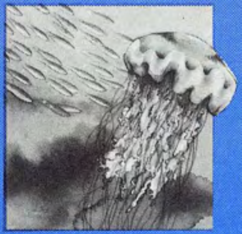
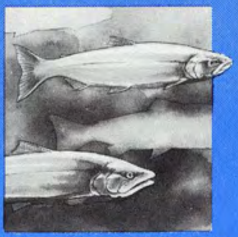
PUGET SOUND WATER QUALITY AUTHORITY

1992 Puget Sound Update

THIRD ANNUAL REPORT OF THE PUGET SOUND AMBIENT MONITORING PROGRAM





1992 Puget Sound Update

THIRD ANNUAL REPORT OF THE PUGET SOUND AMBIENT MONITORING PROGRAM

November 1992

Puget Sound Water Quality Authority
P.O. Box 40900
Olympia, Washington 98504-0900
(206) 493-9300 or
1-800-54-SOUND

ACKNOWLEDGMENTS

This report is a product of the PSAMP Steering Committee, the Monitoring Management Committee and the Puget Sound Water Quality Authority.

Written by Chris Prescott, Puget Sound Water Quality Authority
Edited and produced by Susanne Hindle
Illustrations by Joyce Bergen

The author wishes to thank the following people and organizations who contributed comments, advice and materials to this report.

John Armstrong, Ph.D., U.S. Environmental Protection Agency

Jennifer Cahalan, Washington Department of Fisheries

John Calambokidis, Cascadia Research Collective

Andrea Copping, Ph.D., Washington Sea Grant

Ken Dzinbal, Washington Department of Ecology

Lisa Eisner, Washington Department of Ecology

Stuart Glasoe, Puget Sound Water Quality Authority

Paul J. Harrison, Ph.D., University of British Columbia

Brad Hopkins, Washington Department of Ecology

Carol Janzen, Washington Department of Ecology

Bill Kammin, Washington Department of Ecology

Don Kraege, Washington Department of Wildlife

Frank Merriweather, Washington Department of Health

Mary Mahaffy, U.S. Fish and Wildlife Service

Brian Mar, Ph.D., University of Washington

Tom Mumford, Ph.D., Washington Department of Natural Resources

Dave Nysewander, Washington Department of Wildlife

Sandie O'Neill, Washington Department of Fisheries

Glen Patrick, Washington Department of Health

Vallana Piccolo, Puget Sound Water Quality Authority

Tim Ransom, Ph.D., Puget Sound Water Quality Authority

Cyreis Schmitt, Washington Department of Fisheries

Peter Striplin, Washington Department of Ecology

Curtis Tanner, U.S. Fish and Wildlife Service

Teresa Turk, Washington Department of Fisheries

Ron Thom, Ph.D., Battelle Northwest

Steve Tilley, Puget Sound Water Quality Authority

Michael Wheeler, Puget Sound Water Quality Authority

Bob Woolrich, Washington Department of Health

PSAMP STEERING COMMITTEE

John Armstrong, Ph.D., U.S. Environmental Protection Agency

Ralph Domenowske, Municipality of Metropolitan Seattle (Metro)

Ken Dzinbal, Washington Department of Ecology

Bob Woolrich, Washington Department of Health

Mary Mahaffy, U.S. Fish and Wildlife Service

Tom Mumford, Ph.D., Washington Department of Natural Resources

Dave Nysewander, Washington Department of Wildlife

Chris Prescott, Puget Sound Water Quality Authority

Carl Samuelson, Washington Department of Fisheries

This report has been funded in part by the United States Environmental Protection Agency under assistance agreement CE000493-01-0 to the Puget Sound Water Quality Authority. The contents of this document do not necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsements or recommendations for use.

TABLE OF CONTENTS

SUMMARY

The *1992 Puget Sound Update* is the third annual report of the Puget Sound Ambient Monitoring Program (PSAMP). It reports the results of sampling undertaken in 1991, the most current year for which the data have undergone analysis and quality assurance tests. PSAMP is a comprehensive, long-term monitoring program designed to assess the health of Puget Sound, its resources, and the impact of human activities on both. The program is a coordinated effort among six state and two federal agencies to measure sediment and water quality, population levels and contaminant concentrations in fish, shellfish, marine mammals, and birds, and the amount and types of nearshore habitats within Puget Sound.

PSAMP monitors ambient, or background, conditions in Puget Sound to evaluate the cumulative effects of contamination and habitat degradation. PSAMP is not designed to assess the effects of specific dischargers and so does not measure some of the most contaminated sites, which are located at nearshore areas in close proximity to pollution sources. These areas are monitored by other programs. PSAMP complements these programs by evaluating the degree to which the cumulative effects of numerous pollution sources are transported away from their discharges, affecting offshore sediment and water quality.

The 1991 monitoring results provide further evidence of problems detected in the first two years of PSAMP sampling, point to some new potential problem areas, and provide evidence of water quality improvements, particularly in the quality of fresh water entering Puget Sound.

Sediments. The 1991 sediment sampling results suggest that, with a few exceptions, the high levels of sediment contamination in the nearshore areas of urban bays and industrialized areas remain in the vicinity of their sources. While many nearshore areas exceed state sediment standards for metals and organic chemicals, Sinclair Inlet, Dyes Inlet, and Commencement Bay's City Waterway were the only ambient monitoring program sites that consistently violated state standards over the last three years.

Analyses of benthic communities at Sequim Bay suggest that an unidentified source of contamination is affecting this bay. Chemical analyses indicate that Sequim Bay had the highest levels of beta-coprostanol, a chemical frequently associated with sewage effluents. Wastewater treatment plant discharges, leaking septic systems, or waste from marinas are possible sources.

Marine Water. Sampling of Puget Sound's marine waters indicates that several areas have problems with fecal coliform contamination. Ambient stations in Commencement Bay, Oakland Bay, and Possession Sound exhibited

high fecal coliform levels in the last two years of sampling. Budd Inlet and Nisqually Reach had lower readings this year than in the previous year. West Point's 1991 readings were high compared to 1990 data.

Examination of the physical characteristics of the water column revealed a number of embayments that are susceptible to water quality problems due to stratification and poor mixing, which can lead to algal blooms and low dissolved oxygen levels. A number of semi-enclosed embayments, including most of Hood Canal and several south Sound bays, exhibited water column stratification, nutrient depletion, and algal blooms. These areas may be sensitive to human sources of nutrient discharges, which can produce excessive algal blooms and associated water quality problems.

Fish. English sole tissues sampled in 1991 revealed the presence of metals but few organic contaminants. Copper and mercury were found at levels comparable to 1989. Arsenic was found at slightly higher levels than in 1989, while lead was was found at lower levels. However, differences in the average size of fish sampled in 1989 and 1991 affect the comparison of contaminant levels between the two years. Future sampling will determine whether observed changes are due to natural variation or real changes in exposure to contaminants.

Evaluations of potential health impacts indicate that none of the contaminant concentrations in English sole muscle tissues (the part consumed by humans and marine mammals) pose significant human health threats from regular consumption of Puget Sound fish. Contaminant levels did appear to be affecting the health of English sole within several urban bays, however. Analyses of liver tissues revealed high levels of liver abnormalities in Commencement Bay, Elliott Bay, and Eagle Harbor.

Shellfish. Shellfish harvesting is regulated according to fecal coliform bacteria levels in marine water. High levels of fecal coliform have rendered many productive shellfish areas in Puget Sound unharvestable. The amount of shellfish acreage closed to harvest or threatened with closure because of bacterial contamination has increased dramatically in recent years. 1991 PSAMP results indicate no improvement in fecal contamination of shellfish at Belfair County Park and at Dosewallips and Walker state parks, sites with historically high levels of fecal coliform. The results also suggest that Penrose Point—which has highly variable levels of fecal coliform and is presently open to recreational harvest—may be experiencing increased levels of contamination. To date, few beds closed to harvest have ever been reopened.

Shellfish harvesting is also affected by naturally occurring marine biotoxins, one of which is PSP (paralytic shellfish poisoning). PSP remains a perennial threat to shellfish harvesting, yet the patterns of PSP outbreaks are largely unpredictable. PSP outbreaks were less frequent in 1991 than in previous years—only three sites (Sequim Bay, Agate Pass, and East Sound at Orcas Island) had PSP levels warranting closure.

Contaminants, such as heavy metals, in marine sediments where shellfish grow can also influence shellfish harvestability. Contaminant concentrations in Puget Sound shellfish at the sites sampled for PSAMP were similar

to levels measured in the previous year and did not appear high enough to pose a threat to human health. The low levels may be due to the fact that shellfish sampling stations are located away from immediate sources of contamination. Shellfish living near pollutant discharges could have much higher levels.

Marine Mammals. Results of 1991 marine mammal monitoring conducted by Cascadia Research in Puget Sound suggest that:

- There has been a decrease in the level of PCBs in harbor seals over the last 20 years.
- A disproportionately high number of the whales that enter Puget Sound die within several months, though data are too limited to determine if contaminants within the Sound are responsible.
- Harbor porpoises, once found throughout the Sound, are now limited to northern Puget Sound, possibly due to increasing disturbance from a growing human population.

The Washington Department of Wildlife, which recently received funding for PSAMP activities, plans to enhance monitoring efforts by increasing the frequency and coverage of population censuses and by providing additional funds for monitoring contaminants in marine mammals. This should greatly increase our knowledge of population sizes, movement patterns, and contaminant levels in marine mammals.

Birds. Eggshells from great blue herons and glaucous-winged gulls are significantly thinner when compared to eggshells measured in 1947. Eggshell thinning is often observed in birds exposed to pesticides. The cause of this thinning is not known, since none of the contaminants measured were found at levels associated with eggshell thinning.

The U.S. Fish and Wildlife Service is initiating studies on contaminant levels in pigeon guillemots and surf scoters in Puget Sound. The results of these studies will be reported in future Updates.

Nearshore Habitat. The Washington Department of Natural Resources (DNR) is in the first year of mapping the amount and types of nearshore habitat in Puget Sound. Nearshore habitats are highly productive areas that play crucial roles in nearly every element of the Puget Sound ecosystem. Puget Sound has suffered extensive losses of nearshore habitat. The DNR inventories will help to assess the extent of these losses and provide habitat maps valuable in addressing a number of resource management issues.

Invasion by *Spartina* is a growing threat to nearshore habitats. This species of cordgrass is native to east coast estuaries where it is considered a desirable part of the wetlands ecosystem. In the Puget Sound region, however, *Spartina* crowds out many native northwest plant and animal species and alters the physical characteristics of nearshore habitats. *Spartina* invasion is most advanced in Willapa Bay, but is also present in a number of Puget Sound sites.

Fresh Water. The rivers within the Puget Sound basin vary widely in water quality. Some, such as the Skagit, Nisqually, and Skokomish rivers, have excellent water quality and rarely violate state water quality standards. Others, such as the Sammamish and Puyallup rivers, are heavily degraded by human activities and regularly violate state standards.

Fecal coliform is the freshwater parameter that most frequently violated state standards in Puget Sound rivers. Sources of fecal coliform include sewage treatment plants, failing septic systems, combined sewer overflows, and runoff from agricultural activities. Temperature was the second most frequently violated standard. High temperatures in rivers often result when streamside vegetation is cleared, exposing the water to more sunlight. Improved management practices in forestry, agriculture, and land development—the most frequent causes of streamside clearing—may be required to reduce these violations.

Pollution control efforts within the Puget Sound basin appear to be having a number of positive effects. Removal of the Renton treatment plant outfall from the Green River resulted in dramatic water quality improvements. In addition, a number of rivers showed significant improvements in water quality parameters over the last 10 years. Turbidity, which results from the erosion of uplands and stream banks, decreased significantly in a number of rivers. Decreases in turbidity may be the result of reduced soil disturbance or improved retention of soil in disturbed areas, such as clearcuts and construction sites. Nutrients also decreased significantly in several rivers, which may be the result of improved agricultural practices which reduce fertilizer runoff.

Improvements in the water quality of rivers within the Puget Sound basin are probably having positive effects on the freshwater habitats, but it is not known whether these improvements are reflected by an increase in the quality of Puget Sound waters. Rapid population growth in the Puget Sound area over the last 10 years has dramatically increased pollutant inputs from point and nonpoint sources. These increases have probably masked improvements in freshwater inputs.

INTRODUCTION

WATER QUALITY PROBLEMS WITHIN PUGET SOUND

In the Puget Sound region, our way of life and economic well-being hinge on the health of the Sound. As the population of the region continues to grow, as more land is developed for urban uses, and as more resources are harvested to support a growing population, the quality of the basin's water decreases. Increasing demands on the Sound's resources are resulting in overuse and abuse—the very lifestyle and activities supported by Puget Sound also threaten it. Unless we take steps to minimize the impacts of continuing growth, the delicate balance on which Puget Sound's health depends, and around which we have built our lifestyles, is threatened.

Many natural components of Puget Sound already reflect the effects of poor planning and overuse. Forty percent of commercial shellfish bed acreage has been restricted from harvest because of fecal contamination. Three bays within Puget Sound contain Superfund sites due to chemical contamination of sediments from past industrial practices. Development of waterfront property has severely reduced the amount of nearshore habitat (salt marshes and kelp and eelgrass beds). These highly productive areas play important roles in nearly every element of the Puget Sound ecosystem, so that losses of nearshore habitat have impacts throughout the Sound. Many areas, such as the Puyallup, Duwamish, and Samish river deltas, have lost nearly all of their nearshore habitat to development.

A number of other problems are becoming increasingly critical. Several fisheries stocks are threatened. Many south Sound bays are experiencing water quality problems. Some bird populations may be stressed from the loss of nesting areas and chemical contamination.

THE IMPORTANCE OF MONITORING

It is important that we document the extent of water quality and habitat problems for several reasons:

- To identify the most serious problems, so that corrective actions can be focused effectively and efficiently.
- To evaluate the results of corrective programs.
- To identify emerging problems before they become critical, so that solutions are less expensive and difficult.
- To determine whether the health of Puget Sound is improving or declining over time.

As the human population of the Puget Sound area continues to grow, increasing pressures will be placed on the Sound's resources. A comprehensive measure of the present health of the Sound is necessary to provide baseline data for evaluating the effects of future growth. It is important that these measures are repeated over time, so the data provide an accurate assessment of how conditions in the Sound are changing. The Authority developed the Puget Sound Ambient Monitoring Program (PSAMP) in response to these needs.

WHAT IS PSAMP?

PSAMP monitors elements of the Puget Sound ecosystem that might be affected by chemical contamination or physical destruction of habitat and resources. PSAMP is an ambient monitoring program—it is designed to assess the cumulative effects of human activities and natural biological and physical changes on the overall health of Puget Sound resources. It does not assess the effects of individual sources of contamination in localized areas. Thus many of the most contaminated sites in Puget Sound—industrial ports, municipal and industrial discharge sites, and the nearshore areas of urban bays—are not sampled by PSAMP. These sites are monitored by programs linked to permit requirements for dischargers and site-specific studies. Water quality conditions and potential sources of contamination in these areas are documented in the *1992 Statewide Water Quality Assessment (305(b) Report)* (Ecology, 1992). PSAMP complements these sampling programs by monitoring areas located away from individual sources and on a wider geographic scale. This type of monitoring provides information on how these individual sources interact to affect broader areas of the Sound.

To provide a comprehensive evaluation of Puget Sound, PSAMP monitors eight major components of the natural environment: sediments, marine water column, freshwater inputs, nearshore habitat, fish, shellfish, birds, and marine mammals. Six agencies are charged with monitoring these components: the Washington state departments of Ecology, Fisheries, Health,

Monitoring Puget Sound's health

Environmental sampling and chemical analyses are expensive. Monitoring programs are inevitably faced with tradeoffs between comprehensive coverage of the area they are trying to characterize—which requires many samples to accurately depict variations over space and time—and budget limitations on the number of samples that can be collected. PSAMP scientists use different sampling schedules in an attempt to balance these factors. The different schedules include:

Fixed stations, which are sampled every year. Fixed stations are generally chosen to represent the average conditions within a given area. Thus they may be centrally located within an embayment or located in a well mixed zone where levels of contamination tend to be uniform. Fixed stations may also be chosen because they can provide vital information on a regular basis. An example of this occurs in sediment monitoring, where there are two fixed stations within Commencement Bay due to the high levels of sediment contamination there.

Rotating stations, which are sets of stations that are sampled on a rotating basis. The Sound is divided into north, central, and south sections. Sampling is cycled between the sections, so that rotating stations within each section are sampled for one year out of every three. In 1991, rotating stations were located in north Puget Sound.

Floating stations, which are stations that are sampled for a short period of time and that may or may not be sampled again. These stations are generally used to answer specific, short-term questions, to provide more information for interpreting the data from core and rotating stations, or to investigate emerging water quality problems. Few floating stations have been sampled by PSAMP due to funding constraints.

Task	Rationale for Sampling	Agency
Sediment quality Sediment chemistry Bioassays Benthic invertebrates	Site of contaminant buildup	Ecology
Marine water column Long-term trends Known water quality problems Algal growth	Water quality changes	Ecology
Fish Tissue chemistry (bottomfish) Liver histopathology (bottomfish) Tissue chemistry (cod, rockfish, salmon)	Fish health and human health assessment; accumulation of contaminants in the ecosystem	Fisheries
Shellfish Abundance Bacterial contamination Tissue chemistry Paralytic shellfish poisoning	Human health assessment; water quality assessment; accumulation of contaminants in the ecosystem	Health & Fisheries
Birds Abundance Tissue chemistry	Ecosystem indicator	Wildlife & USFWS
Marine mammals	Ecosystem indicator	Wildlife
Nearshore habitat Area and type	Inventory and health of habitat	Natural Resources
Fresh Water	Input of contaminants to Puget Sound	Ecology

Table 1. Description of full PSAMP design.

Natural Resources, and Wildlife, and the U.S. Fish and Wildlife Service (Table 1). The Puget Sound Water Quality Authority coordinates the program and data management and produces reports of program results.

PSAMP collects data on each of the eight components using consistent methods over time, as outlined in the *Puget Sound Protocols and Guidelines* (PSEP, 1991). These data will be used to assess the condition of Puget Sound. As successive years of data are collected, PSAMP scientists will analyze whether conditions are improving or deteriorating in each component of the Puget Sound ecosystem. This will allow resource managers to focus corrective actions where they are most needed, evaluate the effectiveness of corrective actions already in place, and identify emerging problems so they can be addressed before they become serious and expensive to treat.

This report summarizes the results of 1991 sampling efforts contained in technical reports written by PSAMP implementing agencies and from other monitoring reports and programs. The technical reports contain more detailed information about the specific monitoring program elements and are available from the implementing agencies (see *Contact List*, page 67). More extensive background about PSAMP and the Puget Sound ecosystem is provided in the first two Puget Sound Updates (PSWQA 1990, 1991). The policies and status of environmental programs designed to protect Puget Sound are described in the Authority's *1992 State of the Sound Report* and the *1991 Puget Sound Water Quality Management Plan*.

Other environmental sampling efforts under way within Puget Sound include:

Puget Sound Dredged Disposal Analysis (PSDDA). This project collects data on the chemical composition and toxicity of sediments at dredged material disposal sites.

Discharger monitoring in receiving waters. Some sewage treatment plants and industrial dischargers, as part of their discharge permit requirements, must monitor water and sediment quality in the water bodies to which they discharge. Metro (Municipality of Metropolitan Seattle) and LOTT (Lacey, Olympia, Tumwater, and Thurston County) wastewater treatment plants conduct regular monitoring in the water bodies into which they discharge.

National Status and Trends (NS&T). As part of a nationwide program, NOAA (the National Oceanic and Atmospheric Administration) collects and analyzes bottomfish, sediment, and shellfish from several sites in Puget Sound once a year. NOAA investigators compare the results among regions of the country.

Comprehensive Environmental Response, Compensation, and Liability Act Program (CERCLA). The U.S. Environmental Protection Agency (EPA) collects data as part of the evaluation and cleanup of hazardous materials at Superfund sites.

Washington Department of Ecology surveys. Ecology conducts intensive surveys of areas with conventional and toxic contamination problems in water and sediments.

Washington Department of Health sampling. Health samples marine waters for fecal coliform bacteria to determine contamination of shellfish growing areas.

In addition, local health departments, environmental consulting firms, universities, aquariums, environmental groups, and citizen groups participate in efforts to measure environmental quality. These efforts vary widely in their monitoring methods, spatial coverage, and the time periods over which they are conducted.

PSAMP tracks the results of some of the larger programs, which are normally reported in the annual Puget Sound Update. Many of these programs, such as PSDDA, NS&T, and CERCLA, however, did not have available data collected since the last Update. Results from these programs will be presented in the *1993 Puget Sound Update.*

SEDIMENT QUALITY

BACKGROUND

Below the waters of Puget Sound, a mixture of sand, gravel, and mud—known as sediments—blankets the estuary floor. Sediments provide food and shelter for many marine plants and animals. Because these plants and animals often form the foundation of the marine food web, clean bottom sediments are essential to Puget Sound's entire ecosystem.

Streams and rivers constantly wash new sediments from eroding shorelines and upland areas into the Sound. As these sediments settle to the estuary floor, pollutants in the water—particularly metals and organic chemicals—cling to the particles of sand and silt before currents can carry them out of the estuary. Particles washed into the Sound by stormwater runoff, combined sewer overflows, and other discharges are often already contaminated with toxic chemicals. Consequently, many pollutants ultimately end up in the sand and mud below the Sound's surface. Because most sediments never leave the estuary, these contaminants are usually trapped on the Sound's bottom. Bottom-dwelling organisms, such as worms, shellfish, and bottomfish, absorb the contaminants as they live and feed in, on, or near the sediments. Other animals are exposed to contaminants when sediments are stirred up by dredging or by other animals as they feed or burrow, as the water in contact with the sediments becomes contaminated, or as they feed upon contaminated organisms within the sediments.

Scientists consider the buildup of toxic contaminants in sediments a sign of environmental degradation resulting from human activities. It is important that we monitor sediments to track levels of contamination, assess how contaminants affect resident organisms, and evaluate whether contamination is increasing or decreasing.

The Sediment Triad

To accurately evaluate sediment quality, scientists use two biological measurements—toxicity tests and bioassessments—to complement chemistry tests. Scientists use all three for a comprehensive and accurate evaluation of sediment quality, called the sediment triad (Chapman & Long, 1983).

While chemical measurements effectively identify which pollutants contaminate sediments, they possess limitations that biological methods can overcome. First, it is impossible to analyze a sample for every chemical in the environment, even if cost were not a factor. Second, chemical analyses cannot predict interactions that may occur between chemicals. Two chemicals that are relatively harmless by themselves may produce toxic effects when combined. Third, some chemicals are extremely expensive and technically difficult to quantify. Fourth, some chemicals, such as dioxin, produce toxic effects at or below levels which chemists can routinely detect.

Biological tests overcome these limitations by evaluating the cumulative effect that all chemicals within a sample or location have on resident marine life. Toxicity tests expose sensitive organisms to sediments under controlled laboratory conditions. A relative measure of sediment toxicity is provided by comparing the sampling results of these organisms to the characteristics of organisms exposed to uncontaminated control sediments.

Bioassessments evaluate the biological communities found in sediments at a given site. Scientists can determine the effects of contamination in an area by the number and variety of benthic animals present, taking into consideration the influence of natural variations, such as depth, sediment grain size or the amount of organic matter present. If the numbers of organisms are low or if a community that naturally favors abundant or diverse communities is dominated by only a few species, it is inferred that toxic contamination is responsible for these conditions.

The disadvantage of biological methods is that biological systems naturally have wide variations. This makes it difficult to tell the difference between pollutant effects and biological variability unrelated to pollution.

SEDIMENT CONTAMINATION IN PUGET SOUND

Toxic compounds, including heavy metals and organic chemicals, pose the greatest threat to sediment quality in Puget Sound (PTI 1991a). Some heavy metals, such as lead, copper, and mercury, occur naturally in the environment in low concentrations. Problems arise when discharges from municipal and industrial facilities, stormwater runoff, improper chemical handling procedures, and spills add high concentrations of metals that damage the Puget Sound ecosystem. Naturally occurring metals can also become more harmful when they come into contact with other chemicals in the sediments; the resulting compound is often more toxic than the original contaminant. When arsenic combines with oxygen, for example, inorganic arsenic—a human carcinogen—forms.

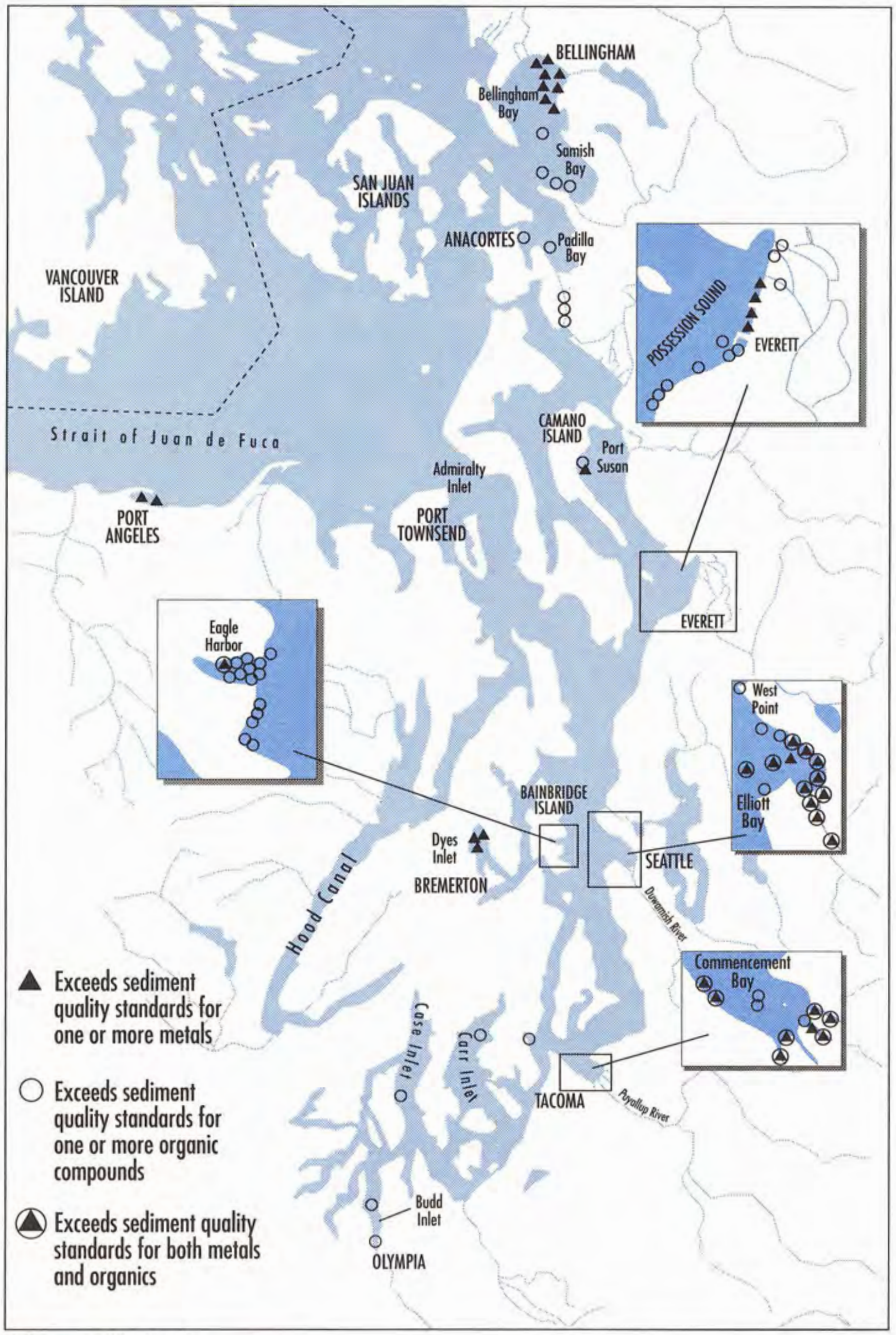
Some organic compounds may also occur naturally, such as petroleum hydrocarbons. Others, such as PCBs (polychlorinated biphenyls) and DDT (dichloro diphenyl trichlorethane), are human-made compounds that occur in the marine environment solely as a result of industrial production. Discharges of toxic organic chemicals that result from human activities may greatly exceed the ability of the Sound to accommodate these products, resulting in harm to the marine environment. Highly toxic in small amounts, certain organic compounds threaten organisms because they bioaccumulate, meaning that they may increase in concentration as they are passed up the food web (Woodwell et al., 1967; Young et al., 1980).

Washington state established Sediment Management Standards (WAC 173-204) in 1991 to protect sediment quality. These standards define maximum allowable concentrations of 47 metals and organic chemicals within sediments in Puget Sound. The standards were derived through extensive analyses of field and laboratory studies of the toxic effects of chemicals on benthic (sediment-dwelling) organisms.

PSAMP SEDIMENT MONITORING DESIGN

PSAMP scientists sample sediments located away from known pollution sources in order to obtain a comprehensive evaluation of changes in sediment contamination over time. Many nearshore sites and urban bays are severely contaminated and fail state sediment standards for metals and organic chemicals (PSWQA, 1992b) (Figure 1). By design, PSAMP does not measure the conditions within some of these most seriously affected portions of the Sound—areas where stormwater runoff, sewage and industrial facilities, and other sources discharge into urban bays. PSAMP measures the cumulative effect of numerous sources and the degree to which they contaminate areas beyond their immediate point of entry into the Sound.

Programs such as EPA's Superfund Program and the Department of Ecology's Urban Bay Action Program collect information about sediment quality at contaminated areas shown in Figure 1. They also identify areas for cleanup and monitor sediment quality at sites where cleanup has occurred, pollution sources have been reduced, or where contaminated sediments have been capped with clean sediments. Areas within Elliott Bay, Commencement Bay, and Eagle Harbor, for example, have been declared Superfund sites by EPA because of high levels of toxic chemicals in their sediments.

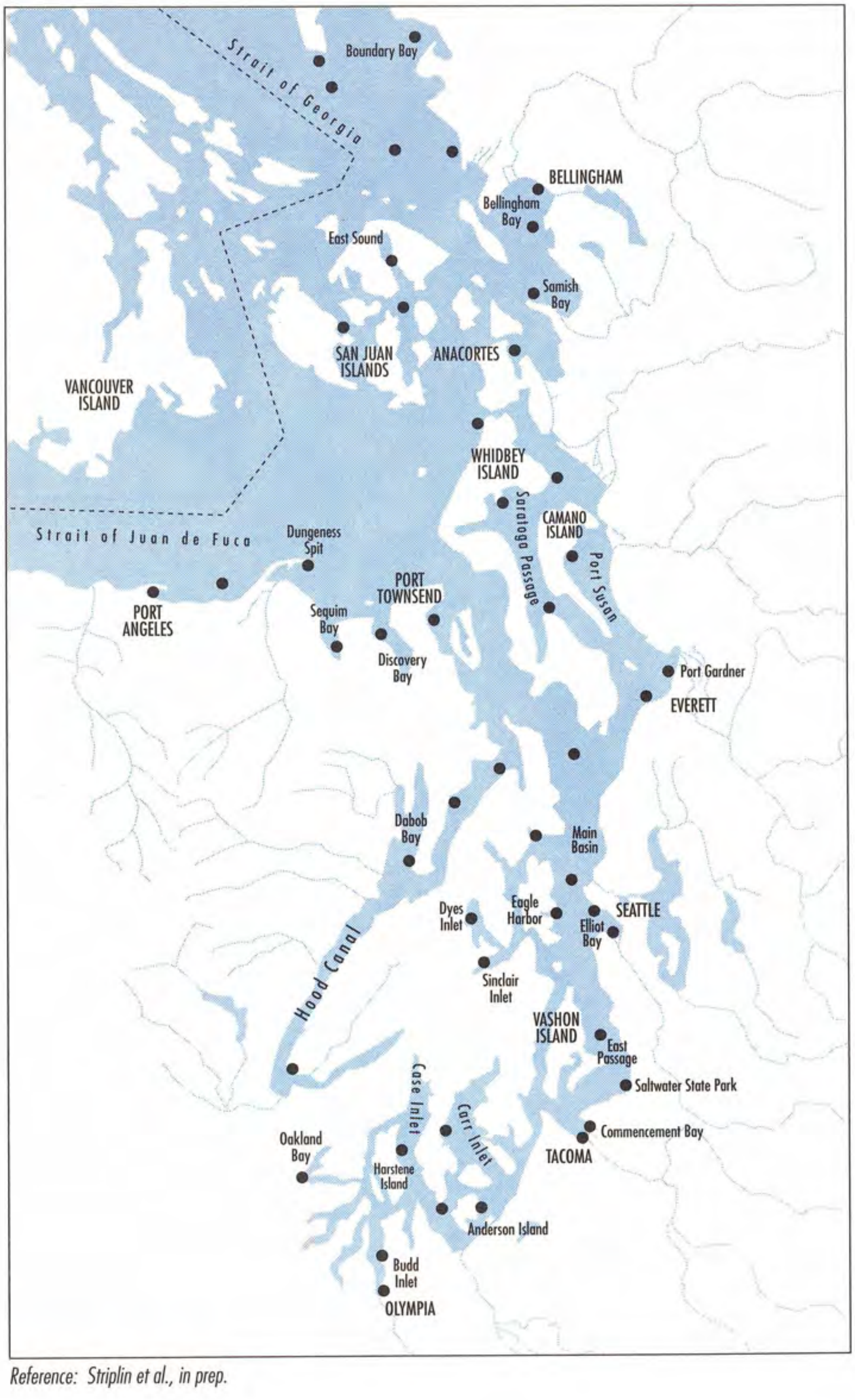


Reference: PSWQA, 1992b

Figure 1. Severe organic and metal contamination of sediments in nearshore areas and urban bays is monitored by programs other than PSAMP.

PSAMP requires three tests that measure the quality of surface marine sediments: *chemical analyses* of the concentrations of heavy metals and organic chemicals in the sediment sample, *toxicity tests* to evaluate the toxic effects of contaminated sediments on laboratory organisms, and *bioassessments* to identify the numbers and types of animals (benthic invertebrates) in the sediment. The combined results of these tests provide an overall measure of sediment quality (see *Sediment Triad*, page 10, for details).

Figure 2. PSAMP sediment sampling stations.



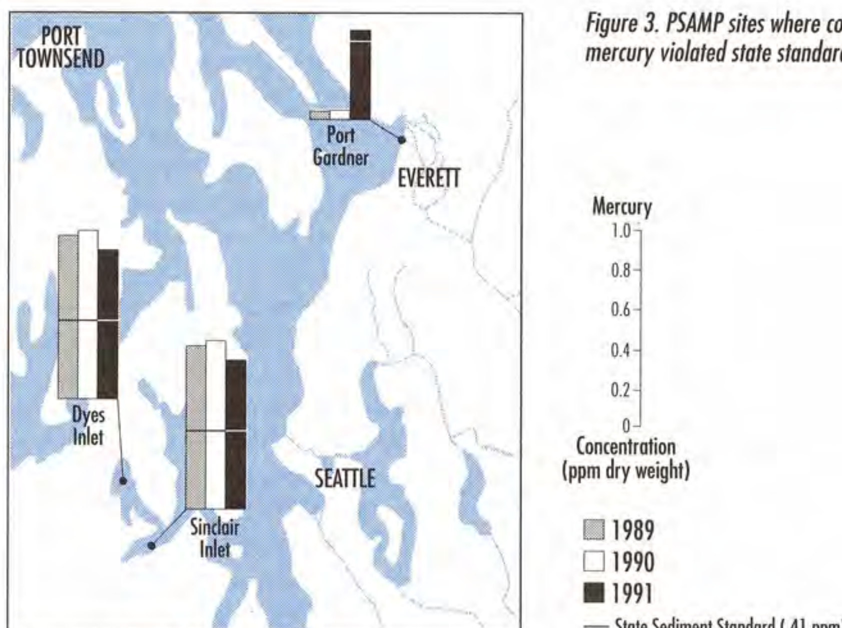
Reference: Striplin et al., in prep.

Scientists sample only surface sediments (the top two centimeters) to focus on the most recent contamination. Each sediment sample is processed and shipped to laboratories for analyses of toxic chemicals, toxicity tests, and counts of benthic invertebrates.

Ecology scientists collect surface sediments at 48 stations throughout Puget Sound each year (Figure 2). Thirty-four of these are fixed stations that are sampled each year. The remaining 14 are rotating stations that are sampled once every three years (see *Monitoring Puget Sound's health*, page 6, for a description of station types). 1991 rotating stations were located in northern Puget Sound. Most samples were collected at stations where water was approximately 20 meters deep; a few were collected from the deep basins of the Sound (approximately 100 to 250 meters deep).

RESULTS OF 1991 SEDIMENT CHEMISTRY

Ecology scientists found measurable levels of toxic metals at all PSAMP sites in 1991 (Striplin et al., in preparation). Mercury was the only metal that exceeded state sediment standards (under the state standards, mercury cannot exceed 0.41 parts per million). Mercury levels exceeded state standards at three sites—Sinclair Inlet (0.74 ppm), Dyes Inlet (0.54 ppm), and Port Gardner (0.48 ppm). Sinclair and Dyes inlets also had high mercury levels in 1989 and 1990 (Figure 3), indicating a chronic mercury contamination problem. Although Port Gardner had low levels of mercury in previous years, the 1991 level was almost 10 times the average of the previous two years. Future sampling will determine whether the high levels reflect an isolated hot spot or whether the contamination is widespread and new sources of mercury caused the dramatic increase. Mercury contamination can result from discharges from a wide range of industrial processes, including the manufacture of chlorine and sodium hydroxide, which are used by paper mills (Bothner, 1973); metals processing; mining and ore production; and from the disposal of industrial and domestic products, such as thermometers and batteries. In its organic form, mercury is highly toxic to aquatic organisms and can damage the brain, kidneys, and developing fetuses in humans.

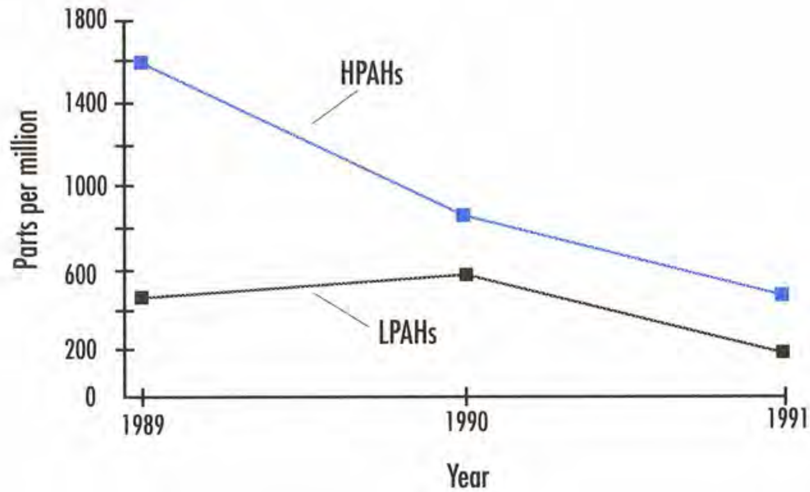


Reference: Striplin et al., in prep.

Figure 3. PSAMP sites where concentrations of mercury violated state standards in 1991.

All other metals were well below state sediment standards. Lead levels, though below state standards, were elevated in some urban and industrialized bays. In Elliott Bay, Sinclair Inlet, and Dyes Inlet, lead levels were two to three times higher than concentrations at other sites. Lead has a wide

Figure 4. PAH levels in City Waterway (Commencement Bay).



Reference: Striplin et al., in prep.

variety of sources, including batteries, auto emissions, and leaded gasoline. Lead is a common component of urban and highway runoff. No other metals appeared to have elevated concentrations at urban or industrial sites.

Ecology scientists found toxic organic contaminants at all 48 PSAMP sites. None, however, exceeded state sediment standard levels. PAH (polynuclear aromatic hydrocarbon) levels were noticeably lower at Commencement Bay's City Waterway than in previous years, when they were measured in excess of state sediment standards (Figure 4). Scientists have defined two types of PAHs. The first, LPAHs (low molecular weight PAHs), are found in high concentrations in petroleum fuel and oil, and in wood preservative products such as creosote. The second, HPAHs (high molecular weight PAHs), are produced during the combustion of petroleum products. The effects of human exposure to PAHs are not well understood, however they are believed to cause cancer and to produce immunological and reproductive effects (PTI, 1991a). Sediment standards for organic chemicals are defined relative to the amount of organic carbon within sediments, to better predict biological effects. LPAH levels at City Waterway measured 201 ppm on an organic carbon basis in 1991 compared to the 521 ppm average of the previous two years. The state sediment standard for LPAHs is 370 ppm on an organic carbon basis. HPAHs measured 500 ppm, compared to an average of 1,279 ppm for 1989 and 1990. The state standard for HPAHs is 960 ppm. These lower levels at City Waterway may reflect either actual decreases in PAH contamination or sampling variability. Because PAHs are measured on an organic carbon basis, measurements may vary widely due to fluctuations in the amount of organic carbon within the sediments.

Despite apparent PAH decreases, analyses of other organic compounds indicate that City Waterway has the most serious organic contamination problem of the sites sampled. Of the 66 organic compounds analyzed at PSAMP locations, one-third of these (23) had their highest concentrations in City Waterway sediments.

RESULTS OF 1991 SEDIMENT BIOLOGY

Bioassessments—the evaluation of benthic communities—during 1991 showed a connection between low species diversity and sediment contamination, especially at Sequim Bay, which is located along the Strait of Juan de Fuca.

Sequim Bay's biological community is characteristic of contaminated sediment conditions. Its benthic species diversity is the lowest of all PSAMP sites sampled—only three species were found in the sediment samples at Sequim Bay. This is less than one-tenth of the diversity measured in Commencement Bay, which had the second lowest diversity.

Chemical analyses of Sequim Bay's sediments support the link between low species diversity and contamination. The bay has the highest concentration of beta-coprostanol (800 µg/kg), a chemical produced by the bacterial breakdown of cholesterol in mammals. Beta-coprostanol is not generally toxic by itself, but it is frequently associated with sewage effluent and pollution from nonpoint sources such as leaking septic systems, and is therefore indicative of pollutant inputs (Murtaugh & Bunch, 1967; Kirchmer, 1971). Since this was the first year for which Sequim Bay was sampled, conclusions cannot yet be drawn (the Sequim Bay monitoring site is a rotating station). Results from the chemical and bioassessment analyses point to possible contamination by a sewage source, such as runoff from failing septic tanks, untreated discharges from boats, or a municipal sewage outfall. However, sampling by the departments of Health and Ecology does not indicate high levels of fecal coliform bacteria or low levels of dissolved oxygen in the water column, both of which usually occur at sites contaminated with untreated sewage. PSAMP scientists will conduct more intensive analyses during 1993 in an attempt to identify the sources of the observed biological effects.

The highest values for beta-coprostanol from the previous two years occurred at Blair/Sitcum Waterway in Commencement Bay, which is adjacent to one of Tacoma's sewage outfalls (Figure 5). The level of beta-coprostanol has decreased dramatically during the three years of sampling at Blair/Sitcum Waterway. This may be due to improvements in wastewater treatment or

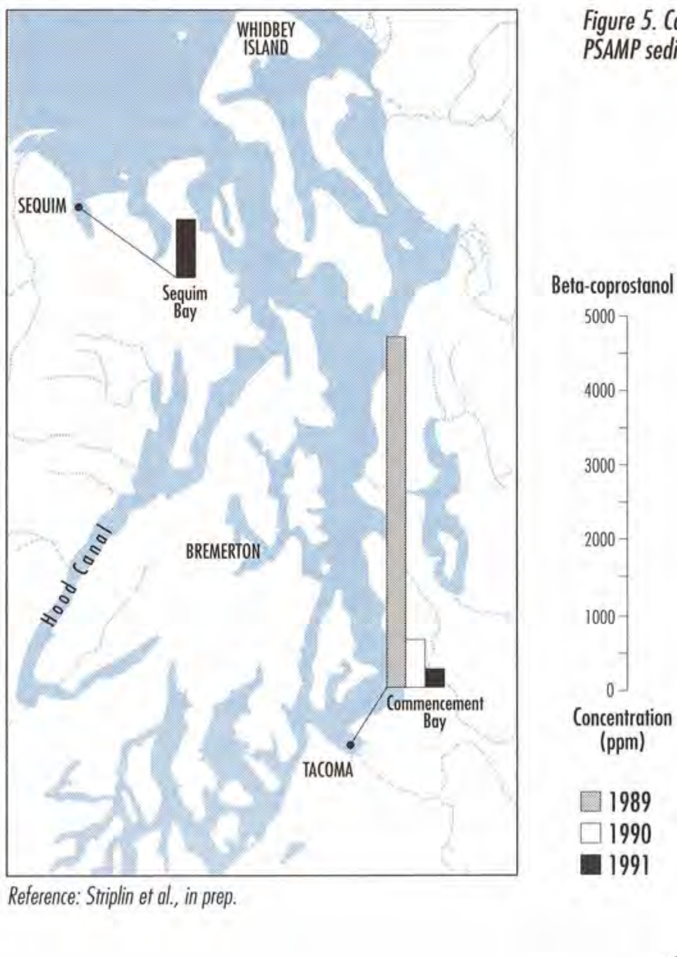


Figure 5. Concentrations of beta-coprostanol in PSAMP sediment samples.

Reference: Striplin et al., in prep.

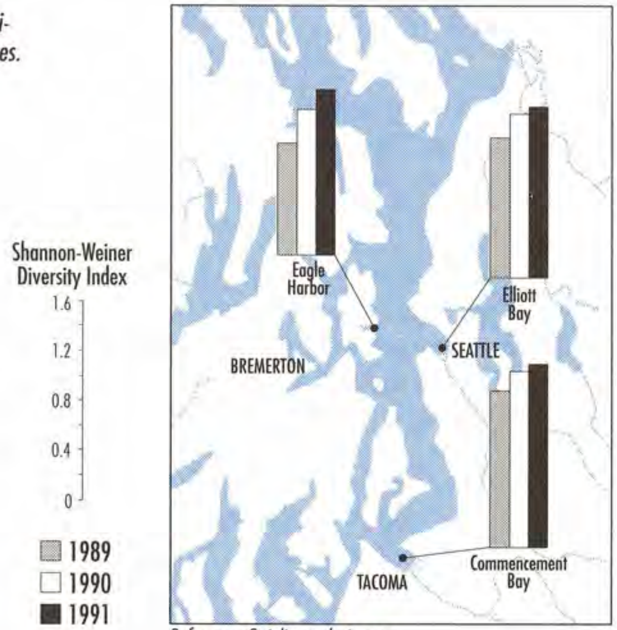


Figure 6. Diversity levels at contaminated PSAMP sediment sampling sites.

Reference: Striplin et al., in prep.

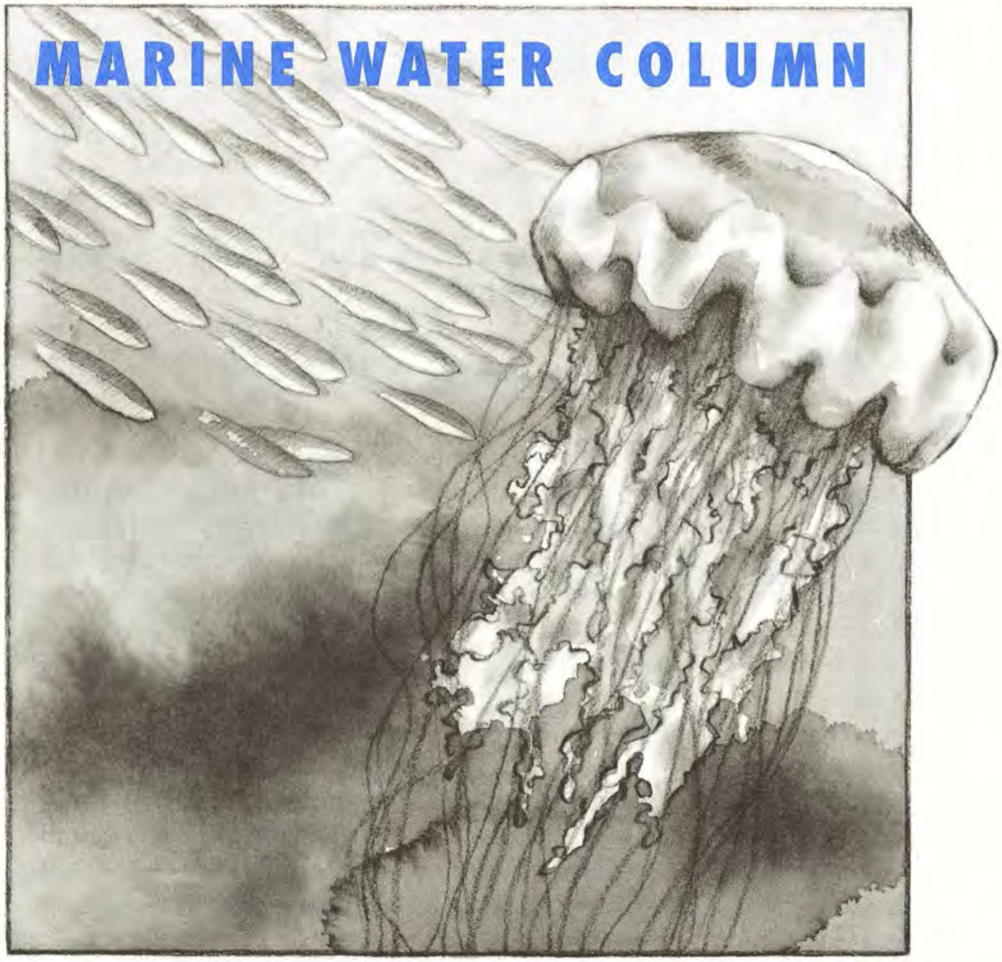
reductions in the number of combined sewer overflows.

The biological communities at this site also reflect contaminated sediment conditions. The Blair/Sitcum Waterway has one of the lowest diversity values in Puget Sound, yet it also has the highest abundance (total number of individual animals=1,694 ind./m^2) of all the sites. This condition frequently occurs in areas affected by organic enrichment, from sources such as sewage outfalls. Poor water or sediment quality resulting from sewage discharges creates conditions unfavorable to most marine life, allowing a few species which can tolerate organic enrichment to dominate. Such species (including certain species of marine worms and mollusks) often utilize organic matter as a food source, especially near sewage outfalls where high levels of organic matter support large populations. Blair/Sitcum Waterway's four most abundant species are all pollution-tolerant.

Three PSAMP sites showed statistically significant increases in the diversity of benthic organisms over the last three years of sampling: Eagle Harbor, Elliott Bay, and City Waterway in Commencement Bay (Figure 6). These contaminated sediment sites have low diversity values and are dominated by pollution-tolerant organisms. The rise in diversity is due to increases in the number of species found at each site and to decreases in the abundance of the pollution-tolerant species that dominate these sites. While the increase in diversity has been small, it does indicate that biological communities may be improving, possibly in response to cleanup efforts at each site.

Although biological tests help to provide answers that chemical tests can not, the limitations inherent in biological methods were evident in 1991 toxicity tests. Contaminated sediments showed few significant differences in toxicity when compared to uncontaminated control samples, due in part to the high variability of the results and the limited sample size. Sediments from several sites had significantly higher mortality rates, but when the effect of sediment grain size was accounted for (some species have a higher mortality rate when sediment grain size is small) the PSAMP station just outside of Oak Harbor was the only site with statistically significant toxicity levels. It is possible that this is a result unrelated to toxic contaminants. The chemistry test results do not point to any obvious cause for this toxicity, since the levels of measured contaminants were not high.

MARINE WATER COLUMN



BACKGROUND

The marine water column, which includes water from bottom sediments to the water surface, is a vital part of the Puget Sound ecosystem. Within the water column grow microscopic free-floating algae, known as phytoplankton, which provide an energy base which fuels much of the Sound's ecosystem. Through photosynthesis, phytoplankton convert the sun's energy into food for other marine life.

Puget Sound's water column is among the most productive in the world. Birds, fish, marine mammals, and humans all find abundant food in the Sound's waters. The quality of the water column is crucial because of its central role in so many of the Sound's activities. Water quality degradation has widespread detrimental effects on the Sound's ecology and on our ability to use its resources and take advantage of its recreational opportunities.

The physical characteristics of Puget Sound—and of toxicants—make it more difficult for pollution to affect the water column than other parts of the basin, such as sediments and shellfish beds. Many toxic chemicals bind to particles, which settle out of the water and onto the basin floor. The pollutants that remain in Puget Sound's open waters are diluted by the tidal exchange of water within the basin and with the Pacific Ocean via the Strait of Juan de Fuca. For this reason, Puget Sound's open waters do not experi-

How fecal coliform bacteria are monitored

PSAMP fecal coliform monitoring sites are located away from nearshore discharge sites in order to assess overall, ambient bacterial contamination in Puget Sound. The Washington Department of Ecology collects one sample a month at each site for an estimate of bacterial contamination. Because only one sample a month cannot accurately assess fecal contamination, Ecology does not use PSAMP data to determine areas that violate state standards for fecal coliform bacteria. Additionally, fecal coliform measurements vary greatly and require 15 or more replicate samples at each site for accurate estimates. Such intensive sampling would greatly increase the cost of the Puget Sound Ambient Monitoring Program. The Washington Department of Health conducts more detailed sampling of nearshore areas in conjunction with shellfish growing waters analyses. If Ecology's monthly sampling indicates that a site has consistently high readings, the Department of Health conducts more intensive sampling in the vicinity.

ence large-scale algal blooms, fish kills, beach closures, and fisheries bans that occur in many estuaries around the world.

However, Puget Sound's marine water column is not immune to the effects of pollution. Semi-enclosed bays (such as Oakland Bay in the south Sound) are easily degraded because water exchange is limited in those areas. Highly polluted industrial areas (such as Commencement Bay) and areas where nonpoint sources of pollution are prominent (such as parts of Hood Canal) are experiencing water quality degradation.

PSAMP WATER COLUMN MONITORING DESIGN

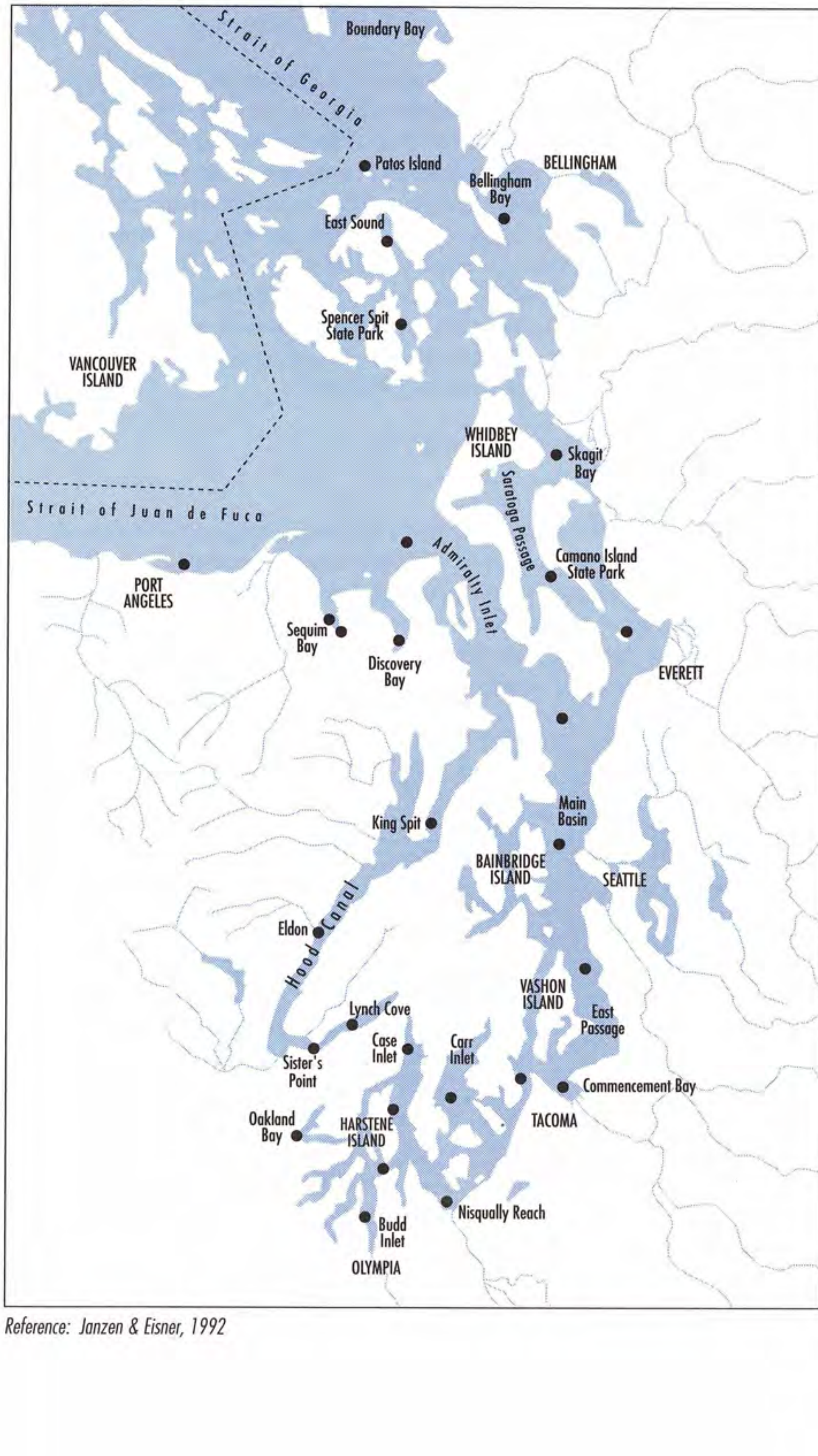
PSAMP scientists measure several variables in the water column to determine the quality of water and its susceptibility to potential problems. Temperature and salinity help scientists evaluate water column stability and the movement of water and dissolved contaminants. Dissolved nutrients and oxygen—essential for plant and animal life—provide information necessary to determine whether excess nutrients, such as nitrates, nitrites, and ammonia, are present. Chlorophyll *a* and phaeopigment levels (two pigments contained in algal cells) indicate the concentration of living and dead algae. Fecal coliform bacteria are monitored to detect fecal contamination which may include pathogens from human and other animal wastes (PSWQA, 1988). PSAMP investigators measure these water quality variables at stations in the open basins and in urban and rural bays and inlets to ascertain conditions throughout the Sound. Toxic contaminants, such as heavy metals and organics, are not sampled in the water column since they generally bind to sediments and thus are present in very low concentrations in the water column (except in extreme cases, such as near an industrial discharge point).

Ecology investigators sampled water column conditions at 13 core stations and 15 north Sound rotating stations in 1990 and 1991 (Figure 7). The results described in this report include 12 months of sampling that overlap two calendar years (Ecology schedules its sampling based on a water year, which runs from October of one year to the following September).

FECAL CONTAMINATION OF PUGET SOUND WATERS

Fecal coliform bacteria, which originate from human and animal waste, pose an increasing threat to the use of Puget Sound's resources. While these bacteria are generally not harmful, they indicate the possible presence of other pathogens, such as bacteria and viruses which can cause diseases such as typhoid, cholera, and hepatitis in humans. Fecal bacteria are monitored because they are easier and less expensive to measure than the pathogens with which they are associated. Fecal coliform bacteria usually appear when human or animal waste is improperly managed and discharged into the water. Fecal coliform bacteria also appear when large amounts of marine mammal feces are present, in places such as harbor seal haulout sites. Fecal bacteria and their related pathogens can render Puget Sound resources, such as shellfish, unacceptable for human consumption.

In the past, Puget Sound's largest source of fecal contamination came from municipal sewage discharges. Improved treatment technologies, the chlorination of sewage, and the enforcement of discharge permits have significantly decreased bacterial contamination from sewage (Tetra Tech, 1988). With the exception of combined sewer overflows during heavy rains and mechanical breakdowns, municipal and industrial sources seldom cause severe fecal contamination problems (Tetra Tech, 1988). However fecal contamination is still a problem. The bacteria now originate from a variety of



Reference: *Janzen & Eisner, 1992*

Figure 7. PSAMP marine water column sampling sites.

smaller sources that are more difficult to control, mainly because they involve the dispersed, daily activities of a growing population. Sources such as urban stormwater runoff, poorly managed animal wastes, sewer overflows, discharges of untreated waste from boats and marinas, and failing septic systems contribute to the Sound's increasing fecal contamination problem. The most serious fecal contamination usually occurs after heavy rains, when high levels of runoff carry bacteria from agricultural and urban areas and upland septic systems to the Sound.

FECAL COLIFORM IN 1990–1991 PSAMP STATIONS

High fecal coliform readings were measured at Possession Sound, Commencement Bay, and Oakland Bay stations during the 1990–1991 PSAMP monitoring (Table 2). These sites, which also had high counts in 1989 and 1990, may have chronic problems from fecal contamination sources, such as stormwater runoff and combined sewer overflows in Commencement Bay and Possession Sound, and failing septic systems or other nonpoint sources of pollution in Oakland Bay. Contamination at other PSAMP stations varied from previous years. Levels measured in the main basin, near the West Point sewage treatment plant outfall, were higher than in 1989-1990. Budd Inlet and Nisqually Reach, which had several high readings in 1989-1990, exhibited lower fecal coliform levels in 1990-1991.

ALGAL BLOOMS IN PUGET SOUND

Nutrients, such as nitrates, nitrites, ammonia, and phosphate compounds, are a normal and necessary part of the Puget Sound ecosystem. Under certain conditions, excess nutrients can enhance the growth of phytoplankton, resulting in excessive algal blooms. When these blooms die, they decompose and deplete dissolved oxygen, causing water quality problems, especially in the slow moving waters of semi-enclosed bays. Phytoplankton also

Table 2. Violations of state fecal coliform standards in Puget Sound.

	1990 Water Year											1991 Water Year								
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Sep.
Commencement Bay	●	●	●	●				●	●			●		●		●	●			
Oakland Bay		●	●		●									●	●				●	●
Possession Sound		●				●	●	●		●				●		●	●			
West Point												●		●		●				
Budd Inlet		●	●					●					●		●					
Nisqually Reach		●	●	●				●		●	●							●		
Bellingham Bay												●								
Skagit Bay																	●			●
Admiralty Inlet												●					●			●
Tacoma Narrows																				
Case Inlet																				

Months with • violated marine fecal coliform standard (14 f.c./100ml). No violation in months without •. Reference: Janzen & Eisner, 1992

deplete oxygen from the water at night when they switch from photosynthesis, which produces oxygen, to respiration, which consumes oxygen. Low levels of dissolved oxygen can harm aquatic life and, under severe conditions, result in fish kills and foul odors from decomposing plants and animals.

Phytoplankton require three conditions to flourish: a stable water column, abundant sunlight, and a sufficient supply of nutrients. Scientists track these conditions carefully to identify areas that are susceptible to uncontrolled algal blooms caused by excess nutrients. These three conditions are generally controlled by nature, although excess nutrient levels can often be traced to human activities. Sewage, failing septic systems, and runoff from animal waste and fertilizer on lawns and farms add excess nutrients to the water.

In a stable water column, bottom water does not mix with surface water. This condition—stratification—favors algae growth because phytoplankton can remain near the surface where sunlight is most abundant. A deep, well-mixed water column, on the other hand, constantly circulates phytoplankton below the sunlit layers so that less growth occurs. Stratification usually occurs in areas with minimal flushing and when less saline fresh water overlays denser salt water (salinity stratification) or warmer water overlays colder, denser water (thermal stratification). Semi-enclosed bays generally exhibit stratification during the summer.

Seasonal variations in sunlight, the depth of phytoplankton within the water column, and water clarity affect the amount of sunlight phytoplankton receive. Day length and the intensity of sunlight are greatest at the summer solstice (around June 21) and least at the winter solstice (around December 21). In certain estuaries, algal populations may reflect these variations, reaching their highest abundance at the summer solstice, as has been shown for the main basin of Puget Sound (Anderson et al., 1984). Algal populations tend to bloom more often when the availability of sunlight is higher; in late spring, summer, and early fall. In highly stratified bays, blooms may occur as early in the year as January (Copping, 1982).

Human activities greatly influence the third condition necessary for phytoplankton growth—nutrients. Puget Sound is a very productive area that naturally supports abundant populations of phytoplankton. Nutrients are supplied to support this productivity by the mixing of nutrient-rich bottom waters with surface waters and through the flows of fresh water from rivers and streams into Puget Sound. Nitrogen compounds in sewage discharges and fertilizer runoff from lawns and farms greatly add to the natural supply of nutrients, which can lead to excessive algal blooms and related water quality problems. Once an algal bloom begins, phytoplankton may grow so rapidly that even high levels of nutrients in the water column are depleted. Scientists look for nutrient depletion as evidence of algal activity and possible sensitivity to additional nutrient inputs from human activities.

Monitoring the Sound's waters

Sampling water at different times provides a complete picture of the dynamics and water quality problems within the marine water column. Three different sampling schedules provide a fairly complete characterization of the quality of the Sound's water column.

Long-term monitoring. This involves sampling at a limited number of open water stations once a month to evaluate long-term water quality trends. Because the open basin stations represent background water quality conditions in Puget Sound, they are located away from shorelines, often in mid-channel and away from the influence of known pollution sources.

Seasonal monitoring. Many localized water quality problems occur on short time scales and are best detected through seasonal monitoring, which involves intense sampling during times of the year when water quality problems are most likely to develop. Algal blooms may develop and subside in less than a month. Fecal coliform bacteria may thrive after a storm event, but die off within a week. While these problems may be of short duration, their effects can persist for some time. Because frequent monitoring is expensive, sampling is focused on the most likely times for problems to develop, and on a few select bays each year. Seasonal monitoring began in the spring of 1992 at Budd, Sinclair, and Dyes inlets. Results of these studies will be available in the next Puget Sound Update.

Solstice Monitoring. The third component of water column monitoring—solstice monitoring—estimates the amount of phytoplankton produced within each bay sampled. Analyzing dissolved nutrients, algal biomass (chlorophyll), sunlight (incident radiation), and phytoplankton species composition for two weeks before and after the winter and summer solstices (around December 21 and June 21) may help predict the maximum and minimum amount of algae that can be expected in a given area (Anderson et al., 1984). Armed with such information, managers can take long-term source control actions, such as amending wastewater permits or relocating poorly sited discharges. Solstice monitoring is scheduled to begin the winter of 1992-1993.

1990–1991 WATER COLUMN CONDITIONS

Stratification. The most noticeable stratification occurred in the 1990–1991 Hood Canal stations, due primarily to the confined nature of this water body, its great depth, and freshwater inputs. Hood Canal exhibited salinity stratification for much of the year and thermal stratification during the summer months. The north Hood Canal station at Bangor showed only weak stratification, probably due to greater mixing with waters from the Strait of Juan de Fuca. Many south Sound bays were also stratified. Budd, Carr, and Case inlets were thermally stratified during the summer. Salinity stratification appeared in Budd Inlet and Oakland Bay during the winter and spring, presumably as a result of higher freshwater discharges during heavy rains.

Bays fed by large rivers often display salinity stratification, particularly in the winter and spring when flows of fresh water are highest. In summer, when rainfall is low, salinity stratification may weaken or disappear. Commencement Bay, Skagit Bay, Possession Sound, and Nisqually Reach exhibited salinity stratification through part or all of the 1990 winter and 1991 spring. Some areas, such as Commencement Bay and Possession Sound, were thermally and salinity stratified in summer. Most of the stations located in the main basin, in open areas of north Sound, or in areas with strong tidal currents showed little or no stratification. Tacoma Narrows, East Pas-

Table 3. Surface nutrient (NO_2–NO_3) depletion in Puget Sound.

	1991						
	March	April	May	June	July	August	September
Admiralty Inlet/Protection Island							
West Point							
Possession Sound		●	●	●	●	●	●
Saratoga Passage		●	●	●	●	●	●
Skagit Bay					●	●	
Admiralty Inlet/Point No Point			●				●
Bellingham Bay				●	●		●
Nisqually Reach							
Budd Inlet/Olympia at Shoal Horn			●	●	●	●	●
Commencement Bay			●				
Carr Inlet/Green Point			●	●	●	●	●
Case Inlet/S. Heron Island			●	●	●	●	●
Case Inlet/Rocky Point							
Discovery Bay at Mill Point	●		●	●	●	●	●
Dana Passage/Brisco Point							
East Passage/Three Tree Point			●	●	●	●	
East Sound/Rosario		●	●	●			
St. Georgia/Patos Island							
Hood Canal/Eldon			●	●	●	●	●
Hood Canal/Sisters Point	●		●	●	●	●	●
Hood Canal/King Spit	●		●		●	●	
Hood Canal/Inner Lynch Cover	●		●	●	●	●	●
Strait of Juan de Fuca/Sequim Bay		●		●	●	●	●
Sequim Bay/Goose Point							
Lopez/Decatur Island				●			
Tacoma Narrows/Pt. Defiance							
Oakland Bay/Eagle Point			●	●	●	●	
Port Angeles/Morse Creek							

Nutrients depleted (.040 or less mg/l NO_2–NO_3) in months with •. No nutrient depletion in months without •.
Reference: Janzen & Eisner, 1992

sage, West Point, Admiralty Inlet, the Straits of Georgia, and the Strait of Juan de Fuca (near Port Angeles) did not appear to stratify in 1991.

Nutrient Depletion. Ecology scientists look for nutrient depletion as a sign of algal activity and to identify areas that may be sensitive to additional nutrient inputs. Because algal growth can be limited by low nutrient levels, phytoplankton in nutrient depleted areas rapidly use up any additional nutrients that result from human activities. If the nutrient supply is great enough, this may cause excessive blooms.

Nitrogen was depleted at over half the Puget Sound stations sampled during the 1991 water year (Table 3). Possession Sound, Saratoga Passage, Hood Canal, Discovery Bay, and several south Sound bays were depleted for the greatest periods of time. Depletion typically occurred during the summer months, when phytoplankton growth was greatest.

Algal Blooms. Ecology scientists found elevated chlorophyll *a* concentrations indicative of algal blooms at several stations throughout the Sound (Table 4). Many south Sound bays displayed elevated chlorophyll *a* concentrations during the summer. Algal blooms were detected in Budd, Carr, and Case inlets and at Dana Passage and Nisqually Reach. Oakland Bay was the only south Sound station without a noticeable summer algal bloom, though it is probable that blooms occurred between monthly samples or at depths not

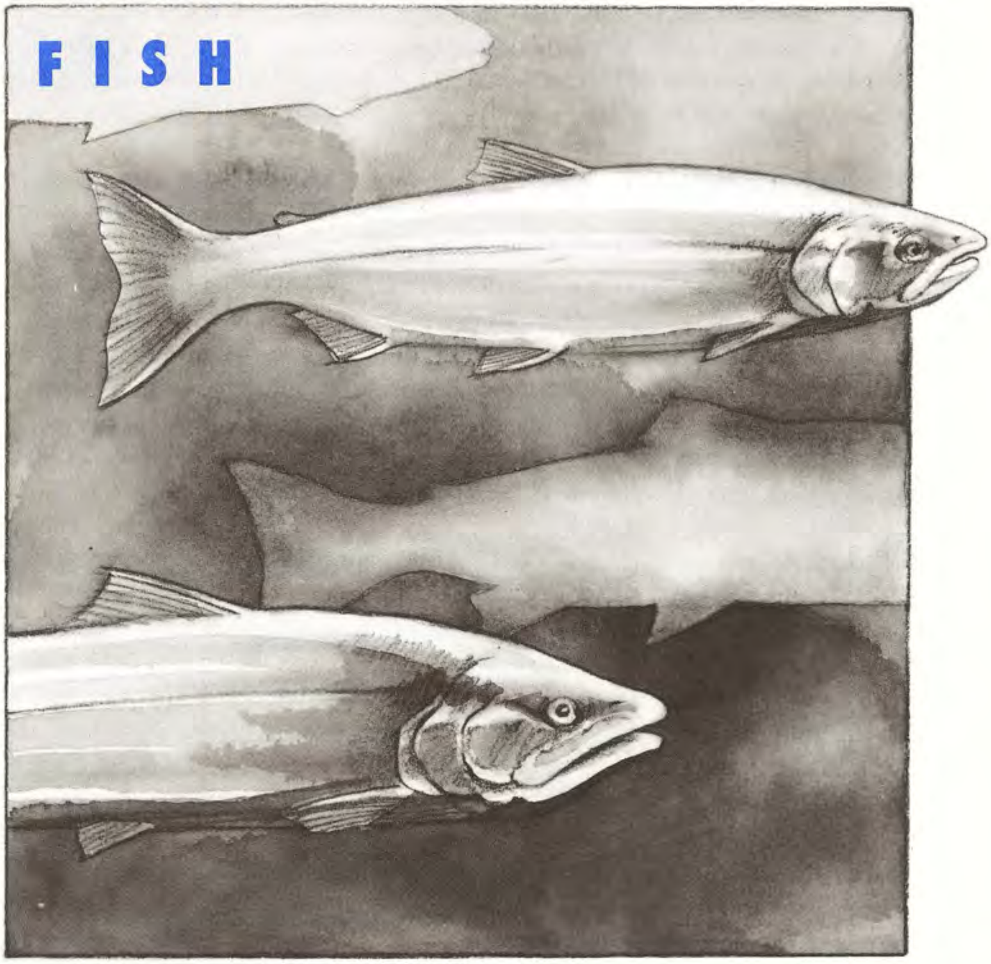
Table 4. Algal blooms in Puget Sound during 1991 PSAMP monitoring.

	1991							
	Feb.	March	April	May	June	July	August	Sept.
Admiralty Inlet/Protection Island								
West Point				•		•		
Possession Sound			•	•				
Saratoga Passage								
Skagit Bay			•					
Admiralty Inlet/Point No Point			•	•		•		
Bellingham Bay					•			
Nisqually Reach				•				
Budd Inlet/Olympia at Shoal Horn				•				
Commencement Bay						•		
Carr Inlet/Green Point				•	•		•	
Case Inlet/S. Heron Island			•	•	•	•	•	
Case Inlet/Rocky Point								
Discovery Bay at Mill Point		•		•				
Dana Passage/Brisco Point				•			•	
East Passage/Three Tree Point		•		•	•	•		
East Sound/Rosario			•	•	•			
St. Georgia/Patos Island								
Hood Canal/Eldon					•			
Hood Canal/Sisters Point		•				•	•	
Hood Canal/King Spit	•			•	•	•		
Hood Canal/Inner Lynch Cover	•				•	•		
Strait of Juan de Fuca/Sequim Bay		•	•		•			
Sequim Bay/Goose Point								
Lopez/Decatur Island					•			
Tacoma Narrows/Pt. Defiance								
Oakland Bay/Eagle Point				•			•	
Port Angeles/Morse Creek								

• = >5 µg/l chlorophyll a. Algal blooms not detected at time of sampling in months without •.
Reference: Janzen & Eisner, 1992

sampled. High chlorophyll *a* concentrations were measured in Hood Canal at King Spit near the mouth of Hood Canal, at Sister's Point near the Great Bend, and in Lynch Cove. These results indicate that Hood Canal is susceptible to algal blooms. Algal blooms also appeared in East Sound at Orcas Island, in Discovery Bay, and in some open water locations, including the main basin near West Point, Admiralty Inlet near Point No Point, and East Passage.

FISH



BACKGROUND

Fish provide us with more than a profitable fishing industry and steady food supply—they also provide valuable information about the health of Puget Sound. More than 220 different types of fish spawn, live, and feed in the sediment, nearshore marshes, fresh waters, and open waters of Puget Sound. The health of these fish reflects the condition of their habitats. The poor health of many of the Sound's fish indicates that problems exist. Fisheries biologists see the effects of pollution reflected as tumors and reproductive problems among fish. Anglers notice there are fewer fish to be caught, mainly due to habitat degradation and destruction and to overfishing.

Documenting the extent of these problems, and their underlying causes, is not easy. Fish populations undergo natural variations from year to year based on such factors as rainfall, water temperature, weather patterns, abundance of food, and losses to predation. Human activities also affect fish populations. Sedimentation and stormwater runoff caused by forestry, agriculture, and development activities degrade and destroy streamside and nearshore habitat. Dams and other structures block fish passage to spawning and feeding grounds. Pollutants in the water and sediments may cause fish tumors and reproductive problems. Overfishing can drastically reduce fish populations. There is also evidence that as wild stocks of salmon dwindle, they are gradually replaced by growing numbers of hatchery-reared

salmon. Hatchery-reared fish may be less adapted to local conditions than the wild salmon which naturally occur there (Hindar et al., 1991). The increasing proportion of hatchery-reared fish may result in weakened stocks with lower genetic diversity.

Indian tribes and the Washington Department of Fisheries (Fisheries) work together to protect and manage fish populations while allowing for a reasonable harvest by commercial fishermen and recreational anglers. Their efforts to determine the cause of declines in fish populations are often hindered by a lack of conclusive information, leaving them with no choice but to close fisheries, reduce seasons, and limit the number of commercial fishing licenses. These actions respond to the problem but do not address the underlying causes. Effective protection of fish will require more information on the status and health of Puget Sound fish stocks and habitats, and on the levels of contaminants found in fish tissue.

Although differing methods of catching and sampling fish and changing natural conditions make it difficult to determine long-term trends in fish stocks, recent results indicate that the condition of some marine fish populations is declining. For example, declining lingcod and walleye pollock populations have joined the ranks of other stocks considered to be in poor condition. Only flatfish and dogfish populations appear to be healthy (Table 5) (Schmitt, 1990, personal communication).

Table 5. Current stock abundance and recent trends for the major groundfish species in Puget Sound.

Species	Condition*	Trend*
Flatfish	Healthy	Stable
Pacific Cod	Low	Declining
Pacific Whiting	Low	Stable
Sunperch	Low	Stable
Walleye Pollock	Low	Stable
Lingcod	Low	Declining
Rockfish	Unknown	Unknown
Dogfish	Healthy	Declining

Healthy—Fish populations for which there are no serious resource conservation concerns. Localized population depletions may occur, but the overall population is in good condition. Harvest regulations are designed to maintain these populations.

Low—Fish populations for which there are conservation concerns. Harvest regulations are designed to rebuild these populations.

Healthy populations with *declining* trends—Fish populations which are presently healthy, but for which recent declines in abundance merit closer attention. Conservation measures and harvest regulations may be necessary in the near future to maintain these stocks in healthy condition.

** Stock conditions and trends are based on the best professional judgement of fisheries experts, using long-term results of commercial and recreational catches and population assessments.*

PSAMP FISH MONITORING

In order to provide an overall measure of the health of Puget Sound fish, PSAMP scientists collect information not systematically gathered by other groups. This includes contaminant levels in fish, the effects of contaminants on fish, and the potential effects on humans who eat fish (PSWQA, 1988). The Department of Fisheries, tribes, fishing organizations, and others collect

information on the population levels of marine and anadromous fish in Puget Sound. The designers of PSAMP chose not to duplicate these efforts, so fish abundance data are not collected by the Puget Sound Ambient Monitoring Program.

English sole, a type of flatfish that lives on the Sound's bottom, are monitored for several indicators of contamination because they live in contact with sediments and may accumulate toxics. PSAMP scientists examine English sole for certain liver conditions as a measure of the health of the fish. Tissue contaminant levels are measured to assess the accumulation of pollutants in the marine food web. Scientists also examine the threat to human health from eating English sole (PSWQA, 1988).

To provide a broad overview of fish contamination, PSAMP investigators also measure contaminants in five other types of fish that are caught recreationally and commercially. The species monitored are copper and quillback rockfish, chinook and coho salmon, and Pacific cod. Each of these fish feed on different organisms, and thus provide information about different pathways by which contaminants accumulate.

Rockfish, which can live for more than 30 years, generally confine themselves to one area of the Sound and can provide information about localized accumulation of toxic chemicals. The longevity of rockfish ensures that contaminants known to accumulate in fish will tend to show up in their muscle tissues. Contaminants in Pacific cod—shorter-lived fish which swim throughout the basin but do not migrate into the open ocean—reflect conditions that the fish may encounter throughout the Sound rather than in a localized area. In past studies, Pacific cod were found to contain higher levels of arsenic and PCBs (polychlorinated biphenyls) than other Puget Sound fish (Landolt et al., 1987). Salmon, which migrate to the open ocean and may accumulate contaminants from sources outside of Puget Sound, are monitored because of their recreational and commercial value.

1991 PSAMP FISH MONITORING

PSAMP funding did not permit the sampling of salmon and Pacific cod in 1991. Rockfish were sampled from five different locations throughout Puget Sound in November and December 1991. The results are not presently available, but will be reported in the next Puget Sound Update. This Update summarizes results from the 1991 English sole survey. This year's results are compared to 1989 data because funding constraints prohibited sampling English sole in 1990.

Many of the nine fixed stations and seven rotating stations sampled in 1991 were located in or near urban bays (Fisheries, in preparation) (Figure 8). Fisheries 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 for arsenic, copper, lead, and mercury contamination, and for many organic compounds, including PCBs and pesticides, which have been found at elevated levels in past Puget Sound studies (Malins et al., 1982).

Bottomfish liver analysis

Fish pathologists generally examine the liver for signs of toxic effects because the liver detoxifies chemicals before they can damage more sensitive organs like the heart and brain. The liver accumulates toxic material and is commonly the site of earliest detectable disease.

The most common types of English sole liver lesions associated with contaminants in Puget Sound are: megalocytic hepatosis (enlarged liver cells); foci of cellular alteration (pre-tumors), where abnormal cells grow rapidly, generally in fish at least a year old; and tumors (benign and malignant) in fish at least three years old. Scientists believe that many of these abnormalities are linked to one another (Myers et al., 1987).

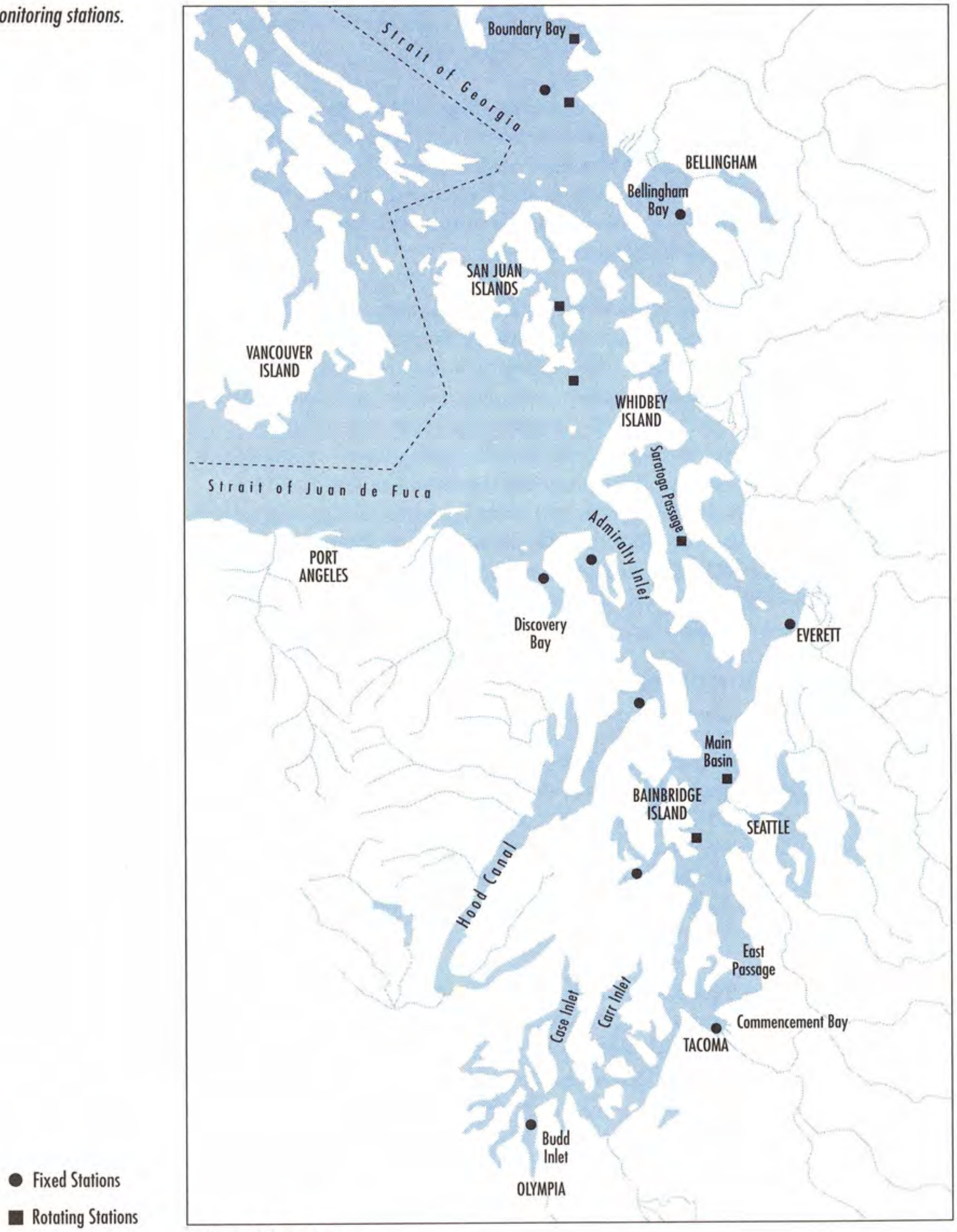
Scientists refer to the percentage of fish sampled which show each of these conditions as the prevalence of each type of liver abnormality.

PAHs—derivatives of petroleum and combustion—are most frequently linked to fish liver disease. Many types of liver lesions constitute liver disease and many of the lesions seem to be forerunners of cancerous tumors. The effect of liver disease on fish is being investigated.

RESULTS OF 1991 ENGLISH SOLE ANALYSIS

English sole sampled in 1991 were generally larger in size than 1989 fish. This complicates statistical comparisons of contaminant levels between years because toxic concentrations may increase with the size of a fish. For this reason, differences in contaminant levels between the two years should be interpreted with caution. PSAMP investigators will conduct statistical

Figure 8. 1991 PSAMP fish monitoring stations.



Reference: Fisheries, in prep.

analyses of the English sole data that factor out the effect of size. This will allow them to determine whether observed differences in contaminant levels are due to natural variation or actual changes in tissue contaminant levels.

Metals. Fisheries scientists found low levels of arsenic, copper, lead, and mercury in English sole muscle tissue at most of the 1991 PSAMP stations. English sole tissue contained levels of copper and mercury similar to those found in 1989 (Fisheries, in preparation). The levels of arsenic were higher in 1991 for nearly every station sampled in both years. This may be partly due to the larger size of sole sampled in 1991. In addition, scientists qualified many of the 1989 arsenic values as estimated, so that direct comparisons with 1991 values can only be qualitative (values are qualified as estimated when there is high variability in sampling results). Ongoing sampling will allow PSAMP investigators to determine whether arsenic levels in bottomfish are changing over time. Arsenic levels varied considerably from site to site, though they did not appear to be correlated with arsenic accumulation in the bottom sediments at these sites.

Overall, lead levels in English sole were lower in 1991 than in 1989 (Figure 9). The significance of this decrease is unknown because contaminant concentrations can vary naturally over time. It will take several years of sampling to establish baseline data necessary to determine whether lead levels are changing significantly over time at a particular site. This is especially true since lead levels measured in the past two years of sampling are near the sampling equipment's lower limit of detection, which makes quantification of the actual values very difficult (see *Chemical detection limits*, page 30).

Toxic Organics. PCB levels in English sole tissue appeared to vary depending on the location of the sampling station and nearby land uses. PCBs were not detected in English sole at any of the rural sites (Strait of Georgia, Saratoga Passage, and Hood Canal). The highest PCB levels occurred in English sole from urban or industrial areas, such as Eagle Harbor, Elliott Bay, Sinclair Inlet, and Commencement Bay. Urban and industrial fixed stations sampled in 1989 reflected similar levels of contamination. PCB values from both years are qualified as estimates, so that comparisons between the

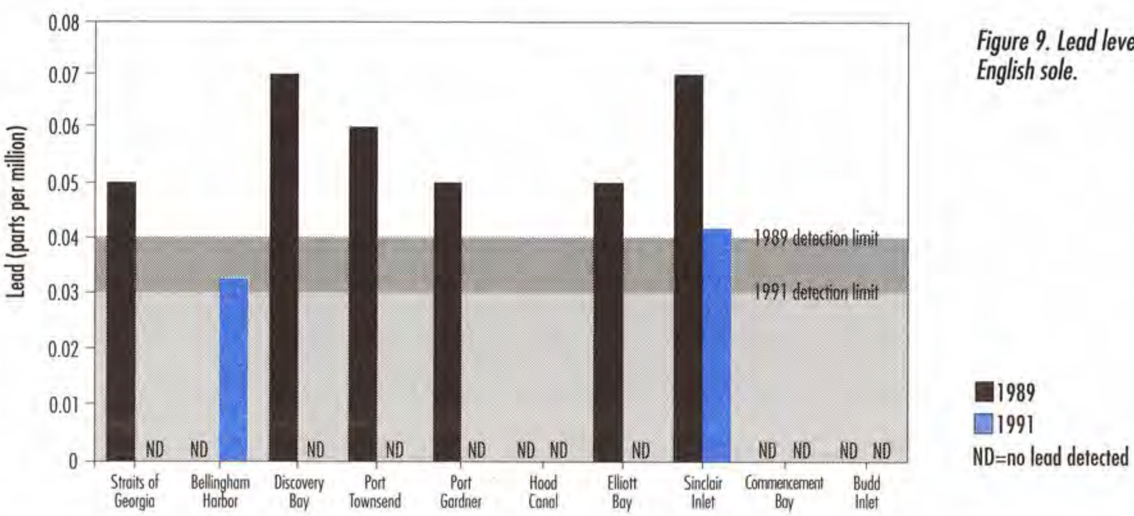


Figure 9. Lead levels in Puget Sound English sole.

Reference: Fisheries, in preparation

Chemical detection limits

Detection limits are the smallest level at which a chemical can be measured by an analysis. Detection limits vary with the type of contaminant, the nature of the sample, and the type of analytical methodology and instrumentation used. The reliability of a chemical measurement improves as contaminant concentrations increase above the detection limit. Near detection limits, the presence of a contaminant may be obscured by a complex mixture of chemicals or by electronic interference from the analytical instrument. To minimize the effects of these factors, scientists try to use methods that will detect the presence of chemicals five to 10 times lower than regulatory levels for each chemical.

Special analyses may be required to measure chemicals which are toxic at very low levels. For instance, the EPA water quality criterion for PCBs is 0.03 ppm for the protection of marine organisms. However, routine analytical methods may only be able to detect PCBs down to 0.1 ppm, so that more specialized methods are used for PCB analysis.

Scientists are able to achieve lower detection limits through continual improvements in analytical instrumentation. For example, scientists at Ecology's Manchester Laboratory recently developed methods for analyzing mercury that reduce detection limits for this chemical by over an order of magnitude. Previous detection limits were 50-200 nanograms/l (ng/l); Ecology scientists can now detect mercury concentrations as low as <5 ng/l.

years can only be qualitative. Low levels of PCBs were present in English sole from four of the five less urbanized sites (Port Townsend, Port Gardner, Shilshole Bay, and Budd Inlet). Outer Bellingham Bay was the only site near an urban area that recorded no PCBs in any of the samples.

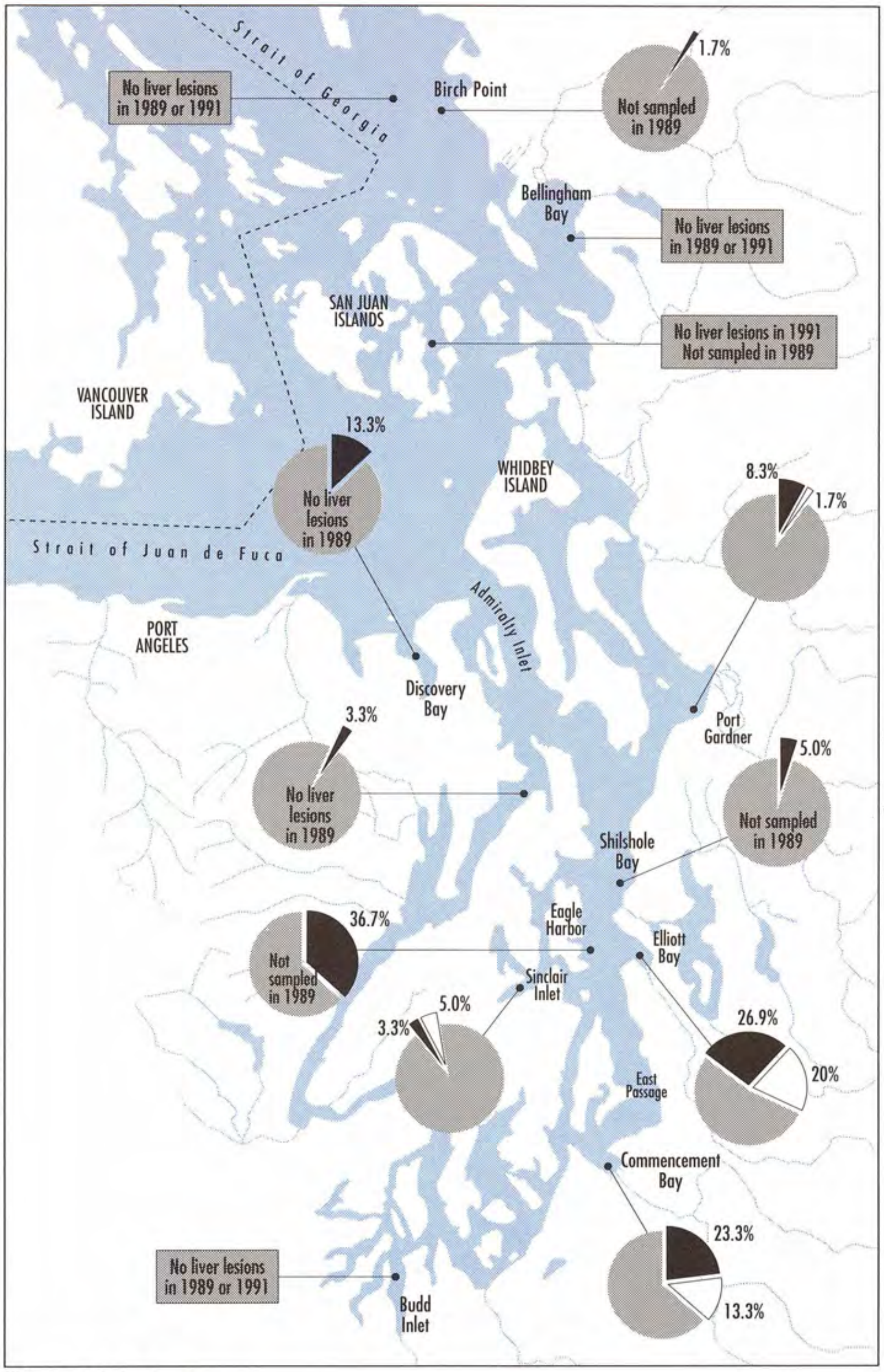
In the past, PCBs were used as coolants and lubricants in electrical equipment. Manufacture of PCBs was banned in 1977, but because these carcinogenic compounds are persistant and bioaccumulate, they are still found in fish tissue and sediments (PTI, 1991a).

After investigating contaminants in English sole tissue, Washington Department of Health investigators concluded that the level of contaminants found at the sampled locations pose no significant health threat to people that eat English sole from Puget Sound (DOH, in preparation a). Health investigators base their evaluations on a subsistence level consumption rate of 20 fish meals per month.

RESULTS OF PSAMP BOTTOMFISH LIVER ANALYSIS

Several types of liver abnormalities were found in the 1991 PSAMP bottomfish samples. The prevalence of liver disease in English sole appeared to vary with the degree of urbanization. The percentage of fish with liver abnormalities from stations in urbanized areas ranged from low (3.3 percent at Sinclair Inlet) to very high (23.3 percent at Commencement Bay, 26.9 percent at Elliot Bay, and 36.7 percent at Eagle Harbor) (Figure 10). Sole from some of the less urbanized sites (outer Bellingham Bay and outer Budd Inlet) showed no evidence of liver disease. Other sites near urban areas (Port Townsend, Shilshole Bay, and Port Gardner) had low to moderate levels of liver disease (three to eight percent of the fish sampled). English sole from the non-urban stations—Hood Canal, East Sound off Orcas Island, Birch Point, Outer Birch Bay, MacArthur Bank, and the Strait of Georgia—had little or no incidence of liver disease (less than 3.5 percent of the fish sampled). A number of other studies revealed that fish living in the open areas of the Sound rarely suffer from liver disease (Malins et al., 1984; Crecelius et al., 1989; PTI, 1991b), while those in urbanized areas, such as Eagle Harbor and the Duwamish waterways adjoining Elliott Bay, had the highest prevalence of liver disease (McCain et al., 1988).

The prevalence of liver disease in English sole sampled from nine of the 10 fixed sites in 1991 was similar to that in 1989. Liver disease occurrences in English sole from one fixed station, Discovery Bay, appeared to increase more than 13 percent between 1989 and 1991. This could be due to the fact that fish sampled in 1991 were older—6.1 years on average compared to 3.3 years in 1989. In addition, fewer fish were sampled in 1991 because Fisheries scientists had difficulty finding sole at this site (14 were sampled in 1991; 60 in 1989). This may have resulted in a sampling bias, producing an artificially high estimate of liver abnormalities.



Reference: Fisheries, in prep.

Figure 10. Percentage of English sole sampled during 1989 and 1991 with liver lesions.

□1989
■1991

SHELLFISH

BACKGROUND

From commercial oyster operations to weekend clam diggers and tribal harvests, few scenes sum up the abundance of Puget Sound's resources like tidelands teeming with healthy shellfish. But signs warning of contamination along once unpolluted shellfish beaches are all too frequent reminders of the fragility of those resources.

We take pride in the fact that Washington is the nation's leading oyster producer. Yet we have only to look at the fate of the previous two leaders—Louisiana and Chesapeake Bay—to realize the precarious position we hold. Oysters from both areas have been devastated by disease, contamination, overharvesting, and excess nutrients. There are signs of similar threats in Washington. Fecal contamination has already claimed 40 percent of Puget Sound's commercial shellfish beds (PSWQA, 1992b). Half of these restrictions occurred over the past decade. Within the last five years, classified commercial harvest restrictions in Washington state have been among the largest in the nation (Table 6) (NOAA, 1991). The dramatic increase in harvest restrictions is due to increasing pollution from a growing population and to the fact that more extensive shellfish monitoring over the past decade is revealing the extent of a problem that has existed for some time. In both cases, pollution remains a serious threat to Washington's shellfish resource.

SHELLFISH CONTAMINANTS

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

Pathogens originate from human and animal waste that enters the water through stormwater runoff from urban, rural, and agricultural lands, municipal sewage, improper waste discharges from boats, and failing septic systems. Fecal coliform bacteria are used as an indicator of the risk of disease-causing bacteria and viruses in shellfish growing waters. Pathogens

Table 6. Washington state commercial shellfish downgrades since 1981.

Growing Area	Year	Downgrade Classification	Acres Affected	Reason
Burley Lagoon	1981	Restricted	480	Rural Nonpoint
Minter Bay	1982	Prohibited	93	Rural Nonpoint
Penn Cove	1983	Prohibited	500	Sewage Treatment Plant
Lower Eld Inlet	1983	Conditionally Approved	600	Rural Nonpoint
North Quilcene Bay	1984	Prohibited	200	Rural Nonpoint
Henderson Inlet	1984	Conditionally Approved	300	Rural Nonpoint
Henderson Inlet	1985	Prohibited	163	Rural Nonpoint
South Skagit Bay	1986	Restricted	2,900	Rural/Agricultural Nonpoint
Port Susan	1987	Restricted	6,100	Agricultural Nonpoint Sewage Treatment Plants
Dosewallips Tidelands	1987	Restricted	180	Marine Mammals (Seals)
Oakland Bay	1987	Restricted (Upgraded to conditionally approved 1987)	820	Urban Point and Nonpoint
Lynch Cove	1987	Prohibited	630	Rural/Urban Nonpoint
Duckabush Tidelands	1988	Restricted	210	Rural Nonpoint
Drayton Harbor	1988	Prohibited	500	Rural Nonpoint
North Skagit Bay	1989	Restricted	2,500	Rural Nonpoint
Bay Center	1989	Restricted (Upgraded to conditionally approved in 1992)	100	Rural Nonpoint
Liberty Bay	1991	Restricted	260	Rural/Urban Nonpoint
North Bay (Case Inlet)	1991	Prohibited (Most of the bay upgraded to conditionally approved in 1992; a portion upgraded to restricted in 1992)	1,387	Rural Nonpoint
Sequim Bay	1992	Prohibited	200	Sewage Treatment Plant
Sequim Bay	1992	Conditionally Approved	2,800	Sewage Treatment Plant
Nisqually Reach	1992	Conditionally Approved	520	Rural Nonpoint

Approved–Dept. of Health surveys indicated that contaminants are not present in dangerous concentrations. Fecal coliform bacteria cannot exceed a geometric mean most probable number (MPN) of 14 per 100 ml; *and* not more than 10 percent of the samples can exceed a MPN of 43 per 100 ml.

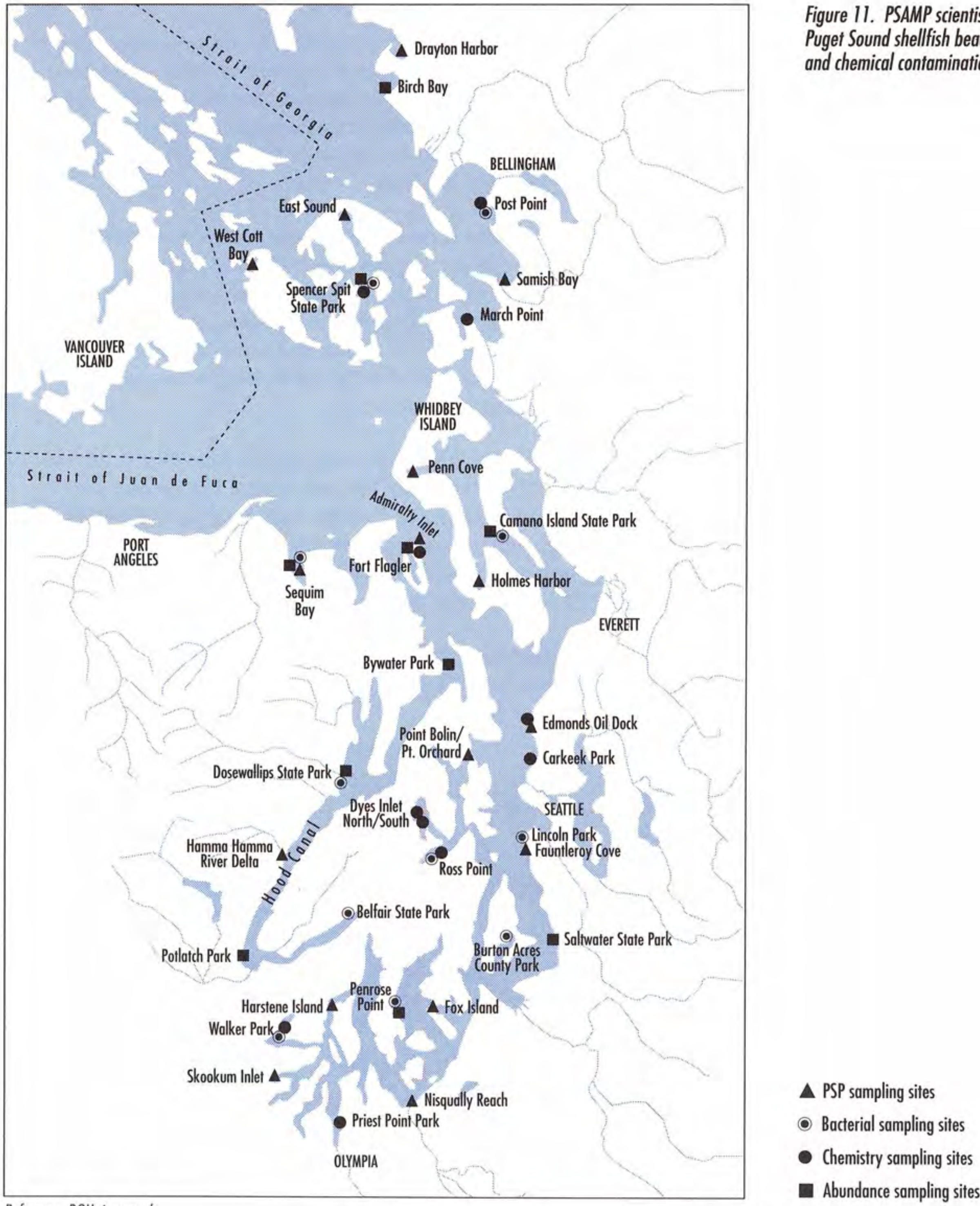
Conditionally Approved–An approved area that is subject to intermittent, but predictable microbiological contamination from predictable seasonal or weather-related pollution events.

Restricted–If water quality of a commercial growing area does not meet the standard for an approved classification, the area may be classified as restricted if the fecal coliform concentration does not exceed a geometric mean MPN of 88 per 100 ml, *and* if not more than 10 percent of the sample exceed an MPN of 260 per 100 ml. Shellfish harvested from restricted areas cannot be marketed directly, but must be relayed to an approved growing area for controlled purification.

Prohibited–Dept. of Health surveys indicate that contaminants are present in dangerous concentrations. Growing areas adjacent to sewage treatment plants and other persistent, unpredictable sources are classified as prohibited. Shellfish from prohibited areas cannot be marketed.

Reference: DOH, 1991

and particles through their bodies as they feed. Shellfish that filter and accumulate concentrations of the plankton *Alexandrium catenella* may cause PSP. The naturally occurring nerve toxin in this plankton can be fatal to humans and other species, but does not harm the shellfish.



Reference: DOH, in prep. b

Figure 11. PSAMP scientists monitor selected Puget Sound shellfish beaches for PSP, bacterial and chemical contamination, and abundance.

Puget Sound shellfish

Two types of shellfish are regularly harvested from Puget Sound beaches: bivalve molluscs, such as clams, oysters, and mussels, and crustaceans, such as shrimp and crabs. Crustaceans move along the Sound's bottom, consuming plants, animals, and debris or capturing free-swimming and floating animals from the water column. Bivalve molluscs, on the other hand, spend most of their adult lives in one location within the sediments. Bivalves filter enormous quantities of water to extract tiny particles of plankton and debris which provide them with nourishment.

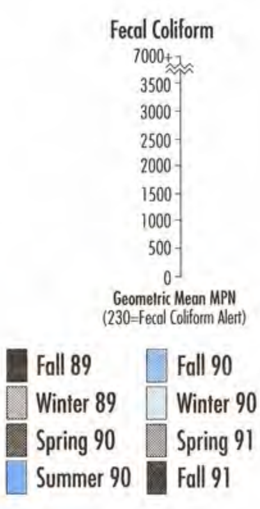
PSAMP shellfish monitoring focuses on bivalve molluscs for several reasons:

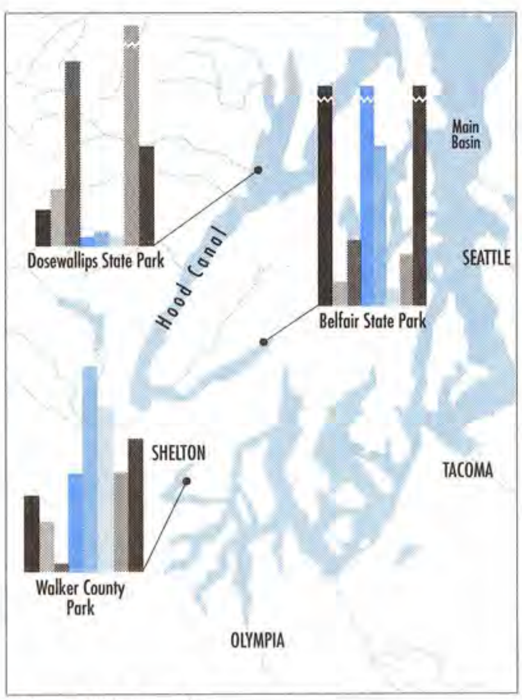
1. The large amount of water and sediments filtered by bivalves places them at greater risk to several types of contamination.

2. Because they are stationary, the degree of contamination can be attributed to sources present at the site from which they are collected.

3. Bivalve molluscs are recreationally harvested to an equal or greater extent than crustaceans. Since commercially harvested shellfish are closely monitored by the Department of Health, PSAMP monitoring focuses on beaches and shellfish which are harvested recreationally.

Figure 12. Puget Sound beaches with high levels of fecal coliform bacteria in clam tissue.





Reference: DOH, in prep. b

PSAMP SHELLFISH MONITORING

Department of Health scientists regularly monitor commercial shellfish and growing waters to protect public health. Since the 1950s, Health officials have restricted or closed commercial beds in many parts of the Sound.

Under PSAMP, Health officials monitor shellfish tissue, not water samples, for bacterial and chemical contamination at selected beaches throughout Puget Sound (Figure 11). Many of these sites are at state or county beaches. PSAMP scientists collect native littleneck clams, manila clams, butter clams, or blue mussels every three months to measure fecal coliform levels and annually in May for chemical analysis.

Commercial shellfish harvest is prohibited in areas close to storm drains, sewage treatment plant outfalls, industrial outfalls, and marinas. This includes the entire eastern shore of Puget Sound from Tacoma to Everett, as well as other areas of the Sound. These discharges may also contaminate many recreational beaches. Shellfish monitoring under PSAMP and other Puget Sound programs helps deter shellfish harvesting at recreational beaches when a public health threat exists.

Every other week, for six months of the year, citizens help Health officials sample shellfish for PSP at more than 100 commercial and recreational beaches in Puget Sound. The rest of the year, from October through March, samples are collected once a month at most sites. PSAMP investigators track monitoring results at 16 of these sites throughout the year in an effort to characterize PSP patterns and trends, which are currently unpredictable.

The Washington Department of Fisheries annually surveys clam populations on public beaches to estimate their abundance. Fisheries scientists estimate the population of clams at each site by calculating the average number of clams found in one square foot samples and multiplying this by the total area surveyed for each beach. A minimum of eight samples per acre are taken at each beach. As part of the annual shellfish population abundance analysis, Fisheries also estimates the number of clams large enough to harvest—clams must measure at least one and a half inches in length to be legally harvested. Harvest levels are then set to prevent overharvesting of shellfish so that enough adult shellfish remain to maintain the population. PSAMP scientists track the results of abun-

dance surveys from 10 beaches as one measure of the abundance of the shellfish resource. These beaches are located around the Sound, in state parks that are popular recreational harvest locations.

While overharvesting affects shellfish populations, natural factors also cause population variations among sites and years. Habitat suitability, reproductive success, and changes in temperature and current patterns (such as occurs in El Niño years) directly influence the abundance of shellfish. As more data become available, scientists will assess shellfish abundance and evaluate whether populations are stable, improving, or declining over time.

BACTERIAL CONTAMINATION IN 1991

The selected recreational beaches monitored in Puget Sound during the winter, spring, and fall of 1991 fell into two distinct groups: beaches with low levels of fecal contamination and beaches with high levels of fecal contamination. Low levels of fecal coliform showed up in the tissues of shellfish in all but three beaches. Geometric means ranged from 0 to 230 MPN (MPN, or most probable number, is an estimate of the number of fecal coliform bacteria present within a shellfish sample, based on geometric means.) (DOH, in preparation b). Shellfish contamination at the remaining three beaches was consistently higher and generally exceeded the state standard (230 organisms/100ml) for commercial shellfish harvesting (DOH, in preparation b).

The three highly contaminated beaches in 1991—Belfair State Park near Lynch Cove in Hood Canal, Walker County Park near Shelton in the south Sound, and Dosewallips State Park along Hood Canal—exhibited high fecal coliform levels in past PSAMP surveys as well, which signals chronic bacterial problems (Figure 12). The geometric means of fecal coliform at the contaminated beaches ranged from 334 to 7,733 MPN at Belfair State Park; 1,873 to 3,018 MPN at Walker County Park; and 128 to 11,064 MPN colonies at Dosewallips State Park (DOH, in preparation b).

Fecal coliform levels at Penrose Point State Park, along Carr Inlet, were once again highly variable, ranging from 34 to 1,962 MPN, with an 1991 annual mean of 151 MPN. These values are considerably higher than the annual mean of 30 MPN in 1990. While the annual means are not high enough to restrict harvesting in this park, occasional high levels of fecal coliform may present a temporary health threat. Levels of contamination will be watched closely in future years to determine if coliform levels continue to increase.

Extensive monitoring of commercial shellfish waters has resulted in harvesting restrictions at a significant portion of the state's shellfish beds. Health officials do not generally close recreational shellfish beds, but instead post warning signs on recreational beaches that exceed commercial standards. However, severe fecal contamination detected by PSAMP at Belfair and Dosewallips state parks prompted closure of these beaches to recreational shellfish harvesting. Seals are suspected as the major source of fecal coliform bacteria in some areas, such as Dosewallips State Park, which is located along Hood Canal.

Citizen monitoring efforts

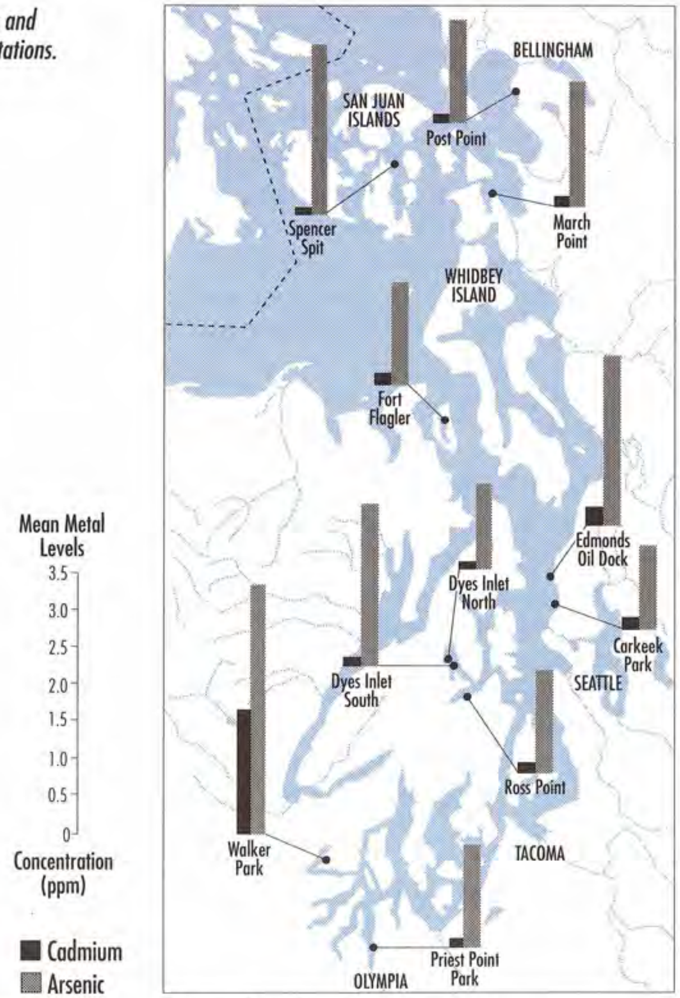
PSAMP created a citizen's monitoring program to promote public education and involvement in monitoring the environmental quality of Puget Sound. Citizen volunteers help reduce monitoring costs, allowing PSAMP agencies to collect data that are otherwise beyond the scope of their budgets.

Funded by the Authority's Public Involvement and Education Fund (PIE Fund), this program began in June 1988. Since then, citizens have helped PSAMP investigators map nearshore habitat, dig clam samples for bacterial, chemical, and PSP analysis, and catch rockfish, salmon, and Pacific cod for tissue chemical analysis. Citizen volunteers have made their largest contribution to PSAMP by collecting shellfish samples. The Authority helps fund two citizen groups—Adopt-a-Beach and Chautauqua Northwest—to provide and manage volunteers for sample collection and other PSAMP tasks. Without their help, many recreational beaches throughout the Sound would not have been monitored for PSP, fecal coliform, or chemical contamination.

All PSAMP citizen monitoring is coordinated by staff at one of the state agencies participating in the program. Authority and agency staff provide training, equipment, and supervision, as well as follow-up reports to citizens.

Expansion of the citizen's monitoring program in the near future will add waterfowl and bird counts, marine mammal counts, and marine water column sampling to the citizen monitoring activities. Individuals or groups interested in becoming involved in volunteer activities or any aspect of the citizen's monitoring program are encouraged to contact the Authority's citizen monitoring coordinator (see the contact list at the end of this report).

Figure 13. Concentrations of arsenic and cadmium at 1991 PSAMP shellfish stations.



Reference: DOH, in prep. b

CHEMICAL CONTAMINATION IN 1991

Shellfish from all 10 PSAMP beaches monitored in May 1991 showed low levels of toxic metals and barely detectable levels of organic contaminants. Chemists analyzed shellfish tissues for six metals (arsenic, cadmium, copper, mercury, lead, and zinc) and almost a hundred organic contaminants, including pesticides and PCBs (polychlorinated biphenyls). Many of these contaminants are known to be harmful in certain concentrations to humans, animals, and plants. Low levels of metals, similar to amounts detected in 1990, were found in shellfish tissue from all 10 PSAMP beaches, as illustrated by Figure 13, which shows arsenic and cadmium contamination. The levels of all the metals were well below levels that are dangerous to human health. Organic contaminants were detected at levels too low to accurately quantify (DOH, in preparation b).

After examination of chemical contaminants in shellfish tissue, Health investigators concluded that they pose little threat to the health of people consuming shellfish from Puget Sound. Their evaluations are based on a subsistence level consumption rate of 20 shellfish meals per month.

PARALYTIC SHELLFISH POISONING IN 1991

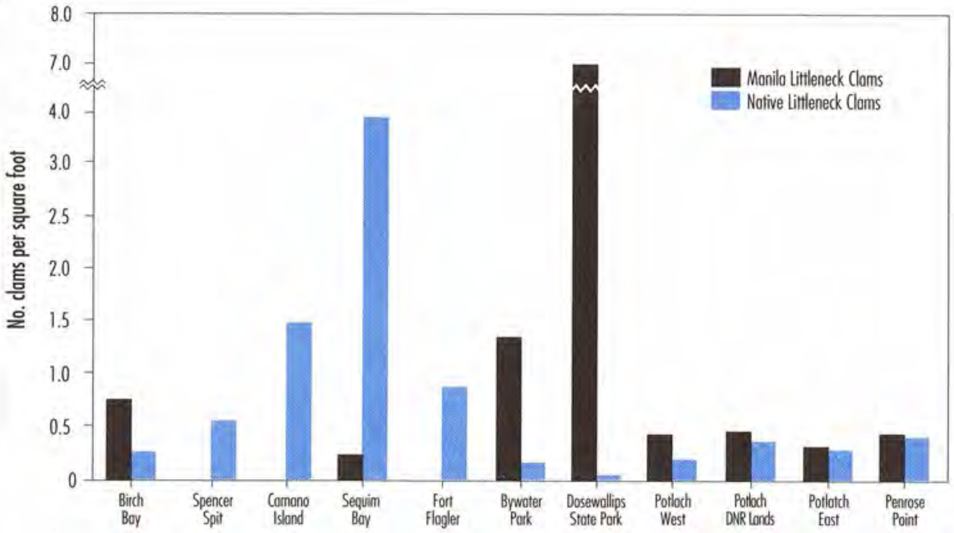
Shellfish from three of the 16 PSAMP beaches sampled in 1991 had enough PSP in their tissues to warrant closing beaches temporarily to public shellfish harvesting (DOH, in preparation b). This is considerably fewer beaches than were closed in past years. Since 1985, on average, half of the 16 beaches monitored by PSAMP have been closed at least once during the year. Sequim Bay exceeded PSP standards in March 1991. Consistently high toxin levels closed Point Bolin, south of Agate Pass, from late February to the end of May. Ship Bay in East Sound (Orcas Island) was affected by high levels of PSP in May and June, with the highest levels of PSP measured in 1991 during September.

Domoic acid in shellfish

In November 1991, Health officials cut short the recreational razor clam season along Washington's Pacific coast after 11 people became ill from eating clams containing domoic acid, a naturally occurring shellfish toxin. Investigators found that the toxin was also present in the tissues of Dungeness crab, resulting in the delayed opening of commercial Dungeness crab fishing during December 1991 and January 1992.

Domoic acid can cause intestinal problems, mental confusion and, in some cases, death. Shellfish can accumulate the toxin by feeding on microscopic, single-celled algae (*Nitzschia pungens* is thought to be responsible) known to produce domoic acid.

To date, domoic acid has not been detected in Puget Sound crab or shellfish populations at levels that resulted in the 1991 Pacific Coast closures. Health officials plan to regularly monitor shellfish from the coastal estuaries, Strait of Juan de Fuca, and Puget Sound for domoic acid.



Reference: Fisheries, in prep.

Figure 14. 1991 Manila and native littleneck clam densities (of clams >1.5 inches) at 11 PSAMP beaches.

SHELLFISH ABUNDANCE

During 1991 sampling, Fisheries found the highest density of native littleneck clams at Sequim Bay, followed by Camano Island, Fort Flagler, and Spencer Spit. These four beaches also had the highest densities over the last four years (Fisheries, in preparation) (Figure 14).

The highest density of Manila clams in 1991 occurred at Dosewallips State Park, where the population was nearly five times denser than the next most concentrated populations at Bywater Bay. The high density of Manila clams at Dosewallips could be the result of harvest restrictions at this park due to fecal contamination, and of the suitable substrate and high natural setting rate on the Dosewallips flats. Following Bywater Bay, the next most densely populated beaches were Birch Bay, Saltwater State Park, and Potlatch. These beaches also had high average densities over the last four years.

MARINE MAMMALS

BACKGROUND

Once appreciated more for their harvestable, economic assets than their aesthetic values, marine mammals have become potent symbols of Puget Sound's beauty. Although changes in our attitude toward these animals helped bring about laws making it illegal to kill or otherwise harm them, humans remain a threat to marine mammals. Damage once inflicted by harpoons is today caused indirectly by the activities of our growing human population.

Eight species of marine mammals are common to Puget Sound. Four are resident (harbor seal, Dall's porpoise, harbor porpoise, and orca whale), while the remaining four are migrants that spend extended periods within Puget Sound (Minke whale, California sea lion, Stellar sea lion, and gray whale). An additional 19 species of whales, seals, and porpoises are occasional, rare, or accidental visitors.

THREATS TO MARINE MAMMALS

Because they are larger than most Puget Sound inhabitants, it is easy to assume that marine mammals might be more resistant to the effects of pollution. But marine mammals rely on clean water and undisturbed habitat

for their well-being and are sensitive to environmental degradation. Poor water quality and degraded habitat cause stress in marine mammals. This is reflected by shifts in feeding and pupping territories and by high levels of toxic contaminants in blubber and internal organs. Population patterns in some marine mammals have also been linked to human activities. California sea lion populations, for example, are attracted to areas where dams and locks block the passage of fish and provide sea lions with an easy source of food.

It is possible that some population and territorial shifts are part of a natural cycle, but evidence indicates that many of the changes occurring in marine mammals are linked to human activities. Commercial and recreational fishing can alter the food supply of marine mammals or result in incidental mortality through entanglement in commercial fishing nets. Shoreline developments can degrade and destroy marine mammal habitats. Toxic chemicals contaminate the plants and animals upon which seals, sea lions, porpoises, and whales feed, and build up in marine mammal tissues.

PSAMP MARINE MAMMAL MONITORING DESIGN

Monitoring marine mammals provides important information about the passage of contaminants through the Puget Sound food web. As consumers of large numbers of marine animals, marine mammals may be early indicators of potential problems associated with a heavy diet of Puget Sound organisms. And because they resemble humans physiologically, marine mammals may provide information on potential health problems which may result from eating contaminated Puget Sound seafood.

PSAMP monitors the abundance and reproduction of marine mammals and tracks chemicals in their tissues (PSWQA, 1988) to assess the status of and changes in marine mammal populations. Monitoring resident animals may tell scientists how much contamination the animals accumulate from eating seafood in Puget Sound. The results of these monitoring efforts can provide information about the effects of contaminants, habitat loss, and other threats to marine mammal populations.

The Washington Department of Wildlife (Wildlife) first received funding for PSAMP monitoring activities in 1991. Initial efforts focused on analyzing past data to determine optimal times and locations for obtaining population estimates of various marine mammals. The results of these analyses will be used to design the sampling plan for a number of marine mammal species, such as gray whales, harbor porpoises, and harbor seals. In addition to research conducted by Wildlife officials, Cascadia Research, an independent non-profit research organization, has conducted extensive monitoring of contaminants in marine mammals and the status of marine mammal populations in Puget Sound.

Beginning in 1992, Cascadia Research will receive PSAMP funding to document gray whale occurrences in Puget Sound. Biologists need this information to estimate how many whales are in Puget Sound, their movement patterns, how long they stay in the Sound, and the proportion that die while there. The National Marine Fisheries Service analyzes whales that die with-

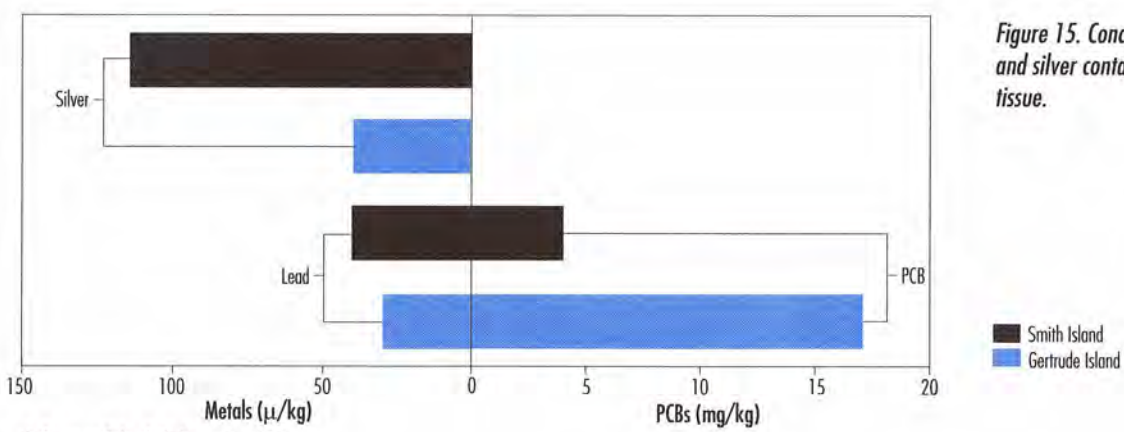
in the Sound for tissue contaminants. Using individual markings to identify whales, scientists can check past sightings to determine whether whales that died spent prolonged periods feeding in areas of potential contamination.

HARBOR SEALS

In a recent EPA funded study, Cascadia Research scientists compared tissue from harbor seal pups at Smith Island in the Strait of Juan de Fuca and at Gertrude Island in south Sound to evaluate contamination differences between north and south Sound seals (Calambokidis et al., 1991). Harbor seal pups from Gertrude Island had significantly higher levels of PCBs than Smith Island pups (Figure 15). This may reflect higher PCB concentrations in south Sound waters, which are more polluted by industrial discharges and have limited water exchange. The level of DDE (a breakdown product of the pesticide DDT) found in pups did not differ between the north and south Sound locations. Few other pesticides were detected.

In contrast, the levels of two metals sampled—lead and silver—were significantly greater in Smith Island pups than in pups from Gertrude Island. Other metal levels (aluminum, arsenic, cadmium, copper, mercury, nickel, selenium, and zinc) did not differ significantly between the two areas. There is no apparent reason for the higher levels of lead and silver in north Sound pups, since Smith Island is in a well-flushed area removed from contaminant sources. Smith Island may be exposed to contamination from the Fraser River in British Columbia.

Compared to past studies in north and south Sound, 1991 Smith Island and Gertrude Island data indicate a substantial decline in PCBs since 1972. The 1977 ban on PCB production probably accounts for this decline. DDE also declined significantly over the same time period at Gertrude Island (Calambokidis et al., 1992b).



Reference: Calambokidis et al., 1991

Figure 15. Concentrations of PCBs, lead, and silver contaminants in harbor seal tissue.

GRAY WHALES

Monitoring conducted by Cascadia Research resulted in the individual identification of gray whales sighted within Puget Sound in 1991. Scientists

sighted 17 different whales on 75 occasions—seven of these were seen more than once (Calambokidis et al., 1992a). The presence of two whales that were also seen in previous years provided evidence that gray whales often return to the same sites each year (Calambokidis et al., 1992a). One whale was sighted 17 different times over 112 days in a number of south Sound locations and in Port Susan, suggesting widespread foraging throughout the Sound. Three of the whales later died within Puget Sound.

The proportion of gray whales that died—three of the 17 sighted—is high for a long-lived animal, particularly considering that these were adults, which generally suffer lower mortality rates than juveniles. Only three whales were documented spending extended periods in south Sound in 1991, and two of these were later found dead. Data from previous research is limited, but also indicate higher than expected mortality in whales sighted in south Sound (Calambokidis et al., 1992a). More research is needed to determine whether gray whales in poor health tend to migrate towards south Sound, or whether conditions in south Sound induce higher mortality rates.

HARBOR PORPOISE

Cascadia Research and the National Marine Mammal Laboratory conducted aerial surveys of harbor porpoises over coastal Washington and Oregon in 1991. This study revealed low numbers of harbor porpoises in Puget Sound (Calambokidis et al., 1992b). An estimated 3,000 porpoises live within the Sound, almost exclusively within the Strait of Juan de Fuca and around the San Juan Islands. For unknown reasons, no porpoises were spotted in central or south Sound. Historical reports indicate that porpoises frequented the lower Sound during the 1940s. Disturbances from increased boat traffic and increased pollution, as well as deaths due to entanglement in fish nets are cited as reasons for the lack of harbor porpoise populations in south Sound (Calambokidis, personal communication).

BIRDS

BACKGROUND

Puget Sound's rocky islands, sandy beaches, wetlands, and forests are ideal habitats for a wide variety of birds. These seasonal and year-round residents include waterfowl (geese, swans, and diving and dabbling ducks), marine birds (gulls, auklets, puffins, pigeon guillemots, and herons), shore birds (sandpipers, snipe, plovers, and killdeer), and raptors (eagles, hawks, and osprey).

Many human activities are making Puget Sound less than ideal for these resident and migratory birds. Oil spills, hunting, and entanglement in marine debris and fishing gear are obvious threats to birds. Even more serious, but less obvious, are the indirect threats related to growth and development—the contamination and reduction of food supplies and the degradation and destruction of critical habitat.

The best way to track the effects of human activities on birds is through year-round population and health estimates. Without this information, wildlife managers cannot effectively protect Puget Sound bird populations. The analysis of toxic chemicals in birds provides information on the accumulation of contaminants through the food web. By monitoring bird species which rely on different food sources, scientists gain information about different pollutant pathways and food web links through the ecosystem.

PSAMP BIRD MONITORING

Past surveys conducted by the Washington Department of Wildlife primarily collected information to support the management of waterfowl harvest. PSAMP investigators will begin initial surveys for waterfowl and marine birds in the winter of 1992. Their goal is to get accurate estimates of the population of major Puget Sound bird species, including those not targeted by hunters (PSWQA, 1988). PSAMP also will focus on monitoring the health of Puget Sound birds, mainly through measurements of reproductive success and the accumulation of toxic chemicals in bird tissues.

In conjunction with PSAMP, the U.S. Fish and Wildlife Service (USFWS) plans to monitor contaminants in pigeon guillemots. Because pigeon guillemot populations may be limited by the amount of nesting habitat available, USFWS is placing nesting boxes at various locations throughout Puget Sound. As these nest boxes are gradually colonized, scientists can easily access the birds for sampling. Strategically placed nesting locations will allow USFWS to observe prey items fed to the young, providing scientists with some indication of how contaminants move through the food web. The number of chicks produced and their growth rate will also be monitored.

USFWS will use radio telemetry to track movements of the migratory surf scoter during the 1992 winter. If the results of this study indicate that surf scoters feed primarily within Puget Sound while overwintering in this area, USFWS will sample scoters for contaminants in the fall, as they arrive in Puget Sound, and again in the spring to obtain information on the concentration of contaminants accumulated while feeding in the Sound. Research scientists have found that contaminants in western grebes and surf scoters increased significantly while overwintering in Commencement Bay (Henny et al., 1991).

CONTAMINANTS IN PUGET SOUND BIRDS

Scientists have examined the eggs from five species of Puget Sound birds to determine whether a connection exists between contaminant levels in the eggs and thinning eggshells. Declines in many bird populations have been traced to eggshells which are so thin that they break before young birds hatch. Pesticides, particularly DDT, are known to cause eggshell thinning (Hickey and Anderson, 1968; Risebrough et al., 1970).

When scientists compared the thicknesses of eggshells from 1947 and 1991, they found significant thinning in great blue heron eggs from 1991 (Speich et al., in press). The degree of thinning was greatest in eggs collected in northern Puget Sound. Eggshells sampled near March Point were 13 percent thinner in 1991, and eggshells from Samish Island were 12 percent thinner. These sites are located in agricultural areas, where pesticide use would presumably be highest. Eggshells from glaucous-winged gulls also exhibited significant thinning at two urban sites, Seattle (10 percent) and Tacoma (nine percent), and at Shelton (eight percent). Double-crested and pelagic cormorant eggs and pigeon guillemot eggs showed no significant thinning.

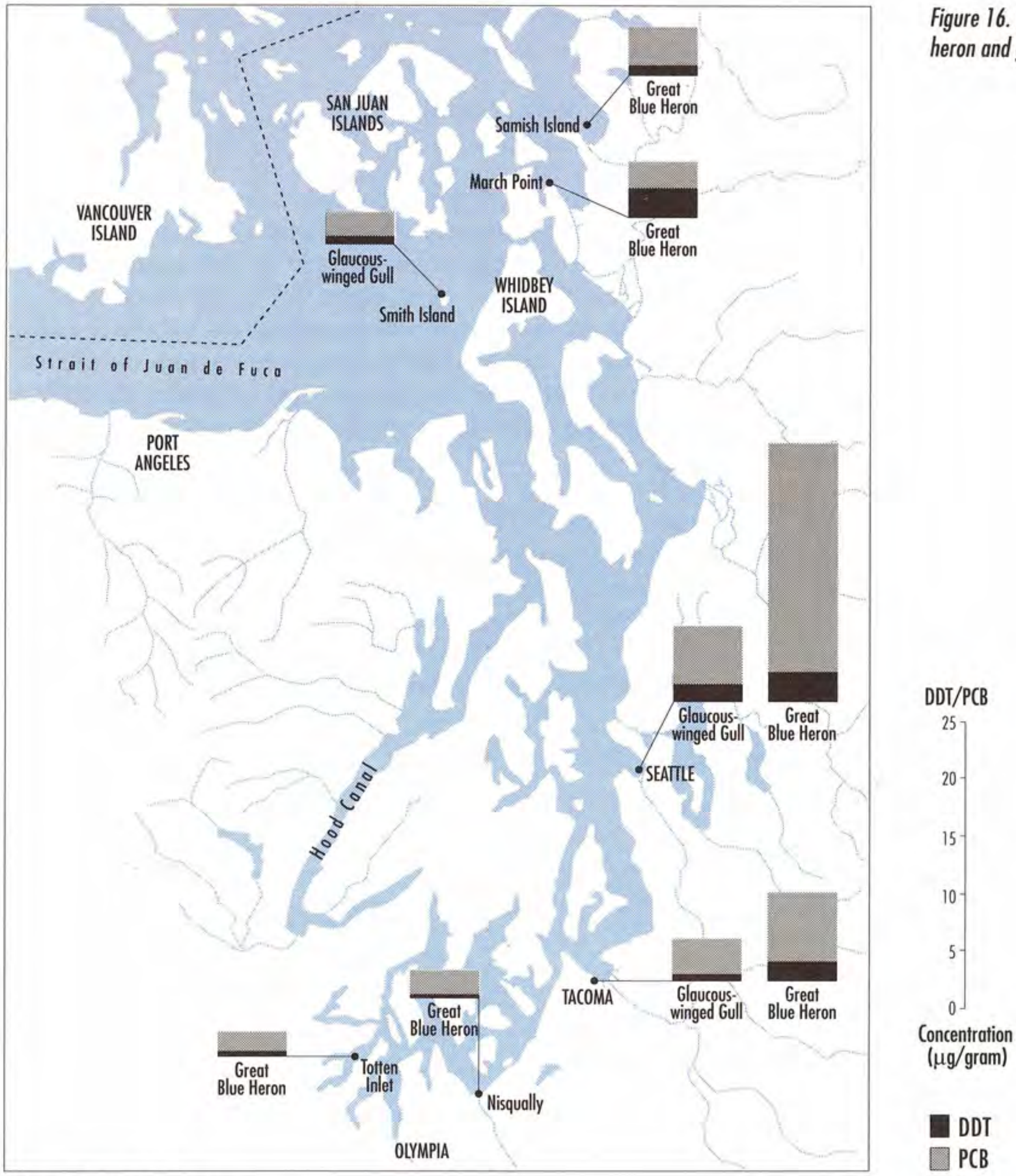


Figure 16. Concentrations of PCB and DDT in heron and gull eggs.

Reference: Speich et al., in press

Scientists found the greatest PCB concentrations in heron and gull eggs from Seattle and Tacoma (Figure 16). DDT in the eggs of both species was also highest at Seattle. The levels of DDT observed in this study were below levels found to cause reproductive problems in similar studies (Henny et al., 1984). PCBs in eggs collected near urban sites were above levels reported to cause reproductive problems in some species (Bush et al., 1974), although signs of reproductive problems (eggshell breaking or flaking, low hatching success) were not evident in this study. Although the degree of eggshell thinning was not high enough to cause eggs to break, heron eggs at Samish Island and March Point were within five percent of levels that cause reproductive failure in California herons (Faber et al., 1972).

Researchers believe that the observed eggshell thinning may be due to exposure of the adults to pesticides, which may not be reflected by concentra-

tions within the egg. Eggshell thinning might also be caused by exposure of the birds to chemicals not measured in the study.

FUTURE PSAMP BIRD MONITORING

More information is needed on the population sizes of several Puget Sound species. Population estimates are regularly calculated for waterfowl populations because of their recreational importance and for bald eagles because of their threatened status. Similar information is lacking for a number of other species such as great blue herons, whose populations may be declining. Without such baseline information it is difficult to evaluate the effects of human activities on Puget Sound bird populations. As part of PSAMP, the Washington Department of Wildlife will begin assessing bird populations in 1992.

More programs are also needed to study the accumulation and effects of contaminants on Puget Sound birds. A number of past studies indicate that contamination of birds from Puget Sound sources may be considerable (Henny et al., 1990, 1991), and that this contamination may physically affect the birds (Speich et al., in press). The U.S. Fish and Wildlife Service is beginning programs that will facilitate the sampling of contaminants in Puget Sound birds.

NEARSHORE HABITAT

BACKGROUND

Nearshore habitats—kelp beds, eelgrass meadows, salt marshes and wetlands, beaches, and mudflats—are vital to the health of Puget Sound. They provide spawning, rearing, and feeding grounds for many marine animals and refuge for juvenile and adult fish, birds, and shellfish. Nearshore habitats protect the shoreline from erosion and filter pollutants from the water column. They can also reduce flooding by retaining stormwater during high flow periods.

Most of Puget Sound's recreational and commercial activities rely on nearshore habitats. Shellfish are grown and harvested on predominantly unvegetated mudflats. Many economically important fish release their eggs on mudflats or within the beds of eelgrass, kelp, and algae that line the shore. When these eggs hatch, the vulnerable larvae and juveniles seek refuge from predators in kelp and eelgrass beds and in salt marshes. Waterfowl and other birds, such as herons, feed within salt marshes and kelp and eelgrass beds. Birds also use the emergent nearshore vegetation for refuge and habitat. Beaches provide summer recreation for Puget Sound residents and tourists, and kelp beds are valued for the diving opportunities they provide.

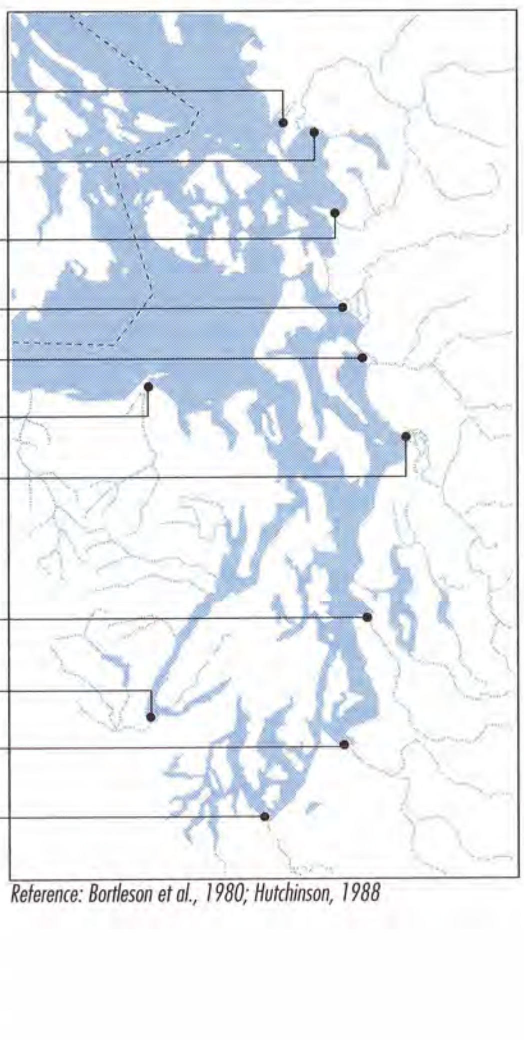
THREATS TO NEARSHORE HABITATS

The location of nearshore habitats—at the boundary between land and water—places them in conflict with many human activities. As we take advantage of the commercial, recreational, and aesthetic benefits of Puget Sound, we often damage the nearshore and waterfront areas through construction and habitat alteration. Salt marsh losses depict the toll our activities are taking on Puget Sound's nearshore habitat (Figure 17). Activities which diminish the quality and quantity of nearshore habitat include:

- Dredging channels for boat access.
- Filling wetlands for nearshore development projects.
- Constructing seawalls and bulkheads, which alter nearshore habitat.
- Dumping debris on beaches.
- Land clearing, logging, and other upland activities which promote erosion and increase the rate of sedimentation onto nearshore habitats.
- Introducing invasive plant species, such as *Spartina*, which dramatically alter the type of nearshore habitats.

The rapid rate of population growth predicted for the Puget Sound area will place increasing pressures on nearshore habitat. It is important that we track the effects of growth on these fragile areas over time by monitoring the types and acreage of nearshore habitat.

Figure 17. Changes in salt marshes in major river deltas.



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

NEARSHORE HABITAT RESTORATION

While there are a number of regulations that protect nearshore habitat, significant losses still occur. Scientists estimate that 144 acres of nearshore estuarine habitat are lost each year in the state of Washington (Canning and Stevens, 1989), with over half the losses occurring in Puget Sound. A number of nearshore areas are already severely damaged by habitat losses, so that even if no further habitat losses were to occur, the valuable functions provided by these habitats (such as flood and erosion control, feeding and rearing grounds) would still be greatly impaired.

In the face of increasing population growth and its associated activities (such as shoreline development, channel dredging, and bulkhead construction), it is important that we develop the skills and knowledge to rehabilitate degraded nearshore habitat and replace habitats which have been entirely lost. Habitat restoration is an evolving science which faces a number of technical difficulties. Even if all the appropriate steps are taken (for example, care is taken to mimic the soils, hydrology, vegetation, and animals normally found at a given habitat type), the end result may not replace the valuable functions associated with the natural habitat. Scientists are hopeful that continuing efforts will improve the success of these projects.

Habitat restoration projects in Commencement Bay and on Jetty Island in Port Gardner were described in the *1991 Puget Sound Update.* More recently, the Army Corps of Engineers, EPA, USFWS, and NOAA have been working together under the Coastal America program to restore and enhance nearshore habitat along the Duwamish River estuary in Seattle. These agencies have identified several sites along the Duwamish for restoration efforts. Habitat will be restored and enhanced by removing large salvage debris present at many sites (including derelict boats and barges), removing fill and regrading nearshore areas to intertidal elevation, providing substrates suitable for establishing nearshore vegetation, building protective berms, and planting appropriate native species in the intertidal areas and adjacent upland areas. The project will provide public access and education at these sites, with walkways and interpretive signs describing the importance of these habitats and their inhabitants.

An important element of these demonstration restoration projects is a commitment to long-term habitat monitoring. Both the physical and biological characteristics of intertidal areas will be studied over 10 years following project completion. Physical site monitoring will include topographic and bathymetric surveys, as well as analyses of sediment characteristics and water quality. The agencies will also monitor biological characteristics such as emergent vegetation, sediment algae, benthic invertebrate populations, and fish and bird populations. These efforts should provide a greater understanding of the effectiveness of habitat restoration techniques in the urban environment. The results of these projects may be reported in future editions of the Puget Sound Update.

PSAMP INVESTIGATIONS INTO NEARSHORE HABITAT

Protection of estuarine nearshore areas presents a challenge to natural resource managers who lack good information on the existing amounts, types, and functions of these habitats. A comprehensive inventory of nearshore habitat resources would help managers make coherent plans to protect the most critical of these habitats.

The Washington Department of Natural Resources (DNR) received funding in 1991 to survey and map Puget Sound's 1,200 miles of shoreline. One-third of the Sound will be surveyed each year, with the first surveys conducted in the summer of 1992. DNR scientists will survey nearshore areas using an aircraft equipped with a remote sensing device known as a multi-spectral scanner. This scanner records 11 wavelengths of light, covering the

ultraviolet, visible, and infrared portions of the spectrum. This advanced technology allows scientists to differentiate between habitat types that could not be distinguished from normal aerial photographs—for example, sand and mud substrates or areas vegetated by different species of kelp.

With this technology, DNR scientists can produce habitat maps accurate to within several meters, a precision that has only recently become possible. This accuracy is achieved by storing satellite locational coordinates with each scanner reading.

1991 NEARSHORE HABITAT MONITORING RESULTS

Much of the recent work in the Sound's nearshore habitats focuses on the invasion of three exotic species of cordgrass: *Spartina alterniflora* (smooth cordgrass), *S. patens* (saltmeadow cordgrass), and *S. anglica* (common cordgrass). Uncontrolled *Spartina* growth could alter the nature of nearshore habitat, affecting wildlife, fisheries, geology, native vegetation, and hydrology (Mumford et al., 1991).

In Washington, *Spartina* currently grows in Puget Sound, Grays Harbor, and in Willapa Bay. The invasion is most advanced at Willapa Bay where *Spartina alterniflora* forms dense, monotypic stands cut by deep channels. Cordgrass spreads rapidly—it now covers 2,500 acres—approximately eight percent—of the intertidal area of Willapa Bay. This is 850 acres more than in 1988. Left unchecked, *Spartina* may cover most of the bay's 30,000 acres by 2010 (DNR, 1992).

Spartina alterniflora is the dominant native species of the lower salt marshes along the Atlantic seaboard and Gulf Coast of the United States. *S. alterniflora* takes hold on substrates, such as cobble, sand, and silt, in waters where salinity can range from fresh water to marine salt water. *S. alterniflora* came to Willapa Bay around 1894, presumably with oyster seed (DNR, 1992). *S. patens* and *S. anglica* are also found in the Puget Sound region.

Researchers report that the transition of Pacific Northwest intertidal areas to *Spartina*-dominated salt marshes results in:

Trapped sediments. *Spartina* plants can capture up to 15 cm (six inches) of new sediments annually, causing a rapid rise in the level of tideflats and, eventually, the loss of intertidal acreage to salt marshes. This has severe implications for flood control and watershed drainage.

Altered habitat. The raised islands formed by *Spartina* stands force tidal waters into smaller channels between the stands. This increases the speed of currents and deepens channels through erosion. The raised islands and deepened channels are no longer suitable habitat for many species typically found in the intertidal zone. These include juvenile fish, some shellfish, migratory waterfowl, and eelgrasses (Mumford et al., 1991).

SPARTINA IN PUGET SOUND

All three species of invasive cordgrass currently grow in Puget Sound (Figure 18). Stands of *Spartina* are not as advanced in the Sound as they are in Willapa Bay. *Spartina alterniflora* is present at Kala Point, Thorndyke Bay, Sequim Bay, and Padilla Bay. *S. anglica* grows at Triangle Cove, Skagit Bay, and Port Susan on and around Camano Island, and Deer Lagoon and Cultus Bay on Whidbey Island. *S. patens* is present at the Dosewallips River.

CONTROLLING SPARTINA IN PUGET SOUND

The Department of Natural Resources is the coordinating agency charged with finding solutions to the state's *Spartina* problems. To this end DNR and Pacific County (where Willapa Bay is located) established the *Spartina* Working Group in 1989. Its members represent state, federal, and local agencies, and interested private parties. The group has issued reports summarizing information about *Spartina* and its control or eradication (DNR, 1992). DNR has recently hired a *Spartina* coordinator to facilitate interagency efforts.

Efforts to control *Spartina* include mechanical and chemical methods of containment and eradication. Mechanical means of controlling cordgrass include mowing, burning, diking, or flooding stands, and covering with black plastic. The only herbicide currently licensed for use in estuarine environments is Rodeo™. DNR sprayed areas infested with *Spartina* in Willapa Bay during the summer of 1992.

Preliminary work is under way to determine the feasibility of biological controls, such as insects, for *Spartina*. Research to determine the effectiveness of biological controls for *Spartina* may take between five and 10 years (DNR, 1992).

Reference: DNR, 1992

Figure 18. Distribution of Spartina in Washington as of December 1991.

FRESH WATER

BACKGROUND

Fresh water flows into Puget Sound from an extensive network of lakes, rivers, and streams. This freshwater network is an important resource for all of Puget Sound's populations. Humans use rivers and lakes for boating, fishing, and swimming. Wildlife find habitat, spawning, and feeding areas in the basin's fresh waters. Humans also rely on fresh water as a source of drinking water, in some cases with little treatment prior to use.

PROBLEMS WITHIN FRESH WATER

Some freshwater streams travel over 100 miles on their way to the Sound, picking up pollution and sediment along the way. Thus even distant activities can affect Puget Sound's water quality—pollution from industrial and stormwater discharges, forestry and farming runoff, improper disposal of household hazardous wastes, and other activities eventually make their way into the Sound.

In addition to polluting Puget Sound, human activities can also degrade freshwater habitats. Poor farming and forestry practices increase erosion, sending excess sediments into the water and threatening fish—particularly salmon whose spawning areas become clogged with sediments. Clearing of

streamside vegetation, which increases the river's exposure to sunlight, can raise the temperature of rivers, endangering salmon and trout, which are sensitive to temperature increases. Sewage plants, industrial facilities, septic systems, and stormwater runoff may discharge harmful chemicals or bacteria into the water, endangering drinking supplies, swimming areas, and habitat. Developed areas, such as buildings, parking lots, and roads, prevent rain and surface water from seeping into the soil, a natural process which slows the flow of runoff and filters pollutants before they reach freshwater resources. Instead, water rapidly runs off developed surfaces, collecting oil, metals, and other contaminants, and drains into rivers and lakes. The increased flow of runoff from developed areas causes flooding problems and erodes natural stream channels.

PSAMP FRESHWATER MONITORING DESIGN

PSAMP managers monitor the quality of freshwater rivers and streams mainly to determine how they affect the Sound's water and sediment quality, habitat, and biological populations. This is done by sampling fresh water at fixed stations near the mouths of the 10 major rivers that enter Puget Sound: the Nooksack, Skagit, Sammamish, Stillaguamish, Snohomish, Cedar, Green-Duwamish, Puyallup, Nisqually, and Skokomish rivers (Figure 19). Sampling these rivers at their point of entry into Puget Sound allows scientists to estimate the effects of upstream pollution on the Sound's water quality.

Scientists also collect monthly samples at upstream locations for comparison with the river mouth stations. These upstream locations provide information on natural background conditions within streams. Comparison with downstream stations provides information on the amount of pollution contributed along the length of the river. Present funding levels allow for monthly sampling at only two upstream stations: the Skagit River at Marblemount and the Green River near Kanasket. In addition, samples from rotating stations within the freshwater monitoring area are used to monitor the river mouths not sampled within the fixed station network, to sample tributaries to rivers with fixed stations, and to focus sampling on rivers and streams with known water quality problems. These stations are sampled every three years.

Freshwater stations are sampled for conventional water quality variables, including temperature, dissolved oxygen, nutrients, pH, suspended sediment, and fecal coliform bacteria. The results for each stream, creek, and river segment are compared to state standards. Future sampling may also monitor metals and toxic organic contaminants, such as pesticides.

Ecology has been sampling fresh water monthly since 1970. Under PSAMP, the design of Ecology's freshwater sampling program was modified to better reflect the goals of the ambient monitoring program. However, many of the elements of Ecology's old program remained unaffected, providing a long history of data that can be analyzed to determine long-term trends in water quality.

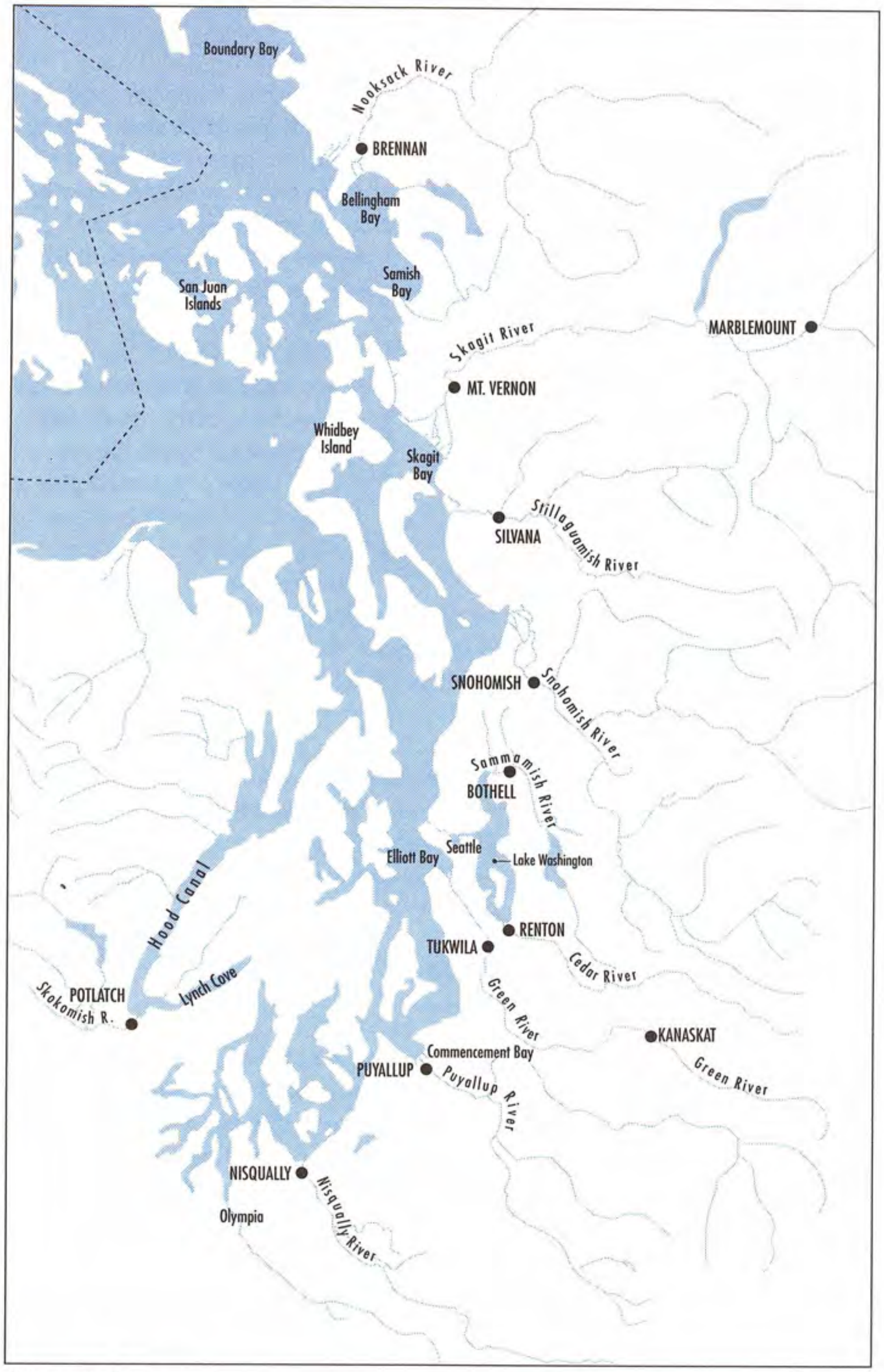


Figure 19. 1991 PSAMP freshwater sampling stations.

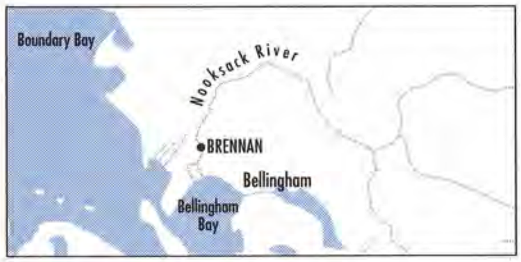
Reference: Hopkins, in press

1991 PSAMP FRESHWATER RESULTS

Analysis of Ecology's data from the past 10 years of river basin monitoring shows significant trends in the quality of Puget Sound's freshwater resources (Hopkins, in press). In addition, this long-term data record allows researchers to determine whether the results for each parameter sampled during 1991 were higher, lower, or within the range of what is expected based on 10 year averages. The results of these analyses for each river basin follow.

NOOKSACK RIVER AT BRENNAN

The Nooksack River has high levels of suspended solids, turbidity, and nutrients. The high levels of solids and turbidity are probably due to large amounts of glacial till (unconsolidated clay, sand, and gravel deposited by glaciers) within this watershed. The high nutrient levels, however, may be caused by agricultural practices and other human activities within the watershed. The Nooksack River also has problems with high levels of fecal coliform bacteria, which regularly violate water quality standards.

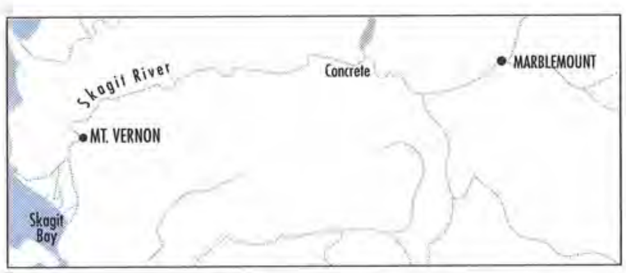


From 1979 to 1990 there were two highly significant trends in water quality. Turbidity decreased 2.2 percent per year, while pH increased at a rate of 0.3 percent per year. Although it is difficult to determine the causes and effects of these trends, both may be positive changes. The increase in pH means that the stream is becoming less acidic; the decrease in turbidity may reflect improved forestry, agricultural, or development practices which decrease levels of erosion and runoff.

Values for each parameter measured in 1991 were similar to values seen over the past 11 years. The only violation of water quality standards occurred in fecal coliform levels in February (800 organisms/100 ml) and September (220 organisms/100 ml). The state standard for fecal coliform levels is 200 organisms/100 ml.

SKAGIT RIVER AT MOUNT VERNON

Skagit River's water quality at Mount Vernon is excellent. There have been no violations of water quality standards in the past 10 years while sampling at this station. Data from the last 10 years show highly significant decreases in turbidity, ammonia, and nitrates. Turbidity decreased by an average of 7.4 percent each year. The decreases in nitrates and ammonia are difficult to quantify since the levels measured are close to the detection limit (the minimum level at which chemists can detect a chemical). These trends may point to the successful control of nonpoint pollution, which is often the source of nutrients and turbidity.



Temperature, flow, and suspended solids measured in 1991 were generally higher than the 10 year average, while dissolved oxygen, pH, and nitrates were generally below average. Despite the overall decreasing trend, turbidity in 1991 was higher than the 10 year average.

Shellfish beds in Skagit Bay are presently closed to commercial harvest due to fecal contamination. The lack of fecal coliform violations at the Skagit River station at Mount Vernon suggests that Skagit Bay's contamination is not due to far upstream sources. Sources along Skagit Bay or below Mount Vernon on the Skagit River, where dairy farms are numerous, are most likely responsible.

STILLAGUAMISH RIVER NEAR SILVANA

The Stillaguamish River violated water quality standards on five sampling dates in 1991. Temperatures exceeded the standard of 18°C in July (18.9°C) and August (20.8°C). The Stillaguamish River violated the fecal coliform standard in December (340 organisms/100 ml), February (230 organisms/100 ml), and September (680 organisms/100 ml). Most of the river's violations over the past 10 years have been for temperature and fecal coliform. Temperature violations are probably the result of forestry or development practices which involve the removal of streamside vegetation, increasing stream and river exposure to sunlight and resulting in higher temperatures.

Turbidity decreased significantly over the 10 year period, at a rate of 2.3 percent annually. Temperature appeared to be the only parameter in 1991 that measured higher than the 10 year average.

SNOHOMISH RIVER AT SNOHOMISH

The Snohomish River frequently violates temperature and fecal coliform standards, though other water quality parameters usually meet water quality standards. Temperature was the only parameter to violate standards in 1991. The August temperature of 21.2°C was among the highest temperatures recorded in over 30 years of sampling at this station.

A number of significant water quality improvements occurred in the Snohomish River over the last 10 years. Each year, on average, fecal coliform levels fell 1.6 percent, nitrates decreased 1.8 percent, and turbidity decreased 2.5 percent. If these trends continue, fecal coliform contamination will become less of a problem and result in fewer violations of the standard. The reasons for these improvements are not presently known, but it may be due to the implementation of best management practices at dairy farms, which are numerous along the Snohomish. High temperature, however, continues to be a problem. Over the last 10 years, half the July and August temperatures exceeded water quality standards.

For 1991, pH and fecal coliform levels were below normal (which accounts for the lack of violations of the fecal coliform standard), while suspended solids in the water ranged above the 10 year average.

SAMMAMISH RIVER AT BOTHELL

The Sammamish River's poor water quality is reflected by a number of the measured parameters. The river regularly violates standards for temperature and dissolved oxygen in the summer and fecal coliform throughout the year. Over the last six years it had the highest average temperature and fecal coliform levels, the second highest nutrient levels, and the second lowest oxygen levels of the rivers sampled.

Despite these violations, the last 10 years of data indicate that a number of parameters are improving. There have been significant decreases in turbidity (8.7 percent per year), fecal coliform (2.2 percent), and nitrates (1.6 percent), while pH has increased (0.2 percent). However, no improvements in temperature and dissolved oxygen—two important parameters which affect fish health—are apparent.

The 1991 monitoring results deviated from the 10 year averages. Turbidity, fecal coliform, phosphorus, ammonia, dissolved oxygen, and suspended solids were below average, while nitrates, flow, pH, conductivity, and temperature were above average. The Sammamish River violated water quality on nine sampling dates in 1991, more than any other river measured by PSAMP. The river exceeded fecal coliform standards in six months of the year, the temperature standard in July (20.8°C) and August (20.2°C), and the dissolved oxygen standard (>8.0 mg/l) in July (7.9 mg/l).

CEDAR RIVER AT RENTON

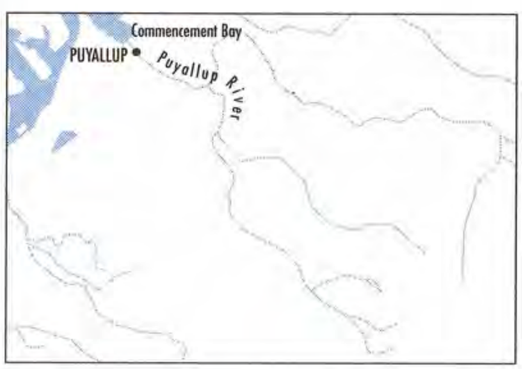
The Cedar River generally has good water quality, although it occasionally violates standards for high temperature and pH, and more frequently for fecal coliform during the fall and winter months. No water quality violations were observed during 1991, however. No significant trends in water quality were detected over the last 10 years.

GREEN RIVER AT TUKWILA

The Green River's water quality—the poorest of the major rivers monitored—was previously degraded by sewage from the Renton treatment plant which discharged into the Green River until 1987 (Hopkins, in press). In 1987, the Renton treatment plant was expanded and modernized and its outfall was moved to the Duwamish River head in Elliott Bay. After relocation of the outfall, a number of water quality parameters significantly improved in the river. Comparing data collected before and after relocation of the outfall, the river's temperature is 4.4 percent cooler, there is 13.3 percent less turbidity, ammonia levels are down 76.3 percent, phosphorus is 48.4 percent lower, and nitrates have decreased 13.9 percent since relocation. Dissolved oxygen (6.3 percent) and pH (1.4 percent) increased significantly. These changes represent marked improvements over previous conditions.

The Green River fixed station was originally located at Allantown in order to evaluate the effects of the outfall on river water quality. Recently the station was moved upstream to Tukwila to eliminate the effects of tidal inflow. Three violations of water quality standards occurred at the new station during 1991. Temperature exceeded state standards in July (18.7°C) and August (19.9°C). Fecal coliform levels exceeded the standard in February (870 organisms/100 ml). The data record at the new station is not long enough to support trend analyses.

PUYALLUP RIVER AT TACOMA



Puyallup River water quality is poor compared to most other major rivers, with high levels of fecal coliform, suspended solids, turbidity, and nutrients. Between May and October of 1991, fecal coliform levels violated state standards at five sampling times.

During 1991 monitoring, only flow levels appeared to be higher than normal in comparison to the past 10 years. Temperature is the only parameter showing a significant trend over the past 10 years, decreasing 1.4 percent annually. Fecal coliform levels do not appear to be decreasing, suggesting that bacterial contamination will continue to be a problem in the future, resulting in regular violations of the state standard unless better source controls are implemented.

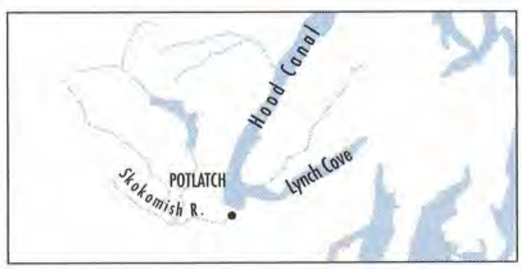
NISQUALLY RIVER AT NISQUALLY

The Nisqually River has excellent water quality and has rarely exceeded water quality standards over the last 10 years. The results from 1991 sampling indicate that water quality conditions are similar to conditions over that period.

Significant increases in pH (0.4 percent per year) and nitrates (2.0 percent) occurred over the last 10 years. The level of nitrates is presently low, but the increasing levels and the magnitude of that trend suggest that more sources of runoff may be affecting the river and should be monitored closely in future years. Decreasing trends in turbidity (1.8 percent per year), fecal coliform (0.1 percent), and ammonia (4.9 percent) were also evident.

The shellfish beds at Nisqually Reach were recently downgraded to conditionally approved. The infrequent fecal coliform violations and the small decreasing trend in fecal coliform levels over the past 10 years suggest that this closure may not be due to upstream sources on the Nisqually River.

SKOKOMISH RIVER NEAR POTLATCH



The Skokomish River rarely violates state water quality standards. There was one atypical violation in 1991. In March, pH was measured at 6.3—lower than the state standard of 6.5-8.5 pH units. This was the only violation of the pH standard in the last eight years for this river. The reason for this violation is not known. The Skokomish River did not exhibit any significant trends in water quality variables over the past eight years.

REFERENCES

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: Renton sewage treatment plant project: Seahurst baseline study. Q.J. Stober and K.K. Chew, eds. Prepared for the Municipality of Metropolitan Seattle. Seattle, WA.

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

Bothner, M.J. 1973. Mercury: some aspects of its marine geochemistry in Puget Sound, Washington. Ph.D. Thesis, University of Washington. Seattle, WA.

Bush, B., C.F. Tumasonis, and F.D. Backer. 1974. Toxicity and persistance of PCB homologs and isomers in the avian system. Archive Environmental Contamination Toxicology: 2:195-212.

Calambokidis, J. Personal communication, July 1992. Cascadia Research Collective.

Calambokidis, J., G.H. Steiger, L.J. Lowenstein, and D.S. Becker. 1991. Chemical contamination of harbor seal pups in Puget Sound. Prepared for the United States Environmental Protection Agency, Region 10. Seattle, WA. EPA contract no. 68-d8-0085.

Calambokidis J., G.H. Steiger, J.R. Evenson, J.C. Cubbage, and R.W. Osborne. 1992a. Individual identification of gray whales in Puget Sound and the Strait of Juan de Fuca. Proceedings of the Second Meeting on Puget Sound Research 1991. Vol. 1, pp. 414-424. Puget Sound Water Quality Authority. Olympia, WA.

Calambokidis, J., J.R. Evenson, J. C. Cubbage, P.J. Gearin, and S.D. Osmek. 1992b. Harbor porpoise distribution and abundance off Oregon and Washington from aerial surveys in 1991. Report to the National Marine Mammal Laboratory. National Marine Fisheries Service. Seattle, WA.

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

Chapman, P.M. and E.R. Long. 1983. The use of bioassays as part of a comprehensive approach to marine pollution assessment. Marine Pollution Bulletin: 14(3):81-84.

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.

Copping, A. E. 1982. The distribution and passage of organic matter in the marine food web using nitrogen as a tracer. Ph.D. dissertation, University of Washington. Seattle, WA.

Faber, R.A., R. W. Risebrough, and H.M. Pratt. 1972. Organochlorines and mercury in common egrets and great blue herons. Environmental Pollutution: 3:111-122.

Henny, C.J., L.J. Blus, R.A. Grove, and S.P. Thompson. 1991. Accumulation of trace elements and organochlorines by surf scoters wintering in the Pacific Northwest. Northwestern Naturalist: 72:43-60.

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, C.J., L.J. Blus, A.J. Krytinsky, and C.M. Bunck. 1984. Current impact of DDE on black-crowned night herons in the intermountain west. Journal of Wildlife Management: 48:1-13.

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

Hindar, K., N. Ryman, and F. Utter. 1991. Genetic effects of cultured fish on natural fish populations. Canadian Journal of Fisheries and Aquatic Science: 48:945-957.

Hopkins, B. In press. Freshwater ambient monitoring report for wateryear 1991. Washington Department of Ecology. Olympia, WA.

Hutchinson, I. 1988. Estuarine marsh dynamics in the Puget Trough—implication for habitat management. In: Proceedings of the First Annual Meeting on Puget Sound Research. pp. 455-462. Puget Sound Water Quality Authority. Seattle, WA.

Janzen, C.D. and L.B. Eisner. 1992. Marine water column monitoring program: annual report for wateryear 1991. Washington State Department of Ecology. Olympia, WA.

Kirchmer, C.J. 1971. 5_-Cholestan-3_-ol: an indicator of fecal pollution. Ph.D. Thesis, University of Florida.

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.

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.

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.

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. Environmental Science Technology: 18:705-713.

McCain, B.B., S.L. Chan, U. Varanasi, et al. 1988. Toxic chemicals in fish: effects on their health and reproduction. In: Puget Sound: Issues, Resources, Status, and Management. pp. 83-110. NOAA Estuary of the Month Seminar Series No. 8. National Oceanic and Atmospheric Administration. Washington, D.C.

Mumford, T.F., Jr., P. Peyton, J.R. Sayce, and S. Harbell, eds. 1991. Spartina workshop record. November 14-15, 1990. Washington SeaGrant Publication WSG-W091-01. Seattle, WA.

Murtaugh, J.J. and R.L. Bunch. 1967. Sterols as a measure of fecal pollution. Journal of the Water Pollution Control Federation: 39:404-409.

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). 1991. 1990 national shellfish register of classified estuarine waters. National Oceanic and Atmospheric Administration. Strategic Assessment Branch. Rockville, MD.

PTI Environmental Services. 1991a. Pollutants of concern in Puget Sound. Prepared for U.S. Environmental Protection Agency, Region 10. Seattle, WA. EPA 910/9-91-003.

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

Puget Sound Estuary Program (PSEP). 1991. Recommended protocols and guidelines for measuring selected environmental variables in Puget Sound. U.S. Environmental Protection Agency, Region 10. Seattle, WA.

Puget Sound Water Quality Authority (PSWQA). 1988. Puget Sound ambient monitoring program. Final Report. Puget Sound Water Quality Authority. Seattle, WA.

Puget Sound Water Quality Authority (PSWQA). 1990. Puget Sound update: first annual report of the Puget Sound ambient monitoring program. Puget Sound Water Quality Authority. Seattle, WA.

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

Puget Sound Water Quality Authority (PSWQA). 1992a. State of the Sound report. Puget Sound Water Quality Authority. Olympia, WA.

Puget Sound Water Quality Authority (PSWQA). 1992b. Puget Sound environmental atlas update. Puget Sound Estuary Program.

Risebrough, R.W., J.D. Davis, and D.W. Anderson. 1970. Effects of various chlorinated hydrocarbons. In: J.R. Gillett (ed.). The biological impacts of pesticides in the environment. Oregon State University. Corvallis, OR.

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

Schmitt, C. Personal communication. Washington Department of Fisheries. September 1992.

Speich, S.M., J. Calambokidis, D. Shea, J. Peard, M. Witter, M. Fry. In press. Eggshell thinning and organochlorine contaminants in western Washington waterbirds. Colonial Waterbirds: 15(1).

Striplin, P.L., P.J. Sparks-McConkey, H. Deitrich, and F.A. Svendsen. In preparation. Puget Sound ambient monitoring program: marine sediment monitoring task, 1991 annual report. Prepared for the Environmental Investigations and Laboratory Services Program of the Washington State Department of Ecology.

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

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

Washington State Department of Ecology (Ecology). 1992. 1992 statewide water quality assessment: 305(b) report. Water Quality Program. Olympia, WA.

Washington State Department of Fisheries (Fisheries). In preparation. Puget Sound ambient monitoring program: fish monitoring task, 1991 annual report. Olympia, Wa.

Washington State Department of Health (DOH). In preparation a. Human health impact assessment of the 1990 PSAMP tissue data. Office of Toxic Substances. Olympia, WA.

Washington State Department of Health (DOH). 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 (DOH). 1991. Fourth annual inventory of commercial and recreational shellfish areas in Puget Sound. Shellfish Section. Olympia, WA.

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

Washington State Department of Natural Resources (DNR). 1992. Spartina legislative report 1992.

Woodwell, G.M., C.F. Wurster, and P.D. Isaacson. 1967. DDT residues in an east coast estuary: a case of biological concentration by a persistant pesticide. Science: 156:821.

Young, D.R., A.J. Means, J. Tsu-Kai, T.C. Husen, M.D. Moore, R.P. Eganhouse, G.P. Hershelman, and R.W. Gossett. 1980. Trophic structure and pollutant concentrations in marine ecosystems of southern California. CalCOF1 Rep. Vol. XXI, 197.

CONTACT LIST

If you would like more information about the Puget Sound Ambient Monitoring Program, please contact the following:

Overall PSAMP Program, Puget Sound Update, Data Management
Puget Sound Water Quality Authority
P.O. Box 40900
Olympia WA 98504-0900
Chris Prescott
(206) 493-9410 or
1-800-54-SOUND

Sediments
Washington Department of Ecology
Pete Striplin
(206) 586-5995

Marine Water Column
Washington Department of Ecology
Carol Janzen
(206) 586-5495

Fish
Washington Department of Fisheries
Sandie O'Neill
(206) 902-2843

Shellfish
Washington Department of Health
Bob Woolrich
(206) 753-5957

Marine Mammal and Bird Abundance
Washington Department of Wildlife
Dave Nysewander
(206) 664-9348

Contaminants in Birds
U.S. Fish and Wildlife Service
Mary Mahaffy
(206) 753-9440

Estuarine Nearshore Habitat
Washington Deptartment of Natural Resources
Tom Mumford
(206) 902-1079

Fresh Water
Washington Department of Ecology
Brad Hopkins
(206) 753-2819

Human Health Effects
Washington Department of Health
Glen Patrick
(206) 753-1930

If you are interested in knowing more about citizen monitoring, please contact the following:

Adopt-a-Beach
Ken Pritchard
(206) 624-6013 (Seattle)

Chautauqua Northwest
Jane Hardy
(206) 223-1378 (Seattle)

Puget Sound Water Quality Authority
Chris Prescott
(206) 493-9300 (Olympia) or
1-800-54-SOUND