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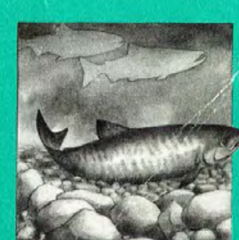
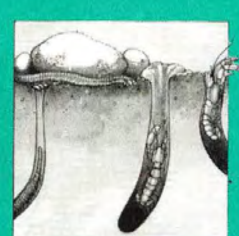
Puget Sound Update

SECOND ANNUAL REPORT OF THE PUGET SOUND AMBIENT MONITORING PROGRAM





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July 1991

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S U M M A R Y

The Puget Sound basin is an area of extraordinary beauty and rich natural resources. The Sound is a system of deep fjord-like estuaries connected to the Pacific Ocean via the Strait of Juan de Fuca. Numerous rivers and streams drain a large watershed, providing fresh water to the Sound. Three million people live in the Puget Sound basin; many others visit the area every year. They use the Sound as their waterway, food source, recreational area, and place of business. The variety and abundance of plants and animals, as well as numerous opportunities for fishing, boating, shellfishing, and hunting, make the Puget Sound area important to the economy of the state, the region, and the nation.

The Sound's attractions have led to rapid population growth, development, and industrialization. Over the past 100 years, the human population in the Puget Sound basin has increased 100-fold, and it is continuing to grow at a rapid pace. Human activities can lead to poor water quality, sediment contamination, and the degradation and destruction of fish and wildlife habitat and other valuable resources. The activities which take the worst toll on the Puget Sound environment include: shoreline development, disposal of toxic chemicals by industries and individuals, sewage disposal, runoff from developed land, poor farming and forestry practices, and the transfer of airborne pollutants to the water.

In order to protect the natural resources and water quality of the Puget Sound basin, managers need information on the status of the resources, how they are changing over time, and how the natural and human-made environment affects them. We also need accurate environmental information to determine whether our source control activities and cleanup efforts are effective. Scientists and managers have been collecting information on the Sound for many years, although most of these studies have been limited in geographic coverage and have have only lasted for short periods of time.

The Puget Sound Ambient Monitoring Program (PSAMP) has been established to expand on these efforts and to coordinate the collection of information on parts of the Puget Sound ecosystem that might be affected by pollution. PSAMP is a comprehensive, long-term monitoring program for measuring ambient, or background conditions in Puget Sound, as well as the cumulative effects of contamination and habitat degradation from many individual human actions. Strong coordination will ensure that PSAMP collects data that are useful to water quality and natural resource managers, in a cost effective manner over time. The information collected by PSAMP investigators will characterize the condition of the water, sediments, plants, animals, and habitats in Puget Sound and its watersheds.

The program is achieved through the coordinated efforts of six state agencies (Washington Departments of Ecology, Fisheries, Health, Natural Resources, Wildlife, and the Puget Sound Water Quality Authority), with support and cooperation from other government agencies, business, industry, volunteer citizen monitors, and the public.

PSAMP data collection began in 1989 with investigators collecting samples for sediment quality, toxics in fish tissue, liver disease in fish, and contaminants in shellfish. State agencies are also carrying out some limited surveys for populations of marine mammals and birds, as well as investigations into marine and fresh water quality.

These investigations show that the health of Puget Sound is generally good, with serious contamination and degradation problems restricted to fairly small areas near the shorelines and urban bays. However, widespread destruction and contamination of natural shoreline areas have decreased the quality and quantity of critical fish and wildlife habitat. There are early warning signs of problems emerging in many areas, such as contaminated sediments, liver tumors in bottomfish, shellfish bed closures due to fecal contamination, and reductions in wild salmon runs and other populations of fish and wildlife.

Virtually no area of Puget Sound is pristine and free from contamination. The worst chemical contamination problems show up in the bottom sediments, where particles associated with toxic chemicals settle. The urban bays contain areas of the most contaminated sediments, which are associated with harm to biological populations living in the sediments, bottomfish disease, and contamination in the flesh of fish and shellfish.

During their 1989 and 1990 surveys, investigators with the Washington Department of Ecology (Ecology) detected toxic chemicals (metals and organics) at sites all over Puget Sound, with the highest concentrations in the urban bays, such as Elliott Bay, Commencement Bay, and Sinclair Inlet. Rural bays and the deep basins of the Sound showed lower levels of contamination. Scientists looked for unusual patterns of bottom-dwelling animals in the sediment at the same stations and determined whether the sediments were toxic to laboratory test animals. They found patterns of bottom-dwelling animals in the urban bays that are consistent with contaminated estuaries in other parts of the country, although sediments from only a few of the most contaminted stations were toxic to test animals.

Investigations of sediment contamination in Puget Sound are also carried out by a number of agencies and organizations other than PSAMP. These investigations focus on long-term trend analysis, the quality of dredged material, the impacts of waste disposal on sediment quality, and special studies in limited geographic areas. Scientists find similar patterns of Puget Sound sediment contamination in all these studies.

The marine waters of Puget Sound are generally clean, although there are some water quality problems in bays with restricted water circulation, and close to the shoreline. Ecology investigators and others found fecal coliform bacteria in nearshore marine waters throughout the Sound, while offshore waters are generally clean. Fecal coliform bacteria are indicative of sewage contamination from sewage treatment plants and nonpoint pollution sources such as failing septic systems, agricultural runoff, and stormwater runoff.

Human activities may be responsible for changes in population levels of fish, marine birds, waterfowl, and marine mammals in Puget Sound. Some fish populations are declining, especially Pacific cod, other marine fish, and wild runs of salmon and steelhead. Many species of marine birds appear to be thriving in the Strait of Juan de Fuca and near the San Juan Islands, but have

almost ceased to breed in the main basin of the Sound. Some populations of waterfowl are declining, probably due to habitat loss. Resident harbor seals are thriving in the north Sound, south Sound, and Hood Canal, but no longer breed in the main basin.

During 1989 and 1990 PSAMP investigators with the Washington Department of Fisheries (WDF) found metals and some organic contaminants in the flesh of English sole, salmon, Pacific cod, and rockfish from several locations around the Sound. They also found evidence of liver disease in English sole that live in the areas of highest sediment contamination, including parts of Elliott Bay, Commencement Bay, and Sinclair Inlet.

The accumulation of toxic chemicals in the flesh of fish, shellfish, birds, and marine mammals should be taken as a warning sign of potential damage to our resources and as a threat to human health. The Washington Department of Health (DOH) considers that the levels of contaminants found in the 1989 and 1990 PSAMP fish samples will not harm the health of those who consume a moderate amount of fish.

Shellfish in many areas of Puget Sound are contaminated by chemicals, bacteria, and paralytic shellfish poisoning (PSP). PSP is a potentially deadly toxin caused by a naturally occurring algae which blooms at unpredictable intervals in Puget Sound. Public health officials have closed many areas to shellfish harvest due to these contaminants, both seasonally and year round.

During 1989 and 1990 PSAMP investigators with DOH detected fecal coliform contamination above the standard allowable for commercial shellfish harvest at three recreational shellfish beds in the Sound: Walker State Park (near Shelton), Belfair State Park (Hood Canal), and Dosewallips State Park (Hood Canal). All three are affected primarily by nonpoint sources of pollution, and have been closed to shellfish harvesting. The DOH investigators found moderate levels of metal contamination and low levels of toxic organic contamination in shellfish during spring 1990.

The vegetated nearshore estuarine habitats in Puget Sound are a mere shadow of their former selves. Over the past 100 years there have been huge losses of nearshore eelgrass and salt marshes in the urbanized estuaries and heavy losses of nearshore and upland wetlands throughout the basin. As these losses continue, they eliminate more and more of the critical refuge, feeding grounds, and nursery areas for fish and wildlife. PSAMP investigators with the Washington Department of Natural Resources (DNR) developed a system to measure the extent of the remaining nearshore estuarine habitat, using remote sensing techniques. They will use these high-tech computerized techniques to inventory nearshore habitat in the future.

The water quality in the freshwater rivers and streams of the Puget Sound basin varies from watershed to watershed, depending on the soils, slopes, and land uses. Many of the rivers and streams suffer from localized water quality problems, including habitat destruction, chemical contamination of fish, and reductions in the populations of fish and wildlife supported by the freshwater corridors. During 1989 and 1990 Ecology investigators and local health department managers found fecal coliform bacteria that exceeded state water quality standards in many rivers and streams. Typically the worst fecal contamination is found downstream in developed areas, while the water quality upstream in less developed areas is better.

There are many programs in place in Puget Sound that are directed toward controlling sources of contamination to the Sound and cleaning up contaminated areas. Most of these programs are mandated as a part of the Puget Sound Water Quality Management Plan, or coordinate closely with the Puget Sound plan. PSAMP is the data collection arm of the Puget Sound plan, providing information to track the effectiveness of the source control and cleanup programs.

In 1990 the Washington State Legislature approved legislation that requires the implementation of PSAMP by state agencies. Many portions of PSAMP are not currently funded, including monitoring marine mammals, birds, and the extent of estuarine nearshore habitat. Other portions of the program have inadequate funding to assess the status and trends of resources throughout the Sound, including contamination levels in fish, shellfish, sediments, and marine and fresh waters. Governor Booth Gardner has requested a substantial increase in PSAMP funding to begin in July 1991. The legislature had not taken action to assure these funds at the time that Puget Sound Update went to press.

Without adequate information in many parts of the Puget Sound ecosystem, major changes in resource populations, levels of contamination, risks to human health, and environmental conditions could go unnoticed until a crisis strikes. Without PSAMP information, managers would be hampered from preventing the same problems from recurring in the future. The cost of future restoration of some of our unique and valuable marine populations could be extremely large. Other natural resources, particularly sensitive habitats, can never be replaced once they have been lost. Information collected by PSAMP about these resources and Puget Sound environmental conditions will play a critical role in preventing some of these losses.

INTRODUCTION

PUGET SOUND — THE RESOURCE WE LOVE AND THREATEN

The beauty and abundance of the Puget Sound ecosystem attracts residents and visitors alike. People come to the Puget Sound area to enjoy the natural beauty and extraordinary marine resources, to boat on the clear waters of the Sound and surrounding lakes and rivers, and to hike the hills and mountains.

Although most residents and visitors value Puget Sound and the surrounding area, their actions threaten the ecosystem and its inhabitants. Inadvertently people degrade the water and the bottom sediments, decimate populations of natural resources, and destroy the homes of resident and migratory animals. Shoreline development, disposal of toxic chemicals by industries and individuals, sewage disposal, runoff from developed land, poor farming and forestry practices, and the transfer of airborne pollutants to the water, all lead to the degradation of Puget Sound and its watersheds. All these activities are products of a developed and industrialized society. Few people wish to give up the benefits of modern society and return to their ancestors' way of life.

The Puget Sound area is experiencing a tremendous influx of people that is predicted to continue indefinitely. In order to maintain the way of life that we hold dear, and to return some of the contaminated areas of the Sound and decimated natural populations to a healthy state, the residents of the Sound must all be aware of the threats to the Sound and strive to reduce them.

PURPOSE OF THIS REPORT

This is the second annual Puget Sound Update. Findings from the first two years of the Puget Sound Ambient Monitoring Program (PSAMP) form the basis of this report. This report briefly describes PSAMP, explains the significance of each type of monitoring, and discusses the results. It provides some background on the workings of the Puget Sound ecosystem and the history of contamination problems in the Sound. The first annual Puget Sound Update (PSWQA, 1990a) provided a more complete description of contamination problems and the Puget Sound ecosystem.

PSAMP is a long-term program of which only parts have been initiated. The scientists who designed PSAMP recognize that five to ten years of data are needed for many parts of the ecosystem before we will begin see changes and identify trends in contamination levels and in natural resource populations. Some of the PSAMP water quality, sediment, and biological variables require extensive periods of time to process and review the collected data. PSAMP managers will report many of the second- year PSAMP results in the next Puget Sound Update.

This report is organized around the many parts of the Puget Sound ecosystem which are monitored by PSAMP. PSAMP information collected during 1989 and 1990 are described for sediments, marine waters, fish, shellfish, marine mammals, birds, nearshore habitat, and freshwater rivers and streams of the Puget Sound basin. For each ecosystem component, the report provides background information, describes the design of PSAMP, presents results from PSAMP and other monitoring efforts, and discusses future PSAMP monitoring. The first Puget Sound Update placed major emphasis on the results of sediment contamination monitoring. This year we will also emphasize fish and shellfish monitoring results. We have attempted to describe the results of PSAMP in maps and graphics wherever possible.

WHAT IS THE PUGET SOUND AMBIENT MONITORING PROGRAM?

PSAMP is a comprehensive long-term program which monitors numerous aspects of the Puget Sound ecosystem that might be affected by pollution, including the cumulative effects of contamination and habitat degradation from many individual actions (PSWQA, 1988). The program looks for trends and changes in water quality, sediment, and biological variables in time and in space. PSAMP is called for in the monitoring program of the Puget Sound Water Quality Management Plan (PSWQA, 1991) and in state regulation (RCW 90.70.065). The program functions through the coordinated efforts of state government agencies, with support and cooperation from other government agencies, business, industry, and the public (PSWQA, 1988).

Scientists from six state agencies carry out PSAMP. The Washington Department of Ecology (Ecology) is responsible for sediment, marine water, and freshwater monitoring; the Washington Department of Fisheries (WDF) monitors fish; the Shellfish Section of the Washington Department of Health (DOH) monitors shellfish; the Aquatic Lands Division of the Washington Department of Natural Resources (DNR) is responsible for monitoring the

nearshore estuarine habitat portion of PSAMP; the Washington Department of Wildlife (WDW) will monitor birds and marine mammals; and the Puget Sound Water Quality Authority (PSWQA) has data management and coordination responsibilities (PSWQA, 1988).

Although there have been many studies of Puget Sound in the past, there has not been a consistent and comprehensive system for measuring the condition of Puget Sound and its watersheds, and for gauging the effectiveness of preventive and cleanup actions (PSWQA, 1986a). PSAMP was developed to collect baseline and long-term information which will be used to detect trends and changes in the Puget Sound environment (PSWQA, 1988). The scientists who designed PSAMP purposely located sampling stations away from the influence of single sources of contamination (PSWQA, 1988). PSAMP results should not be used to estimate the amount of contamination or change from individual projects or actions. Monitoring programs linked to the granting of permits for wastewater discharges and studies associated with regulations for shoreline development, dredged material disposal, and other activities provide information about the impact of individual development projects. Natural resource managers and water quality planners also need information about the larger Soundwide impacts of numerous human-induced changes; PSAMP has been designed to provide this information (PSWQA, 1988).

PSAMP investigators will collect and record information on the Sound and its inhabitants using consistent techniques over time. This information will document the health of the Sound, status and trends in contamination and the effects of contamination on the Sound's natural resources, as well as changes in the Puget Sound ecosystem due to natural causes. As PSAMP continues into the future, we will have a solid record with which to assess conditions in the Sound, to aid in making decisions about the cleanup of contaminated areas, and to prevent further harm from occurring to valuable resources.

PSAMP was designed by a group of scientists and managers (the Monitoring Management Committee or MMC) appointed by the PSWQA, representing the public and private sector (PSWQA, 1988). The MMC members have expertise in water quality or natural resource management; most have responsibilities for protecting and cleaning up Puget Sound and its resources. PSAMP is implemented and managed by an intergovernmental effort represented by the PSAMP Steering Committee (PSWQA, 1988).

PSAMP was designed during 1987 and 1988; data have been collected under PSAMP since 1989. State agencies are carrying out portions of PSAMP with their existing funds, and the Washington State Legislature allocated $400,000 of additional funding to PSAMP for the period July 1989 through June 1991. As of this writing, only about 30 percent of the full PSAMP design has been funded. Until the program is fully funded, information on many parts of the environment, natural resource populations, and fish and wildlife habitats will not be gathered. Information that will not be collected in 1991 due to lack of funds will be described in this report. Agencies and other organizations with an interest in PSAMP are seeking additional sources of future funding.

WHAT DOES PSAMP MEASURE AND WHY?

In designing PSAMP, the MMC examined the major components of the Puget Sound ecosystem and decided which ones would give the best all-around picture of past, present, and future environmental conditions. They considered the technical feasibility and cost of each type of data collection, the results of past monitoring studies, and the ability of agencies and other organizations to carry out each monitoring task. The MMC members settled on gathering information from eight compartments of the ecosystem, each represented by a PSAMP sampling and analysis task. The full design of PSAMP, the rationale behind each type of sample collection, and the frequency of sample collection are summarized in Table 1. Table 2 indicates the monitoring performed during 1989-1991.

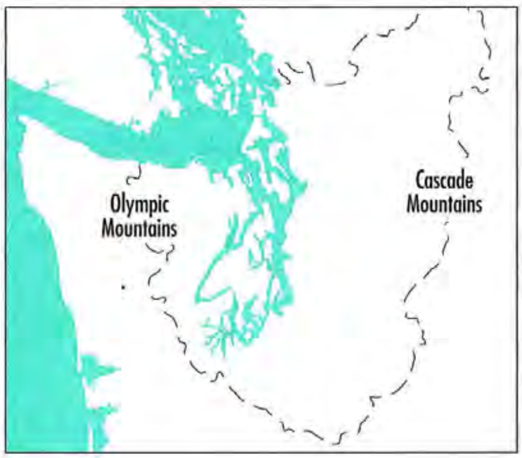


Figure 1. Puget Sound basin.

HOW PUGET SOUND WORKS

Puget Sound is defined to include the waters of the Strait of Juan de Fuca east of Port Angeles and the Strait of Georgia to the Canadian border, Puget Sound south of Admiralty Inlet, and the surrounding watersheds (RCW 90.70.005) (Figure 1). The straits provide the link between Puget Sound and the Pacific Ocean. The Strait of Juan de Fuca connects directly to the ocean at Cape Flattery, and the Strait of Georgia connects to the ocean north and west of Vancouver Island (Figure 2).

The portion of Puget Sound south of Admiralty Inlet is a system of deep fjords carved by glaciers. There are sills or shallow areas, separating basins of the Sound, at Admiralty Inlet, Deception Pass, the Tacoma Narrows, northern Hood Canal, Nisqually Reach, and Dabob Bay. Tidal action causes the flow of water to be turbulent over the sills. This turbulence is largely responsible for the circulation pattern that we see in the Sound.

A very large volume of water is exchanged between Puget Sound and the ocean on each tidal cycle. Salty ocean water enters the Strait of Juan de Fuca at Cape Flattery with each flood tide, and flows east and south into the basins of Puget Sound via Admiralty Inlet. Because the ocean water is cold and salty, it stays in the deep basins of Puget Sound, mixing partially with fresher, less salty water above.

The 10 major rivers of the Puget Sound basin, and numerous smaller rivers and streams, discharge about 10 billion gallons of fresh water into the Sound each year, mostly during the winter rainy season or after the snowpack melts from the Cascade and Olympic Mountains. The fresher water stays mainly on the surface, gradually mixing with the underlying saltier water, and flows

Table 1. Description of full PSAMP design.

Task	Rationale for Sampling	Number of Stations/Surveys	Frequency of Sampling	Agency
Sediment quality	Site for contaminant buildup	75 throughout Puget Sound	Annually - spring	Ecology
Sediment chemistry				
Bioassays				
Benthic invertebrates				
Marine water column	Water quality changes			Ecology
Long-term trends		10-12 throughout Puget Sound	Monthly	
Known water quality problems		5-10 in selected bays	Seasonally	
Algal growth		5-10 in selected bays	Summer & winter solstices	
Fish	Fish health & human health assessment			Fisheries
Tissue chemistry (bottomfish)		21 stations	Annually - early summer	
Liver histopathology (bottomfish)		21 stations	Annually - early summer	
Tissue chemistry (cod, rockfish, salmon)		5-10 stations	Annually, depending on species	
Shellfish	Human health assessment			Health
Abundance		35 beaches	Annually	
Bacterial contamination		35 beaches	Quarterly	
Tissue chemistry		35 beaches	Annually	
Paralytic shellfish poisoning		35 beaches	Monthly (or more often)	
Birds	Ecosystem indicator	Surveys throughout Puget Sound	Monthly, annually	Wildlife
Marine mammals	Ecosystem indicator	Surveys throughout Puget Sound	Monthly, annually	Wildlife
Nearshore habitat	Inventory & health of habitat	One-third of Puget Sound	Annually	Natural Resources
Freshwater	Input of contaminants to Puget Sound	75 throughout watersheds	Monthly	Ecology

northward toward Admiralty Inlet and the Straits. The Sound's two-billion-gallon tidal exchange moves water swiftly over great distances. Tidal currents distribute the marine water and its associated particles and contaminants, as well as many plants and animals, throughout the Sound.

As contaminants enter the Sound from the land or from outfalls, they are either attached to particles or they are dissolved in the water. The dissolved contaminants may later become attached to particles, or they may remain in the water to be distributed throughout the basins and waterways of Puget Sound. The volume of Puget Sound water rapidly dilutes most dissolved contaminants to harmless levels.

Contaminants attached to particles tend to sink out of the water to join the bottom sediments. These particles settle at varying distances from their source, depending upon their size and density and the speed of tidal currents. Most toxic chemicals which enter the Sound are attached to particles and are removed from the water fairly quickly, where they can be taken up by bottom-dwelling creatures and enter the food web. For this reason, we search for toxic chemicals in the sediments and bottom-dwelling plants and animals, as well as in some Puget Sound fish, marine mammals, and wildlife, rather than in the water.

While the waters of the Sound move considerable distances, many particles which enter Puget Sound sink and are trapped in the basins. The particles entering the Sound may consist of clean sediment, dead plants and animals, or pollutants attached to sediment particles. Because many of the particles are trapped in the Sound, a portion of the wastes that we dump into the water remain in Puget Sound for long periods of time.

Figure 2. Location map.

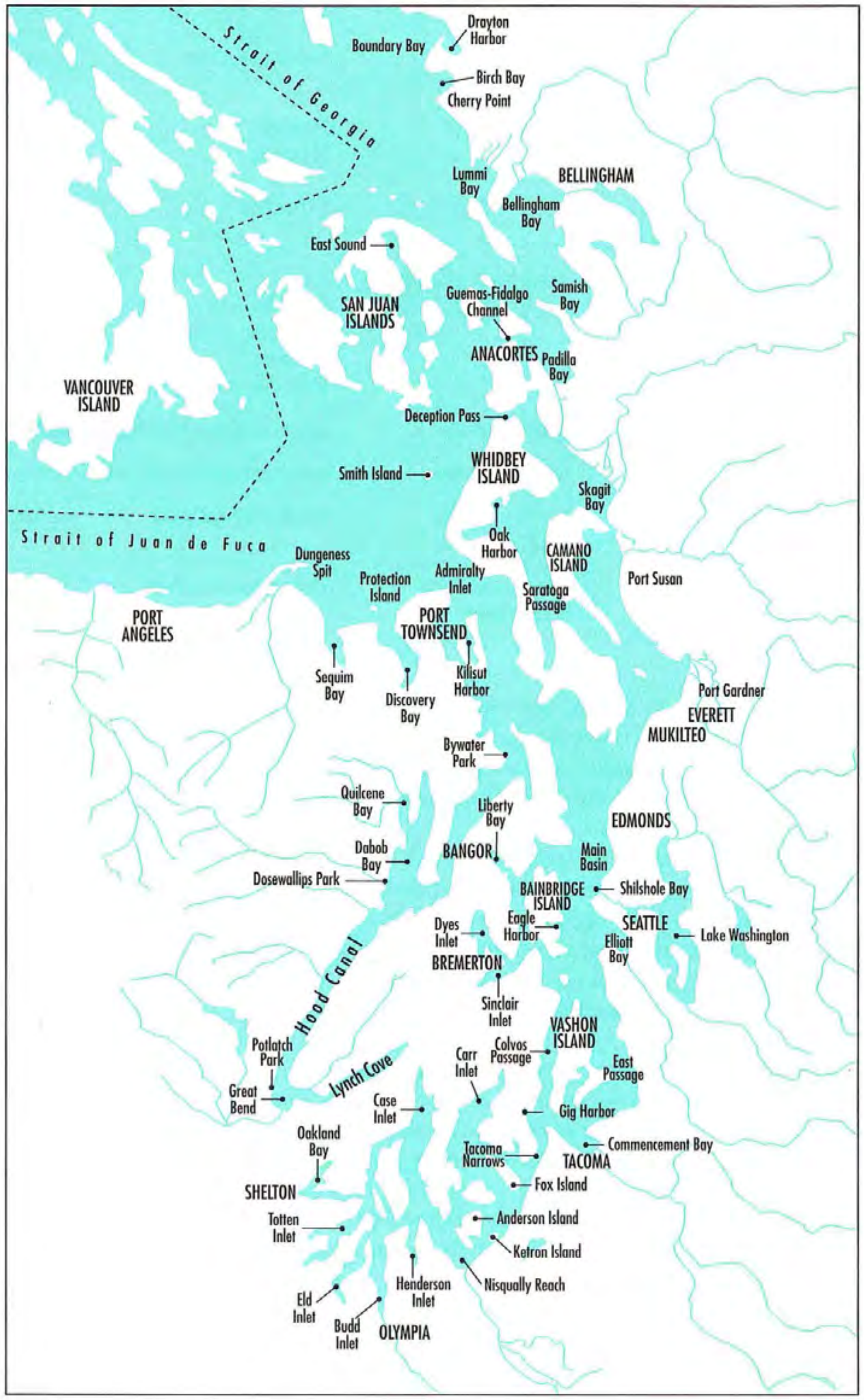


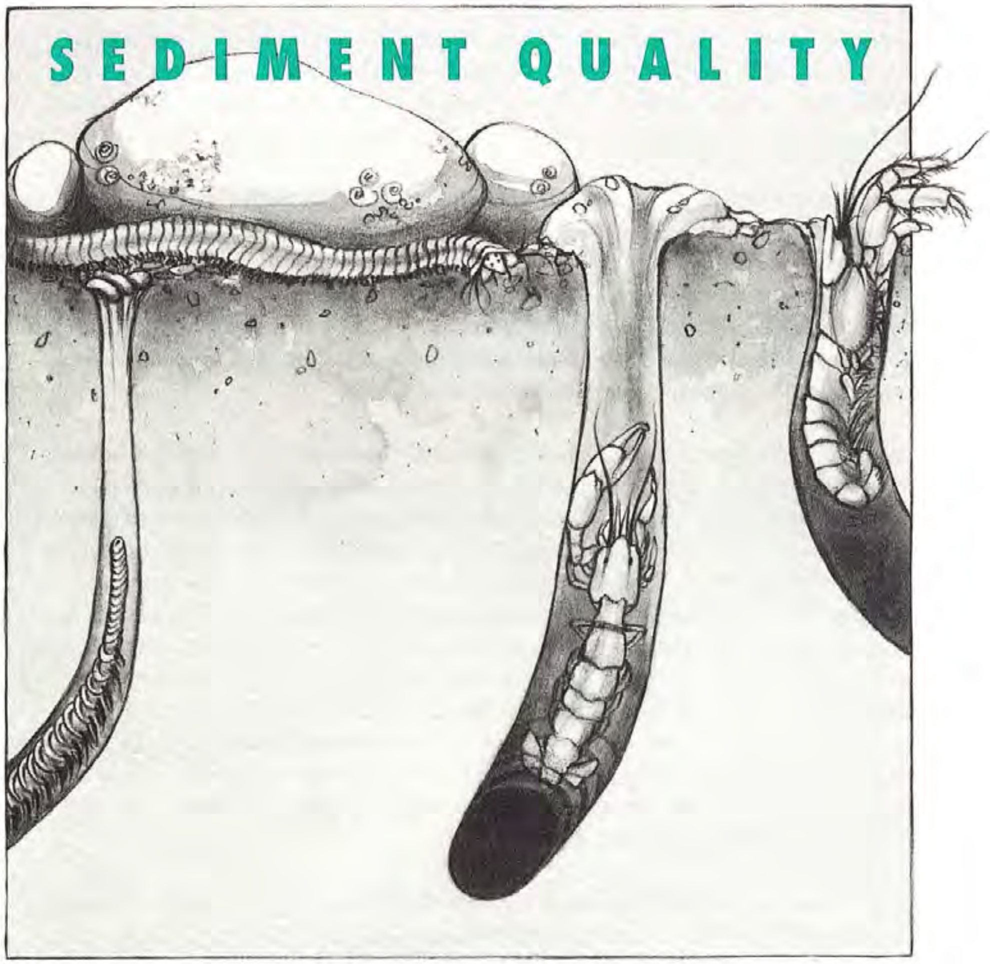
Table 2. 1989-1991 PSAMP implementation.

Task	Rationale for Sampling	Number of Stations/Surveys	Sampling Dates/Frequencies	Agency
Sediment quality Sediment chemistry Bioassays Benthic invertebrates	Site for contaminant buildup	50 throughout Puget Sound	March - April 1989, 1990, 1991	Ecology
Marine water column Long-term trends	Water quality changes	24 throughout Puget Sound	Monthly	Ecology
Fish Tissue chemistry (bottomfish) Liver histopathology (bottomfish) Tissue chemistry	Fish health & human health assessment	10 stations 10 stations 4 stations	May 1989, 1991 May 1989, 1991 September 1989 - rockfish February 1990 - Pacific cod April 1990 - salmon	Fisheries
Shellfish Abundance Bacterial contamination Tissue chemistry Paralytic shellfish poisoning	Human health assessment	10 beaches 10 beaches 10 beaches 16 beaches	May 1990 Quarterly April 1990, 1991 Monthly (or more often)	Health
Birds	Ecosystem indicator	No activity		Wildlife
Marine mammals	Ecosystem indicator	No activity		Wildlife
Nearshore habitat	Inventory & health of habitat	No activity		Natural Resources
Freshwater	Input of contaminants to Puget Sound	35 throughout watersheds (limited parameters)	Monthly	Ecology

Puget Sound is a complex and interconnected ecosystem, rich with plants and animals. The abundance and distribution of most Puget Sound plants and animals are dependent on both physical forces and the chemical environment produced by the mixing of salt water with fresh water. The natural topography of Puget Sound; the tidal currents and circulatory patterns which move water great distances while trapping particles; wind, waves, and weather patterns; and the chemical mix of estuarine water, help to shape the Puget Sound ecosystem. Physical and chemical factors create the abundance and diversity of food supplies and shelter that attract and maintain populations of algae, seagrasses, invertebrates, fish, birds, and marine mammals.

In order to protect Puget Sound, we must have an understanding of how different parts of the ecosystem interact and how they are changing over time. PSAMP has been designed to provide an essential link in our understanding of Puget Sound by identifying and monitoring some of the most important components of the ecosystem.

SEDIMENT QUALITY



BACKGROUND

Sediments, the sand and mud that lie on the bottom of Puget Sound, are an important part of the Sound's ecology; they provide food, shelter, and rearing grounds for marine plants and animals. Many of the benthic plants and animals (those living on or near the bottom) form the base of the food web which supports commercially and recreationally important species such as salmon, cod, rockfish, and Dungeness crab.

Most of the new sediment entering Puget Sound comes from rivers or is the result of shoreline erosion. Natural sediments contain a variety of elements including metals. Some of the same metals are considered to be contaminants when they are introduced into Puget Sound in much higher concentrations than occur naturally. Sediments can become contaminated with toxic organic compounds and heavy metals from anthropogenic (human-related) sources, such as municipal and industrial wastewater, stormwater runoff, and spills. Most toxic chemicals bond to particles which sink out of the water to join the sediments. Scientists have found that molecules of toxic compounds are most likely to be found associated with small-size particles; a smaller amount of contaminants attach to large particles. Scientists measure concentrations of chemicals in the sediments as an indicator of chemical buildup and environmental degradation resulting from human activities.

Because chemicals bond to particles, bottom sediments are the final resting place for much of the contamination that enters the Sound. In some areas benthic animals may accumulate contaminants by consuming, and living in contact with, these sediments. The health of the benthic communities that live in and on the sediments is a measure of the cumulative effects of contamination.

The primary sediment chemicals of concern in Puget Sound are heavy metals and organics. Although many heavy metals (such as lead, copper, and mercury) exist naturally, some alter their form in the presence of other chemicals in sediments and may accumulate in the tissues of plants and animals, resulting in injury or death. For example, mercury is only moderately harmful until it forms methyl mercury which accumulates in the liver and muscle tissue of animals, where it may cause disabilities and death.

Two types of organic chemicals are found in the sediments of Puget Sound: those which are naturally occurring and those which have been created by humans (synthetic organics). Naturally occurring organics are the fuel upon which the marine system runs, but they can cause harm to marine life when their supply to the sediments is greatly increased through anthropogenic or other means. For example, petroleum hydrocarbons, such as oil, are naturally occurring organic molecules. These chemicals become harmful in the marine environment when they are introduced in large quantities. The synthetic organics are not naturally occurring, but can be absorbed by organisms, accumulate in their tissues, and cause injury or death. Toxic forms of synthetic organics can be very long-lasting. Well-known examples that may cause harm in the marine environment are polychlorinated biphenyls (PCBs) and organochlorine pesticides like DDT.

Scientists have studied sediment contamination in Puget Sound's urban bays, including Elliott Bay (Seattle), Commencement Bay (Tacoma), Everett Harbor, Sinclair Inlet (Bremerton), and Bellingham Bay. Urban bays show the effects of stormwater and sewage discharges, as well as past and present industrial practices, which contribute many different contaminants to the sediments. Shoreline modifications are common in urban bays, causing disturbances in the amount of natural sediment that reaches the water. Dredging and dredged material disposal moves sediment and associated contaminants from place to place in urban bays. In general, the sediments in the nearshore areas of urbanized bays are more contaminated than those in open water or less-developed areas (PTI, 1988a). The deep basins of the Sound show much lower contamination levels than the urban bays.

Sediments in the nearshore areas of less-developed bays may also be contaminated due to past and present industrial, stormwater, and sewage discharge practices. Among these areas are Eagle Harbor (Bainbridge Island) and Shilshole Bay (at the mouth of the Lake Washington ship canal) (Malins et al., 1984; Tetra Tech, 1988a).

In order to preserve healthy plant and animal populations in Puget Sound, we must protect their habitats and food supplies. Sediment contamination may affect not only the health of the organisms living in direct contact with the sediment, like bottomfish and invertebrates, but also those animals which prey on the benthic creatures. Similarly, the predators of these animals may be affected, and so on up the marine food web, affecting pelagic fish like salmon and cod, birds, and marine mammals like seals, sea lions, whales, and ultimately humans.

PSAMP SEDIMENT MONITORING

PSAMP has been designed to establish baseline conditions for sediment quality in Puget Sound and to track changes over time at certain locations (PSWQA, 1988). Scientists with the Washington Department of Ecology (Ecology) will use sediment quality data to compare changes over time at each station location. They will also compare differences among specific sediment sites; however, they cannot compare large areas of Puget Sound to one another as there are not enough PSAMP stations to characterize whole bays or regions. In order to determine how sediment quality conditions are changing throughout the Sound, the designers of PSAMP chose station locations to integrate contamination from many sources. The stations were not placed in close proximity to any single source of contamination (such as a major discharge pipe) or any known "hot spots" (areas with unusually high concentrations of toxic chemicals). Some PSAMP sediment stations were placed in relatively clean areas of the Sound to act as reference or control stations (PSWQA, 1988; Tetra Tech, 1990).

There are other programs in Puget Sound, including the Urban Bay Action Programs, Superfund, and others, that are collecting information about sediment quality at known "hot spots." Managers of these programs undertake studies to identify areas that should be cleaned up, to monitor sediment quality in areas that have undergone cleanup, and to monitor improvements in areas where sources of contamination have been reduced and clean sediments are burying contaminated sediments. PSAMP collects information about the many areas of Puget Sound where sediments are not known to be highly contaminated.

Scientists with Ecology sample the surface sediments for three distinct measures of sediment quality. They analyze for the amount of heavy metals and organics in the sediment; they expose laboratory organisms to the sediment to gauge their sensitivity to the chemicals contained in the sediment (bioassays); and they identify and count the number of animals (benthic invertebrates) living in the sediment. The combined results of all three measures provide us with a comprehensive picture of the quality of the sediments.

1990 PSAMP SEDIMENT MONITORING

During March 1990 scientists with Ecology collected surface sediments using a grab sampler at 50 sediment stations throughout Puget Sound (Figure 3) (Striplin et al., in preparation). The scientists who designed PSAMP proposed that a total of 76 sediment stations be sampled in order to characterize Puget Sound sediments (PSWQA, 1988). Ecology sampled 50 stations in 1989 (Tetra Tech, 1990), 32 of which they repeated in 1990. Many of the remaining 18 stations sampled in 1990 were clustered in south Sound in order to provide managers with more intensive coverage of south Sound sediments (Figure 3). During both the 1989 and 1990 surveys, samples were taken from water depths of 20 meters and in the deep basins of the Sound (approximately 100 to 250 meters deep). Each sediment sample was processed and shipped to laboratories for analysis of toxic chemicals, for bioassays, and for counts of benthic invertebrates.

Experts with Ecology performed some preliminary analysis on the data collected from the 1990 survey. For the purposes of this report they have examined the chemical levels in sediments and distributions of benthic inverte-

Washington State sediment standards

The state of Washington is a pioneer in establishing standards for sediment quality in the marine environment. For many years the U. S. Environmental Protection Agency (EPA) and many states (including Washington) have worked with standards for water quality which protect beneficial uses (the ways in which humans use the waters). The Washington Department of Ecology (Ecology) has developed a similar system for sediments.

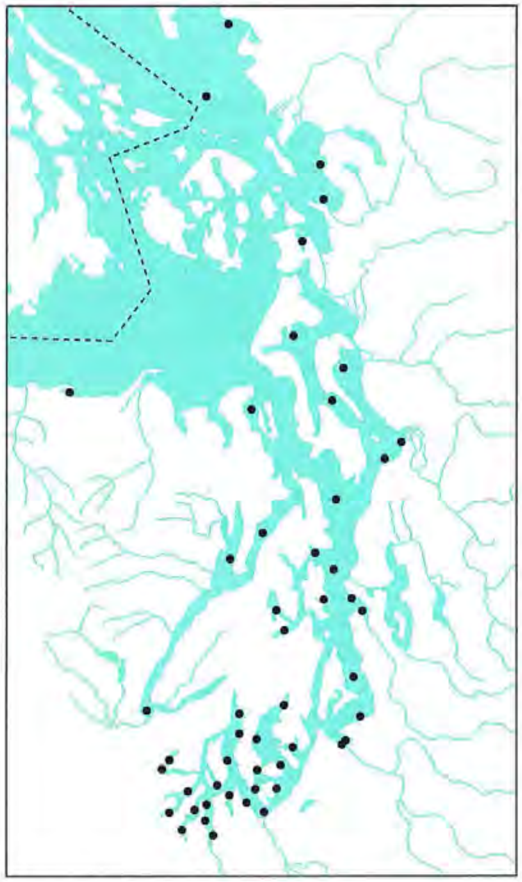
Since the early 1970s, scientists with the National Oceanic and Atmospheric Administration (NOAA), EPA, and other organizations have focused their studies on toxic chemicals and their effects on marine organisms in Puget Sound. Ecology managers have commissioned extensive technical and scientific studies to determine the levels of some chemicals which harm organisms living in Puget Sound sediments. Water quality and natural resource managers have been able to benefit from the extensive database of sediment chemistry, bioassay results, and benthic invertebrate counts in establishing these levels. The database of sediment toxicity results will be continually updated with results of new studies including PSAMP.

Ecology developed Sediment Management Standards (Chapter 173-204 WAC) for 47 chemicals and five biological tests for measuring sediment quality in Puget Sound. The rule establishing these standards also defines how much waste can be contributed to the sediments around a discharge; what level of contamination can trigger a cleanup action by the parties responsible for the contamination; and to what level the sediments must be cleaned up. The sediment standards were adopted by the State of Washington on March 27, 1991, and went into effect on April 27, 1991.

Standards for a few chemicals include:

- Mercury: 0.41 parts per million (ppm)
- Arsenic: 57 ppm
- Lead: 450 ppm
- Phenanthrene (PAH): 100 ppm (on an organic carbon basis)

Figure 3. Locations sampled in 1990 for sediment quality monitoring.



Reference: Striplin et al., in preparation.

brates. They have not yet completed the analysis and review of the 1990 sediment quality data, including those for amphipod bioassays. After all the analysis has been completed and they have further opportunity to examine the results, Ecology will develop an assessment of sediment quality in Puget Sound, as shown by the 1990 survey. Results of this assessment will appear in Ecology's technical report (Striplin et al., in preparation), as well as next year's Puget Sound Update.

PRELIMINARY RESULTS OF 1990 SEDIMENT CHEMISTRY

Ecology found measurable levels of metals in the sediments at all 50 sites (Striplin et al., in preparation). The levels of metals were all below the state sediment standards (SIDEBAR) with the exception of mercury at one site in Sinclair Inlet, which was 0.87 ppm (the state sediment standard is 0.41 ppm). In 1989 Ecology found mercury in sediments from Sinclair Inlet (0.86 ppm) and Dyes Inlet (0.51 ppm) (Tetra Tech, 1990) that exceeded the state sediment standards.

Ecology scientists found that the levels of all the metals were generally low at most stations away from the urban bays and other known sources of contaminants. During 1990 Ecology observed higher levels of most metals in the urban bays (Elliott Bay, Commencement Bay, Everett Harbor, Sinclair Inlet, Bellingham Bay) than in the rural bays. They also observed higher levels of at least one toxic metal in Dyes Inlet (copper and lead), Port Susan (nickel), Oak Harbor (chromium), Carr Inlet (cadmium), and at the south end of Hood Canal (arsenic) (Striplin et al., in preparation). Several of these metals occur naturally in soils in the Pacific Northwest, notably cadmium, chromium, nickel, and arsenic, and may not be indicative of contamination related to human activities in these areas.

Ecology scientists found similar levels of most toxic metals at the same stations that were sampled during the 1989 survey (Tetra Tech, 1990). Levels of copper, lead, and cadmium varied slightly at a few stations between 1989 and 1990, but these differences are well within the natural variability that can be expected from year to year. The concentrations of metals that they observed at the 1990 sediment stations, like those found in 1989, are similar to those that have been measured in past Puget Sound studies (Long, 1982; Dexter et al., 1985). This indicates that, so far, PSAMP data do not indicate a change in metal contamination in Puget Sound sediments over levels measured in the late 1970s and early 1980s.

Ecology scientists found low levels of toxic organic chemicals at many of the 1990 survey stations (Striplin et al., in preparation). Like the metals, they observed the highest concentrations of toxic organic compounds in the urban bays and the lowest levels away from known contamination sources. Ecology scientists observed high levels of polynuclear aromatic hydrocarbons (PAHs) in one of the highly contaminated waterways of Commencement Bay. PAHs are a group of compounds found in petroleum products and that form as a result of petroleum or wood combustion.

In 1990 Ecology found patterns of toxic organic contamination similar to those found at many of the same stations in 1989 (Tetra Tech, 1990). At a site in the City Waterway in Commencement Bay, they found levels of a PAH, phenanthrene (214 ppm on an organic carbon basis), which exceeded the state sediment standards. Several other organic compounds also exceeded the state sediment standards at one or more stations in 1989. Similar levels of toxic organic chemicals have been found in past Puget Sound studies (Long, 1982; Dexter et al., 1985). As with the metals, PSAMP cannot document a change in toxic organic chemicals in Puget Sound sediments from the late 1970s or early 1980s to 1990.

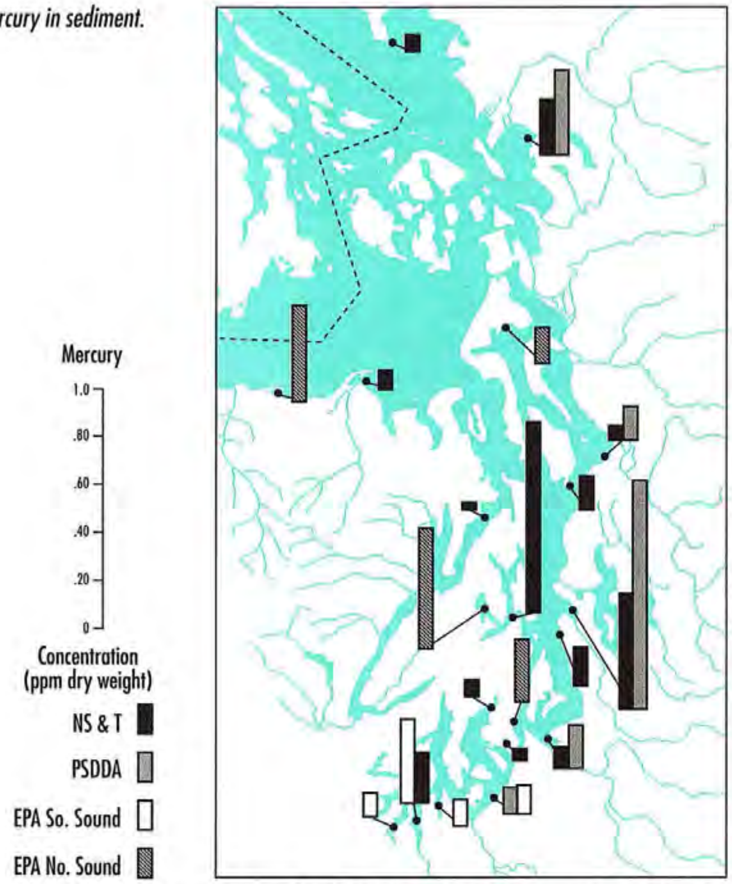
PSAMP managers did not expect to see any conclusive changes in sediment chemistry between 1989 and 1990. Additional years of chemical data are needed, along with results of bioassays and benthic invertebrate counts, to determine whether there are significant changes in Puget Sound sediment quality.

OTHER RECENT STUDIES OF SEDIMENT CONTAMINATION IN PUGET SOUND

Scientists from several organizations have measured contamination in Puget Sound sediments in recent years. Most notable among these studies have been the annual sampling for the National Status and Trends (NS&T) program carried out by the National Oceanic and Atmospheric Administration (NOAA); surveys for the Puget Sound Dredged Disposal Analysis (PSDDA) conducted jointly by the US Army Corps of Engineers (COE), the U.S. Environmental Protection Agency (EPA), the Washington Department of Natural Resources (DNR), and the Washington Department of Ecology (Ecology); reconnaissance studies in north and south Sound performed for EPA; studies carried out in Elliott Bay by the Municipality of Metropolitan Seattle (Metro); and a series of tests of metal contamination in sediments conducted by the U.S. Navy at Bangor (Hood Canal). Ecology also carries out special sediment surveys for a variety of purposes.

NS&T, PSDDA, EPA reconnaissance studies, Metro's Elliott Bay studies, and the Navy Bangor studies all show contamination of Puget Sound sediments by a variety of toxic metals and organic compounds. PSAMP managers found that there were only a few chemicals that were common to all these studies and that had been measured in a comparable way. This report will focus on these chemicals, including three metals (arsenic, mercury, and lead) and one organic compound (phenanthrene, a polyaromatic hydrocarbon). This focus allows the comparison of results of some of these studies at a few locations around Puget Sound.

Figure 4. Concentrations of mercury in sediment.



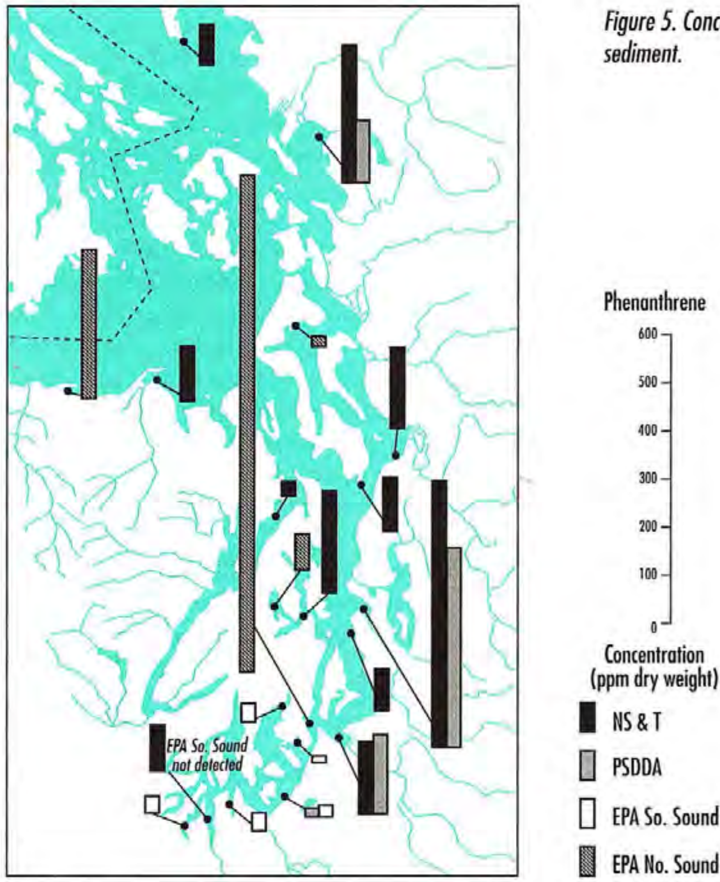
References: NOAA, 1991; Varanasi et al., 1989; Crecelius et al., 1989; PTI, 1988b; PTI 1989; PTI, 1991a.

National Status and Trends Program — The National Status and Trends (NS&T) program looks at contamination at many locations throughout the United States. NOAA investigators sample 14 sites in Puget Sound; most are in the urban bays. NOAA investigators found measurable levels of arsenic in the urban bays during annual NS&T surveys between 1984 and 1989, with the highest Puget Sound levels in Bellingham Bay and Budd Inlet (NOAA, 1991). None of the samples exceeded the state sediment standard for arsenic. They found that sites in Sinclair Inlet and Elliott Bay (north of Harbor Island) had the highest levels of mercury in the sediments (NOAA, 1991; Varanasi et al., 1989) (Figure 4); the mean mercury levels exceeded the state sediment standard. Sinclair Inlet and Elliott Bay (north of Harbor Island) headed the list for lead (NOAA, 1991; Varanasi et al., 1989); none of the samples exceeded the state sediment standard. NOAA investigators found the greatest elevations of phenanthrene in Elliott Bay (north of Harbor Island), Bellingham Bay, and Sinclair Inlet (NOAA, 1991; Varanasi et al., 1989) (Figure 5); none of the mean levels exceeded the state sediment standard. NOAA investigators did not distinguish any changes in the levels of these chemicals from 1984 to 1989.

PSDDA Studies — Scientists designed and carried out studies of sediment contamination under PSDDA in order to find open water disposal locations for relatively clean sediment from dredging operations. PSDDA managers need continuing information about the levels of contamination at the PSDDA disposal sites, information about contamination of sediments that might be disposed of at the sites, and ongoing monitoring information at the sites after disposal. PSDDA investigators sampled sediments in five areas: Commencement Bay, Elliott Bay, Port Gardner, Anderson and Ketron Islands (south Sound), and Bellingham Bay. Many of the PSDDA sites are close to the urban bays where much of the dredged sediment may originate.

During 1988 and 1989 PSDDA investigators found that sediments from Elliott Bay and Commencement Bay had the highest levels of arsenic, lead, and phenanthrene (PTI, 1988b; 1989); none of the mean values for any of the PSDDA sites exceeded the state sediment standards for these chemicals (Figure 5). They observed the highest levels of mercury at sites in Elliott Bay and Bellingham Bay (PTI, 1988b; 1989) (Figure 4). The mean of the Elliott Bay sites exceeded the state sediment standard for mercury; the Bellingham Bay sites did not.

EPA North and South Sound Reconnaissance Surveys — Scientists working for EPA Region 10 in Seattle measured chemicals in sediments from 10 locations in north and south Sound in 1988 and 1989 (Crecelius et al., 1989; PTI, 1991a). The EPA reconnaissance survey stations were generally not placed in urban bays. EPA ordered the study to help determine the levels of contamination in areas that have seldom been sampled for sediment contamination. The reconnaissance survey data can be used by managers of other programs, notably PSAMP, to better design their sediment sampling programs.



References: NOAA, 1991; Varanasi et al., 1989; Crecelius et al., 1989; PTI, 1988b; PTI 1989; PTI, 1991a.

Figure 5. Concentrations of phenanthrene in sediment.

The EPA survey found measurable levels of arsenic, mercury, and lead at several of the stations, although the levels were generally not as high as those observed in the urban bays by other studies. Dyes Inlet and Budd Inlet sediments had the highest levels of arsenic (Crecelius et al., 1989; PTI, 1991a), although none of the sample means exceeded the state sediment standards. The scientists found that Dyes Inlet, Port Angeles Harbor, and Gig Harbor (Pierce County) sediments had the highest mercury levels (Crecelius et al., 1989; PTI, 1991a) (Figure 4). Most of the Dyes Inlet samples, some of the Port Angeles Harbor samples, and none of the Gig Harbor samples exceeded the state sediment standard for mercury. They observed the highest levels of lead in samples from Dyes Inlet, Gig Harbor, and Budd Inlet (Crecelius et al., 1989; PTI, 1991a); none of them were over the state sediment standard. The EPA reconnaissance studies found the highest levels of phenanthrene at stations in Gig Harbor (Crecelius et al., 1989; PTI, 1991a), although the mean levels were below the state sediment standard (Figure 5).

Metro Studies in Elliott Bay —Investigators with Metro have sampled sediments in the vicinity of the West Point sewage treatment plant outfall, the Duwamish Head outfall, and other locations in and around Elliott Bay for several years. The Metro studies are carried out to determine the impacts of Metro outfalls on sediments. By gathering information on sediment contamination levels over time, managers can determine whether improvements in treatment technologies are translating into improvements in the environment.

Results of Metro's sediment chemistry studies between 1985 and 1989 show declines in several toxic metals (zinc, copper, lead, chromium, nickel, and silver) and a number of organic compounds in the sediments in outer Elliott Bay (Metro, 1990). Metro investigators continue to find high levels of many metals and organic compounds in the sediments at 48 stations in inner Elliott

Bay, with some stations along the Seattle waterfront exceeding the state sediment standards for PAHs, PCBs, or mercury (Metro, 1990). Inner Elliott Bay is directly influenced by the Duwamish River and sources along the waterfront. Metro capped contaminated sediments near the Denny Way CSO in 1990 and is planning other cleanup actions in the area in the near future (Metro, 1990).

U.S. Navy Submarine Base at Bangor —Investigators for the U.S. Navy have been sampling metals in sediments from the intertidal and subtidal areas near the submarine base at Bangor since 1975. The Navy ordered annual studies of the intertidal and subtidal sediments to determine the extent of any possible contamination as a follow-up to the 1975 environmental impact statement for the Trident missile support site at Bangor. The Navy is concerned about potential contamination of sediments on and near the base because of the nature of their operations, and because there has been a substantial increase in the activity of the Bangor base since the 1970s.

By examining data from 1982 and subsequent years, scientists working for the Navy observed that mercury and lead may have decreased slightly in the intertidal area, while chromium, copper, and zinc may have increased slightly in the intertidal and subtidal areas (Ribic and Swartzman, 1989). None of the metals measured in sediments in 1988 exceeded the state sediment standards.

PSAMP MEASUREMENT OF BENTHIC INVERTEBRATE POPULATIONS

Vast numbers of benthic species live in Puget Sound, including many types of worms (polychaetes), clams and snails (molluscs), and shrimp-like creatures (crustaceans). The number of species and the number of individuals per species found in the benthos are affected by many factors, including sediment grain size, water depth, amount of organic matter present, salinity of the water between the sediment particles, degree of contamination, and interactions among species.

Scientists with Ecology identified and counted the benthic invertebrates in some of the samples collected from each of the 1990 PSAMP survey stations (Striplin et al., in preparation). To bring order to the vast numbers and types of benthic organisms, scientists describe a benthic invertebrate community by reporting the number of species (species richness), the number of individuals of each species (abundance), diversity (an index that relates the number of individuals to the number of species), and the dominance of the community by greater numbers of one or more species groups (dominance). Scientists also evaluate the presence of certain benthic species as being pollution-tolerant or pollution-sensitive.

Ecology investigators examined the 1990 benthic invertebrate data and compared stations with similar grain size. They also compared the benthic invertebrate counts from 1990 to those collected from the same locations in 1989. They found that although there were minor differences at some stations in abundance, species richness, and dominance between years at the same station, there were no overall shifts in Puget Sound benthic invertebrate communities between 1989 and 1990 (Striplin et al., in preparation). PSAMP managers did not expect to see any conclusive changes in benthic communities over two years. More benthic invertebrate data are needed, along with

results of chemical analysis of the sediments and bioassay results, to distinguish changes due to the natural variability of populations from changes due to contamination.

During the 1990 survey Ecology observed that pollution-tolerant species were numerically dominant at many sites (a greater number of these species were present than any other species) (Striplin et al., in preparation). These sites included the City Waterway and the Blair/Sitcum Waterway in Commencement Bay, Eagle Harbor on Bainbridge Island, and Elliott Bay. All of these locations are in the vicinity of federal Superfund sites and are highly contaminated with an array of metal and/or organic compounds.

Ecology also examined the results of benthic invertebrate surveys that other scientists have conducted at the same stations as the 1989 and 1990 PSAMP surveys. There are two stations in the center of the main basin, and one in the center of East Passage, where benthic biologists have measured the changes in the benthic invertebrate community over time (Nichols, 1988). The results of a 25-year study of these benthic communities in Puget Sound showed that benthic communities change over multi-year periods as individual species gradually become more or less abundant (Nichols, 1988). Scientists do not know the reason for these changes, although natural changes due to gradual climatic shifts may be at least part of the cause (Nichols, 1988). In addition, some scientists consider that these changes could be related to sediment contamination (Tetra Tech, 1990). Ecology scientists have measured benthic invertebrates at one of Nichols' main basin stations and at the East Passage station. Because they have the long-term trend information supplied by Nichols at these stations, PSAMP managers are confident that, with additional years of PSAMP sediment chemistry, bioassay, and benthic invertebrate survey data, they will be able to track both contamination-related and natural changes in Puget Sound benthic populations.

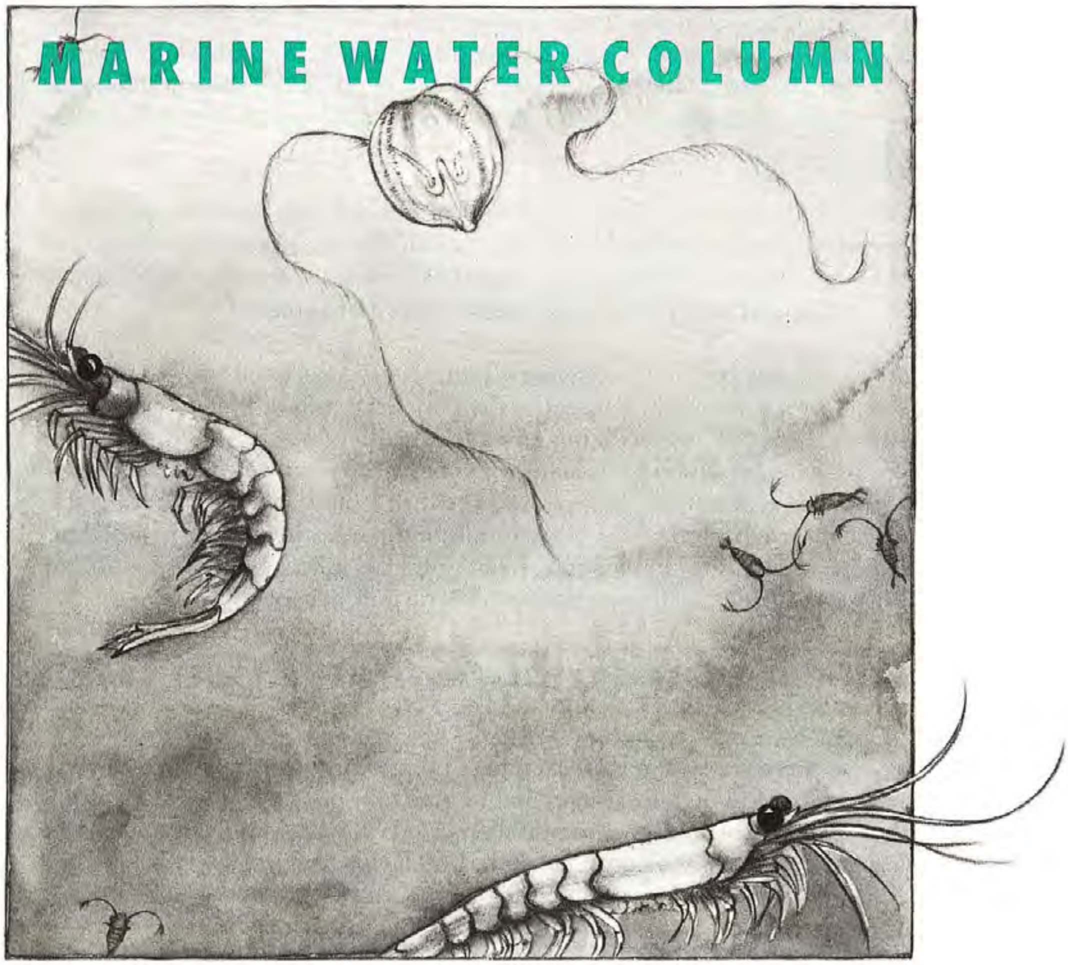
FUTURE PSAMP SEDIMENT QUALITY MONITORING

The third PSAMP sediment quality survey took place during March-April 1991. PSAMP managers made some changes to the sediment sampling scheme based on 1989 and 1990 results, including relocating some stations away from areas where coarse sediments or rocks make sample collection difficult.

Thirty-two of the 50 stations sampled in 1989 and 1990 were visited in 1991 as part of the fixed station network. Ecology placed 18 additional sampling stations in northern Puget Sound during the 1991 PSAMP survey to provide more intensive coverage of that area.

Current PSAMP sediment monitoring does not allow investigators to collect all the samples that they had planned. Unexpected results and emerging trends may take longer to confirm, and more years of sediment sampling will be needed to establish a baseline of Puget Sound sediment quality. During this time, managers may not have sufficient information to recognize ongoing changes in sediment quality in Puget Sound.

MARINE WATER COLUMN



BACKGROUND

The water between the floor of Puget Sound and the water surface is known as the water column. This water transports dissolved gases, nutrients and chemicals, particles, and small floating plants and animals (plankton) throughout Puget Sound. The water column is home to free-swimming (pelagic) fish like salmon, cod, and rockfish and mammals like seals, sea lions, and whales. Sediment washed from the land by rivers, particles and contaminants discharged from pipes and storm drains, and young forms of many marine animals pass through the water column on their way to the sediments.

The health of the water column is often referred to as the water quality of a body of water. Water quality problems may affect the water and its inhabitants, or diminish the usefulness of water column and nearshore resources to humans (beneficial uses). Examples of water quality problems can include low dissolved oxygen that can cause fish kills, concentrations of toxic algae and pathogens which can contaminate shellfish beds, mats of malodorous algae, and discolored water from spills and discharges.

Conventional and toxic contaminants can affect Puget Sound waters, although the effects are generally localized. The so-called conventional pollutants, such as particles (suspended sediments), dissolved nutrients, material which draws oxygen from the water (biological oxygen demand, or BOD), and temperature and salinity changes, can upset the natural balance of plant growth, resulting

in water quality problems. These problems may include large overgrowths of algae, known as blooms. After microscopic algae (also known as phytoplankton) have bloomed, they die and decompose, robbing the water of life-sustaining oxygen. Foul odors and fish kills can result, although these are rarely seen in Puget Sound.

Toxic contaminants are most commonly associated with particles and are generally found in very low concentrations in the water. For this reason scientists seldom look for contaminants in the water column or in the plankton, but instead look for them in sediments and in animals.

Disease-causing bacteria and viruses (pathogens) associated with sewage from humans and animals are a threat to the beneficial uses of Puget Sound. In general, these pathogens do not affect the health of marine organisms, but they are a health threat to humans who come into contact with contaminated water or who eat raw or undercooked shellfish from contaminated waters. Fecal coliform bacteria (which are found in the intestines of warm-blooded animals) are monitored by public health officials in water and in shellfish to indicate the presence of pathogenic bacteria and viruses.

ARE THERE WATER QUALITY PROBLEMS IN PUGET SOUND?

Because there is a strong tidal exchange of water with the Pacific Ocean, via the Strait of Juan de Fuca, Puget Sound generally does not exhibit many of the water quality problems of other industrialized estuaries. Puget Sound does not have large-scale algal blooms, fish kills, beach closures, or fishery bans, which can result from contamination by chemicals, nutrients, and particles from land runoff or discharges from industrial and municipal sewage plants.

However, some areas of Puget Sound have experienced water quality problems in the past, particularly those areas affected by lumber and pulp mill wastes. These have included fish kills and widespread toxicity to developing oyster larvae (Cardwell and Woelke, 1979). During the 1970s strong source control programs were put in place to reduce the amount of waste from the forest products industry. These controls were very effective in reducing many water quality problems. Similar controls, in the form of permits issued to municipal and industrial dischargers of wastewater, are in place to reduce the discharge of conventional pollutants to Puget Sound. These permits are presently being examined to determine how they should be regulate the discharge of toxic pollutants into the Sound.

Despite these efforts, localized areas of Puget Sound (non-urban as well as urban areas) still experience water quality problems. Fecal contamination from human and animal sources is the most common problem. Chronic sources of fecal contamination include failing septic systems, marine mammal feces, and agricultural runoff from poor animal management practices. Fecal contamination may also occur following heavy rains, or whenever a spill, broken sewer line, or storm drain pours untreated waste into the Sound. Many areas are closed to shellfish harvest due to excessive fecal coliform bacteria in the water. A few isolated embayments, such as Budd Inlet in the south Sound (URS, 1986) and Lynch Cove in southern Hood Canal (Curl and Paulson, 1991), experience eutrophication (the overgrowth and die-off of algae), generally during the summer or early fall.

As the human population in the Puget Sound basin grows, increased development in nearshore areas and in the watersheds, and the need to dispose of escalating quantities of waste, may increase the burden on the natural systems of the Sound. If strong preventive measures are not taken, we may see an increase in water quality problems.

PSAMP MARINE WATER COLUMN MONITORING

The PSAMP water column task was designed to measure water quality throughout Puget Sound, in a three-part scheme (PSWQA, 1988). The scientists who designed PSAMP saw the need to collect baseline and long-term water column data in many areas of Puget Sound to detect changes in water quality conditions over time. Regional planners and managers may use PSAMP information on long-term changes in the Sound's water quality to make decisions about future growth and development in the basin. Water quality managers will use PSAMP data to compare the water quality among areas of Puget Sound, allowing them to set priorities for management actions among the bays, inlets, and open basins of the Sound.

The first part of the PSAMP water column design involves sampling a limited number of open water stations, once a month, to evaluate long-term water quality trends. The open basin stations are intended to represent overall 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 point sources. Data from these stations will be added to information that has been collected in the Sound since the 1930s by University of Washington scientists and others (Tetra Tech, 1988b), and long-term trends will be examined.

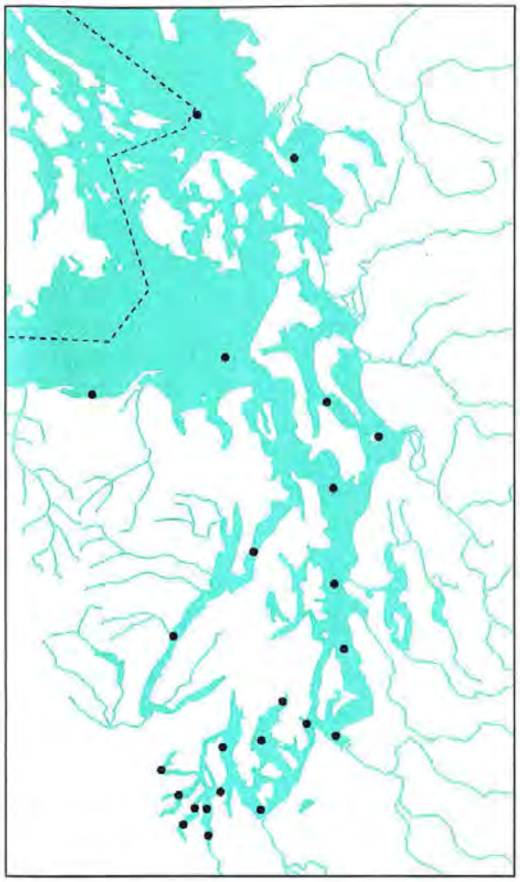
The second part of PSAMP water column monitoring looks at areas with known or suspected water quality problems. Based on previous Puget Sound studies (Campbell et al., 1977; Anderson et al., 1984), the scientists who designed PSAMP saw the need to monitor water quality changes which occur on short time scales in localized areas. PSAMP investigators will monitor water quality parameters in bays and inlets with restricted water circulation and where water quality problems are known or suspected. These studies will allow water quality managers to predict the impacts of waste discharges and to tailor wastewater permits and other actions in the Sound.

The third part of PSAMP water column monitoring, known as "solstice monitoring," documents the total amount of Puget Sound phytoplankton produced. For two weeks on either side of the winter and summer solstices (December 21 and June 21, respectively), samples will be taken from several locations around Puget Sound for analysis of dissolved nutrients, algal populations (chlorophyll), and sunlight (incident radiation). Measuring these parameters at the time of the solstices allows for the prediction of the maximum and minimum amount of algae that can be expected (Anderson et al., 1984). This information can aid water quality managers in predicting which bays may be most at risk for eutrophication, allowing them to take long-term source control actions, such as amending wastewater permits or relocating poorly sited discharges.

What does PSAMP measure and why?

The designers of PSAMP chose to measure water column variables which yield information on the distribution of contaminants and naturally occurring chemicals in the water column. The variables include: *temperature and salinity*, which provide information about the movement of the water and dissolved contaminants, as well as the layering of salty and fresher water in the water column; *dissolved nutrients and oxygen*, which are essential chemicals for plant and animal life; *chlorophyll*, which is a measure of algal mass; and *fecal coliform bacteria*, which indicate whether fecal contamination is present (PSWQA, 1988). PSAMP investigators measure these water quality variables at stations in the open basins as well as in bays and inlets of the Sound.

Figure 6. Locations sampled in 1990 for marine water quality monitoring.



Reference: Janzen, in preparation.

Scientists with the Washington Department of Ecology (Ecology) have sampled the surface waters of Puget Sound on a routine basis for the last two decades. The design of the Ecology long-term monitoring program has been evolving to meet the goals of PSAMP since 1988. Traditionally Ecology investigators scheduled their sampling on the fresh water "water year" which runs from October of one year to the following September.

Ecology scientists sampled 24 long-term monitoring stations monthly from October 1989 through September 1990 (Figure 6) (Janzen, in preparation). Due to funding constraints, they have not initiated PSAMP surveys of areas with known or suspected water quality problems, or studies of algal mass ("solstice monitoring").

Ecology scientists performed some preliminary analysis on the data collected from the 1990 monthly monitoring. For the purposes of this report they have examined distributions of fecal coliform contamination in Puget Sound, and water column conditions and dissolved nutrient levels at several north Sound stations. After the data analysis has been completed for water column work, Ecology staff will develop a detailed assessment of water quality in Puget Sound, as shown by the 1989-90 survey. Results of this assessment will appear in Ecology's technical report (Janzen, in preparation) and in next year's Puget Sound Update.

Based on the 1989-1990 water column stations, Ecology scientists concluded that the overall water quality of Puget Sound is good. The 1989-1990 stations generally represented the deep basins, open water areas, and a few bays. Until studies can be initiated in areas with known or suspected water quality problems and "solstice monitoring" can be started, we will know little about the overall quality of the bays, inlets, and nearshore Puget Sound waters in many areas.

For the purposes of this report, we will focus on Soundwide patterns of fecal coliform contamination. We will also examine some water quality variables at five stations sampled by Ecology investigators in northern Puget Sound.

FECAL CONTAMINATION OF PUGET SOUND WATERS

Water quality professionals measure fecal coliform bacteria in the water as an indicator of fecal contamination, which may harbor pathogenic (disease-causing) bacteria and viruses. There are numerous sources of fecal coliform bacteria. In the past, scientists found that sewage discharges were the largest source. As treatment technologies, chlorination of sewage effluent, and enforcement of municipal discharge permits have improved, water quality managers believe that sewage discharges from municipal and industrial sources seldom cause severe fecal contamination problems (Tetra Tech, 1988b).

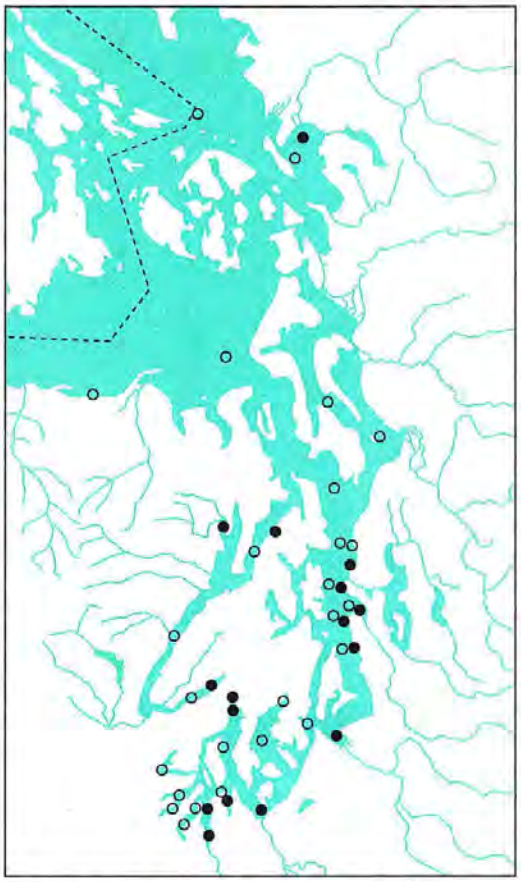


Figure 7. Exceedances of marine fecal coliform standards for 1988-1990.

References: Janzen, in preparation; Metro, 1990; Mason County, unpublished data; Hofstad, 1990; Starry, 1990a; Starry, 1990b, Goldsmith, 1989; Becker et al., 1989; Tetra Tech, 1988c; U.S. Navy, unpublished data; Sequim Bay Watershed Management Committee, 1989.

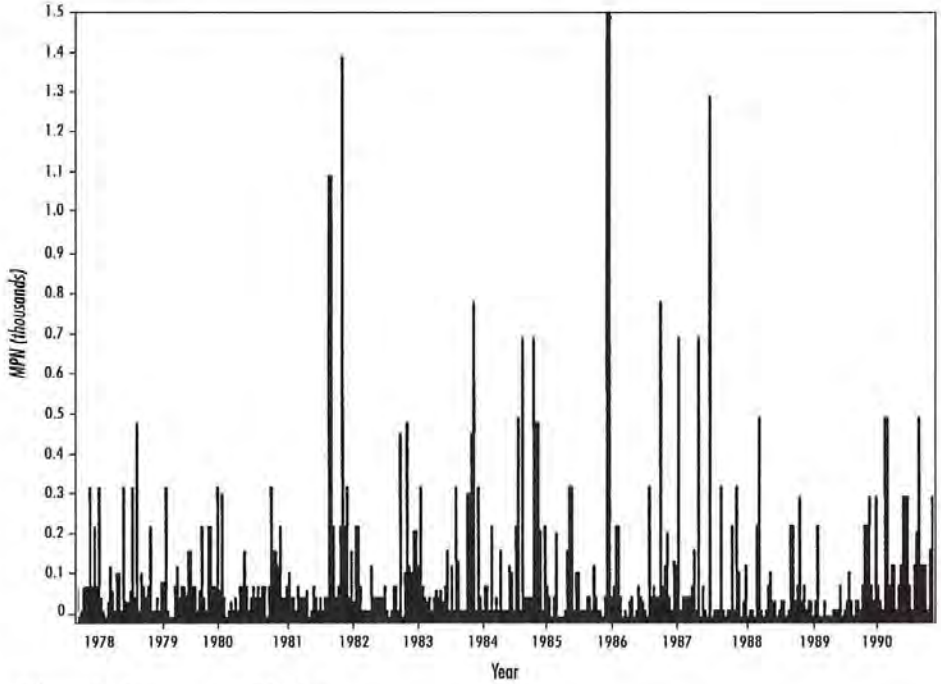
Water quality managers are now focussing on nonpoint source pollution as a major cause of fecal contamination in most parts of the Sound. Nonpoint sources are diffuse sources of pollution which do not have discharge permits associated with them. Nonpoint sources are important contributors of fecal contamination to Puget Sound. These sources include: animal waste in stormwater runoff from urban, rural, and agricultural lands; sewer overflow events (occurs when sewage treatment plants cannot handle large volumes of water from a heavy rain); discharges from boats and marinas; failing septic systems; contaminated water carried by rivers and streams; and feces from marine mammals.

Water quality managers consider the Sound's rural and agricultural areas to have the most fecal contamination, due to nonpoint sources of pollution (PSWQA, 1986b). These areas, particularly those influenced by the major rivers, show unacceptable levels of fecal contamination year round and are frequently closed to commercial shellfish harvesting (Figure 7). Invariably we find that the nearshore areas are contaminated by fecal contamination, while natural processes of dilution and bacterial die-off keep the offshore waters clean (PSWQA, 1986).

Although fecal contamination in the urban areas has been largely controlled through improvements to point source discharges, scientists continue to find periodic high bacterial counts. For example, total coliform counts (which include fecal coliforms) have been made weekly at the 40-foot deep seawater intake at the Seattle Aquarium in downtown Seattle (inner Elliott Bay) since

1977. The Aquarium's data show no significant changes in the number of total coliforms between 1977 and 1989, with bacterial levels frequently spiking above the state water quality standard (Figure 8) (Seattle Aquarium, unpublished data). Nonpoint sources in the downtown Seattle area, including stormwater, storm-caused sewer overflows, and runoff, may account for this contamination.

Figure 8. Total coliform bacteria in Seattle Aquarium intake water, Elliott Bay.



Reference: Seattle Aquarium, unpublished data.

WATER COLUMN CONDITIONS AT NORTH SOUND STATIONS IN 1989-1990

Ecology investigators have examined the results of five water quality stations in the north Sound that they sampled every month from October 1989 to September 1990 (Figure 6) (Janzen, in preparation). The stations (Strait of Georgia, Saratoga Passage, Port Gardner, Bellingham Bay, and Port Angeles) were chosen to provide geographic coverage of the north Sound. These stations also represent several water column regimes (seasonal patterns) that are typical of Puget Sound.

Scientists have generally found that the slower water circulation of water in isolated bays and inlets makes them more prone to water quality problems than areas with greater water exchange. Also, the more stable the water column is in an area, the more prone the area is to water quality problems.

A typical body of saltwater has lighter (less dense) water lying on top of heavier (denser) water. Water becomes denser by being colder, or saltier, or both. Warming by the sun makes water lighter, as does the addition of fresh water. Typically, a body of salt water will become warmer on the surface during the summer, and fresher during times of peak river discharge (frequently in the late winter or spring). The degree to which a body of water maintains less dense water on top of denser water is known as the stability of the water column.

Oceanographers describe two major types of water bodies in Puget Sound: the open basins, and isolated bays and inlets. The water in the open basins is influenced largely by strong tidal mixing, while in some Puget Sound bays and inlets, restricted circulation allows local conditions to control water quality. Local influences include freshwater discharge from rivers and streams, discharges from municipal and industrial facilities, and contaminant buildup. Many areas of the Sound show features of both the open basin and the isolated bay and inlet regimes.

During 1989-90 Ecology scientists examined information from two of the north Sound stations which show largely open basin conditions (Strait of Georgia and Port Angeles) (Janzen, in preparation). They found that the water at the top of both stations was fairly well mixed; tidal currents mixed surface water warmed by the summer sun and the fresh water discharge from the rivers with the underlying dense water. The best example of this from the 1989-90 PSAMP surveys is the Strait of Georgia station, which was well mixed year round. Researchers from British Columbia have sampled another nearby station and found that the water is not well mixed in the summer (Harrison et al., 1991).

Water at the Port Angeles PSAMP station is also fairly well mixed all year round. However, because the station is closer to shore, Ecology investigators find that it is influenced by freshwater discharge from a nearby stream, and by the transport of deep ocean water from depth to the surface (upwelling) (Janzen, in preparation). Other Puget Sound areas that are well mixed most of the year include the open areas of the main basin, East Passage, Colvos Passage, Admiralty Inlet, Tacoma Narrows, the mouth of Hood Canal, and the Strait of Juan de Fuca.

Tidal currents tends to mix the water less rapidly at the other three north Sound stations sampled during 1989-90 (Bellingham Bay, Port Gardner, and Saratoga Passage) (Janzen, in preparation). These stations are influenced by local nearshore conditions including discharges from pipes and rivers. The Bellingham Bay station is in an urban bay which is heavily influenced by seasonal discharge from the Nooksack River, as well as municipal and industrial discharges from the city of Bellingham. The Saratoga Passage station is in a narrow waterway through which water moves rapidly. This station is influenced by both the Skagit and Snohomish Rivers. The Port Gardner station is intermediate between the more isolated stations and the open basin conditions. Although the Port Gardner station is some distance from the Snohomish River and discharges from the city of Everett, these freshwater inputs and contaminants influence the stations's water quality.

The water in many Puget Sound bays and inlets, including most of the south Sound bays and inlets, is more isolated than that of the three north Sound stations. These bays and inlets are more prone to water quality problems than the north Sound stations.

DISSOLVED NUTRIENTS IN PUGET SOUND

Dissolved nutrients are supplied to the water column by runoff, by river input, and by mixing with nutrient-rich ocean water. Nutrients are also recycled in the water column through elimination of wastes by plants and animals. Phytoplankton absorb nutrients from the water and use them for growth.

When the water column is stable (with lighter water remaining on top of heavier water), sunlight reaches populations of phytoplankton. The phytoplankton cells take up nutrients from the water and their numbers increase. Dissolved nutrients are not constantly renewed by natural processes. The phytoplankton use up all the dissolved nutrients in the upper layer of water, and may sink and die. If nutrients from human activities are added to the water in these areas, and if there is ample sunlight, phytoplankton can grow unchecked.

During the winter phytoplankton populations tend to be small, their growth limited by the absence of sunlight. As the days become longer in the spring, phytoplankton start to grow, using available nutrient supplies. In areas that are not well mixed, phytoplankton may grow rapidly (bloom) as sunlight increases in the spring. By summertime, the phytoplankton cells may have used up all the available nutrients; they sink and die due to nutrient limitation. In the fall, cooling of the surface water will cause mixing of the stable water column. Deep water containing nutrients will come to the surface. If there is still sufficient sunlight (especially during a clear warm fall), the phytoplankton will grow, forming the characteristic fall bloom that we see in many Puget Sound bays and inlets.

When the water column is well mixed (stability is low), phytoplankton are likely to be mixed out of the upper sunlit layer before they can grow enough to deplete the dissolved nutrients. Nutrients are constantly mixed from deep water into the upper layer of the water column, providing a continuing supply of nutrients. In order to grow well, phytoplankton need some mixing to bring nutrients to the surface. Too much mixing takes the phytoplankton cells deep into the water, where they cannot grow.

The water column in most North American estuaries stabilizes during the summer. The growth of phytoplankton in most of these estuaries is limited by the availability of nutrients (rather than limited by light) during the summer. When an area is nutrient-limited, adding anthropogenic nutrients makes the water susceptible to eutrophication (the overgrowth of phytoplankton, caused by excessive input of nutrients). Estuaries like Chesapeake Bay have suffered badly from eutrophication which has caused massive kills of fish and other natural resource populations, as well as eradicating expanses of critical nearshore habitat by killing off submerged grasses and other plants.

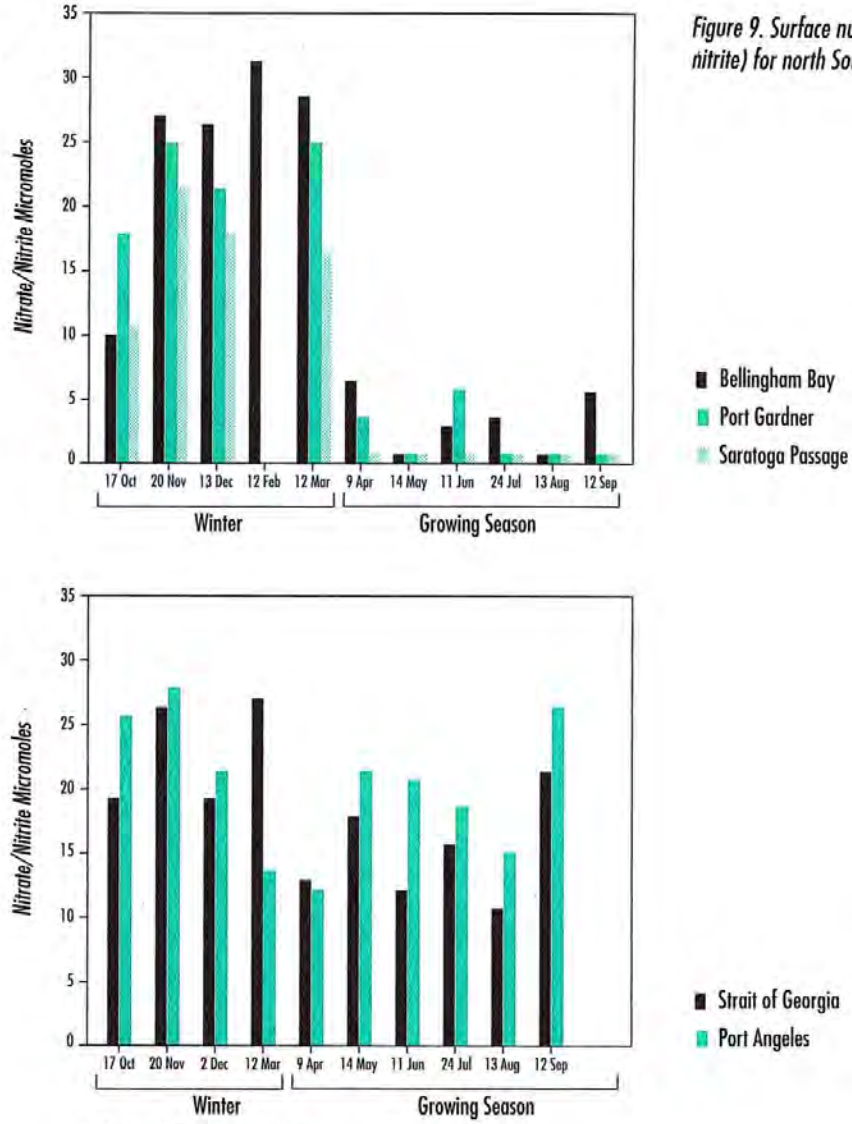
Puget Sound is almost unique on this continent (along with some of the smaller fjords and estuaries of the British Columbia coast) in that large areas of the Sound have a well-mixed water column year-round. Water quality managers do not generally focus on eutrophication as a problem in Puget Sound. However, recent evidence from several areas, and the threat of escalating human population growth in the basin, have prompted Puget Sound managers to reexamine the potential threat of eutrophication in Puget Sound (PTI, in preparation,a).

DISSOLVED NUTRIENTS IN NORTH SOUND STATIONS 1989-90

During 1989-90 Ecology scientists saw two distinct patterns in the use of dissolved nutrients by water column phytoplankton at the five north Sound stations they examined (Janzen, in preparation). The two patterns are most easily explained in terms of water column stability.

Ecology observed that the stations in the Strait of Georgia and (to a lesser extent) Port Angeles are well mixed and have a constant supply of dissolved nutrients. The scientists did not measure any decrease in water column nutrient concentrations during the summer 1990 growing season (Figure 9) (Janzen, in preparation). British Columbia scientists observed large blooms of algae and decreases in nutrients at stations in the Strait of Georgia during periods of low tidal mixing (neap tides) (Harrison et al., 1991).

Figure 9. Surface nutrient levels (nitrate plus nitrite) for north Sound stations 1989-1990.



Reference: Janzen, in preparation.

Ecology measured a drop in the dissolved nutrients at the Bellingham Bay, Saratoga Passage, and Port Gardner stations during the 1990 summer growing season (Figure 9) (Janzen, in preparation). These three stations are in areas where the water column stabilizes during the spring and summer. Ecology scientists believe that river runoff accounts for a significant portion of the nutrient input to the Bellingham Bay and Port Gardner stations. There is little nutrient input to these areas when seasonal runoff drops in the late spring.

We have evidence of a small number of areas where, despite a stable water column, phytoplankton growth continues throughout the summer and early fall due to the anthropogenic input of nutrients. These areas include Budd Inlet in south Sound (URS, 1986) and Lynch Cove at the end of Hood Canal (Curl and Paulson, 1991). In these areas, the sustained growth of phytoplankton over the summer and early fall can result in a large die-off of algae. The human and animal populations of the Puget Sound basin are affected by the results which may include fish kills, smothering of bottom creatures, and stinking algal mats.

By understanding the oceanographic conditions in the open basins and bays of Puget Sound, managers can turn their attention to those bays and inlets that are likely to be influenced by the addition of nutrients. With this informa-

tion, managers could place restrictions on new outfalls contributing nutrients to a bay, or order the control of nonpoint sources of nutrients in a watershed.

Based on the preliminary analysis of the 1989-90 north Sound stations, PSAMP investigators do not envision that these areas are likely to experience water quality problems from anthropogenic nutrient inputs in the near future (Janzen, in preparation).

FUTURE PSAMP WATER COLUMN MONITORING

The overall health of Puget Sound's water column appears to be good, although scientists see signs of degradation in some isolated bays and inlets (like Budd Inlet and Lynch Cove), and nearshore areas.

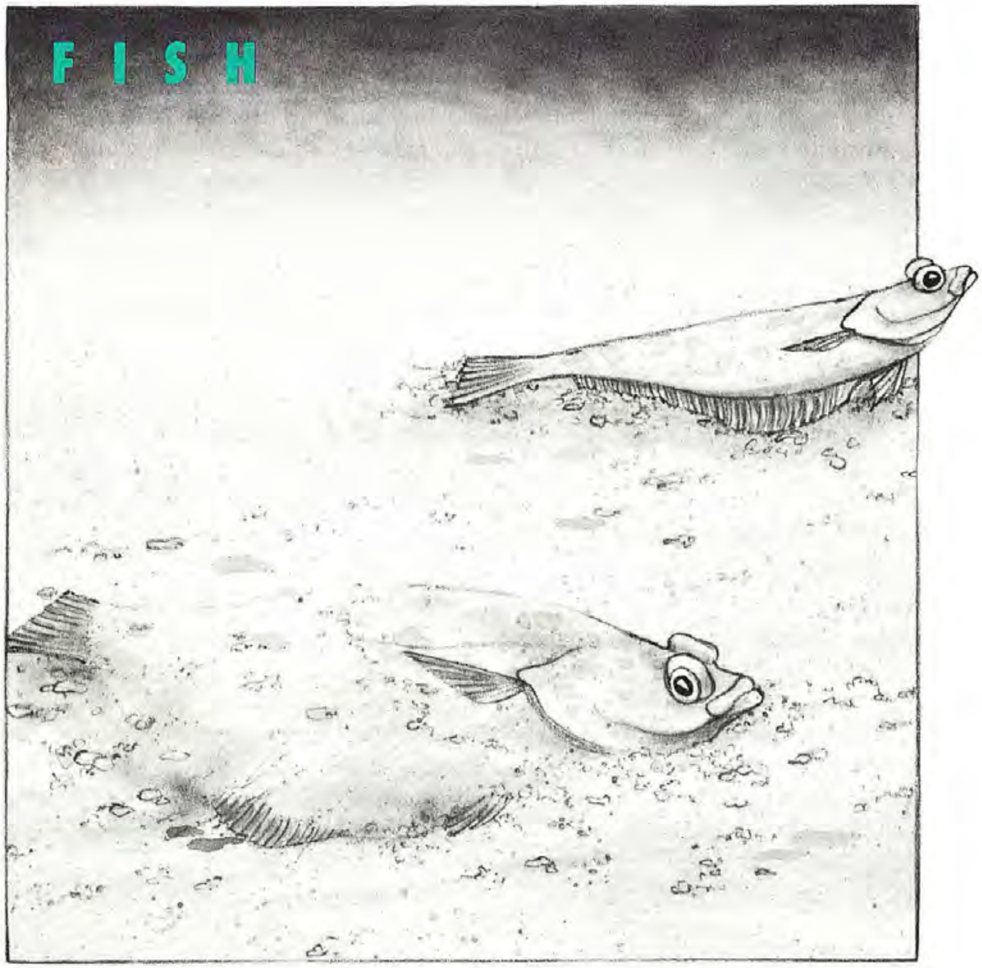
PSAMP managers believe that monthly monitoring of the water column will provide long-term information about the overall condition of Puget Sound waters. Scientists know that it is necessary to have a long-term record of conditions in order to distinguish natural fluctuations in water quality conditions and phytoplankton populations from those caused by human activities.

Long-term monthly water column data are limited in their utility, however; they are merely a snapshot in time of a dynamic changing system. Scientists cannot use these data to describe the severity or geographic extent of a water quality problem. PSAMP managers recognize the need to couple long-term trend information with more detailed monitoring of water quality conditions in the bays, inlets, and nearshore areas of the Sound.

The current PSAMP marine water column monitoring is being carried out by Ecology scientists using existing Ecology funds. At present, less than 30 percent of the necessary PSAMP water column program is being carried out. As additional PSAMP water column monitoring is added, Ecology investigators will direct their efforts towards the second and third parts of the PSAMP water column design: monitoring of areas with known and suspected water quality problems and "solstice monitoring."

By combining these three types of water column monitoring, PSAMP managers are confident that they can get a comprehensive picture of the water quality of Puget Sound and how it is changing over time. Without comprehensive monitoring of the water column, water quality managers may not be able to detect new and emerging water quality problems until serious damage is done to the Sound's natural resources.

FISH



BACKGROUND

Fish are an important ecological, economic, and cultural element of the Puget Sound area. Many residents and visitors to the area equate the abundance of fish, particularly salmon, with the health of Puget Sound. In 1989 the Washington Department of Fisheries determined that the commercial catch of salmon in Puget Sound was worth over $55 million (Hooper, personal communication). In 1988 Fisheries estimated that the commercial catch of groundfish was worth $1.6 million (Schmitt et al., 1991). Estimates of the dollars spent on catching recreational salmon and marine fish are even greater. Landmark judicial decisions have determined the rights of native Americans and others to their share of the fisheries harvest and co-management of the resource.

There are more than 220 species of fish in Puget Sound, living in many different habitats, and occupying many different positions in the marine food web. Anadromous fish like salmon, steelhead, and searun cutthroat trout hatch in fresh water, migrate long distances to marine water to feed, and return to fresh water to spawn. Marine fish live in a number of different habitats in Puget Sound, never entering fresh water at all. Some rockfish, for example, spend their lives on a single reef while other marine fish, like herring, swim through wide-ranging areas of marine and estuarine waters. Flatfish, like sole, flounder, and halibut, spend most of their adult lives on or near sandy or muddy bottoms.

Puget Sound is home to teeming populations of fish, but fisheries biologists and anglers have noticed declines in some species. The largest stocks of anadromous fish are those grown in hatcheries and through other enhancement programs. Some populations of marine fish, as well as wild stocks of anadromous fish, have declined due to natural or unknown causes, while others have been affected by overfishing. Human development and waste disposal have probably taken the greatest toll on Puget Sound fisheries. The construction of dams, dredging and filling of nearshore lands, and runoff from storm drains have destroyed fish habitat and led to contamination of food supplies. Fisheries biologists must manage fish runs to protect the fish populations while allowing for a reasonable harvest by commercial fishermen and recreational anglers. Often the fisheries managers do not have sufficient monitoring information to determine the cause of a decline in a fish population and must act conservatively to protect the stock. Fisheries closures, reduced seasons, and limited numbers of commercial fishing licenses are the result. Information is needed about the status of Puget Sound fish stocks, the health of those stocks, and the levels of contaminants found in fish tissue in order to protect the fish stocks and human health.

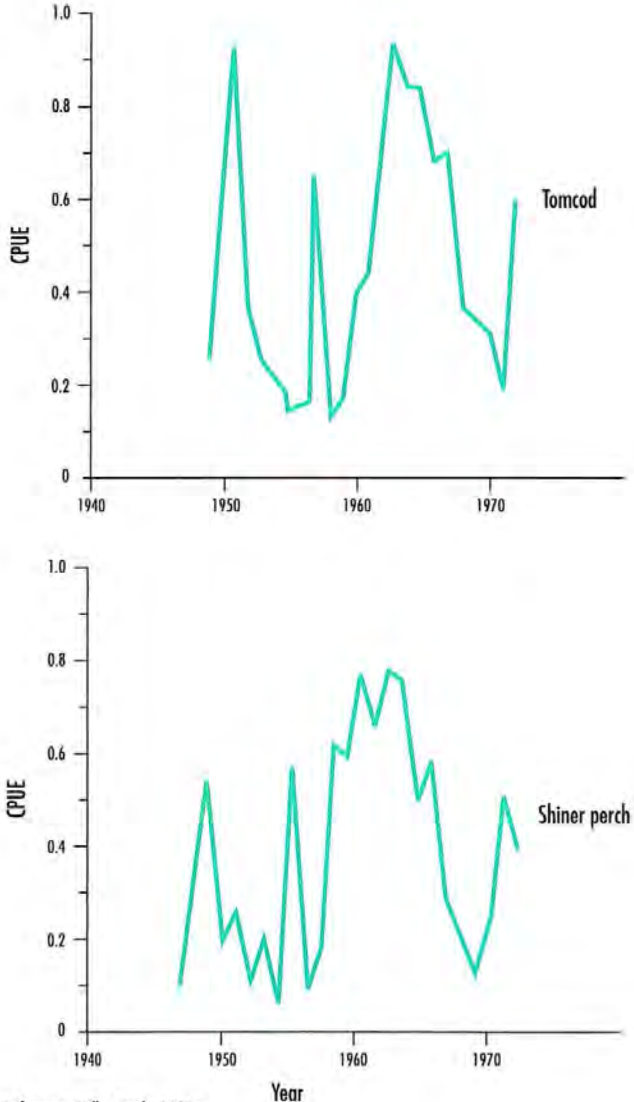
LONG-TERM TRENDS IN PUGET SOUND FISH POPULATIONS

Fisheries biologists and researchers have been catching, identifying, and counting Puget Sound fish since about 1863 (Miller et al., 1991a). The resource management agencies (Washington Departments of Fisheries (WDF) and Wildlife (WDW), U.S. Fish and Wildlife Service, the National Marine Fisheries Service, and the tribes), University of Washington (UW) researchers, and others have conducted systematic surveys for many species of marine and anadromous fish.

Fisheries biologists use survey information to better understand the life history of the fish, to estimate the size and timing of fish runs, and to determine what the fish are feeding on. Unfortunately, differing catch techniques including net size and shape, time of year of surveys, and location of surveys, make it difficult to determine how individual fish populations are changing from year to year. Also, changes in natural conditions such as rainfall and ocean currents can cause fluctuations in fish populations from year to year, further complicating our ability to determine long-term trends in fish stocks.

Despite the inconsistent and incomplete nature of some of the information, fisheries biologists at WDF and UW have found some long-term trends in Puget Sound fish populations (Miller et al., 1991b). Using information from research trawls, the fisheries biologists determined that the population abundance of several common species of Puget Sound fish, including shiner perch, sculpins, and tomcod, increased between 1960 and 1968 (Figure 10). After 1968, these fish populations returned to their pre-1960 levels (Miller et al., 1991a). The University researchers found no similar trend for other species, including ratfish, dogfish, Pacific cod, copper rockfish, lingcod, and starry flounder. There is no comparable information to determine how these populations of fish have changed in recent years.

Fisheries biologists with WDF collected information on the commercial and recreational catch of fish in Puget Sound (Schmitt, 1990). They standardized the data by the number of hours of fishing that were needed to catch the fish (catch per unit of effort, CPUE). An increase in CPUE means that fish are caught more easily, while a declining CPUE shows that more effort is needed



Reference: Miller et al., 1991a.

Figure 10. Population abundance (CPUE) of tomcod and shiner perch in Puget Sound.

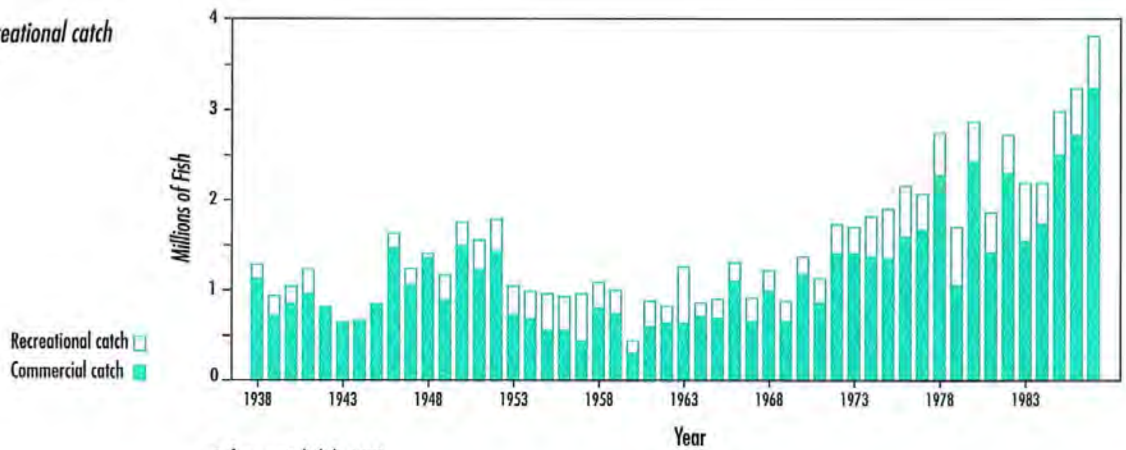
to catch the same number of fish. The fisheries biologists found that the CPUE for Pacific cod declined in areas south of Port Townsend but remained constant in the northern parts of the Sound; English sole showed a peak CPUE between 1960 and 1968; and surfperch CPUE declined from 1972 to 1984 (Schmitt, 1990). The WDF biologists felt that catch data for other species were not complete enough to determine trends.

UW researchers looked at the number of species (species richness) of fish present at Golden Gardens (near Seattle's Shilshole Bay Marina) between 1950 and 1972, and at Port Gardner (Everett Harbor) between 1965 and 1986. They observed a decline in the species richness at Golden Gardens (Miller et al., 1991b). This decline was most apparent after the construction of the nearby Shilshole Bay Marina breakwater in 1957-58. The researchers found that the fish species richness at Port Gardner remained constant from 1965 to 1986, but the catch of English sole declined over that time period (Miller et al., 1991b). No single event can be suggested as the cause of Port Gardner English sole decline, although sediments in the Everett Harbor area are known to be contaminated (PTI and Tetra Tech, 1988).

HEALTH OF ANADROMOUS FISH STOCKS IN PUGET SOUND

Fisheries managers with WDF, WDW, and the tribes believe that the overall salmon stocks in Puget Sound are generally healthy. While overall numbers of salmon in Puget Sound are stable, some wild runs of salmon have declined significantly in the past few decades. Hatchery-bred fish have replaced the wild runs in many areas. Fisheries managers set goals for the number of salmon that they expect to see returning to the hatcheries and streams to spawn, as well as the number that they expect will be caught by people fishing commercially and recreationally. Puget Sound salmon runs are generally meeting these goals (Williams and Graves, 1990). Since 1938 there has been a dramatic increase in the commercial catch of salmon, as well as increases in recreational catch (Sekulich, 1990). For many Puget Sound fisheries, the increased catch can be attributed to increased fish production from hatcheries and other enhancement programs. Since 1938 there has also been a large increase in the human population in the Puget Sound basin. As more people have moved to the Puget Sound area, they have caught more fish (Figure 11).

Figure 11. Commercial and recreational catch of salmon in Puget Sound.



Reference: Sekulich, 1990.

In general, most of the Puget Sound steelhead populations are not thriving, even though most of the steelhead caught in Puget Sound come from hatcheries (Nielson, 1990). Hatchery returns of Puget Sound steelhead increased during the early 1980s, but have been decreasing since the mid 1980s (Leland, personal communication). The runs that are the most affected include the Lake Washington run, which is being decimated by sea lion predation at the Ballard locks, and the Green River and Samish/Nooksack runs, due to unknown causes (Leland, personal communication).

Fisheries managers manage Dolly Varden char and searun cutthroat trout by setting size limits on catch and by closing streams when they see declines in the number of fish. The managers know less about populations of Dolly Varden and cutthroat than they do about salmon and steelhead (Nielson, 1990). Additional monitoring of these stocks is needed to adequately protect their numbers from the growing demand of recreational anglers in the Puget Sound basin. There are a number of threats to these fish, both within Puget Sound and in the ocean. Populations of salmon, steelhead, Dolly Varden char, and searun cutthroat are facing ever-increasing threats as human development degrades their upstream spawning and nursery habitat. Fishermen from some

Pacific Rim countries catch Puget Sound fish in drift nets set in the Pacific ocean, and seals, sea lions, and killer whales dine regularly on the anadromous fish. These catches affect the number of fish, particularly salmonids, that return to their homes to spawn a new generation to swim in Puget Sound waters.

OTHER PUGET SOUND FISH POPULATIONS

Fisheries biologists with WDF collect information on many other Puget Sound fish populations. They have noted changes in some of those populations in recent years. Pacific cod has been one of the most popular species caught by Puget Sound anglers (Palsson, 1991), but the populations have declined sharply in recent years. Fisheries biologists believe that the cod declines are largely due to changes in environmental conditions, although heavy fishing may have had some effect as well.

Commercial fishermen catch large quantities of herring, as well as harvesting herring roe (eggs) from kelp in Puget Sound. While the total weight of herring caught at most main basin sites is increasing, the herring stock in Port Susan has shown a dramatic decline since 1985 (Stick, 1990).

PSAMP FISH MONITORING

WDF, tribes, fishing organizations, and others collect information on the population levels of marine and anadromous fish in Puget Sound. The scientists who designed PSAMP chose not to duplicate those efforts. Instead, the PSAMP design concentrates on measuring contaminant levels in fish, the effects of contaminants on the fish, and the potential effects on humans who eat the fish (PSWQA, 1988). There is still a need for better information on fish stocks in the Sound above and beyond what the resource agencies and others can provide; PSAMP managers may consider monitoring fish populations in the future.

PSAMP fish monitoring examines English sole for the occurrence of certain types of liver disease (as one measure of the health of the fish), and measures tissue contaminant levels as a measure of the accumulation of contaminants in the marine food web, as well as the threat to human health from eating English sole) (PSWQA, 1988). English sole are bottomfish which live in contact with sediments and may accumulate contaminants from sediments in contaminated areas.

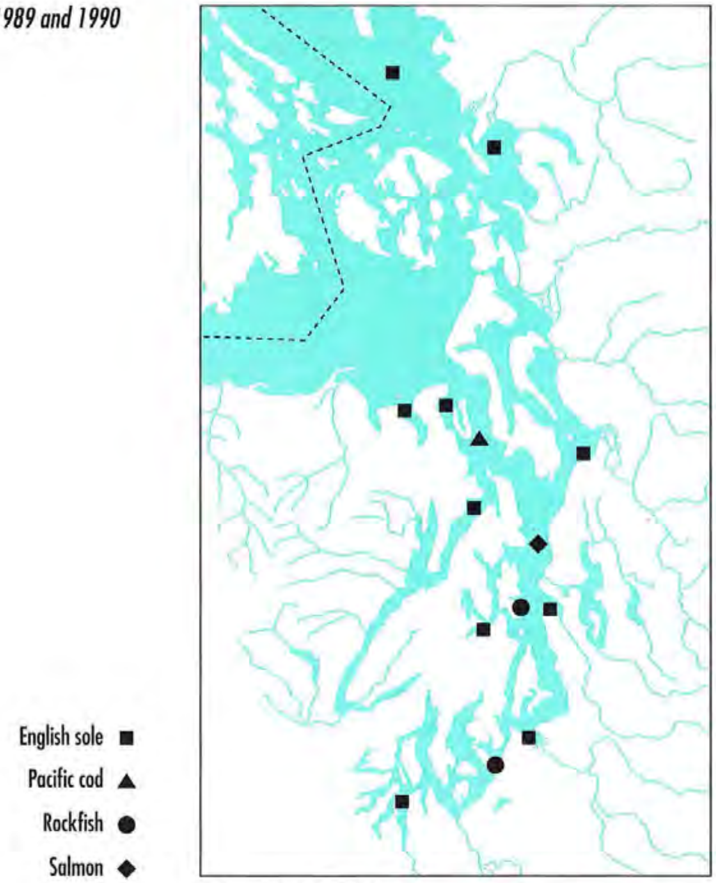
Because few people eat a steady diet of English sole, PSAMP investigators also measure contaminants in five species of fish that are caught recreationally and commercially (PSWQA, 1988). The species are copper and quillback rockfish, chinook and coho salmon, and Pacific cod.

Rockfish may live for 30 years or longer and spend much of their lives near a single reef or in one rocky area. PSAMP investigators believe that toxic chemicals measured in rockfish tissue have been accumulated in a localized area. Also, the longevity of rockfish ensures that contaminants which are known to accumulate in fish tissue will show up in their muscles.

Salmon and Pacific cod are shorter-lived and highly migratory. Muscle tissue contamination levels in these species are representative of conditions that fish

may encounter throughout Puget Sound rather than in one small area. PSAMP investigators monitor resident salmon (those that spend most of their time feeding in Puget Sound), rather than those that migrate to the north Pacific Ocean, to ensure that toxic chemicals in the salmon tissue represent Puget Sound conditions. Pacific cod swim throughout Puget Sound but generally do not migrate to the open ocean. This species has previously been shown to contain higher levels of arsenic and PCBs than other Puget Sound fish (Landolt et al., 1985, 1987).

Figure 12. Locations sampled in 1989 and 1990 for fish monitoring.



Reference: O'Neill and Schmitt, in preparation.

PSAMP RESULTS FROM 1989 AND 1990

PSAMP investigators from WDF collected samples of the six species during 1989 and 1990. They collected English sole from 10 stations in Puget Sound during May 1989 (Figure 12), many of which were located in or near the urban bays (WDF, in preparation). This survey covered a larger geographic area than most previous studies. PSAMP investigators examined the English sole for parasites and other obvious health problems (such as fin erosion), and noted their length, weight, sex, and reproductive maturity. Chemists analyzed muscle tissue from the fish for four metals (arsenic, copper, lead, and mercury) and for many organic compounds, including PCBs and pesticides, which have been found at elevated levels in fish in past Puget Sound studies. Fish pathologists cut thin slices of the fish livers and examined them microscopically to detect tumors and other signs of liver disease.

PSAMP investigators sampled rockfish for muscle tissue contaminants at two locations in the Sound during October and November 1989; Pacific cod from Admiralty Inlet during March 1990; and two species of salmon from two different locations during April and May 1990 (Figure 12) (O'Neill and Schmitt, 1991; O'Neill and Schmitt, in preparation). Chemists analyzed the muscle tissue from these fish for the same toxic metals and organics as the bottomfish.

RESULTS OF PSAMP BOTTOMFISH TISSUE ANALYSIS

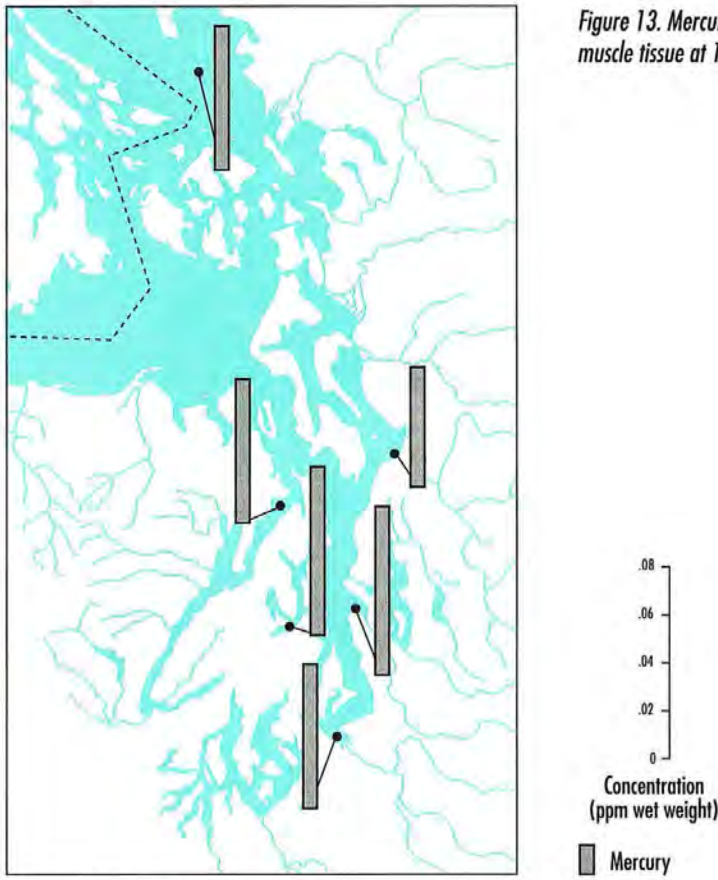
As reported in the first Puget Sound Update (May 1990), PSAMP investigators found low levels of lead, copper, and mercury in English sole tissue at most of the 1989 PSAMP stations (O'Neill and Schmitt, 1991; O'Neill and Schmitt, in preparation). Arsenic was found in all the English sole as well, sometimes at

higher levels than the other metals. The tissue levels of all four metals are similar to those that have been found in previous studies from urban and less-developed areas (Tetra Tech, 1985; Landolt et al., 1985).

PSAMP investigators have reexamined the levels of mercury reported for English sole in the 1990 Puget Sound Update report (PSWQA, 1990) and have determined that some of the values were incorrect; the correct levels are shown in Figure 13.

The English sole muscle tissue measured during 1989 contained very few toxic organic compounds (O'Neill and Schmitt, in preparation). PSAMP investigators found PCBs at low levels in all of the urban bay samples. Recent studies of PCBs in bottomfish (Crecelius et al., 1989; Landolt et al., 1985) showed similar levels.

Figure 13. Mercury concentrations in English sole muscle tissue at 1989 PSAMP stations.



Reference: O'Neill and Schmitt, in preparation.

RESULTS OF PSAMP BOTTOMFISH LIVER ANALYSIS

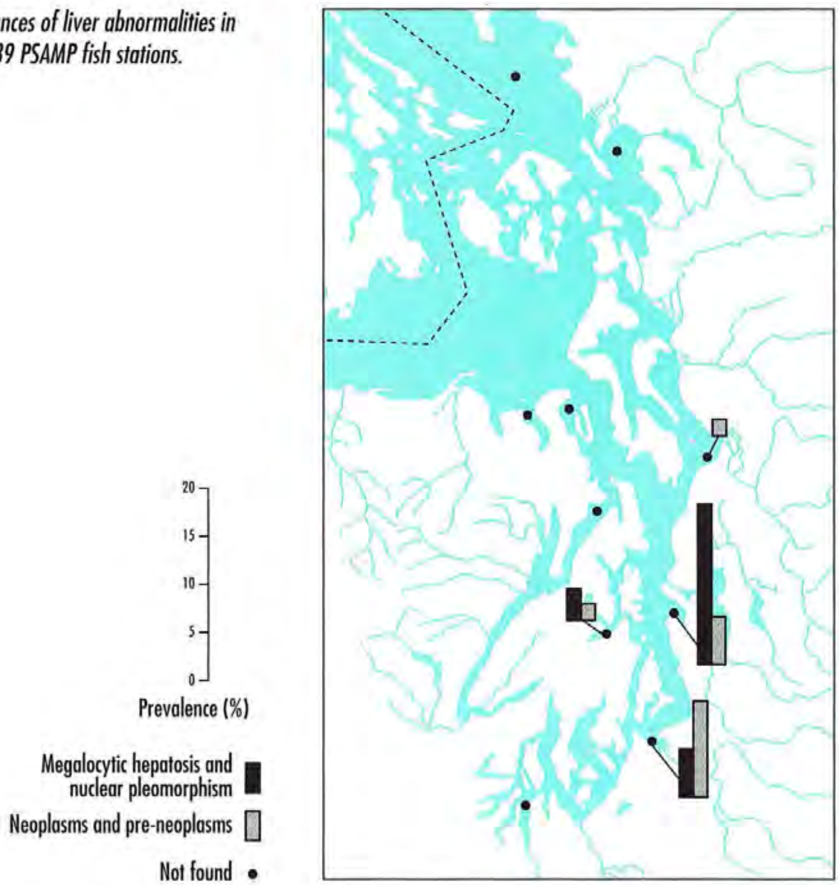
Fish pathologists sliced thin sections of the bottomfish livers and examined them under a microscope to determine the prevalence of tumors and other abnormalities. Scientists have found that fish with liver abnormalities like those measured in the 1989 PSAMP work show signs of liver failure similar to that seen in humans with liver disease (Casillas et al., 1985).

Several different types of liver abnormalities were found in the 1989 PSAMP bottomfish samples. Scientists believe that many of these abnormalities are linked to one another (Myers et al., 1987). Scientists refer to the percentage of fish sampled with each of these conditions as the prevalence of each type of liver abnormality.

At six of the 10 sites sampled for bottomfish in 1989, PSAMP investigators found no prevalence of abnormal liver conditions. At Port Gardner, located near urban Everett Harbor, the fish sampled were found to have a very low prevalence of liver abnormalities. In the three urban bays sampled (Sinclair Inlet, Commencement Bay, and Elliott Bay), PSAMP investigators found higher prevalences of liver abnormalities (Figure 14) (O'Neill and Schmitt, 1991; O'Neill and Schmitt, in preparation).

The prevalence of liver abnormalities in bottomfish found by PSAMP investigators in 1989 is similar to that found in recent studies in Puget Sound. Most

Figure 14. Prevalances of liver abnormalities in English sole at 1989 PSAMP fish stations.



Reference: O'Neill and Schmitt, in preparation.

studies of liver abnormalities in English sole have focused in and around the urban bays. Scientists have shown that most sole living in the rural bays and the open areas of the Sound rarely suffer from liver disease (Malins et al., 1984; Crecelius et al., 1989; PTI, 1991a). The highest prevalences of malignant tumors (cancer) in fish livers have been found in Eagle Harbor and in the Duwamish waterways (McCain et al., 1988). These areas are known to contain high levels of organic contaminants, particularly PAHs. Canadian scientists have found high prevalences of liver abnormalities in bottomfish from the highly industrialized areas of Vancouver Harbor in British Columbia (Goyette et al., 1988). Scientists generally find that populations of fish seldom have prevalences of liver abnormalities of more than 20 percent, even in the most contaminated areas.

Scientists have been able to cause liver abnormalities in English sole in laboratory studies by exposing the fish to high levels of PAHs (Schiewe et al., in press). Other researchers have found that English sole living in areas with high PAHs and PCBs in the sediment are less likely to reproduce successfully than those living in cleaner areas (Casillas et al., in press). PAHs and PCBs may play a role in both liver disease and poor reproduction of bottomfish, but there is no evidence that fish with liver disease have reproductive problems (Johnson et al., 1988).

RESULTS OF ROCKFISH TISSUE ANALYSIS

PSAMP investigators found low levels of four metals (arsenic, mercury, lead, and copper) in quillback and copper rockfish tissue from Blakely Rock (off Bainbridge Island) and Day Island (Tacoma Narrows) (O'Neill and Schmitt, in preparation). Both areas are away from the direct influence of urban or industrialized areas. In past rockfish studies from nearby areas, scientists have found higher levels of arsenic, similar levels of lead and copper, and lower levels of mercury than those found in the 1989 PSAMP study (Gahler et al., 1982; Landolt et al., 1985, 1987).

PSAMP investigators found low levels of the organic contaminants PCB, DDE (a breakdown product of the pesticide DDT), and phenanthrene (a low molecular weight PAH) in the rockfish tissue (WDF, in preparation). The PCB and DDE levels are much lower than those found in Puget Sound studies focused in the urban bays (Landolt et al., 1985, 1987). PAHs generally do not

accumulate in the tissue of most fish species and are seldom analyzed for in Puget Sound studies. A few other Puget Sound studies have detected phenanthrene in rockfish (Landolt et al., 1987), and in perch from Eagle Harbor (EPA, 1991).

RESULTS OF PACIFIC COD TISSUE ANALYSIS

In May 1990 PSAMP investigators spent many days attempting to catch a sufficient quantity of Pacific cod by hook and line to perform chemical analyses on their tissue. In desperation, the investigators purchased cod from a bottom trawler fishing in the Admiralty Inlet area.

PSAMP investigators found four metals (arsenic, lead, mercury, and copper) in the cod tissue, generally at low levels, although mercury levels were somewhat higher than levels found in other species (O'Neill and Schmitt, in preparation). These results agree well with previous Puget Sound studies (Malins et al., 1982; Gahler et al., 1982; Romberg et al., 1984; Landolt et al., 1985, 1987). No organic contaminants were found in the 1989 PSAMP Pacific cod tissue (O'Neill and Schmitt, in preparation), although PCBs, DDE, and phenanthrene have been detected in cod from Puget Sound urban bays in the past (Malins, 1982 et al.; Landolt et al., 1985, 1987).

RESULTS OF SALMON TISSUE ANALYSIS

The scientists who designed PSAMP chose to sample resident Pacific salmon, since these fish spend most of their lives feeding in Puget Sound. The scientists felt that this would ensure that any contaminants found in the salmon tissue were accumulated in Puget Sound. PSAMP investigators chose small salmon (sub-legal and small legal size during April) to ensure that they were residents. These fish may not have had sufficient time to accumulate contaminants in their tissue and therefore may not be as contaminated as older fish. PSAMP fisheries biologists readily caught enough resident coho and chinook salmon at a site in the main basin of Puget Sound but were unable to capture enough for chemical analysis at a second site in South Sound.

The PSAMP investigators found that the main basin salmon were very clean with only minute traces of lead and DDE, and somewhat higher levels of copper and mercury (O'Neill and Schmitt, in preparation). In the past, other researchers have found higher levels of arsenic, copper, lead, mercury, PCBs, and DDE (EVS, 1979; Malins et al., 1982; Galvin et al., 1984; Tetra Tech, 1988c) in salmon tissue from Puget Sound and the Fraser River in British Columbia. Many of these studies targeted older salmon, some of which may not have been resident in Puget Sound. The non-resident fish may have accumulated higher levels of toxicants in their tissues at other locations along their migration routes.

SUMMARY OF CONTAMINANTS IN PUGET SOUND FISH

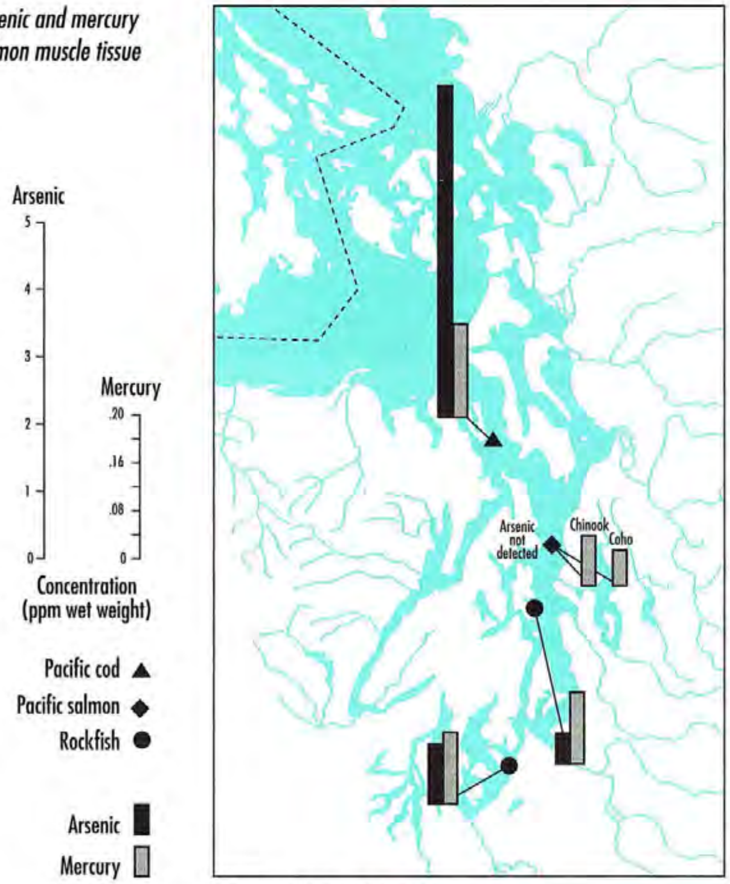
During 1989 and 1990, PSAMP investigators found that most Puget Sound fish tissue measured contained metals but few organic contaminants. Arsenic was found in all the English sole (1.8 to 11 ppm) and Pacific cod (1.5 to 6.5 ppm) samples, as well as small amounts in the rockfish (0.29 to 2.0ppm) (Figure 15). Copper levels were slightly higher in salmon than in the other species (0.23 to

What is fish liver disease?

Fish pathologists examine the internal organs of fish for signs of disease. They generally examine the liver of fish for signs of toxic effects because the liver is the organ that detoxifies chemicals before they can damage sensitive organs like the heart and brain. As a result of its role in detoxifying chemicals, the liver accumulates toxic material and is commonly the site of earliest detectable disease. Fish pathologists microscopically examine liver cells in thin pieces of tissue. By comparing the liver cells of a fish from a contaminated area to normal fish liver cells, the pathologists can determine whether the fish liver is diseased.

Fish pathologists have seen several types of liver disease in English sole from areas of Puget Sound which have contaminated sediments. PAHs (which are derivatives of petroleum and combustion) are the contaminants that are most frequently associated with fish liver disease. A few of the diseases seem to be forerunners of cancerous tumors. The most common types of English sole liver disease in contaminated areas of Puget Sound are: megalocytic hepatosis (enlarged liver cells); pre-tumors (foci of cellular alteration) where abnormal cells grow rapidly, generally in fish at least a year old; and tumors (adenomas or benign tumors, and carcinomas or malignant tumors) in fish at least three years old. We still do not really know what harm these liver diseases cause the fish.

Figure 15. Concentration of arsenic and mercury in rockfish, Pacific cod, and salmon muscle tissue at 1990 PSAMP fish stations.



Reference: O'Neill and Schmitt, in preparation.

0.29 ppm). Mercury was found in all the fish species, with the highest levels in rockfish (0.06 to 0.19 ppm) and Pacific cod (0.11 to 0.18 ppm) (Figure 15). Lead levels were generally low in all the fish (0 to 0.11 ppm) (O'Neill and Schmitt, in preparation).

The four metals occur naturally in Puget Sound sediments and soils, but high concentrations of them are also discharged into Puget Sound from urban and industrial activities. Mercury and copper are common contaminants from industrial processes, while automobile exhaust particles washed from the air and the land carry a significant amount of the lead seen in the Sound. The ASARCO smelter in Commencement Bay was a heavy contributor of arsenic to Puget Sound until it was closed in the early 1980s. A large amount of the arsenic in Puget Sound comes from north Pacific Ocean water via the Strait of Juan de Fuca. There are no natural sources of organic contaminants such as PCBs and pesticides. Their presence in fish is traceable to human uses.

ASSESSING HUMAN HEALTH EFFECTS

The Washington Department of Health (DOH) reviewed the concentrations of 17 different contaminants found in the 1989-1990 PSAMP fish and shellfish tissue samples. They assessed potential health effects from eating contaminated seafood, and they provided some suggestions on how Puget Sound residents can minimize potential health effects from contaminated fish (DOH, in preparation, a).

The DOH assessment of human health effects applies only to the concentrations of chemicals found in the six species of fish and one species of clam from the locations sampled by PSAMP. DOH looked at the maximum level of each chemical found in the fish and shellfish, and they assumed a consumption rate of seafood that would encompass the eating habits of 95 percent of the people in the Puget Sound area (about six meals per week). The Environmental Protection Agency (EPA) has developed reference levels for many different chemicals that predict that humans will not be harmed by consuming chemicals at those levels. DOH identified chemicals of concern using the EPA reference levels. Scientists with DOH compared the maximum PSAMP fish and shellfish chemical levels to the EPA screening levels. They searched the scientific literature on human and animal toxicology to determine potential

human health effects for those chemicals where PSAMP fish and shellfish exceeded the EPA reference level, as well as for chemicals for which there is no established reference level.

Most of the chemicals that are found in seafood are also found in other foods that we commonly eat. Also, people are exposed to many of these contaminants through air and water. DOH also compared the contribution of each chemical of concern from the PSAMP seafood samples to other known sources of the same chemical.

CONTAMINANTS IN 1989-90 PSAMP FISH SAMPLES: HUMAN HEALTH EFFECTS

DOH determined that concentrations of several chemicals detected in the PSAMP fish samples equated to levels below the EPA reference level. As the EPA reference levels are protective of human health, DOH feels confident that the levels of these chemicals found in the fish sampled by PSAMP in 1989 are not a threat to human health (DOH, in preparation, a).

The maximum concentrations of the chemicals that were found in PSAMP samples are shown in Table 3, along with the species and location where they were found. In reviewing these chemical levels, DOH found that the highest mercury levels were well below the FDA limit of 1 ppm, and would expose people to considerably less mercury than is commonly found in canned tuna. They felt that all the arsenic is in a non-toxic form in the animals' tissue. Although there is truly no safe level for lead exposure to humans, DOH found that eating fish sampled by PSAMP would contribute very little additional lead to humans. DOH found that the amount of the synthetic organic contaminants in the PSAMP fish was too low to be of concern to human health (DOH, in preparation, a).

Based on their analysis of the PSAMP fish tissue data, DOH believes that there will be no adverse human health effects from eating these types of fish (DOH, in preparation, a). However, PSAMP fish samples are generally not collected from the most contaminated areas of the Sound; the health effects from eating fish from more polluted areas may be somewhat higher. DOH's health analysis was based on a high consumption rate of fish (approximately six meals per week). The average person in the Puget Sound area probably eats fish less often, making health concerns even lower.

The Washington Department of Health's assessment of the human health risks from eating chemically contaminated Puget Sound shellfish is reported in the chapter on shellfish.

ASSESSING THE LIKELIHOOD OF DEVELOPING CANCER FROM EATING CONTAMINATED SEAFOOD

EPA and other agencies calculate the probability of developing cancer by consuming, breathing, or touching certain chemical contaminants. This procedure is known as risk assessment. Scientists who have developed risk assessment models use a very conservative approach, building in wide margins of safety. The risk assessment models are very protective; people will probably suffer fewer health effects than the models predict.

Guidelines for reducing your exposure to contaminants in fish

The medical community generally agrees that there are many benefits from eating fish, particularly in place of red meat. The average person should have few concerns about eating Puget Sound fish, particularly if they take steps to further reduce their exposure to chemical contaminants in the fish.

There are several ways that you and your family can decrease your exposure to some of the chemicals in fish from Puget Sound and elsewhere. The best way is to avoid fish that are likely to be chemically contaminated. Public health officials warn against eating fish from urban and industrialized areas. Fish from all the Puget Sound urban bays show some degree of chemical contamination, as do those from Eagle Harbor and other industrialized sites. Fish caught in the rural bays and the deep basins of the Sound generally have little or no chemical contamination.

For those who catch fish in urban bays, avoiding areas close to shore and near obvious sources of contamination, like large factories and storm drains, can minimize chemical exposure. Eating younger and smaller fish will also reduce your risks, as these fish commonly have lower levels of contaminants.

Because many organic contaminants bond with fat, removing the skin and fat deposits from fish before cooking can reduce human exposure. Cooking fish will remove some of the contaminants, particularly cooking in such a way that allows fat to drip from the fish.

Finally, avoiding the internal organs of fish will reduce human exposure to chemicals. The liver, kidneys, and other organs accumulate chemicals in the process of detoxifying and filtering poisons from the fish.

Table 3. Contaminants assessed for human health effects.

Chemical	Maximum Concentration	Species	Location Sampled
Mercury	0.19 ppm	Copper rockfish	Blakely Rock (off Bainbridge Island)
Arsenic	11 ppm	English sole	Sinclair Inlet
Lead	0.11 pp	English sole	Discovery Bay
DDE	2.8 ppb	English sole	Commencement Bay
DDD	0.18 ppb	Quillback rockfish	Day Island (Tacoma Narrows)
PCBs	100 ppb	English sole	Sinclair Inlet
NDPA	20 ppb	Coho salmon	Puget Sound main basin

EPA scientists separate effects of toxic chemicals into those that cause cancer and those that cause other health problems (non-cancer). For those chemicals that cause cancer, EPA scientists assume that there is no safe exposure level for humans; for chemicals that cause non-cancer effects, they assume that there is some safe level. For chemicals that cause cancer, the amount by which a person might increase his or her cancer risk due to a certain chemical is expressed as the increased probability of getting cancer over a lifetime.

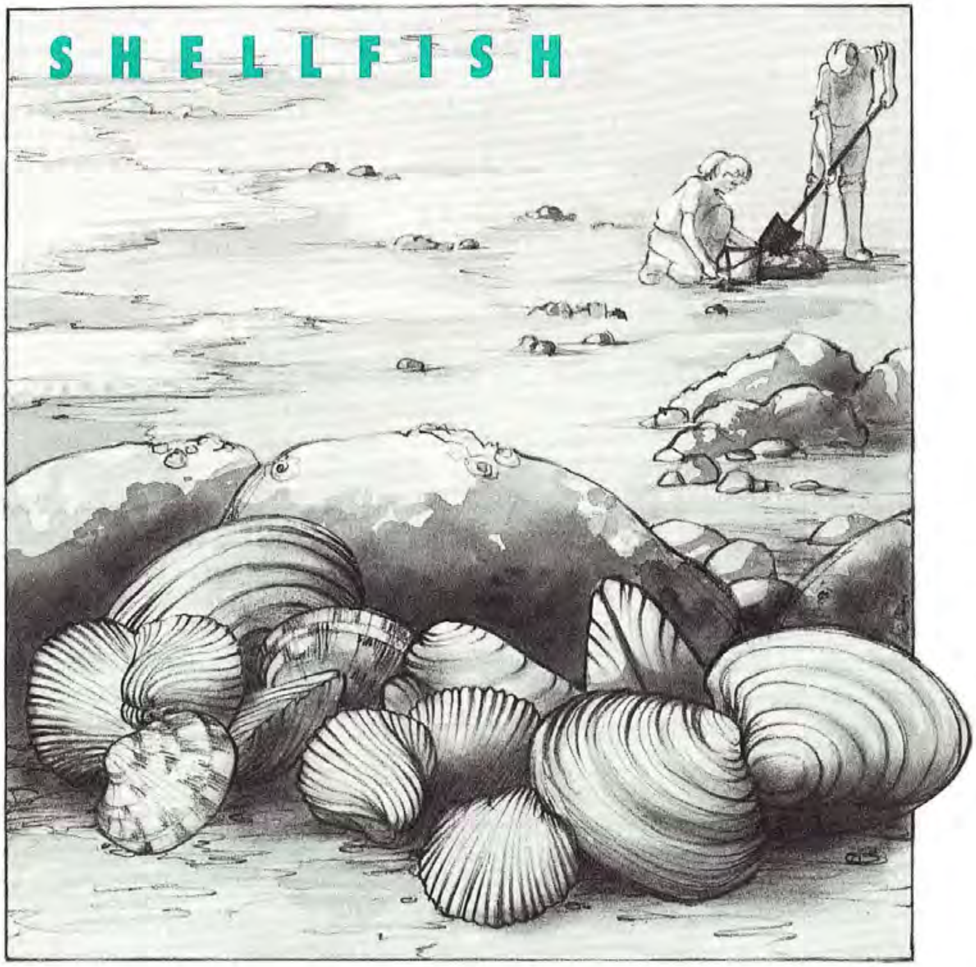
Based on the EPA health risk assessment of chemical contaminants in seafood (Tetra Tech, 1988d), PSAMP managers estimate that the greatest risk to humans from Puget Sound seafood, as shown by the 1989-1990 PSAMP fish and shellfish samples, would come from PCBs in Sinclair Inlet English sole. The concentration of PCBs in these fish could increase a person's cancer risk by one in ten thousand (10^{-4}) over a 70-year lifetime of eating an average amount of fish (10 meals a month). To put this in perspective, the average person living in the United States has a total lifetime probability of getting cancer of one in four.

FUTURE PSAMP FISH MONITORING

During 1991 and 1992, PSAMP investigators plan to continue sampling Puget Sound fish for tissue contaminants and liver disease. Beginning in 1991 PSAMP investigators will collect muscle and liver tissue from English sole for chemical analysis, as well as liver samples for histopathology analysis. PSAMP investigators and managers will consider using larger salmon for future PSAMP fish contaminant studies to ensure that the fish are old enough to have been exposed to representative Puget Sound conditions of contamination for longer periods. WDF biologists will sample fish at 21 bottomfish sites (for tissue chemistry and histopathology), and at 5 to 10 sites for salmon, rockfish, and Pacific cod (for tissue chemistry).

Without increased monitoring of fish for contaminants and measures of fish health, fisheries managers will have a limited ability to determine whether fish in many parts of Puget Sound are healthy. Public health officials will also be limited in their ability to tell the public whether Puget Sound fish in most areas are safe to eat.

SHELLFISH



BACKGROUND

Shellfish represent an important commercial, recreational, and aesthetic resource to people living in the Puget Sound region. Oyster growers, commercial harvesters of clams, crabs, and geoducks, tribal members, weekend clam diggers, beachcombers, and children tidepooling all enjoy the diversity and richness of shellfish grown in Puget Sound. The commercial value of shellfish in the Sound in 1987 was $26 million (WDF, 1988). While there appears to be an abundance of shellfish, particularly bivalves, in Puget Sound, many of the shellfish beds are contaminated with bacteria and chemicals, posing a potential risk to humans who consume them.

Most bivalve shellfish (such as clams and oysters) are sedentary animals which live their adult lives in one spot on the floor of Puget Sound. Bivalves filter enormous quantities of water to extract tiny particles of plankton and debris which provide them with nourishment. This filtering process places bivalves at risk for accumulating contaminants from the water. Even though the contaminants may be very dilute in the water, shellfish can accumulate them in their tissues.

The non-bivalve shellfish (crabs and shrimp) spend most of their lives consuming plants, animals, and debris from the bottom of Puget Sound or capturing free-swimming and floating animals from the water column. Crabs and benthic shrimp (generally bottom scavengers) can also accumulate chemicals from contaminated sediments.

Resource managers and public health officials are concerned about shellfish contamination because harm may occur to the shellfish themselves, and because humans may face health risks from consuming contaminated shellfish.

PUBLIC HEALTH CONCERNS ABOUT SHELLFISH

There are three types of potential threats to public health from consuming contaminated shellfish: pathogens (disease-causing organisms such as bacteria and viruses), paralytic shellfish poisoning (PSP), and chemical contamination.

Pathogens can be transmitted to water and to shellfish from infected humans (and other animals) via their feces. Sources of pathogens include discharges of wastewater from sewage treatment plants, stormwater runoff, runoff from failing septic system drainfields, and the release of animal feces into the water from farms, forests, and developed areas. Heavy rainfall can wash fecal material from the land and cause contamination of nearshore shellfish beds. Scientists find different amounts of contamination in shellfish at different times of the year. Generally, the more fecal coliform bacteria present in the water, the more contamination will show up in the shellfish. Typically, fecal coliform bacteria are found most frequently in marine waters following heavy rains, and throughout the winter in the Puget Sound area, although counts may be highest in summer in areas with heavy boat traffic and around marinas (DOH, 1989).

Most fecal contamination is caused by nonpoint source pollution. Nonpoint sources are diffuse sources of pollution which include animal waste in stormwater runoff from urban, rural, and agricultural lands; sewer overflow events (occurs when sewage treatment plants cannot handle large volumes of water from a heavy rain); discharges from boats and marinas; failing septic systems; contaminated water carried by rivers and streams; and feces from marine mammals.

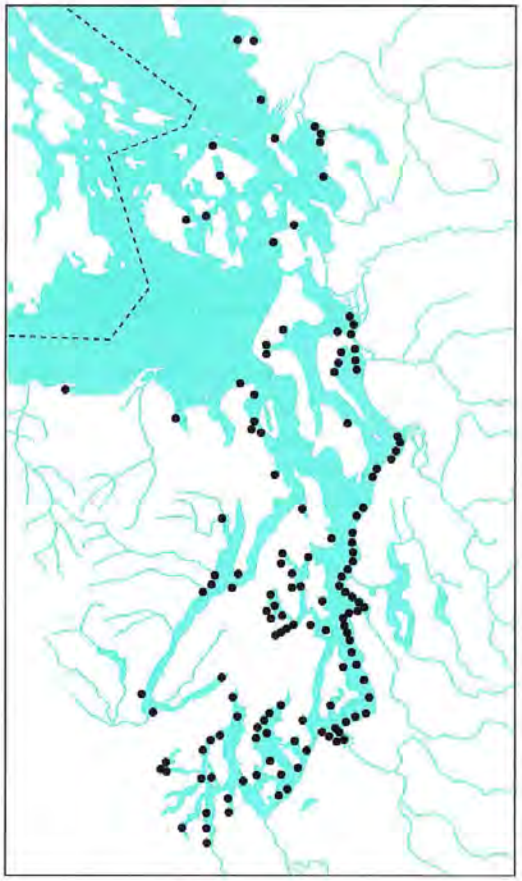
The Washington Department of Health (DOH) routinely monitors commercial shellfish and shellfish growing waters for fecal coliform bacteria, which are indicators of potential pathogen contamination. DOH officials have been classifying waters for commercial shellfish growing and harvesting since the 1920s. As a part of that program, they have reclassified (restricted) beaches in many parts of the Sound since the 1950s (Figure 16). Since 1987 DOH investigators have been monitoring recreational shellfish beaches as well.

DOH prohibits commercial shellfishing along the eastern shore of the main basin of Puget Sound, from Tacoma to Everett (and in other areas of the Sound), due to potential bacterial and chemical contamination caused by discharges from storm drains, residences, sewage treatment plants, and industries. DOH officials have identified many recreational beaches that are also being affected by these discharges. Shellfish monitoring under PSAMP and other Puget Sound programs will provide public health officials with the information they need to selectively restrict shellfish harvesting at recreational beaches when a public health threat exists.

Since 1981 DOH has downgraded the classification of 16,113 acres of commercial shellfish beds to restrict or prohibit shellfish harvesting. In 1981, 17 percent of the classified commercial shellfish areas in the Sound were restricted; in 1990, 38 percent were restricted (DOH, 1990). Most recently, all of

Liberty Bay and parts of Case Inlet (North Bay) were downgraded in May 1991 (Figure 2) (Melvin, 1991a; 1991b). Scientists with the National Oceanic and Atmospheric Administration estimate that, between 1985 and 1990, bacterial contamination resulted in restrictions to classified commercial harvest areas that are among the largest in the nation (NOAA, in press).

Public health officials and natural resource managers are concerned that the continued closure of shellfish beds is a sign that serious nonpoint problems are not improving with time. In many cases local governments are responsible for correcting nonpoint pollution problems; many receive grants from the state to help in this effort. Since 1987 the state has provided almost $3 million in grants to local governments.



Reference: DOH, 1990; Melvin, 1991a; Melvin, 1991b.

Figure 16. Shellfish beds where commercial harvest is not permitted.

Paralytic shellfish poisoning (PSP), commonly known as red tide, is a naturally occurring nerve toxin which can accumulate in the tissues of shellfish that filter certain algae (*Alexandrium catenella*) from the water. The algae which is responsible for PSP grows rapidly in our waters on a frequent but unpredictable basis. When sufficient levels of the algae are present in the water, the shellfish can concentrate enough toxin to make their meat dangerous, if not fatal, to humans. Because of the potential life-threatening nature of PSP, DOH scientists routinely monitor 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.

Chemical contamination of bivalve shellfish can occur in two ways. They can concentrate chemical contaminants by filtering large amounts of water, and they can absorb material resuspended from contaminated sediments. Both the public health effects and the effects on the shellfish themselves are not well known. Public health officials realize the need for careful monitoring of chemicals in shellfish and for further information on the effects that chemical contaminants have on shellfish and on consumers.

WHAT CAN WE DO TO RESTORE RESTRICTED SHELLFISH BEDS?

Local governments, tribes, the state, and the public use a multi-pronged approach to reduce nonpoint source pollution affecting shellfish which includes education, planning and monitoring, enforcement, and remedial action. Under the nonpoint source program of the Puget Sound Water Quality

Bacterial contamination of shellfish on King County beaches

Metro scientists and technicians measure fecal coliform bacteria in shellfish from King County beaches as a measure of water quality near Metro sewage outfalls. Commercial shellfish harvesting is prohibited along the eastern shore of the main basin of the Sound. The Seattle-King County Department of Health does not recommend harvesting shellfish from any of the King County beaches near urban areas. The harvesting of shellfish from Seattle city parks is prohibited.

During 1988 and 1989 Metro scientists found that clams from Alki Beach and Fauntleroy Cove in the Seattle area consistently had the highest levels of fecal coliforms of all the beaches they sampled. Most of the contamination at Fauntleroy comes from streams which drain onto the beach (Metro, 1990). Fecal contamination in the streams may result from the introduction of pet and wild animal waste upstream. Metro scientists found that clams from Richmond Beach (North Seattle) were relatively clean in 1988-89, while shellfish from Alki, Fauntleroy, Carkeek Park (North Seattle), West Point and Seahurst Park (Seattle), Faye Bainbridge Park (on Bainbridge Island), and Maury Island (near Vashon Island) contained levels of fecal coliforms that are higher than the commercial shellfish harvest standard, but lower than those from Alki Beach and Fauntleroy Cove (Metro, 1990).

Management Plan county governments rank their watersheds for nonpoint water quality problems. The counties rely heavily on public input to develop their rankings. As funds becomes available, the counties must address the nonpoint problems, devise solutions, and carry them out in the highest ranked watersheds. A major part of that process involves the formation of watershed action committees of interested citizens. The committees determine the most important nonpoint problems and help find solutions. As of 1991, there have been watershed action committees formed in 26 watersheds around the Sound. They have been instrumental in gaining cooperation from fellow citizens in cleaning up nonpoint problems.

As part of the watershed planning process, local governments, tribes, and state agency staff establish education programs which are directed at influencing individual and group behavior which leads to nonpoint pollution. Staff prepare and implement plans for shellfish bed restoration which may include increased shellfish and water quality monitoring. They work to modify local regulations to prevent additional contamination. Local governments and the state initiate cleanup efforts including correcting septic systems failures, fencing livestock out of streams, improving manure handling operations, and providing pumpout facilities for boats.

Local governments, tribes, and the state find that restoring contaminated shellfish beds is a difficult task. There are usually many different sources of contamination to track down and correct. They have only a limited number of staff and limited funding to carry out cleanup or enforcement actions. There are success stories around Puget Sound, however. Managers find that when nonpoint sources are cleaned up, bacterial contamination is reduced in the water overlying shellfish beds.

Based on continuing closures of shellfish beds, public health officials and managers are concerned that education and the largely voluntary cleanup efforts are not solving the problem. Stronger regulatory actions, and stronger financial incentives for those who follow the regulations, may be needed to turn the tide of shellfish closures.

PSAMP SHELLFISH MONITORING

The focus of PSAMP shellfish monitoring is on the threat to human health from consuming contaminated shellfish, and on the numbers of shellfish present on Puget Sound beaches. Because commercial growers and harvesters of shellfish must have their shellfish checked regularly for bacterial contamination and PSP, PSAMP investigators focus their sampling on public recreational beaches where many Puget Sound residents harvest shellfish (PSWQA, 1988). Most people gather shellfish from rural areas, although many continue to take clams, mussels, and oysters from urban and industrialized areas as well. PSAMP investigators focus their sampling efforts for bacterial contamination on rural recreational beaches; many of these beaches have known sources of nonpoint pollution. The designers of PSAMP also thought that shellfish living near urbanized areas are exposed to a myriad of chemical contaminants and that their tissue should be measured for toxic chemicals.

Once every three months, beginning in November 1989, DOH investigators have sampled bivalves (native littleneck clams, manila clams, butter clams, and blue mussels) for bacterial contamination (fecal coliforms) (DOH, in preparation b). During 1989-1990 the investigators and citizen volunteers collected clams at 10 recreational shellfish beaches in rural Puget Sound (Figure 17). Many of the sampling sites are in state or county parks.

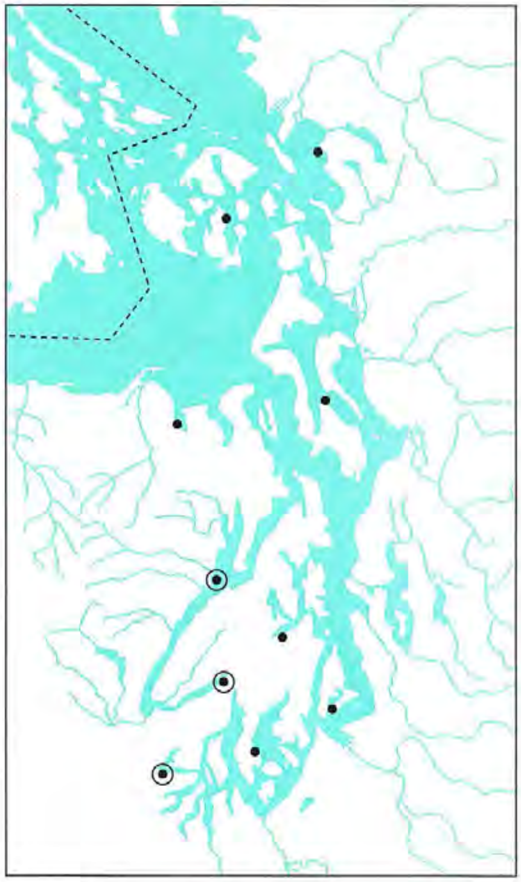


Figure 17. Locations sampled in 1989-1990 for fecal contamination in shellfish.

Reference: DOH, in preparation, b.

During May 1990 DOH investigators collected shellfish for toxic chemical analysis at three beaches which have a history of chemical contamination from nearby urban sources, and from one beach which has few known sources of chemical contamination.

DOH carries out an intensive PSP sampling and analysis program at many commercial and recreational beaches throughout the Sound. With the help of citizen volunteers, DOH officials sample for PSP contamination every other week, for six months of the year. During the winter months (October through March), samples are collected once a month at most sites. PSP is measured at more than 100 beaches throughout the Sound; PSAMP investigators selected for PSP trend analysis 16 of these that are consistently sampled throughout the year.

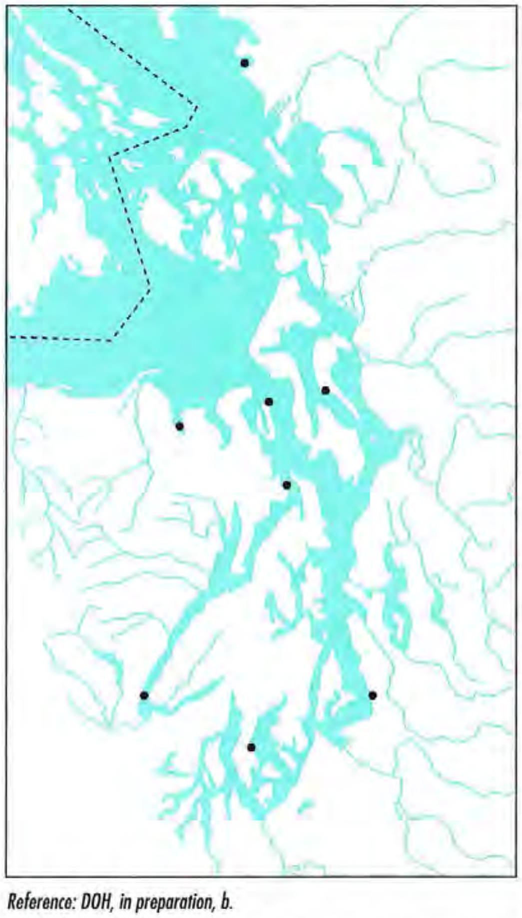
During the spring of 1990 shellfish experts from the Washington Department of Fisheries (WDF) surveyed recreational beaches for the abundance of harvestable shellfish. PSAMP investigators have assembled these data to estimate the number of shellfish on a few beaches and to determine where to focus their monitoring efforts.

1989-1990 PSAMP SHELLFISH RESULTS: SHELLFISH ABUNDANCE

Shellfish biologists with WDF counted and weighed butter clams and cockles at eight PSAMP sites (Figure 18). All the sites are public beaches where Puget Sound residents harvest shellfish recreationally.

PSAMP managers examined the shellfish abundance information from 1988, 1989, and 1990. They determined that Bywater State Park at the head of Hood Canal had the greatest number of butter clams per square foot in all three years, as well as the greatest weight of butter clams per square foot in 1988 and

Figure 18. Locations sampled in 1990 for shellfish abundance.



Reference: DOH, in preparation, b.

1989 (WDF, unpublished data).

Shellfish biologists found that cockles were most abundant at Sequim Bay State Park in all three years, and that the greatest weight per square foot of cockles was at Sequim Bay in 1988 and at Camano State Park in 1989 and 1990 (WDF, unpublished data).

PSAMP managers calculated that, in 1990, Bywater State Park had no cockles; Penrose State Park (Carr Inlet) had the fewest butter clams per square foot; and Potlatch State Park (southern Hood Canal) had the lowest weight of butter clams per square foot.

PSAMP managers are cautious in recognizing trends in shellfish abundance with only three years of information. Preliminary trends at the eight sites from 1988, 1989, and 1990 show that the number and the weight of butter clams declined from 1988 to 1990 at the eight beaches sampled. Similarly, there was a decrease in the number and weight of cockles from 1988 to 1989, with an increase again in 1990.

How shellfish harvesting is regulated

DOH scientists routinely measure fecal coliform bacteria in the water which lies over commercial shellfish beds. If the investigators consistently find that 100 milliliters (about half a cup) of water contains 14 fecal coliform bacteria which develop into colonies (measured as the geometric mean in most probable number, MPN), the shellfish bed will be closed to harvesting. In addition, shellfish tissue is regularly tested for fecal coliform bacteria. If 100 grams of the shellfish meat (about 4 ounces) contains 230 MPN fecal coliform bacteria, health inspectors will retest the shellfish. If the shellfish continue to fail the tests, DOH officials will not allow the batch of shellfish to reach the marketplace.

The levels at which commercial shellfish are rejected by interstate shellfish shippers for the wholesale market are set nationally by the U.S. Food and Drug Administration. In Washington state, DOH, aided by county, local, and tribal health departments, enforces the standards. Although there are no similar national standards for recreational shellfish beaches, the Washington State Board of Health applies the commercial standards to recreational beaches. If DOH officials find that a recreational beach fails to meet the commercial standards, they may restrict shellfish harvesting on the beach by posting signs to warn the public against digging shellfish.

1989-1990 PSAMP SHELLFISH RESULTS: BACTERIAL CONTAMINATION

PSAMP investigators measured the fecal coliform content of shellfish from 10 recreational beaches (Figure 17) in Puget Sound at five different times from November 1989 to November 1990.

Throughout the sampling period, the 10 beaches were clearly divided into two groups. Shellfish from seven of the 10 beaches generally had low levels of fecal coliforms in their tissues; geometric means ranged from 0 to 470 most probable number (MPN) (DOH, in preparation b). Shellfish contamination at the remaining three beaches was consistently higher and generally exceeded the state standards for commercial shellfish harvesting (Figure 17) (DOH, in preparation b). The three contaminated beaches were Belfair State Park near Lynch Cove in Hood Canal, Walker County Park near Shelton in the south Sound, and Dosewallips State Park in Hood Canal. The geometric means of fecal coliforms at the contaminated beaches ranged from 430 to 12,000 MPN at Belfair State Park; 150 to 3800 MPN at Walker County Park; and 110 to 3400 MPN colonies at Dosewallips State Park (DOH, in preparation b). DOH officials believe that they know the primary cause of contamination at each of these beaches (Belfair: failing septic systems; Walker: stormwater runoff from

an urban area and proximity to a sewage treatment plant discharge; and Dosewallips: contamination by harbor seal feces).

In addition, PSAMP investigators found highly variable levels of fecal coliform bacteria during 1989-90 at Penrose State Park (Carr Inlet) (DOH, in preparation, b). DOH scientists have collected information on bacterial contamination in the water and in shellfish tissue from this beach. DOH officials will use these data, along with the results of more intensive PSAMP sampling in 1991, to determine whether there is a significant contamination problem at Penrose State Park.

Based on the results of the 1989-90 PSAMP sampling, DOH and the Washington State Parks and Recreation Commission (State Parks) officials closed beaches to recreational shellfish harvesting at Belfair State Park (Lynch Cove) and Dosewallips State Park. In an effort to reopen the beach at Belfair State Park to shellfish harvest, DOH is working with Mason County to encourage the Belfair community to install a sewage treatment system that would discharge into outer Case Inlet or some other location. At Dosewallips State Park, State Parks is installing barriers to prevent seals from entering some of the sloughs. State Parks is also installing log rafts offshore to encourage seals to haul out and rest away from the beach. DOH has increased monitoring activities at both these parks in order to track improvements in shellfish quality as a result of these actions. If these restoration activities are successful, DOH officials will reopen the beaches to public shellfish digging.

The 1989-90 PSAMP results confirm previous DOH findings of high levels of fecal coliforms in the water and shellfish tissue at Walker County Park (Shelton). The park is located near Shelton's wastewater treatment plant outfall and may be affected by stormwater discharges and other nonpoint sources of pollution. DOH officials have restricted recreational shellfish harvesting on the beach. Based on the complex contamination problems at Walker Park, Health officials are not optimistic that the beach will be reopened to shellfish harvesting in the near future.

1989-1990 PSAMP SHELLFISH RESULTS: CHEMICAL CONTAMINATION

PSAMP investigators measured toxic metals and organic contaminants in shellfish from four beaches in Puget Sound (Figure 19). Laboratory chemists analyzed the shellfish tissue for chemical contaminants that have been found in Puget Sound; the "Puget Sound Chemicals of Concern" (PTI, 1991b). The chemists analyzed for six metals (arsenic, cadmium, copper, mercury, lead, and zinc), and almost a hundred organic contaminants, including pesticides and PCBs. Many of these chemicals are known to be harmful to humans, animals, and/or plants in large quantities.

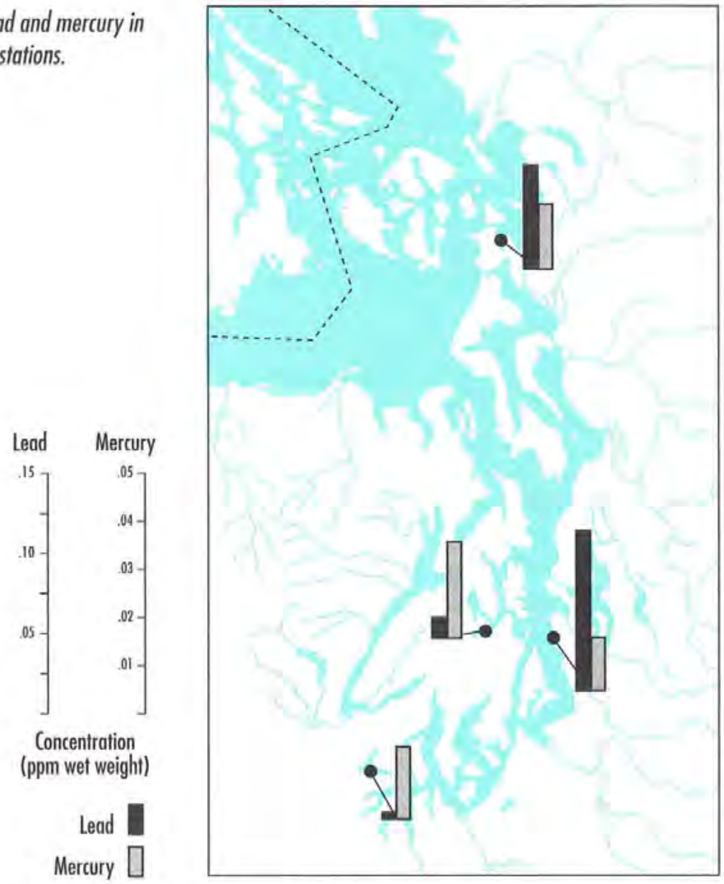
DOH scientists found that shellfish tissue from all four beaches sampled in May 1990 contained low levels of the six metals (Figure 19) (DOH, in preparation, b). The effects of the metals on the shellfish are unknown. Other studies have found similar concentrations of metals in shellfish tissue (Romberg et al., 1984; Faigenblum, 1988).

DOH investigators found very little evidence of organic contaminants in the shellfish sampled (DOH, in preparation b). PSAMP scientists need more samples from more Puget Sound beaches in order to determine whether there

How have chemical contaminants in Puget Sound shellfish changed?

As a part of a nationwide program, investigators with the National Oceanic and Atmospheric Administration's (NOAA) National Status and Trends Program (NS&T) have been examining a wide array of chemical contaminants in Puget Sound mussels at eight or more sites since 1986. PSAMP managers examined the results of the mussel tissue analysis for the years 1986 through 1989; 1990 data were also examined (Lauenstein, personal communication). Most of the chemicals measured by NS&T scientists showed no significant changes over the four years (NOAA, 1989; NOAA, unpublished data). PSAMP managers found some preliminary trends, including: significant decreases in total PCBs in Elliott Bay; significant decreases in DDT in Commencement Bay; and a significant increase in the amount of lead in Bellingham Bay. There are no obvious explanations that can be provided for these changes; preliminary trends of this sort help to focus monitoring efforts and provide managers with indications of areas to watch for further changes.

Figure 19. Concentrations of lead and mercury in clams at 1990 PSAMP shellfish stations.



Reference: DOH, in preparation, b.

is a significant toxic chemical contamination problem in Puget Sound shellfish. Past studies of shellfish in Puget Sound have found organic contaminants, particularly PCBs and organochlorine pesticides such as DDT (Mearns et al., 1988; NOAA, 1989). Scientists believe that levels of PCBs and organochlorine pesticides have declined in the environment in recent years because the manufacture and use of these chemicals has sharply decreased in the past two decades. The absence of significant chemical contamination in the 1990 PSAMP samples may show this decline.

DOH scientists reviewed the levels of chemical contaminants found in the 1990 PSAMP shellfish samples. They concluded that none of the chemicals presented a health threat to people eating clams at the four beaches sampled by PSAMP (DOH, in preparation, a). We have reported on the health effects assessment in more detail in the fish chapter.

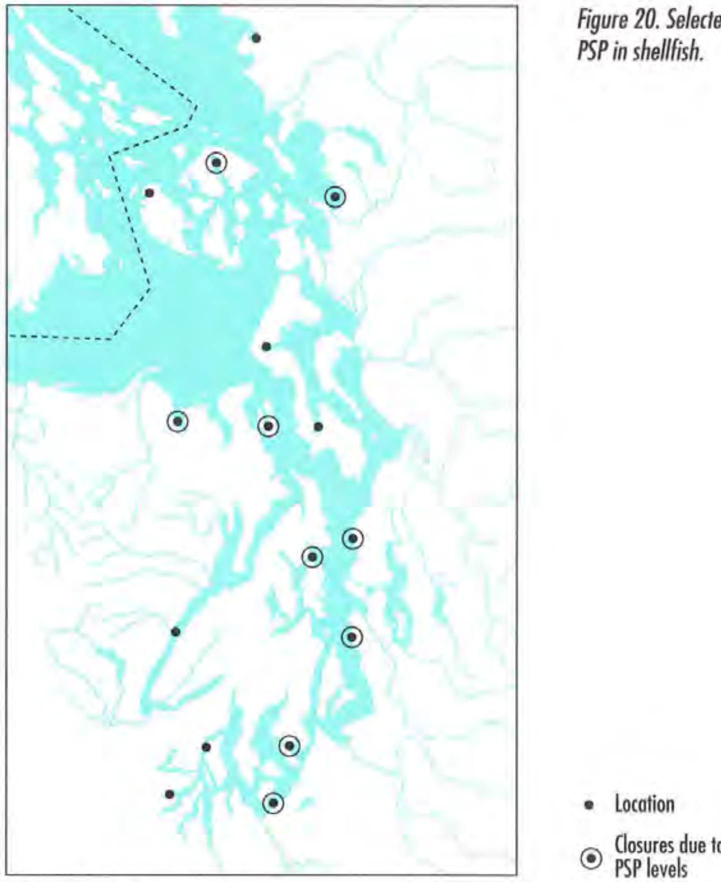
1989-1990 PSAMP SHELLFISH RESULTS: PSP

DOH investigators gathered together data from 16 areas where shellfish are regularly tested for PSP contamination in Puget Sound (Figure 20).

Between October 1989 and December 1990 DOH scientists found that on one occasion at least, shellfish from nine of the 16 beaches had enough PSP in their tissue to warrant closing beaches to public shellfish harvesting (DOH, in preparation, b). PSAMP investigators found that shellfish at the other seven beaches did not contain the PSP toxin. Six of the nine beaches were contaminated during the summer (Ship Bay in Eastsound, Samish Bay, Edmonds Oil Dock, Fauntleroy Cove, Fox Island Bridge, and Dupont Wharf near Nisqually Reach). Other shellfish contained high PSP levels during the fall or winter (Blyn in Sequim Bay; Scow Bay in Kilisut Harbor; Fauntleroy Cove; and Fox Island Bridge) (DOH, in preparation, b). PSAMP investigators found contaminated shellfish at some beaches at both times of the year. In the past scientists believed that PSP outbreaks in Puget Sound were generally a summertime event; they now recognize that PSP outbreaks can occur at other times of the year as well (DOH, 1990).

In 1989 PSAMP investigators found PSP toxin in bivalve shellfish from six of

the same 16 beaches (DOH, in preparation b). During 1988 DOH scientists found that shellfish from the northern parts of Puget Sound generally had lower PSP levels than had been measured in previous years, while shellfish from beaches in the south Sound had higher levels of the toxin. In 1989 there were higher levels of PSP at the northern Puget Sound sites than those in the south Sound (DSHS, 1989).



Reference: DOH, in preparation, b.

Figure 20. Selected locations sampled in 1990 for PSP in shellfish.

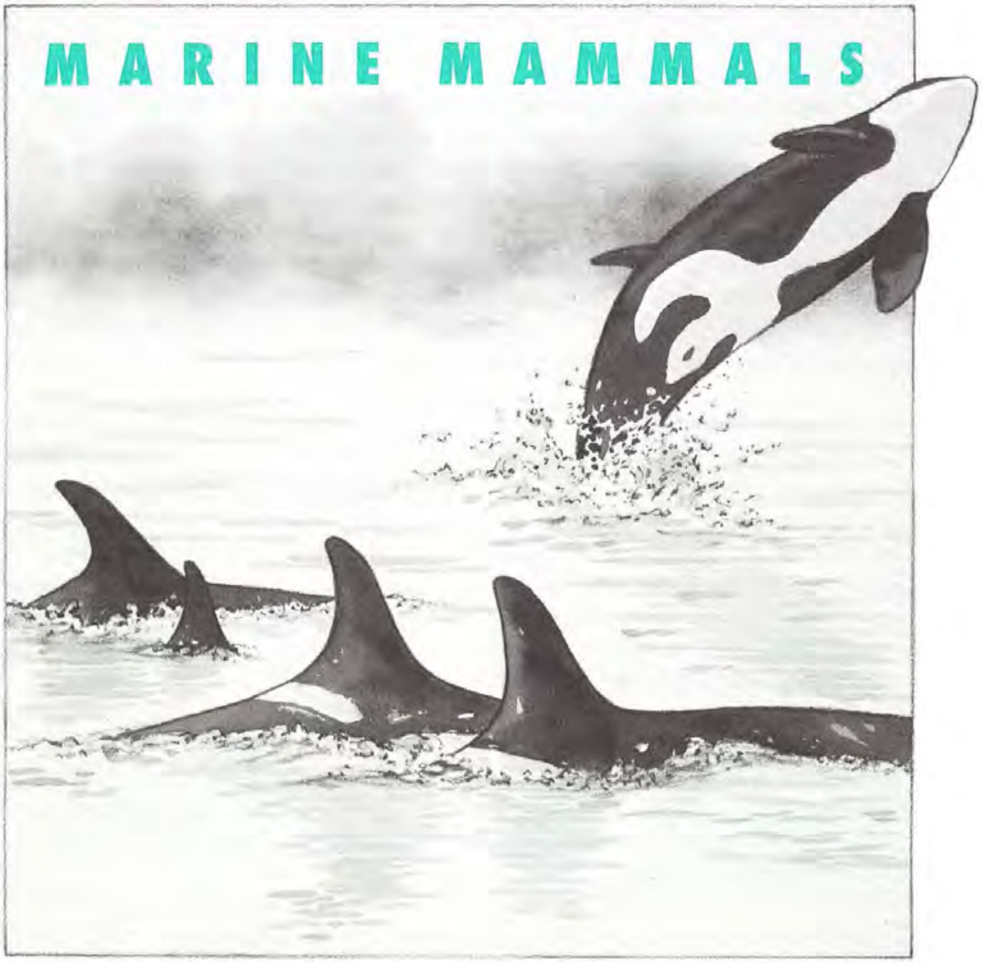
Scientists puzzle over why the PSP-causing plankton cells multiply at certain times and in certain locations. Occurrences of PSP contamination are common in Puget Sound and in the coastal waters from California to Alaska and have been recorded since the 18th century. However, the conditions which cause the organisms to grow rapidly in the water are unknown. Researchers continue to probe why different species of shellfish retain the toxin longer than others, and whether pollution may play a role in worldwide increases in PSP and other marine biotoxins.

FUTURE PSAMP SHELLFISH MONITORING

DOH scientists will continue to collect shellfish for bacterial, chemical, and PSP analysis; WDF biologists will count shellfish abundance on Puget Sound beaches. DOH scientists plan to sample the same 10 beaches for shellfish fecal coliform bacterial contamination every three months during 1991. During May 1991 PSAMP investigators collected shellfish for chemical contamination at 10 beaches in the Sound. Information on PSP at 16 beaches and shellfish abundance at 10 sites will again be included in the PSAMP database.

Until DOH investigators are able to monitor the 35 shellfish sites throughout the Sound that the designers of PSAMP felt were necessary, we will have an incomplete idea of the patterns of shellfish contamination in the Sound, and incomplete information with which to judge potential human health effects from eating contaminated shellfish.

MARINE MAMMALS



BACKGROUND

People living in the Puget Sound area enjoy the grace and playfulness of the whales, porpoises, and seals that are prevalent in our waters. People are drawn to these shy creatures and enjoy observing them on the water, and through photographs and film. Marine mammals are the only major Puget Sound living resource that we do not harvest. However, by threatening fish and shellfish resources, some Puget Sound marine mammals have drawn the ire of the basin's human residents; California sea lions have gobbled steelhead at the Ballard locks, and harbor seals have polluted shellfish beds in Hood Canal with their feces.

Marine mammals are heavily dependent on good water quality and undisturbed habitat for their health. Monitoring top predators like marine mammals will give us information on the passage of contaminants through the Puget Sound food web. Because marine mammals resemble humans physiologically, monitoring of marine mammals may provide information on potential health problems from eating contaminated Puget Sound seafood.

Seven species of marine mammals are common to Puget Sound. Four are resident (harbor seal, Dall's porpoise, harbor porpoise, and orca or killer whale), while the remaining four are migrants (California sea lions, stellar sea lions, Minke whales, and gray whales). In addition, 19 other species of whales, seals, and porpoises are occasional, rare, or accidental visitors.

THREATS TO MARINE MAMMALS

Most marine mammal populations in Puget Sound are stable while a few, like harbor seals, are undergoing rapid population growth in some areas. Biologists have detected signs of stress in some marine mammal populations in Puget Sound, including shifts in feeding and pupping territories, toxic contaminants in blubber and internal organs, and shifts in population sizes. Scientists generally do not have enough historical information to determine whether the population and territorial changes are a part of a natural cycle. However, there is ample evidence that many of the changes in marine mammals are due to the activities of humans in the Puget Sound basin.

By killing and capturing marine mammals, people have directly affected these Puget Sound populations. Thousands of seals and sea lions were killed under a state bounty program between 1900 and 1960. Orcas and other marine mammals have been captured in Puget Sound for display in aquariums and zoos. The federal Marine Mammal Protection Act of 1972 and similar state laws passed during the 1970s have made it a crime to kill, capture, or harass marine mammals. The inadvertent capture of marine mammals in fishing nets and other gear, and unlawful hunting, are the only remaining direct threats to marine mammal populations from human activities.

Humans indirectly interfere with marine mammals through commercial and recreational fishing, which can alter the marine mammals' food supply; by shoreline development projects, which can destroy and degrade marine mammal habitat; and by releasing toxic chemicals into Puget Sound, which can accumulate in marine mammal tissue.

There are many incidences of people unlawfully harassing marine mammals in Puget Sound. Generally, people do not want to disturb the animals but are seeking a closer look. Without proper training or facilities that will allow the public to view marine mammals without disturbing them, this harassment will continue. Marine mammals which haul out on land to rest, to mate, and to bear their young, like seals and sea lions, are particularly susceptible to harassment. Scientists are unsure whether the overall populations of marine mammals are affected by these disturbances. There is sufficient evidence, however, that human disturbances cause the animals stress (Calambokidis et al., 1991a).

PSAMP MARINE MAMMAL MONITORING

The design of PSAMP calls for monitoring the abundance and reproductive success of marine mammal populations, and tracking chemical toxicant levels in their tissue (PSWQA, 1988). This information will allow natural resource managers to assess the status of and changes in marine mammal populations. Managers will also be able to estimate the amount of contamination that the animals have accumulated from eating seafood in Puget Sound, and the effects that contaminants, habitat loss, and other threats are having on the marine mammal populations. Washington Department of Wildlife (WDW) scientists will monitor resident marine mammals because they know that the populations are affected by conditions in Puget Sound, which may include contamination and habitat loss.

The first phase of PSAMP marine mammal monitoring will focus on population estimates of the resident harbor seal (PSWQA, 1988). No funds have been available for PSAMP marine mammal monitoring during the 1989-1991

period. Currently WDW is conducting surveys to estimate population size and reproductive rates of harbor seals. Their program is not adequate to monitor marine mammal abundance and reproductive success Soundwide, however. Because there is no routine collection or analysis of marine mammal tissue for toxic chemicals in Puget Sound at this time, we do not know if marine mammals have high levels of toxicants in their tissues. Researchers have found elevated tissue contaminant levels and reproductive failures in Puget Sound marine mammals in the past (Calambokidis et al., 1985).

Recently biologists have gathered together extensive information on contaminants in Puget Sound marine mammals (Calambokidis et al., in preparation). WDW managers will use this information to evaluate contamination levels in Puget Sound populations and to identify PSAMP monitoring needs.

HARBOR SEALS

WDW biologists estimate that there are approximately 6,000 harbor seals in Washington inland waters, which includes Puget Sound, the coastal estuaries, and the Strait of Juan de Fuca. At least 1,000 of these seals live in southern Puget Sound (Jeffries, 1990). Wildlife biologists study populations of harbor seals because these animals are found in Puget Sound year-round and appear to be residents. Wildlife biologists have studied populations of harbor seals at their preferred haulout sites in the south Sound, north Sound, and Hood Canal (Figure 21). These populations increased dramatically during the 1970s and early 1980s, especially in the south Sound (Figure 22) (Calambokidis, et al., 1985; 1988). Harbor seal populations in Puget Sound have increased less rapidly since 1984 (Calambokidis et al., 1988).

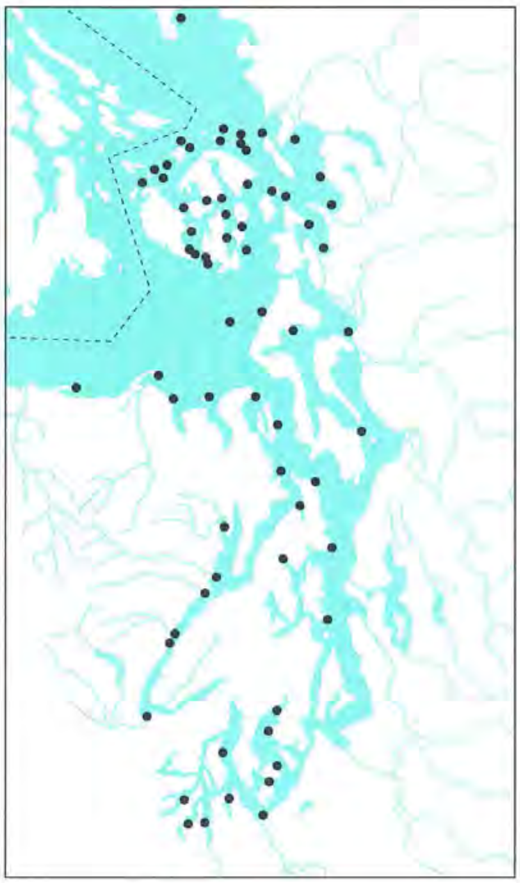


Figure 21. Harbor seal haulout sites in Puget Sound.

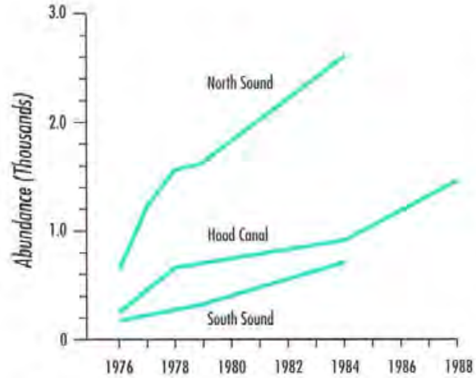
WDW managers and public health officials are particularly concerned about the large population of harbor seals near the Dosewallips River in Hood Canal. Harbor seals haul out in large numbers in the sloughs and tidal flats in the river delta. Upon reentering the water, the animals disperse their feces into the water, spreading fecal contamination to the shellfish resources in the vicinity of the haulout area.

Managers from state, federal, and local agencies have been working with scientists to devise ways to lure the harbor seals away from the sloughs and tidal flats of the Dosewallips River (Calambokidis et al., 1990). They have had

The role of PSAMP in identifying harbor seal contamination of shellfish resources

Based on concerns about large numbers of harbor seals congregating in the Dosewallips delta, Washington Department of Health (DOH) investigators placed a station at Dosewallips State Park to assess the bacteriological contamination of shellfish, as a part of PSAMP. The beach at Dosewallips State Park is a popular site for recreational shellfish digging. Despite the relative remoteness of the beach, low tides on summer weekends attract numerous harvesters. DOH found consistently high levels of fecal contamination in shellfish from Dosewallips State Park (DOH, in preparation, b). These findings led DOH officials to post the beach, warning the public of unsafe shellfish. Park rangers with the State Parks and Recreation Commission help to inform the public of the danger of consuming the shellfish. Public health concerns led State Parks to study the harbor seal problem and to devise a practical solution (Calambokidis et al., 1990).

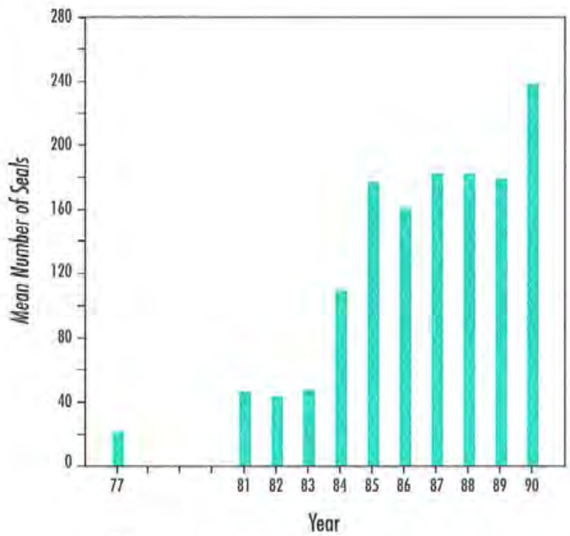
Figure 22. Harbor seal abundances in Puget Sound.



Data from Everitt et al., 1979, 1980; Calambokidis et al., 1979, 1985, 1988.

some initial success in getting some seals to relocate to a float located offshore from the river. The float was put in place as an experiment to see if the seals would use it. Natural resource managers plan to place permanent seal haulout platforms offshore from the delta and to fence the seals out of some of the more vulnerable sloughs. The managers are hopeful that when these improvements are put in place in 1991, the harbor seal "problem" at Dosewallips will be reduced.

Figure 23. Peak counts of harbor seals in Woodard Bay, Henderson Inlet.



Reference: Calambokidis et al., 1991a.

Harbor seal numbers have also increased greatly in Woodard Bay in Henderson Inlet (south Sound) since 1977 (Figure 23) (Calambokidis et al., 1991a). While scientists feel that reproduction in the Woodard Bay harbor seal population has stabilized, it appears that other seals are moving into the area (Calambokidis et al., 1991a).

Wildlife biologists are concerned that seals in Woodard Bay face a great deal of harassment, particularly by boaters during the summer, on weekends, and on weekday evenings (Calambokidis et al., 1991a). The Washington Department of Natural Resources (DNR) may develop a public viewing area close to seal haulout areas, which will be shielded from the seals. DNR managers feel that this viewing area, along with a prohibition on boating near the seal haulouts, will provide the public with good opportunities to learn more about seals while protecting the animals from disturbances (Calambokidis et al., 1991a).

Historically, Puget Sound harbor seals have carried very high burdens of contaminants in their bodies, particularly PCBs and DDT in the blubber of south Sound seals (Calambokidis et al., 1988). Scientists believe that levels of these contaminants have declined since the 1970s, although there is evidence that PCBs, DDT, and other contaminants are still present in significant concentrations in harbor seals in several parts of the Sound (Calambokidis et al. 1985). Adult male harbor seals have the highest levels of contaminants in their bodies (Calambokidis et al., in preparation). Scientists have found evidence of premature births and birth defects in harbor seals in the south Sound (Newby, 1971; Newby, 1973; Calambokidis et al., 1978), which may be related to contaminants.

HARBOR PORPOISE

Harbor porpoises were once abundant throughout Puget Sound; since the 1940s they have been found only in the Strait of Juan de Fuca, around the San Juan Islands, and near the outer Washington coast (Osborne et al., 1988). Wildlife biologists believe that the disappearance of harbor porpoises from Puget Sound south of Admiralty Inlet is due largely to human disturbances like ship traffic, capture in fishing nets, and perhaps contamination (Calambokidis et al., in preparation). Wildlife biologists that, in 1989-90, there were about 8,800 harbor porpoises in the Washington coast/Straits population (Turncock et al., in press; Calambokidis, in press). Scientists have little historical information to determine how this population compares with that before 1940. In 1988 the National Marine Fisheries Service (NMFS) of NOAA in Seattle began an annual monitoring program for harbor porpoise populations in Washington (Turncock et al., in press).

Scientists have very little information on contaminants in harbor porpoises. They have found that some Washington coast/Straits harbor porpoises have PCBs and DDT in their blubber, comparable to levels in Puget Sound harbor seals (Calambokidis and Barlow, 1991). Natural resource scientists and managers from other countries suspect that PCBs and DDT have caused reproductive problems and population declines in harbor porpoises (Otterlind, 1976; Wolff, 1982).

GRAY WHALES

Gray whales are migrants which are spotted regularly in many locations in Puget Sound and the Strait of Juan de Fuca (Figure 24) (Calambokidis et al., 1991b). As many as 10 gray whales have been found in Puget Sound at a time, most of them young animals. Biologists believe that many of these whales may spend up to four months feeding in the Sound.

Figure 24. Gray whale sightings in Puget Sound in 1990.

Reference: Calambokidis et al., 1991b.

The present worldwide population of 20,000 gray whales is probably close to what it was before commercial whaling began to diminish whale populations in the 19th and 20th centuries (Jeffries, 1990.)

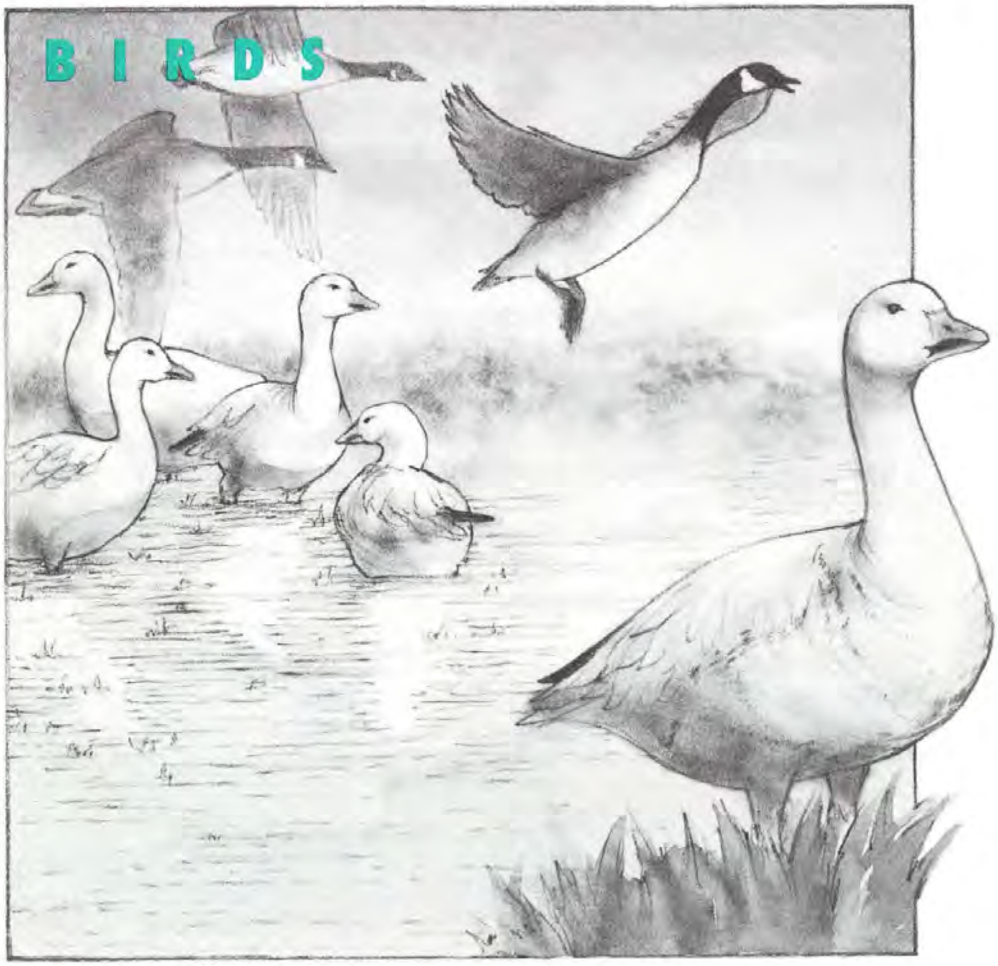
Scientists with NMFS have measured contaminants in the blubber, liver, stomach, and kidneys of gray whales stranded in Puget Sound (NOAA, unpublished data). The NMFS scientists found the highest levels of toxic organic and metal contaminants in the blubber and stomachs of the whales. However, these contaminant levels were lower than those found in whales from other areas.

In recent years a number of gray whales have washed up dead in Puget Sound and surrounding waters. In most cases scientists have not been able to determine the cause of death of the whales. Some whales found along the Washington coast apparently died from being tangled in fishing nets, after collisions with boats, and after attacks by killer whales (orcas) (Calambokidis, personal communication). Despite intense public interest and speculation on the role of contaminants in the death of gray whales, there has been relatively little scientific research done on the biology of gray whales and their response to contaminants. Until more information becomes available, scientists cannot evaluate the extent to which contaminants may be affecting these animals.

FUTURE PSAMP MARINE MAMMAL MONITORING

In the future WDW scientists will initiate Soundwide monitoring for harbor seal abundance, followed later by monitoring of other resident species. With better estimates of populations of marine mammals, managers will be able to improve their management of the marine mammals' prey, many of which are important commercial and recreational species. WDW investigators will measure the reproductive success of harbor seals by carrying out pupping surveys, and by examining causes of pup mortality in seal populations. WDW will also collect and analyze tissue from stranded marine mammals for toxics.

Until WDW scientists can carry out additional marine mammal monitoring, we will have very limited information on the populations, reproductive rates, and contamination levels of Puget Sound marine mammals. Extensive losses of some marine mammal species, and population explosions of others, could go unnoticed without accurate information on the present marine mammal population sizes. In order to explain the causes of large fluctuations in marine mammal numbers, managers need information on the size and health of these populations.



BACKGROUND

Large flocks of ducks and geese, gulls grazing at the shoreline, herons wading in the shallows, eagles soaring over the treetops, and shorebirds rising and settling in unison, are all a part of the scenery and wildlife that Puget Sound residents admire. As birdwatchers, hunters, and casual observers, we value the presence of resident and migratory marine birds and waterfowl. Many species of birds make Puget Sound their home, including: waterfowl (diving and dabbling ducks, geese, and swans), marine birds (gulls, auklets, puffins, pigeon guillemots, and herons), shore birds (sandpipers, snipe, and killdeer), raptors (eagles, hawks, and osprey), and kingfishers. These birds need high-quality habitat for nesting, mating, and rearing their young, as well as a clean and plentiful source of food.

Resident and migratory birds are vulnerable to harm from human activities including hunting, contamination or elimination of food supplies, and destruction of critical habitat. There are examples from around the world of bird species that have been drastically reduced in numbers by the consequences of human development.

Wildlife managers need good year-round estimates of the population and health of marine birds and waterfowl in order to adequately manage and protect Puget Sound bird populations. By monitoring Puget Sound birds, we can examine the condition of mid-level and top predators in the ecosystem,

which may be at risk from the accumulation of contaminants through the food web. By monitoring different bird species, scientists gain information about different pollutant pathways and food web links through the ecosystem. This information can be used to protect Puget Sound birds and other natural resources.

PSAMP BIRD MONITORING

Biologists with the Washington Department of Wildlife (WDW) have carried out monitoring surveys for birds in Puget Sound for many years, primarily to support the harvest of waterfowl. There have been very few accurate population estimates of marine birds and waterfowl, however. The object of PSAMP bird monitoring is to get accurate estimates of the population of major Puget Sound bird species, including those not targeted by hunters (PSWQA, 1988). The PSAMP designers also felt that an estimate of the health of bird populations, as measured by reproductive success and the accumulation of toxic chemicals in their tissues, was needed to adequately protect common and threatened species of Puget Sound birds (PSWQA, 1988).

No funding has been available for PSAMP monitoring of Puget Sound birds for 1989-91. However, WDW, the U.S. Fish and Wildlife Service (USF&WS), and volunteers involved in the National Audubon Society Christmas Bird Count are collecting some information on waterfowl and marine birds in the Sound.

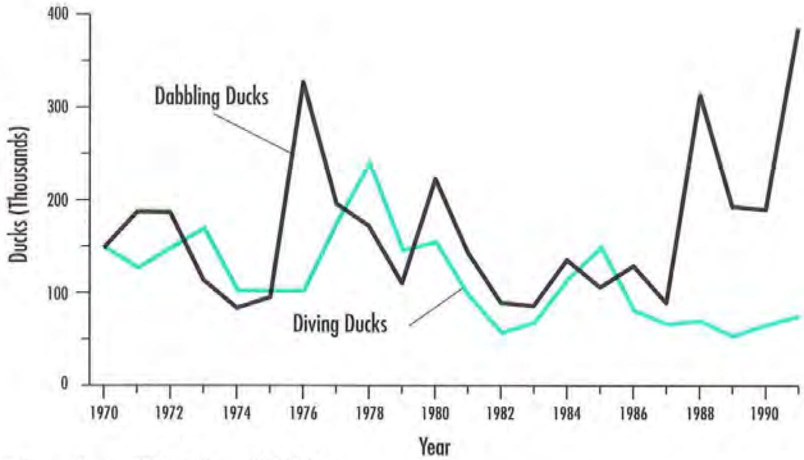
Recently biologists have gathered together extensive information on contaminants in Puget Sound birds (Calambokidis et al., in preparation). WDW managers will use this information to evaluate contamination levels in Puget Sound bird populations and to identify PSAMP monitoring needs.

PUGET SOUND BIRD POPULATIONS

Waterfowl which visit Puget Sound as a stopover on the Pacific flyway, as well as those who breed and live year-round in Puget Sound, include 26 species of ducks, 10 species or subspecies of geese, and two species of swans. The number of waterfowl in Puget Sound varies seasonally. Waterfowl are affected by hunting, localized changes and degradation in habitat, and shifts in migration routes due to weather patterns.

The large and relatively undeveloped estuaries and uplands of northern Puget Sound, including Port Susan and Skagit, Padilla, and Samish Bays, provide a winter home for enormous flocks of waterfowl. The dabbling ducks (primarily mallard, widgeon, green-winged teal, and northern pintail), as well as geese and swans, feed primarily in the brackish nearshore and freshwater areas of the northern estuaries. The diving ducks (primarily scoter, goldeneye, scaup, and bufflehead) prefer saltwater for foraging and are found throughout Puget Sound, particularly south of Port Susan.

WDW biologists have kept track of the number of ducks in the Puget Sound basin since 1970. Over that time period, the population of dabbling ducks has varied from year to year, but the overall trend was stable until the late 1980s. Since 1987 the dabbling ducks have increased in number (Figure 25) (Kraege,

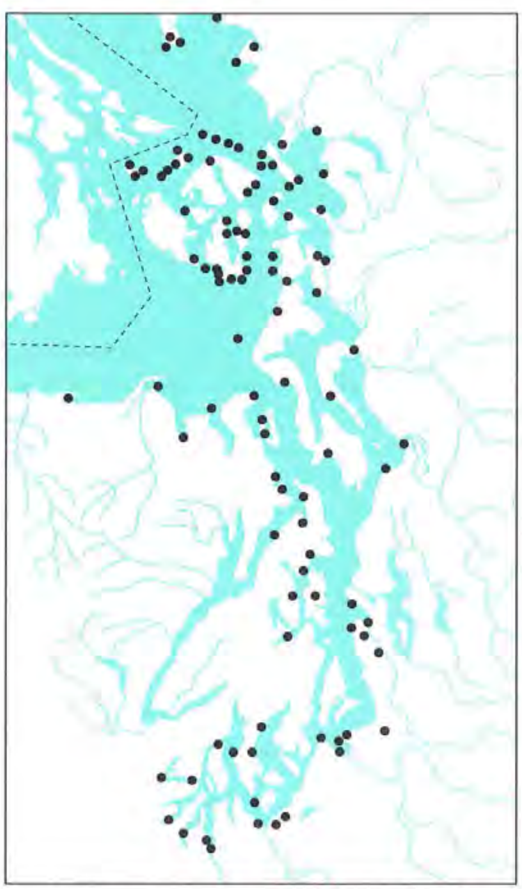


Reference: Kraege, 1990; WDW, unpublished data.

Figure 25. Abundances of ducks in Puget Sound.

1990; WDW, unpublished data). The number of diving ducks has also changed from year to year, with an overall downward trend since 1978 (Kraege, 1990). Although the populations of diving ducks are low by historical standards, WDW biologists believe that recent data on the diving ducks may show the beginning of a recovery in the population (Figure 25). Populations of several species of geese, including brant and snow geese, continue to increase in number as hunting of these birds has been restricted (Kraege, 1990; WDW, unpublished data).

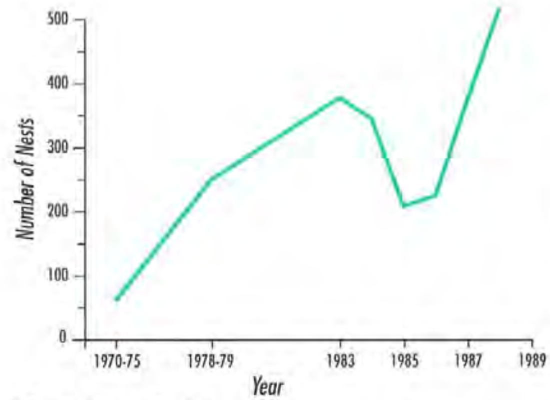
Marine birds spend their lives in saltwater, feeding on fish and marine invertebrates and sleeping on the surface of the water. Most marine birds go ashore only to nest, choosing protected and inaccessible sites (Figure 26). These birds are extremely vulnerable to human disturbances and have left nesting sites as humans encroach on their habitat. Scientists have seen dramatic declines in populations of marbled murrelets (Cummins et al., 1990) which may result in the birds being listed as an Endangered Species. While disturbances in Puget Sound and other marine waters may account for part of the marbled murrelet decline, cutting of old-growth forests where the birds nest is probably responsible for the sharpest decline. Double-crested cormorants have left most of their historical nesting sites on four of the San Juan Islands for the isolation and inaccessibility of Smith and Protection Islands in northern



Data from Salo, 1975; Manuwal et al., 1979; Wahl et al., 1981; Wahl and Speich, 1984; Calambokidis et al., 1985; Speich and Wahl, 1989.

Figure 26. Breeding colony sites for marine birds in Puget Sound.

Figure 27. Nests of cormorants in Puget Sound.



Reference: Henny et al., 1989.

Puget Sound where their numbers are increasing (Figure 27) (Henny et al., 1989).

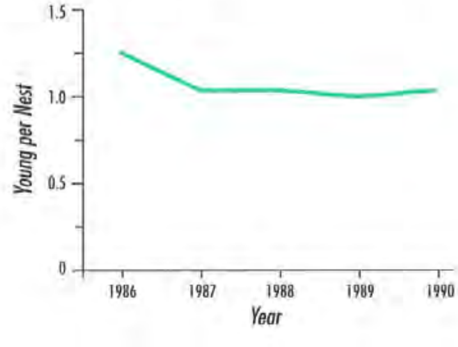
Bald eagles are predators that feed extensively in Puget Sound watersheds and in some nearshore marine areas. Bald eagles are most frequently seen in the San Juan Islands and in other areas of northern Puget Sound, including the Skagit and Nooksack River basins (Salo, 1975). Spawning salmon and other fish make up a substantial portion of the eagles' diet at certain times of the year. Because the bald eagle is an endangered (or threatened) species, WDW biologists track eagle populations, nesting sites, and the number of nestlings. The amount of optimal eagle habitat that is actually occupied by eagles in the Puget Sound area is increasing, but there are fewer young eagles in each nest (Figure 28). These statistics suggest that bald eagle populations are still at risk (WDW, unpublished data). As the human population of the Puget Sound basin continues to increase, WDW biologists may see further degradation and loss of bald eagle habitat, which may cause a long-term decline in the bird populations (Cummins, personal communication).

CONTAMINANTS IN PUGET SOUND BIRDS

Many species of Puget Sound waterfowl, marine birds, raptors, and shorebirds have low levels of contaminants in their tissues, especially DDE (a breakdown product of the pesticide DDT) and PCBs (Riley et al., 1983). Scientists have found low levels of lead and mercury in many bald eagle nestlings from the San Juan Islands (Wiemeyer et al., 1989).

Scientists have found that some Puget Sound marine birds have had reproductive problems, including glaucous-winged gulls and great blue herons (Speich et al., 1988), pigeon guillemots (Calambokidis et al., 1985), and cormorants (Cummins et al., 1990). There is only limited evidence that these problems are caused by contaminants. There is evidence, however, from other areas that contaminants have affected the reproductive success of raptors including bald eagles (Hickey and Anderson, 1968; Reichel et al., 1984), osprey (Wiemeyer et al. 1978), peregrine falcons (Lindberg and Odsjo, 1983), and merlins (Fox and Donald, 1980).

Figure 28. Breeding success of bald eagles in the Puget Sound basin.



Reference: WDW, unpublished data.

NEARSHORE HABITAT

BACKGROUND

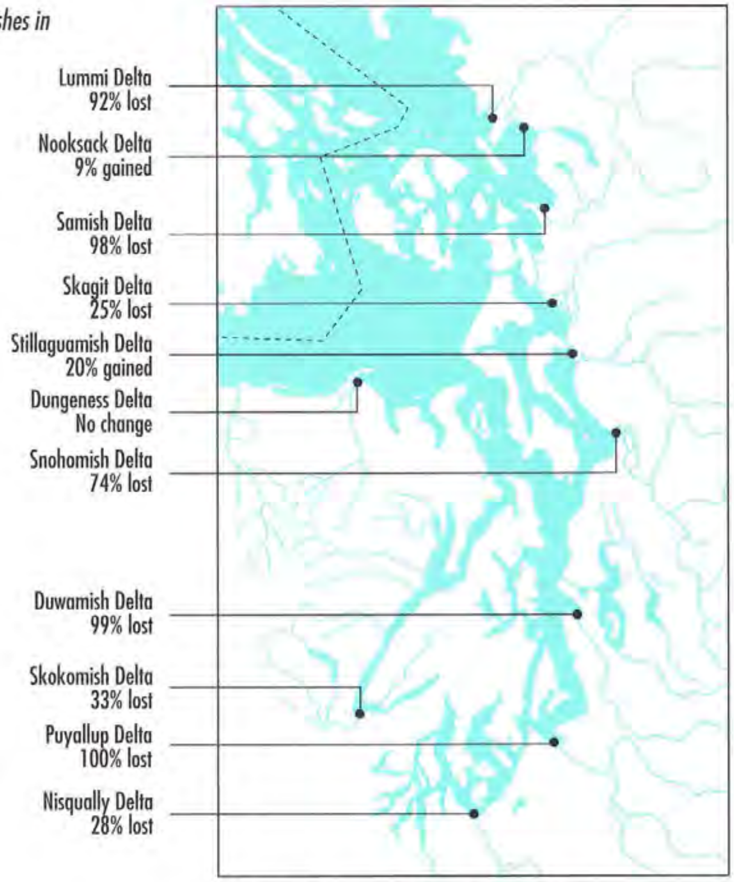
People living in the Puget Sound area visit and enjoy the beaches, tidal flats, and marshes more frequently than any other part of the Sound. These features and the shallow water areas immediately offshore are also the most productive areas of the Sound and support numerous species of plants and animals.

Many types of Puget Sound sea creatures spend at least part of their lives in the narrow fringing eelgrass meadows, kelp beds, and salt marshes of Puget Sound. These vegetated nearshore habitats (those areas that provide a home, shelter, and food) provide feeding and nursery grounds for juvenile salmon and other fish, food and refuge for many marine invertebrates which form the base of the benthic food web, and refuge, feeding, and stopping grounds for ducks, geese, and marine birds.

Salt marshes (which are homes for plants that can tolerate salt water) perform a number of other vital functions. They reduce flooding in coastal and lowland areas, control shoreline erosion, filter pollutants from stormwater, and provide recreational, educational, and scenic opportunities for the inhabitants of the Puget Sound basin.

Puget Sound once had broad expanses of salt marshes in the Puyallup, Skagit, and Duwamish deltas, but they have been largely eliminated through diking and filling (Figure 29) (Bortleson et al., 1980; Hutchinson, 1988)). The few

Figure 29. Changes in salt marshes in major river deltas.



Reference: Bortleson et al., 1980; Hutchinson, 1988.

broad areas of vegetated nearshore habitat that still exist in Puget Sound include the sweeping eelgrass meadows of Padilla Bay and the remnant salt marshes of the Skagit, Nisqually, and Stillaguamish river deltas.

Beaches without seaweeds or sea grasses are also important in Puget Sound. These areas include the extensive mudflats of the Skagit and Nisqually river deltas. Some commercial and recreational species of fish release their eggs on mud and sand flats, and shellfish like oysters make the unvegetated beaches their home. Juvenile salmon and shorebirds also feed on these flats. Human residents of the Puget Sound basin use the beaches extensively for recreational activities such as clam digging, walking, and beachcombing.

Other important nearshore habitats are not influenced by salt water. Upland wetlands (those that are away from the coast, on higher ground), as well as wetlands associated with rivers and lakes, all provide vital habitats for fish and wildlife species in the Puget Sound basin. These wetlands help to maintain the abundance and diversity of native Northwest species in the Puget Sound region. Many fish and birds (such as salmon and herons) use both saltwater and wetland habitats associated with rivers at different stages in their lives.

THREATS TO NEARSHORE HABITATS

The growth and development of the Puget Sound area over the past hundred years has severely degraded and reduced areas of nearshore habitat, particularly in the deltas of the largest rivers. Dredging and filling for nearshore development projects, building of seawalls and bulkheads to reduce shoreline erosion, and dumping of debris on beaches diminishes both the quantity and the quality of valuable nearshore habitat (Boulé et al., 1983). Scientists have recently estimated that approximately 144 acres of nearshore estuarine habitat continue to be lost each year in the state of Washington (Canning and Stevens, 1989). Other estimates of wetland losses are even higher (Rylko and Storn, 1991). More than half of the statewide loss is in Puget Sound. Wetland biologists estimate that the rate of loss of wetland habitat in Puget Sound is much slower today than it was prior to 1960, due to increased awareness of the valuable functions provided by wetlands, the dwindling supply of accessible wetland property, and the coincident increase in regulations prohibiting draining and filling of wetlands.

PSAMP INVESTIGATIONS INTO NEARSHORE HABITAT

Natural resource managers know very little about estuarine nearshore habitats, including how many acres of each type of habitat exists, the natural functions of these habitats, or how these habitats change over time. Managers recognize that these habitats play an important ecological role in the functioning of the Puget Sound ecosystem, and that we must act quickly to prevent their further loss. Until we know the extent of the nearshore habitat resources through a comprehensive inventory, managers cannot make coherent plans to protect the most critical of these habitats.

The design of PSAMP calls for an inventory of the estuarine nearshore habitat of Puget Sound (PSWQA, 1988). Surveying and mapping the roughly 1,200 miles of Puget Sound shoreline is an awesome task that could take scientists and technicians years to complete. There have been no PSAMP funds available for surveying nearshore habitat during the 1989-1990 period.

The Environmental Protection Agency (EPA), the Washington Department of Natural Resources (DNR), and the Puget Sound Water Quality Authority (PSWQA) funded a pilot project to explore the use of remote sensing for coastal habitat inventories. The results of this pilot study shaped the design of PSAMP nearshore habitat monitoring.

During the summer of 1988, a specially equipped aircraft from EPA's Environmental Mapping and Survey Laboratories (EMSL) in Las Vegas flew over about two-thirds of the coastline of Puget Sound. The EMSL plane was equipped with a multi-spectral scanner (MSS), which is a sensor similar to those carried on satellites such as Landsat. The MSS records different wavelengths of energy (colors). The plane was also equipped to take color infra-red photographs (pictures which record heat as well as visible images). The aircraft flew at about 6,600 feet above the shoreline, recording data from the nearshore habitat. At the same time, trained technicians from DNR, aided by volunteers, walked the beaches at six test sites (Figure 30) in order to check the aerial photographs and sensor data. The DNR technicians and volunteers placed black tarpaulins which could be seen from the plane to help determine the exact location of important habitat features; they identified and took measurements of eelgrass beds, salt marshes and kelp fronds; and they counted the animals and plants present on the beaches (Mumford et al., in preparation).

Following the aerial flights, DNR and EPA scientists developed methods to convert the information from the MSS into usable maps of Puget Sound nearshore habitat. The DNR staff checked the maps against the information gathered by the field crews, and verified them against the color infra-red photographs. The MSS information is used to identify eelgrass and kelp beds, unvegetated beaches, and other habitats. Finally, the MSS data were transferred into a computerized geographic information system (GIS). A GIS can be used to create maps and to zoom in on shoreline features. Scientists can also use GIS information to calculate the size of eelgrass or kelp beds, and, combined with other monitoring data, to compare the overlap between fish and wildlife populations and critical nearshore habitat. Examples of this information from two different areas of the Sound are shown in Figure 31 (Mumford et al., in preparation).

Habitat mitigation – lessening the impacts of habitat loss

In order to preserve important nearshore habitat we must ensure that little of the remaining habitat is converted for other uses. Stronger environmental laws and stepped-up enforcement of those laws have slowed losses dramatically. If habitat loss cannot be avoided, habitat mitigation (the replacement, rehabilitation, or creation of habitat) can improve the quality of degraded habitats and create new nearshore habitat from other disturbed areas.

The creation and rehabilitation of nearshore habitat, as well as other wetland habitat, is technically very difficult. Even if all the proper sediment, drainage, plant species, and animals are put together in an area, there is no guarantee that the area will begin to operate as a natural ecosystem. Experience tells us that most wetlands mitigations are not highly successful. For example, in order to rehabilitate or create even a small amount of natural marsh habitat, large tracts must be planted and protected from damaging influences.

The Lincoln Avenue wetlands in Commencement Bay and Jetty Island off Everett Harbor are recent examples of nearshore habitat creation in Puget Sound. The Lincoln Avenue project was created as mitigation for wetland losses associated with port development in the Commencement Bay area. To create the mitigation site, scientists directed the excavation of a landfill site down to the tide level and planted about 50,000 sedge plants. After four years, and a cost of $2.2 million, the 10-acre site has been partially successful in replacing lost habitat (Thom, personal communication).

Jetty Island is a 100-acre island in Port Gardner, off the City of Everett. The island was formed by material dredged from the Snohomish River channel. The Port of Everett and the Army Corps of Engineers brought additional clean sediment to the island in 1989 and 1990 to form a protective berm on the western wave-swept side of the island. In 1990 biologists and volunteers planted a variety of salt marsh plants inside the berm. With the results of the 1989 pilot project in mind, biologists will plant additional plants in the spring of 1991. They will continue to monitor the resulting ecosystem over the next few years to see if it acts as a natural habitat for fish and wildlife (Arden and Smith, 1991).

Figure 30. Test sites for DNR for habitat inventory in 1988.

Reference: Mumford et al., in preparation.

After two years of intensive work, DNR scientists have developed a system that will allow them to update the nearshore habitat inventory using overflights by the MSS-equipped aircraft. They will use this information to update the GIS, and to establish trends in nearshore eelgrass, kelp, and salt marshes. With this information managers could focus restoration efforts on areas where critical habitat is being lost or take action to prevent further loss.

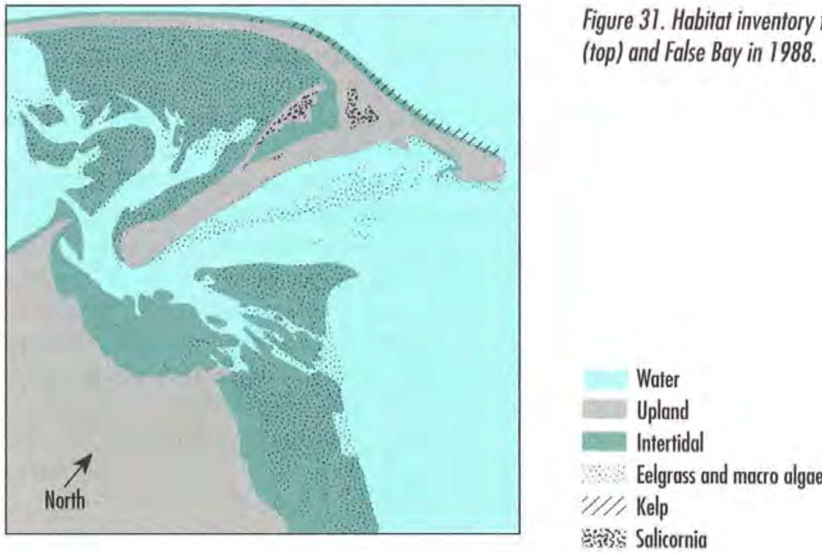
By using the newly available technology of the MSS and GIS, DNR scientists are confident that PSAMP will be able to collect accurate and cost-effective inventory data on nearshore habitat. As this technology is further enhanced, the accuracy and cost-effectiveness of the method will improve even more.

HISTORICAL CHANGES IN SALT MARSHES, EELGRASS, AND KELP IN PUGET SOUND

At one time, salt marshes were extensive in the Puget Sound basin. The first surveys of salt marshes and swamps were made in the 1880s (Nesbit, 1885). Since that time there has been a 73 percent decline in the area covered by Puget Sound salt marshes (Thom and Hallum, 1990). At the time of the first recorded surveys there had already been significant losses of nearshore habitat due to diking in the Stillaguamish and Skagit deltas (Nesbit, 1885). Puget Sound scientists have found some evidence that the size of the Skagit and Stillaguamish marshes has increased since the 1950s due to natural processes (Brewer, 1980). Before human activities began to affect them, fresh water wetlands in the Puget Sound basin probably covered an area three to four times as large as the saltwater wetlands (Nesbit, 1885).

Eelgrass meadows are perhaps the most productive and fragile of the nearshore habitats common to Puget Sound. By slowing water currents and trapping organic material, eelgrass meadows provide a sheltered area for young fish, such as English sole and chum salmon, and invertebrates, such as Dungeness crab, to feed and become strong before taking their places in the more open and treacherous waters of the Sound. Eelgrass blades grow rapidly and act as a base for a thick fuzz of algae which provides additional food for grazing invertebrates and fish. Many of the animals which live at least part of their lives in the protective and nurturing environment of an eelgrass bed support the fish and wildlife populations that we treasure so highly.

Scientists have estimated that, at a minimum, 25 percent of the Puget Sound coastline is fringed by eelgrass (Thom and Hallum, 1990). Unfortunately, there are no good historical records of eelgrass meadows throughout Puget Sound. However, using old navigation charts, scientists believe that the shoreline fringed by eelgrass has declined by 30 percent in Bellingham Bay and by 12 percent in the Snohomish River delta (Thom and Hallum, 1990). Losses of eelgrass in these areas may have reduced the amount of critical nursery and feeding grounds for juvenile fish and other sea life. In contrast, scientists have seen a marked increase in the area covered by eelgrass in Padilla Bay (Thom and Hallum, 1990). Wetland biologists are confident that declines in the amount of eelgrass in Bellingham Bay and in the Snohomish River delta are the result of human activities including diking, draining, filling, and contamination. Ironically, the increase of eelgrass in Padilla Bay is not entirely due to the optimal growing conditions in the bay (Padilla Bay is protected as an estuarine research reserve), but is partially the result of an invasion by a non-native species of eelgrass which flourishes on previously unvegetated beaches. This species of eelgrass was introduced into Puget Sound after 1960 (Webber et al., 1987)



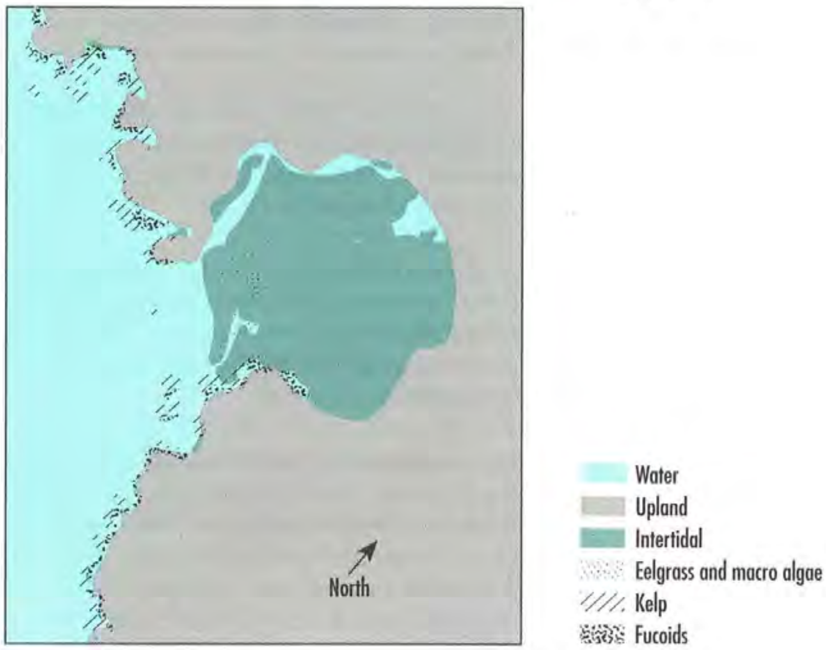


Figure 31. Habitat inventory for Dungeness Spit (top) and False Bay in 1988.

Kelp is a large marine plant that forms dense forests in shallow offshore waters. The plants are securely anchored to the bottom and stretch up to the surface with long stalks and broad fronds. Many types of fish, invertebrates, and other marine plants find a home within the dense growth of kelp plants, depending on the kelp forest for food, for attachment, for refuge, and as a place to lay their eggs. Changes in the extent of kelp beds in Puget Sound could affect populations of fish and other marine creatures that live in this unique habitat.

During 1911 and 1912 scientists used a boat to map kelp beds on most of the 2,000 miles of Puget Sound shoreline (Rigg, 1915). Wildlife biologists repeated the process in 1977, this time from an airplane (Albright et al., 1980). The length of shoreline covered by kelp beds increased by 53 percent between those two intervals (Thom and Hallum, 1990). Scientists believe that the increase of kelp along Puget Sound shorelines is a sign of habitat change due

to the increased presence of humans in the basin. The increase in kelp may be beneficial to populations of some Puget Sound fish and invertebrates.

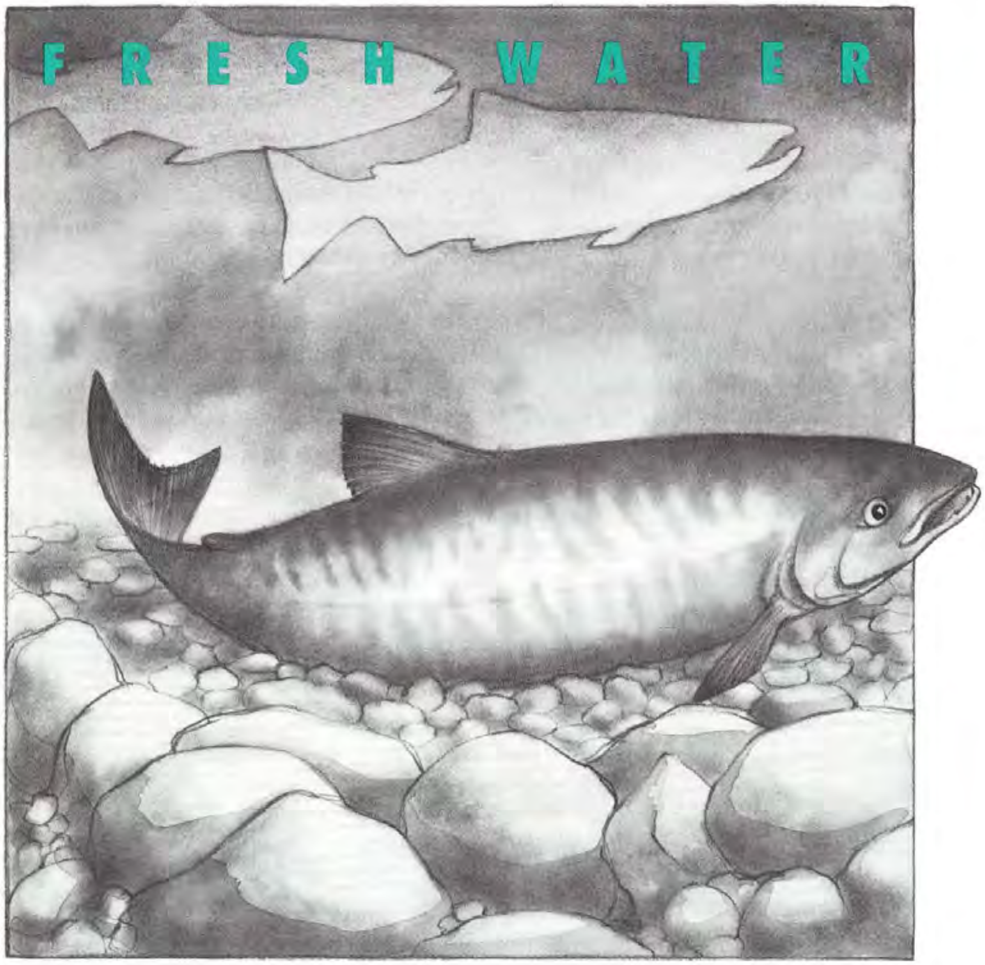
Scientists have taken a closer look at the extent of kelp bed coverage at Lincoln Park beach at West Seattle in the main basin. Recent surveys of the Lincoln Park kelp bed (Thom, 1978; Thom and Hampel, 1985; Thom and Hallum, 1990) have revealed that it has more than tripled in length since 1912. Scientists suspect that this increase is due to changing currents and sedimentation patterns caused by the construction of a seawall at Lincoln Park in the 1930s (Thom and Hampel, 1985). Similar changes in shorelines throughout Puget Sound may account in part for changes in kelp bed coverage in other areas of the Sound as well. The greatest increases in kelp bed coverage have occurred in those basins of the Sound where human development has been the greatest (main basin, south Sound), while scientists have observed less change in those areas least affected by human activities (Hood Canal, Strait of Juan de Fuca).

FUTURE PSAMP NEARSHORE HABITAT MONITORING

The design of PSAMP calls for continuing the assessment of nearshore habitat by inventorying one-third of the Sound each year. Future phases of PSAMP will examine the value that each type of habitat provides to fish and wildlife in different areas of the Sound.

As a part of the remote sensing pilot project, DNR scientists have processed information on only a few portions of the Puget Sound coastline. Having established that the system is effective, PSAMP investigators hope to finish processing the information gathered in 1988 and to begin flying one-third of the coastline each year.

Unless the work of the DNR scientists is continued, the effort and money that has gone into developing the complex methodology for measuring nearshore habitat by remote sensing may have been wasted, and we will not be able to benefit from information gathered during the aerial surveys. Without further surveys at frequent intervals, we will have no idea of the extent or health of vegetated nearshore habitat in most of Puget Sound, nor will we know whether there are changes occurring in the valuable nearshore habitat throughout the Sound.



BACKGROUND

Human residents of the Puget Sound basin are drawn to the streams, rivers, and lakes, as well as the saltier waters of the Sound. Many who do not live on Puget Sound choose to live on lakes or rivers. Puget Sound residents find numerous recreational opportunities in fresh water, including boating, fishing, birdwatching, and strolling the river corridors. We have integrated the lakes, waterways, and rivers of the area into our urban and rural lives. By their close association with the freshwater resources of the area, people living in the Sound's watersheds show that they value and depend upon the flowing water.

The freshwater rivers and streams of the Puget Sound basin drain approximately 16,000 square miles of upland and lowland terrain. In addition to providing important habitat for many species of fish and wildlife within their corridors, the rivers and streams transport billions of gallons of water each year into Puget Sound. This water carries a diverse mixture of particles and dissolved material, including sediment, dissolved nutrients, toxic chemicals (like pesticides, herbicides, metals), oil and grease, and miscellaneous organic matter. Maintaining good water quality in the rivers and streams of the Puget Sound basin is necessary for the health of the inhabitants of the watersheds, and is critical to protecting the health of Puget Sound.

Water quality and habitats in Puget Sound rivers and streams are threatened by physical scouring of the streambeds by sediments, burial of critical habitat and biological resources by excessive sedimentation, and contaminants carried

Pesticides in Puget Sound freshwater sediments

Organochlorine pesticides, such as DDT, are no longer in use in the Puget Sound basin but can still be measured in sediments and animal tissues. Because many of the modern pesticides are less persistent in the environment and are technically very difficult to measure, we have little information on their presence in fresh water, sediments, or animal tissue.

Scientists recently sampled water and sediments from five Puget Sound creeks to look for pesticides. They found measurable levels of the pesticide diazinon in water from Swamp Creek (which drains into Lake Washington) and in freshwater sediments from Big Ditch Slough (Skagit River) (PTI, in preparation, b). These levels may be hazardous to freshwater and marine animals. The scientists also found potentially hazardous levels of endosulfan 1 in sediments from Mercer Creek (Lake Washington) and diuron from water in Muck Creek (Nisqually area) and Big Ditch Slough (PTI, in preparation, b). Scientists surveyed pesticide use in the Puget Sound basin in 1988 and found that diazinon, an organophosphate pesticide, is one of the 10 most commonly used pesticides (Tetra Tech, 1988e); diuron, a carbamate pesticide, is one of the top 20 most commonly used pesticides; and, while endosulfan 1 is not commonly used in the Puget Sound basin, it is a very persistent pesticide, remaining in sediments and tissues for years.

by excessive runoff (often the result of vegetation removal and development by humans in upstream areas). In fresh water, water quality managers must be concerned about toxicants (metals and organics) and conventional pollutants, as each has a role in threatening critical resources and beneficial uses.

Excessive input of dissolved nutrients, in particular, can cause major algal blooms and eutrophication in rivers, lakes, and streams. Differences in the natural chemistry and circulation of fresh water versus marine water can cause eutrophication in fresh water which we seldom see in Puget Sound.

Many pathogens (as indicated by fecal coliform bacteria) enter the nearshore area of Puget Sound from rivers and streams, or from storm drains. Urban, suburban, agricultural, rural, and managed forest areas all contribute bacteria and viruses which affect the use of nearshore shellfish beds and recreational beaches.

Environmental managers are also concerned about toxic chemicals in rivers and streams. The chemicals of greatest concern include those released to rivers from industrial and municipal wastewater treatment plants and storm drains, as well as pesticides and herbicides from agriculture, forestry, and home gardening. Most of these chemicals are swept downstream and come to rest in the sediments of Puget Sound.

PSAMP FRESHWATER MONITORING

Because the focus of PSAMP is on characterizing and tracking changes in Puget Sound, PSAMP managers are interested in the quality of freshwater rivers and streams principally as they affect Puget Sound water quality, sediment quality, habitat, and biological populations (PSWQA, 1988). The large volume of fresh water which enters the Sound and the large deltas created by Puget Sound rivers have an influence on many nearshore areas of the Sound. The freshwater information gathered by PSAMP will not allow managers to calculate the total amount of sediment and contaminants that rivers contribute to the Sound because not enough freshwater information is gathered, but it will show trends in river water quality and sediment loading over time. Using this information, managers will be able to estimate the risk to nearshore resources (such as shellfish beds threatened by fecal coliform contamination) and take appropriate source control measures in the watersheds.

PSAMP designers do not intend to collect detailed freshwater monitoring data about the water quality, sediment quality, habitat, and biological resources in the watersheds. There are many other monitoring programs in the Puget Sound basin which are designed to provide necessary information for watershed and nonpoint source control activities. Many of the watershed monitoring programs measure conventional pollutants (such as fecal coliform bacteria, nutrients, suspended solids, and oil and grease) and/or habitat quality in the watersheds; a few measure toxic chemicals in river water, sediment, and biota. At full funding, PSAMP will provide additional toxics information which will be useful to watershed and natural resource managers.

The PSAMP design calls for sampling conventional pollutants and metals at 75 freshwater stations in the Puget Sound basin (PSWQA, 1988). Tissue from resident fish will be collected for toxic chemical analysis. Currently only a small portion (about 20 percent) of the necessary PSAMP program is being funded by the Washington Department of Ecology (Ecology). During 1989-1991

Ecology investigators sampled conventional pollutants at a limited number of stations on major rivers (Figure 32).

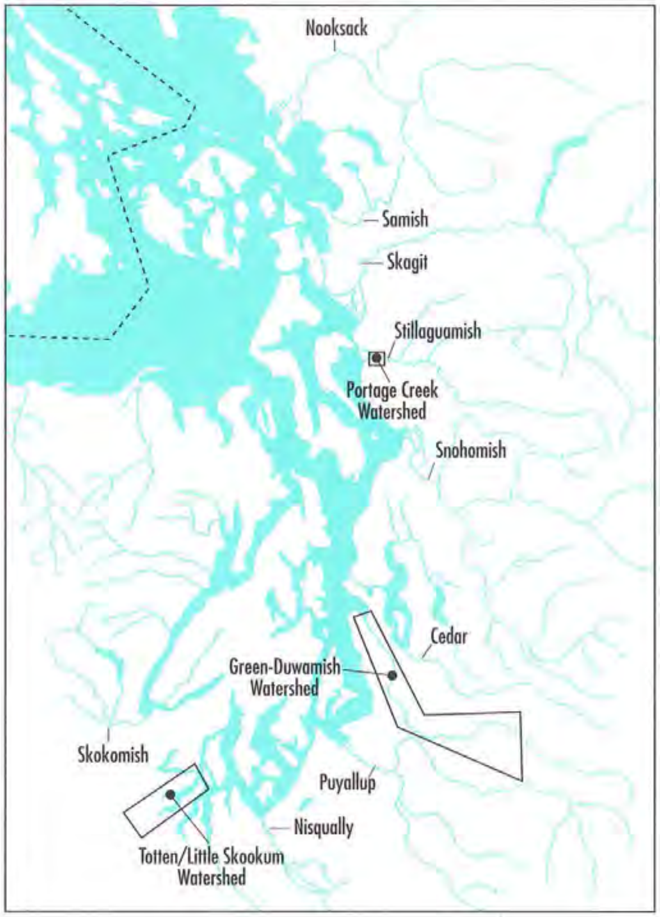


Figure 32. Rivers and watersheds of the Puget Sound basin.

Ecology investigators measure the water quality of 10 major Puget Sound rivers every month. They measure conventional water quality variables including temperature, dissolved oxygen, suspended sediment, and fecal coliform bacteria. Every year Ecology water quality managers analyze the results of the fresh water sampling and compare them to state standards for each stream, creek, and river segment. Figure 33 illustrates the results of this analysis for fecal contamination collected between 1988 and 1990 (Hopkins et al., in preparation). Ecology managers find the best water quality at stations high in the mountains, removed from the direct influence of human activities. Water quality stations at downstream locations, particularly those in highly developed watersheds, tend to show poorer water quality and to exceed the state standards for water quality (Hopkins et al., in preparation).

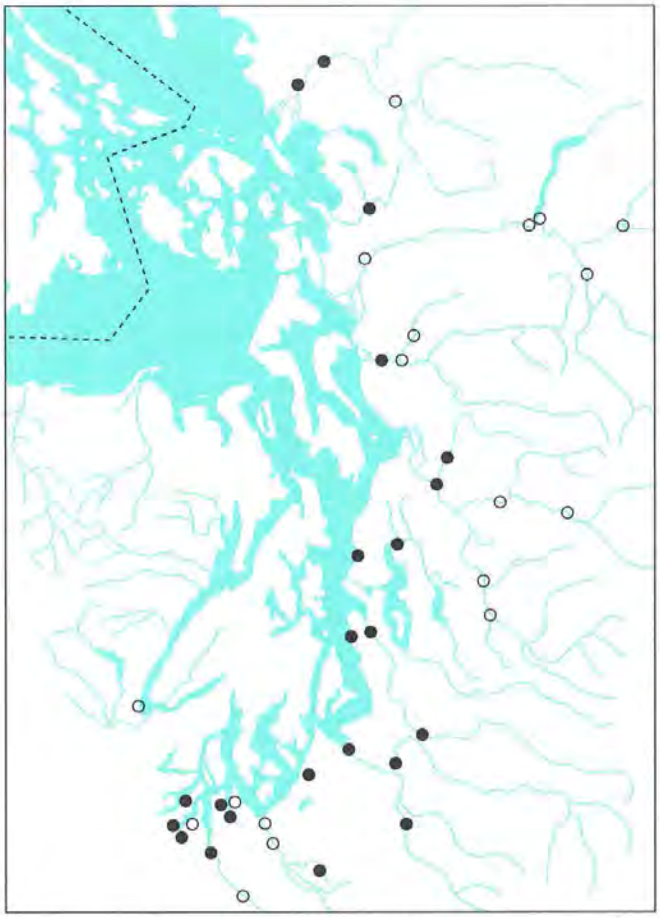
WATER QUALITY IN THREE PUGET SOUND WATERSHEDS

In order to illustrate the state of water quality in the watersheds surrounding Puget Sound, we have chosen three different watersheds: the Green/Duwa–mish in King County, Totten Inlet watershed in the south Sound, and Portage Creek which drains into the Stillaguamish River in Snohomish County (Figure 32). The three watersheds vary in size, in the type of freshwater rivers and streams they contain, and in land use. We will discuss fecal coliform contamination and other water quality variables in each of the three watersheds.

GREEN/DUWAMISH WATERSHED

The Green/Duwamish watershed is the largest of the three watersheds, draining an area of 480 square miles (Figure 34). The watershed is completely contained in King County and is home to 250,000 people (King County and Metro, 1989). The headwaters begin as the upper Green River, rising in forested lands near Stampede Pass and Green Pass. The river runs through agricultural fields and suburban areas, and into the commercial/industrial region of the Green River Valley, flowing through Auburn, Kent, and Renton. The river ends its journey as the heavily industrialized Duwamish River, emptying into inner Elliott Bay and the Seattle waterfront. There are several

Figure 33. Exceedances of fresh–water fecal coliform standards for 1988-1990.



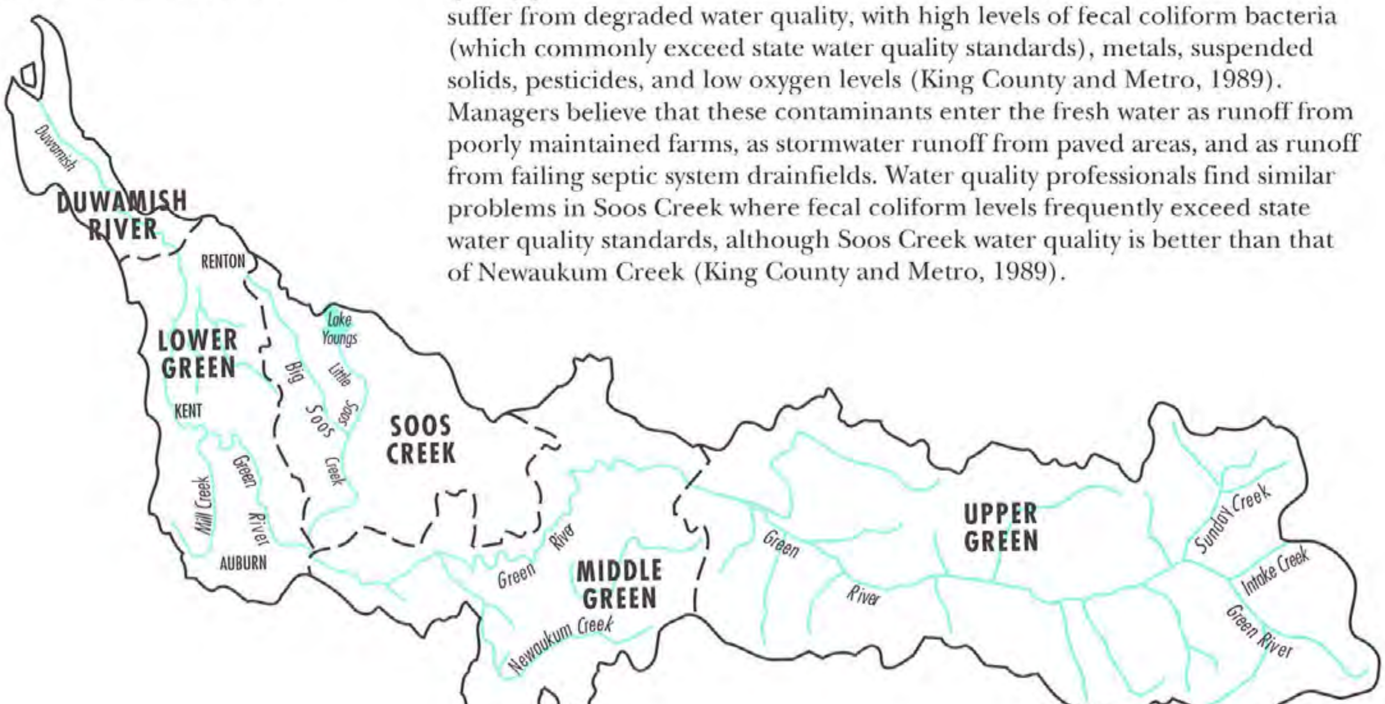
Exceeded standard of 100/100 ml ●
No exceedance ○

References: Hofstad, 1990; Starry, 1990a; Hopkins et al., in preparation; Metro, 1990; Starry, 1990b; Moore, 1990; King County and Metro, 1989.

hundred miles of freshwater rivers and streams in the Green/Duwamish system. The upper Green River watershed is almost completely undeveloped, while land uses in the lower reaches are divided among residential, agricultural, and commercial/industrial (King County and Metro, 1989).

Water quality professionals with Metro and Ecology routinely measure water quality at several locations on the Green/Duwamish River. They find that the quality of fresh water in the Green/Duwamish River worsens with the distance from the river's source, and as development and industrialization increase (King County and Metro, 1989). The water quality in the upper Green River is good with low levels of fecal coliform contamination and few suspended solids. This portion of the river serves as a drinking water source for the City of Tacoma, and supports wild and hatchery runs of salmon and steelhead. Further downstream, water quality professionals find that the middle Green River and Newaukum Creek suffer from degraded water quality, with high levels of fecal coliform bacteria (which commonly exceed state water quality standards), metals, suspended solids, pesticides, and low oxygen levels (King County and Metro, 1989). Managers believe that these contaminants enter the fresh water as runoff from poorly maintained farms, as stormwater runoff from paved areas, and as runoff from failing septic system drainfields. Water quality professionals find similar problems in Soos Creek where fecal coliform levels frequently exceed state water quality standards, although Soos Creek water quality is better than that of Newaukum Creek (King County and Metro, 1989).

Figure 34. Green/Duwamish watershed.



Reference: King County and Metro, 1989.

Managers have been concerned about water quality in the highly industrialized lower Green and Duwamish rivers for many years. In 1984 Ecology scientists found DDT, PCBs, copper, and mercury in fish (bridgelip suckers and northern squawfish) living in the upper Duwamish river (Hopkins et al, 1985).

In response to concerns about the water quality of the Duwamish river, in 1987 Metro moved the outfall from the Sound's largest municipal wastewater discharge out of the Duwamish River to the outer portion of Elliott Bay. Water quality managers have seen declines in phosphorus and ammonia, as well as increases in life-giving oxygen, since the diversion of the treated wastewater effluent (King County and Metro, 1989).

Managers are concerned with poor water quality and habitat degradation in other creeks and streams that drain into the lower Green River. These concerns include stormwater releases into the Black River which cause high levels of sedimentation, erosion, and landslides; dredging operations in Mill Creek which contribute to high levels of fecal coliform bacteria and diminished oxygen levels; drainage from a highly contaminated hazardous waste site into Springbrook Creek which contributes unacceptably high levels of fecal bacteria and metals to the creek; and the effects of combined sewer overflows and stormwater runoff from urban and industrialized areas flowing into the Duwamish River (King County and Metro, 1989). Scientists have measured high levels of many contaminants in water from the Duwamish River. However, since 1981 they have seen decreases in dissolved lead, copper, and zinc (Paulson et al., 1989).

TOTTEN INLET WATERSHED

Totten/Little Skookum watershed is the next largest of the three watersheds, covering an area of 70 square miles (Figure 35). The watershed drains into Totten Inlet in south Sound and forms the boundary between Mason and Thurston Counties. About 82 percent of the Totten Inlet watershed is forested, 8 percent is undeveloped, 5 percent is used for agriculture, 4 percent is residential, and less than 1 percent is developed for industrial and commercial use (Starry, 1990a). Totten/Little Skookum Inlet watershed is home to about 6,000 people. Natural resource managers, public health officials, and shellfish growers are concerned about water quality in the creeks which drain the watershed, as Totten Inlet is a rich shellfish growing and harvesting area.

Despite the seemingly pristine nature of the watershed, water quality professionals with Ecology and Thurston County have found that four out of five creeks they have sampled do not meet state water quality standards for fecal coliform bacteria (Starry, 1990a). Scientists find that two of the creeks with the poorest water quality have very low water flows during the summer. They believe that the fecal coliform contamination is caused by poor animal management practices at small farms adjacent to the creeks. They have discovered that the one Totten Inlet creek that does meet the standards is in an undeveloped subbasin (Starry, 1990a).

How are waters of the state classified?

In order to determine whether fresh waters of the state are meeting water quality standards, Ecology set up a water body classification system. With the help of the public, managers with Ecology determine the ways in which humans presently use the waters and the uses to which they could be used in future. These are known as beneficial uses. Each stream, creek, or river segment is assigned a classification: AA, A, or B, based on the beneficial uses of the waterbody. Class AA requires the highest quality water to support its beneficial uses. In order to illustrate the system, we have included a partial list of beneficial uses, and used dissolved oxygen (DO) levels as a representative water quality standard:

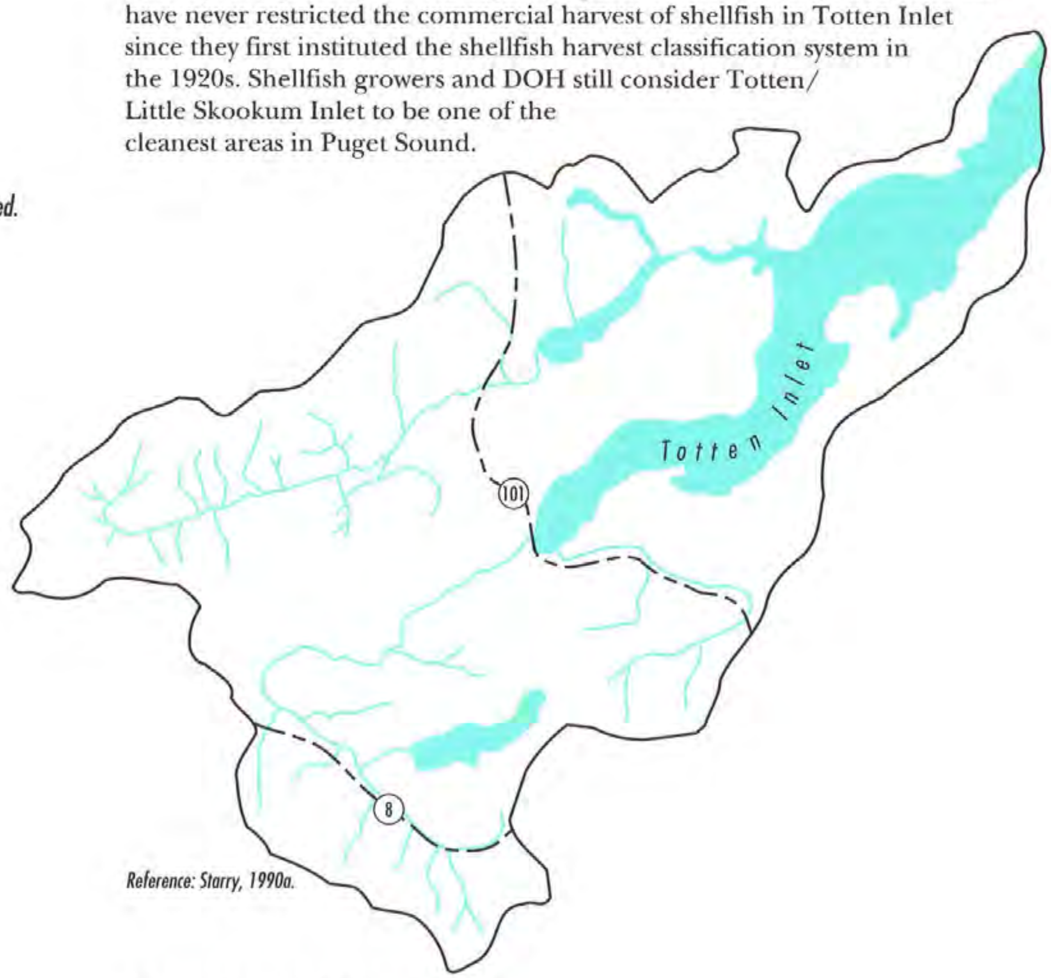
Class.	Beneficial Uses	Dissolved Oxygen Standards
AA	Shellfish Rearing Fish Rearing, Fishing Recreational Uses	Most Stringent: Highest Levels of DO (9.5 mg/l)
A	Fishing Recreational Uses	Less Stringent: Lower Levels of DO (8 mg/l)
B	Recreational Uses	Least Stringent: Lowest Levels of DO (6.5 mg/l)

Ecology managers determine whether the water quality of a specific waterbody (stream, creek, or river segment) meets its classification. If the water quality does not meet the standards, the managers will investigate the source of water quality degradation and take action to correct the problem.

When a waterbody consistently fails to meet the standards for its class, it may be downgraded and certain beneficial uses, such as shellfish rearing, may be prohibited. Similarly, managers may upgrade the classification of a waterbody if consistent improvements in water quality can be demonstrated.

Historically, Totten Inlet was the home of the Olympia oyster. This native shellfish is no longer abundant in Puget Sound due to overharvesting and past water quality problems. Washington Department of Health (DOH) officials have never restricted the commercial harvest of shellfish in Totten Inlet since they first instituted the shellfish harvest classification system in the 1920s. Shellfish growers and DOH still consider Totten/Little Skookum Inlet to be one of the cleanest areas in Puget Sound.

Figure 35. Totten/Little Skookum watershed.



Reference: Starry, 1990a.

PORTAGE CREEK

Portage Creek, in Snohomish County, is the smallest of the three watersheds, measuring 18 square miles (Figure 36) (SNOMET, 1977). Portage Creek and its tributaries drain into the Stillaguamish River. Parts of the watershed are considered to contain some of the richest coho salmon spawning habitat on the lower Stillaguamish River. Water quality managers began to take an interest in the watershed in 1974 when it was identified as the major source of fecal coliform contamination to the Stillaguamish River (SNOMET, 1977).

About 45 percent of the Portage Creek watershed is forested, 29 percent is used for agriculture, 12 percent is developed for residential use, and 3 percent is used for commercial and industrial purposes (PSWQA, 1990b). There are approximately 5,000 people living in the Portage Creek watershed, 90% of whom have septic systems. Many of the septic systems are in poorly drained soils.

Water quality professionals with Ecology have found that some of the streams in the Portage Creek watershed have levels of fecal bacteria and oxygen which violate state water quality standards. In 1989 Ecology found that Portage Creek at Arlington had good water quality as measured by bacteria and dissolved oxygen. However, they found degraded water quality downstream with high levels of fecal bacteria (PSWQA, 1990b). Water quality managers blame water

quality problems in Portage Creek on agricultural practices, including manure spreading and cattle grazing from large and small farms, and on failing septic systems. Managers are concerned that the predicted population growth in the Portage Creek watershed will exacerbate the existing water quality problems (PSWQA, 1990b). As the number of septic systems increases, the number of failures is likely to increase. Similarly, an increased number of small farms increases the chances of poor agricultural practices.

Natural resource managers find that about half of the length of Portage Creek suffers from degraded fish habitat due to removal of the vegetation from the river banks, erosion of the river banks, and increased sedimentation due to livestock in the river (PSWQA, 1990b). Managers are also concerned about the presence of elevated levels of toxic metals in stream sediments near an overpass of Interstate 5.

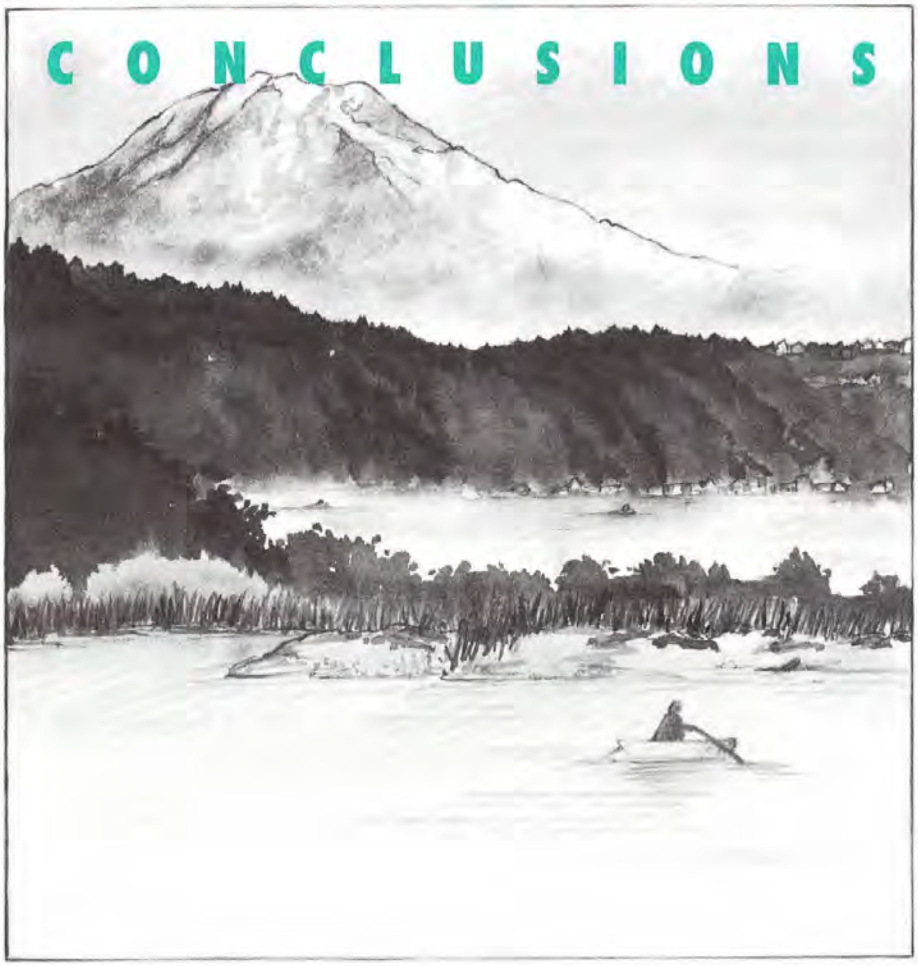
FUTURE PSAMP FRESHWATER MONITORING

Freshwater monitoring under PSAMP is currently funded through existing Ecology programs. Ecology investigators will continue to sample freshwater rivers during 1991. When PSAMP freshwater monitoring funds become available, they will sample additional stations on Puget Sound rivers and streams, analyze river water samples for metals, and measure toxicants (metals and organics) in suspended sediment. Ecology investigators will also measure toxicants in the tissue of resident fish to determine if there is a human health risk from eating the fish.

Without further freshwater monitoring, we risk knowing very little about the water quality and contaminant contribution to Puget Sound by the smaller rivers and streams in the basin. Also, we will have little information on levels of toxic chemicals in water and fish found in Puget Sound's watersheds and the cumulative effects of source control programs to control freshwater pollutants.

Figure 36. Portage Creek watershed.

Reference: PSWQA, 1990b.



This is the second annual report of the Puget Sound Ambient Monitoring Program (PSAMP), a long-term monitoring program. In this report the PSAMP managers have attempted to present the overall design and philosophy behind PSAMP, the results available from the first two years' of monitoring and other related studies, as well as some background information on Puget Sound. Considerably more detail on the Puget Sound ecosystem and the PSAMP design were presented in last year's report (PSWQA, 1990a).

In this concluding chapter, we summarize our current understanding of overall conditions of Puget Sound waters, sediments, and biological populations. This overall analysis is based on the results of PSAMP and many other studies, some of which have been discussed in other chapters of this report and in last year's report. We present the direction for future monitoring that PSAMP managers have established, as well as the price that we may pay if we do not monitor Puget Sound. Following this chapter, we include the references used in preparing this report, and a list of contacts for finding out more about PSAMP or for getting involved with citizen monitoring.

THE OVERALL STATUS OF PUGET SOUND

The health of Puget Sound is generally good, with serious contamination and degradation problems restricted to fairly small areas near the shorelines and the urban bays. The problems that we encounter in the urban bays and a few other areas, however, are often severe. In addition, widespread degradation of

natural shoreline areas has diminished the quality and quantity of critical fish and wildlife habitat. There are early warning signs of problems emerging in many other areas also, such as contaminated sediments, liver tumors in bottomfish, chemical contaminants in fish tissue, shellfish bed closures due to fecal contamination, and reductions in some populations of fish and wildlife.

Virtually no area of Puget Sound is pristine and free from contamination. The 19th-century influx of immigrants and the gradual development and industrialization of the Puget Sound basin have spread low levels of contamination to all parts of the Sound. Many areas of Puget Sound still remain in a reasonably uncontaminated condition, however, including many of the rural bays, the deep basins, and many parts of the Straits. Between these relatively clean areas and the contaminated urban bays lies the majority of Puget Sound, with low levels of assorted contaminants, many of which may not cause direct harm to plant, animal, or human inhabitants of the basin. We know very little about the cumulative effects of human activities such as dredging, filling, fishing and hunting, and waste disposal on Puget Sound biological populations.

We are seeing some of the effects of the pollutant load that we are inflicting on the Sound. Closures of shellfish beds to harvesting, diseases in bottomfish, and occasional fish kills are related to the contaminants we dispose of in the Sound. Human activities also affect populations of living resources. Many seabirds and marine mammals, such as porpoises, are not as abundant as in the past due to habitat loss from development; some fish runs have been severely reduced due to habitat loss and overfishing; and stands of native seagrasses and populations of shellfish are reduced due to competition from imported species.

SEDIMENT CONTAMINATION

The worst chemical contamination problems show up in the bottom sediments, where particles and their associated metals and organics settle. The urban bays contain the largest areas of contaminated sediments; rural bays and the deep basins of the Sound collect contaminants in their sediments as well, although generally at lower concentrations. In areas that are removed from sources, contaminants are greatly diluted by clean sediment. Contaminated sediments in many areas of the Sound would be cleaned up by natural processes if the sources of contamination were curtailed. Scientists find that harm to biological populations, as suggested by bioassays, changes in indigenous benthic invertebrate populations, bottomfish tumors, and reproductive problems in bottomfish, are greatest in areas of high sediment contamination.

MARINE WATERS

The marine waters of Puget Sound are generally clean, due to the tremendous volume, tidal mixing, and exchange with ocean water. However, there may be many chemical contaminants in the water at low or immeasurable levels. Nearshore areas are often affected by bacterial contamination caused by activities in the watersheds. Water quality managers are keeping a sharp watch on areas of restricted water circulation and have discovered eutrophication problems in Budd Inlet and Lynch Cove, as well as fecal contamination of

shellfish beds and nearshore areas in many bays. Managers are also on the lookout for other potential problems, including pesticide contamination near river mouths that drain agricultural and developed watersheds, eutrophication in small enclosed bays, and further degradation of shellfish growing areas by fecal contamination.

CONTAMINATION OF BIOLOGICAL POPULATIONS

There is evidence of chemical contaminants in the flesh of fish, shellfish, birds, and marine mammals, as well as some evidence of reproductive problems in birds, bottomfish, and marine mammals. The accumulation of toxic chemicals in the bodies of Puget Sound animals does not necessarily mean that they are being harmed, but these chemicals must be taken as a warning sign of potential damage to our resources and a threat to human health.

Changes in population levels of fish, marine birds, waterfowl, and marine mammals seem to indicate the effects that human activities are having on biological resources. Managers believe that the greatest impacts on fish and wildlife populations result from the loss of habitat critical to rearing, feeding, and refuge for many species. Development, waste disposal, overharvesting, and other factors may also cause damage to these resources.

HABITATS

The vegetated nearshore estuarine habitats in Puget Sound are a mere shadow of their former selves. Over the past 100 years there have been staggering losses of nearshore eelgrass beds and salt marshes in the urbanized estuaries and heavy losses of nearshore and upland wetlands throughout the basin. We cannot accurately document the extent of fish and wildlife losses due to habitat destruction, but evidence from other parts of the country, and some local information, suggest that the impacts have been enormous. The loss of Puget Sound nearshore habitat, despite many regulatory constraints, continues at an alarming rate. Losing the nearshore habitat eliminates more and more homes for the fish and wildlife which help make the Puget Sound area such a desirable place to live. Historically, the losses of important freshwater and terrestrial habitat in the Puget Sound basin have also been staggering. Large tracts of these habitats are still being lost including vegetated river and stream corridors, in-stream salmonid spawning habitat, freshwater wetlands, and forest lands.

FRESH WATER

The rivers and streams of Puget Sound suffer from many localized water quality problems, but the systems are resilient and no recent widespread degradation of water quality has been seen. Managers see water quality improvements in a few select rivers and streams, including the lower Duwamish River.

Water quality varies greatly from watershed to watershed, depending on the nature of the soils, slopes, and land uses. Riverine habitat destruction, reductions in the populations of fish and wildlife supported by the freshwater

Puget Sound fish and shellfish advisories

County health departments in the Puget Sound basin issue health advisories for locations where bacterial or chemical contamination may make fish, shellfish, and other seafood unsafe for human consumption. These health advisories differ from county to county, but, in general, they alert the public to those areas where it is unwise to catch fish or harvest shellfish. The advisories often provide information on ways to decrease the health effects from mildly contaminated seafood. The state also issues health advisories and restricts the harvest of commercial shellfish and other fisheries based on bacterial and chemical contamination.

As of May 1991, five Puget Sound counties (Kitsap, King, Pierce, Snohomish, and Thurston) had health advisories in effect. The other seven Puget Sound counties had no health advisories in effect (Clallam, Island, Jefferson, Mason, San Juan, Skagit, and Whatcom).

Advisories in Kitsap County cover Dyes Inlet, Sinclair Inlet, and Eagle Harbor. The Seattle-King County Health Department advises against eating seafood from any urban beaches, and posts advisories for the Duwamish River (downstream from the Spokane Street Bridge) and for Elliott Bay public fishing piers. Pierce County health advisories cover the Commencement Bay waterways. The Snohomish County Health Department advises against eating seafood from inner Everett Harbor or near the Mukilteo oil storage facility. Thurston County health advisories cover the harvesting of shellfish from the Priests Point Park and the Cascade Pole site in Budd Inlet.

For more information about Puget Sound health advisories, the species of fish and shellfish that are covered by the advisories, and instructions for preparing seafood in the safest manner, contact your local county health department.

corridors, and the press of human development in the watersheds are indications that we are stressing the system and that further breakdowns in the health of rivers and streams may follow.

HUMAN HEALTH EFFECTS FROM EATING PUGET SOUND SEAFOOD

Fish, shellfish, marine algae, and other natural resources are important to the diet of many people living in the Puget Sound area; others depend on the Sound's bounty for their livelihood. Washington Department of Health (DOH) officials are finding increasing numbers of commercial and recreational shellfish beds that are contaminated with fecal bacteria. Levels of paralytic shellfish poisoning (PSP) reach dangerous proportions in Puget Sound shellfish almost every summer. Scientists are finding chemical contaminants in fish and shellfish, although the levels of chemicals found in all but the most contaminated areas of Puget Sound are unlikely to affect people who consume seafood in moderate amounts.

DOH and the county health departments are responsible for monitoring shellfish for potential health threats like bacteria and PSP. They restrict harvest at commercial shellfish beds, warn the public against harvesting shellfish on recreational beaches, and issue advisories against consuming fish and other seafood from urban and industrialized areas. DOH, the U.S. Environmental Protection Agency (EPA), and other agencies assess health effects and health risks associated with contaminants for two purposes: to determine whether sediments, soils, and animal tissues need to undergo cleanup (Superfund and other programs); and to assess whether seafood contaminant levels pose a threat to human health.

WHAT IS BEING DONE TO CLEAN UP PUGET SOUND?

There are many programs and projects underway to protect and improve the quality of the Sound's waters, sediments, and biological populations. Many of these programs have been mentioned throughout this report, and are carried out through the efforts of state, federal, local, and tribal governments, as well as the private sector, environmental and community groups, and the public. We provided more information on some Puget Sound programs in last year's Puget Sound Update; additional information can be obtained by contacting the organization initiating each program.

Many of these programs have been initiated by, or coordinate closely with, the Puget Sound Water Quality Management Plan (PSWQA, 1991). The 1991 Puget Sound Water Quality Management Plan was adopted in November 1990. In May 1991 the plan was approved as the federal Comprehensive Conservation and Management Plan (CCMP) for Puget Sound under the Clean Water Act, as part of EPA's National Estuary Program.

Programs such as the Urban Bay Action Teams (Washington Department of Ecology), industrial pre-treatment programs which reduce the toxicity of industrial effluent before it reaches the sewage treatment plants (Ecology and Metro), NPDES wastewater discharge permits (Ecology), and watershed nonpoint source control programs (Ecology and counties) will reduce the amount of microbiological and chemical contamination that can be disposed

of in Puget Sound. Through source control, these programs will reduce the flow of waste that accumulates in Puget Sound sediments and animal tissues. Other programs focus on cleanup activities for contaminated sediment, including capping of contaminated sediments by Metro in Elliott Bay and by Simpson Kraft in Commencement Bay, decisions about the open water disposal of dredged material by the Puget Sound Dredged Disposal Analysis (PSDDA) (U.S. Army Corps of Engineers, EPA, Washington Department of Natural Resources, and Ecology) based on contaminant levels in the sediment, and the removal of contaminated soil and sediment at Superfund sites in Commencement Bay, Eagle Harbor, Harbor Island, and other sites in the Puget Sound basin (EPA and Ecology).

Managers and scientists are working toward habitat protection through a number of programs, including setting limits for development projects at the federal (EPA, U.S. Army Corps of Engineers, US Fish and Wildlife Service), state (Washington Departments of Ecology, Fisheries, and Wildlife), and local (counties and cities) levels; growth management plans under development by the counties (counties and Washington Department of Community Development); and habitat mitigation projects.

The Washington Departments of Wildlife and Fisheries, the U.S. Fish and Wildlife Service, the National Marine Fisheries Service, and the tribes are responsible for protecting populations of fish and wildlife in Puget Sound. In addition to statewide and nationwide programs to protect fish and wildlife, these agencies and tribes are cooperating in monitoring and habitat protection programs under the Puget Sound plan. The U.S. Fish and Wildlife Service has recently started a Puget Sound Initiative that will allow them to participate more fully in Puget Sound programs.

Many public and private sector organizations are involved in monitoring the state of Puget Sound. The largest ongoing program is PSAMP, which involves state, federal, local, and tribal agencies, as well as citizen monitors, environmental groups, and the private sector. Other ongoing monitoring programs include the National Oceanic and Atmospheric Administration's National Status and Trends program, Canadian monitoring programs (British Columbia Department of the Environment and Environment Canada) which collect information on the other side of the international boundary, and watershed action plans (Ecology and counties).

RECOMMENDATIONS FOR FUTURE PSAMP MONITORING

After two years of information collection under PSAMP, managers feel confident that the coordinated and comprehensive ecosystem approach to monitoring will give us the most accurate and cost-effective information on the status of Puget Sound waters, sediments, and biological populations. During 1989 and 1990 PSAMP investigators collected baseline information for some parts of the ecosystem, including sediments, fish, shellfish, and marine and fresh waters. PSAMP managers have set the framework for analysis and interpretation of PSAMP information through both the technical reports and Puget Sound Update. We have attempted to analyze and interpret PSAMP and other Puget Sound data to determine patterns of contamination in the Sound, threats to human health from consuming Puget Sound seafood, and the status of biological populations. There is a need to build on this foundation, and to include those ecosystem components where PSAMP monitoring has not been initiated (marine mammals, birds, and nearshore habitat).

PSAMP managers will make some changes to the PSAMP design in upcoming years. During 1991 PSAMP managers are reviewing the program with the help of outside experts. Based on recommendations from the reviewers, PSAMP managers may relocate some monitoring stations, fill in geographic station coverage, add or delete some parameters, and sample additional ecosystem components.

There are many portions of PSAMP which are not currently funded, or where funding is inadequate to assess the status and trends of resources throughout the Sound. Managers have had to make tough choices about which parts of the ecosystem will not be sampled, and what areas of the Sound will not be monitored, until more funds are available.

In 1990 the Washington State Legislature passed legislation that requires the implementation of PSAMP by state agencies. During the 1991 state legislative session the Governor Booth Gardner requested a substantial increase in funds for implementing PSAMP. The legislature had not yet acted on this request when Puget Sound Update went to press.

WHAT HAPPENS IF WE DON'T MONITOR?

Certain components of the Puget Sound ecosystem are receiving minimal monitoring under PSAMP or any other program. Scientists and managers are measuring contamination in fish and shellfish resources in only a few areas of the Sound, and may not inventory estuarine nearshore habitats again in the near future. There is inadequate monitoring of marine and fresh water to keep track of changing conditions. Without information on these parts of the ecosystem, major changes could occur and shifts in resource populations or levels of contamination could go unnoticed until a crisis strikes. Alternately, changes in ecosystem components could occur and managers would have inadequate information to decide whether the changes were due to natural or anthropogenic causes. Without information of this type, managers may not be able to recognize and correct problems before they become costly and difficult to correct.

We are collecting little or no information on some parts of the ecosystem, particularly assessments of biological populations like birds, marine mammals, fish, and shellfish. Without information about these populations and the threats that they are facing, the public may incur staggering future costs to restore affected resources, or we may see great reductions or even total loss of some of our unique and valuable marine populations.

There are many worldwide examples of over-exploitation of resources, decimation of biological populations by pollution, and human illnesses from eating contaminated seafood that must be an example to us in the Puget Sound area. In addition, managers will continue to have only limited information with which to evaluate the effectiveness of source control and cleanup programs.

As compared to many of the industrialized estuaries in the United States and abroad, most of Puget Sound is in generally good condition. We have a chance to avoid further degradation of Puget Sound waters, sediments, and biological populations through cleanup and source control efforts. We are still in a position to avoid some of the crises that have befallen other areas, including

massive fish kills, widespread closures of fisheries, devastating oil and chemical spills which debilitate or destroy wildlife, and serious contamination of seafood which may be hazardous to humans.

The information that PSAMP investigators are collecting, and the actions that will be taken as a result of PSAMP, will provide a level of protection for Puget Sound, its biological resources, and human health that is critical for maintaining a healthy and diverse Puget Sound.

FINALLY

Puget Sound is a large and complex system with rich and interconnected resources and living populations. We expect the Sound to act as waterway, food pantry, recreational area, and place of business for three million humans. Each one of us has the opportunity to benefit from the Sound; we also have the ability to contribute to its decline, or to protect its future. Without a sense of stewardship for this marvelous resource, we are unlikely to sustain the quality of life that we cherish in this area. Many people genuinely wish to protect and clean up Puget Sound, even if it entails some changes in their actions and way of life, but are lacking the necessary information to make those changes. We hope that this document has helped Puget Sound residents to understand some of the natural workings of the Puget Sound system; the present condition of, and threats to, Puget Sound resources; and the changes that we may expect in the future. Armed with this information about the Sound, we believe that Puget Sound residents will want to learn more about the Sound and ways in which they may help protect it.

REFERENCES

Albright, R.R. Hirschi, R. Vanbianchi and C. Vita. 1980. Coastal zone atlas of Washington land cover/land use narrative. Washington State Department of Ecology. Olympia, WA.

Anderson, J., A. Copping, T. Jagielo, J. Postel, W. Peterson, B. Dumbauld, G. Heron, R. Hood, and M. Strom. 1984. Water column ecology. Volume III. Section 4. *In*: Q.J. Stober and K.K. Chew (eds.). Renton sewage treatment plant project: Seahurst baseline study. Prepared for the Municipality of Metropolitan Seattle, Seattle, WA.

Arden, H., and J. Smith. 1991. Beneficial use of dredged material for salt marsh development at Jetty Island, Everett, Washington. In: Proceedings, Puget Sound Research '91. Puget Sound Water Quality Authority, Olympia, WA. Vol. 2.

Becker, D.S., R. Sonnerup, and J.J. Greene. 1989. Bellingham Bay action program: Initial data summaries and problem identification. Prepared for U.S. Environmental Protection Agency, Region 10. Seattle, WA. 124 pp. + appendices.

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.

Boulé, M.E., N. Olmsted, and T. Miller. 1983. Inventory of wetland resources and evaluation of wetland management in western Washington. Prepared for Washington Department of Ecology, Olympia, WA. 102 pp.

Brewer, L.W. 1980. Waterfowl habitat inventory. Project NO. W-27-R-28. Washington Department of Game, Olympia, WA.

Calambokidis, John. Personal Communication. Cascadia Research Collective. May 1991.

Calambokidis, J. In press. Vessel surveys for harbor porpoise off the Washington coast. In: Kajimura, H. (ed). Harbor porpoise abundance and interaction with Makah salmon set-net fishery in coastal Washington waters, 1988-89. NOAA Technical Report.

Calambokidis, J. and J. Barlow. 1991. Chlorinated hydrocarbon concentrations and their use for describing population discreteness in harbor porpoise from Washington, Oregon, and California. In: Proceedings of the Second Marine Mammal Stranding Workshop, 3-5 December 1987, Miami, FL. J.E. Reynolds and D.K. Odell (eds.). National Oceanic and Atmospheric Administration Technical Report.

Calambokidis, J., K. Bowman, S.D. Carter, J.C. Cubbage, P. Dawson, T. Fleischner, J. Schuett-Hames, J.W. Skidmore, B. Taylor, and S.G. Herman. 1978. Chlorinated hydrocarbon concentrations and the ecology and behavior of harbor seals in Washington state waters. Final report to National Science Foundation, The Evergreen State College, Olympia, WA. 121 pp.

Calambokidis, J., J.B. Buchanan, G.H. Steiger, and J.R. Evenson. In preparation. Toxic contaminants in Puget Sound wildlife, literature review and recommendations for research and monitoring. For U.S. Environmental Protection Agency Region 10, Seattle, WA.

Calambokidis, J., S.M. Speich, J. Peard, G.H. Steiger, and J.C. Cubbage. 1985. Biology of Puget Sound marine mammals and marine birds: Population health and evidence of pollution effects. NOAA Technical Memorandum NOS OMA 18. National Oceanic and Atmospheric Administration, Rockville, MD. 159 pp.

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.

Calambokidis, J., G.H. Steiger, J.R. Evenson, J.C. Cubbage, and R.W. Osborne. 1991b. Gray whales in Puget Sound and the Strait of Juan de Fuca. In: Proceedings, Puget Sound Research '91. Puget Sound Water Quality Authority, Olympia, WA. Vol. 1, pp.414-424.

Calambokidis, J., G.H. Steiger, J.R. Evenson, and S.J. Jefferies.1991a. Censuses and disturbance of harbor seals at Woodard Bay and recommendations for protection. Final Report. Prepared for Washington Department of Natural Resources. 44 pp.

Calambodidis, J., G. H. Steiger, B.D. McLaughlin, J. R. Evenson. 1990. Harbor seal haul-out habitat and the feasibility of shifting haul-out locations at Dosewallips State Park, Washington. Prepared for Washington State Parks and Recreation Commission, Olympia, WA. 70 pp.

Campbell, S.A., W.K. Peterson, and J.R. Postel. 1977. Phytoplankton production and standing stock in the main basin of Puget Sound. Final report to the Municipality of Metropolitan Seattle, Puget Sound Interim Studies. Municipality of Metropolitan Seattle, Seattle, WA. 132 pp.

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

Cardwell, R.D., and C.E. Woelke. 1979. Marine water quality compendium for Washington state. Washington Department of Fisheries, Olympia WA. Two volumes.

Casillas, E., D.A. Misitano, L.L. Johnson, L.D. Rhodes, T.K. Collier, J.E. Stein, B.B. McCain, and U. Varanasi. In Press. Inducibility of spawning and reproductive success of female English sole (*Parophrys vetulus*) from urban and nonurban areas of Puget Sound, Washington. Mar. Environ. Res.

Casillas, E., M.S. Myers, L.D. Rhodes, and B.B. McCain. 1985. Serum chemistry of diseased English sole, *Parophrys vetulus Girard*, from polluted areas of Puget Sound, Washington. J. Fish. Disease 8:437-449.

Crecelius, E.A., D.L. Woodruff, and M.S. Myers. 1989. 1988 reconnaissance survey of environmental conditions in 13 Puget Sound locations. EPA 910/9-89-005. Battelle, Duxbury, MA. 95 pp. + appendices.

Cummins, Eric. Personal Communication. Washington State Department of Wildlife. March 1, 1991.

Cummins, E.B., U. Wilson, and M. McMinn. 1990. Cooperative management of marine birds in Washington. pp. 171-182 *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.

Curl, H.C. and A.J. Paulson. 1991. The biochemistry of oxygen and nutrients in Hood Canal. In: Proceedings, Puget Sound Research '91. Puget Sound Water Quality Authority, Olympia, WA. Vol. 1, pp.109-115.

Dexter, R.N., L.S. Goldstein, P.M. Chapman, and E.A. Quinlan. 1985. Temporal trends in selected environmental parameters monitored in Puget Sound. NOAA Technical Memorandum NOS OMA 19. National Oceanic and Atmospheric Administration, Rockville, MD. 166 pp.

Everitt, R.D., C.H. Fiscus, and R.L. Delong. 1980. Northern Puget Sound marine mammals. DOC/EPA Interagency Energy/Environment Research and Development Program Report, EPA 600/7-80-139. U.S. Environmental Protection Agency, Washington, D.C. 134 pp.

Everitt, R.D., C.H. Fiscus, and R.L. Delong. 1979. Marine mammals of northern Puget Sound and the Strait of Juan de Fuca: A report on investigations November 1, 1977 - October 31, 1978. NOAA Technical Memorandum ERL MESA 41. National Oceanic and Atmospheric Administration, Rockville, MD. 191 pp.

EVS. 1979. Identification of heavy metals in organisms within an area for the Fraser River Estuary receiving a major municipal industrial and stormwater discharge. Report for the Canadian Department of Fisheries and Environment, DSS File 075B, KF 10-8-SPO65, EVS Consultants Ltd. North Vancouver, British Columbia. 112 pp.

Faigenblum, J. 1988. Chemicals and bacteriological organisms in recreational shellfish. Prepared for U.S. Environmental Protection Agency by the Washington Department of Social and Health Services. 109 pp. + appendices.

Fox, G.A., and T. Donald. 1980. Organochlorine pollutants, nest-defense behavior, and reproductive success in merlins. Condor 82:81-84.

Gahler, A.R., J.M. Cummins, J.N. Blazevich, R.H. Rieck, R.L. Arp, C.E. Gangmark, S.V.W. Pope, and S. Filip. 1982. Chemical contaminants in edible, non-salmonid fish and crabs from Commencement Bay, WA. EPA 910/9-82-093. U.S. Environmental Protection Agency, Washington, D.C.

Galvin, D.V., G.P. Romberg, D.R. Houck, and J.H. Lesniak. 1984. Toxicant Pretreatment Planning Study summary report. Municipality of Metropolitan Seattle, Seattle, WA. 201 pp. + appendices.

Goldsmith, D. 1989. Quilcene/Dabob Bays Watershed Action Plan Jefferson County. 27pp + appendices.

Goyette, D., D. Brand, and M. Thomas. 1988. Prevalence of idiopathic liver lesions in English Sole and epidermal abnormalities in Flatfish from Vancouver Harbour, British Columbia, 1986. Regional Program Report 87-09. 40 pp. + appendix.

Harrison, P.J., P.J. Clifford, W. P. Cochlan, K. Yin, M.A. St.John, P.A. Thompson, M.J. Sibbald, and L.J. Albright, 1991. Nutrient and Plankton Dynamics in the Fraser River Plume, Strait of Georgia, British Columbia. Mar. Ecol. Prog. Ser. Vol.70: 291-304.

Henny, C.J., L.J. Blus, R.A. Grove, and S.P. Thompson. In press. Accumulation of trace elements and organochlorines by surf scoters wintering in the Pacific Northwest. Northwestern Naturalist Volume 72.

Henny, C.J., L.J. Blus, and R.A. Grove. 1990. Western Grebe, *Aechmorphorus occidentalis*, wintering biology and contaminant accumulation in Commencement Bay, Puget Sound, Washington. Canadian Field-Naturalist. 104(3):460-472.

Henny, L.J., L.J. Blus, S.P. Thompson, and Ulrich W. Wilson. 1989. Environmental contaminants, human disturbance and nesting of double-crested cormorants in northwestern Washington. Colonial Waterbirds 12(2): 198-206.

Hickey, J.J., and D.W. Anderson. 1968. Chlorinated hydrocarbons and eggshell changes in raptorial and fish-eating birds. Science 162:271-273.

Hofstad, L. L. 1990. Eld Inlet and Watershed 1987-1989 A Water Quality and Remedial Action Report. Prepared for Washington State Department of Ecology, Olympia, WA. 108 pp. + appendices.

Hopkins, B.S., D.K. Clark, M. Schlender, and M. Stinson. 1985. Basic water monitoring program fish tissue, and sediment sampling for 1984. Washington State Department of Ecology, Water Quality Investigations Sections. 25 pp. + appendices.

Hopkins, B.S., D.D. Hallock, J. Bernhardt, and B. James. In preparation. Freshwater Ambient Monitoring Program for Washington State.

Hooper, Thom. Washington Department of Fisheries. Personal Communication. February 14, 1991.

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

Janzen, C.D. In preparation. Washington State Department of Ecology Marine Ambient Monitoring: 1989-1990 Annual Report. Prepared for Environmental Investigations and Laboratory Services.

Jeffries, S.J. 1990. Management of Washington's marine mammals under the Marine Mammal Protection Act: paradox or opportunity? pp. 171-182 *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.

Johnson, L.L., E. Casillas, T.K. Collier, B.B. McCain, and U. Varanasi. 1988. Contaminant effects on ovarian maturation in English sole (*Parophrys vetulus*) from Puget Sound, WA. pp. 651-661 *In*: Proceedings of the first annual meeting on Puget Sound research. Puget Sound Water Quality Authority, Seattle, WA.

King County and Municipality of Metropolitan Seattle (Metro). 1989. Green-Duwamish watershed nonpoint action plan. Revised draft. December 89.

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.

Landolt, M.L., F.R. Hafer, A. Nevissi, G. van Belle, K. Van Ness, and C. Rockwell. 1985. Potential toxicant exposure among consumers of recreationally caught fish from urban embayments of Puget Sound. NOAA Technical Memorandum NOS OMA 23. National Oceanic and Atmospheric Administration, Rockville, MD. 104 pp.

Landolt, M.L., D.L. Kalman, A. Nevissi, G. van Belle, K. Van Ness, and F.R. Hafer. 1987. Potential toxicant exposure among consumers of recreationally caught fish from urban embayments of Puget Sound. Final report. NOAA Technical Memorandum NOS OMA 33. National Oceanic and Atmospheric Administration, Rockville, MD. 111 pp.

Lauenstein, Gunnar. Personal communication. National Oceanic and Atmospheric Administration. Ocean Assessments Division. Rockville, Maryland. May, 1991.

Leland, Robert. Washington Department of Wildlife. Personal communication. May 1991.

Lindberg, P., and T. Odsjo. 1983. Mercury levels in feathers of peregrine falcon (*falco peregrinus*) compared with total mercury content in some of its prey species in Sweden. Environmental Pollution (series B) 5:297-318.

Long, E.R. 1982. Assessment of marine pollution in Puget Sound. Mar. Pollut. Bull. 13(11):380-382.

Malins, D.C., B.B. McCain, D.W. Brown, S.-L. Chan, M.S. Myers, J.T. Landahl, P.G. Prohaska, A.J. Friedman, L.D. Rhodes, D.G. Burrows, W.D. Gronlund, and H.O. Hodgins. 1984. Chemical pollutants in sediments and diseases of bottom-dwelling fish in Puget Sound, Washington. Environ. Sci. Technol. 18:705-713.

Malins, D.C., B.B. McCain, D.W. Brown, A.K. Sparks, H.O. Hodgins, and S.L. Chan. 1982. Chemical contaminants and abnormalities in fish and invertebrates from Puget Sound. NOAA Technical Memorandum OMPA 19. National Oceanic and Atmospheric Administration, Boulder, CO. 168 pp.

Manuwal, D.A., T.R. Wahl, and S.M. Speich. 1979. The seasonal distribution and abundance of marine bird populations in the Strait of Juan de Fuca and northern Puget Sound in 1978. NOAA Technical Memorandum ERL MESA 44. National Oceanic and Atmospheric Administration, Boulder, CO. 391 pp.

McCain, B.B., S.L. Chan, U. Varanasi, et al. 1988. Toxic chemicals in fish: effects on their health and reproduction. pp. 83-110 *In*: Puget Sound: issues, resources, status, and management. NOAA Estuary-of-the-month seminar series No. 8. National Oceanic and Atmospheric Administration, Washington, D.C.

Mearns, A.J., M.B. Matta, D. Simecek-Beatty, M.F. Buchman, G. Shigenaka, and W.A. Wert. 1988. PCB and chlorinated pesticide contamination in U.S. fish and shellfish: a historical assessment report. NOAA Technical Memorandum NOS OMA 39. National Oceanic and Atmospheric Administration, Seattle, WA. 140 pp.

Melvin, D.J. 1991b. Growing Areas Classification Report, North Bay. Prepared for Washington State Department of Health.

Melvin, D.J. 1991a. Growing Area Classification Report, Liberty Bay. Prepared for Washington State Department of Health.

Miller, B. S., L.L. Moulton, and J.H. Stadler. 1991a. Long term trends in Puget Sound Marine Fishes: an examination of selected data sets. Prepared for USEPA Region 10, Seattle, WA. 38 pp. EPA 910/9-91-010.

Miller, B.S., J.H. Stadler, and L.L. Moulton. 1991b. Long-term trends in Puget Sound marine fishes: an examination of selected data sets. In proceedings, Puget Sound Research '91. Puget Sound Water Quality Authority, Olympia, WA. Vol 1, pp 393-399.

Moore, R. N. 1990. Tenmile Creek Watershed Management Plan. 101 pp. Public hearing draft. May, 1990.

Mumford, T.F., D.J. Saul, J.A. Shaffer, A. Bailey, E. Calvert, and R.M. Thom. In preparation. Protocol for the characterization of Puget Sound nearshore habitats. Washington Department of Natural Resources, Olympia, Wa.

Municipality of Metropolitan Seattle (Metro). 1990. Water quality status report for marine waters 1989. Publication 171. 120 pp. + appendices.

Myers, M.S., L.D. Rhodes, and B.B. McCain. 1987. Pathologic anatomy and patterns of occurrence of hepatic neoplasms, putative preneoplastic lesions, and other idiopathic hepatic conditions in English sole (*Parophrys vetulus*) from Puget Sound, WA. Journal of the National Cancer Institute 78:333-363.

National Oceanic and Atmospheric Administration (NOAA). In press. 1990 National Shellfish Register of Classified Estuarine Waters. National Oceanic and Atmospheric Administration, Strategic Assessment Branch, Rockville, Maryland.

National Oceanic Atmospheric Administration (NOAA). 1991. Second summary of data on chemical concentrations in sediments from the national status and trends program. NOAA Technical Memboradum NOS OMA 59. 29 pp. + appendices.

National Oceanic Atmospheric Administration (NOAA). 1989. A summary of data on tissue contamination from the first three years (1986-1988) of the mussel watch project. NOAA Technical Memorandum NOS OMA 49. 22 pp. + appendices.

Nesbit, D.M. 1885. Tide marshes of the United States. Department of Agriculture miscellaneous special report No. 7. Washington, D. C.

Newby, T.C. 1973. Changes in the Washington state harbor seal population. Murrelet 54:4-6.

Newby, T.C. 1971. Distribution, population dynamics, and ecology of the harbor seal, *Phoca vitulina richardii*, of the southern Puget Sound, Washington. Masters of Science Thesis, University of Puget Sound, Tacoma, WA. 75 pp.

Nichols, F.H. 1988. Long-term changes in a deep Puget Sound benthic community: local or basin-wide? pp 65-71. In: Proceedings of the first annual meeting on Puget Sound research. Puget Sound Water Quality Authority, Seattle, WA.

Nielson, J. 1990. Status of anadromous game fish in Puget Sound. pp 93-107. *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.

O'Neill, S.M. and C. C. Schmitt. In preparation. Puget Sound Ambient Monitoring Program, 1989. A progress report of the fish monitoring program. Washington State Department of Fisheries.

O'Neill, S.M. and C.C. Schmitt. 1991. What contaminants are in our fish? In: Proceedings, Puget Sound Research '91. Puget Sound Water Quality Authority, Olympia, WA. Vol. 1, pp.192-207.

Osborne, R., J. Calambokidis, and E.M. Dorsey. 1988. A guide to marine mammals of greater Puget Sound. The Whale Museum and Island Publishers, Friday Harbor, WA. 191 pp.

Otterlind, G. 1976. The harbour porpoise (*Phocoena phocoena*) endangered in Swedish waters. Internation Council for the Exploration of the Seas C.M. 1976/N:16.

PTI Environmental Services. In preparation, a. Nutrients and phytoplankton: status of potential problems in Puget Sound. For U.S. Environmental Protection Agency Region 10, Seattle, WA.

PTI Environmental Services. In preparation, b. 1990 Puget Sound pesticide reconnaissance survey. For U.S. Environmental Protection Agency Region 10, Office of Puget Sound, Seattle, WA.

PTI Environmental Services. 1991a. Reconnaissance survey of chemical contamination and biological effects in southern Puget Sound. Prepared for U.S. Environmental Protection Agency Region 10, Office of Puget Sound, Seattle, WA. 75 pp. + appendices. EPA 910/9-90-025.

PTI Environmental Services. 1991b. Pollutants of Concern in Puget Sound. Prepared for U.S. Environmental Protection Agency Region 10, Seattle, WA. EPA 910/9-91-003. 107pp. + appendices.

PTI Environmental Services. 1989. Puget Sound dredged disposal analysis baseline survey of phase II disposal sites. Prepared for Washington Department of Ecology. 67 pp. + appendices.

PTI Environmental Services. 1988a. Briefing Report to the EPA Science Advisory Board. The Apparent Effects Threshold Approach. Prepared for U. S. Environmental Protection Agency. Seattle, WA. 56 pp.

PTI Environmental Services. 1988b. Puget Sound dredged disposal analysis baseline survey of phase I disposal sites. Prepared for the Washington Department of Ecology. 126 pp. + appendices.

PTI Environmental Services and Tetra Tech, Inc. 1988. Everett Harbor action program: analysis of toxic problem areas. Final report. Prepared for U.S. Environmental Protection Agency Region 10, Office of Puget Sound, Seattle, WA. 286 pp.

Paulson, A.J., T. Hubbard, H. Curl, R. Feely, T. Sample, and R. Swartz. 1989. Decreased fluxes of Pb, Cu and Zn from Elliott Bay. In: Proceedings of the 6th symposium on coastal management. Charleston, S.C., July 11-14, 1989.

Palsson, W.A. 1991. The status of Pacific cod (*Gadus macrocephalus*) in Puget Sound, WA. Washington Department of Fisheries, Technical Report

Puget Sound Water Quality Authority (PSWQA). 1991. 1991 Puget Sound Water Quality Management Plan. 344 pp.

Puget Sound Water Quality Authority (PSWQA). 1990a. Puget Sound update: first annual report of the Puget Sound Ambient Monitoring Program. Puget Sound Water Quality Authority, Seattle, WA. 89 pp.

Puget Sound Water Quality Authority (PSWQA). 1990b. Analyzing nonpoint source pollution in a Puget Sound watershed: a cooperative project using geographic information systems. Final report: geographic information system pilot project in Portage Creek. Puget Sound Water Quality Authority, Seattle, WA. 62 pp.

Puget Sound Water Quality Authority (PSWQA). 1988. Puget Sound Ambient Monitoring Program, Monitoring Management Committee. Final report. Puget Sound Water Quality Authority, Seattle, WA. 145 pp.

Puget Sound Water Quality Authority (PSWQA). 1986a. Issue Paper: Comprehensive Monitoring of Puget Sound. 34 pp + appendices.

Puget Sound Water Quality Authority (PSWQA). 1986b. Issue Paper: Nonpoint Source Pollution.

Reichel, W. L., S.K. Schmeling, E. Cromartie, T. E. Kaiser, A.J. Krynitsky, T. G. Lamont, B. M. Mulhern, R. M. Prouty, C.J. Stafford, and D. M. Swineford. 1984. Pesticide, PCB, and lead residues and necropsy data for Bald Eages from 32 states, 1978-81. Environmental Monitoring and Assessment 4:395-403.

Ribic, C.A., and G.L. Swartzman. 1989. Analysis of SUBASE Bangor heavy metal monitoring data. Final report prepared for U.S. Navy. 89 pp.

Rigg, G. B. 1915. The kelp beds of Puget Sound. Part 3. Pages 50-59. In: Cameron, F.K. Potash from kelp. U.S.D.A. report No. 100. Washington, D. C.

Riley, R.G., E.A. Crecelius, R.E. Fitzner, B.L. Thomas, J.M. Gurtisen, and N.S. Bloom. 1983. Organic and inorganic toxicants in sediment and marine birds from Puget Sound. NOAA Technical Memorandum NOS OMS 1. National Oceanic and Atmospheric Administration, Rockville, MD. 125 pp.

Romberg, G.P., S.P. Pavlou, R.F. Shokes, W. Hom, E.A. Crecelius, P. Hamilton, J.T. Gunn, R.D. Muench, and J. Minelli. 1984. Toxicant Pretreatment Planning Study technical report C1: Presence, distribution and fate of toxicants in Puget Sound and Lake Washington. Municipality of Metropolitan Seattle, Seattle, WA. 231 pp. and appendices.

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.

Salo, L.J. 1975. A baseline survey of significant marine birds in Washington state. Coastal Zone Environmental Studies Report No. 1. Washington Department of Game, Olympia, WA. 417 pp.

Schiewe, M.H., D.D. Weber, M.S. Myers, F.J. Jacques, W. L. Reichert, C.A. Krone, D.C. Malins, B.B. McCain. S-L. Chan, and U. Varanasi. In press. Induction of foci of cellular alteration and other hepatic lesions in English sole (*Parophrys vetulus*) exposed to an extract of an urban marine sediment. Can. J. Fish. Aquat. Sci.

Schmitt, C. 1990. Marine fish users and managers: How are we doing? pp 118-141. *In*: Armstrong, J.W. & A. E. Copping, eds. Status and Management of Puget Sound's Biological Resources. EPA 910/9-90-001 US Environmental Protection Agency, Seattle, WA.

Schmitt, C., S. Quinnell, M. Rickey, and M. Stanley. 1991. Groundfish statistics from commercial fisheries in Puget Sound, 1970-1988. State of Washington Department of Fisheries Progress Report No. 285.

Sekulich, P.T. 1990. Hood Canal salmon—a contemporary management issue in Puget Sound. pp. 108-117 *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.

Sequim Bay Watershed Management Committee. 1989. Sequim Bay Watershed Management Plan. Prepared for Clallam County Department of Community Development.

SNOMET. 1977. Snohomish County Metropolitan Municipal Corporation/King County 208 Areawide Water Quality Management Plan. Snohomish County Metropolitan Corporation/King County/City of Everett.

Speich, S.M., J. Calambokidis, R.J. Peard, D.M. Fry, and M. Witter. 1988. Puget Sound glaucous-winged gulls: biology and contaminants. pp.598-607 *In*: Proceedings of the first annual meeting on Puget Sound research. Puget Sound Water Quality Authority, Seattle, WA.

Speich, S.M., and T.R. Wahl. 1989. Catalog of Washington seabird colonies. Biological Report 88(6), OCS Study MMS 89-0054. U.S. Fish and Wildlife Service, Portland, OR. 510 pp.

Starry, A. 1990a. Totten and Little Skookum Inlets and watersheds 1987 - 1989, a water quality and remedial action report. Prepared for the Washington State Department of Ecology.

Starry, A. 1990b. Henderson Inlet and Watershed 1987-1989, a water quality and remedial action report. Prepared for Washington State Department of Ecology, Olympia, WA. 101 pp. + appendices.

Stick, K. 1990. Summary of 1989 pacific herring spawning ground surveys in Washington state waters. State of Washington Department of Fisheries Progress Report No. 280. 42 pp + appendices

Striplin, P., D. Davis, P. Sparks, F. Svendsen and S. Thompson. In preparation. Puget Sound Ambient Monitoring Program: Marine Sediment Monitoring Task, 1990 Annual Report. Prepared for the Environmental Investigations and Laboratory Services Program of the Washington State Department of Ecology.

Tetra Tech, Inc. 1990. Puget Sound ambient monitoring program 1989: marine sediment monitoring. Final report. Prepared for the Washington Department of Ecology. 262 pp. + appendices.

Tetra Tech, Inc. 1988a. Assessment of potential toxic problems in non-urban areas of Puget Sound. Prepared for U.S. Environmental Protection Agency, Seattle, WA. 172 pp.

Tetra Tech, Inc. 1988b. Characterization of spatial and temporal trends in water quality in Puget Sound. Prepared for U.S. Environmental Protection Agency, Seattle, WA. 396 pp.

Tetra Tech, Inc. 1988c. Sinclair and Dyes Inlets Action Program: Initial Data Summaries and Problem Identification. Prepared for U. S. Environmental Protection Agency, Seattle, WA. 193 pp. + appendices.

Tetra Tech, Inc. 1988d. Health risk assessment of chemical contamination in Puget Sound Seafood. Prepared for U.S. Environmental Protection Agency, Seattle, WA. 102 pp. + appendices.

Tetra Tech, Inc. 1988e. Pesticides of concern in the Puget Sound basin: A review of contemporary pesticide usage. Final Report. Prepared for U.S. Environmental Protection Agency Region 10, Office of Puget Sound, Seattle, WA. Tetra Tech, Inc. Bellevue, WA. 97 pp. + appendices.

Tetra Tech, Inc. 1985. Commencement Bay Nearshore/Tideflats Remedial Investigation. Volume I. Prepared for Washington State Department of Ecology, Olympia, WA, and U.S. Environmental Protection Agency, Seattle, WA.

Thom, Ron. Personal Communication. Battelle NW Lab. Sequim, WA. May, 1991.

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. 52pp + appendices.

Thom, R.M. 1978. The composition, growth, seasonal periodicity and habitats ofbenthic algae on the eastern shore of central Puget Sound, with special reference to sewage pollution. Ph.D. Dissertation, University of Washington, Seattle. WA.

Thom, R.M. and J. Hampel. 1985. Benthic resource assessment of Lincoln Park beach, Seattle, Washington. Final report to Seattle District, Corps of Engineers. Seattle. WA.

Turnock, B.J., S.J. Jefferies, and R.F. Brown. In press. Population abundance of harbor porpoise (*Phocoena phocoena*), from aerial surveys off the coast of Oregon, Washington, Strait of Juan de Fuca, and Vancouver Island. In: Kajimura, H. (ed). Harbor porpoise abundance and interaction with Makah salmon set-net fishery in coastal Washington waters, 1988-89. NOAA Technical Report.

URS, Inc. 1986. Comprehensive circulation and water quality study at Budd Inlet. Prepared for Washington Department of Ecology, Olympia, WA. 271 pp.

U.S. Environmental Protection Agency (EPA). 1991. Eagle Harbor remedial investigation/feasibility study, technical memorandum 13, task FI.FB marine biota tissue sampling and analysis. Project SEA 69104.DE.DE. 50 pp. + appendices.

Varanasi, U., S-L. Chan, B.B. McCain, J.T. Landahl, M.H. Schiewe, R.C. Clark, D.W. Brown, M.S. Myers, M.M. Krahn, W.D. Gronlund, and W.D. MacLeod, Jr. 1989. National benthic surveillance project: pacific coast, part II technical presentation of the results for cycles I to III (1984-85). National Oceanic and Atmospheric Administration (NOAA) technical memorandum NMFS F/NWC-170. 159 pp. + appendix.

Wahl, T.R., and S.M. Speich. 1984. Survey of marine birds in Puget Sound, Hood Canal and waters east of Whidbey Island, Washington, in summer 1982. West. Birds 15:1-14.

Wahl, T.R., S.M. Speich, D.A. Manuwal, K.V. Hirsch, and C. Miller. 1981. Marine bird populations of the Strait of Juan de Fuca, Strait of Georgia, and adjacent waters in 1978 and 1979. DOC/EPA Interagency Energy/Environment Research and Development Program Report, EPA 600/7-81-156. U.S. Environmental Protection Agency, Washinton D.C. 789 pp.

Washington State Department of Fisheries, 1988. 1988 Fisheries Statistical Report. Olympia, WA. 90 pp.

Washington State Department of Health. In preparation, b. Department of Health 1990 Technical Report Shellfish Tasks for Puget Sound Ambient Monitoring Program. Office of Shellfish Programs. Olympia, WA.

Washington State Department of Health. In preparation, a. Human Health Impact Assessment of the 1990 PSAMP Tissue Data. Office of Toxic Substances, Olympia, WA.

Washington State Department of Health. 1990. Third annual inventory of commercial and recreational shellfish areas in Puget Sound. 18 pp. + maps.

Washington State Department of Health. 1989. The effect of sewage discharges from pleasure craft on Puget Sound waters and shellfish quality. Shellfish Section, Washington Department of Health, Olympia, WA. 88 pp.

Webber, H.H., T. F. Mumford and J. Eby. 1987. Remote sensing inventory of the seagrass meadow of the Padilla Bay National Estuarine Research reserve: aerial extent and estimation of biomass. NOAA Tech Report. Series OCRM/MEMD. Washington, D.C.

Wiemeyer, S.N., D.M. Swineford, P.R. Spitzer, P.D. McLain. 1978. Organochlorine residues in New Jersey osprey eggs. Bulletin of Environmental Contamination and Toxicology 19:56-63.

Wiemeyer, S.N., R.W. Frenzel, R.G. Anthony, B.R. McClelland, and R.L. Knight. 1989. Environmental contaminants in blood of western bald eagles. Journal of Raptor Research 23:140-146.

Williams, T., and G.R. Graves. 1990. Puget Sound tribal fisheries management - a cooperative approach. pp 79-92. In: Armstrong, J.W. and A.E. Copping, eds. Status and Management of Puget Sound's Biological Resources. EPA 910/9-90-001. US Environmental Protection Agency, Seattle, WA.

Wolff, W.J. 1982. Status of marine mammals in the Wadden Sea area. pp.7-14. In: P.J. H. Reijnders and W. J. Wolff (eds.). Marine Mammals of the Wadden Sea. Final report of the Wadden Sea Working Group. Report 7.

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