling every two hours) to assess water quality conditions over the tidal cycle and daily cycle. The seasonal study revealed a great deal about the dynamics of water quality in Budd Inlet.

Stratification

Stratification of Budd Inlet waters was strongest in the inner bay, and decreased from the head to the mouth of the inlet (Figure 50). Differences in salinity were the primary drivers of this stratification, so that the numerous freshwater sources in the inner bay (e.g., the Deschutes River, Capitol Lake and LOTT discharges) are the likely cause for stronger stratification in the inner bay. Stratification was strongest during March and July in the inner bay, although some degree of stratification was present throughout the inlet over the entire study (from March to October).

Nutrient and Phytoplankton Dynamics

The persistent stratification present in Budd Inlet creates conditions favorable for phytoplankton growth. Blooms of phytoplankton (defined here as chlorophyll *a* concentrations of more than 10 µg/l) occurred throughout the inlet during the survey. The highest chlorophyll *a* concentrations consistently occurred in the central inlet, from July through September. During these blooms, nitrogen concentrations (nitrite + nitrate-N and ammonium-



Reference: *Eisner et al., 1994*

Figure 50. Relative stratification (surface to near-bottom density difference) in Budd Inlet.

The June 11, 1992, samples were taken during ebb tide (central and outer bay) and low tide (inner bay). Density differences were obtained by subtracting the 1-m density (sigma-t) value from the near-bottom density (sigma-t) value. Higher numbers indicate greater relative stratification.

● Stations at which density measurements were taken

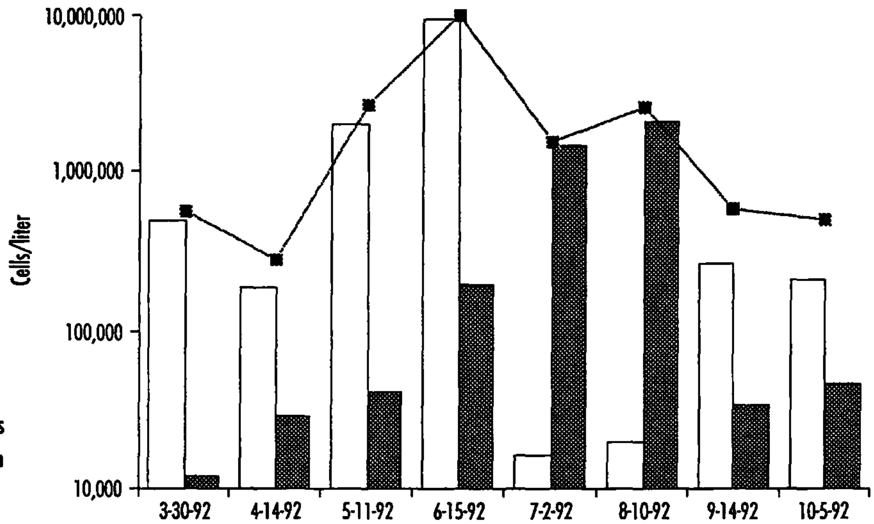
— Contour lines, indicating lines of equal stratification

N) in surface waters typically fell below reporting limits, with the exception of the inner bay. Surface nitrite + nitrate-N and ammonium-N concentrations were rarely below reporting limits in the inner bay, probably due to a combination of lower phytoplankton concentrations and proximity to LOTT discharges, Deschutes River and Capitol Lake outflows, and urban nonpoint pollution sources. The reason for lower phytoplankton abundances in the inner inlet is unclear at this time, since nutrients were more abundant and stratification stronger than in the central inlet (where the highest chlorophyll *a* values were measured).

Ecology identified phytoplankton species present during these blooms and found several patterns of interest. In spring, diatom species were dominant. During this time, surface nitrite + nitrate-N and ammonium-N gradually decreased in the inner and central portion of the inlet. The dominant phytoplankton type changed from diatoms to dinoflagellates at the end of June (Figure 51). At this time, there was a substantial increase in the abundance of the dinoflagellate *Ceratium fusus*, which is known to migrate vertically. Vertically migrating dinoflagellates would be favored under conditions of low surface nutrients, as they are able to migrate between deeper waters at night—where nutrients are abundant— and surface waters during the day—where sunlight is abundant. This process was evident from vertical profiles of chlorophyll *a* concentrations, which showed high concentrations

Figure 51. Diatom, dinoflagellate and total phytoplankton concentrations between March and October 1992 in central Budd Inlet.

Samples were collected at 0.5 m, except on August 10, when the sample was collected at 2.5 m. Note logarithmic scale.



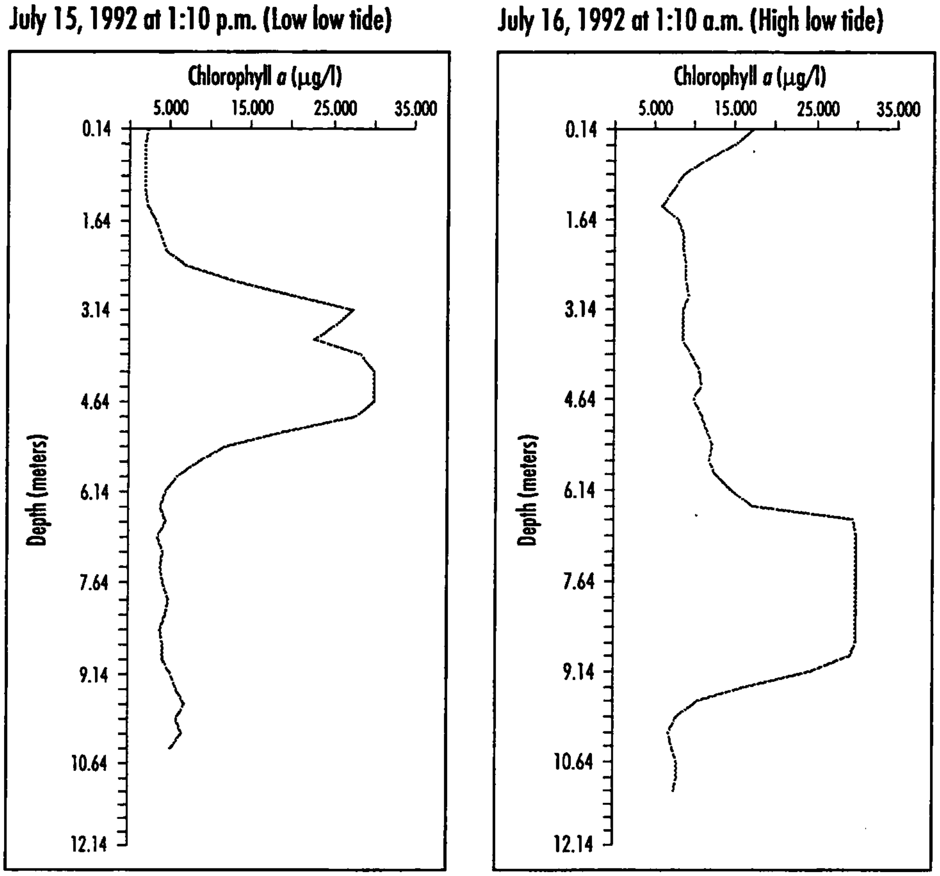
Reference: Eisner et al., 1994

of chlorophyll *a* at the surface during daylight hours, and at depth during the night (Figure 52). Toward the end of summer, nitrite + nitrate-N and ammonium-N concentrations in bottom waters also decreased below reporting levels, suggesting nitrogen depletion by *Ceratium fusus.*

Ecology also observed concentrations of two potentially harmful phytoplankton species—*Pseudonitzchia pungens* and *Heterosigma carterae*—in Budd Inlet. *Pseudonitzchia pungens* is one of the diatom species that can produce domoic acid, a neurotoxin that causes amnesic shellfish poisoning in humans. However, there are two forms of this diatom—one of which does not cause amnesic shellfish poisoning—and it is difficult to distinguish between the two with standard taxonomic procedures. It is not known at what concentration the toxic form produces harmful effects, so human health threats cannot be evaluated from these observations. Heterosigma carterae is a small flagellate that can cause fish kills. Again, the concentrations associated with these effects are not known, so it is difficult to determine whether the observed concentrations were high enough to produce adverse effects.

Dissolved Oxygen

Poor flushing, persistent stratification, and respiration and decay of phytoplankton blooms are factors that lower dissolved oxygen concentrations. In Budd Inlet, the seasonal study clearly showed that these conditions are all present. As would be expected, the results indicate that low dissolved oxygen concentrations are also present in many parts of the inlet. Dissolved oxygen concentrations below 5.0 mg/l were observed consistently in late summer and early fall in the central and inner inlet. Values below 5.0 mg/l occurred most frequently at West Bay in near-bottom waters, and to a lesser extent in the central inlet near the eastern shore. Ecology observed the lowest dissolved oxygen concentrations in the near-bottom depths of the inner inlet within East Bay and West Bay. In these areas, values below 3.0 mg/l were observed during late August and early October.



Reference: Eisner et al., 1994

Figure 52. In situ fluorometer profile data for a central Budd Inlet station at low tide during the July 15-17, 1992, tidal cycle survey.

Fluorometer chlorophyll a maximum = 30 µg/l. The fluorometer cannot read chlorophyll a concentrations higher than 30 µg/l. When the fluorometer reads 30 µg/l, the true value could be greater.

Effects of Tidal and Daily Cycles on Water Quality

The vast majority of marine monitoring programs do not take into account the effects of tidal and daily cycles on water quality. There are many practical reasons why this is difficult to do. Accounting for tidal and daily cycles entails sampling at all times and tides including nights, which is more time-consuming, expensive and dangerous than sampling during daylight hours. In addition, the logistics of sampling are such that it is generally too expensive or time consuming to sample all stations within a water body with the regularity required to account for these cycles.

In spite of these difficulties, it is important to gain some understanding of the effects of tidal and daily cycles on water quality. For example, sampling dissolved oxygen only during the daytime may not capture the periods of lowest dissolved oxygen, since phytoplankton cease photosynthesis (which produces oxygen) at night. Comparing results over time or among locations may be misleading if the results being compared were collected during different tidal cycles, since water quality conditions during low tides can be considerably different than during high tides. While a program may not be able to consistently sample during a particular time of day or tide, it should be able to assess how representative the chosen sampling time was, and account for differences in the portion of the cycle sampled when comparing over time or among sites.

Ecology investigated tidal and daily cycle effects on water quality in its seasonal study of Budd Inlet by sampling three stations every two hours throughout two complete daily and tidal cycles (52 hours). Their results indicated dramatic effects of these two cycles. Some results were consistent with expectations. For example, dissolved oxygen concentrations in surface waters tended to be higher during the day than the night. Concentrations were also higher during high tides than low tides. The daily effect on dissolved oxygen is likely due to photosynthesis, whereas the tidal effect is probably a result of the inflow of ambient Sound waters with higher dissolved oxygen levels during flood tides (Eisner et al., 1994). In addition, phytoplankton blooms tended to be further inward in the inlet during high tide than low tide, probably due to transport during flood tides. Other results were less predictable. The vertical migration of dinoflagellates discussed earlier and the tendency of phytoplankton to be found in deeper water during the night were results that explained some of the observed dynamics in water quality, such as the decrease in near-bottom nitrogen to levels below reporting limits during late summer.

In general, the Budd Inlet seasonal monitoring study has greatly expanded our knowledge of water quality dynamics in an area of Puget Sound most susceptible to problems with conventional water quality. Partly due to water quality problems evident in Budd Inlet, the LOTT treatment plant implemented state-of-the-art nitrogen removal processes in the spring of 1994. This study provides an excellent baseline for assessing the effects of the changes in treatment on water quality conditions. Ecology repeated this study in 1993 and 1994, which will allow a comparison of annual variability, as well as pre- and post-treatment water quality. The results will be reported in a future *Puget Sound Update.*

AVAILABLE RESOURCES FOR ASSESSING CONVENTIONAL WATER QUALITY

PSAMP Reports

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Whitmore, C.M., C.E. Warren, and P. Doudoroff. 1960. Avoidance reactions of salmonid and centrarchid fishes to low oxygen concentrations. Trans. Am. Fish. Soc. 89:17-26.

PSAMP CONTACTS

Data on conventional water quality is also available from the PSAMP central database. Contact the Puget Sound Water Quality Authority, (360) 407-7300.

Washington Department of Ecology
Jan Newton, Ph.D.
(360) 407-6675

Data Available: Monthly conventional water quality parameters in marine waters. Five to ten year data records for core sites monitored every year. Less frequent for rotational sites. Seasonal monitoring of conventional water quality in Budd Inlet, 1992 - 1994. Seasonal monitoring in Sinclair Inlet, 1992. Seasonal monitoring in Sequim Bay, 1993.