PUGET SOUND WATER QUALITY AUTHORITY

1993 Puget Sound Update

FOURTH ANNUAL REPORT OF THE PUGET SOUND AMBIENT MONITORING PROGRAM

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SUMMARY

Declining salmon populations, extensive loss of nearshore habitats, toxic chemical contaminants in most urbanized bays. The first question people usually ask upon hearing these facts is "how healthy is Puget Sound?" After four years of monitoring through the Puget Sound Ambient Monitoring Program (PSAMP), we are better able to answer that question. The information collected for this program tells us what types of problems are most serious, where those problems are most evident, and the changes that occur over seasons and between years.

The growing body of information on Puget Sound's water quality suggests that no area is entirely free from the consequences of human activities. The degree to which these activities affect different parts of the Puget Sound ecosystem varies widely. Some resources, such as sediments, shellfish, and nearshore habitats, show signs of widespread and serious degradation from past and present activities. Others, such as the water column (the water itself), do not show the serious contamination problems found in many estuaries across the nation.

So how does PSAMP diagnose Puget Sound's health? By examining five key indicators which measure the extent to which human activities adversely affect different parts of Puget Sound's ecosystem. The indicators are chemical contamination of sediments and biological organisms; fecal contamination of marine waters, fresh waters, and shellfish; types and amounts of nearshore habitat; abundance of biological resources; and conventional water quality.

1992 monitoring results for these indicators point to the following conclusions about the overall condition of Puget Sound:

CHEMICAL CONTAMINATION

Past monitoring has shown that chemical contamination poses a serious threat to Puget Sound. For example, birds show significant increases in tissue contaminants when feeding in Commencement Bay sediments and salmon migrating through urban estuaries may retain toxic contaminants for considerable periods of time, leading to lowered growth and survival rates. Data from several PSAMP sites support the hypothesis that organic enrichment (such as sewage) allows, for the most part, only pollution-tolerant species to flourish.

The worst problems occur in the sediments of urbanized bays. Sediments in portions of four urban bays—Commencement Bay, Eagle Harbor, Elliott Bay, and the area near the Naval Shipyard in Sinclair Inlet—are so contaminated that they have been declared Superfund sites by the Environmental

Reporting results of the Puget Sound Ambient Monitoring Program

The *1993 Puget Sound Update* is the fourth annual report of the Puget Sound Ambient Monitoring Program (PSAMP). It reports the results of sampling undertaken in 1992, the most current year for which the data have undergone analysis and quality assurance tests.

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. Monitoring is conducted away from the immediate proximity of pollution sources to evaluate the extent to which these pollution sources affect wider areas of the Sound.

Protection Agency (EPA). Throughout the Sound, most urbanized bays violate some sediment standards for metal or organic contaminants.

Chemical contamination of these bays is especially troublesome because contaminants tend to settle rapidly, accumulating in sediments close to their source. Contamination can be severe and long lasting in these areas because the toxic chemicals, for the most part, are not dissipating. However, because contaminants diminish rapidly with distance from their source, the effects of toxic chemicals on the overall health of Puget Sound are not as severe. PSAMP collects samples away from the immediate vicinity of pollution sources and, as a result, most of the sites monitored for the program do not show severe levels of sediment contamination.

1992 monitoring indicates that Sinclair and Dyes inlets exhibit chronic mercury contamination—ambient sites in these inlets exceeded sediment quality standards for mercury for the fourth consecutive year. For the first time, ambient sites in Elliott Bay exceeded sediment standards for PCBs (polychlorinated biphenyls). The significance of this violation is not known because of uncertainties that arose during chemical analysis. However, the Puget Sound Dredge Disposal Analysis Program also found PCB violations in a nearby station, supporting the conclusion that PCB contamination in Elliott Bay may be dispersing to ambient sites. Four years of sampling Commencement Bay sediments suggests that PAH (polynuclear aromatic hydrocarbon) levels are decreasing at the ambient stations, although there is not yet sufficient data to demonstrate this statistically.

Past studies, coupled with recent monitoring data, show that plant and animal life in Puget Sound can accumulate contaminants from sediments and in some cases experience adverse effects. Puget Sound harbor seals at one time had the highest measured levels of PCBs and DDTs in the world. These levels have decreased, but still remain high. English sole from several urban bays have an alarming prevalence of liver diseases. Birds wintering in Commencement Bay show significant increases in tissue contaminants over the four months in which they feed in Commencement Bay sediments.

Contaminants in the portions of marine animals most frequently consumed by people—such as the muscle tissues of fish and shellfish, do not appear to be at levels that threaten human health. Contaminants do not appear to pose a danger to human health because, in large part, we generally do not eat the most contaminated tissues within those organisms (the liver and gall bladder, for example). Toxic chemicals do, however, appear to jeopardize the health of the contaminated organisms themselves. In addition, people who depend almost exclusively on Puget Sound seafood for subsistence, or who consume whole organisms, may be exposed to higher levels of contaminants than estimated in studies used to assess human health threats.

FECAL CONTAMINATION

Fecal contamination is a tremendous problem that affects every part of the Sound, and sources of fecal coliform bacteria can be expected to increase as population continues to grow. Fecal contamination has already claimed over 40 percent of Puget Sound's commercial shellfish beds. More than half of the harvest restrictions in commercial beds have occurred during the last decade. Many of the recent shellfish bed closures or downgrades occurred because improved monitoring detected a problem that has existed for some time. More extensive monitoring has led to the improved safety of shellfish products, and as a result, Washington state now produces some of the safest shellfish in the world.

The fact that many other areas of Puget Sound continue to show historic levels of fecal coliform bacteria indicates that contamination is still a problem. Fecal coliform bacteria, found in mammal feces, indicate the possible presence of disease-causing bacteria in marine and fresh waters.

Increased monitoring in recent years has greatly expanded our knowledge of fecal contamination, enabling state, local, and tribal governments to more efficiently address problems in their communities. One of the first upgrades of shellfish beds closed during the past decade occurred last year at North Bay in Case Inlet. Several other recent upgrades seem to mark a turning point in the struggle to reduce fecal contamination. Since 1989, the Department of Health has upgraded 5,330 acres of commercial shellfish beds in Puget Sound.

For marine waters, lower levels of fecal coliform bacteria were present in 1992 than in previous years, probably due to lower levels of rainfall. Sinclair Inlet was the only ambient station violating standards for fecal coliform, which is the lowest number of violations observed in the program over the last three years. Offshore ambient stations monitored by the program often do not show high levels of fecal coliform bacteria, since the indicator bacteria used to track fecal contamination are thought to survive poorly in cold marine waters.

Of the ten major freshwater rivers in the Puget Sound basin, five exceeded fecal coliform standards: the Nooksack River at Brennan, the Stillaguamish River at Silvana, the Sammamish River at Bothell, the Green River at Tukwila, and the Puyallup River at Tacoma. These five rivers also violated standards in 1991, suggesting chronic problems with fecal contamination.

The Washington Department of Health recently evaluated the results of its sampling of shellfish for fecal coliform bacteria over the last several years. They found that bacteria levels in shellfish have not changed substantially since initial sampling,which was conducted in 1986-87. They also concluded that shellfish bacterial levels found at particular recreational sites are consistent with the classifications of adjacent commercial shellfish growing areas.

TYPES AND AMOUNTS OF NEARSHORE HABITAT

Nearshore habitats are extremely important to the health of Puget Sound and its marine life. These habitats—including mud flats, vegetation, cobble, and sand—not only provide critical spawning, rearing, and feeding areas, but also protect the shoreline from erosion and filter pollutants from the water. Nearshore salt marshes can also reduce flooding by retaining stormwater during high flow periods. Yet as important as these habitats are, we know little about the types, amounts, and locations of nearshore habitats, and even less about how habitat coverage is changing over time. What limited data we do have are disturbing, and indicate that much of the historical habitat, particularly in urban areas, has been destroyed or altered by human development.

Several efforts are beginning to document the composition and coverage of nearshore habitats throughout Puget Sound. The Washington Department of Natural Resources found that Commencement Bay—an urbanized water body—has a high percentage of altered habitat and artificial substrate, such as pilings, docks, and seawalls. Natural habitats such as mud flats and eelgrass are present, but tend to be confined to isolated areas where habitat alteration is less severe. In contrast, they found that Forest Beach—a rural water body—has a small percentage of artificial substrate, and is dominated by gravel, sea lettuce, and sandy substrates.

In evaluating the historical records of Commencement Bay's nearshore habitats the Army Corps of Engineers found evidence of widespread and dramatic habitat destruction. They estimate that 90 percent of the intertidal mudflats and 99 percent of the emergent marsh habitats have been destroyed since the earliest records dating back to 1877.

As these monitoring efforts continue, they will provide important information on the rate of habitat losses, the types of habitat that are most threatened, and the areas in which the most severe losses are occurring. Without this information we cannot evaluate the cumulative impacts of human activities on habitat coverage, and it becomes difficult if not impossible to effectively manage those activities to minimize damaging habitat losses.

ABUNDANCE OF BIOLOGICAL RESOURCES

Monitoring the abundance of biological resources has just begun during the last year. Many programs are in the early stages of collecting the long-term data needed to evaluate natural population variation and the effects of human activities on the abundance of natural populations. Except in cases where severe depletion or extinction has occurred, these programs need more time before much can be said about human effects on plant and animal populations.

The Washington Department of Fisheries analyzed the results of shellfish abundance surveys from 1991 and 1992. Over the course of these two years, they found significant decreases in the density of Manila clams at five of the 14 beaches sampled for PSAMP: North Sequim Bay State Park, Bywater Bay

(Wolfe Property and Shine Tidelands), Potlatch State Park West, and Penrose Point State Park. Native littlenecks decreased significantly at two beaches (Potlatch State Park East and Penrose Point State Park) and increased significantly at North Sequim Bay State Park. Oyster densities did not change significantly at any of the three beaches sampled for PSAMP.

Since only two years of data are available, it is not yet possible to determine the causes or importance of the observed changes. Wide variations from year to year in response to factors such as temperature, storms, food supply, reproductive success, and predation make it difficult to distinguish which of these changes in abundance were caused by human activities and which were a result of natural factors. It often requires many years of data merely to assess the degree of variation that occurs between years.

A recent study, the Salmon and Steelhead Stock Inventory, evaluated the health of stocks throughout the state. For the Puget Sound basin, the inventory found that 44 percent of the existing stocks are "healthy," 21 percent are "depressed," five percent are in "critical" condition, and the status of 29 percent of the stocks is unknown. Other sources of information indicate that nine stocks are extinct within Puget Sound.

The Washington Department of Wildlife collected data on bird abundances during summer 1992 and winter 1992-93 surveys, the first round of continuing semi-annual surveys. They found that birds appeared to be more abundant in the south Sound bays in the winter survey than in the summer survey. Birds also seemed to be more concentrated along shorelines, river deltas, and in protected bays in the winter. The San Juan Islands, Admiralty Inlet, and the Strait of Juan de Fuca had higher concentrations of birds in the summer than in the winter. These observed concentrations may reflect migration and feeding patterns, or a preference for sheltered sites and avoidance of open and exposed parts of the Sound during the colder and windier winter season. However, it is not known whether these concentrations are consistent between years, since the observations are based on only one set of surveys.

CONVENTIONAL WATER QUALITY

PSAMP also monitors Puget Sound for conventional water quality problems—nutrient enrichment, low dissolved oxygen, excessive acidity or alkalinity and high water temperatures. Unlike many East Coast estuaries, eutrophication, or excessive organic enrichment, does not appear to be one of the more serious problems affecting Puget Sound's water quality. This may be due to the fact that the open bays and basins of the Sound are generally well-mixed. These conditions may work to make the Sound more resistant to human sources of nutrients than other estuaries, such as Chesapeake Bay, where eutrophication is such a serious problem.

In some of the shallow or poorly mixed bays of Puget Sound, however, the early signs of eutrophication are evident. Areas in Hood Canal and South Sound have frequent algal blooms and nutrient depletion in the summer. At nearly all of the Hood Canal sites, oxygen depletion is a chronic problem. The concentrations of ammonia present in several areas—including Sinclair

Inlet, Liberty Bay, Budd Inlet, Commencement Bay, Dyes Inlet, and Oakland Bay—indicate significant human sources of nutrients, most likely from improperly treated sewage or failing on-site sewage systems (also referred to as septic systems).

Other conventional water quality problems are evident in the rivers of the Puget Sound Basin. Four rivers—the Stillaguamish, Snohomish, Sammamish, and the Green—have exceeded temperature standards for the last two years. The Sammamish River was also the only one of the ten major rivers in the basin that violated oxygen standards, which it did for five consecutive months. In general, the data over the last two years make it clear that the Sammamish River has some of the poorest water quality of the ten major rivers in the Puget Sound basin.

INTRODUCTION

HOW HEALTHY IS PUGET SOUND?

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

Today, in many ways, PSAMP is reaching a critical point—we are increasingly seeing the benefits of initial and ongoing monitoring. As the body of data grows, our knowledge of the types and dynamics of water quality problems becomes more definitive. At the same time, the growing body of information on the Sound's water quality suggests there is no simple answer to the question, "how healthy is Puget Sound?" No area is entirely free from the effects of human activities, but the degree to which these activities affect different parts of the Puget Sound ecosystem varies widely. Some resources, such as sediments, shellfish, and nearshore habitats, exhibit widespread and serious degradation. Others, such as the marine water

Table 1. Description of full PSAMP design and implementation.

Task	Agency	FULL IMPLEMENTATION Number of Stations/Surveys	Frequency of Sampling	1989 - 1992 IMPLEMENTATION Number of Stations/Surveys	Sampling dates/ frequency
Sediment quality Sediment chemistry Bioassays Benthic invertebrates	Ecology	75 throughout PS	Annually - spring	48 throughout PS	March-April, 1989-92
Marine water column	Ecology				
Long-term trends		10-12 throughout PS	Monthly	24 throughout PS	Monthly, 1990-92
Known water quality problems		5-10 in selected bays	Seasonally	3 selected bays	Seasonally, 1992
Algal growth		5-10 in selected bays	Summer/winter solstices	No activity	No activity
Fish	Fisheries				
Tissue chemistry (bottomfish)		21 stations	Annually - early summer	10 stations	May 1989, 1991, 1992
Liver histopathology (bottomfish)		21 stations	Annually - early summer	10 stations	May 1989, 1991, 1992
Tissue chemistry (cod, rockfish, salmon)		5-10 stations	Annually, depending on species	2-6 stations	Pacific cod - Feb. 1990, 1992 Rockfish - Oct. 1989, 1991 Salmon - April 1990
Shellfish	Health & Fisheries				
Abundance		35 beaches	Annually	10 beaches	Summer 1991, 1992
Bacterial contamination		35 beaches	Quarterly	20 beaches	Quarterly, 1990-92
Tissue chemistry		35 beaches	Annually	10 - 20 beaches	Annually, 1990-92
Paralytic shellfish poisoning		35 beaches	Monthly (or more often)	16 beaches	Monthly (or more), 1990-92
Birds	Wildlife & USFWS				
Abundance		Surveys throughout PS	Semi-annually	Surveys throughout PS	Summer 1992, Winter 1992-93
Tissue chemistry		3-5 stations	Semi-annually	No activity	No activity
Marine mammals	Wildlife	Surveys throughout PS	Annually	Surveys throughout PS	Summer 1992, Winter 1992-93
Nearshore habitat Area and type	Natural Resources	One-third of PS	Annually	Surveys throughout PS	Summer 1991, 1992
Fresh Water	Ecology	75 throughout watersheds	Monthly	10 major PS basin	Monthly, 1990-92

column, do not appear to be seriously contaminated.

The *1993 Puget Sound Update*—the fourth annual report of this program—evaluates the data collected by PSAMP in 1992 (the most recent year for which the data have undergone quality assurance review and interpretation) and compares these data to past information on Puget Sound water quality. Where data are available from other programs, they are included to provide a more complete assessment of water quality conditions within the Sound.

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

The six implementing agencies are responsible for collecting data and producing technical reports on monitoring results. The Puget Sound Water Quality Authority is responsible for program coordination and data management, as well as annual production of the Puget Sound Update. The agency technical reports contain more detailed information about specific findings from each monitoring task, and are available from the implementing agencies (please see the contact list provided at the end of this report). More extensive background information 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 *1992 State of the Sound* (PSWQA, 1992) and the Puget Sound Water Quality Management Plan.

DETERMINING THE HEALTH OF PUGET SOUND

We measure the condition of Puget Sound by looking at five key indicators of estuarine health. These indicators are a measure of the extent to which human activities harm different parts of the Puget Sound ecosystem. The indicators are:

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

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

Fecal contamination. Failing on-site sewage systems (septic systems), improper sewage treatment, boat waste discharge, stormwater runoff, marine mammal feces, and runoff from pet and farm animal waste introduce pathogens contained within fecal matter into estuarine waters. Shellfish, which filter estuarine waters for food, can accumulate these pathogens and become contaminated.

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

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

Monitoring Puget Sound's health

PSAMP agencies use three types of monitoring to evaluate the effect of human activities on water quality: compliance monitoring, intensive surveys, and ambient monitoring.

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

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

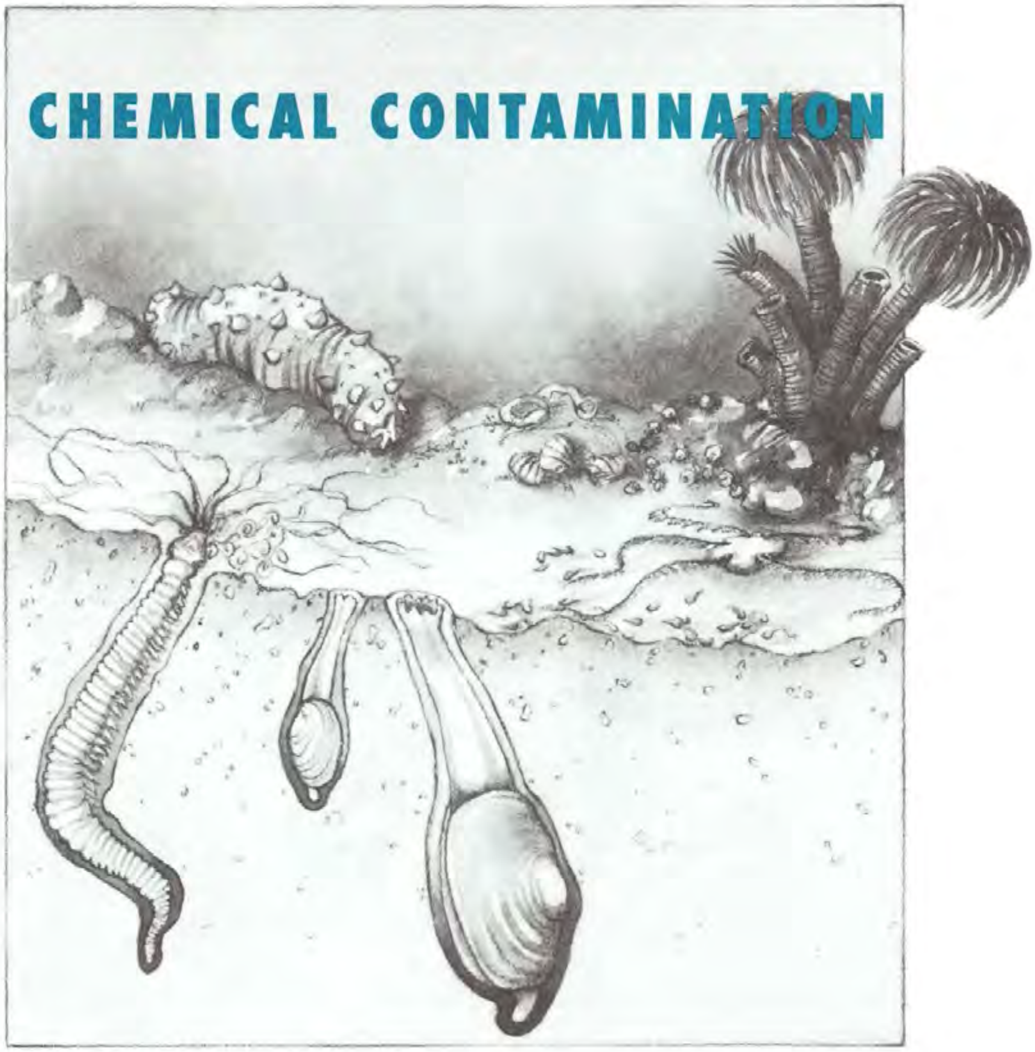
Ambient monitoring is conducted away from the immediate proximity of pollution sources and evaluates the extent to which these sources affect wider areas of the Sound. To be useful, ambient monitoring must be conducted over long periods at regular intervals (usually monthly or annually). Sampling is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

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

Conventional water quality. Conventional water quality problems include oxygen depletion, sedimentation, excessive acidity or alkalinity, and high water temperatures, all of which are caused by a variety of activities. Eutrophication is one of the more common and serious conventional water quality problems affecting estuaries across the nation. It is caused by a number of human activities that contribute nutrients and organic matter to the estuarine environment. In waters with limited circulation, this can result in algal blooms, oxygen depletion, foul odors, and fish kills—all signs of eutrophication.

Editor's Note: The 1993 Puget Sound Update's chapters have been reorganized based on the five indicators used to determine the condition of Puget Sound. Our intention is to make it easier for you to access monitoring results and determine how they fit into the overall patterns of Puget Sound's water quality. Reviewing the table of contents, which provides a outline of each chapter, will familiarize you with the new organization.

CHEMICAL CONTAMINATION

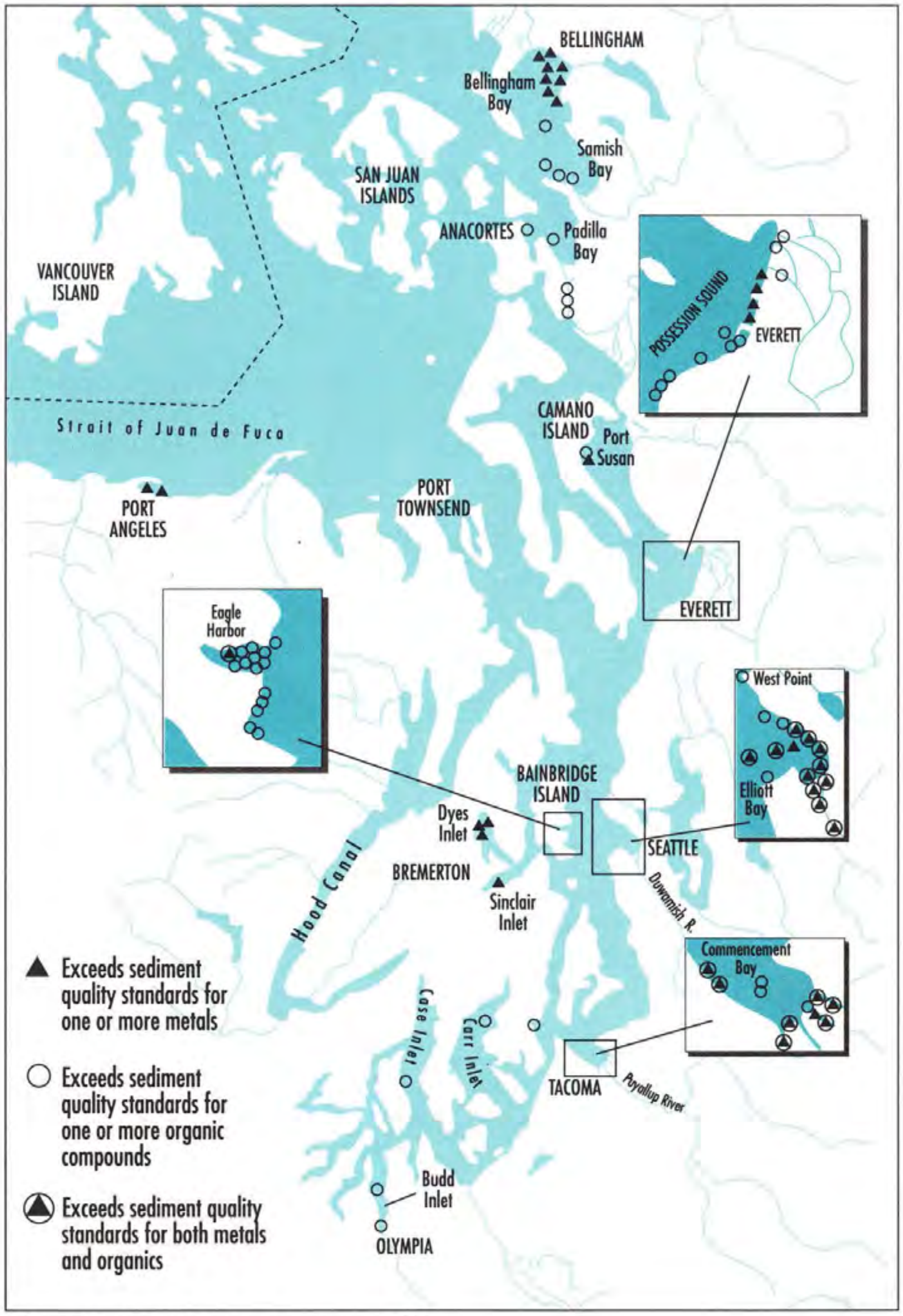


BACKGROUND

From polycyclic aromatic hydrocarbons in Eagle Harbor to mercury in Sinclair Inlet, chemical contamination of Puget Sound is a serious problem. Sediments in urban bays, where industries and sewage treatment plants are concentrated and stormwater runs off developed areas, contain the highest levels of metals and organic chemicals. Scientists have found evidence that these contaminants are taking their toll on the Sound's biological resources—English sole from several urban bays have an alarming prevalence of liver diseases (Fisheries, in preparation) and birds feeding in Commencement Bay sediments during the winter showed significant increases in tissue contaminants during their short stay (Henney et al., 1990, 1991).

Three sites in central Puget Sound—within Commencement Bay, Elliott Bay, and Eagle Harbor—have been declared Superfund sites by the Environmental Protection Agency (EPA) because of the extremely high levels of toxic chemicals found in their sediments. A fourth—near the Naval Shipyard within Sinclair Inlet—was added in 1993. Many other nearshore sites and urban bays are severely contaminated and exceed state sediment standards for metals or organic chemicals (Figure 1).

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



Reference: PSWQA, 1992; Dutch et al., in preparation, 1993

The Puget Sound Water Quality Management Plan (PSWQA, 1991) defines a contaminant as "a substance that is not naturally present in the environment or is present in amounts that can, in sufficient concentration, adversely affect the environment." Chemical contaminants are primarily heavy metals and a variety of organic chemicals. Many of these, including all metals and petroleum hydrocarbons, occur naturally. Others, such as synthetic organic chemicals (chlorinated pesticides, for example) occur in the environment solely as a result of human production. In either case, when concentrations in the water exceed the capacity of the marine environment to assimilate them, these substances can harm Puget Sound.

EFFECTS OF CHEMICAL CONTAMINANTS

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

When evaluating the effect of metals and organic chemicals on Puget Sound, scientists measure contaminant concentrations in sediments and their effects on biological populations most likely exposed to sediment contaminants (bottomfish, shellfish, benthic communities). Results from this monitoring provide an assessment of the amount of contaminants in the Sound, how chemical contaminants affect fish, birds, and mammals in the Sound, and the potential risk to humans consuming these resources. Because chemical contaminants are generally found in low or undetectable amounts in the water itself—particularly at the ambient sites sampled by PSAMP—the program does not monitor metals or organic chemicals in the water column.

The results compiled by PSAMP indicate that, with a few exceptions, sediments and their associated contaminants tend to settle out in the vicinity of their sources (PSWQA, 1992). While this means that the chemical contaminants introduced in large amounts into urban bays are less likely to affect broader areas of the Sound, it also means that these contaminants are not dispersing or diluting. Instead they are continuously accumulating near their sources—in a sense creating toxic "banks" of pollution that do not disperse readily—and can only be cleaned up by dredging, treating, and disposing the sediments in which they are contained, or by covering them up with clean sediments.

The tendency of chemical contaminants to accumulate within the sediments rather than the water column does not mean that these pollutants are unlikely to cause harm. Sediments are an extremely important and productive part of the Puget Sound ecosystem. They provide food, shelter, and rearing grounds for many marine plants and animals. Crabs, shrimp, clams, oysters, and bottomfish rely on sediments for food or habitat. Even seemingly inconsequential species, such as the abundant and diverse species of worms typically found in sediments, are important because they are a significant food source for birds and fish. When sediments become contaminated, species feeding on them are also likely to become contaminated, and their health and populations may be threatened. In addition, whether people eat those species directly or feed upon organisms that have fed upon contaminated sediment dwellers, humans are exposed to those contaminants.

SOURCES OF CHEMICAL CONTAMINANTS

Chemical contamination often conjures images of industrial plants spewing dark toxics into the water or large farms spraying clouds of pesticides. But government, industrial, and agricultural programs developed over the last several decades are significantly reducing chemical pollutants from these sources. Industrial pretreatment programs, tighter regulation and monitoring of industrial and municipal discharges, implementation of environmentally responsible agricultural practices, and educational programs are a few examples of efforts that have reduced pollutants.

This is not to say that pollution from municipal, industrial, and agricultural sources no longer occurs. To date, no treatment method can completely remove all traces of pollutants, and even the most careful application of pesticides may produce some runoff into nearby waters. In addition, the technologies available to treat many pollutants are extremely expensive or only partially effective. For example, the best available technologies cannot remove highly toxic chlorinated dioxins—produced during the paper bleaching process—in wastewater to levels that are completely safe for the environment. Furthermore, malfunctions in treatment facilities, spills, and illegal chemical dumping introduce large quantities of chemical pollutants into Puget Sound.

But industrial and agricultural practices are only part of the chemical contamination problem. Improved environmental monitoring of potential chemical sources is revealing that many other activities send significant amounts of metals and organic chemicals into Puget Sound every day. Improper disposal of household hazardous wastes (such as paint, used motor oil, and household cleaners) and improper application of household pesticides and herbicides can contaminate Puget Sound. One of the biggest culprits is the automobile. Leaking oil, gasoline drips and spills, zinc and other metals contained in tires, and numerous compounds contained in exhaust are all deposited on roads and driveways and (in the case of exhaust) in the air. Rains then wash these compounds into storm drains, and out to Puget Sound.

1992 SEDIMENT MONITORING RESULTS

As part of the Puget Sound Ambient Monitoring Program, Washington Department of Ecology (Ecology) scientists sample marine sediments for three distinct measures of sediment quality:

- The amount of heavy metals and organic chemicals in sediments.
- Toxic effects on laboratory organisms exposed to sediments (bioassays).
- The numbers and types of animals (benthic invertebrates) living in the sediment.

The latter two measures—known as biological methods—provide important information that complements chemistry data. It would be impractical and prohibitively expensive to measure all of the hundreds of thousands of chemicals present in the environment, and some chemicals can interact in unpredictable ways that increase their toxicity (synergism). Biological methods are sensitive to toxic conditions that chemical analyses alone may not detect.

Ecology collects surface layer sediments (0-2 cm) using a grab sampler at 48 stations per year throughout Puget Sound (Figure 2). Thirty-four of these are stations that are sampled once each year. The remaining 14 are rotating stations that are cycled between north, central, and south Puget Sound every three years.

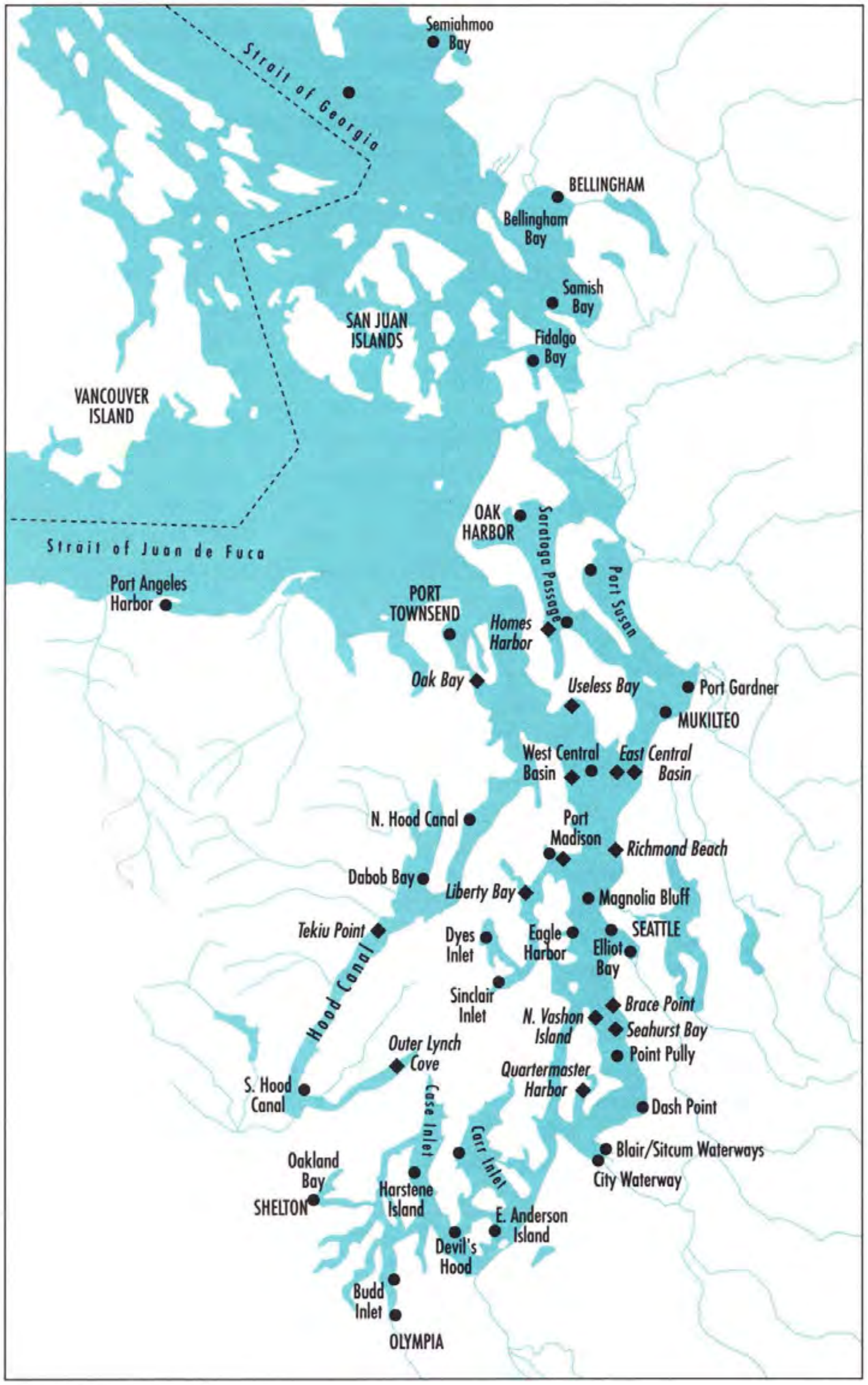


Figure 2. 1992 PSAMP sediment monitoring stations.

Reference: Dutch et. al., 1993

The rotating stations in 1992 were located in central Puget Sound. Most samples were taken from water depths of 20 meters, with a few collected from the deep basins of the Sound (approximately 100 to 250 meters deep). Each sediment sample is processed and shipped to laboratories for analysis of toxic chemicals, for bioassays, and taxonomic identification of benthic invertebrates. Most of the chemicals monitored for the program are chosen because they are "chemicals of concern" that pose potential threats to human health and the environment. Some are also monitored because they are associated with industrial discharges, are breakdown products of harmful chemicals (for example, DDE is a breakdown product of DDT), or are otherwise associated with harmful substances (for example, beta coprostanol is commonly associated with sewage).

1992 SEDIMENT CHEMISTRY MONITORING RESULTS

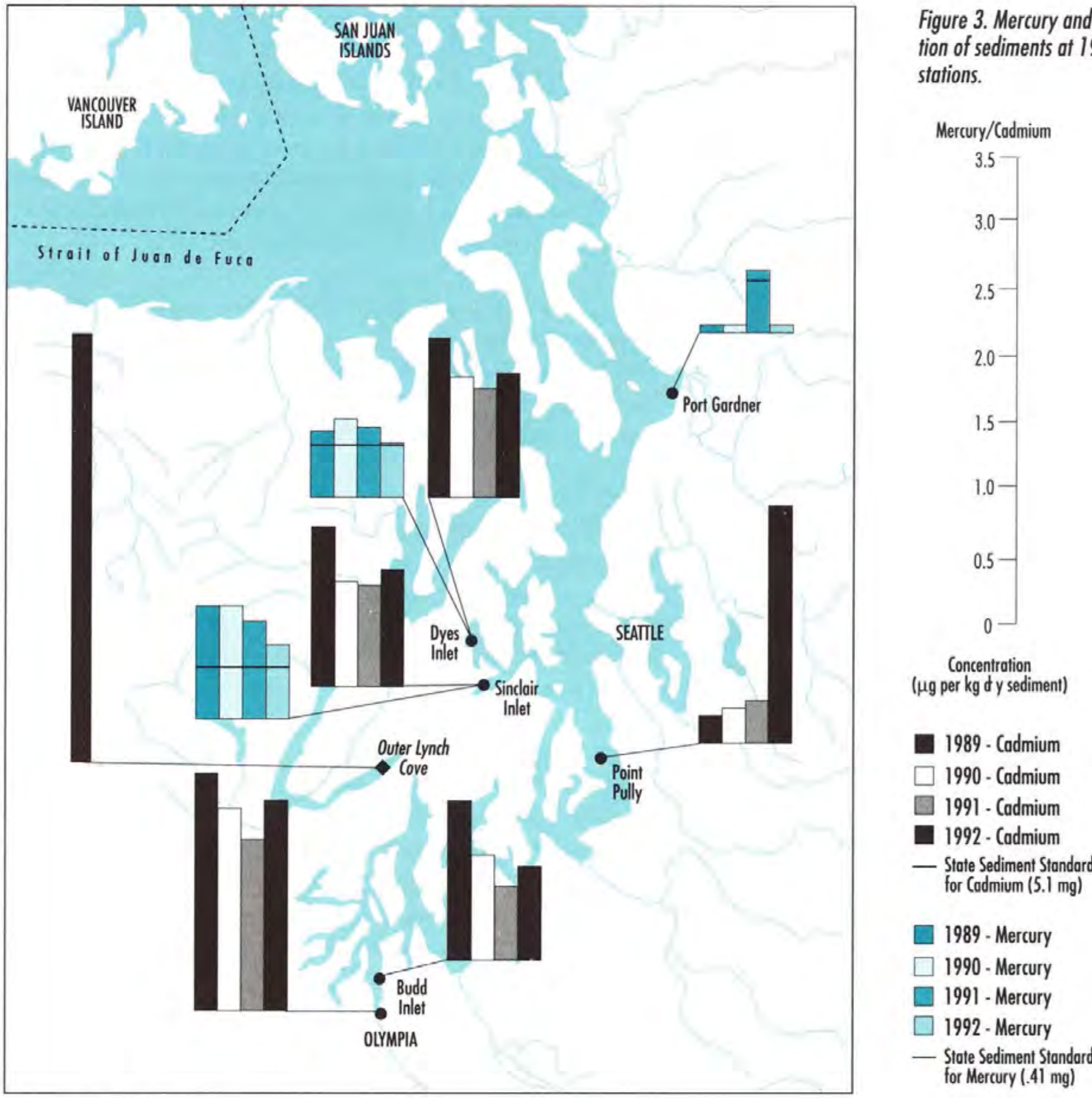
Monitoring shows that sediment contamination is most severe near pollution sources and diminishes rapidly with distance from its source since toxic contaminants settle out rapidly (Figure 1) (PSWQA, 1992). Because PSAMP is an ambient monitoring program that samples conditions away from the immediate vicinity of pollution sources, most of the sites monitored for PSAMP do not show severe levels of sediment contamination. Thus, for example, Commencement Bay—which contains Superfund sites and has highly contaminated sediments in the waterways—does not exceed sediment standards at the ambient stations sampled by the program. However, information from ambient stations describes important baseline conditions and long-term trends within the Puget Sound basin. In addition, ambient sites act as an early warning network, alerting us if contamination spreads from the vicinity of its sources to wider areas of the Sound. Ambient sites that exceed sediment quality standards are indicative of severe contamination in the nearshore areas closer to sources.

The Washington Department of Ecology (Dutch et al., 1993) found the following results from 1992 sediment chemistry monitoring:

Metals

Ecology found measurable levels of metals in the sediments at all 48 sampling stations. Mercury was the only metal found at levels above state sediment standards at ambient sites. For the fourth consecutive year, the Sinclair Inlet and Dyes Inlet sites exceeded the mercury standard of 0.41 parts per million (ppm) (Figure 3). It is clear that this area has a chronic mercury contamination problem. Possible sources of mercury include a number of industrial processes, such as mining operations and chloralki production, as well as improper disposal of industrial and domestic products, such as thermometers and batteries. In the past, mercury was also used as an antifouling agent in marine paint, frequently resulting in sediment contamination near marinas and ship repair facilities (PTI, 1991a). The Department of Ecology is working with the Naval Shipyard in Bremerton to evaluate the sources and extent of sediment contamination in Sinclair Inlet. Preliminary indications are that some of the mercury contamination may be coming from spent sandblast grit containing mercury-based paint chips used as backfill material at the shipyard. During storms, runoff and infiltration

Figure 3. Mercury and cadmium contamination of sediments at 1992 PSAMP sampling stations.



Reference: Dutch et al., 1993

from fill areas may wash metals associated with such debris into nearby sediments (Rogowski, Ecology, personal communication).

Port Gardner, where Ecology found mercury levels above state standards in 1991, had low levels in 1992. It is probable that the 1991 mercury value is the result of sampling a hot spot (an isolated area with high contaminant levels). Ecology reviewed quality assurance/quality control reports and could find no evidence that the 1991 measurement was in error. Hot spots can result from sampling near an isolated pollution source (for example, a disposed battery) and are not necessarily indicative of more widespread conditions. Results from the other three years of sampling suggest that mercury contamination is not a serious problem at Port Gardner (Figure 3).

Results from the Puget Sound Dredged Disposal Analysis Program (PSDDA) indicate mercury exceedances in Elliott Bay not detected by PSAMP sampling. Station EBS02 exceeded sediment standards for mercury with 0.59 ppm, and all three replicates at station EBB02 exceeded sediment standards (the mean is 0.50 ppm; standard deviation 0.01 ppm) (SAIC, in preparation). The exceedance of the mercury standard at two separate sites, and in three different replicates for one of these sites, strongly indicates that mercury contamination is a problem in parts of Elliott Bay.

Results from sampling at PSAMP and PSDDA sites within Elliott Bay, however, indicate that mercury contamination is not serious throughout all of Elliott Bay. The value measured at the PSAMP site in 1992 (0.14 ppm) is much lower than the values at EBS02 and EBB02. In addition, other PSDDA stations in Elliott Bay did not exceed the mercury standard in 1992.

The only other metal measured at levels approaching state standards was cadmium at Lynch Cove near Belfair (Figure 3), at 63 percent of the standard. The sources of cadmium at this site are not known. As with most metals, cadmium occurs naturally, although the level at this site is almost twice as high as at any other PSAMP station in the Sound measured in the last four years. Cadmium can result from a number of activities, including metal plating, fossil fuel combustion, and incineration of municipal waste.

All other metals measured well below (less than 50 percent) the state sediment standards. The results for other metals suggest that Sinclair and Dyes inlets may have general problems with metal contamination. Sinclair Inlet had the highest concentration of six metals: barium (90.5 ppm), copper (116 ppm), lead (72.6 ppm), mercury, silver (1.8 ppm), and zinc (172 ppm). Dyes Inlet had the second highest concentration of lead (64.6 ppm), mercury, silver (0.84 ppm), and zinc (131.0 ppm), and the fourth highest concentration of copper (72.7 ppm). Metal concentrations at Sinclair and Dyes inlets were consistently within the ten highest concentrations for nearly every metal analyzed. While these concentrations are well below standards, the pattern is consistent and notable, given that PSAMP stations are located well away from contamination sources. In nearshore areas close to sources, concentrations are likely to be much higher, in some cases exceeding state standards.

A few additional stations had consistently elevated levels of metals when compared to other PSAMP stations. There was a marked increase in cadmium at Point Pully in East Passage, the site with the second highest concentration in 1992. As with Port Gardner this may be due to sampling variability, which will be determined by future sampling. Point Pully had the second highest level of cadmium at 1.78 ppm. Cadmium levels in one of the four replicates at this station were an order of magnitude higher than the other values, suggesting that a hot spot was sampled. The ranking of the other metals was unaffected by inclusion of this replicate. Point Pully also had the third highest levels of arsenic (13.2 ppm), lead (60.6 ppm), and silver (0.50 ppm), and the fifth highest concentration of mercury (0.18 ppm). The highest levels of cadmium and arsenic (16.8 ppm) showed up in Lynch Cove, which also had the third highest levels of chromium (64.8 ppm) and copper (90.9 ppm). Holmes Harbor on Whidbey Island had the second highest levels of arsenic (15.8ppm) and chromium (73.3 ppm), and the fourth highest zinc levels (99.9 ppm). These metals all occur naturally in Puget Sound sediments and are well below levels thought to adversely effect benthic communities (PTI, 1988). However, the patterns of elevated metal concentrations are notable, since many of these sites also have sparse benthic communities (see page 23).

Organic Chemicals

Ecology found low levels of toxic organic chemicals at stations surveyed in 1992. As in past years, organic chemicals tended to be most concentrated in urban and industrial bays. Elliott Bay, Eagle Harbor, City Waterway in Commencement Bay, and Dyes Inlet had the highest concentrations of polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs).

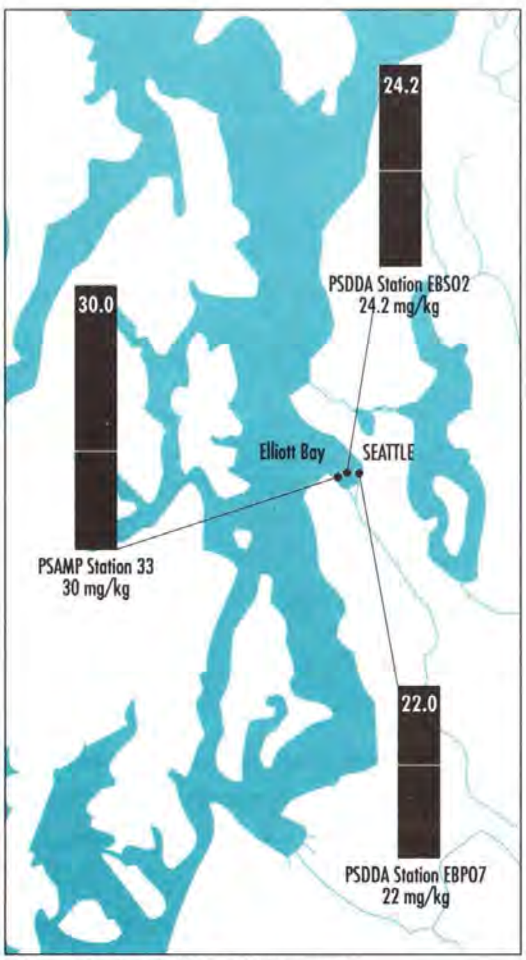
The levels of total PCBs and several PAH compounds in the sample from Elliott Bay were above state sediment standards in 1992 (Figures 4, 5 and 6). Several caveats apply to the violations of sediment standards at Elliott Bay. They relate to uncertainties in the chemical analysis of sediments and to the conservative approach state sediment quality standards use when chemicals are undetected in a sample (see "Analytical uncertainties in PCB violations at Elliott Bay," page 21). While the PCB values should be interpreted with caution, the PAH values contain fewer uncertainties and for several compounds exceed the standard by 50 percent or more.

PCBs and PAHs in Puget Sound

PCBs (polychlorinated biphenyls) are highly toxic, persistent chemicals that were used as coolants and lubricants in electrical equipment such as transformers before being banned in 1977. Because old electrical equipment is still in service and because these compounds are extremely persistent, PCBs continue to appear in sediment samples. PAHs (polycyclic aromatic hyrdocarbons) are breakdown products of petroleum hydrocarbons, such as oil and gasoline, and other organic materials, such as wood. PAH concentrations are usually highest in urban areas, where automobiles, oil spills, and petroleum products are most concentrated. HPAHs (high molecular weight PAHs) are derived from the combustion of organic compounds. LPAHs (low molecular weight PAHs) are derived from uncombusted organic materials.

It is not known whether the levels measured in the Elliott Bay sample adversely effect the benthic communities. Toxicity tests and benthic community assessments did not indicate negative impacts on the biological communities (Dutch et al., 1993).

While there are several uncertainties in the PCB values from Elliott Bay, data from the Puget Sound Dredged Disposal Analysis Program (PSDDA) provide strong support that PCB contamination in Elliott Bay exceeds state standards. The PSDDA program monitors sediment quality at dredged disposal sites to assess toxic effects from sediment disposal. In 1992 PSDDA measured levels of PCBs above the state sediment standards at site EBS02 (Figure 4). The organic carbon normalized value for total PCBs at this site was 24.2 ppm



Reference: Dutch et al., 1993; SAIC, in preparation

Figure 4. Exceedances of PCB sediment quality standard in Elliott Bay.

— State standard (12 mg/kg organic carbon)

Figure 5. 1992 LPAH levels in Elliott Bay, south side (Dutch et al., 1993)

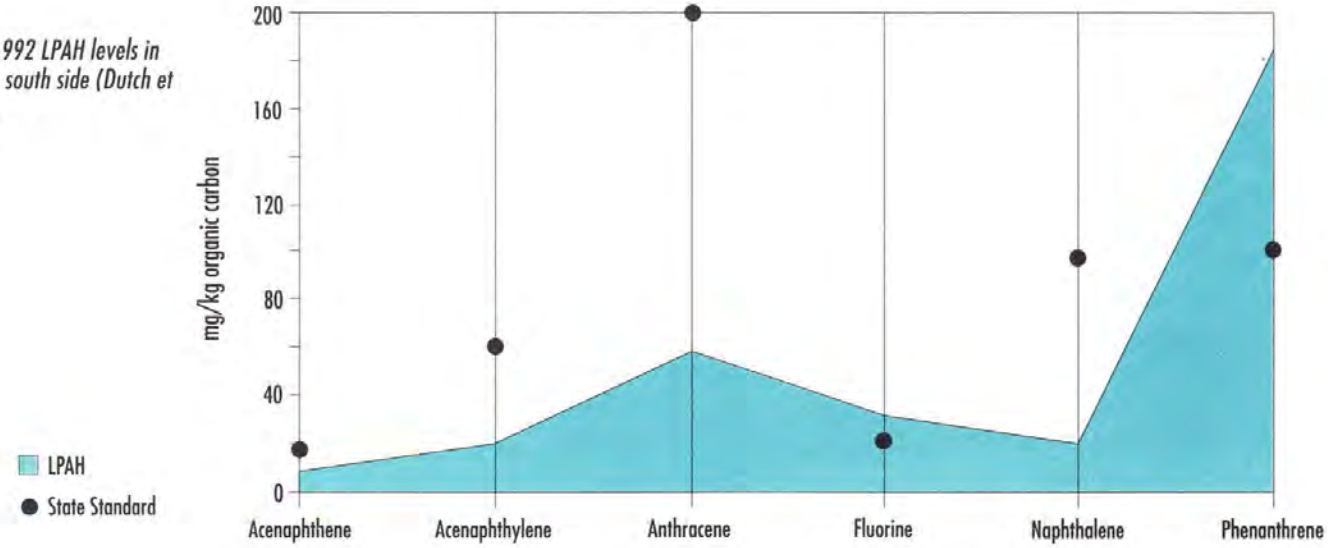
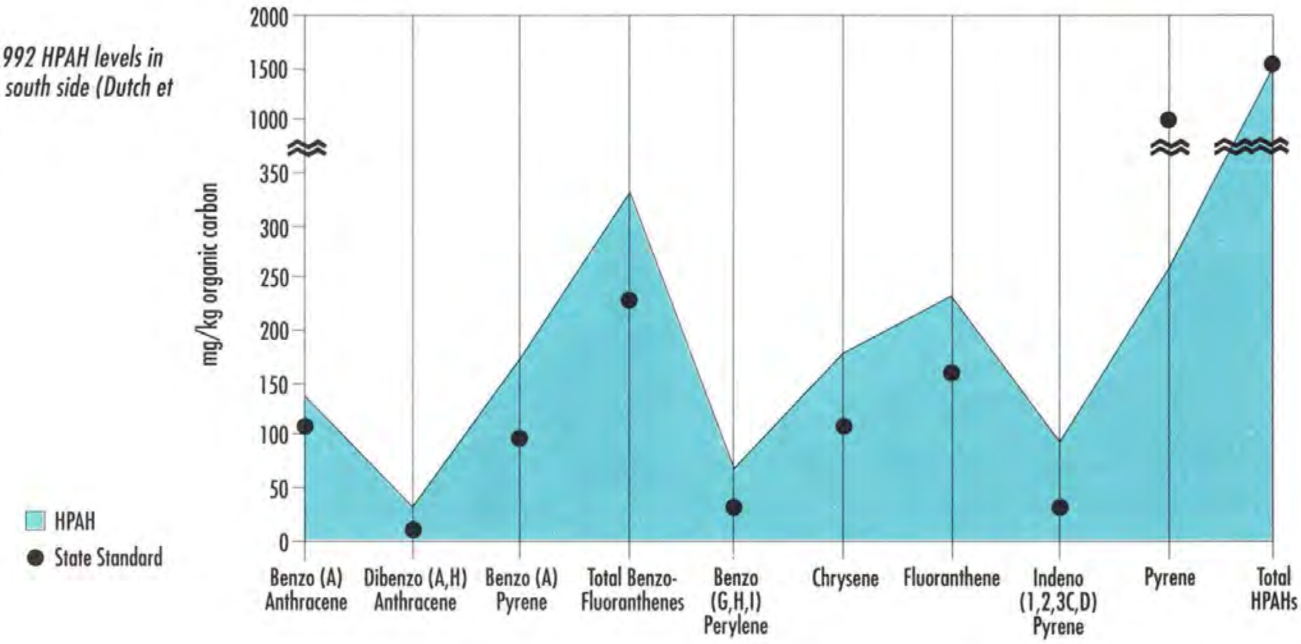


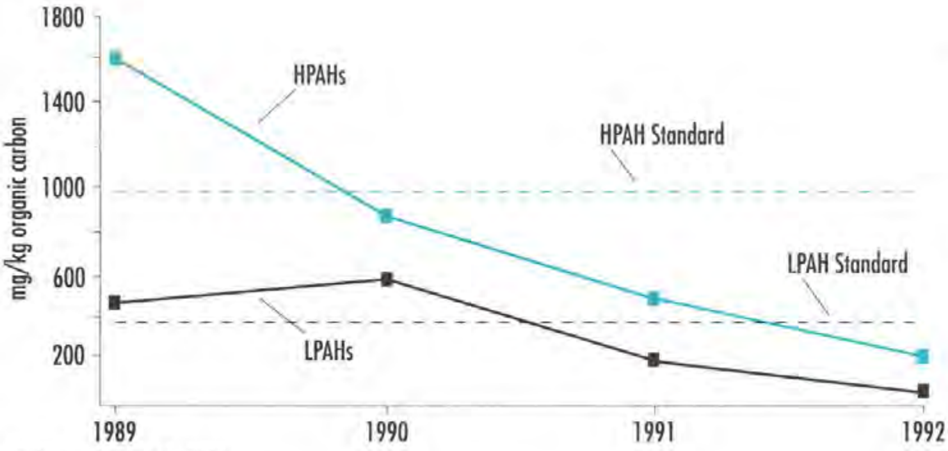
Figure 6. 1992 HPAH levels in Elliott Bay, south side (Dutch et al., 1993)



carbon, which is twice the standard (see "Analytical uncertainties in PCB violations at Elliott Bay," page 21, for a definition of organic carbon normalization). This site had an organic carbon content of 1.4 percent, which is typical of Puget Sound sediments. Station EBP07 also violated PCB standards. The average organic carbon normalized value for total PCBs was 22 ppm carbon; all three replicate samples taken at this site exceeded standards.

The exceedances of mercury and PCB standards at the Elliott Bay PSDDA sites are not due to the disposal of dredged material (Revelas, DNR, personal communication). Dredged material has not yet been placed at EBS02, and EBP07 lies outside of the disposal site boundary. In fact, mercury values at EBS02 were much higher in the baseline survey in 1988, which was prior to the disposal of any dredged material in this area.

Ecology found no other organic chemicals above state standards. PAH con-



Reference: Dutch et al., 1993

Figure 7. PAHs in City Waterway sediments.

centrations at the ambient station off the Thea Foss Waterway within Commencement Bay have exceeded state standards in the past (PSWQA, 1992). For the last two years, however, both LPAH and HPAH concentrations have been below standards (Figure 7). Although it appears that levels are gradually decreasing, several more years of data are needed before a statistically valid trend can be identified. Nevertheless, the limited data available suggest that stormwater controls or point source improvements are helping to reduce the concentration of these contaminants.

Beta coprostanol is an organic chemical produced by the bacterial breakdown of cholesterol in mammals. Beta coprostanol is not generally toxic by itself, but is frequently associated with sewage effluent and nonpoint pollution sources such as leaking on-site sewage systems (septic tanks) or runoff from dairy farms, and is therefore a valuable indicator of pollutant sources. In 1992 the highest values of beta coprostanol occurred within urban bays. As in 1989 and 1990, the Blair/Sitcum Waterway in Commencement Bay had the highest level of this chemical, with a concentration more than twice that of any other PSAMP station. Port Gardner, Sinclair Inlet, Bellingham Bay, and City Waterway in Commencement Bay also had elevated values when compared to other PSAMP stations sampled in 1992. The high values of beta coprostanol at two stations within Commencement Bay—and at Blair/Sitcum Waterway for the three previous years of sampling—argues strongly that this bay has a serious problem with sewage or nonpoint sources (or a combination of these). Sinclair Inlet and Commencement Bay have also exceeded state standards for fecal coliform bacteria at ambient sites (see the chapter on fecal contamination), providing further evidence of serious fecal contamination.

Analytical uncertainties in PCB violations at Elliott Bay

- Concentrations of total PCBs and PAHs are determined by summing the individual concentrations of chemicals that make up these compounds. The standard states that if a chemical is not detected in a sample, its detection limit (minimum concentration at which that chemical can be detected) is the concentration used for comparing to standards (WAC 173-204-320). This is a conservative approach, since the actual concentration is probably below the detection limit. In 1992, two of the three PCBs analyzed in Elliott Bay were undetected. However, Elliott Bay still exceeds the standard even if the undetected chemical concentrations are set to zero. All PAHs were above detection limits.

- The only detected PCB (congener 1254) was qualified as an estimate (it could not be accurately quantified because of interferences in chemical analyses or improper processing). Only one of the HPAHs (benzo(g,h,i) perylene) and none of the LPAHs were qualified as estimates.

- The standards are based on "organic carbon normalization," which means chemical concentrations are divided by the amount of organic matter present within the sediment. This is done to account for the fact that organic contaminants are less toxic if more organic matter is present. 1992 sediment samples from Elliott Bay had a very low organic matter content (0.19 percent), thus driving up the carbon-normalized values. A typical range for organic carbon in Puget Sound marine sediments is 0.5 to 3.0 percent (Michelson, 1992). Carbon normalization may be misleading at such low concentrations, since even background amounts of organic chemicals may exceed sediment standards at these levels.

1992 SEDIMENT TOXICITY MONITORING RESULTS

In 1992 Ecology found that sediments from 17 of 48 stations were marginally toxic (from 12.5 to 24.5 percent mortality) or clearly toxic (24.5 percent or higher mortality) to benthic communities based on guidelines presented by Mearns et al. (1986) (Table 2). The average mortality rates in sediments from these stations were all significantly higher than in control (uncontaminated) sediments collected from West Beach on Whidbey Island (control mortality averaged from zero to three percent). The toxicity of contaminated sediments to the benthic community is evaluated by exposing the sediment-dwelling amphipod *Rhepoxynius abronius* to sediment samples and determining mortality percentages after ten days.

Table 2. Stations with sediment samples exhibiting elevated mortalities.

Station	Mean % Mortality	Station	Mean % Mortality
Marginally Toxic:	**12.5 – 24.5**	**Clearly Toxic:**	**≥24.5**
North Budd Inlet	24.0	Port Townsend	32.0
Holmes Harbor	23.0	Saratoga Passage	32.0
South Budd Inlet	23.0	Tekiu Point	26.0
North Hood Canal	22.0	South Hood Canal	25.0
Shelton	21.0		
Blair/Sitcum Waterways	19.0		
Semiahmoo Bay	18.0		
Strait of Georgia	18.0		
Dyes Inlet	16.0		
Sinclair Inlet	16.0		
Point Pully	15.0		
Port Susan	15.0		
East Central Basin	13.0		

Toxicity tests can be difficult to interpret, since toxicity may result from natural factors unrelated to contamination. Amphipod mortality at the Strait of Georgia site, for example, may be caused by naturally high levels of sulfides at that site, while mortality at Semiahmoo Bay may be the result of a high percentage of fine-grained sediments (*Rhepoxynius abronius* has higher mortality rates in fine-grained sediments). Based on a model that controls for the effect of grain size (DeWitt et al., 1988), Ecology concluded that amphipod mortality at all stations was more likely a result of grain size than of toxic levels of contaminants (Dutch et al., 1993).

Historically, results from PSAMP sediment toxicity tests have not reflected patterns of sediment chemical contamination. Sediment stations exceeding sediment chemical standards often do not exhibit significant amphipod mortality in laboratory tests, whereas some rural stations with low levels of contaminants have shown high levels of amphipod mortality (Striplin et al., 1992; Striplin et al., in preparation). Sediments collected in close proximity to the control sediments in 1991 had the highest mortality rates. PSAMP will evaluate toxicity testing methods in the coming year to identify ways of increasing their reliability.

1992 BENTHIC COMMUNITY MONITORING RESULTS

Scientists can evaluate the effects of contamination in an area by looking at the number and variety of benthic animals present, taking into consideration natural factors that affect abundance such as sediment composition or the amount of organic matter present. If low numbers of organisms are present or if a community is dominated by a small number of species while natural conditions favor abundant or diverse communities, it is possible that toxic contamination is responsible for these conditions. Ecology was only able to process four of the five replicates at each station in 1992, so benthic infaunal results should only be considered preliminary indications of benthic community structure.

The five highest (Table 3) and lowest (Table 4) values for total abundance, number of species, and diversity indices of species indicate several patterns of interest. The rotating station at Lynch Cove had the fewest species, the lowest diversity, and the fifth fewest total number of individuals. In addition, this site had the highest percentage—76 percent—of pollution tolerant species (species tolerant of organic enrichment from sewage). This was more than double the next highest value.

Table 3. Highest values for selected benthic infaunal indices in 1992.

Total Abundance		Species Richness		Diversity	
Station	*# indiv./01m²*	*Station*	*# taxa./0.1m²*	*Station*	*H' value*
Port Gardner	1160	N. Vashon Island	118.7	N. Vashon Island	1.70
Sinclair Inlet	923.5	Case Inlet	109.5	Case Inlet	1.65
West Central Basin	916.7	Richmond Beach	103	E. Anderson Island	1.61
Blair/Sitcum Waterway	891	E. Anderson Island	91.8	Magnolia Bluff	1.55
Carr Inlet	858.7	Magnolia Bluff	87.5	Port Angeles	1.54

Table 4. Lowest values for selected benthic infaunal indices in 1992.

Total Abundance		Species Richness		Diversity	
Station	*# indiv./01m²*	*Station*	*# taxa./0.1m²*	*Station*	*H' value*
Tekiu Point	61.5	Outer Lynch Cove	9.5	Outer Lynch Cove	0.47
Shelton	84	Tekiu Point	17	Shelton	0.60
Saratoga Passage	87	Holmes Harbor	17.2	Shilshole Bay	0.64
Holmes Harbor	89	South Hood Canal	18.5	North Budd Inlet	0.68
Outer Lynch Cove	97	Shelton	21.2	Semiahmoo Bay	0.80

The concurrence of several benthic indices are a strong indication that sediment quality in Lynch Cove is poor. The sparse benthic community at this site is probably a result of low oxygen levels due to poor flushing and the decay of organic matter. Lynch Cove is often anoxic (oxygen depleted) at the bottom (Janzen and Eisner, 1993) and it had one of the highest percentages of organic matter in the sediments for 1992. These conditions may be natural, since Lynch Cove flushes poorly, but they could also be a result of sewage discharge from Belfair, which has resulted in shellfish harvest closures in this area. Lynch Cove also had elevated levels of several metals (arsenic, cadmium, chromium, and copper). While these levels are well below amounts thought to adversely affect benthic organisms (PTI, 1988), they may be reacting in combination to produce toxic conditions (synergism).

The station at Shelton had the second fewest individuals, fifth lowest number of species, and the second lowest diversity out of the 48 stations, potentially indicating contaminated sediment conditions. However, the sediment sample from this site did not exhibit elevated levels of metals, organic compounds, organic carbon, or sulfides relative to other PSAMP stations, so the reasons underlying the sparse benthic communities are unknown.

Holmes Harbor and Tekiu Point also had sparse benthic communities. Holmes Harbor had the fourth lowest total abundance and the third fewest number of species. The low values for these indices at Holmes Harbor may relate to high levels of sulfide (more than 245 ppm), elevated levels of several metals, or to natural conditions or contaminants not measured by PSAMP. Tekiu Point had the lowest total abundance and the second fewest number of species in 1992. The sediments from this station also exhibited high toxicity (Table 2). Although the levels of a few metals at this station were slightly elevated relative to other PSAMP stations (with the third highest level of zinc [104.0 ppm] and the sixth highest levels of copper [56.4 ppm] and lead [29.8 ppm]), they are well below amounts thought to harm benthic communities.

High values for total abundance—particularly when diversity levels within a benthic community are low—sometimes indicate areas affected by organic enrichment, such as sewage. Poor water or sediment quality resulting from sewage discharge creates conditions unfavorable to most species. This allows a few species which can tolerate organic enrichment to dominate. Such species (including certain species of marine worms and mollusks) often rely on organic matter as a food source, and the high levels of organic matter present near sewage outfalls support large populations.

Several of the sites listed in Table 3 support the hypothesis that organic enrichment may result in high total abundance and low diversity values. Of the five stations listed, Carr Inlet was the only station with high abundances that had diversity values above the average value for all the stations sampled in 1992. With the exception of the central basin station, the remaining stations all exhibit signs of organic enrichment. Blair/Sitcum Waterway, Port Gardner, and Sinclair Inlet had the three highest values of beta coprostanol, an organic compound associated with sewage effluents. Monitoring results for fecal contamination and conventional water quality indicators provide additional indications that these areas are affected by sewage discharge or pollution from nonpoint sources such as leaking on-site sewage systems (see the chapters on fecal contamination and conventional water quality for details).

In contrast, the benthic communities at several sites were indicative of good sediment quality. North Vashon Island had the highest number of species and the greatest diversity. Case Inlet had the second highest number of species and the second greatest diversity. East Anderson Island had the third greatest diversity and fourth highest number of species. Magnolia Bluff had the fourth greatest diversity and fifth highest number of species.

FISH TISSUE MONITORING RESULTS

PSAMP studies of toxic chemicals in fish tissue were generally consistent with findings from past years, with most levels falling below state standards. PSAMP measures tissue contaminant levels in fish to evaluate the accumulation of contaminants in the marine food web and the threat to human health from eating fish (PSWQA, 1988). Washington Department of Fisheries (Fisheries) scientists monitor English sole (*Parophrys vetulus*) annually, since these bottomfish live in contact with sediments and may accumulate toxic chemicals from sediments in contaminated areas. Fisheries measures contaminants in muscle tissue—the portion of fish generally consumed by humans. To assess the effects of contaminants on the health of English sole, Fisheries scientists also measure contaminants in liver tissue (since the liver tends to concentrate toxic chemicals) and examine individuals for the occurrence of certain types of liver disease.

To provide a broader overview of fish contamination, PSAMP investigators also measure muscle contaminants in five other species of fish that are caught recreationally and commercially (PSWQA, 1988). The species monitored are copper rockfish (*Sebastes caurinus*) and quillback rockfish (*S. maliger*), chinook salmon (*Oncorhynchus tshawytscha*) and coho salmon (*O. kisutch*), and Pacific cod (*Gadus macrocephalus*). These species feed on different organisms and thus provide information about different pathways by which fish may accumulate contaminants.

Rockfish generally confine themselves to particular reef areas of the Sound and can provide information about localized accumulation of toxic chemicals. The longevity of rockfish (more than 30 years) ensures that contaminants known to accumulate in fish will tend to show up in their muscle tissues. In contrast, Pacific cod are shorter-lived fish which swim throughout Puget Sound but do not migrate into the open ocean. Contaminants in these fish reflect conditions that fish may encounter throughout the Sound rather than in a localized area. PSAMP also monitors salmon because of their recreational, commercial, and cultural value. Because salmon typically spend part of their life cycle in the open ocean, they can accumulate contaminants from sources outside Puget Sound.

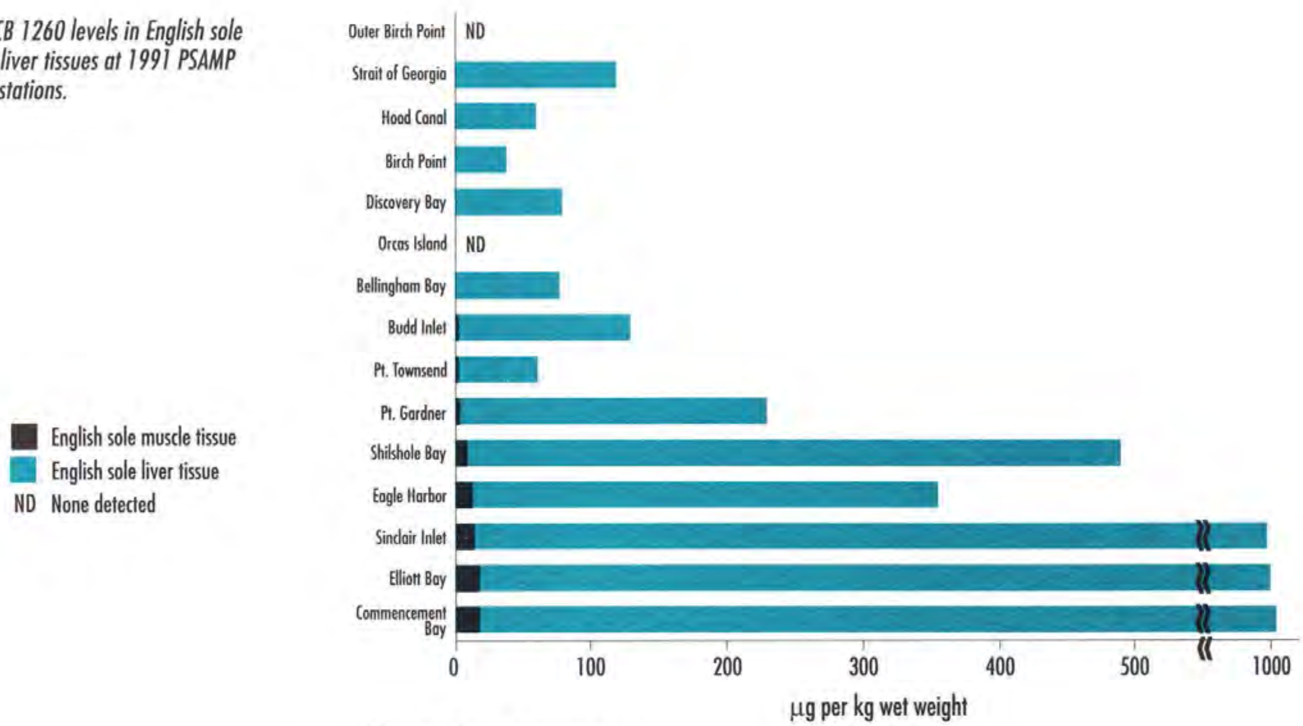
English sole

At the writing of this report, Fisheries did not have results available from English sole tissue analyses collected in 1992. However, results from liver tissue analyses collected in 1991, which were not reported in the last Puget Sound Update, are available.

Fisheries scientists conducted their first analysis of English sole liver tissue in 1991, measuring the concentration of PCBs. Liver tissue detection limits were high—20 to 60 times higher than in muscle tissue—because of limited amounts of tissue available and because this was the first time the analytical laboratory had conducted analyses on liver tissue. Due to the limited amount of tissue available, analyses were only conducted for PCBs. Only one PCB congener was detected—congener 1260. Levels of PCB 1260 were 20 to 70 times higher in liver tissue than in muscle tissue. Higher contaminant levels would be expected in the liver, since one of the functions of this organ is to filter and metabolize toxic compounds. Patterns of contamination were similar to muscle tissue, however, with the highest levels tending to be in urban bays (Figure 8).

The high levels of PCBs found in English sole liver tissue are important for two reasons. First, human health assessments are generally based on analyses of muscle tissue, since this is the portion generally consumed by humans. These guidelines do not apply when individuals consume whole fish, particularly livers. Second, because fish concentrate contaminants within their livers, they may experience adverse health impacts even when contaminant levels in muscle tissue are low. This may explain why English sole can develop liver lesions, in spite of the fact that contaminants in muscle tissue are generally found at levels that do not threaten human health.

Figure 8. PCB 1260 levels in English sole muscle and liver tissues at 1991 PSAMP monitoring stations.



Reference: Fisheries, in preparation

Rockfish

Between November 1991 and January 1992 (the most recent data available) the Department of Fisheries sampled quillback rockfish at Triton Cove, Parker Reef, and Double Bluff; copper rockfish at Day Island; and both copper and quillback rockfish at Blakely Rock (Figure 9).

Levels of contaminants can vary significantly with age in fish. Older fish may have higher levels of toxic chemicals in their tissues since they have been exposed to contaminants present in the environment for a longer time. For this reason, Fisheries determines the age of all fish sampled for chemical analyses. With this information they can statistically control for any age-related differences when comparing contaminant levels among sites or years.

Fisheries found that age did not vary significantly among sites for either copper rockfish or quillback rockfish (Fisheries, in preparation). However, quillback were significantly older than copper rockfish, which affects com-

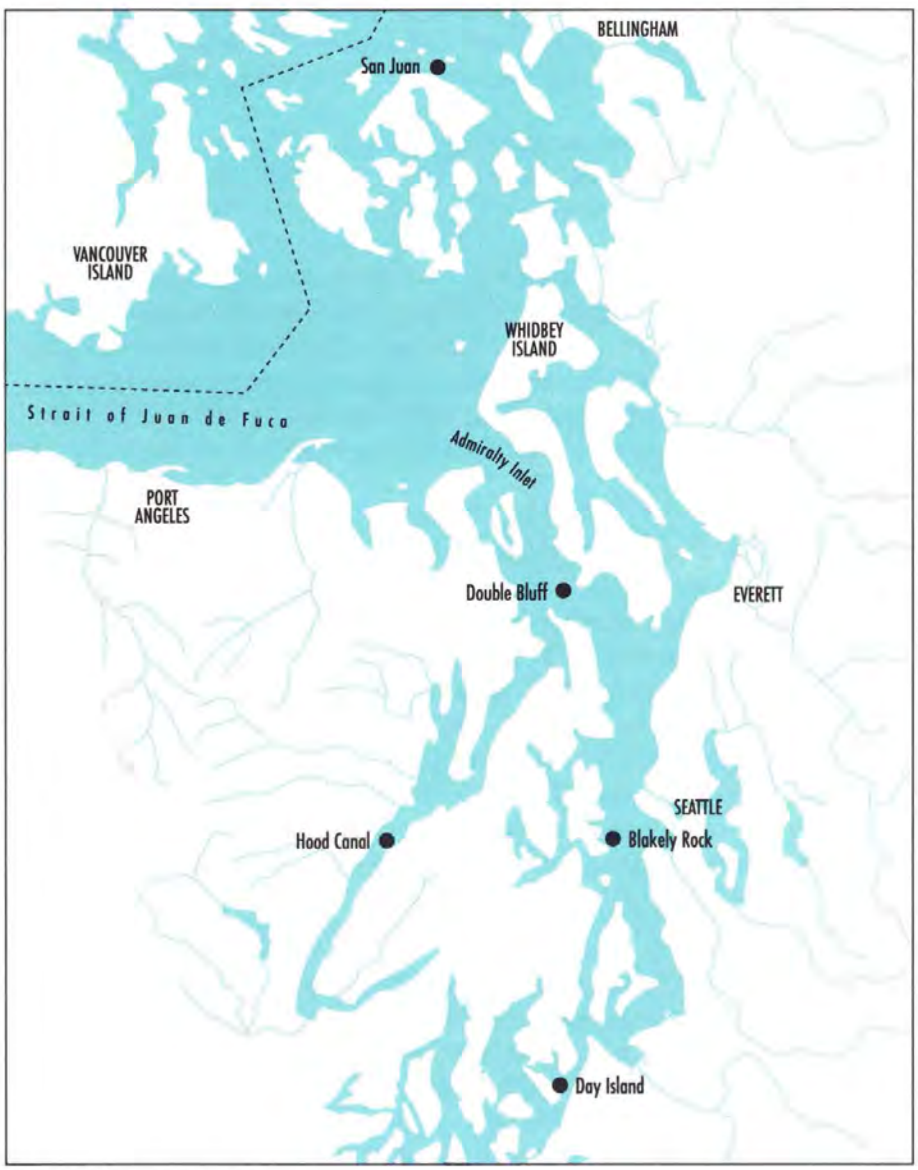


Figure 9. PSAMP rockfish monitoring sites.

Reference: Fisheries, in preparation

parisons of contaminant levels between species.

Metals. Fisheries found no lead in the muscle tissue of any of the rockfish sampled. Low levels of copper, between 0.1 ppm and 0.3 ppm, were present in most samples. One sample from Double Bluff contained copper levels of 1.1 ppm. Copper in the other five replicates from this site was low (0.1 ppm to 0.2 ppm), suggesting that the Double Bluff sample was not representative of copper levels at that site. There were no significant differences in copper levels among sites for either species. Copper levels were similar to levels found at the two sites sampled in 1989 (Blakely Rock and Day Island).

The amount of arsenic detected varied significantly among sites in the muscle tissue of quillback rockfish. Mean levels at Triton Cove (4.3 ppm) and Blakely Rock (3.1 ppm) were significantly higher than at Parker Reef (1.5 ppm) and Double Bluff (1.8 ppm). Arsenic levels in copper rockfish did not appear to vary between sites. Arsenic levels in rockfish tissue in 1991 appeared to be much higher than levels in 1989. However, all but one of the values measured in 1989 were qualified as estimates, so it is difficult to tell whether this apparent increase is due to actual increases in tissue contaminants or to improved methods of arsenic detection. Although arsenic levels in 1992 are higher, they are still below levels of concern for human health.

Mercury values in rockfish ranged from 0.1 ppm to 0.4 ppm. There were no differences in levels between sites, or—for the two sites sampled in both 1989 and 1991—between years.

Organic Chemicals. Fisheries detected two organic compounds in rockfish muscle tissue: 4,4-DDE and bis(2-ethylhexyl phthalate). DDE is a breakdown product of the pesticide DDT. The use of DDT was banned in 1972, but because it was so widely used and is a highly persistent chemical, it is still found in environmental samples. Bis(2-ethylhexyl phthalate) is widely used in plastic production and has been shown to bioconcentrate in aquatic animals (PTI, 1991a).

DDE was not detected in copper rockfish, and was only found at low levels in three of the 23 quillback samples. Bis(2-ethylhexyl phthalate) ranged from levels below the detection limit of 35 ppb (parts per billion) all the way up to 320 ppb. There appeared to be significant differences among sites, although all levels were qualified as estimates and all samples required "blank correction," so that the accuracy of the observed differences is unknown. Blank correction is a quality assurance procedure which corrects for contaminants introduced during sampling and analysis. It is a particularly important correction for bis(2-ethylhexyl phthalate), since this may be present in plastic containers used in sampling and analysis.

Pacific cod

Because of low Soundwide abundances of Pacific cod, Fisheries scientists did not collect this species, but purchased cod taken from commercial trawlers. Cod were only available from two sites: Admiralty Inlet, which was also sampled in 1990, and Alden Bank.

As with rockfish, Fisheries did not detect any lead in Pacific cod muscle tissue, which is consistent with results from 1990. Low levels of copper, ranging from 0.22 ppm to 0.33 ppm, were present in all samples. Copper levels did not differ between the two sites, and were similar to the levels detected at Admiralty Inlet in 1990.

Arsenic was present in all samples, and ranged from 2.0 ppm to 6.0 ppm. Pacific cod sampled at Admiralty Inlet had significantly higher levels of arsenic (mean = 4.6 ppm) than cod at Alden Bank (mean = 2.6 ppm) (Figure 10). Low levels of mercury, ranging from 0.07 ppm to 0.16 ppm, were present in all samples and were similar to levels detected in 1990.

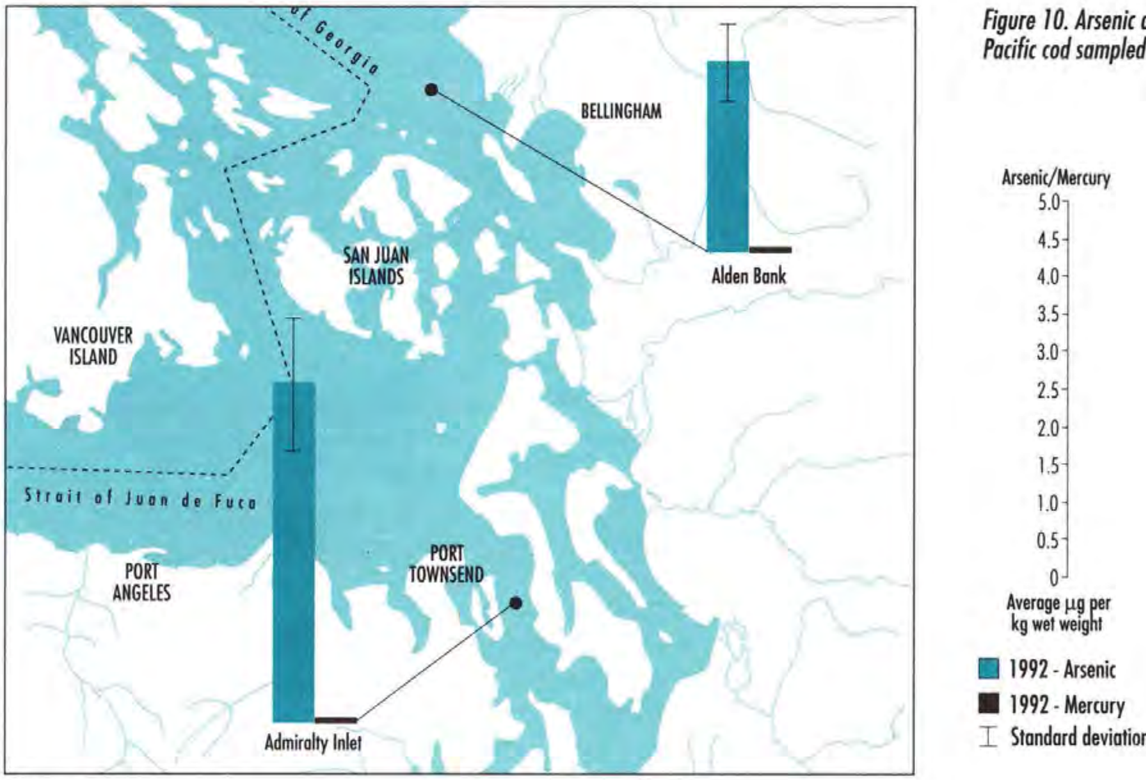


Figure 10. Arsenic and mercury levels in Pacific cod sampled in 1992.

Reference: Fisheries, in preparation

Studies from Other Monitoring Efforts

Contaminants in fish and clams in Sinclair and Dyes inlets. Ecology sampled tissue contaminants in fish and clams in Sinclair and Dyes inlets to assess whether contaminants in the sediments of these inlets were accumulating in resident marine organisms (Cubbage, 1992). Comparison of Department of Ecology data with Department of Fisheries data collected for PSAMP indicate similar values for arsenic, although the range for the Ecology data is wider (Table 5). The ranges for copper, lead, and mercury levels in Ecology tissue samples tended to be much higher.

The differences in these results are probably due to two factors. First, Ecology sampled several stations throughout Sinclair and Dyes inlets, whereas Fisheries only sampled one station within the area (that station did not correspond to any of the Ecology stations). Second, Ecology used tissues from several different species of bottomfish, whereas Fisheries only sampled English sole at Sinclair Inlet. The Ecology data are informative since they pro-

Table 5. Comparison of Ecology and Fisheries fish tissue sampling data for Sinclair Inlet.

Metal	Dept. of Ecology[†]	Dept. of Fisheries
Arsenic	3.3 ppm – 21.1[E]	6.5 ppm – 12 ppm
Copper	0.31 ppm – 2.0 ppm	0.25 ppm – 0.32 ppm
Lead	0.36 ppm – 4.6 ppm[E]	0.04 ppm – 0.07 ppm
Mercury	0.07 ppm – 0.39 ppm	0.05 ppm – 0.09 ppm

** Fisheries data collected in 1989-1992*
E indicates that a quantity is estimated due to quality control problems.
† (Cubbage et al., 1992)

vide an indication of the range of contaminant levels in other species and at other sites throughout Sinclair and Dyes inlets.

Contaminant Effects on Salmon. The National Oceanic and Atmospheric Administration (NOAA) recently completed a study on the effects of contaminants on juvenile chinook salmon emigrating from urban and non-urban estuaries in Puget Sound (Varanasi et al., 1993). The study was designed to determine the exposure levels of juvenile salmon to contaminants as they migrate through estuaries to the ocean, and to determine the effects of contaminant exposure on salmon health. The study was conducted in four estuaries: the Duwamish waterway in Elliott Bay, the Puyallup River entering Commencement Bay (both representative of urban estuaries), the Snohomish River entering Port Gardner (a semi-urban estuary), and the Nisqually River estuary (a non-urban estuary).

The study revealed a number of important findings:

- *Diet is a potential source of contaminants.* PAH and PCB concentrations were significantly higher in stomach contents of juvenile chinook salmon from the Duwamish and Puyallup estuaries than in salmon from the Nisqually estuary and in fish collected from hatcheries located on the river above these estuaries. Contaminants in fish stomach contents from the Snohomish estuary were not significantly higher than in salmon from the Nisqually estuary or from the hatcheries. The presence of these contaminants in fish stomachs, and their variation with degree of site contamination, suggests that diet is a potential source of these contaminants.

Similarly, levels of PCBs in the liver and fluorescent aromatic compounds (metabolites of PAHs) in the bile were higher in salmon from the Duwamish and Puyallup estuaries than from the Nisqually estuary or the hatcheries. These compounds were not significantly higher in salmon from the Snohomish estuary when compared to fish from the Nisqually estuary or the hatcheries.

- *Salmon migrating through urban estuaries may retain contaminants to which they are exposed.* The levels of PCBs in salmon tissue from the Duwamish waterway persisted more than three months after fish were removed from the estuary and held in laboratory seawater tanks, at which point the study ended. This suggests that salmon migrating through urban estuaries may retain contaminants to which they are exposed for considerable periods of time after leaving the estuaries.

• *Fish from urban estuaries had higher levels of enzymes which aid in the detoxification of contaminants.* Fish produce many compounds—including enzymes such as aryl hydrocarbon hydroxylase (AHH)—that perform critical functions in detoxifying contaminants. The activity of these compounds increases rapidly after exposure to certain contaminants. NOAA found that AHH activity was higher in salmon from the Duwamish and Puyallup estuaries. They also found that contaminants in fish from the Duwamish and Puyallup were binding to a greater degree to liver DNA than in fish from the other estuaries or the hatcheries. Binding of contaminants to DNA is thought to be an early step in the process of carcinogenesis and other toxic effects.

• *Fish from urban bays may be more susceptible to infections.* The immune systems of juvenile fish from the Duwamish were found to be less responsive than in fish from the Nisqually estuary or the hatcheries. This finding suggests that fish from urban bays may have a higher susceptibility to infections. NOAA was able to attribute this effect to contaminants present in the Duwamish estuary by injecting chemicals extracted from the sediment into laboratory fish. In fish injected with extracts from Duwamish sediments, immune response was suppressed when compared to controls.

• *Growth and survival of juvenile chinook from the Duwamish estuary in the laboratory was significantly less than in fish from the Nisqually estuary.*

These findings support two important hypotheses about the effect of contaminants on estuarine organisms.

1) Fish present in contaminated urban embayments—even for short periods of time—are exposed to higher levels of contaminants than fish from non-urban embayments. Exposure to PAHs is often not reflected in muscle tissue contaminant levels, as fish rapidly biotransform many contaminants. Other contaminants, such as PCBs, can persist in fish tissues for long periods of time after the fish leave contaminated environments.

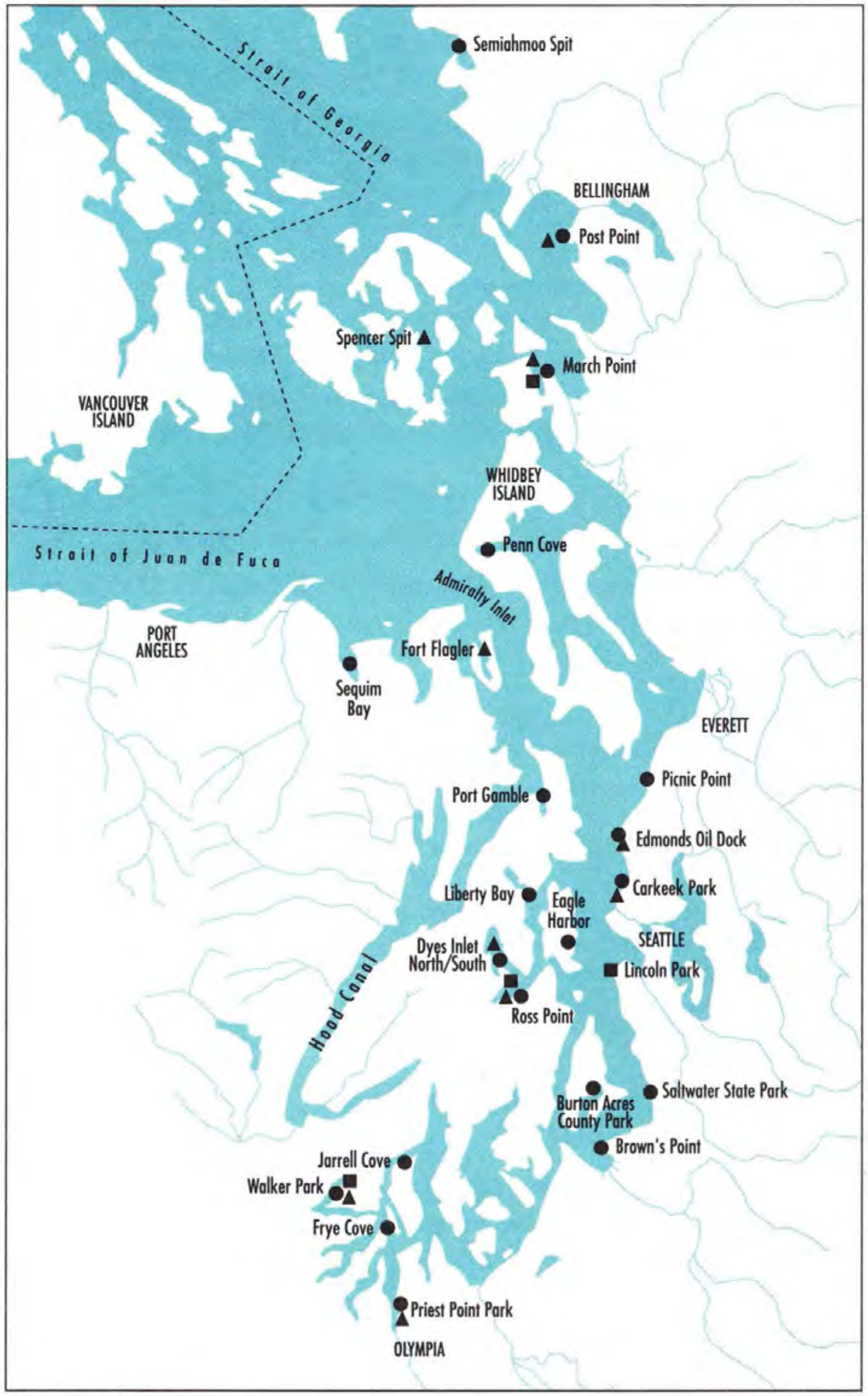
2) Contaminants have measurable effects on the biological functions of these organisms. Effects range from early indications of potential carcinogenesis (contaminant binding to DNA) to reduced immune response to lowered growth and survival rates. Demonstration of these effects in a fish that is only present in contaminated estuaries for a short period of time and that does not live in constant contact with sediments (as do bottomfish) suggests that impacts from estuarine contaminants on biological populations may be much more extensive than previously thought.

1992 SHELLFISH MONITORING RESULTS

The Washington Department of Health (Health) reviewed the levels of chemical contaminants found in native littleneck clams (*Protothaca staminea*) sampled from 1990-92 (Health, in preparation). Health officials analyzed shellfish tissue for six metals (arsenic, cadmium, copper, lead, mercury, and zinc) and nearly a hundred organic contaminants, including pesticides, PCBs, and PAHs. From 1990 to 1992, Health collected shellfish tissue for chemical analyses at 25 sites throughout the Sound, although most sites were not sampled each year (Figure 11).

Health officials detected low levels of metals in all samples from each site. With the exception of lead and mercury, most metals showed little variation in concentration among the different sites or among years. Levels of lead were approximately three times higher in shellfish from Eagle Harbor than in all other sites sampled. Mercury was almost twice as high in Eagle Harbor shellfish as in most other sites sampled.

Figure 11. PSAMP shellfish sampling stations monitored by the Department of Health.



■ Sampled in 1990
▲ Sampled in 1991
● Sampled in 1992

Reference: Health, in preparation

In general, Eagle Harbor, Burton County Park, Dyes Inlet, Edmonds, and Spencer Spit tended to rank highly for several metals when compared to the other sample locations (Table 6).

Table 6. 1990-1992 PSAMP sites with the five highest mean concentrations of each metal in shellfish tissue (ppm).

Arsenic		Cadmium		Copper		Lead		Mercury		Zinc	
Spencer Spit	2.27	Spencer Spit	0.34	Eagle Harbor	1.83	Eagle Harbor	1.03	Eagle Harbor	0.06	Ross Point	15.22
Liberty Bay	2.17	Sequim Bay	0.29	Burton Park	1.80	Burton Park	0.33	Dyes Inlet	0.03	Dyes Inlet	14.33
Dyes Inlet	2.13	Frye Cove	0.26	Narrows Point	1.70	Dyes Inlet	0.24	Burton Park	0.03	Carkeek Park	14.33
Burton Park	2.07	Burton Park	0.24	Edmonds	1.65	Dyes Inlet	0.17	Post Point	0.02	Priest Point	14.17
Sequim Bay	2.05	Edmonds	0.23	Post Point	1.43	Spencer Spit	0.16	Liberty Bay	0.02	Edmonds	14.17
3-year averages (all sites)											
	1.73		0.19		1.19		0.13		0.02		12.43

Reference: Health, in preparation

The Department of Health detected only nine organic compounds over the three years of sampling:

- benzoic acid
- benzyl alcohol
- bis(2-ethylhexyl)phth.
- butylbenzylphthalate
- 4,4-DDE
- diethylphthalate
- di-n-butylphthalate
- fluoranthene
- phenanthrene

Organic contaminant levels varied considerably more than levels of metals among sites. Few patterns of contamination were obvious, although Eagle Harbor had much higher levels of flouranthene (a PAH compound) and benzyl alcohol (a compound used in several industrial processes) than shellfish from the few other sites where these contaminants were detected. As with metals, no changes in the levels of contaminants over time were obvious.

Eagle Harbor has long been associated with shipbuilding, ship repair, and wood preservative industrial activities. The harbor currently contains a Superfund cleanup site due to contamination from PAHs, copper, lead, and mercury. This may explain why the highest concentration of these contaminants were found at this site.

Health evaluated the human health impacts from consuming shellfish from the sites sampled. They concluded that the levels of contaminants found in these shellfish pose no significant health threat.

Studies from Other Monitoring Efforts

EPA funded a reconnaissance (one-time exploration) study of dioxin and furan concentrations in Puget Sound crabs (PTI, 1991b). Dioxins and furans—highly toxic organic contaminants—are waste products of pulp and paper manufacturing and other industrial processes such as chlorophenol manufacturing. EPA collected crabs at sites near pulp mills, oil refineries, wastewater treatment facilities, wood treatment facilities, and agricultural areas to assess the degree of contamination from these sources. They also sampled in a reference site—Dungeness Bay—to provide information on background levels of these compounds in areas removed from sources. EPA focused its study on Dungeness crabs (*Cancer magister*), but collected red rock (*Cancer productus*) and graceful crabs (*Cancer gacilis*) in areas where Dungeness crabs were not available.

The study found dioxins and furans in much more concentrated levels in the hepatopancreatic tissues (a tissue analogous to the vertebrate liver) than in muscle tissues. Crabs collected near sources of dioxins and furans had greater levels of these contaminants in hepatopancreatic tissues than crabs at the reference area. However, concentrations in muscle tissues did not appear elevated relative to the reference site.

In comparing levels found in this study to a nationwide survey of dioxin contamination (EPA, 1987), EPA found that most values were within the range found in the nationwide study. The only exception was the hepatopancreatic tissues of crabs from Everett Harbor, which, at 62 ng/kg, were elevated above the range found in the nationwide study. In contrast, crabs collected near pulp mills in several Canadian studies had dioxin levels one to two orders of magnitude higher than crabs in Puget Sound (Terpenning, unpublished data as cited in PTI, 1991). However, the analytical methods used in the Canadian studies are unknown, so it is not clear if these data are comparable to the Puget Sound data.

In assessing the health risks associated with the observed contaminant levels, EPA found that the conclusions varied according to the method of health assessment chosen. The general conclusions, however, were that consumption of crab muscle tissue does not present an unacceptable health risk. Consumption of the hepatopancreatic tissue (or "crab butter") on an infrequent basis is also relatively safe, but these tissues should not be consumed regularly, as they contain higher concentrations of contaminants.

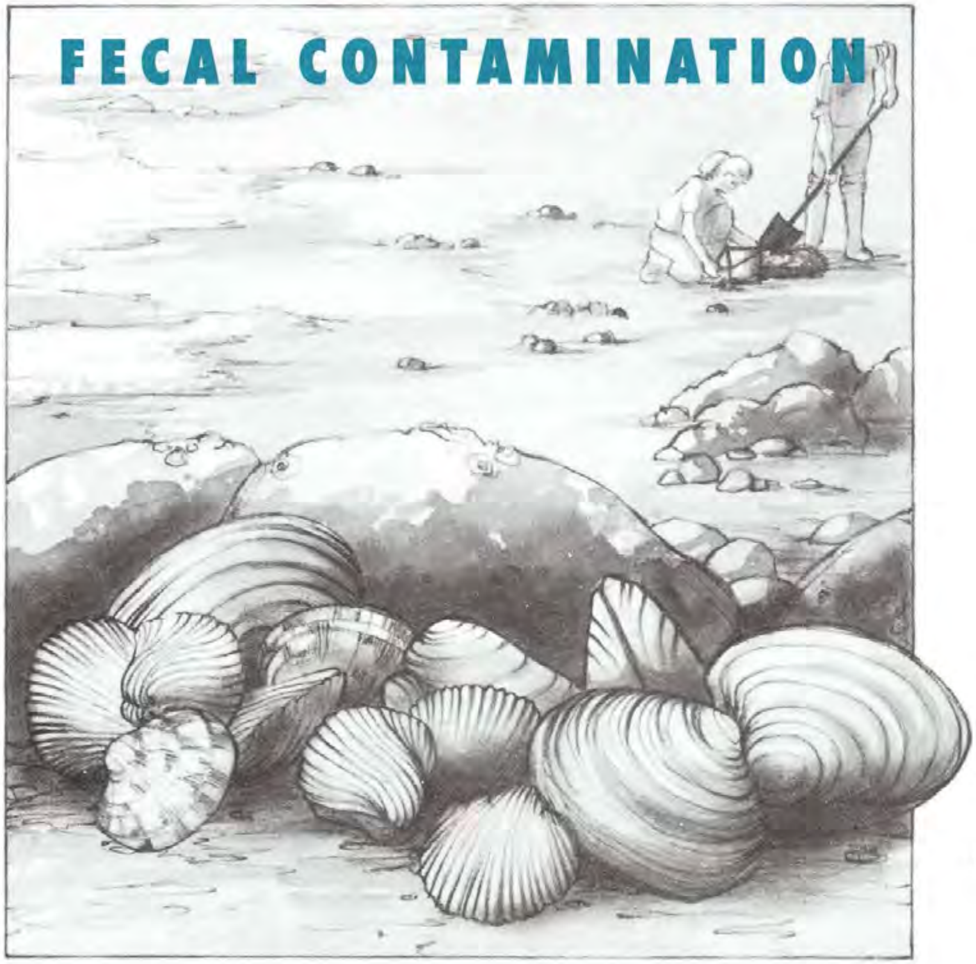
RESULTS OF MARINE MAMMAL STUDIES

The National Marine Fisheries Service (NMFS) has been sampling tissues of beached gray whales (*Eschrichtius robustus*) to determine whether high levels of chemical contaminants are responsible for their deaths (Varanasi et al., in preparation). From 1988 through 1991, NMFS sampled 22 gray whales that were found stranded in Puget Sound, along the outer Washington Coast, at Kodiak Island in Alaska, and in San Francisco Bay. The range of sites from the relatively pristine waters of Alaska to the urbanized areas of San Francisco and Puget Sound permitted comparisons of tissue contaminants to determine whether a relationship existed between contaminant levels in whale tissue and the degree of contamination at the stranding sites. Scientists conducted chemical analyses on stomach contents and tissues such as liver, blubber, brain, and kidneys.

Scientists found that chemical concentrations in tissues were relatively low when compared to other marine mammals that feed on species from higher trophic levels, such as fish. The relative proportions of the different chemicals analyzed in tissues were similar to proportions found in sediments, which is consistent with the fact that gray whales ingest sediments while feeding on benthic invertebrates. However, the National Marine Fisheries Service found no significant differences in chemical concentrations in tissues of whales from the different sites, indicating that whales that strand in urban areas do not possess higher levels of contaminants than whales stranding in pristine areas.

Further conclusions from the data were precluded by the fact that tissue samples from healthy gray whales were not available. This information is needed to determine whether levels of contaminants in stranded whales are higher than in healthy whales. Without this information, scientists cannot determine whether stranding of gray whales is related to contaminant exposure. Scientists are investigating methods for obtaining tissues from live whales without harming them in order to provide these data.

FECAL CONTAMINATION



BACKGROUND

In 1989 the Washington Department of Health (Health) issued the first upgrade of a commercial shellfish growing area previously closed due to fecal contamination in the history of Puget Sound. 1,380 acres in Oakland Bay were upgraded from restricted to conditionally approved because of improvements in water quality. Since then an additional 4,980 acres have received upgrades.

But long-term monitoring indicates that fecal contamination of shellfish beds remains a serious problem in Puget Sound. Since 1980, fecal contamination has claimed an estimated 28 percent of Puget Sound's historic commercial shellfish bed acreage. When added to restrictions in place prior to 1980, total restrictions account for over 40 percent of the Sound's historic commercial shellfish acreage (PSWQA, 1992). Within the last five years, classified commercial harvest restrictions in Washington state have been among the largest in the nation (NOAA, 1991). The dramatic increase in 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.

Lower levels of fecal coliform bacteria were detected in marine sampling stations during 1992, but this was almost certainly due to light rainfall

State standards for fecal coliform bacteria

Water quality standards for fecal coliform in Washington are stated relative to a surface water's classification. Surface water classifications range from Class AA (extraordinary) to Class C (fair). They are based on the designated uses (such as water supply, recreation, sustaining biological resources) that a given waterbody must support. They support these uses by attaining specified criteria for water quality. All waters monitored by PSAMP are designated Class AA or Class A. The following standards for fecal coliform bacteria apply to marine and freshwaters in these classes:

Marine:
Class AA; Class A - fecal coliform bacteria shall not exceed a geometric mean of 14 organisms/100 ml; not more than ten percent of all samples shall exceed a value of 43 organisms/100 ml.

Freshwater:
Class AA - fecal coliform bacteria shall not exceed a geometric mean of 50 organisms/100 ml; not more than ten percent of all samples shall exceed a value of 100 organisms/100 ml.

Class A - fecal coliform bacteria shall not exceed a geometric mean of 100 organisms/100 ml; not more than ten percent of all samples shall exceed a value of 200 organisms/100 ml.

rather than actual decreases in fecal coliform bacteria. Half of the ten major rivers entering Puget Sound exceeded the state standard for fecal coliforms in freshwater. Four of those also exceeded standards in 1991, indicating chronic contamination problems.

As monitoring reveals more about fecal contamination, we are learning that its sources are numerous and widespread. Insufficiently treated human and animal fecal wastes continue to introduce disease-causing bacteria and viruses into streams, lakes, and Puget Sound. Wastewater treatment plant discharges and combined sewer overflows are only part of the problem. As treatment and disinfection of these sources improve, fecal coliform contributions from smaller, more disperse sources—failing on-site sewage systems (septic systems), farm animal waste runoff, boat waste discharges—are becoming more apparent. Continued monitoring will tell us more about the relative contribution from different sources of fecal contamination, which sources are most serious, and how these sources are changing over time.

EFFECTS OF FECAL CONTAMINATION

Fecal wastes pose serious human health threats because they may contain bacteria and viruses that are associated with typhoid, cholera, salmonella, hepatitis, and other diseases. Because so many types of pathogens exist, and many are difficult to detect, scientists do not monitor these pathogens directly, but instead measure the concentrations of fecal coliform bacteria as indicators of the presence of fecal wastes. Fecal coliform bacteria are bacteria that are commonly found in the intestines and feces of warm blooded animals, including humans. While a few strains of these bacteria are harmful to humans (as evidenced by the recent *E. coli* poisonings), most fecal coliform bacteria do not by themselves present human health threats. However their presence is a likely indication that fecal wastes from mammals have found their way into the water, and that pathogens associated with fecal wastes may be present.

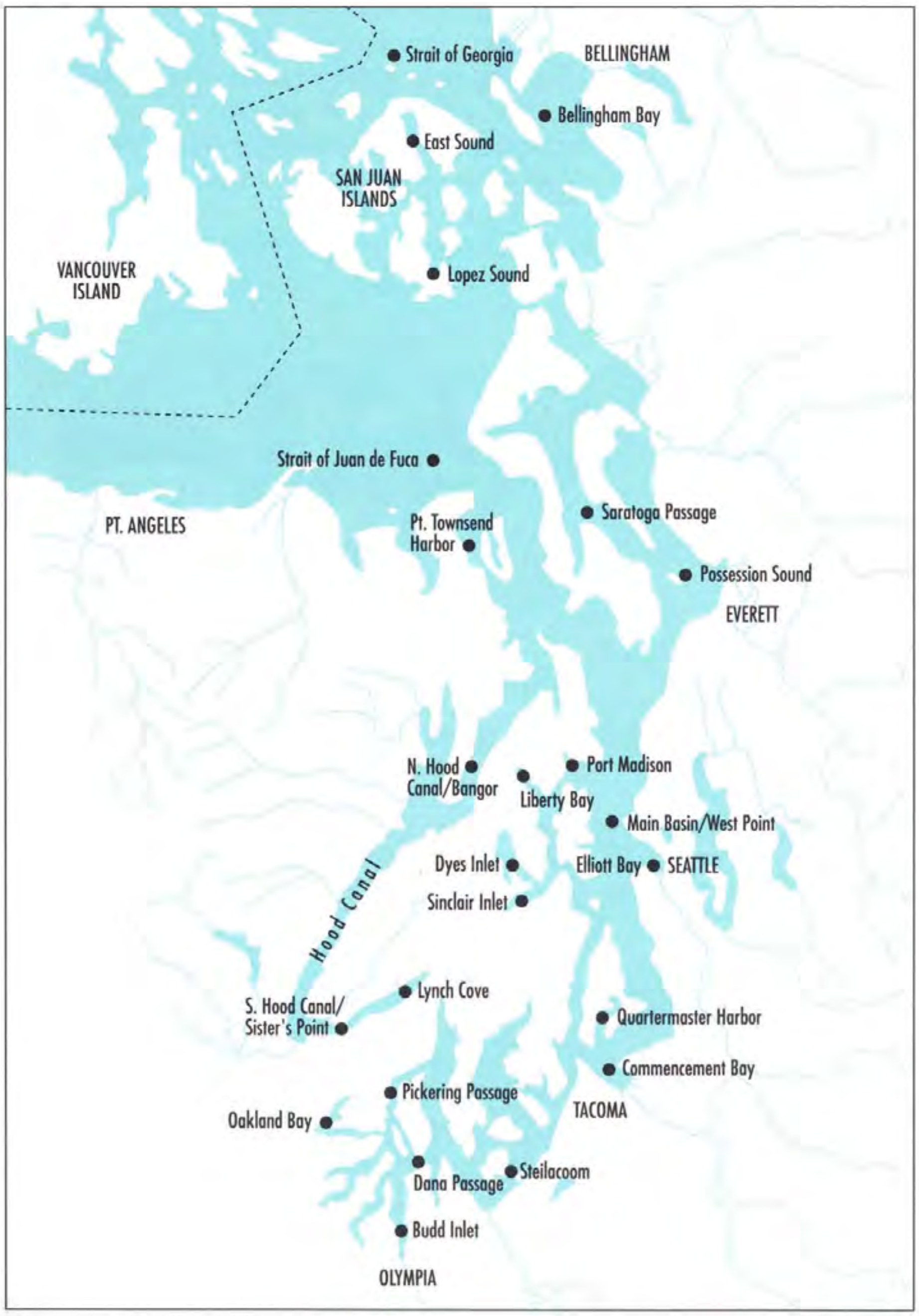
One of the most damaging effects of fecal contamination in Puget Sound is the degradation of Puget Sound's shellfish. Oysters, clams, and other bivalve molluskan shellfish feed by filtering phytoplankton and other particulates from the surrounding water. In the process, they accumulate and concentrate pathogens present in the water and sediments. Generally, these pathogens do not harm the shellfish, but render them unfit for human consumption. When people eat contaminated shellfish, particularly when raw or undercooked, they are exposed to the pathogens accumulated within the shellfish tissues and may develop the diseases caused by these pathogens.

Sources of fecal contaminants from rivers can cause significant harm. River deltas—the point at which rivers enter the Sound—are highly productive habitats that often support large populations of shellfish. If the freshwaters flowing into these deltas are contaminated, then the shellfish resources within the delta are also likely to be contaminated.

SOURCES OF FECAL CONTAMINATION

Improperly sited or maintained on-site sewage systems (septic systems), sewage treatment plant malfunctions and combined sewer overflows, boat waste discharges, urban stormwater runoff, and marine mammal, pet, and farm animal wastes all have the potential to introduce fecal matter into nearby waters.

Farm animals and pets leave fecal wastes and their associated pathogens on the land's surface and in streams. If wastes on land are not properly managed, runoff from rain carries these wastes into nearby waters. On-site sewage systems (septic systems) treat sewage as it flows through unsaturat-



Reference: Janzen and Eisner, 1993

Figure 12. PSAMP marine water monitoring stations for fecal coliform bacteria in Puget Sound for wateryear 1992.

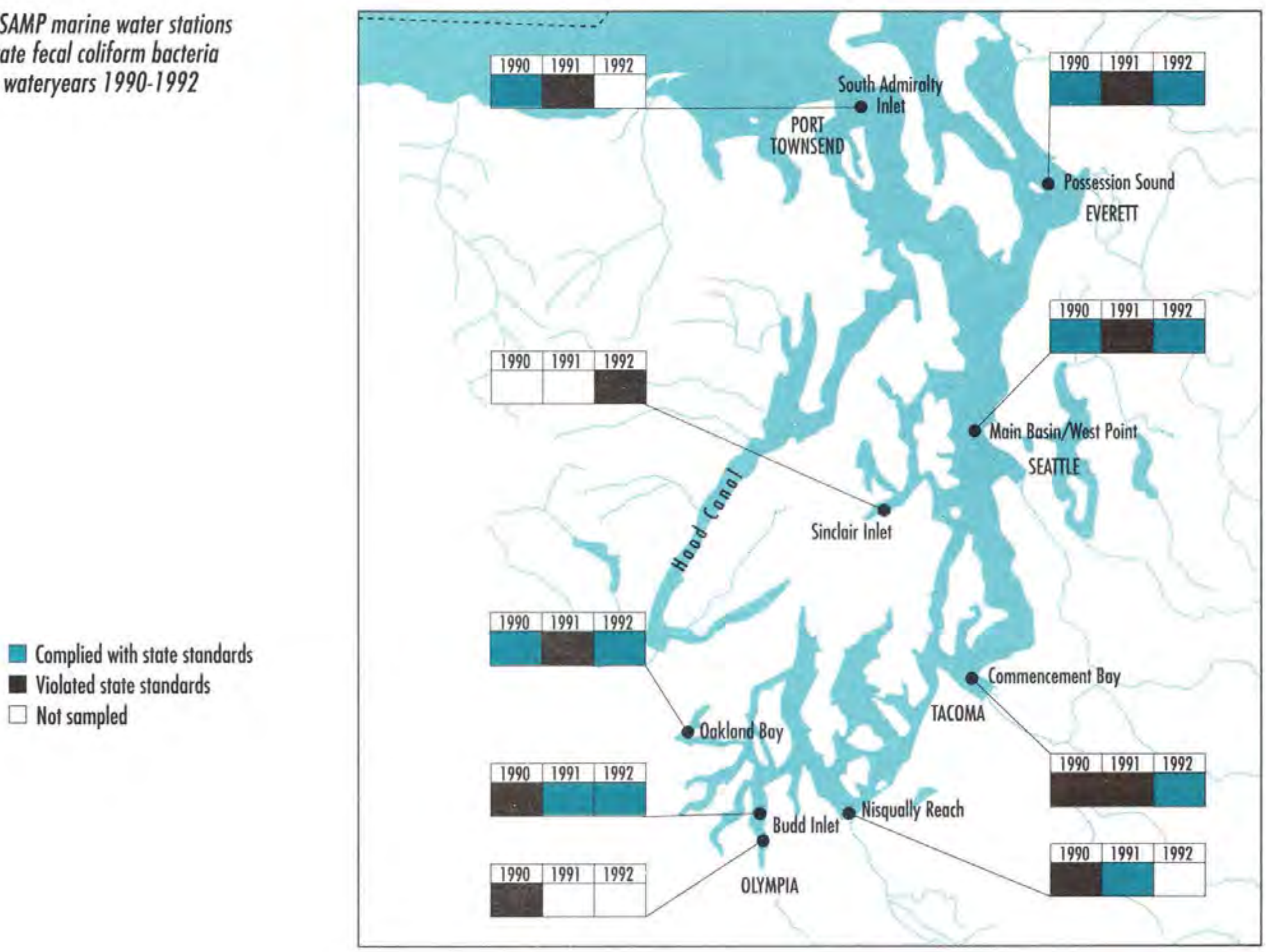
ed soil below drainfields. If the soil is saturated, or if the system malfunctions, untreated wastes may be carried to nearby waters. Improperly treated sewage discharges and boat wastes also introduce pathogens into surface waters.

1992 MARINE WATER COLUMN MONITORING RESULTS

The Department of Ecology samples monthly for fecal coliform bacteria (one sample per station) at a number of stations throughout Puget Sound to assess fecal contamination of marine waters (Figure 12). Ecology collects and summarizes their data on surface waters based on wateryears, which run from October to September. Over the last three wateryears, several stations exceeded state standards for fecal coliform bacteria (Figure 13). Commencement Bay was the only station that exceeded standards for more than one year, suggesting that this bay may experience chronic fecal contamination problems. Some of the other stations exhibiting exceedances were rotating stations, however, and have only been sampled one year out of the past three years. Sampling in future years will determine whether these rotating stations have chronic fecal contamination problems.

For the most recent wateryear (October 1991 - September 1992), Ecology found fewer exceedances than in previous years. Sinclair Inlet was the only

Figure 13. PSAMP marine water stations exceeding state fecal coliform bacteria standards in wateryears 1990-1992



Reference: Janzen and Eisner, 1993

station which exceeded state standards over this period. This may be due to the low levels of rainfall during the spring and summer of 1992. Lower levels of rainfall tend to reduce the amount of fecal wastes carried into adjacent water bodies by runoff.

The Municipality of Metropolitan Seattle (Metro) conducts extensive ambient monitoring in the marine waters offshore from several of its sewage treatment plant discharges. Their results are consistent with the results from Ecology's sampling. The only offshore stations which exceeded water quality standards for fecal coliform bacteria were located near the West Point sewage treatment plant in 1990 and 1991. As with Ecology's sampling, qualitative comparison suggests that levels of fecal coliform bacteria were lower in 1992, when no exceedances were observed at the offshore stations.

1992 FRESHWATER MONITORING RESULTS

In 1992, Ecology found that four of the ten stations sampled exceeded the state standard for fecal coliform in fresh water. These stations were located on the Nooksack River at Brennan, the Sammamish River at Bothell, the Green River at Tukwila, and the Puyallup River at Tacoma. These four rivers also exceeded standards in 1991, and probably have chronic problems with fecal contamination. In addition, the Stillaguamish River near Silvana may have problems with fecal contamination. This station exceeded standards in 1991 and, depending on how compliance is calculated (see sidebar), barely complied with or exceeded standards in 1992.

The results from the Stillaguamish River sampling illustrate the difficulties in applying the state standard for fecal coliform. In this report, annual geometric means (based on ten to 12 monthly samples collected within one wateryear) are used in the marine and freshwater analyses as a measure of annual compliance with the fecal coliform standard. The annual geometric means indicate that the station at Silvana just barely complied with the standard (the second highest sample in 1992 is equal to 200 organisms/100 ml, and the standard states that ten percent of the samples cannot exceed 200 organisms/100 ml). However, if Department of Health guidelines using the most recent 15 samples are used, the station exceeded standards in 1992 because of high values measured in 1991.

Ecology scientists sample freshwater quality monthly at stations near the mouths of the 10 major rivers entering Puget Sound—the Nooksack, Skagit, Sammamish, Stillaguamish, Snohomish, Cedar, Green-Duwamish, Puyallup, Nisqually, and Skokomish (Figure 14). Sampling at the mouths of these rivers, where they enter Puget Sound, allows scientists to estimate the input of upstream sources of pollution into the Sound.

Applying the state standard for fecal coliform bacteria

Applying the state standard for fecal coliform bacteria can pose difficulties, since the standard does not state the minimum number of samples that must be taken to determine compliance. For example, if an investigator took eight samples of marine water and one of the samples exceeded 43 organisms/100 ml, the water would exceed the second part of the standard (more than ten percent of the samples exceed 43 organisms/100 ml). If the investigator decided to take four more samples and they were all below 43 organisms/100 ml, the water would not exceed the standard (only one of 12 samples exceeds 43 organisms/100 ml). Because the standard does not state the number of samples required to determine compliance, both cases are technically correct.

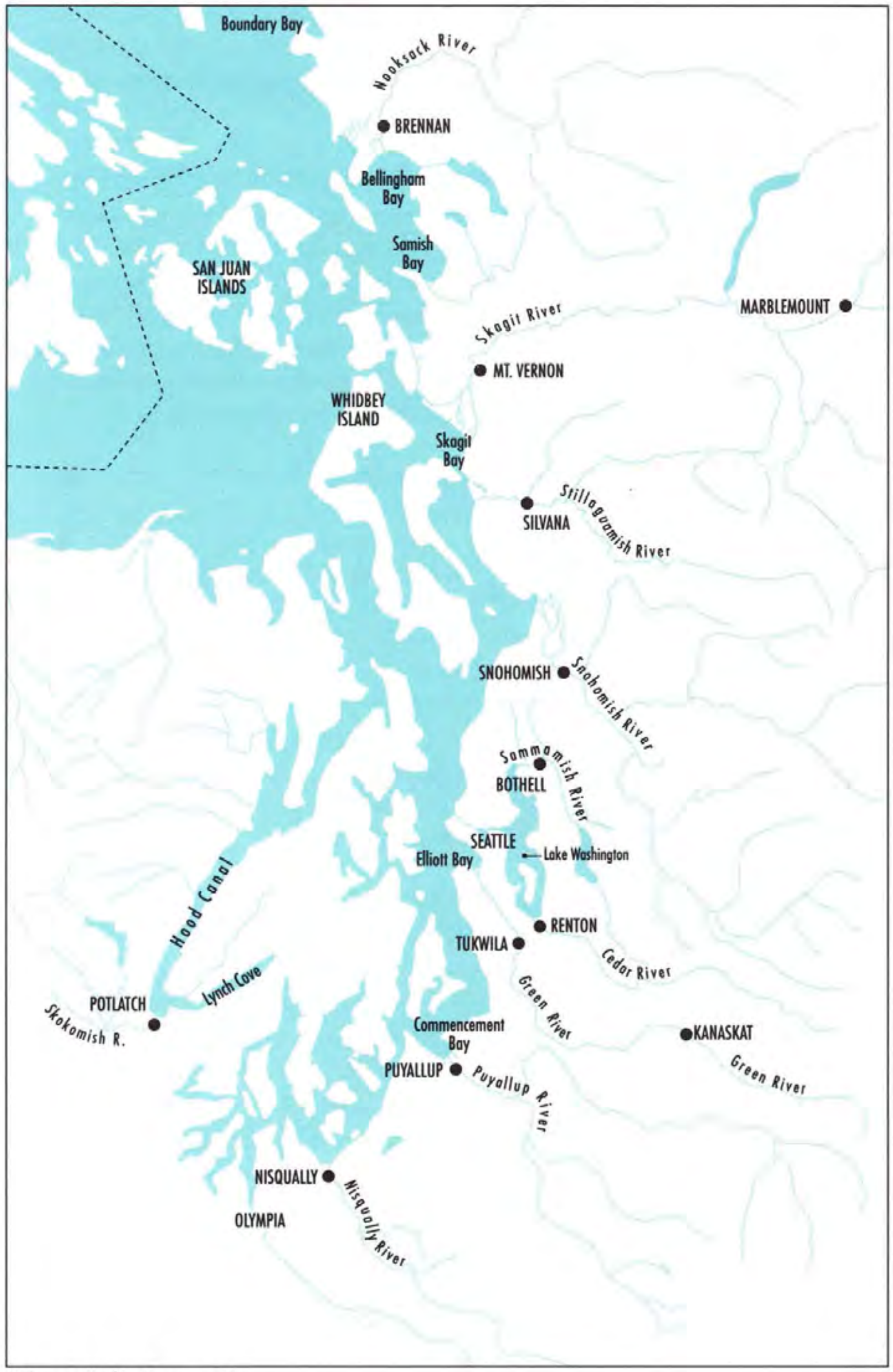
The Washington Department of Health, which classifies commercial shellfish growing areas, presently uses a minimum of 15 monthly water samples to evaluate fecal contamination. Measurements of fecal coliform bacteria can vary widely, even in samples that are collected simultaneously in the same body of water. A larger number of samples reduces the effect of this variability and ensures that one artificially high sample will not result in a violation of the standard. However, it would be prohibitively expensive to collect 15 samples each month at all the sites which Health monitors. To provide adequate coverage of a number of sites over time, the agency collects one sample at most sites monthly. They then assess the water quality of each site by evaluating the last 15 samples collected over time and compare the results to the marine water standard.

In the analyses presented in the marine water and freshwater sections of this chapter, annual geometric means (generally based on ten to 12 monthly samples) are used to evaluate exceedances. These are used for two reasons:

1. Several stations are sampled on a rotational basis and only have one year of monthly samples on which to base compliance.

2. The annual geometric means provide a discrete evaluation of water quality for a given wateryear, without relying on samples taken in a previous wateryear.

Figure 14. 1992 PSAMP freshwater sampling stations.



Reference: Hopkins, in preparation

Other Freshwater Studies

The City of Seattle Drainage and Wastewater Utility recently studied sources of fecal contamination in Pipers Creek, an urban stream at the northwestern edge of the Seattle city limits. The Pipers Creek watershed action plan, completed in 1990, identifies fecal contamination as one of the two most significant water quality problems affecting the watershed. High levels of fecal coliform bacteria have been found in the creek, in stormwater draining to the creek, and in shellfish collected from Puget Sound near the mouth of the creek (Herrera Environmental Consultants, 1993).

Potential sources of fecal contamination into Pipers Creek include leaking sewer pipes, abandoned on-site sewage systems (septic systems), the Carkeek sewage treatment plant, and pets and other animals living in the urban environment (Pipers Creek Watershed Management Committee, 1990). With such a wide range of potential sources, it is difficult to identify efficient means of reducing bacterial contamination in Pipers Creek. The city of Seattle used ribosomal tracking to determine the origin of bacteria found within the creek. Ribosomal tracking identifies specific strains of *Escherichia coli*—an intestinal fecal coliform bacterium. The study identified the strains of bacteria found within the creek and compared them to strains found in a number of potential sources, such as sewage treatment plants, pet feces, and bird feces.

Forty-three percent of the strains found within the creek were identified in sources of fecal matter within the watershed. Thirty percent of the strains were found in cat feces, seven percent in dog feces, and three percent in duck feces. An additional three percent were of a strain observed in both dogs and sewage sources, and so could not be tracked to a single source.

The study found that the sources for a majority (57 percent) of the bacterial strains found within the creek could not be identified. This is to be expected since ribosomal tracking is a highly specific procedure, and strains of *E. coli* can vary even from individual to individual. Thus, for example, if several individuals of a species are sampled for bacterial strains, the strains may not match—even if the species is a major contributor of fecal matter—if the specific individual contributing fecal matter is not sampled. At the same time, some strains are shared by more than one species. In these cases it is not possible to determine which source contributed the bacterial strain.

These results are both surprising and informative, but should be interpreted with several caveats:

- *The results should not be used to infer the percentage of fecal contamination originating from a particular source (one cannot assume from this that 30 percent of the contamination is due to cats).* The methods only provide information about how many different strains are contributed by a source, not how much of the total bacteria originates from that source. A species may only contribute one strain, but if it is the most abundant strain present, that species is an important source.

- *A majority of the strains remain unidentified*, meaning that sources for a large percentage of fecal contamination to Pipers Creek have not been identified.

- *While these results provide evidence that cats may be a significant source of fecal contamination in Pipers Creek, it is unlikely that cats are a major source of fecal contamination throughout Puget Sound.* The Pipers Creek watershed is not representative of all watersheds throughout Puget Sound, particularly rural watersheds where fecal contamination is a major threat to abundant shellfish resources. The Pipers Creek watershed is completely sewered, has no on-site sewage systems (septic systems) in use and none of the sewer outfalls discharge into the watershed (although contamination can still occur from leaking pipes). Many of the other major sources of fecal contamination identified throughout Puget Sound (such as farm animal waste) are not present. With nearly all of the human waste in this watershed treated at a sewage plant and discharged outside the watershed, domestic pets remain the major source of fecal contaminants. In other urban watersheds with similar conditions, domestic pets may also be major sources of fecal contaminants.

In spite of these caveats, application of ribosomal tracking technology in the Pipers Creek watershed marks an important breakthrough in our knowledge of the causes of fecal contamination. Not only does it identify sources of urban contamination which need to be addressed, it has also demonstrated the utility of a method that can be applied to other watersheds to identify sources. The major limitations in applying these methods elsewhere are the costs of analyses. Ribosomal tracking is expensive, although it may be money well spent in watersheds where large amounts of money will be invested in reducing sources of fecal contamination.

1992 SHELLFISH MONITORING RESULTS

The Washington Department of Health collects shellfish quarterly at 20 recreational beaches for analyses of fecal contamination in shellfish tissues. Health officials recently evaluated the results of sampling over the past three years (1989 to 1992) (Health, in preparation). They found that the levels of fecal coliform bacteria in shellfish tissue at a given site can vary widely over time. Bacteria levels at Dosewallips State Park ranged from 110 to 11,065 organisms/100 g shellfish tissue; at Saltwater State Park levels ranged from 14 to 1,977 organisms/100 g tissue. This means that either the presence of fecal wastes varied dramatically over time, or that measurements of bacteria in shellfish tissue are highly variable, so that a single measurement has limited usefulness.

The results also indicate that fecal coliform levels in shellfish tissues at many of the public beaches are consistent with the classifications of the adjacent commercial growing areas (based on marine water standards). There is no state standard for the concentration of fecal coliform bacteria in shellfish tissue. However, Health uses 230 organisms/100 g as a general guideline above which shellfish tissue are significantly contaminated and likely to present a health threat. The agency arranged the results into three categories: those falling below 30 organisms/100 g; those ranging from 30 to 230 organisms/100 g; and those with more than 230 organisms/100 g. All beaches in commercially prohibited areas (with one exception) had a majority of their values in the higher two categories (Figure 15). The majority of the values at Belfair, Dosewallips, and Walker parks, and at Vaughn Spit were in the highest category. The results at Ross Point and Jarrell Cove do not appear as high as the other prohibited sites. Health officials believe that the results at Ross Point may reflect improvements in the West Bremerton sewage treatment plant (Health, in preparation). Jarrell Cove is classified as a prohibited area because of its proximity to boat waste discharge. Fecal contamination from boat waste is a highly episodic event and is easily missed by quarterly sampling (Woolrich, Health, personal communication). Shellfish tissues sampled within commercially approved and conditionally approved growing waters all had a majority of their values within the lowest category.

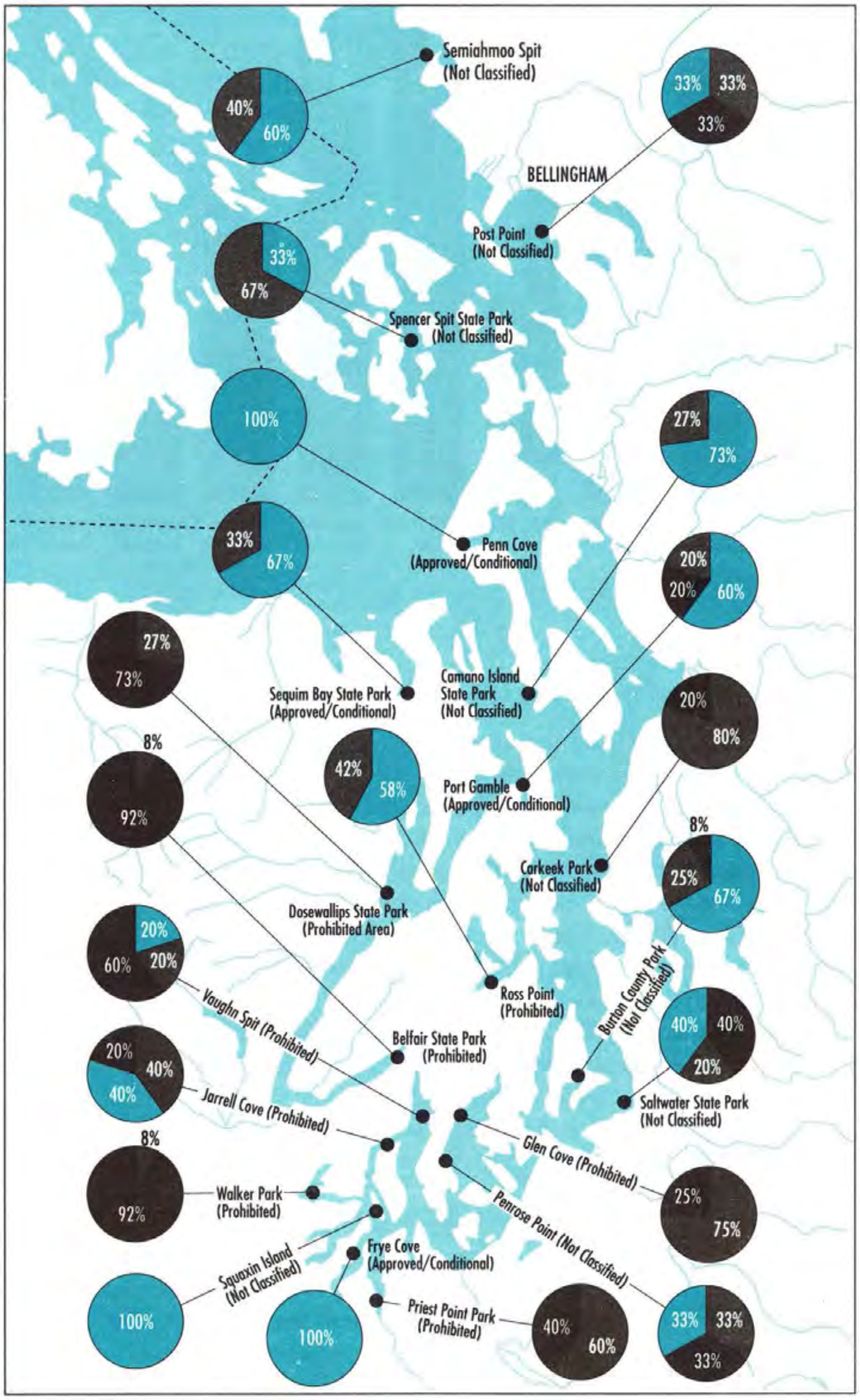


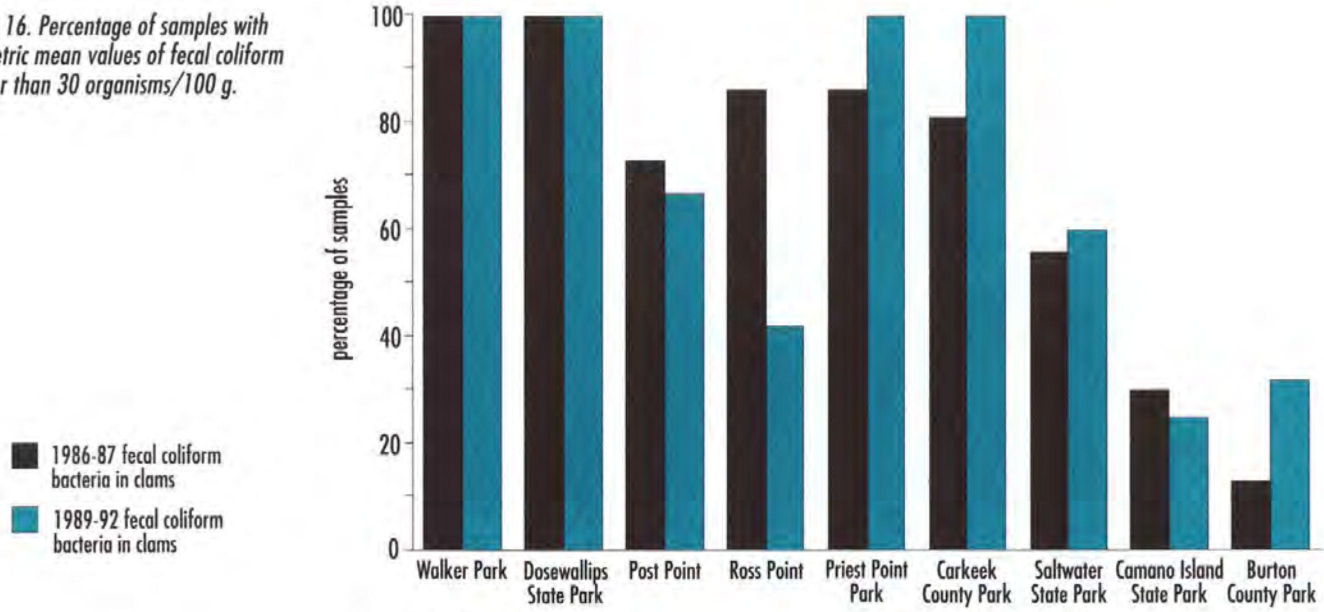
Figure 15. Fecal coliform bacteria concentrations in 1992 shellfish tissue samples (classifications of adjacent growing areas are noted in parentheses–see page 47 for a description of shellfish bed classifications).

Reference: Health, in preparation

< 30 MPN (good)
31-230 MPN (moderate)
> 230 MPN (poor)

Health compared results from this evaluation to results from a study in 1986-87 at the nine sites sampled in both studies. They found that results were very similar from the two time periods, suggesting that there have been no changes in fecal contamination of shellfish at the sites studied (Figure 16). The one exception was at Ross Point which, as mentioned, may be due to improvements in the West Bremerton sewage treatment plant.

Figure 16. Percentage of samples with geometric mean values of fecal coliform greater than 30 organisms/100 g.



Reference: Health, in preparation

Trends in Commercial Shellfish Bed Acreage Since 1981

The Department of Health uses four classifications in regulating the harvest of shellfish from commercial beds (see "Shellfish bed classifications," page 47). Over the last 12 years, significant changes in total acreage within each classification have occurred (Figure 17). From 1981 to 1985, changes in acreage classification were relatively small. After 1985, large amounts of approved acreage were downgraded to restricted. One of the largest losses of approved acreage occurred in 1987, when Health downgraded 11,900 acres in Port Susan because of agricultural nonpoint pollution and proximity to the Warm Beach sewage treatment plant. In 1989 there was another large downgrade of 9,540 acres in North Skagit Bay due to rural nonpoint pollution. In 1989 Health also issued the first shellfish bed upgrade in the history of Puget Sound, reclassifying 1,380 acres in Oakland Bay from restricted to conditionally approved due to improvements in water quality (Health, 1992).

Harvest restrictions in commercial beds since 1989 have been minimal relative to previous years. This is due in large part to increased application of conditionally approved classifications. Because of increased monitoring, Health is now better able to define the conditions leading to contamination of shellfish growing waters. For example, by correlating fecal coliform levels with rainfall, Health can determine the amount of rainfall that results in unacceptable levels of fecal bacteria. When these high rainfall conditions occur, Health temporarily closes the bed until water quality improves.

Downgrades of approved acreage due to fecal contamination still occur. However, the majority of downgrades since 1989 have been to conditionally approved classifications, which allow harvest when water quality conditions are favorable. Since 1989 the amount of prohibited acreage has increased slightly and restricted acreage has decreased. Conditionally approved acreage has increased dramatically since 1991 (Figure 17).

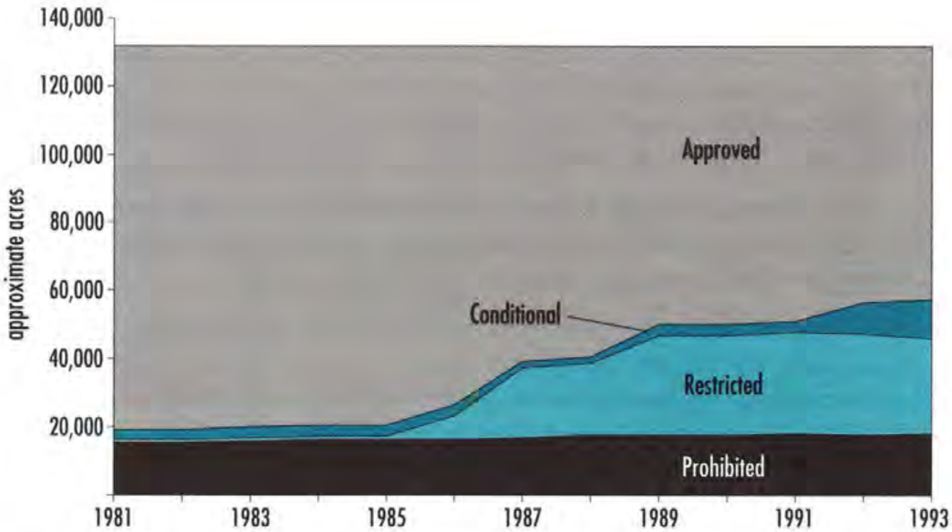


Figure 17. Upgrades and downgrades of commercially classified shellfish beds from 1981 to 1993 (does not include newly classified beds).

Reference: Health, 1992

These changes seem to mark a turning point in the struggle to reduce fecal contamination. Since 1989, Health has upgraded a total of 5,330 acres of commercial shellfish beds within Puget Sound. In the last two years alone, Health upgraded 3,500 acres within six commercial beds. While fecal contamination of shellfish beds remains a serious problem that merits priority attention, our efforts and investments in education, monitoring and enforcement appear to be paying off.

Studies from Other Monitoring Efforts

Penrose Point State Park. Information collected on fecal contamination in shellfish at Penrose Point State Park in Carr Inlet have historically indicated highly variable levels of fecal coliform bacteria (PSWQA, 1992). Over the last three years, PSAMP results indicate that fecal coliform concentrations ranged from ten to 1,962 organisms/100 g of shellfish tissue, with a geometric mean of 96 organisms/100 g. While the annual means are not high enough to restrict harvesting in this park, the levels of fecal coliform are occasionally very high, and may periodically present a health threat.

Several agencies recently participated in a study to assess the sources and patterns of contamination at Penrose Point to better understand the reasons underlying the highly variable levels of water quality at this site (Determan et al., 1992). The Tacoma-Pierce Health Department, the Department of Ecology, and the U.S. Environmental Protection Agency conducted a comprehensive assessment of fecal contamination in fresh water, marine water, and shellfish in the area.

The study yielded a number of important findings.

- *Streams leading into Mayo Cove in Penrose Point State Park had higher concentrations of fecal coliform bacteria in the drier summer months (April through September) than during the wet season (October through March).* However, the total amount of bacteria contributed to the cove by these streams was higher in the wet season, due to higher streamflow.

Shellfish bed classifications

Approved–Department of Health surveys indicate that contaminants are not present in dangerous concentrations. Fecal coliform bacteria cannot exceed a geometric mean most probable number (MPN) of 14/100 ml; and not more than ten percent of the samples can exceed a MPN of 43/100 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 88/100 ml, and if not more than ten percent of the sample exceed an MPN of 260/100 ml. Shellfish harvested from restricted areas cannot be marketed directly, but must be relayed to an approved growing area for controlled purification.

Prohibited–Department 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 or relayed to approved areas for later harvesting.

• *Intensive sampling during storm events indicated that loads of fecal coliform bacteria from freshwater inputs were 100 times higher than the average load determined during routine sampling.* This result underscores the fact that routine sampling, which misses or is even precluded by major storm events, may not capture important aspects of water quality dynamics.

• *Within Mayo Cove, levels of fecal coliform bacteria in marine waters were significantly higher in the inner cove, which exceeded water quality standards for fecal coliform, than in the outer cove, which complied with standards.*

• *While the total amount of fecal coliform carried into Mayo Cove by streams varied seasonally, the levels of fecal coliform bacteria within the cove did not.* In addition, calculations of the total amount of fecal coliform bacteria contributed by all freshwater sources were below the actual levels measured within the cove. These two results suggest that sources other than upland runoff contribute to contamination of the marine waters of the cove.

• *During a summer survey in which light to moderate boat activity occurred in the cove, levels of fecal coliforms were lower than at any other time during the project.* During a subsequent survey on Labor Day, when boating activity was heavy, fecal coliform levels were the highest measured at any time during the project. Calculations of the total amount of fecal coliform bacteria contributed by all freshwater sources during this summer survey were an order of magnitude below the actual levels measured within the cove.

The investigators concluded from the results that boat waste discharge is a significant contributor of fecal contamination to Mayo Cove. This finding is consistent with the highly variable levels of fecal coliform bacteria found in shellfish over the last three years, as boat use of Penrose Point State Park is highly episodic. In addition, PSAMP shellfish data indicate that the highest levels of fecal coliform invariably occur in the summer and fall, when boat use is highest.

Dosewallips State Park. PSAMP data indicate that shellfish at Dosewallips State Park, historically one of the largest recreational shellfish areas in Puget Sound, had consistently high levels of fecal coliform bacteria over the last three years (Figure 18). Shellfish are abundant at this site (PSWQA, 1992), in part because it has been closed to harvest for several years. Because of the abundant shellfish resources there, documenting the causes of bacterial contamination and identifying effective means of improving water quality are a high priority for the Department of Health and State Parks and Recreation.

Health officials conducted shoreline surveys to evaluate sources of bacterial contaminants into this area. The surveys revealed that on-site sewage systems (septic systems) do not appear to be the primary source of fecal contaminants, and that bacterial inputs from rivers and streams in this area appear to be minimal. Health concluded that harbor seals (*Phoca vitulina richardsi*), which haul out in high numbers in this area, were likely the cause of fecal contamination at Dosewallips. Subsequent sampling indicated that levels of fecal coliform bacteria were very high in sediments and shellfish in proximity to seal haulout sites.

The State Parks and Recreation Department, tribes, National Marine Fisheries Service, Cascadia Research Collective, and others worked together to develop a restoration plan which reduced fecal contamination of shellfish from seals without harming or otherwise affecting seal populations. The first portion of the project involved constructing floats to provide alternative haulout sites away from the shellfish growing areas. Seals readily used these floats for haulouts, but also continued to use former haulouts near

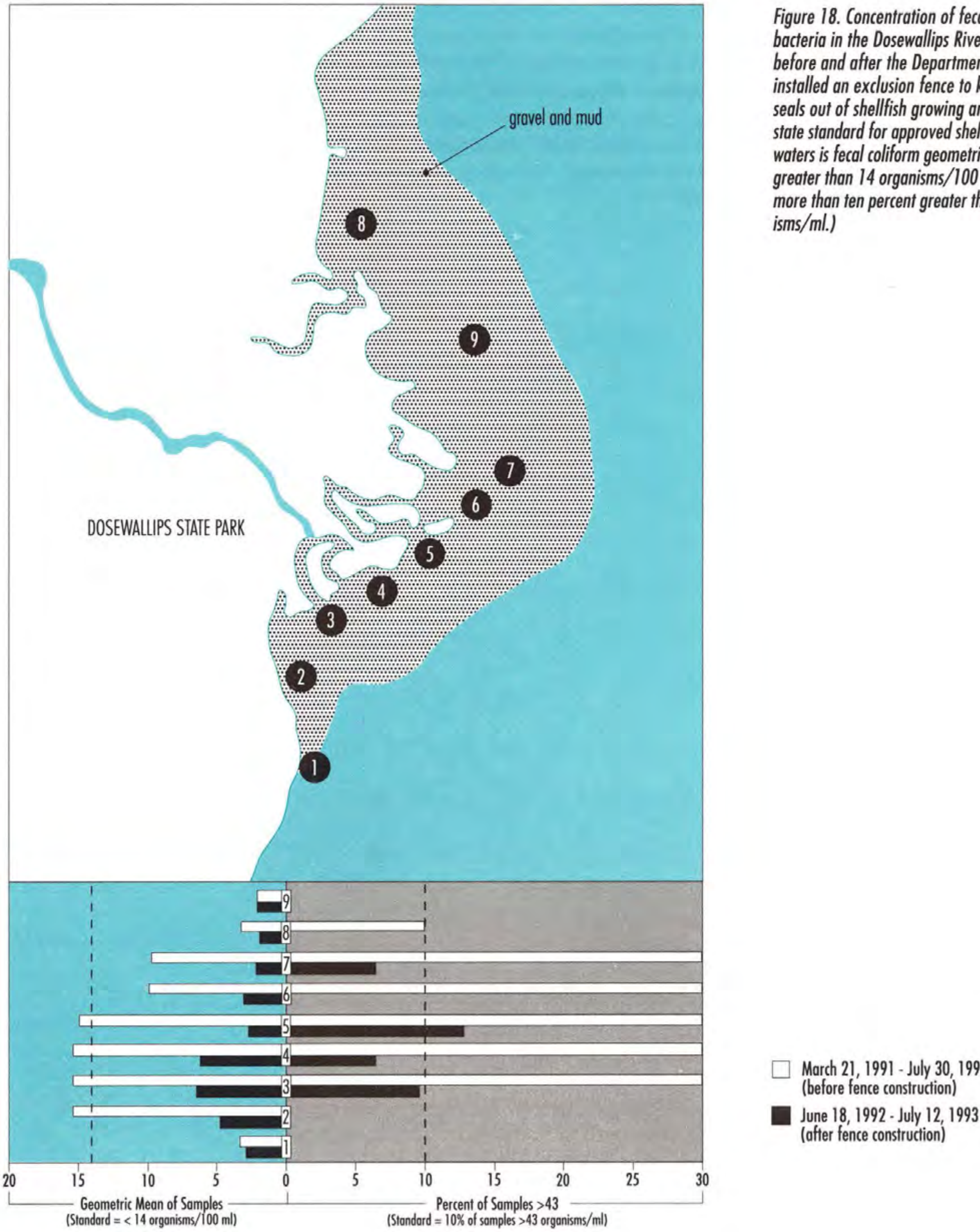


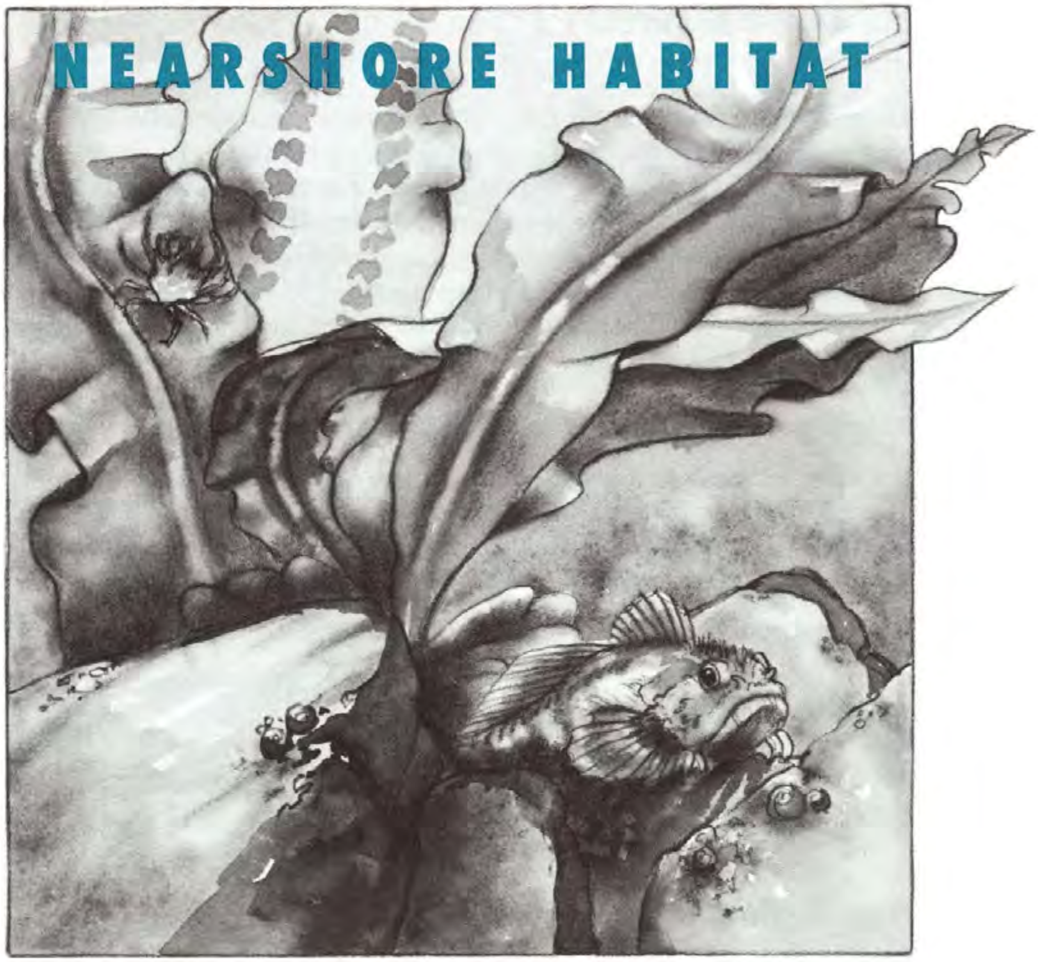
Figure 18. Concentration of fecal coliform bacteria in the Dosewallips River Delta before and after the Department of Health installed an exclusion fence to keep harbor seals out of shellfish growing areas. (The state standard for approved shellfish growing waters is fecal coliform geometric mean not greater than 14 organisms/100 ml with not more than ten percent greater than 43 organisms/ml.)

Reference: unpublished Health data

shellfish beds. In June 1992, Parks installed a fence that prevents seals from hauling out on a portion of the Dosewallips Delta near shellfish beds.

Department of Health monitoring before and after construction of the exclusion fence has shown improvement in water quality (Figure 18). In 1991, five sites (those in closest proximity to harbor seal haulout sites) exceeded water quality standards for fecal coliform bacteria. Sampling conducted after construction of the fence—from June 1992 to July 1993—reveals that the geometric means of fecal coliforms at all stations are below the state standard, although one site exceeds the second part of the standard (not more than ten percent of samples shall exceed 43 organisms/100ml). Based on the water quality improvements documented over the course of a year, Parks reopened a 400-foot section of the park for harvest in early August 1993.

NEARSHORE HABITAT



BACKGROUND

Nearshore habitats are extremely important to the health of Puget Sound and its marine life. These intertidal and subtidal areas along Puget Sound's shorelines not only provide critical spawning, rearing, and feeding habitats, but also protect the shoreline from erosion and filter pollutants from the water. Nearshore salt marshes can reduce flooding by retaining stormwater during high flow periods. Other nearshore habitats include kelp beds, eelgrass beds, sand and mud flats, and cobble and rocky shorelines.

The data presented in this chapter are a result of several efforts that are beginning to document the composition and coverage of nearshore habitats throughout Puget Sound. As these efforts continue into the future, they will provide important information on the rate of habitat losses, the types of habitat that are most threatened, and the areas in which the most severe losses are occurring. Without this information we cannot evaluate the cumulative impacts of human activities on habitat coverage and it becomes difficult, if not impossible, to effectively manage those activities to minimize damaging habitat losses.

THREATS TO NEARSHORE HABITATS

The location of nearshore habitats—at the boundary between land and water—places them in conflict with many human activities. The shorelines of Puget Sound are some of the most valuable real estate in the region. Industries locate along shorelines for access to transportation and discharge of wastewater. Residential development is intense along shorelines because of the aesthetic and recreational benefits provided by the Sound. Many other activities that occur along shorelines can destroy or degrade nearshore habitats, including:

- Dredging channels and constructing piers.
- Filling wetlands or tidelands for nearshore development projects.
- Conversion of nearshore habitat for agricultural uses.
- Constructing seawalls and bulkheads to reduce shoreline erosion.
- Dumping debris on beaches.
- Land clearing, logging, or other activities which promote erosion and increase the rate of sedimentation onto nearshore habitats.
- Spills of oil and hazardous substances.
- Introducing invasive plant species, such as the cordgrass *Spartina*, which dramatically alters the characteristics of nearshore habitats.

EFFECTS OF NEARSHORE HABITAT LOSSES

As we destroy or degrade nearshore habitats through activities such as development and agriculture we are damaging one of the foundations on which a majority of the life within Puget Sound depends. Yet as important as nearshore habitats are to the ecological integrity of Puget Sound, little is known about how much of each habitat type exists, or how rapidly they are being destroyed. What little data exists indicates that much of the historical habitat, particularly in urban areas, has been converted by human development (Bortleson et al., 1980; Canning and Stevens, 1989).

It is critical that baseline data on the amount and location of nearshore habitats be established. Dramatic losses have already occurred and it is important to document conditions before further destruction occurs. With the availability of high-quality baseline data, the rate of future habitat losses can be accurately determined. The baseline data will also help determine the types of habitat that are most threatened and the areas in which the most severe losses are occurring.

Information about the location and composition of nearshore habitats is also important for resource agencies which prepare spill response plans that protect biological resources in the event of oil and other hazardous substance spills. These agencies need accurate maps to identify critical areas most in need of protection during spills and to assess the amount of resource damage caused in areas where spills have occurred.

1992 NEARSHORE HABITAT MONITORING RESULTS

The Washington Department of Natural Resources (Natural Resources) surveys the type and areal extent of intertidal nearshore habitats using remote-sensing imagery. The maps developed from these remote-sensing images are verified by groundtruthing obtained during site visits. Groundtruthing involves confirming remote sensing data through on-the-ground surveys. These efforts represent the first attempt at a statewide inventory of nearshore habitat.

Natural Resources, in conjunction with EPA's Environmental Monitoring Systems Laboratory, collected remote-sensing images along the majority of Puget Sound shorelines in 1992. However, they have run into several difficulties in translating the remote-sensing data into habitat maps. Because of

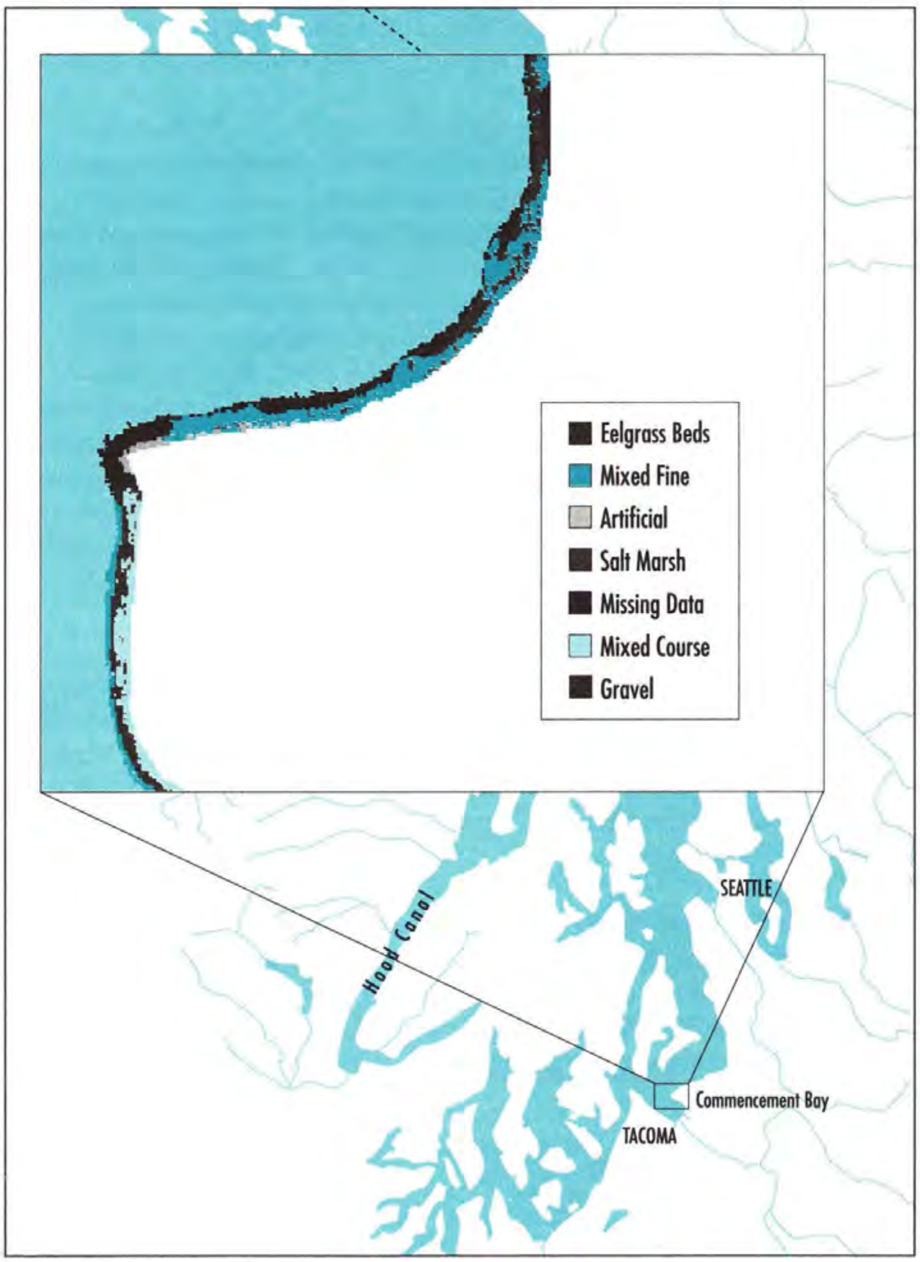


Figure 19. Portion of nearshore habitat inventory in Commencement Bay. Surface areas are determined by the Department of Natural Resources using remote sensing imagery.

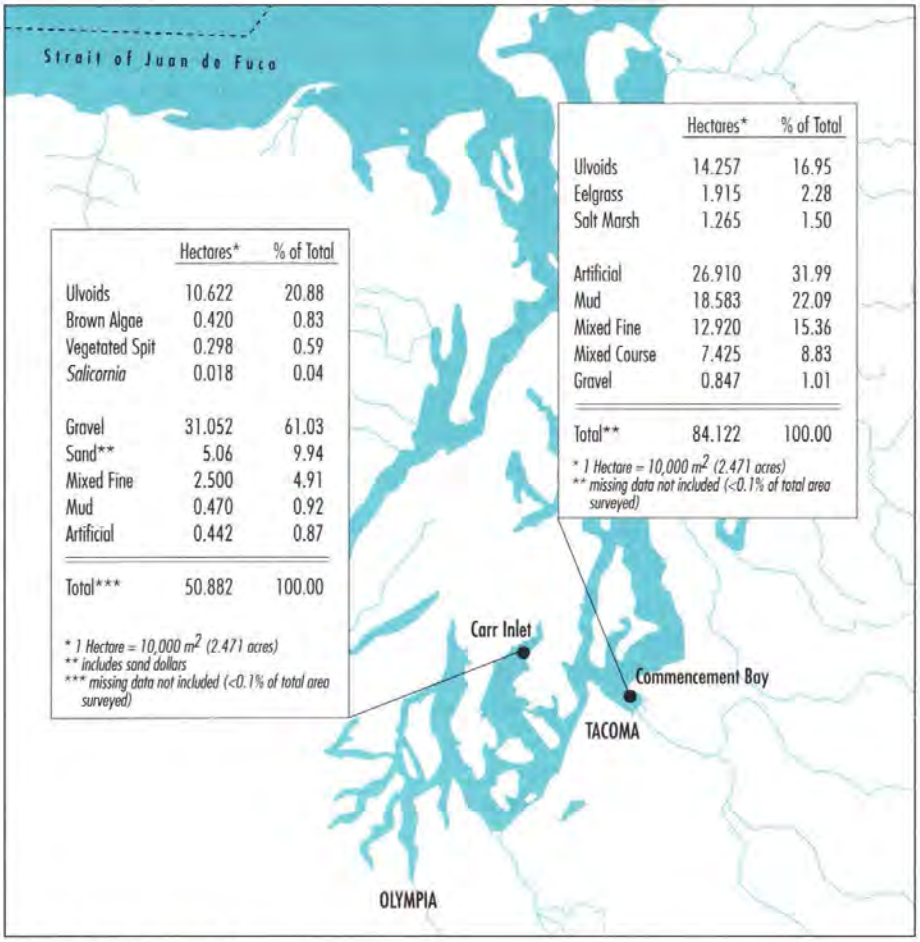
Reference: Natural Resources, in preparation difficulties in correcting for aircraft movements (pitch, yawl, roll) during data collection, EPA has not been able to rectify the remote-sensing images as accurately as envisioned. In addition, correcting these problems has delayed the production of habitat maps. Remote sensing of habitat types is an evolving technology, and it is inevitable that the use of state-of-the-art technology involves overcoming unforeseen obstacles.

Because of these difficulties, Natural Resources has processed only a small portion of the imagery collected in 1992. The two sites they processed were Commencement Bay, and Forest Beach in Carr Inlet. Figure 19 shows a sample of the type of images collected along a portion of Commencement Bay. (Because these inventory maps are in full-color, we could not accurately reproduce them in *Puget Sound Update*. Complete maps can be obtained through the Department of Natural Resources contact person listed in the contacts section at the end of this report.) These results are preliminary, since the maps have not been fully groundtruthed. They are presented here to indicate the type of information Natural Resources will have available throughout the Sound when they have corrected problems in data processing.

The preliminary habitat maps indicate that the two sites have dramatically different nearshore areas. Commencement Bay is a heavily urbanized area with a high percentage of altered nearshore habitat. In the intertidal zone, the most common component is artificial substrate, including docks, pilings, log booms, and bulkheads. In addition, many of the areas classified as upland in the map are filled or constructed areas that were formerly nearshore habitat (David Evans and Associates, 1991). After artificial substrate, mud is the next most common type of substrate, although it is almost all located within one area of the Hylebos Waterway. Mixed fine substrates and ulvoids (aquatic algae also known as sea lettuce) are almost as common as mud substrates, and are distributed throughout the mapped region. Eelgrass is present along the shoreline north of Brown's Point. Other types of habitat present include mixed coarse substrate, and small amounts of salt marsh and gravel (Figure 20).

In contrast to Commencement Bay, Forest Beach has a small percentage of artificial substrate and is dominated by gravel substrates. Ulvoids are also abundant throughout the intertidal zone. In order of decreasing coverage, sand, mixed fine substrates, artificial substrates, brown algae, and *Salicornia* (also known as pickleweed or saltwort) are also present in the intertidal zone.

This type of information is a preview of the kind of data Natural Resources will have available throughout the Sound. Although they have been delayed in processing much of the data, the department has surveyed over two-thirds of the Sound. These data will provide an important baseline to compare with future surveys to evaluate the changes in nearshore habitat type and coverage.



Carr Inlet:

	Hectares*	% of Total
Ulvoids	10.622	20.88
Brown Algae	0.420	0.83
Vegetated Spit	0.298	0.59
Salicornia	0.018	0.04
Gravel	31.052	61.03
Sand**	5.06	9.94
Mixed Fine	2.500	4.91
Mud	0.470	0.92
Artificial	0.442	0.87
Total***	50.882	100.00

** 1 Hectare = 10,000 m^2 (2.471 acres)*
*** includes sand dollars*
**** missing data not included (<0.1% of total area surveyed)*

Commencement Bay:

	Hectares*	% of Total
Ulvoids	14.257	16.95
Eelgrass	1.915	2.28
Salt Marsh	1.265	1.50
Artificial	26.910	31.99
Mud	18.583	22.09
Mixed Fine	12.920	15.36
Mixed Course	7.425	8.83
Gravel	0.847	1.01
Total**	84.122	100.00

** 1 Hectare = 10,000 m^2 (2.471 acres)*
*** missing data not included (<0.1% of total area surveyed)*

Figure 20. Nearshore habitat inventory in Carr Inlet and Commencement Bay.

Reference: Natural Resources, in preparation

Other Studies

Monitoring by Natural Resources is presently one of the few efforts collecting Soundwide data on habitat coverage and composition. However, a number of special studies and assessments of individual sites have occurred. These studies provide valuable information for evaluating the success of habitat mitigation projects (projects which attempt to recreate or rehabilitate habitat to compensate for habitat lost during construction), identifying sensitive areas in need of protection as required by the Washington state Growth Management Act, identifying areas for protection during oils spills, and for other resource management issues.

Commencement Bay. In addition to the Department of Natural Resources survey described previously, the U.S. Army Corps of Engineers evaluated the historical changes in habitat in Commencement Bay from 1877 to the present (Dave Evans and Associates, 1991). The study relied on extensive literature review and analyses of photographs and maps. They found that of the original 834 hectares of intertidal mudflats estimated to exist in 1877, only 75 hectares remain—a 90 percent loss. Of the estimated 1,558 hectares of emergent marsh habitat, 23 hectares—or a little over one percent—remains. Some of the remaining marsh is habitat that has been recreated through mitigation efforts. The report cites filling for port development, flood control activities, and agricultural development as major causes of the extensive habitat loss.

Thurston County. A number of counties are also conducting inventories of nearshore habitat and upland wetlands. These inventories are crucial for compliance with part of the state's Growth Management Act, which requires local governments to develop plans to minimize future growth in critical areas. Critical areas include: wetlands, frequently flooded areas, geologically hazardous areas, fish and wildlife habitat conservation areas, and critical aquifer recharge areas. Many of the critical areas (wetlands, fish and wildlife habitat conservation areas, and critical aquifer recharge areas) are identified as such because population growth in these areas will adversely affect water quality or biological resources. As a first step towards protecting critical areas, many counties are identifying the amount, type, and location of these areas. Once critical areas have been located and identified, they can be set aside for conservation to minimize the impacts of growth on water quality and biological resources.

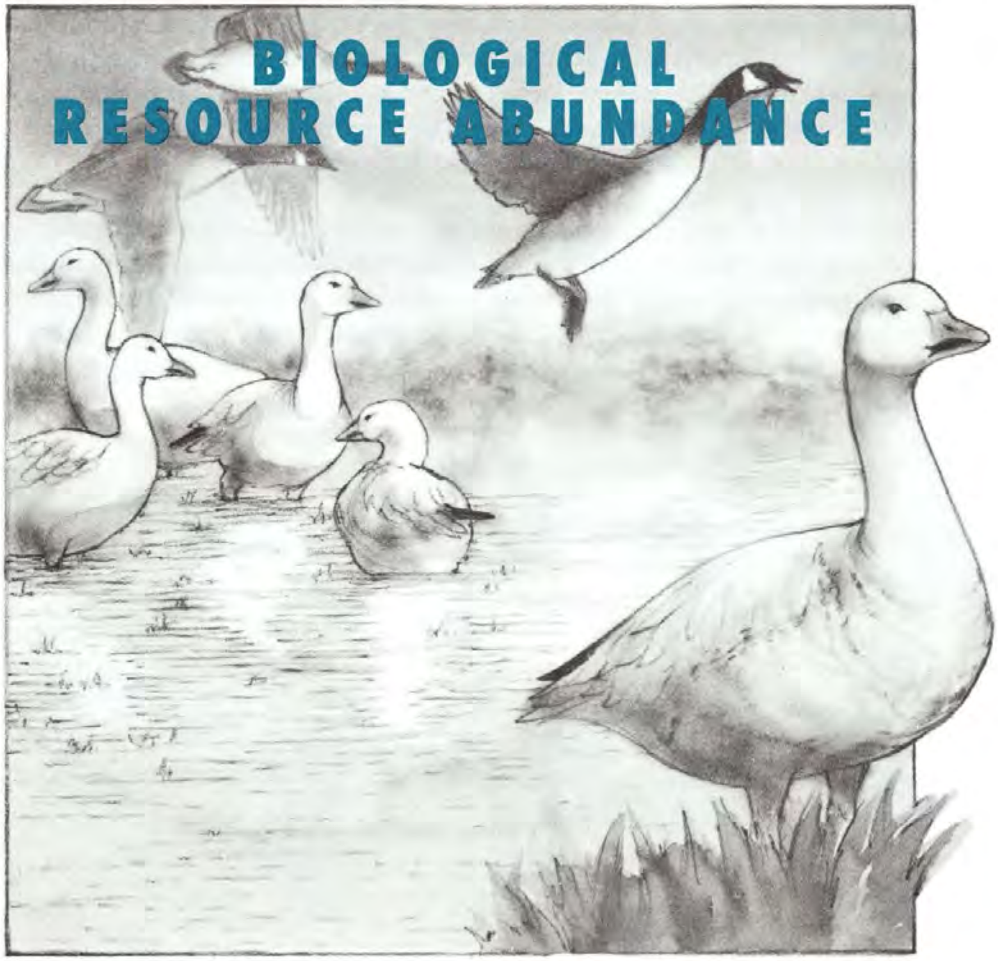
The Thurston Regional Planning Council recently completed an inventory of wetlands and stream corridors within northern Thurston County. The inventory relied on infrared aerial photography and photo-interpretation to identify wetlands of all types using the National Wetlands Inventory category system. Because PSAMP focuses on estuarine environments, only intertidal nearshore habitats will be considered here.

Table 7. Thurston County intertidal estuarine habitat

Habitat Types	Coverage
Unconsolidated shoreline	1,535.73 hectares
Emergent intertidal	165.56 hectares
Aquatic beds	4.17 hectares
Miscellaneous (primarily streambed)	4.29 hectares
TOTAL	1,709.75 hectares

Within northern Thurston County, 1,690 hectares of intertidal estuarine habitat are present (Table 7) (Morrison and Keeny, in preparation). Of this total acreage, unconsolidated shoreline, composed of cobble, sand, and mud flats, was the largest category, covering 1,518 hectares. Emergent intertidal wetlands—primarily salt marshes—cover 164 hectares of the county, mostly within the Nisqually National Wildlife Refuge. While this area is now preserved, Bortleson et al. (1980) estimate that approximately 25 percent of the Nisqually Delta salt marsh acreage was lost prior to preservation. In other deltas around the Sound that have not been preserved, losses are much higher, with up to 100 percent loss in urbanized deltas such as the Puyallup. Only four hectares of aquatic beds, which include eelgrass and kelp beds, exist throughout the northern part of the county, although additional small stands may be dispersed throughout other habitat types.

BIOLOGICAL RESOURCE ABUNDANCE



BACKGROUND

Many of the problems mentioned in the previous chapters—chemical contamination, eutrophication, and loss of nearshore habitat—can adversely affect the health or survival of the plants and animals in Puget Sound and reduce their populations. In addition, overharvesting can reduce these populations to low levels. In extreme cases, habitat loss, chemical and bacterial contaminants and overharvesting may result in their extinction.

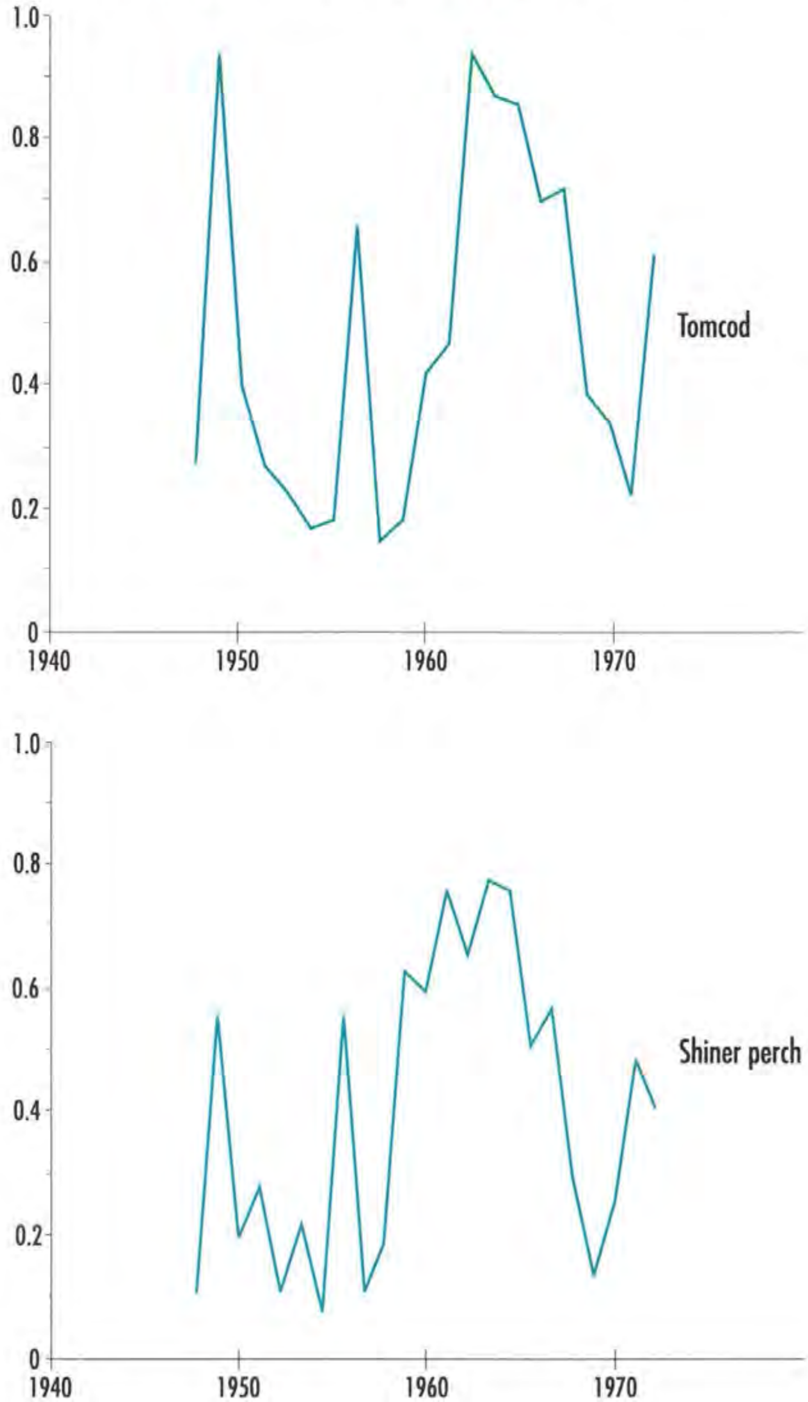
For many of the natural populations in Puget Sound, we do not yet have the data required to assess natural variability and human impacts. Many programs are in the early stages of collecting the long-term data needed to evaluate these factors. These programs are rapidly providing useful information on patterns of abundance. However, except in cases where severe depletion or extinction has occurred, these programs require more time before much can be said about human effects on populations of plants and animals.

EFFECTS OF BIOLOGICAL RESOURCE DEPLETION

Evaluating the effects of human activities on the abundance of natural populations is an extremely difficult task. Populations naturally undergo wide variations from year to year in response to factors such as temperature, storms, food supply, reproductive success, and predation. Ecological textbooks are filled with examples of populations—even those that are not harvested or otherwise likely to be affected by humans—which undergo dramatic and often uninterpretable variation between years.

In the midst of such wide-ranging natural variation, it is difficult to distinguish changes in abundance that are due to human activities from those that are a result of natural factors. Many years of data are often required merely to assess the degree of variation that occurs among years. Without a sufficient data record, resource managers may reach incorrect conclusions,

Figure 21. Population abundance of tomcod and shiner perch in Puget Sound.



Reference: Miller et al., 1991

resulting in inappropriate management actions. Figure 21 provides a good illustration of this. With only a part of the data available in these graphs, even for data records as long as five years, we might conclude that this population is drastically declining or dramatically improving. The truth appears to be that this population undergoes wide variations, and points out the need for an adaptive management strategy. Harvest levels set during peak abundance periods are likely to be totally inappropriate when population levels are lower, and may result in population depletion or even extinction. Nevertheless, as we collect more data on the biological populations of Puget Sound, we are better able to understand their natural dynamics, and evaluate changes due to human impacts before these impacts are so severe that drastic measures are required.

CAUSES OF BIOLOGICAL RESOURCE DEPLETION

The two most frequently cited reasons for the depletion of biological populations are habitat destruction and overharvesting. Reduced amounts of habitat on which a species depends for shelter, breeding, or feeding decreases the number of individuals that are able to survive. The declines of species dependent on old growth forests (spotted owls, marbled murrelets) are recent examples of this. In addition, if we overharvest a species, we take more individuals than the population is capable of replacing and population levels decline.

There are also examples of population declines resulting from poor water quality. If the quality of the waters in which a species lives is degraded, it may damage its health so that reproduction and survival are reduced or eliminated. Bald eagles provide an example of the effects of chemical contamination (from DDT) on population levels, and the success that improving water quality can have on returning populations to acceptable levels.

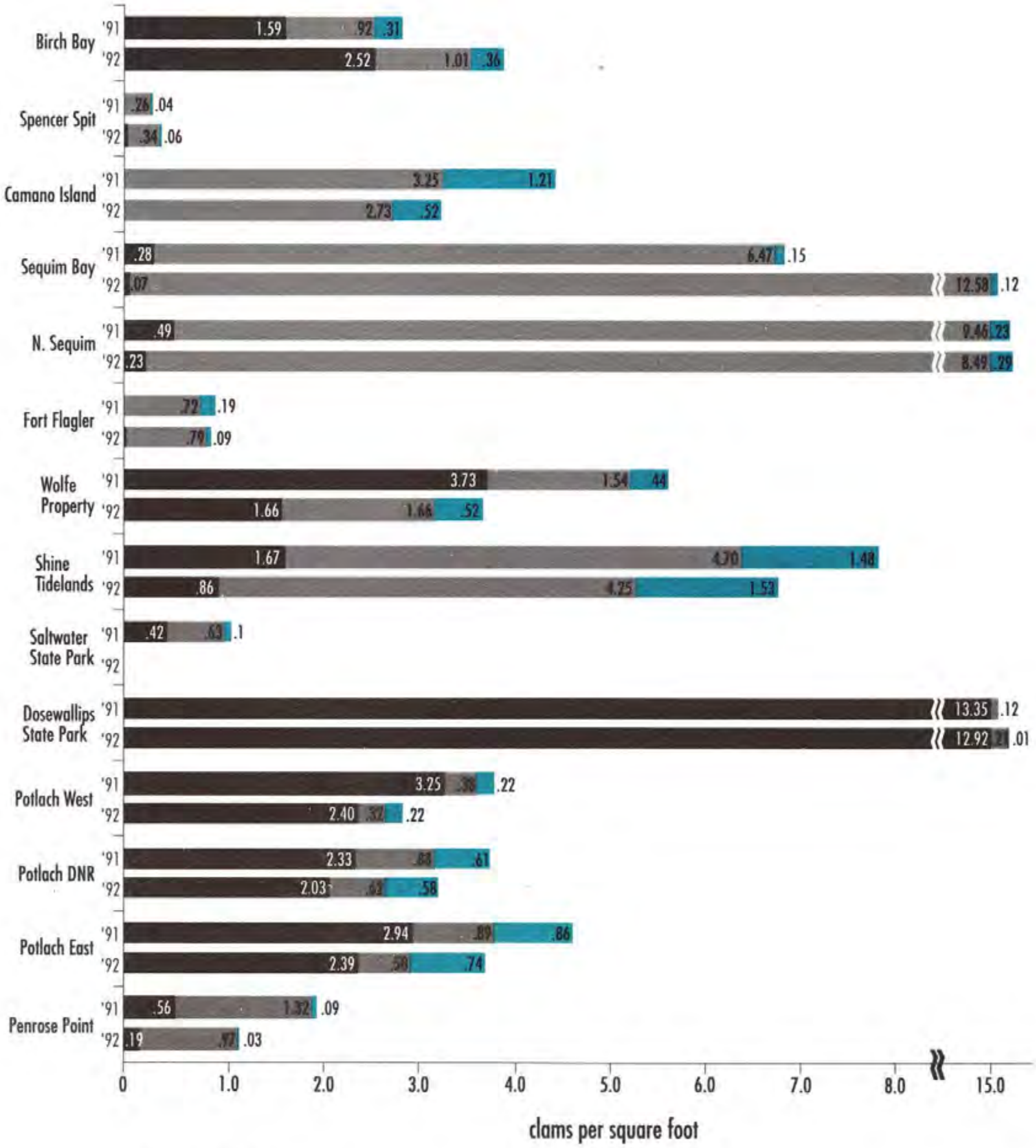
Different causes of population decline can also interact. Populations depleted by habitat degradation may be particularly susceptible to additional impacts from overharvesting. A species that can no longer survive in an area because of poor water quality may be devastated by the destruction or degradation of remaining habitat.

1992 SHELLFISH MONITORING RESULTS

The Washington Department of Fisheries (Fisheries) annually surveys clam and oyster populations on public beaches to estimate their abundance. Fisheries estimates the population of clams and oysters at each site by calculating the average number of animals per square foot and multiplying this by the total area surveyed for each beach. A minimum of eight samples per acre are taken at each beach. Fisheries uses these surveys for setting harvest levels to prevent overharvesting of shellfish so that enough adult shellfish remain to maintain the population. PSAMP scientists track the results of abundance surveys from 14 of the beaches sampled by Fisheries 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.

Fisheries analyzed results of shellfish abundance surveys from 1991 and 1992. The densities of shellfish on many beaches did not differ significantly between 1991 and 1992, while others exhibited a significant decline in density (Fisheries, 1993). Five of the 14 beaches monitored for PSAMP (North Sequim Bay State Park, Bywater Bay [Wolfe Property and Shine Tidelands], Potlatch State Park West, and Penrose Point State Park) had significant declines in Manila clam (*Tapes philippinarum*) density (Figure 22). Native littleneck clams (*Protothaca staminea*) decreased significantly at two beaches (Potlatch State Park East and Penrose Point State Park) and increased significantly at Sequim Bay State Park. Butter clam (*Saxidomus giganteus*) density declined at Camano Island, Potlatch East, and Penrose State Parks. Oyster (*Crassostrea gigas*) densities did not change significantly at any of the three beaches monitored for PSAMP.

Figure 22. Clam densities on state park beaches.



Reference: Health, in preparation

With only two years of data, it is not possible to say whether these declines are due to natural recruitment variation (variation is the production and survival of offspring), environmental factors, or to increased harvest pressures. Fisheries does have data that indicate that harvest pressures may have increased from 1991 to 1992 (Fisheries, 1993), but other factors, such as rainfall, also varied significantly and may explain part or all of the observed decline. As Fisheries officials collect more data in future years and can better estimate natural levels of variability between years, they will be able to correlate population changes with factors such as harvest pressures and temperature changes.

1992 FISH MONITORING RESULTS

Recently the Washington departments of Fisheries and Wildlife and the Western Washington Treaty Indian Tribes conducted a comprehensive evaluation of salmon and steelhead stocks throughout the state. The inventory was part of the Wild Stock Restoration Initiative, whose goal is to "maintain and restore healthy wild salmon and steelhead stocks and their habitats in order to support the region's fisheries, economies, and other societal values" (SASSI, 1992). The first objective of the initiative is to complete and maintain a resource status inventory of Washington's wild salmon and steelhead stocks. By starting with a comprehensive inventory, the Wild Stock Restoration Initiative can identify the most serious problems and highest priorities for management action. In addition, the inventory provides a baseline against which to evaluate the successes of management efforts.

The inventory, known as the Salmon and Steelhead Stock Inventory (SASSI), is organized into Puget Sound, coastal, and Columbia River regions. SASSI identified 209 stocks within Puget Sound, defining stocks as "the fish spawning in a particular lake or stream(s) at a particular season, which to a substantial degree do not interbreed with any group spawning in a different place, or in the same place at a different season." Stocks are often genetically unique. They are generally adapted to local conditions existing in the lakes and streams from which they originated (Hindar et al., 1991), and thus cannot merely be replaced by individuals from other stocks.

State and tribal biologists then evaluated the health of each stock, using the categories described in the sidebar. They found that many of the stocks in Puget Sound (44 percent) could be categorized as "healthy." Twenty-one percent of the stocks were rated "depressed," five percent were rated "critical," and the status of a large percentage of the stocks (29 percent) were rated "unknown"(Figure 23).

SASSI made several important points about these findings.

- *The healthy category is a broad category that ranges from stocks with consistently robust production to stocks that are maintaining sustainable levels without providing any surplus production for directed harvests.* Thus, categorizing a stock as healthy does not mean that managers have no current concerns about a stock's production status. Even given this wide definition of healthy stocks, less than half of the stocks within Puget Sound can be categorized as such, although some of the stocks of unknown status may be cat-

Definitions of stock status ratings

The Salmon and Steelhead Stock Inventory (SASSI) relies on the following definitions in classifying stock status:

Healthy: A stock of fish experiencing production levels consistent with its available habitat and within the natural variations in survival for the stock.

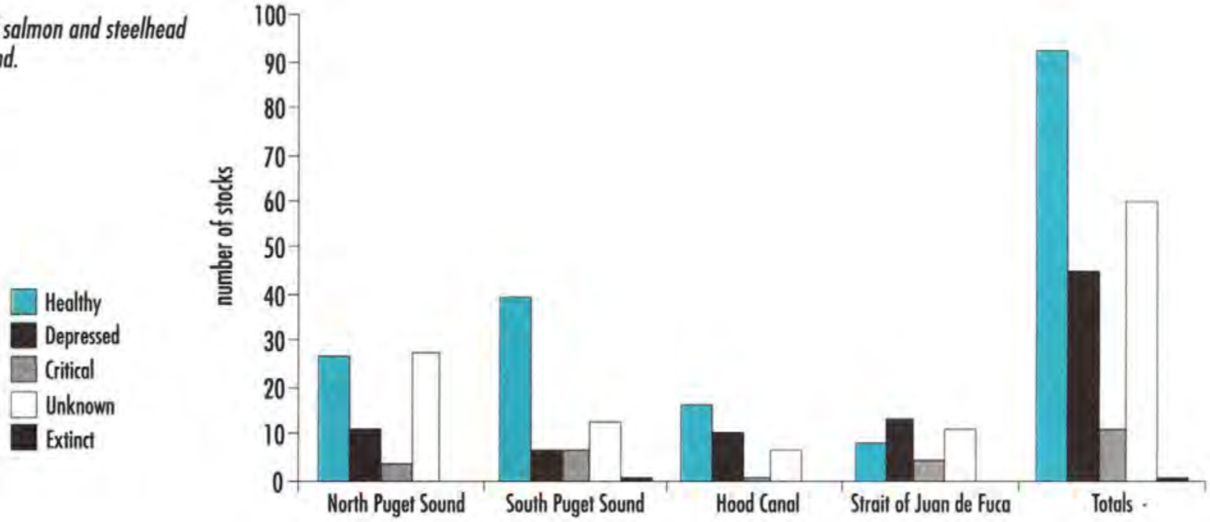
Depressed: A stock of fish whose production is below expected levels based on available habitat and natural variations in survival rates, but above the level where permanent damage to the stock is likely.

Critical: A stock of fish experiencing production levels so low that permanent damage to the stock is likely or has already occurred.

Unknown: There is insufficient information to rate stock status.

Extinct: A stock of fish that is no longer present in its original range, or as a distinct stock elsewhere. Individuals of the same species may be observed in very low numbers, consistent with straying from other stocks.

Figure 23. Status of salmon and steelhead stocks in Puget Sound.



Reference: SASSI, 1992

egorized as healthy when more information becomes available.

- *The large proportion of the stocks classified as unknown status makes it clear that there is an immediate need for information on these stocks to determine what management actions, if any, are needed to protect them.* This finding is in keeping with one of the goals of the project, which is to set priorities for needed information.

- *The extinct category only includes runs that have recently become extinct.* SASSI is an inventory of the current status of salmon and steelhead stocks, and is an effort to measure the success of management programs for maintaining and improving those stocks. SASSI chose to rely on recent data of known quality, and on a time period that reflects the efforts of the program. The one SASSI stock defined as a recent extinction was the Chambers Creek summer chum.

Nelson et al. (1991) recently reviewed information on salmon, steelhead, and sea-run cutthroat stocks in California, Oregon, Idaho, and Washington. Although they used a different classification system in assessing the health of these stocks, they provide information complementary to the SASSI report because they reviewed historical records to identify stocks which are now extinct. Within the Puget Sound basin they found records for eight stocks that are now extinct (Table 8). Since their study did not list the

Table 8. Extinct salmon stocks within Puget Sound.

Extinct Salmon Stocks within Puget Sound
Nisqually River Chum
Elwha River Sockeye (*Oncorhynchus nerka*)
Mason Lake Sockeye
Snohomish River Chinook (spring) (*Oncorhynchus tshawytscha*)
Duwamish-Green River Chinook (spring)
Puyallup River Chinook (spring)
Nisqually River Chinook
Pysht River Chinook (fall)
Chambers Creek Chum (summer)

Reference: Nelson et al., 1991; SASSI, 1993.

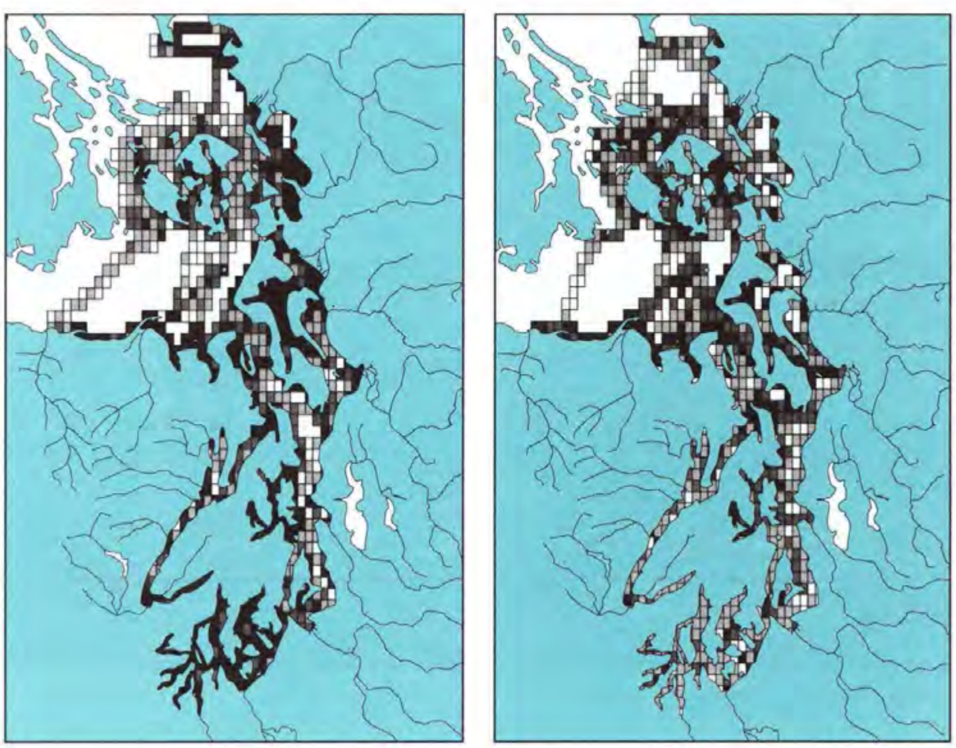
Chambers Creek summer chum stock identified as recently extinct in the SASSI study, the total number of stocks that have gone extinct within the Puget Sound basin is at least nine since records have been kept.

1992 BIRD MONITORING RESULTS

The Washington Department of Wildlife (Wildlife) has been conducting surveys of sea birds in Puget Sound since 1992. Wildlife officials fly transects throughout Puget Sound and count and identify all birds seen along these transects. They use these numbers to estimate the total number of each species found in the Sound, and to determine how population densities vary throughout the Sound. Observers are not always able to identify each individual down to the species level, since differentiation of closely-related species often requires close inspection that is precluded during aerial flights. In these cases, observers identify individuals down to the lowest possible taxonomic level (usually at least to genus).

Wildlife conducts these surveys in summer (July through August) and winter (December through February) to determine seasonal variations in population abundances and to inventory species which may be present in the Sound for only part of the year, such as migratory species.

Wildlife has processed data collected during the summer 1992 and winter 1992-93 surveys. In comparing total bird abundances between the two surveys, they found several patterns of interest. Birds appeared to be more abundant in the south Sound bays in the winter survey than in the summer survey (Figures 24 and 25). Birds also seemed to be more concentrated along shorelines, river deltas, and in protected bays in the winter (Nysewander, in



Figures 24 and 25. Overall bird densities in winter, Dec. - Jan. 1992-93, (left) and summer, July 1992, (right).

Areas Sampled
1-25 birds
25-75 birds
75-200 birds
200-400 birds
400-7,900 birds (400-7,400 in winter)

Reference: Nysewander, in preparation

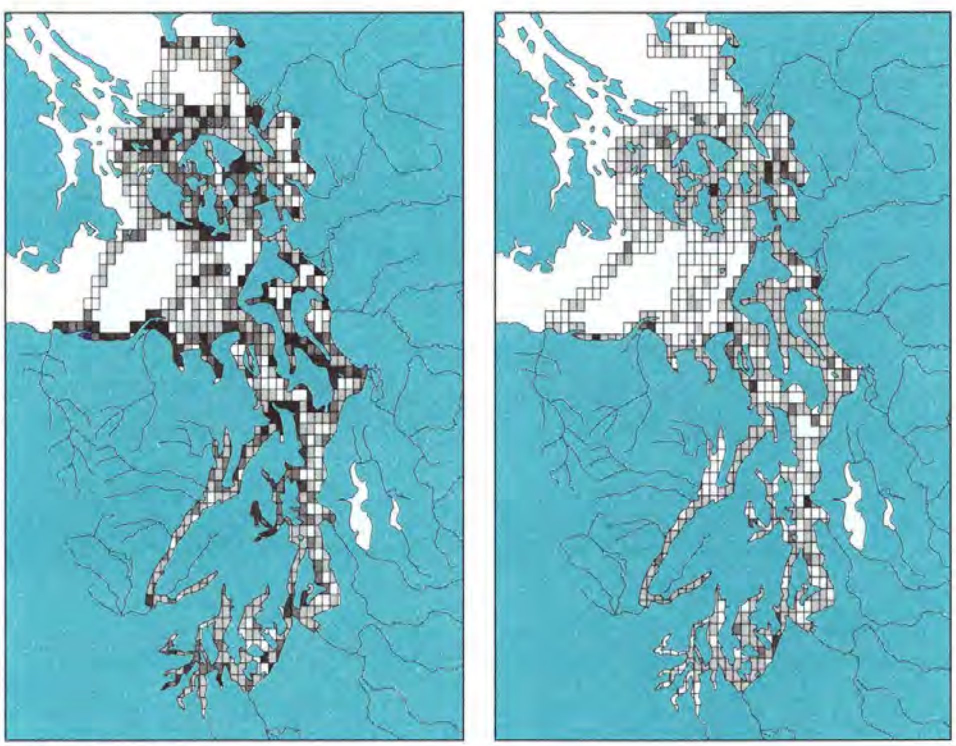
preparation). The San Juan Islands, Admiralty Inlet, and the Strait of Juan de Fuca had higher concentrations of birds in the summer than in the winter. These concentrations may reflect a preference for sheltered sites while avoiding open and exposed parts of the Sound during the colder and windier winter season. It is not known whether these concentrations are consistent between years, since the observations are based on only one set of surveys, but the patterns are consistent with information from other sources (e.g., Lewis and Sharpe, 1987).

In analyzing the data, Wildlife found the following results (Nysewander, in preparation).

Gulls. In the summer, gulls were by far the most numerous birds. Glaucous-winged gulls (*Larus glaucescens*) were the most abundant gull species; Bonaparte's gulls (*L. philadelphia*), California gulls (*L. californicus*), and Heerman's gulls (*L. heermanni*) were also abundant. Ring-billed gulls (*L. delawarensis*), western (*L. occidentalis*)/glaucous-winged gull hybrids, herring gulls (*L. argentatus*), and Caspian terns (*Sterna caspia*) were present but not numerous (Figure 26).

Winter patterns of gull abundance were considerably different. In the winter, Heerman's gull was no longer present, and Bonaparte's and California gulls were only present in low numbers. Glaucous-winged gulls were still abundant, but far less numerous than in the summer survey. Western/glaucous-winged hybrids and herring gulls were more numerous than in the summer survey and mew gulls (*L. canus*), which were not observed in the summer, were moderately abundant in the winter (Figure 27).

Figures 26 and 27. Gull densities in summer, July 1992, (left) and winter, Dec. - Jan. 1992-93, (right).



Areas Sampled
1-20 birds
20-75 birds
75-200 birds
200-500 birds
500-5,000 birds (500-3,400 in winter)

Reference: Nysewander, in preparation

Ducks, Geese, and Swans. Ducks, geese, and swans were far more numerous in the winter than in the summer. Ducks were the most abundant group of birds in the winter. Of the diving ducks, scoters were very numerous; surf (*Melanitta perspicillata*) and white-winged scoters (*M. fusca*), common goldeneyes (*B. clangula*), and Barrow's goldeneyes (*Bucephala islandica*) were abundant while black scoters (*M. nigra*) were present but not numerous. Bufflehead (*Bucephala albeola*) were also quite numerous. In addition, scaup (*Aythya spp.*), ruddy ducks (*Oxyura jamaicensis*), red breasted (*Mergus serrator*), common (*M. merganser*), and hooded mergansers (*Lophodytes cucullatus*), harlequin ducks (*Histrionicus histrionicus*), canvasbacks (*Aythya valisineria*), oldsquaws (*Clangula hyemalis*), and other unidentified diving ducks were present.

Dabbling ducks were also numerous in the winter. American wigeon (*Anas Americana*), mallards (*A. platyrhynchos*), northern pintails (*A. acuta*), and puddle ducks (not identified to species) were abundant. Green winged teal (*A. crecca*) and gadwall (*A. strepera*) were present but not abundant. Of the geese and swans, snow geese (*Chen caerulescens*) and black brant (*Branta bernicla*) were numerous. Canada geese (*B. canadensis*), tundra swans (*Cygnus columbianus*), and trumpeter swans (*C. buccinator*) were also present.

In the summer, surf scoters were the only species that were abundant, although they were approximately one-third as abundant as in the winter. Mallards, common mergansers, Canada geese, harlequin ducks, white-winged scoters and unidentified species of goldeneyes were also present but not numerous.

Alcids. Common murres (*Uria aalge*) and rhinoceros auklets (*Cerorhinca monocerata*) were abundant in the summer and were concentrated at Admiralty Inlet, eastern Strait of Juan de Fuca, and around the San Juan Islands (Figure 28). Pigeon guillemots (*Cepphus columba*)—the third most abundant species—were widespread along shorelines. A small number of marbled murrelets (*Brachyramphus marmoratus*) were observed, although this species is usually underestimated by aerial surveys. Other alcids were not identified to species.

In the winter, murres and pigeon guillemots were less numerous but more widely and evenly distributed over the Sound. Common murres were approximately half as abundant, while rhinoceros auklets were at very low densities. Marbled and ancient murrelets (*Synthliboramphus antiquus*) were present at low densities, as were other unidentified alcids.

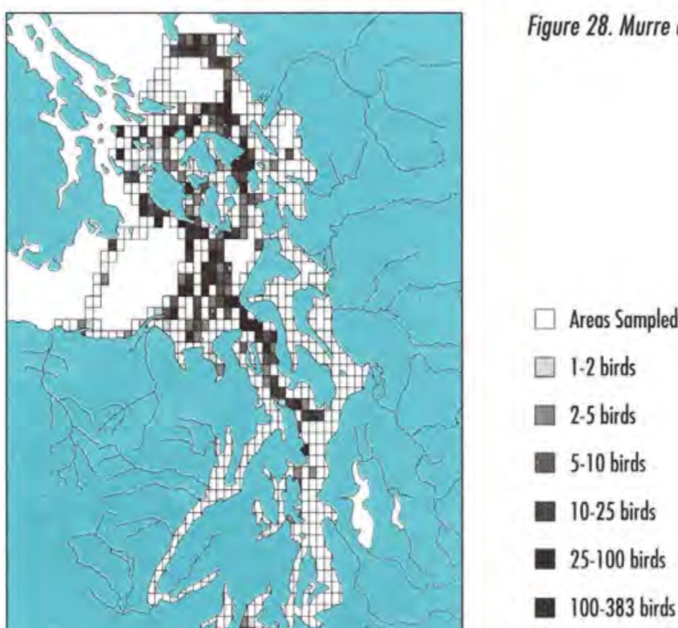


Figure 28. Murre densities in July 1992.

Reference: Nysewander, in preparation

Shorebirds. Dunlins (*Calidris alpina*) were one of the most abundant of all bird species in the winter, but were totally absent from bird counts in the summer. In contrast, blue herons (*Ardea herodias*) were fairly common in the summer, but were approximately half as abundant in the winter. Other identified shorebirds include: sanderlings (*Calidris alba*), black turnstones (*Arenaria melanocephala*), black-bellied plovers (*Pluvialis squatarola*), surfbirds (*Aphriza virgata*), and black oystercatchers (*Haematopus bachmani*).

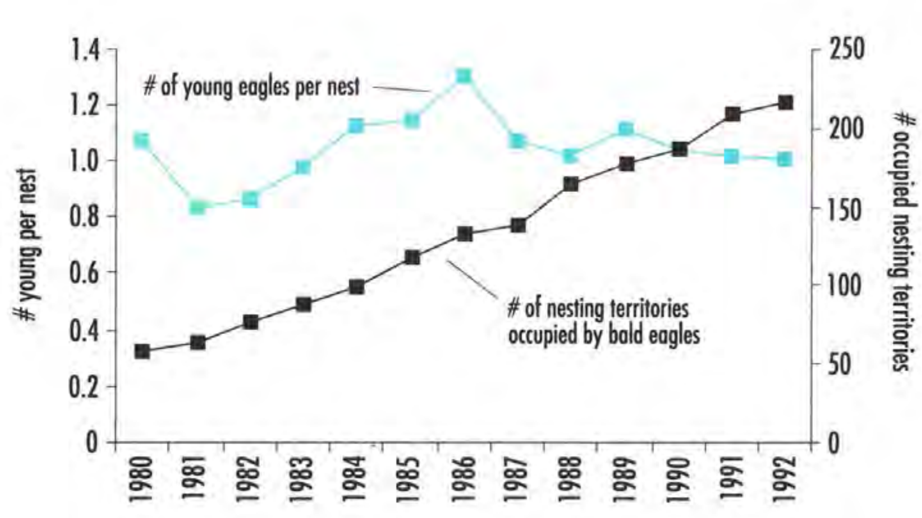
Other Species. Western grebes (*Aechmophorus occidentalis*) were very numerous in the winter, but sparse in the summer. Ospreys (*Pandion haliaetus*), bald eagles (*Haliaeetus leucocephalus*), northern harriers (*Circus cyaneus*), red-tailed hawks (*Buteo jamaicensis*), northwestern crows (*Corvus brachyrhynchos*), whimbrels (*Numenius phaeopus*), belted kingfishers (*Ceryle alcyon*), red-necked grebes (*Podiceps grisegena*), horned grebes (*P. auritus*), common (*Gavia immer*), Pacific (*G. pacifica*), and red-throated loons (*G. stellata*), and double-crested (*Phalacrocorax auritus*), pelagic (*P. pelagicus*), and Brandts' cormorants (*P. penicillatus*) were also identified. Of these, only the northwestern crow was abundant. The abundance of this species did not appear to vary with season.

Studies from Other Bird Monitoring Efforts

Bald Eagles. Bald eagles are predators that feed extensively in Puget Sound watersheds and in some nearshore marine areas. Bald eagles are most frequently seen in the San Juan Islands and in other areas of northern Puget Sound, including the Skagit and Nooksack River basins (Salo, 1975). Spawning salmon and other fish make up a substantial portion of the eagles' diet at certain times of the year. Because the bald eagle is an endangered (or threatened) species, Department of Wildlife biologists track eagle populations, nesting sites, and the number of nestlings.

Since 1982, the number of territories occupied by bald eagles in the Puget Sound area has increased dramatically (Wildlife, unpublished data). Over the same time period, the number of young produced per nest has fluctuated, but averaged around one chick per nest with no apparent trend over time. Because of the increase in the number of occupied nests, however, the

Figure 29. Bald eagle nesting trends in Puget Sound, 1980-1992.



Reference: Wildlife, unpublished data

total number of young produced has steadily increased almost 400 percent since 1982 (Figure 29). These numbers suggest that bald eagle breeding pairs in this area have increased over time, resulting in more young being produced each year. The numbers also emphasize the need to protect bald eagle habitat—particularly nesting sites—as the availability of additional nesting sites are critical to the recovery of these populations.

1992 MARINE MAMMAL MONITORING RESULTS

Gray Whales

PSAMP funded the Cascadia Research Collective to track gray whale (*Eschrichtius robustus*) occurrences within Puget Sound in 1992. Cascadia tracks movement patterns of individual gray whales using unique markings on their skin. Biologists need this information to estimate how many whales visit Puget Sound, their movement patterns, their length of stay in the Sound, and the mortality rate of whales that visit the Sound. As described in the chapter on chemical contamination, the National Marine Fisheries Service analyzes whales that die within the Sound for tissue contaminants. By tracking each individual's movement patterns within Puget Sound, scientists can determine whether whales that died spent prolonged periods feeding in areas of potential contamination.

Cascadia found that fewer gray whales were present in Puget Sound in 1992 than in the previous two years. Six different individuals were sighted on a number of occasions. All of the gray whales sighted in Puget Sound in 1992 were in the Port Susan/Whidbey Island area (four individuals) and in the southwestern portion of the Strait of Juan de Fuca (two individuals). There were no confirmed gray whale sightings in south Puget Sound in 1992. In addition, there were no gray whale strandings in Puget Sound in 1992. Three dead gray whales did wash up on the outer coast of Washington in 1992, but none of these had previously been seen in Puget Sound.

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

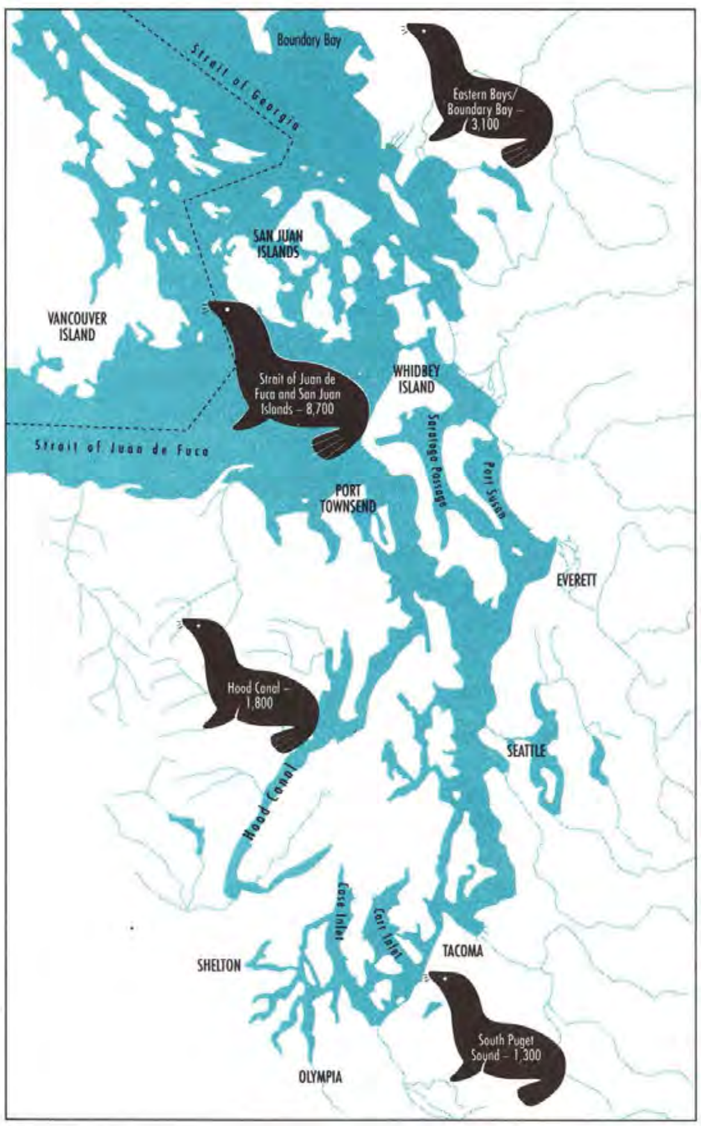
Two different patterns of use are apparent for gray whales that enter Puget Sound. Gray whales found in the Port Susan/Whidbey Island area tend to be "returnees" (they are often individuals that have been sighted in this area in previous years). Individuals that are found dead in this area tend to be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

Harbor Seals

The National Marine Mammal Laboratory, Washington Department of Wildlife, and Oregon Department of Fish and Wildlife began a three-year project in 1991 to assess the status and abundance of harbor seals (*Phoca vitulina richardsi*) in Washington and Oregon (Huber et al., 1992). The study was initiated to address the need to set limits for the incidental take of harbor seals in commercial fisheries, as required by the 1988 reauthorization of the Marine Mammal Protection Act.

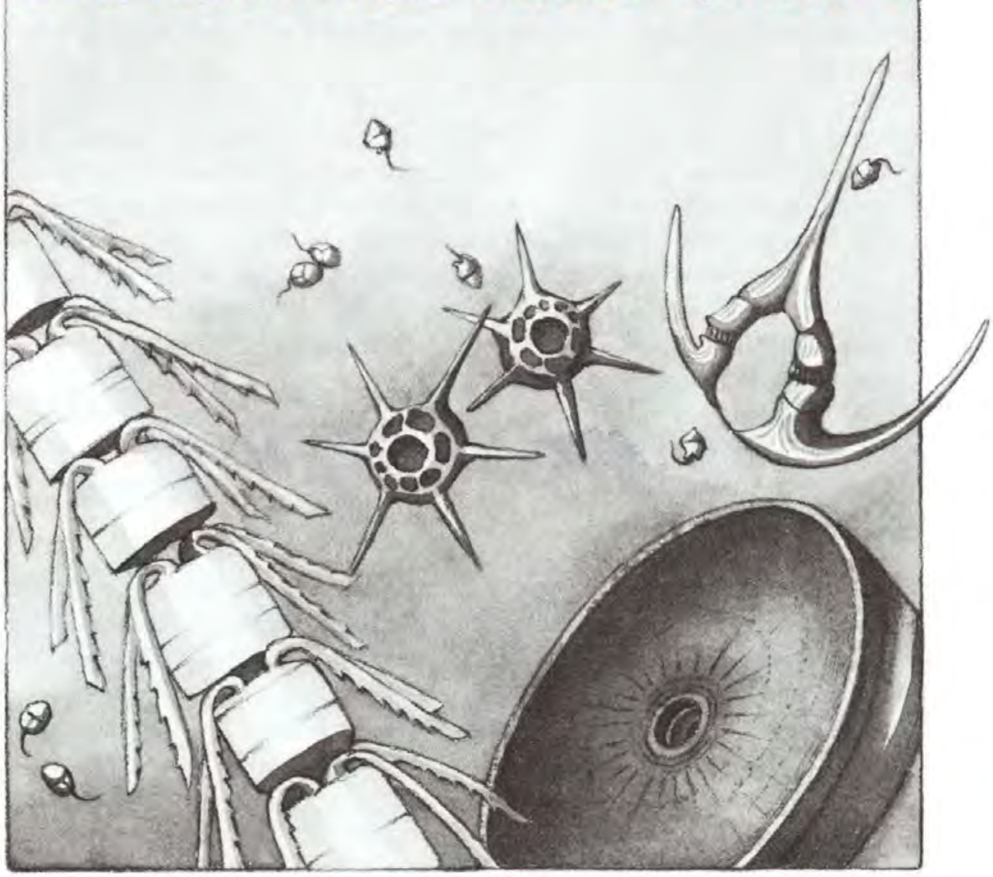
The study estimated that approximately 34,100 harbor seals were present in the entire state of Washington (including coastal areas outside of Puget Sound) in 1991, and approximately 32,700 were present in 1992. In 1992, the total population in Puget Sound was estimated as approximately 13,800 (Figure 30). The study did not provide a breakdown of population distribution throughout Puget Sound for 1991.

Figure 30. 1992 abundance estimates of harbor seals in Puget Sound.



Reference: Huber et al., 1993

CONVENTIONAL WATER QUALITY



BACKGROUND

"Conventional" water quality problems are generally caused by contaminants other than toxic compounds such as the metals and organic chemicals described in the chapter on chemical contamination. Examples of conventional water quality problems include oxygen depletion, sedimentation, excessive acidity or alkalinity, and high water temperatures.

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

Unlike many East Coast estuaries, eutrophication does not appear to be one of the more serious problems affecting Puget Sound's water quality. This may be due to the fact that the Sound is a deep body of water that—at least in the more open bays—is generally well-mixed. These conditions may make the Sound more resistant to human sources of nutrients than other estuaries, such as Chesapeake Bay, where eutrophication is a serious problem.

In some of the shallow or poorly mixed bays, however, the early signs of eutrophication are evident. Areas in Hood Canal and south Puget Sound have frequent algal blooms and nutrient depletion (an indicator of algal activity) in the summer. At nearly all of the Hood Canal sites, oxygen depletion is a chronic problem.

Other conventional water quality problems are evident in the rivers of the Puget Sound Basin. Four rivers—the Stillaguamish, Snohomish, Sammamish, and the Green—exceeded temperature standards for the last two years. The Sammamish River was also the only one of the rivers sampled for the program that exceeded oxygen standards, which it did for five consecutive months. In general, the data over the last two years make it clear that the Sammamish River has some of the poorest water quality of the rivers within the Puget Sound basin.

EFFECTS OF CONVENTIONAL WATER QUALITY PROBLEMS

Eutrophication

In the last several decades, it has become increasingly clear that eutrophication is a serious problem in many estuaries throughout the United States. The Chesapeake Bay Estuary Program has made the reduction of nutrient inputs one of its highest priorities because of eutrophication problems in the bay. Many other estuaries are experiencing serious water quality impacts from eutrophication. NOAA (the National Oceanographic and Atmospheric Administration) is conducting a nationwide survey of eutrophication in estuaries because "nutrient enrichment and eutrophication events have been a persistent and recurring problem in U.S. estuaries for decades."

Within the Puget Sound estuary, eutrophication does not seem to be as serious a problem as in other U.S. estuaries, largely due to the degree of mixing and dilution that occurs in the Sound. In the open bays and basins of Puget Sound, waters tend to be well-mixed and exchange freely with the Pacific Ocean via the Strait of Juan de Fuca. Large tidal currents and the presence of sills (which enhance vertical mixing by forcing deeper waters to the surface) prevent the stratification of the water column that promotes eutrophication. Puget Sound is also a very deep estuary (up to 900 feet deep in some areas) compared to many East Coast estuaries (which may have maximum depths of 100 to 150 feet). In deep estuaries, inputs of dissolved nutrients may be diluted to a greater extent. Within Puget Sound, signs of eutrophication are evident primarily in poorly mixed bays, such as Budd Inlet and Hood Canal (Janzen and Eisner, 1992, 1993) and in some shallow nearshore areas (Thom et al., 1988).

Eutrophication results from the complex suite of conditions that occur when excessive nutrients are introduced into surface waters. Because algal populations may be limited by nutrient availability, they may rapidly grow or bloom when large amounts of nutrients and adequate sunlight are present. Seasonal phytoplankton blooms are a normal and necessary part of the ecology of estuaries. However, when blooms become too dense or frequent they result in water quality problems. Large phytoplankton blooms can deplete oxygen in the water column at night when they cease photosynthesizing (a process that produces oxygen), but continue to respire (which consumes oxygen).

Oxygen is also consumed during the decomposition of dead phytoplankton. While a proportion of the population continually dies through senescence, the algal bloom as a whole may "crash" when it has depleted its nutrient supply. These dead phytoplankton then decompose by the activity of oxygen-consuming bacteria. In this way, large amounts of decomposing organic matter (phytoplankton or other) can rob the water of oxygen. As most aquatic organisms depend on dissolved oxygen for respiration, severely lowered levels can result in fish kills, as well as foul odors caused by the proliferation of anaerobic bacteria. Water bodies exhibiting these conditions are considered eutrophic.

Similarly, sources of organic matter (sewage, pulp waste, farm animal waste) can create problems in excessive concentrations. Organic matter introduced into water is decomposed by bacteria which, as mentioned previously, can deplete oxygen. In addition, bacterial decomposition breaks organic matter down into simpler chemical components. One of the more abundant components of organic matter is nutrients. As these nutrients are made available through decomposition, they may in turn stimulate algal blooms. This can lead to the process described above.

In many of the semi-enclosed south Sound bays, including Hood Canal, water circulation is limited so that nutrients are not flushed out and waters stratify. Water bodies that are poorly-mixed or stratified are more susceptible to eutrophication because:

- *Algal blooms are more likely to develop in stratified waters, since phytoplankton can remain at the surface where sunlight levels are higher.* In contrast, blooms are less likely to develop in well-mixed, unstratified waters where currents regularly carry phytoplankton into deeper, darker waters, which limits algal growth.

- *Stratified waters are also more likely to become anoxic (oxygen-depleted) in the bottom layers.* Stratification prevents oxygen-rich surface waters from mixing with deeper waters that are lower in oxygen.

Although eutrophication may affect some slow moving rivers, their flowing waters often prevent the stratification leading to eutrophication. In rivers, other conventional water quality problems (described on the following page) are more likely to be evident. Eutrophication is a very serious problem in lakes, however, because lakes are smaller bodies of water with limited mixing and water exchange, and added nutrients and organic matter dilute poorly. Lake Washington provided one of the most famous examples of eutrophication caused by sewage discharge in the 1960s. It has since provided an example of successful recovery when sources of nutrients and organic matter are reduced.

Other Conventional Water Quality Problems

The marine environments of Puget Sound are largely unaffected by conventional water quality problems other than eutrophication. Marine waters are heavily buffered by calcium carbonate and other substances naturally present in seawater, and so are highly resistant to changes in pH. In addition, because the main body of Puget Sound is very deep, sediment loading is not nearly as damaging as it is within rivers, although river deltas and shallow areas near river mouths within the Sound may be adversely affected by excessive sedimentation.

The rivers and streams within the Puget Sound basin, however, are highly susceptible to other conventional water quality problems such as sediment loading, changes in pH, or high water temperatures. The impacts of these problems are most evident in their effects on salmon and trout populations. Salmon and trout are very sensitive to changes in pH and temperature increases, and sedimentation interferes with spawning (Emmett et al., 1991). Other fish species, amphibians, and the aquatic invertebrates on which salmon feed are also affected by conventional water quality problems.

SOURCES OF CONVENTIONAL WATER QUALITY PROBLEMS

Conventional water quality problems are caused by a variety of activities. The sources and effects of conventional water quality problems differ between the marine and freshwater environments of the Puget Sound basin. In marine waters, eutrophication is the primary conventional water quality problem of concern. Eutrophication may be caused by excessive sources of nutrients from agriculture and landscaping activities and organic matter contained in wastewater discharges, leaking on-site sewage systems (septic systems), and stormwater runoff. Nutrients (which include nitrate, nitrite, ammonia, phosphate, and silicate compounds) and organic matter are normal and necessary parts of the Puget Sound ecosystem. High concentrations of these substances, however, can lead to excessive algal blooms, depleted oxygen, and associated water quality problems.

In the rivers of the Puget Sound basin, elevated water temperatures, high sediment loads, low pH, and low levels of dissolved oxygen are the primary conventional water quality problems of concern. Elevated water temperatures and sediment loads may be caused by clearing streamside and (in the case of sediment loads) upland vegetation. Streamside vegetation plays a critical role in shading streams, protecting streambanks from erosion, and trapping eroded soils to reduce sedimentation of streams. High water temperatures may in turn reduce the amount of oxygen a river is capable of carrying, resulting in low levels of dissolved oxygen. Low pH may be caused by the introduction of acidic substances (from sources such as acid mine drainages and industrial discharges) into surface waters.

1992 CONVENTIONAL WATER QUALITY MONITORING IN MARINE WATERS

Eutrophication

Because eutrophication has a number of characteristics, we may look at several water quality parameters for evidence of eutrophication. Nutrient levels, phytoplankton standing stock, levels of dissolved oxygen, and, in extreme cases, frequency of fish kills can all be used to assess eutrophication. However, each of these parameters has its limitation in detecting eutrophic conditions. For instance, while frequency and intensity of algal blooms might be indicators, algal populations can bloom and crash on such a short time scale (within days) that monthly or even semi-monthly sampling may miss a significant portion of blooms that occur, giving false impressions as to the trophic status of the water body.

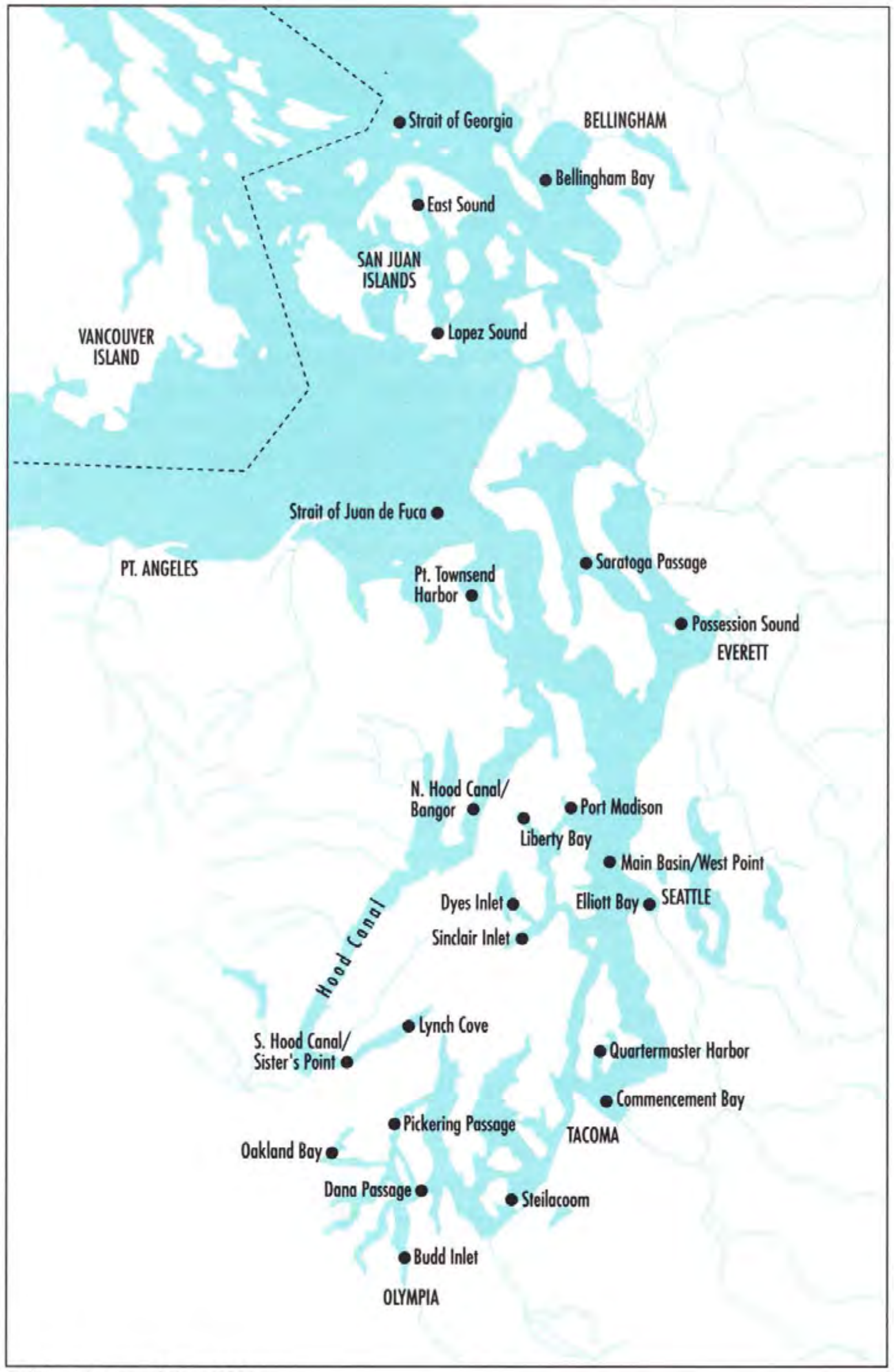
Nutrient levels are another likely indicator, but if phytoplankton populations happen to be blooming at the time of sampling, a majority of the nutrients may be incorporated into phytoplankton growth and reproduction, so that ambient nutrient levels would not appear high. In fact, scientists often look for nutrient depletion as one indicator of eutrophication. When nutrient depletion occurs frequently, it is a sign that algal populations have been actively growing and reproducing, and have removed most of the nutrients from the water column. Even in waters for which human inputs of nutrients are high, phytoplankton growth rates in surface waters may be great enough that the rate of uptake by algae exceeds the rate of input. In some urbanized areas, however, extreme levels of nutrient inputs might mask nutrient depletion from algal activity.

Oxygen depletion is a fairly reliable indicator of eutrophication. Some waters may go anoxic for natural reasons unrelated to eutrophication, but such waters would be particularly sensitive to eutrophication from any additional inputs of nutrients and organic matter. In conjunction with other parameters mentioned above, oxygen levels help to provide a clear picture of the eutrophic status of a waterbody. Fish kills occur only in severe cases of oxygen depletion, and have other potential causes (toxic contaminants, toxic algae blooms). They are therefore not a particularly sensitive or reliable indicator of eutrophication.

Since algal blooms and oxygen depletion are more likely to occur in poorly-mixed and stratified waters, scientists also look at the stratification of water bodies to determine their susceptibility to eutrophication. Scientists look at temperature and salinity profiles (two determinants of density) to gauge stratification. If warmer or less saline waters overlie colder or saltier waters, then the water column is stable (i.e., stratified), since less dense water overlays denser water. Water bodies that are consistently stratified during peak algal growth periods (primarily the summer), such as Hood Canal, are likely to be sensitive to eutrophication.

PSAMP scientists measure several water column variables to determine the quality of the water column and its susceptibility to eutrophication. These variables include: temperature and salinity, which provide information

Figure 31. 1992 PSAMP monitoring stations for conventional water quality in the marine water column.



Reference: Janzen and Eisner, 1993

about stratification of the water column, as well as the movement of water and dissolved contaminants; dissolved nutrients (nitrate, nitrite ammonia, and ortho-phosphate), which in sufficient concentrations may lead to eutrophication; dissolved oxygen, which is essential for animal life and is depressed in eutrophic waters; and chlorophyll *a* and phaeopigments, which are phytoplankton pigments that provide a measure of algal biomass. PSAMP investigators with the Department of Ecology measure these water quality variables at stations in open basins as well as in urban and rural bays and inlets to depict conditions throughout the Sound (Figure 31).

Algal Blooms

The dynamics of algal populations are poorly detected by monthly sampling, since phytoplankton may bloom and die off over a period of days. In addition, Ecology scientists sample for chlorophyll *a* at discrete depths of zero, ten, and 30 meters, and blooms frequently occur between these depths. Thus such widely spaced sampling may miss many bloom events. Nevertheless, monthly sampling does provide a rough though limited indicator of algal activity.

Algal activity in Puget Sound, as in most water bodies, is seasonal. In winter, when sunlight levels are low, algal growth rates are slowed and population levels are lower. Nutrient levels are high during these months because algae consume fewer nutrients and because of high runoff from rain. As light and temperature levels increase in the spring and into the summer, algal populations grow, driving down nutrient levels in the process. Soundwide nutrient and chlorophyll *a* data from 1992 generally illustrate this pattern, although there is a large degree of variation in the pattern in sites throughout Puget Sound (Figure 32).

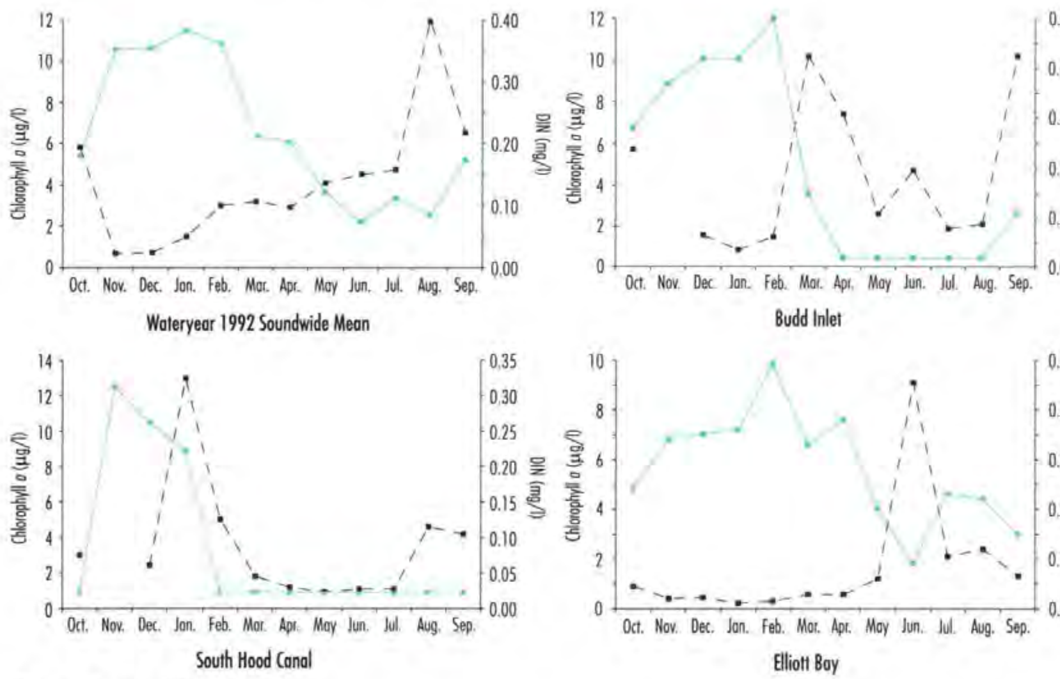


Figure 32. Patterns of nitrogen and chlorophyll a concentrations in wateryear 1992.

Reference: Janzen and Eisner, 1993

In wateryear 1992 (October 1991 through September 1992), several stations exhibited frequent algal blooms in surface (0.5 meter depth) waters. Dana Passage in south Sound, and Quartermaster Harbor on Vashon Island had the most frequent blooms in wateryear 1992. All stations, with the exception of the station located near Steilacoom, had at least one bloom during monthly sampling over the time period (Table 9). Ecology generally observed blooms between the months of March and October, although they observed blooms in the south Hood Canal station as early as January (Janzen and Eisner, 1993).

Table 9. Chlorophyll–nitrogen relations for wateryear 1992. (Only stations with Chl a >5 mg/l AND <0.04 mg/l N are included in this table.)

		Wateryear 1992											
		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.
Dana Passage	Chl *a*	5	NS				6		9	6	6	47	8
	N		NS									●	
Sinclair Inlet	Chl *a*											23	6
	N											●	●
Saratoga Passage	Chl *a*	29	NS			NS			11	NS			6
	N	●	NS			NS			●	●	●	●	
Dyes Inlet	Chl *a*									6		18	10
	N								●	●		●	●
Liberty Bay	Chl *a*							7				9	19
	N									●		●	●
Port Madison	Chl *a*											17	
	N											●	
North Hood Canal	Chl *a*		NS			26		6					
	N	●				●		●	●				
Outer Possession Sound	Chl *a*	19							12	NS			
	N	●							●	●	●	●	
Port Townsend	Chl *a*	7	NS			NS			10	NS	5	12	
	N		NS			NS				●		●	
Quartermaster Harbor	Chl *a*	9					5	6			6		12
	N							●		●	●	●	
Bellingham Bay	Chl *a*	16	NS			NS	7		9	NS			
	N	●	NS			NS			●	●	●	●	
Strait of Georgia	Chl *a*		NS			NS	15			NS		NS	
	N		NS			NS				●	●	NS	
South Hood Canal	Chl *a*		NS		13	5							
	N	●				●	●	●	●	●	●	●	●
Oakland Bay	Chl *a*		NS									8	
	N							●	●	●	●	●	●
West Point – Main Basin	Chl *a*									12			
	N									●			
Commencement Bay	Chl *a*									11			
	N						●			●			
Budd Inlet	Chl *a*	6	NS			NS	10	7					7
	N							●	●	●	●	●	

Chl a = Chlorophyll a (values in mg/m3)
N = Nitrate-nitrite
● Nitrogen depletion (<0.04 mg/l)
NS: Not Sampled
Note: Algal blooms were defined as chlorophyll a values less than 5 µg/l. This low value was chosen to increase the chance of detecting blooms, which are patchy phenomenon. With only one station per bay each month, the chances of peak chlorophyll values occurring at the exact location or time of sampling are low. The assumption behind using a low level of chlorophyll is that the value sampled is not the peak, and higher values more indicative of blooms were present.

Reference: Janzen and Eisner, 1993

Toxic Algal Blooms

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

Presently there is little that resource managers can do to reduce or eliminate PSP or domoic acid outbreaks. The conditions that lead to these outbreaks are poorly understood. It does not appear that they are caused or made worse by human activities, although there is some evidence that eutrophic conditions may promote or prolong outbreaks (see PTIc, 1991 for review).

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

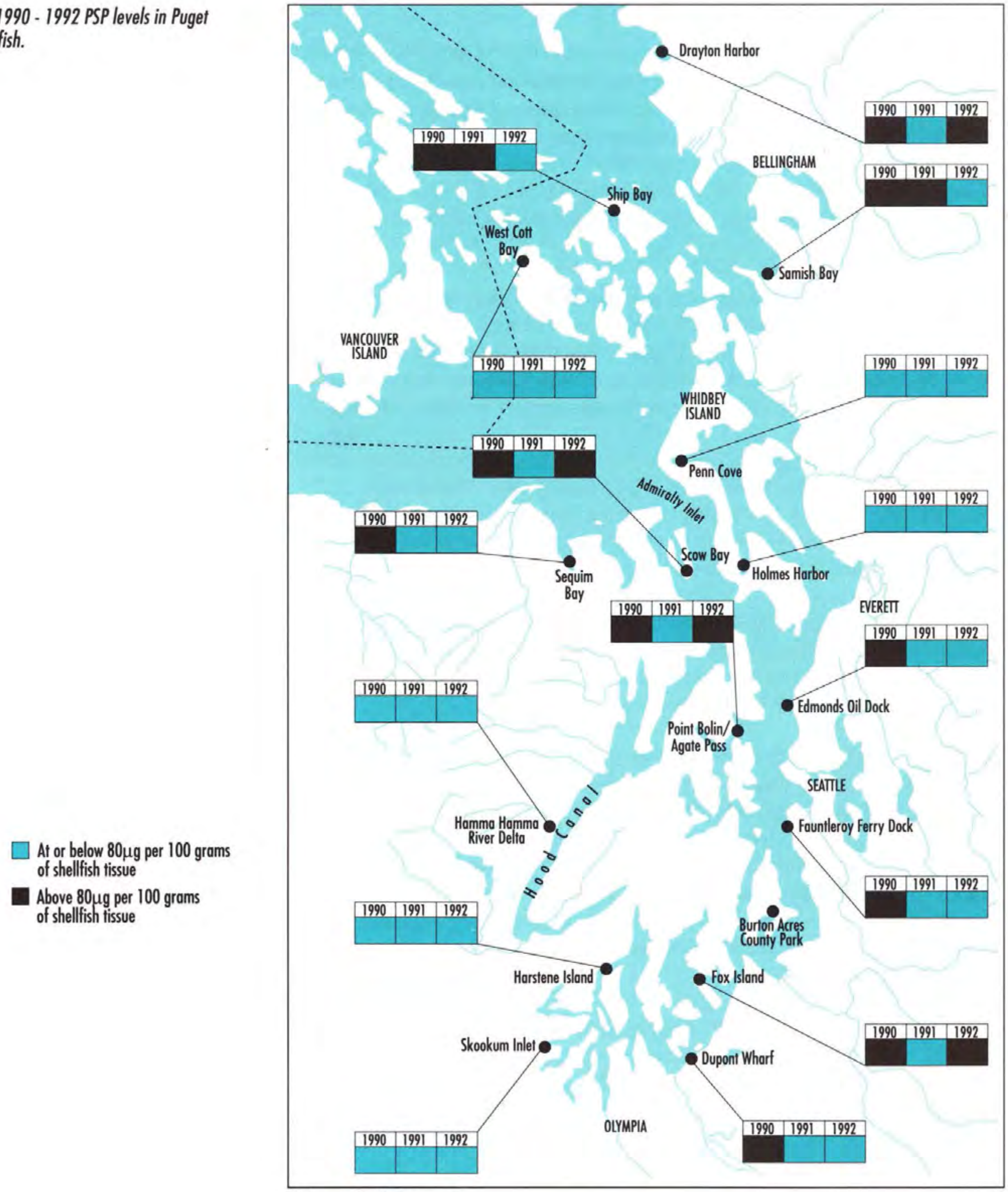
PSAMP tracks the results of PSP monitoring at 16 beaches throughout Puget Sound (Figure 33). In 1992, five of the sixteen sites had levels of toxin exceeding the Food and Drug Administration standard of 80 μg/100 g shellfish tissue, compared to two sites in 1991 and nine in 1990. PSP contamination in Puget Sound was particularly bad in 1990; outbreaks were not only more frequent, but appeared to last for longer periods of time. In contrast, 1991 appeared to be a mild year, with very few outbreaks that lasted for short periods. The values for 1992 were intermediate between these two years.

Amnesic Shellfish Poisoning (ASP or domoic acid). Another type of marine biotoxin, called domoic acid, was first detected in this area in razor clams and Dungeness crabs off the coasts of Washington and Oregon in 1991. Domoic acid is produced by various species of the marine diatom *Nitzschia* spp., and causes a human illness known as amnesic shellfish poisoning.

The persistence of domoic acid above the U.S. Food and Drug Administration (FDA) standard of 20 μg/g edible tissue resulted in the closure of the 1991 fall and 1992 spring recreational razor clam seasons, as well as postponement of the 1991 commercial Dungeness crab season. As of the summer of 1992, the Department of Health had identified 21 cases of ASP due to consumption of razor clams (Health, 1991).

To date, Health has not detected any domoic acid within Puget Sound. Health officials responded rapidly to the discovery of domoic acid by imple-

Figure 33. 1990 - 1992 PSP levels in Puget Sound shellfish.



Reference: Health, in preparation

menting an extensive monitoring program funded by FDA. Health monitors shellfish in all coastal and inland waters weekly or biweekly throughout the year.

Nutrients

Nutrient depletion is an indicator of algal activity, and signifies conditions where nutrients are limiting and algal blooms have occurred or may be stimulated by the addition of nutrients. In wateryear 1992, a number of stations exhibited surface nutrient depletion (defined as dissolved nitrate-nitrite concentrations less than 0.04 mg/l) for one or more months. Southern Hood Canal at Sisters Point was nutrient-depleted at the surface for the longest period, exhibiting depletion throughout the entire wateryear except between November 1991 and January 1992. The surface waters of most of the south Sound bays, including Hood Canal, were nutrient depleted for four or more months (Table 9). In addition, Quartermaster Harbor, Dyes Inlet, Outer Possession Sound, Bellingham Bay, and Saratoga Passage were nutrient-depleted at the surface for four or more months. Outer Possession Sound and Saratoga Passage were also nutrient-depleted for half of wateryear 1991, indicating that these sites appear to have consistently high algal activity.

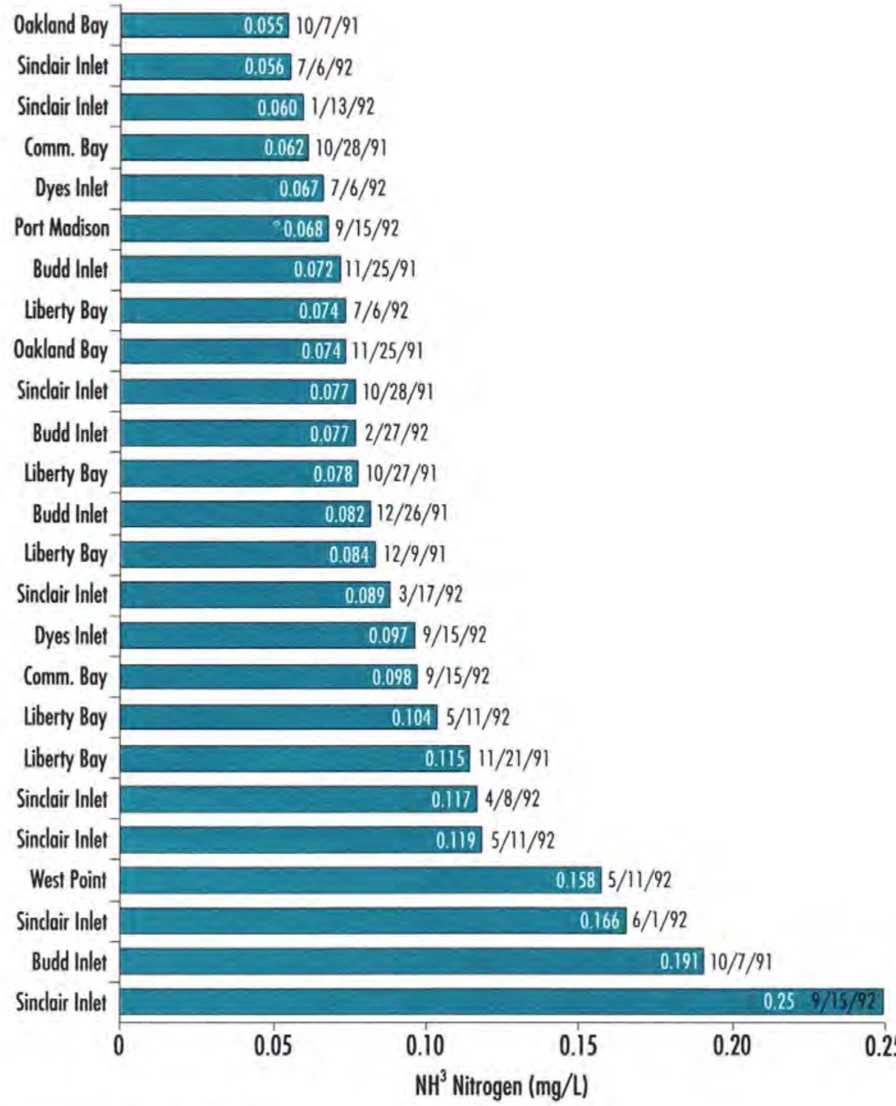
Dana Passage was the only south Sound site that was not nutrient-depleted at the surface for several months. This may be due to the fact that currents in this site are strong, so that nutrients used by phytoplankton are rapidly replaced, or because stratification does not occur so that phytoplankton growth is not favored.

The type of nutrients present within a water body can also provide information on sources of nutrients and organic matter. For instance, ammonia generally occurs in very low concentrations in the marine environment (Harris, 1986). Because this form of nitrogen is rapidly utilized by algae, any ammonia that is present from natural sources (e.g., animal excretion) tends to be quickly removed. At ambient sites, dissolved ammonia is commonly at or below detection levels (0.01 mg/l). However, ammonia is also a major component of sewage. Ambient sites that show measurable concentrations of ammonia are likely to be areas that receive significant quantities of sewage effluent.

For wateryear 1992, ranking of all surface measurements of dissolved ammonia over the year (a total of over 280 measurements at 24 sites) reveals some patterns of interest (Figure 34). Almost all of the sites that had the highest levels of ammonia are urban bays or are located near sewage outfalls. It is clear that Sinclair Inlet has significant ammonia inputs, as eight of the monthly readings fall within the top 25 values. Sinclair Inlet also exceeded water quality standards for fecal coliform in wateryear 1992 (for details, refer to the chapter on fecal contamination), strongly suggesting that this bay is affected by insufficient sewage treatment, combined sewer overflows, or improperly functioning on-site sewage systems (septic systems).

Surprisingly, Liberty Bay had five of the highest 25 ammonia readings. There are no sewage treatment plant discharges in Liberty Bay. The shellfish beds in this bay were downgraded in 1991 due to rural and urban nonpoint sources of pollution (Health, 1992), so that leaking on-site sewage systems (septic systems), boat waste discharge, agricultural runoff, or stormwater runoff are likely sources of ammonia in this bay. Based on its high frequency of nutrient depletion, PTI (1991c) listed Liberty Bay as a site sensi-

Figure 34. Concentration of dissolved ammonia (NH3) nitrogen in marine water. Values shown represent the 25 highest concentrations measured in surface waters sampled during wateryear 1992.



Reference: Janzen and Eisner, 1993

tive to human sources of nutrients. The ammonia levels indicate that there are human sources of nutrients in this bay. Evidence of algal blooms coupled with depletion of dissolved nitrite-nitrate (Table 9), though not excessive, suggest that these sources are producing some of the characteristics of eutrophication.

Other sites with high surface ammonia levels include Budd Inlet, Commencement Bay, Dyes Inlet, Oakland Bay, West Point, and Port Madison. Most of these bays are near urban centers, with the exception of West Point and Port Madison. West Point is near a Municipality of Metropolitan outfall, and the Port Madison station is near the Suquamish sewage treatment plant outfall. Budd Inlet, which had four of the top 25 values, is the receiving water for the LOTT (Lacey, Olympia, Tumwater, Thurston County) sewage treatment plant outfall. This plant will be installing state-of-the-art denitrification equipment, so that levels of ammonia should decrease in the future.

In contrast, several stations had consistently low ammonia levels (less than 0.04 mg/l). These are Admiralty Inlet, Bellingham Bay, Strait of Georgia, Possession Sound, and Saratoga Passage.

Oxygen Depletion

Several sites had levels of dissolved oxygen below water quality standards in 1992 (Tables 10 and 11). It is clear that oxygen depletion is a problem throughout most of Hood Canal. In particular, levels of dissolved oxygen at the southern stations were below standards for a majority of the year at water depths of ten and 30 meters. Hood Canal at Sisters Point was oxygen-depleted for the entirety of wateryear 1992 at 30 meters, and for eight of the 12 months at ten meters. Lynch Cove was also oxygen-depleted for the entire year at the bottom (the Lynch Cove Station is less than 30 meters deep), and for eight of the 12 months at ten meters. North Hood Canal, which receives more water circulation since it is closer to the mouth of Hood Canal, was below standards for three months at ten meters and half the year at 30 meters. None of the Hood Canal stations were below dissolved oxygen standards at the surface. It is clear from the data that oxygen

Table 10. Oxygen violations at sampling stations in wateryear 1992. (Standard = Class AA: 7mg/l, Class A: 6mg/l; NV = no violation detected; NS = not sampled)

	Wateryear 1992				
	Class	0 meters	10 meters	30 meters	# samples
Outer Admiralty	AA	2	3	5	10
Budd Inlet	A	NV	NV	NS	
Commencement Bay	A	NV	NV	NV	
Dana Passage	AA	NV	NV	NV	
Strait of Georgia	AA	NV	2	2	9
South Hood Canal	AA	NV	8	12	12
North Hood Canal	AA	NV	3	6	12
Oakland Bay	A	NV	NV	NS	
West Point/Main Basin	AA	NV	NV	3	12
Outer Possession Sound	A	NV	NV	3	10
Saratoga Passage	A	NV	NV	5	10
Bellingham Bay	A	NV	NV	NS	
Dyes Inlet (R)	A	NV	NV	NS	
East Sound (R)	AA	NV	1	NS	10
Elliott Bay	A	NV	NV	NS	
Lynch Cove (R)	AA	NV	8	NS	12
Lopez Sound (R)	AA	1	2	NS	10
Port Madison (R)	AA	NV	NV	2	12
Liberty Bay (R)	A	NV	NV	NS	
Port Townsend	A	NV	NV	3	10
Quartermaster Harbor	AA	NV	NV	NS	
Sinclair Inlet	A	NV	NV	NS	
Pickering Passage (F)	A	NV	NV	NS	
Steilacoom (F)	AA	NV	NV	NS	

Reference: Janzen and Eisner, 1993

Table 11. PSAMP fixed stations with one or more oxygen violations in wateryears 1990-1992. Entries indicate the number of violations/number of times the station was sampled. (Standard = Class AA: 7mg/l, Class A: 6mg/l; NV = no violation detected; NS = not sampled)

		Wateryears 1990 - 1992		
	Class	0 meters	10 meters	30 meters
Outer Admiralty	AA	7/25	9/25	13/25
Budd Inlet	A	1/34	–	–
Commencement Bay	A	–	1/30	1/30
Dana Passage	AA	2/34	2/34	2/33
Strait of Georgia	AA	2/26	8/26	10/26
South Hood Canal	AA	–	13/22	22/22
North Hood Canal	AA	1/32	5/32	14/31
Oakland Bay	A?	1/33	–	–
West Point/Main Basin	AA	1/31	1/30	5/30
Outer Possession Sound	A	–	–	6/27
Saratoga Passage	A	–	–	7/29

Reference: Janzen and Eisner, 1993

depletion is more frequent and prolonged in the bottom layers, where exchange with well-oxygenated surface layers is limited.

Surprisingly, two of the sites with the highest amount of water exchange—Admiralty Inlet and the Strait of Georgia—had levels of dissolved oxygen below standards for part of the year. For Admiralty Inlet, even surface waters were below standards for two of the ten sampling events. Low dissolved oxygen in surface waters is infrequent at stations monitored by PSAMP, since wind turbulence and algal photosynthesis generally keep oxygen levels high. Levels of dissolved oxygen below standards were also detected at depths of ten meters (for three months) and 30 meters (for five months) during the ten months sampled at Admiralty Inlet, and for two of the nine months sampled at the Strait of Georgia at both ten and 30 meters.

One potential explanation for low oxygen concentrations at these well-circulated sites is that they are located near shallow sills which force deep, oxygen-poor waters toward the surface. These apparent violations of standards may therefore be due to natural conditions, since deep waters, particularly from 200 meters or deeper, are naturally low in oxygen. Water quality standards allow for stations with low dissolved oxygen resulting from natural conditions, stating that "when natural conditions, such as upwelling, occur, causing the dissolved oxygen to be depressed near or below [the standard], natural dissolved oxygen levels may be degraded by up to 0.2 mg/l by human caused activities" (WAC 173-201A).

1992 CONVENTIONAL WATER QUALITY PROBLEMS IN RIVERS

The Department of Ecology evaluates conventional water quality in rivers by measuring variables such as temperature, pH, nutrients, suspended solids (a measure of the sediment load carried by a river or stream), and dissolved oxygen. Ecology monitors these parameters monthly near the mouths of the ten major rivers entering Puget Sound (Figure 35): the Nooksack, Skagit, Sammamish, Stillaguamish, Snohomish, Cedar, Green-

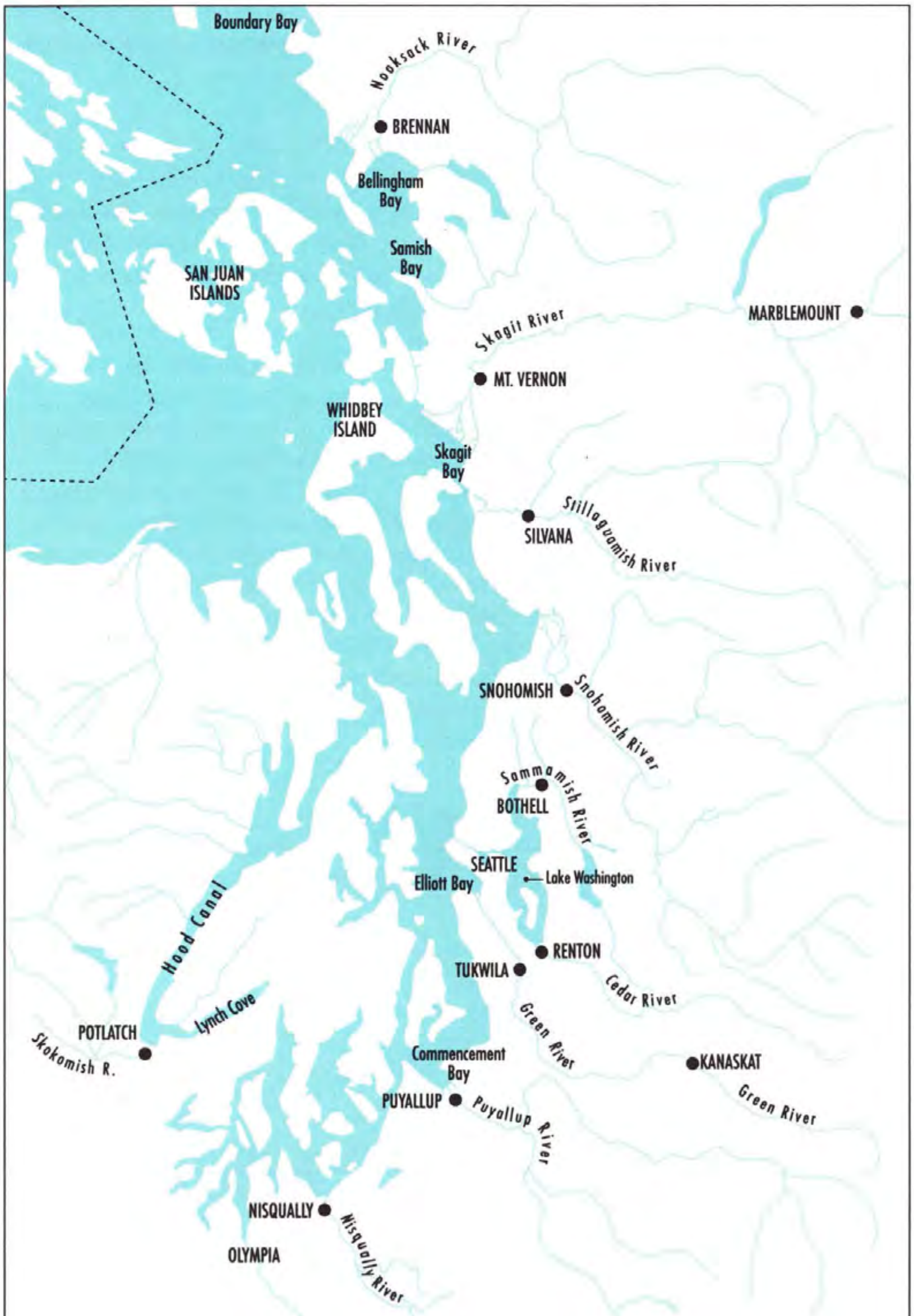


Figure 35. 1992 PSAMP freshwater sampling stations.

Reference: Hopkins, in preparation

Duwamish, Puyallup, Nisqually, and Skokomish.

Temperature

The average annual temperature in all of the ten major Puget Sound rivers was higher in 1992 than in 1991. This was probably a result of climatic conditions, as 1992 was warm and dry. The temperature standard for freshwater rivers is less than 16°C for class AA waters, and less than 18°C for class A waters. Four of the ten Puget Sound rivers exceeded temperature standards in 1992: the Stillaguamish (August), the Snohomish (July, August), the Sammamish (July, August), and the Green (August). These rivers also exceeded temperature standards in the summer of 1991, suggesting that temperature exceedances are a chronic problem in these rivers.

Dissolved Oxygen

In rivers, low dissolved oxygen is usually linked to high temperatures rather than eutrophication processes. As temperature increases, the water's ability to hold oxygen decreases. The standards require that class AA waters have oxygen concentrations less than 9.5 mg/l and that class A waters have concentrations less than 8.0 mg/l.

Not surprisingly, the river with highest temperatures over the last two years—the Sammamish—was also the only one of the ten major Puget Sound rivers with oxygen levels below standards. Levels below oxygen standards were present for six consecutive months from June 1992 to November 1992. The Sammamish River was also the only river sampled by PSAMP that exceeded oxygen standards in 1991, during which oxygen levels were below the standard for five consecutive months. Given the severity and length of oxygen depletion in this river, and the fact that no other rivers in the basin violated oxygen standards, it is clear that the Sammamish River has serious problems with oxygen concentrations. Though the impacts of these consistent violations are not yet known, oxygen is critical for nearly all aquatic life, and species such as salmon are particularly sensitive to even small decreases in dissolved oxygen.

pH

Water quality standards state that pH must be between 6.5 and 8.5 pH units. None of the ten major Puget Sound rivers exceeded oxygen standards in 1992.

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Marine Water Column
Washington Department of Ecology
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Fish
Washington Department of Fisheries
Sandie O'Neill
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Shellfish
Washington Department of Health
Bob Woolrich
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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
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Estuarine Nearshore Habitat
Washington Deptartment of Natural Resources
Tom Mumford
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Fresh Water
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Human Health Effects
Washington Department of Health
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If you are interested in knowing more about citizen monitoring, please contact the following:

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Chautauqua Northwest
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1-800-54-SOUND