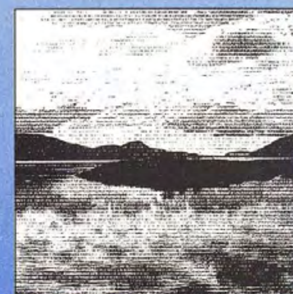
PUGET SOUND WATER QUALITY ACTION TEAM

1998 Puget Sound Update

SIXTH REPORT OF THE PUGET SOUND AMBIENT MONITORING PROGRAM



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February 1998

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SUMMARY

Recent findings about the health of Puget Sound indicate that, although some aspects of the Sound's environmental health may be improving, its ecosystem and biological resources continue to suffer damaging effects resulting from the actions and by-products of our society.

Improvements documented over the past several years include steady or increasing populations of some organisms in Puget Sound and decreases in some types of contamination in some areas of Puget Sound. Evidence of continued problems, including the poor or declining condition of a wide variety of marine organisms in Puget Sound, tempers these observations. The continuing problems may be related, at least in part, to changes our society has made to the physical environment and to contamination of the environment by toxic chemicals, fecal bacteria and excess nutrients.

This is the sixth *Puget Sound Update*, a report for residents of the region about the overall health of Puget Sound. The conclusions in the Update are based mainly on scientific results of the Puget Sound Ambient Monitoring Program (PSAMP). This report looks beyond the PSAMP as well, including monitoring data from other important efforts to evaluate Puget Sound's waters, sediments, nearshore habitats and biological resources. Information generally reflects conditions through 1995, though in some cases only older data were available and in other cases results we were able to access data through 1996 and 1997.

SUMMARY OF FINDINGS

Biological Resources

The stocks and populations of many marine organisms in Puget Sound are declining or in poor condition. A 1997 review for the international Puget Sound/Georgia Basin Task Force identified 13 species of fish, seabirds, marine mammals and marine invertebrates that are declining in Puget Sound. Among the species are the Olympia oyster, copper rockfish, harbor porpoise and marbled murrelet.

Several commercially and recreationally important stocks of fish are in poor condition or on the decline. Some stocks of other types of fish, notably salmon and Pacific herring, are also in poor condition. The proposed listing of several salmon species, including Puget Sound chinook and Hood Canal chum, as threatened under the Endangered Species Act underscores the poor condition of fish populations in Puget Sound.

Other findings about the condition of Puget Sound biological resources are less gloomy. The density of most diving ducks has not declined notably since 1979. Of these marine birds, only scoters and scaup showed declining

Ten Years of the Puget Sound Ambient Monitoring Program

Where We've Been

In 1987 the *Puget Sound Water Quality Management Plan* called for a comprehensive program to monitor Puget Sound. The committee that developed the Puget Sound Ambient Monitoring Program (PSAMP) said it should "provide coherent data which increases our understanding of Puget Sound, its resources and the effects of human activities." In 1989 the PSAMP began collecting data to fulfill this purpose. Today, the PSAMP helps agencies make informed decisions about environmental protection by identifying problem areas and trends, measuring the success of the management efforts, and continually assessing the health of the Sound.

What We've Learned About Monitoring

In addition to the scientific findings of the monitoring program, the PSAMP has provided some lessons related to a coordinated multi-agency monitoring program. For example:

- Clearly state goals and objectives for monitoring (what are we measuring and why?) and then evaluate results based on these objectives to determine how well the monitoring is working.

- Combine scientific and management knowledge to ensure that studies use the best possible designs given available budgets. A good design might, for example, measure things that are important to people in ways that provide useful information.

- Collaborate with others who monitor the environment—state agencies alone cannot fully assess the health of Puget Sound.

- Get the word out. Communicating findings is crucial—our work isn't complete until results have been shared with all levels governments, affected groups and the public.

- We have done a relatively good job of characterizing the current condition of the environment and geographic patterns within Puget Sound. In contrast, we find it more difficult to study and distinguish patterns over time, especially those that may be related to changes in resource management, because of the variability we observe in many aspects of the natural system.

conditions. The acreage and density of kelp—a valuable habitat—along the Strait of Juan de Fuca has remained fairly constant since the late 1980s. Finally, the number of harbor seals living in Puget Sound continues to increase, probably as a result of their protection under the Marine Mammal Protection Act.

In addition to the influences of other stresses on Puget Sound's marine organisms, scientists and resource managers are now focusing on threats from invasions of non-native species of plants and marine life. Non-native species can damage the environment by modifying habitat, preying on and competing with native species, and introducing diseases and parasites to an invaded area. Species of concern include *Spartina*, a cordgrass that infests the Whidbey basin of Puget Sound and is the focus of intensive control efforts, and the European green crab, which has not yet been observed in Puget Sound but appears to be headed this way as its range extends north from California up the Pacific coast.

Physical Environment

The development of Puget Sound with buildings, roads, dikes, bulkheads and other structures has changed—and continues to change—Puget Sound's physical environment. One-third of Puget Sound's shoreline has been modified since the time of European settlement. These changes can be very disruptive to the ecosystem because of the importance of nearshore areas in supporting sensitive life stages of many marine organisms.

Human activities may also be changing the quality of habitat in Puget Sound's marine waters. Several areas of Puget Sound appear to be susceptible to water quality degradation resulting from excess nutrients, such as fertilizers and sewage. Scientists are concerned that, in these areas, nutrients above normal levels could stimulate excess growth of phytoplankton. Through a series of ecosystem interactions, this growth could decrease oxygen levels at lower depths, stressing and restricting the diversity of bottom-dwelling communities.

Toxic Contaminants

The widespread distribution of toxic contaminants throughout Puget Sound is well documented. This Update supports previous conclusions that toxic contamination is heaviest and its effects are most severe in waters near urban areas in Puget Sound. The good news is that concentrations of some contaminants are decreasing in mussels from locations scattered throughout Puget Sound.

Studies of fish from 49 urban sites where concentrations of toxic substances exceed regulatory cleanup screening levels (Elliott Bay, Commencement Bay, Eagle Harbor on Bainbridge Island, Sinclair and Dyes inlets, Bellingham Bay, Everett Harbor, and Budd Inlet) linked contamination of fish to areas of sediment contamination.

No trends of increasing or decreasing contaminants in fish and sediments were observed from data spanning the late 1980s to the mid-1990s. However, the amounts of some toxic contaminants in mussel tissue appear to have declined through the 1980s and early 1990s. For example,

concentrations of polychlorinated biphenyls measured in mussel tissue during the 1990s in the Duwamish River and in Elliott Bay were lower than concentrations in the 1970s and mid-1980s. Mussels filter large quantities of water and the observed decrease in concentrations indicates that water quality in Elliott Bay and the Duwamish River is improving.

Pathogens and Nutrients

Fecal bacteria from human and animal wastes and an overload of nutrients, such as fertilizers, are causing or threaten to cause problems in localized areas around Puget Sound.

Fecal coliform is measured in the marine waters of shellfish growing areas to assure the safety of shellfish harvested for human consumption. Detailed evaluations of three commercial shellfish growing areas in south Puget Sound showed that conditions differ in each area, but they may represent patterns occurring elsewhere:

- In Burley Lagoon (Kitsap and Pierce counties) water quality is improving or remaining steady, reflecting the positive environmental effects of successful local efforts to find and fix pollution problems.
- In Henderson Inlet (Thurston County) concentrations of fecal coliform bacteria are increasing steadily, indicating that the pressures of population growth and development could overwhelm existing water quality management efforts and that pollution control efforts should be intensified.
- In Oakland Bay (Mason County) conditions at some sampling stations do not comply with water quality standards though conditions appear to be improving, possibly reflecting residual problems from localized sources that become apparent only after major sources of contamination have been addressed (in this case, the partial renovation of Shelton's sewage system).

Patterns of fecal coliform contamination in the open marine waters of Puget Sound appear to reflect contaminants from freshwater rivers and streams that drain into the Puget Sound basin.

Degradation of water quality caused by excess loading of nutrients in Puget Sound appears to be limited to semi-enclosed inlets, bays and passages. The combination of poorly mixed marine waters and excess nutrient contributions from watersheds creates problems primarily in some areas of lower Hood Canal and the bays and inlets of south Puget Sound and the Whidbey basin.

Human Health

Three types of contamination threaten human health in Puget Sound: toxic substances in fish and fecal bacteria and biotoxins in shellfish.

The risks of eating Puget Sound seafood contaminated with toxic substances has not been formally evaluated with a risk assessment or health analysis. However, scientists used the results of a risk assessment generated by studies from the lower Columbia River to conclude that people consuming English sole from urban areas of Puget Sound or salmon from any Puget

Where We're Going

As we continue to improve the design and implementation of the PSAMP, we look forward to advancing in new directions. In 1995 a national panel of scientific monitoring experts reviewed the program to assess how well it was working. Their review led to a number of recommended improvements in the program, including:

- A new, two-tier organization for program coordination, in which the implementing agencies are represented by managers on a management committee and by scientists (the program's principal investigators) on a steering committee.
- Development of a conceptual model of Puget Sound that relates human activities and natural changes (such as algae blooms) to ecosystem stressors (such as alterations in light and turbidity) and management actions (for example, wastewater management).
- Closer coordination between the monitoring program and the resource-management goals of agencies.
- A two-year schedule for reviewing the program to allow the PSAMP to adapt to its findings and establish new directions and priorities in the Puget Sound Water Quality Management Plan and biennial work plans.
- Greater involvement of other scientists and citizens outside the monitoring program's core group.
- Improved data management and access to monitoring data.

The PSAMP is currently implementing many of the review panel's recommendations. The 1995 review is summarized in Panel Findings and Recommendations: Based on the First Comprehensive Review of the Puget Sound Ambient Monitoring Program (Shen, 1995).

Sound location face an increased risk of cancer due to PCB contamination. The risks to humans from mercury found in Puget Sound are not so clear; one of two approaches used in the Columbia River assessment suggests that mercury concentrations observed in Puget Sound rockfish are high enough to adversely affect the health of people who eat these fish.

Risks of illness from consuming Puget Sound shellfish tainted by pathogens and biotoxins are managed by state and local health departments, which evaluate environmental quality in areas where shellfish are harvested.

In the late 1980s, relatively high levels of fecal contamination resulted in the prohibition or restriction of shellfish harvesting from many shellfish growing areas in Puget Sound. Since the early 1990s, improvements in water quality have resulted in fewer new prohibitions or restrictions on harvest areas. Cleaner water in many areas also has meant that commercial shellfishers are again harvesting from areas that were previously prohibited or restricted.

In the last five years, two-thirds of Puget Sounds recreational shellfish beaches have been evaluated and classified. Local health districts and the state Department of Health also evaluate conditions at and classify recreational shellfish beaches. As of 1996, 52 of 98 Puget Sound beaches were listed as open to harvest.

To protect shellfish consumers from paralytic shellfish poisoning (PSP), the Department of Health assesses concentrations of biotoxins in mussels from a network of sampling locations throughout Puget Sound. As in previous years, high biotoxin concentrations from 1995 through 1997 necessitated temporary closures of shellfish growing beaches in many parts of Puget Sound. Three sites—two on the Strait of Juan de Fuca and one in Quartermaster Harbor (between Vashon and Maury islands)—had concentrations of the PSP biotoxin high enough to shut down harvest for more than 100 days through the three-year period. Eight more sites had high PSP biotoxin concentrations for at least 30 days during this time. Four of these eight locations are in south Puget Sound, where high levels of the PSP biotoxin occurred during an atypical bloom late in the year in 1997.

USING MONITORING RESULTS TO PROTECT PUGET SOUND

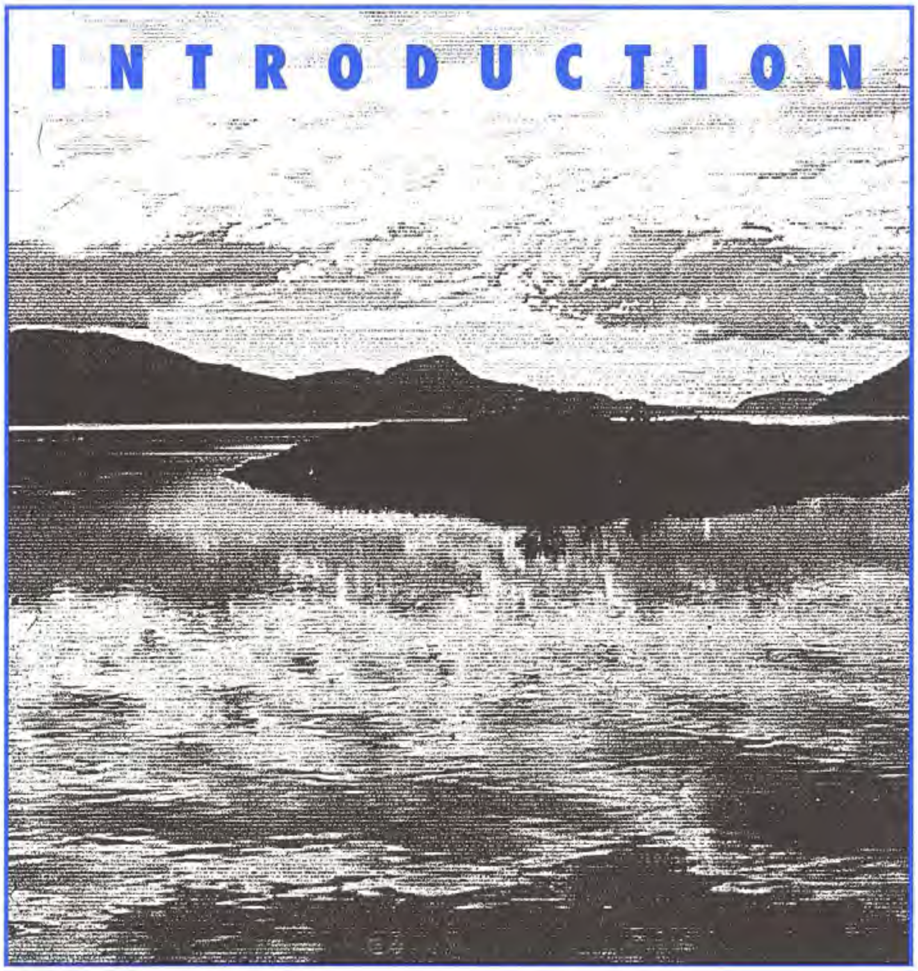
Information from monitoring is being used by resource managers to guide protection efforts and more effectively target restoration and cleanup. A few general examples include:

Maps of nearshore vegetation have helped guide land-use decisions and assisted in evaluating proposed projects that might affect critical habitats.

Information about mixing and circulation of water has helped resource managers estimate the effects of toxic contaminants introduced by combined sewer overflows and sewage discharges.

Monitoring of toxic contaminants in fish led the state Department of Health and the Bremerton-Kitsap County Health District to advise people against consuming rockfish from Sinclair Inlet.

Data collected about the susceptibility of bays and inlets to increased nutrients is helping regulatory agencies decide on appropriate conditions and restrictions to place on permits for discharging wastewater into Puget Sound.



ASSESSING THE HEALTH OF PUGET SOUND

Nestled between the Cascade and Olympic mountains in Washington state lies Puget Sound, the nation's second largest estuary. The entire Puget Sound basin (Figure 1) covers more than 16,000 square miles in northwestern Washington, 20 percent of which is water. This marine-water system is an intricate network of bays, inlets and waterways that extends more than 90 miles inland from the Strait of Juan de Fuca. Puget Sound is part of a larger marine-water system that spans north into Canada and includes the Georgia Basin. The Olympic Peninsula and Vancouver Island protect Puget Sound and the Georgia Basin from the open Pacific Ocean.

We apply the term Puget Sound to all of Washington's inland marine waters inside the international boundary with Canada. This includes part of the Strait of Georgia, the Strait of Juan de Fuca, Hood Canal and Puget Sound proper (everything south of Admiralty Inlet, the channel between Port Townsend and Whidbey Island).

We recognize that the international border between British Columbia and Washington artificially divides the natural system of these inland waters and their drainage areas. A complete assessment of this marine-water system should consider both Canadian and U.S. lands and waters. Although work to measure the health of the entire system is under way,

Figure 1. Puget Sound Basin.

> ### *Why Monitor?*
>
> Keeping watch over water quality and biological resources can tell us about the successes and challenges of managing Puget Sound's environment. Long-term monitoring can teach us about changes in our environment caused by shifts in natural systems, such as El Niño cycles and global changes in the climate or weather patterns. It reveals the effects of changing human influences, such as increased development along the Interstate-5 corridor or bulkhead construction along the Sound's shoreline. Information from the Puget Sound Ambient Monitoring Program and other efforts to assess the quality of water and biological resources helps us understand the condition of Puget Sound and improvements and declines in its health.

this report focuses on monitoring within the state of Washington and Puget Sound. Some results of studies from British Columbia are included, but they fall short of providing a complete picture of conditions in the Georgia Basin.

THE PUGET SOUND AMBIENT MONITORING PROGRAM (PSAMP)

The Puget Sound Ambient Monitoring Program (PSAMP) is a long-term effort to investigate environmental trends, improve decision-making and prevent overlaps and duplication in monitoring efforts. Under the authority of the Puget Sound Water Quality Action Team and the *Puget Sound Water Quality Management Plan,* two committees direct and oversee the design and implementation of the PSAMP. These committees are comprised of scientists and managers from government agencies that help implement the program.

Government agencies that monitor portions of the Puget Sound ecosystem as part of the PSAMP include the Washington state departments of Ecology, Fish and Wildlife, Health, and Natural Resources, the U.S. Environmental

Protection Agency (EPA), the U.S. Fish and Wildlife Service, and the King County Department of Natural Resources. The Action Team support staff coordinates the PSAMP activities of these agencies.

WHO MONITORS WHAT?

- Washington Department of Ecology: Fresh water, marine water and sediments
- Washington Department of Fish and Wildlife: Fish contaminants and marine birds and mammals
- Washington Department of Health: Shellfish growing areas
- Washington Department of Natural Resources: Nearshore habitat
- King County Department of Natural Resources: Marine water, sediments, shellfish and nearshore habitat
- U.S. Fish and Wildlife Service: Marine bird contaminants

OUR UNDERSTANDING OF THE THREATS TO PUGET SOUND

Through our day-to-day observations, we are all familiar with the remarkable diversity of Puget Sound's shorelines, waters and living resources. It provides vitality to the Puget Sound region and contributes to the high quality of life that residents of this unique natural environment experience. However, this diversity also complicates the answer to our questions about the health of Puget Sound.

Past monitoring has shown that the severity of many problems depends on:

- The proximity to urban and industrial centers.
- The character of the various stresses caused by humans.
- Natural factors that make areas of the Sound more susceptible to problems.

To make sense of the many varied connections between human actions and their effects on the environment, PSAMP scientists drafted a conceptual model that describes their understanding of and assumptions about these connections. Figure 2 provides a general overview of this model. This model is based on fundamental relationships between humans and the environment—human actions can stress the environment; these stresses can alter parts of the ecosystem; and management activities can moderate the effects of human actions on the environment. In its more detailed forms, the conceptual model helps identify ecosystem components and environmental stresses that are important to monitor. It also helps relate monitoring results to environmental protection and resource management.

Based on the model, the PSAMP organized its monitoring based on topics that relate to specific ecosystem characteristics or human-influenced stresses on the environment:

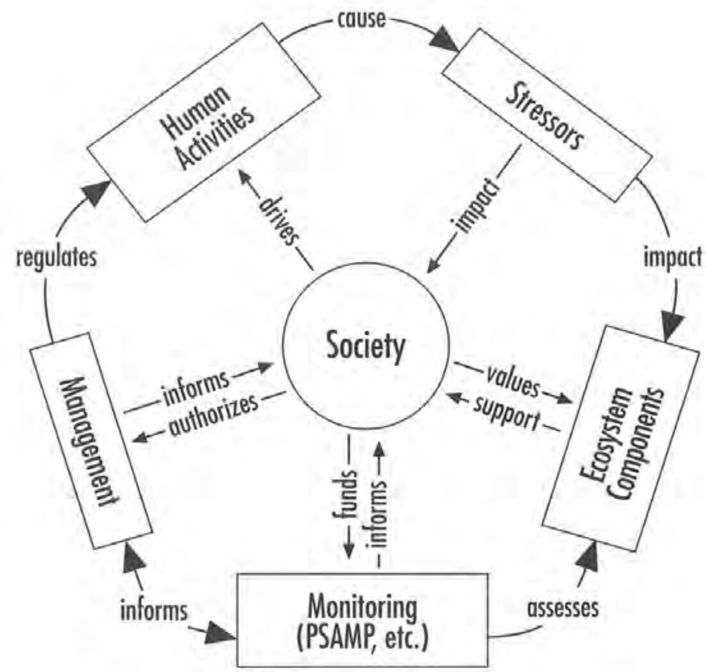
Environmental Indicators

Woven throughout this report is information from various efforts to assess the status of Puget Sound's overall health by monitoring the condition of key indicators of environmental health. Sustainable Seattle (1996) defines an environmental indicator as a measurement that relates to the long-term health and vitality of the environment.

Throughout this report we highlight some of the measurements of the PSAMP as environmental indicators. We also present information from the Puget Sound Water Quality Action Team's effort to measure key environmental indicators. The results of the Action Team's project will be reported in Spring 1998.

Indicators provide a simplified, somewhat limited view of the environment. While we appreciate the usefulness of indicators to help us communicate the health of the Puget Sound environment, we recognize that they do not reflect our full understanding of the Puget Sound ecosystem. Therefore, the PSAMP will continue to develop other measures of environmental health and more fully assess the broad spectrum of conditions of the Puget Sound environment.

Figure 2. Conceptual Model of Puget Sound.



- *Biological Resources:* What are the status and trends of Puget Sound's biological resources?
- *Physical Environment:* Are the physical environments of Puget Sound changing and, if so, how do these changes affect Puget Sound's biological resources?
- *Toxic Contamination:* What are the status and trends of toxic contamination in Puget Sound? How does toxic contamination affect the Sound's biological resources and humans who consume them?
- *Pathogens and Nutrients:* What are the status and trends of pathogens and nutrients in Puget Sound? How do they affect the Sound's biological resources?
- *Human Health:* What are the risks to human health from consuming seafood from Puget Sound?

These are big questions and broad topics. Each topic relates to many human activities and to management actions to restore and protect Puget Sound. Monitoring for each topic is addressed through multiple PSAMP studies and additional assessments by other programs not affiliated with the PSAMP. Table 1 illustrates how the PSAMP integrates studies by monitoring topic. This integration supports synthesis of results and allows a variety of scientific perspectives to be presented in reports such as this *Puget Sound Update.*

This report and the work of the PSAMP primarily address the state of the environment. As an ambient monitoring program, the PSAMP cannot, and should not be expected to, focus its limited resources on why the environment is in the state that we observe. When monitoring results point out significant changes in the health of organisms or habitats, resource management agencies can initiate research projects and specific investigations to uncover causes and better evaluate the nature of

Table 1. Relationships between PSAMP Topics and Monitoring Components Studied by Agencies.

	TOPIC				
Agency & Component Study	**Biological Resources**	**Physical Environment**	**Toxics**	**Nutrients & Pathogens**	**Human Health**
Washington Department of Ecology *Marine Waters*	❍	●		●	❍
Washington Department of Ecology *Sediments and Bottom-Dwelling Organisms*	●	❍	●	❍	❍
Washington Department of Ecology *Fresh Water*	❍	●	❍	●	❍
Washington Department of Fish and Wildlife *Fish*	❍	❍	●		●
Washington Department of Fish and Wildlife *Birds and Marine Mammals*	●		●		
Washington Department of Health *Shellfish*				●	●
Washington Department of Natural Resources *Nearshore Habitat*	●	●			
King County Department of Natural Resources *Marine Water, Sediment, and Other Studies*	❍	●	●	●	❍
U.S. Fish and Wildlife Service *Birds*	❍		●		

● Major aspect of component
❍ Minor aspect of component
Blank cells indicate limited or no involvement in study of a topic.

problems. Where information is available, the PSAMP can help begin this process by discussing associated findings that may relate to underlying causes. When possible, this Update presents information on such associations, identifies suggested or known causes of observed problems, and references the work of others who are following up on the results of monitoring.

A ROAD MAP TO THIS PUGET SOUND UPDATE

In this *Puget Sound Update* you'll find recent information on the condition of the Sound that advances our understanding of the basin and its complex, interconnected components. This edition discusses monitoring results somewhat differently than previous Updates. Each of the remaining chapters of this report addresses one of the five monitoring topics discussed on page 10.

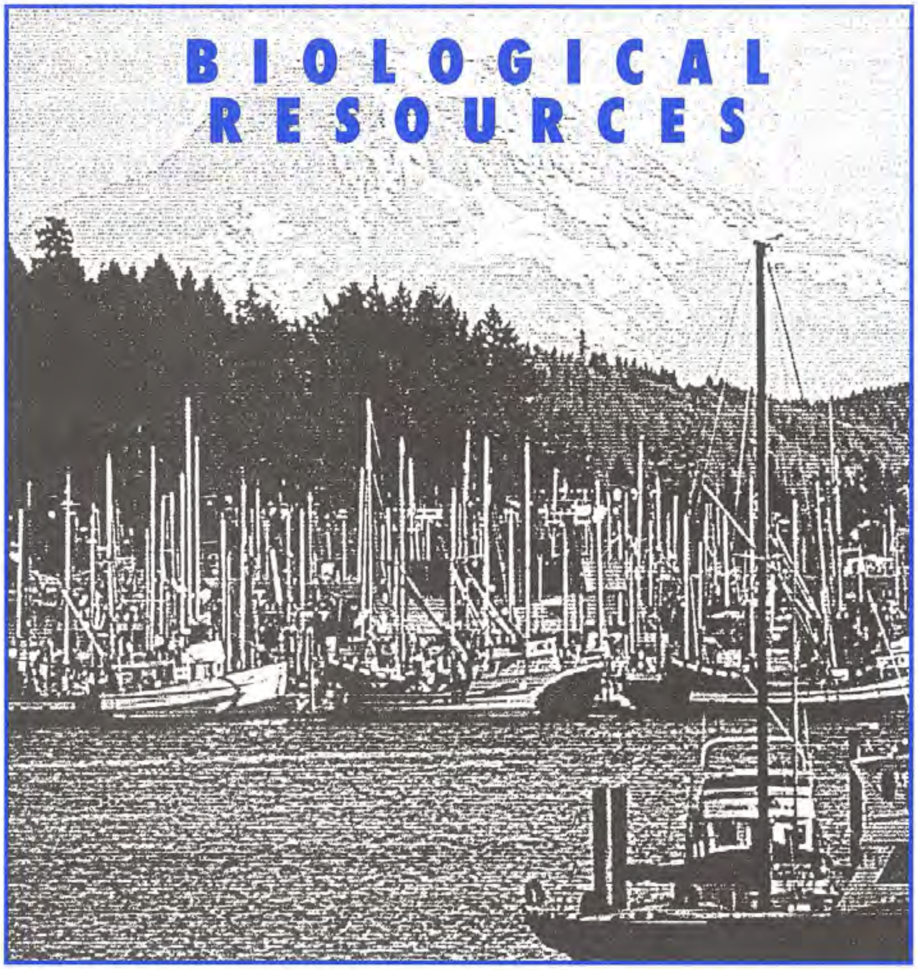
Each chapter contains:

- *A summary of the topic,* including a discussion of the link between the topic and environmental management of Puget Sound.
- *A description of recent findings* of PSAMP studies and pertinent studies from programs not affiliated with the PSAMP.
- *Information on how monitoring or assessment findings are used* to protect and enhance Puget Sound's water and sediment quality, fish and shellfish, and wetlands and other habitats (the strategy for achieving the goal of the *Puget Sound Water Quality Management Plan*).

At the end of this report is a list of resources—primarily documents and web sites—that provide additional information about Puget Sound monitoring and a list of PSAMP scientists who can provide up-to-date information and answer questions about specific studies, results and monitoring topics.

To maintain a level of detail that is informative but not overly dense or technical, this report includes very little information on study design, methods of sampling and analysis, and data quality. Please refer to the documents cited in this Update or contact the appropriate scientists listed at the end of the report for more detailed information about the topics and studies addressed in this Update.

BIOLOGICAL RESOURCES



SUMMARY

Evidence from a variety of sources indicates that the stocks and populations of many marine organisms of Puget Sound are declining. The results presented in this chapter and a review conducted for the Puget Sound/ Georgia Basin International Task Force (West, 1997) reveal that the population of may species in Puget Sound have been decreasing in recent years. Not all species are declining, but a range of organisms appears to be affected by various causes. This leads us to conclude that human activities and recent fluctuations in natural influences place significant pressure on the Puget Sound ecosystem. Reducing or eliminating our stresses on the system and its sensitive organisms may require that we manage human activities differently.

We all share concerns about the condition of Puget Sound's biological resources. Many of us harvest fish and shellfish from Puget Sound as a source of fresh, quality food and a welcome recreational opportunity. Our aesthetic enjoyment of Puget Sound's marine mammals supports tourism and boating. These activities help foster stewardship of the basin's resources. They allow us to recognize and appreciate the importance of the diversity of Puget Sound's marine organisms. For example, we can readily appreciate the direct role that herring and other baitfish play in supporting our commercial and recreational fisheries. Less obvious, but of fundamental

importance, are the key roles played by planktonic algae, attached vegetation and other small organisms that make it possible for the Puget Sound ecosystem to flourish.

This chapter addresses the condition of marine organisms in the waters of Puget Sound. It presents information on the status of marine birds and mammals, nearshore vegetation, phytoplankton, sediment-dwelling invertebrates, marine and diadromous fish and a few other marine organisms. Diadromous fish, such as salmon, migrate between fresh and marine waters. By studying this diversity of organisms we can develop and present evidence to support both specific and general conclusions about the health of Puget Sound's biological resources.

This chapter begins the story of how well Puget Sound is doing. We often cannot identify with much certainty the underlying causes of many shifts in the condition of the Sound's biological resources. However, we must consider the connections among Puget Sound's marine organisms, the quantity and quality of habitats provided through the diverse settings of the Sound, and natural and human-caused stresses that might influence organisms and their habitat.

Our Concerns for the Health of Puget Sound's Marine Organisms

In a simple visualization of how humans and natural influences affect Puget Sound, the Puget Sound Ambient Monitoring Program (PSAMP) identifies four types of threats to Puget Sound's marine life:

- Direct alteration of biological resources.
- Changes to the physical environment (such as destroying or degrading habitat).
- Contamination by toxic substances.
- Contamination by pathogens and overloading of nutrients.

The latter three threats are addressed in the next three chapters. Humans can directly alter the character of Puget Sound marine life in several ways, including:

- Introducing non-native species, either accidentally or intentionally.
- Changing the abundance of a species and the composition of biological communities through activities such as harvesting fish or releasing hatchery-raised fish.

Natural processes, such as El Niño, can also affect the condition of the Sound's biological resources. For example, new species might enter Puget Sound through a climate-driven extension of their range.

FINDINGS

The PSAMP's investigation of the status of Puget Sound's biological resources is limited to the Department of Fish and Wildlife's (Fish and Wildlife) studies of the populations and distribution of marine birds and

harbor seals, the Department of Natural Resources' (Natural Resources) inventories of near-shore vegetation, and the Department of Ecology's (Ecology) investigations of Puget Sound's sediment-dwelling organisms and estimates of phytoplankton biomass (measured as chlorophyll-*a*). This section presents recent findings of these studies and rounds out the story of the health of Puget Sound's organisms with findings from other significant reports and studies.

Marine Birds

Diving Ducks. Puget Sound is a migratory route, or flyway, for many diving ducks and other marine birds. Scoters are the most numerous diving duck in Puget Sound during the winter. Scientists from Fish and Wildlife conducted winter and summer aerial surveys of marine birds from 1992 to 1997. Recent findings indicate that the number of scoters may have dropped at least 50 percent over the last 15 to 30 years. Figure 3 presents data on scoters and scaup in northern Puget Sound in 1979 and during the PSAMP study years of the 1990s. This information supports other data that suggest declining numbers of scoters throughout the Pacific flyway.

Although other species of diving ducks—like golden-eye and bufflehead—spend their winters in Puget Sound and use nearshore habitat similar to that used by scoters, they do not show the same pattern of declining numbers in Puget Sound (Figure 4). The numbers and density of scaup wintering in Puget Sound have decreased over the last 15 to 20 years as noted by comparisons with historic data (Figure 3) and reports from Fish and Wildlife biologists.

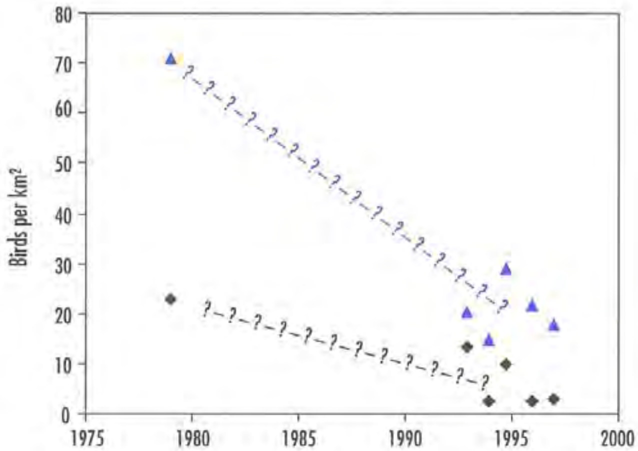


Figure 3. Declinging Densities of Scoters and Scaup in Northern Puget Sound.

Note: 40 to 50 km² were covered by northern Puget Sound transects in December and January of each winter period: The 1979 survey was Puget Sound Marine Ecosystem Analysis (MESA); 1993 to 1997 surveys were PSAMP.

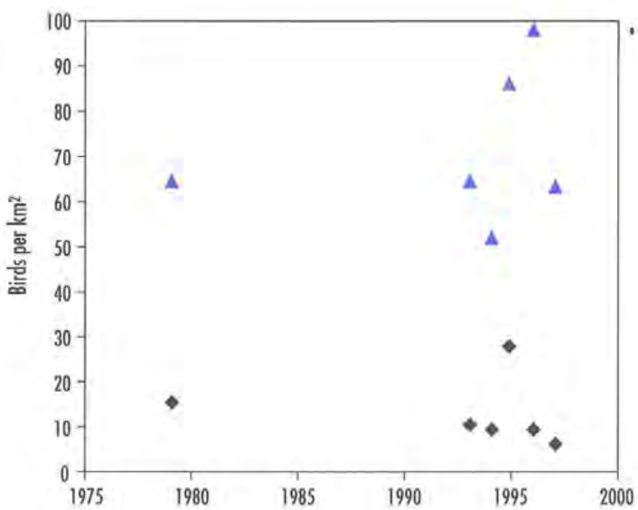
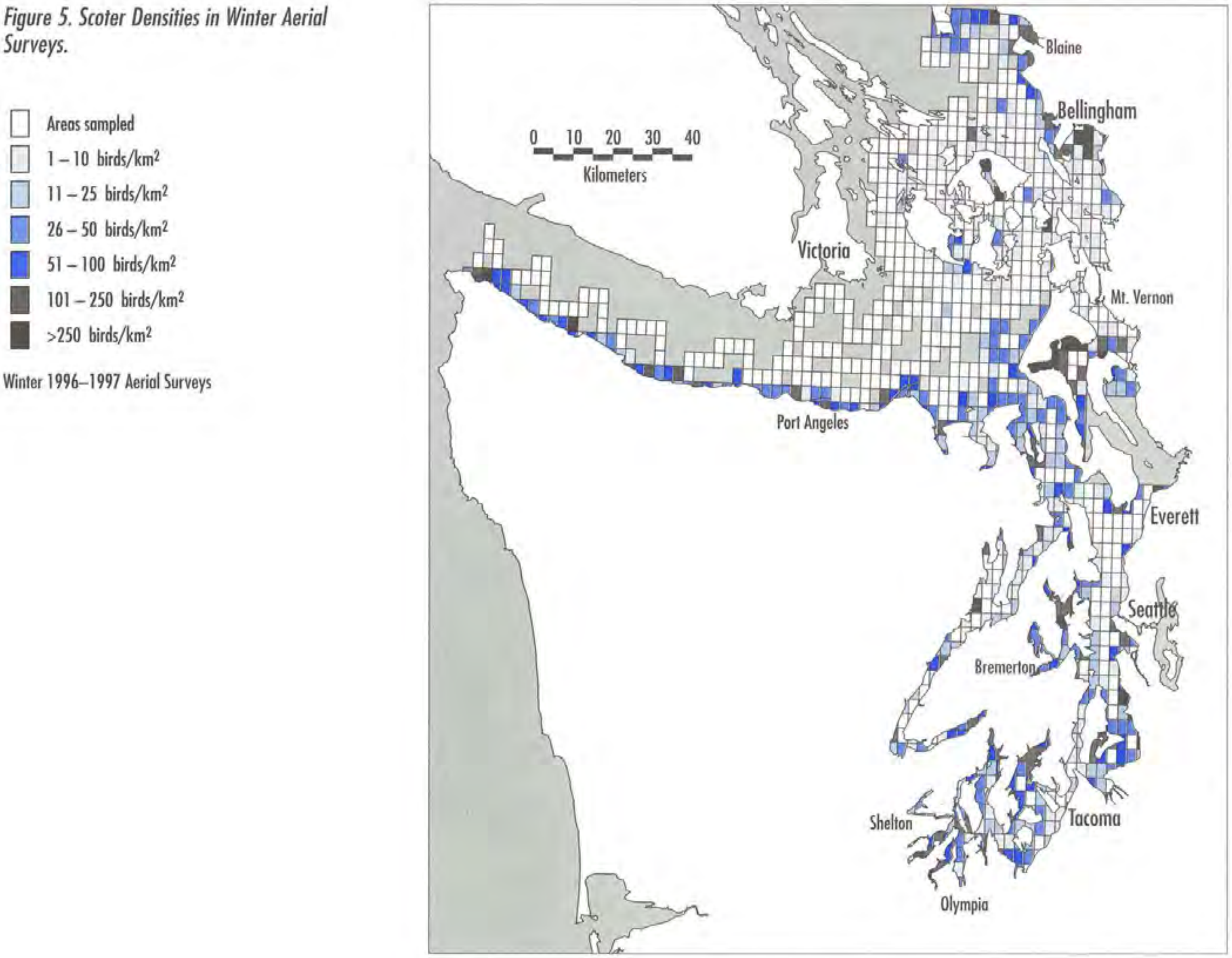


Figure 4. Density of Goldeneye and Bufflehead in Northern Puget Sound.

Note: 40 to 50 km² were covered by northern Puget Sound transects in December and January of each winter period: The 1979 survey was Puget Sound Marine Ecosystem Analysis (MESA); 1993 to 1997 surveys were PSAMP.

Figure 5. Scoter Densities in Winter Aerial Surveys.



Unlike scoters, there is uncertainty whether this decline occurs all along the West Coast or reflects a movement of scaup to other habitats, such as the Columbia River. The clumped distribution of scaup also makes estimates of population and density difficult.

Figures 5 and 6 show the 1996-97 winter distributions of scoters and western grebes throughout Puget Sound. These distributions are fairly stable from year to year.

This information helps identify which species may be more susceptible to stresses or changes in specific areas of the Sound. For instance, the decline in herring stock in Port Orchard (as discussed on page 25) might affect the distribution and number of western grebes that spend the winter in this area.

Marbled Murrelets. Marbled murrelets nest inland in old-growth, coniferous forests and forage for prey in the nearshore waters of Puget Sound and other coastal areas. The population of this species is low in the Puget Sound basin and is listed as threatened under the federal Endangered Species Act. Because their nest sites are difficult to access and observe, Fish and Wildlife is using marine bird surveys to investigate the productivity of marbled murrelets.

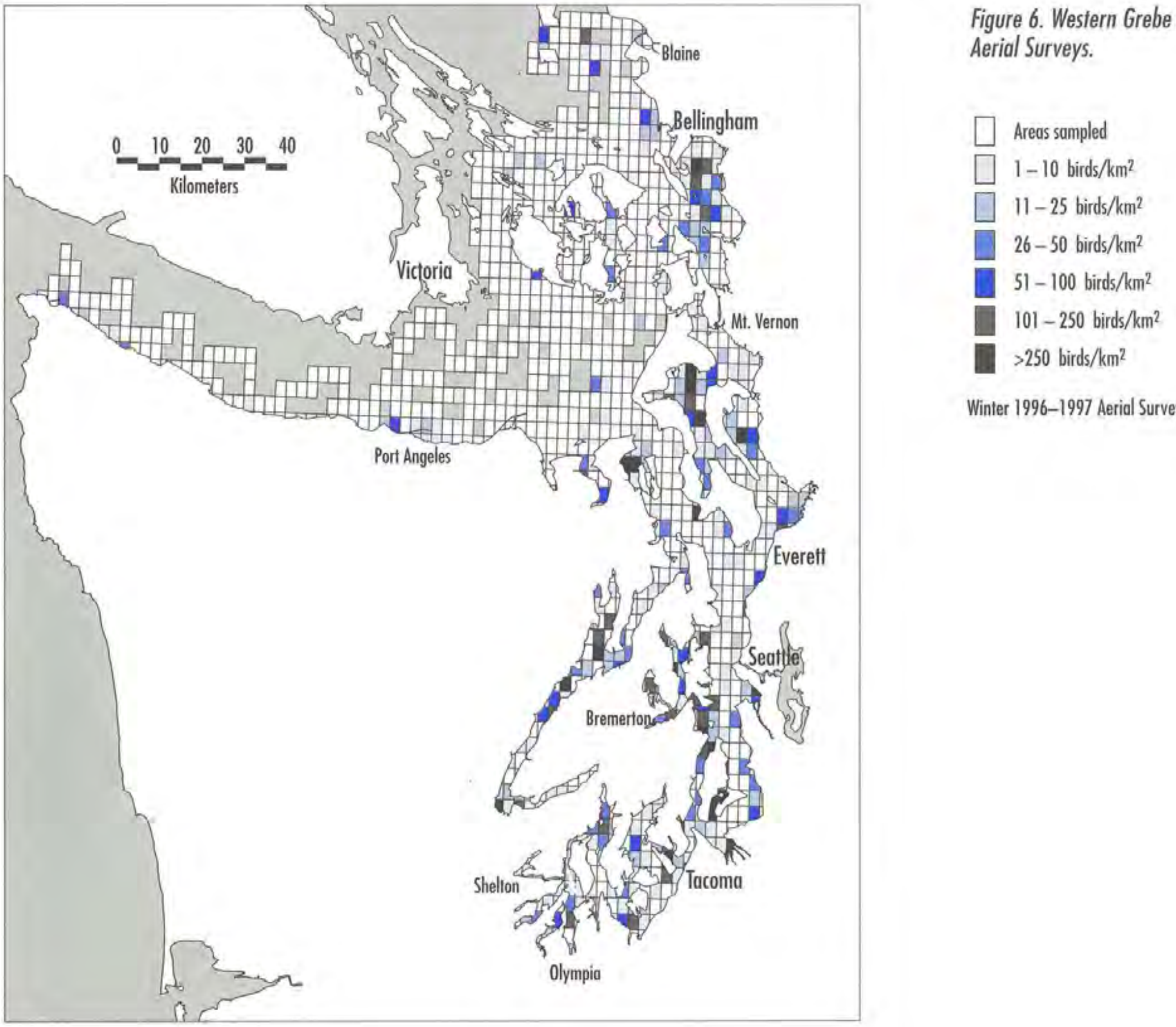


Figure 6. Western Grebe Densities Winter Aerial Surveys.

In 1993 Fish and Wildlife started using surveys to estimate the ratios of juvenile to adult marbled murrelets. The observed ratios are higher in Puget Sound than those observed along the outer coast of Washington and in Oregon. The higher ratios may indicate higher productivity in the Puget Sound area than in other monitored areas. Using this information to make definitive statements about the birds' productivity is difficult, however, and alternative theories might also explain the observed higher ratio in Puget Sound. PSAMP investigators are working with scientists from Fish and Wildlife, federal management programs and universities to answer some of these questions and to standardize a monitoring method to evaluate the condition of marbled murrelets in Puget Sound and the larger region.

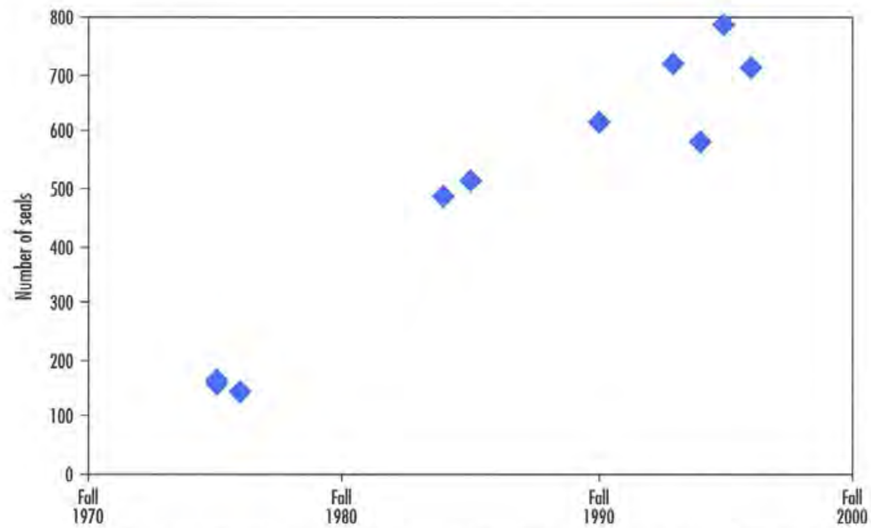
Harbor Seals

Seal Population Status. Harbor seals are by far the most abundant marine mammal in the inland marine waters of Washington. Their numbers have increased substantially since the mid-1970s. In 1996, as part of ongoing cooperation between the Department of Fish and Wildlife and the National Marine Fisheries Service, aerial surveys were conducted to estimate the number of harbor seals in Puget Sound. Fish and Wildlife surveyed all known harbor seal haulout areas in Puget Sound from the air. The 1996 aerial survey helped scientists estimate that about 17,000 seals live in Puget

Many Marine Birds are Part-time Residents of Puget Sound

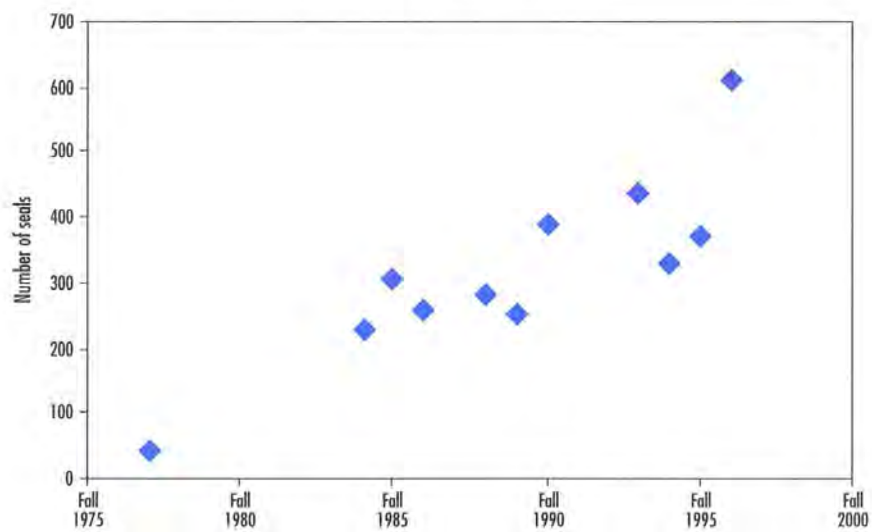
An important and visible part of the Puget Sound ecosystem, many of the marine birds studied by the Department of Fish and Wildlife reside in Puget Sound only part of the year. For example, each fall sea ducks migrate from their nesting areas (often far inland or far north)to Puget Sound. They spend the winter here, feeding on Puget Sound's productive marine life to store energy for a spring return to their nesting grounds. For this reason, we talk about many marine birds as wintering or overwintering in Puget Sound. The Department of Fish and Wildlife evaluates bird numbers during their winter stay.

Figure 7. Peak Harbor Seal Counts at Gertrude Island.



The fall count occurred from August through October each year. 1975–1977 data from Jefferies and Johnson, 1990; 1984 data from Calambokidis et al., 1985; 1985 data from Calambokidis pers. comm.; and 1993–1996 data from the PSAMP, Department of Fish and Wildlife and National Marine Fisheries Service, unpublished data.

Figure 8. Peak Harbor Seal Counts at Henderson Inlet.



The fall count occurred from July through October each year. 1977 data from Calambokidis et al., 1978; 1984 data from Calambokidis et al., 1985; 1985–1990 data from Calambokidis et al., 1991; and 1993–1996 data from the PSAMP, Department of Fish and Wildlife and National Marine Fisheries Service, unpublished data.

Sound. While the overall number of harbor seals in central and southern Puget Sound grew 10 percent each year from 1991 and 1996, regional differences suggest that the increases in seal numbers seen over the last 13 years have varied around the Sound. The largest increases occurred in the San Juan Islands and the Strait of Juan de Fuca. The numbers of seals in Boundary Bay, other eastern bays of northern Puget Sound and Hood Canal did not increase or increased very little. Fish and Wildlife continued land-based monitoring of harbor seals at two sites in southern Puget Sound—Gertrude Island and Woodard Bay in Henderson Inlet. Peak counts at these areas in 1996 were 714 and 608 animals, respectively. These numbers include 280 pups. Figures 7 and 8 show maximum autumn numbers of seals at Gertrude Island and Henderson Inlet. Harbor seal counts in these areas have increased almost four-fold in the last 20 years.

Seal Health Status. Researchers captured and handled 116 harbor seals at Gertrude Island (near McNeil Island in south Puget Sound), Eagle Island, Woodard Bay and Boundary Bay. The seals were screened for three diseases—Phocine Distemper Virus (PDV), leptospirosis and brucellosis—to determine the baseline health of the population. PDV is believed to cause massive die-offs of harbor seals, gray seals and Baikal seals on the Atlantic coast, in Europe and Eurasia. Recent testing of harbor seals in southeast Alaska and the Gulf of Alaska showed evidence of exposure to PDV antigens. Leptospirosis and brucellosis can cause reproductive failure, which could affect harbor seal populations.

Disease screening in 1996 provided no evidence of exposure to PDV or leptospirosis in seals from south Puget Sound. However, nearly 25 percent of the harbor seals screened from south Puget Sound tested positive or suspected positive for exposure to brucellosis, a bacterial disease that affects livestock, humans, and other types of mammals. This is the first observance of positive exposure to brucellosis in West Coast harbor seals.

The Department of Fish and Wildlife also received numerous reports of stranded marine mammals in Puget Sound. The agency responded to 31 cases where harbor seal carcasses were examined. Five of these animals tested positive for exposure to brucellosis. Four of five carried a brucella strain similar to a strain found in seals in the United Kingdom. The significance of isolating this strain of brucellosis from Puget Sound harbor seals is not known. However, as with other types of brucellosis, there is a potential health risk to terrestrial wildlife, domestic livestock and humans. ← follow up?

Fish and Wildlife scientists continued permanent marking of harbor seals at the Gertrude Island study site in 1996. Long-term observations of these branded animals will provide estimates of how old harbor seals are when they first produce and their productivity and survival at specific ages. It will also provide an assessment of individual reproductive success and longevity for Puget Sound's harbor seal population. ← follow up?

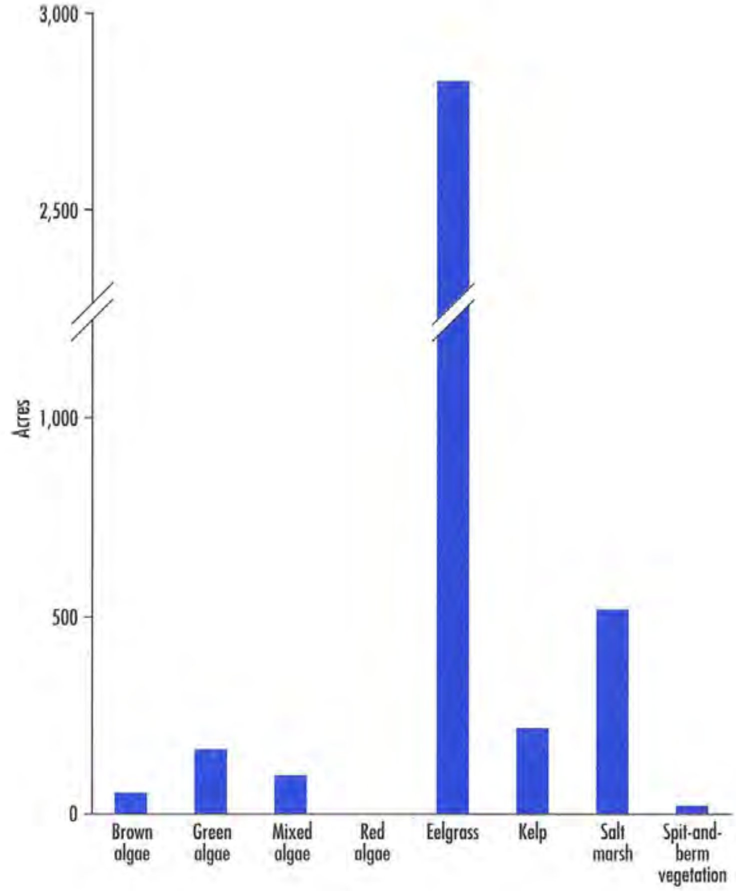
★ food habits of seals

Nearshore Vegetation

Nearshore Vegetation Mapping. Scientists with the Department of Natural Resources' (Natural Resources) nearshore habitat program surveyed shorelines to map the location and types of nearshore vegetation. Maps and digital geographic information developed from the surveys identify the following types of vegetation in Puget Sound: brown algae, kelp, eelgrass, green algae, red algae, mixed algae, salt marsh, and spit-and-berm communities.

The agency's 1995 inventory of Whatcom County updated information in the Coastal Zone Atlas (Ecology, 1977). More than 35 percent of the study area was newly inventoried; the Coastal Zone Atlas did not map federal or tribal lands. Figure 9 (in the color section at the end of this report) provides an example of the type of maps developed from the Department of Natural Resources' surveys. Note the diversity of vegetation types and the level of detail. Figure 10 lists acreage information for the nearshore vegetation types mapped in Whatcom County by Natural Resources in 1995. Eelgrass is the most abundant vegetation along Whatcom County's shoreline.

Figure 10. Breakdown of Various Types of Nearshore Vegetation Found in the Department of Natural Resources' 1995 Survey of Whatcom County.



Kelp Along the Strait of Juan de Fuca. Kelp, large brown algae, often forms large beds that dominate a marine landscape. Washington is home to 26 species of kelp, more than is found in any other area worldwide (Druehl, 1969).

Kelp beds consisting of giant kelp and bull kelp stretch along approximately 12 percent of the Puget Sound shoreline, especially along the Strait of Juan de Fuca (Thom and Hallum, 1990). These species have float-like structures that hold the upper portion of the plant at the surface. The multi-canopied beds provide habitat for diverse communities, including many important commercial and sport fish, such as juvenile and adult salmon, rockfish, herring and lingcod, and many invertebrates, including abalone and crab (Strickland and Chasan, 1989).

Since 1988 Natural Resources, other agencies and consultants have used aerial photography to map floating kelp in the Strait of Juan de Fuca and along the outer coast. This effort provides annual information on the extent and vitality of the kelp beds.

Seventy-eight percent of all kelp between Port Townsend and the Columbia River grows along the Strait of Juan de Fuca (Van Wagenen, 1996). In 1996 kelp beds in the Strait of Juan de Fuca covered 6,600 acres, with bull kelp being the dominant species. Kelp beds in the Strait of Juan de Fuca make up 82 percent of all bull kelp found west of Port Townsend. Similarly, the Strait's population of giant kelp represents 73 percent of Washington's total resource of this species.

	1991	1992	1994	1995	1996	Five-Year Average	Percent of Total
Bull Kelp	4,250	3,090	2,950	3,300	3,910	3,500	58%
Giant Kelp	2,120	2,240	2,790	3,030	2,730	2,580	42%
Total	6,370	5,330	5,740	6,330	6,640	6,080	

Table 2. Kelp Bed Area Along the Strait of Juan de Fuca (Acres).

Despite fluctuations among years, the total area of floating kelp beds along the Strait of Juan de Fuca has not changed significantly over the last five years (Table 2). This suggests that fluctuations between 1995 and 1996, for example, are within the range of normal year-to-year acreage changes. Significant changes that may be occurring over longer periods or within smaller areas are a focus of ongoing research.

Phytoplankton

The Department of Ecology (Ecology) monitors the abundance of phytoplankton in Puget Sound's open marine waters by analyzing concentrations of chlorophyll near the surface each month. Ecology indirectly quantifies phytoplankton density through this readily measured indicator, but does not directly assess phytoplankton populations, communities or growth rates.

Based on monitoring results, Ecology has characterized seasonal patterns of chlorophyll-*a* concentrations and, by extension, phytoplankton biomass (Newton et al., 1997). In Puget Sound waters, chlorophyll-*a* abundance follows a typical seasonal pattern for temperate climates, with higher concentrations from late spring through early fall than in winter. Winter levels are lower because light is limited and because phytoplankton are readily dispersed as waters mix more thoroughly. The following two patterns are evident within this seasonal framework.

- *Typical temperate.* Some parts of Puget Sound (including Dyes Inlet and Elliott Bay) exhibit a typical temperate pattern of spring and fall blooms of phytoplankton and relatively low mid-summer concentrations. The relatively low mid-summer values at these locations likely reflect limited nutrients (for example, spring growth depletes the nutrients, which are not replaced by physical mixing of the water).

- *Summer blooms.* Some parts of the Sound, especially Budd Inlet, East Sound at Orcas Island, and lower Hood Canal, show elevated chlorophyll-*a* concentrations, and even blooms, in summer. This indicates that the supply of nutrients is adequate to maintain high rates of phytoplankton growth. The nutrient supply may result from natural or human sources.

King County staff also evaluate chlorophyll-*a* concentrations in Puget Sound waters to assess phytoplankton. King County's ambient monitoring stations in the main stem of central Puget Sound reflect the typical temperate pattern—higher concentrations in late spring and early fall than in mid-winter.

Large phytoplankton blooms are naturally occuring events. However, similar to declines in populations of other biological resources, very large or very frequent blooms of phytoplankton can indicate an imbalance in the marine ecosystem and can cause concern. The chapter on nutrients and pathogens (page 61) addresses the links among nutrient concentrations, nutrient sources, susceptibility to eutrophication (which refers to the process of making a system overly nutrient-rich), and the effects of eutrophication in Puget Sound.

Sediment-Dwelling Organisms

As part of the PSAMP, Ecology has been collecting and identifying organisms from the subtidal sediments of Puget Sound since 1989. Ecology staff recently evaluated data from the first five years of this effort to define and describe the communities of sediment-dwelling organisms that occur in various types of sediment habitat throughout Puget Sound.

Ecology's sampling of sediments through 1995 was focused away from the most highly polluted parts of the Sound. This approach complements discharger monitoring and assessments of contaminated sites in the vicinity of pollutant sources. By studying locations distant from sources, the PSAMP monitoring supports broad assessments of toxic impacts to Puget Sound's health.

Based on the relatively clean conditions observed at most PSAMP sampling locations, Ecology is using the PSAMP results to indicate the type and diversity of organisms expected in particular sediment habitats in the absence of high levels of pollution. From findings in other environments and studies, some organisms are likely to be sensitive to pollution, while others tolerate pollution stresses relatively well. Knowing which community of organisms to expect in relatively unpolluted areas provides scientists and resource managers a point of reference from which to interpret the communities observed in more polluted areas. It helps determine how pollution and other stresses might be affecting the Puget Sound ecosystem.

Using the results of the PSAMP study, Ecology distinguished communities of sediment-dwelling organisms in sand, mixed sediments (sand, silt and clay) and mud (silt and clay). The communities, however, did not have distinct boundaries, and exhibited a great deal of overlap in species distribution. For example, some organisms were characteristic of deep muddy stations and others of broad distribution, occurring in all sediment types. Using the PSAMP data, Ecology identified 84 specific polychaete worms, 25 amphipods and 23 bivalves that showed strong fidelity to narrow ranges of substrate conditions.

Ecology is preparing a report that will provide more detailed information on the results of this community characterization. If the representation of sediment-dwelling organisms in some areas does not coincide with expected organisms, toxic contaminants, low dissolved oxygen conditions, physical disturbances, or other stresses might be affecting the biological community in this area.

Ecology's evaluation identified a group of stations with consistently low numbers of species. Stations in this group were located at the head (upper end) or middle reaches of inlets in south Puget Sound, in bays or inlets with restricted water circulation, such as Sequim Bay and Lynch Cove, and in deep basins such as Saratoga Passage. The low observed diversity of species in these relatively unpolluted areas may indicate that natural stresses (for example, low dissolved oxygen, salinity variations) are influencing community structure and composition.

King County scientists study sediment-dwelling organisms in central Puget Sound as part of an ongoing monitoring program associated with the county's wastewater discharges. County staff sampled four stations in 1994 and 1996 to investigate whether discharges from wastewater treatment plants in King County appeared to be affecting these communities. Based on the high diversity of organisms observed from sampling stations near the county's treated wastewater discharges and the similarity of these communities to those in other parts of Puget Sound, King County drew a preliminary conclusion that the discharges probably are not negatively affecting sediment-dwelling organisms.

"Stressed" Marine Organisms in the Inland Marine Waters of Washington State

The Puget Sound/Georgia Basin International Task Force recently commissioned a review (West, 1997) of the status of 13 species or groups of species identified as having undergone substantial declines in regional population abundance in recent years. The organisms assessed in this review include:

- Invertebrates (Olympia oyster, pinto abalone, and a large, general group termed "unclassified marine invertebrates").
- Finfish species or groups of species (Pacific herring, Pacific cod, Pacific hake, walleye pollock, three species of rockfish associated with the sea floor, and lingcod).
- Seabirds (marbled murrelet, common murre and tufted puffin).
- Marine mammals (harbor porpoise).

The review summarized the known and potential effects of four human-caused stressors on these organisms. The human causes reported to have major effects (or potential effects) on the species and groups evaluated include:

- Harvest, including targeted harvest and bycatch, was considered a major stressor on 11 of the 13 species (all except Pacific herring and tufted puffin).
- Habitat loss and degradation were considered major stressors on the Olympia oyster and "unclassified marine invertebrates."
- Disturbance was a major stressor for harbor porpoise and nesting tufted puffins.

The review also discussed the effects of natural factors that limit these species or groups. Natural limiting factors are thought to affect most

Table 3. Status of Puget Sound's Bottomfish Stocks (based on Palsson et al., 1996).

North Sound—Strait of Juan de Fuca, Strait of Georgia, San Juan Archipelago, and Bellingham Bay

	Above Average Condition	Average Condition	Below Average Condition	Depressed Condition	Critical Condition
Increasing Numbers	Skates Pacific hake* Sablefish* Greenlings* English sole Sand sole	Sculpins*			
No Trend	Spiny dogfish	Rockfish	Starry flounder	Pacific cod	
Declining Numbers			Pacific halibut	Lingcod Rock sole Dover sole	Walleye pollock Pile perch*

South Sound—Puget Sound South of Admiralty Inlet, Port Susan, Saratoga Passage, Skagit Bay and Hood Canal

	Above Average Condition	Average Condition	Below Average Condition	Depressed Condition	Critical Condition
Increasing Numbers	Sculpins*				
No Trend	Spiny dogfish		Rockfish Pile perch*		
Declining Numbers	Lingcod		Greenlings*		Pacific hake Pacific cod Walleye pollock Sablefish*

Unknown status and trend—Spotted ratfish, north and south; south Sound stocks of skates, rock sole, Dover sole, English sole, starry flounder, and sand sole.

* indicates poor data quality; fair data quality for all others, except good data quality for south Sound Pacific hake.

of the studied species. For example, recent shifts in environmental conditions may influence declines in abundance of Pacific cod, walleye pollock, and Pacific hake in Puget Sound; and variability in the abundance of prey is believed to affect the three seabird species.

What Do We Mean By Stock?

The term "stock" refers to a group of fish which is isolated from other fish of its species or which is fished separately from other groups of fish of the species. A number of stocks contribute to the total population of each species of fish found in Puget Sound.

Fish

Bottomfish. Department of Fish and Wildlife scientists evaluated the status and trends of 27 stocks of Puget Sound bottomfish in 1995 (Palsson et al., 1996). Table 3 summarizes the information from Fish and Wildlife. Fifteen of the 27 evaluated stocks were below average, depressed, or in critical condition. The poor condition of bottomfish stocks appears to be most acute for south Puget Sound, where nearly three-quarters of all evaluated stocks were in below average or worse condition. Not all bottomfish stocks are in poor condition; the abundance of nearly one-third of the evaluated stocks was increasing.

Wild Salmon Stocks. Figure 11 shows the status of the 209 Puget Sound wild salmon (and steelhead) stocks as of 1992. While a good proportion of the stocks (44 percent) was healthy, the status of 29 percent of the stocks was unknown, 21 percent were depressed (production was lower than

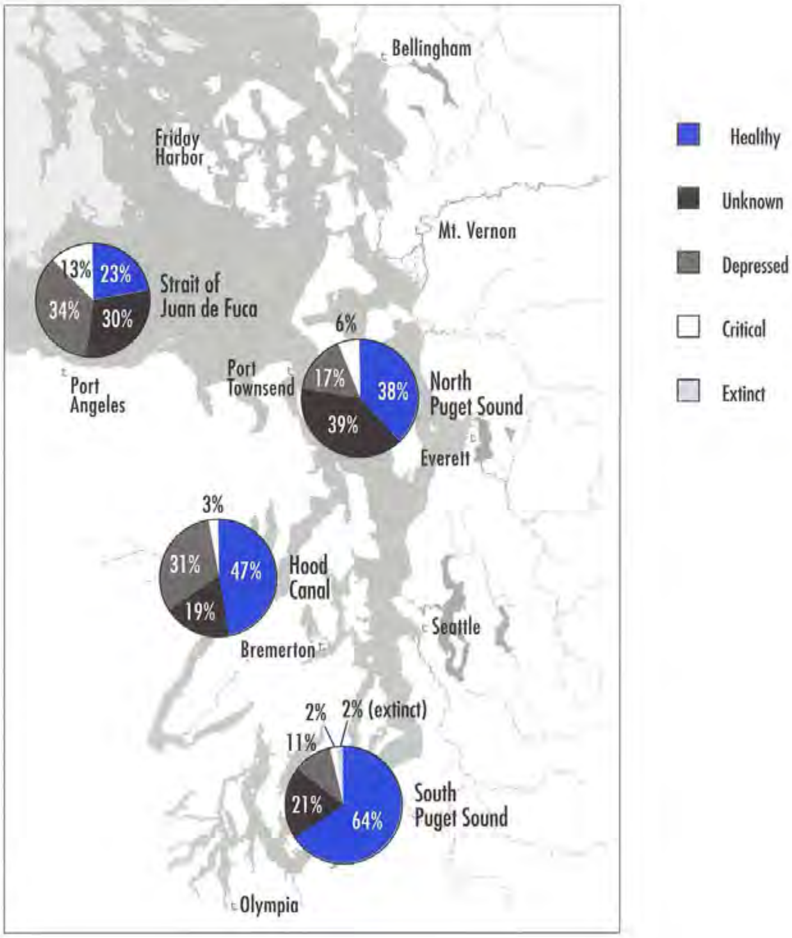


Figure 11. Status of Puget Sound Salmon Stocks (1992).

expected but permanent damage was not anticipated), and five percent were characterized as critical, meaning that permanent damage had occurred. As of 1992, one chum salmon stock from south Puget Sound was listed as extinct.

Herring Stocks. Figure 12 shows the estimated total weight of herring in north and south Puget Sound and in the Strait of Juan de Fuca over the last 20 years. This graph indicates modest declines in herring tonnage during this time.

The Department of Fish and Wildlife's 1994 analysis indicated that many of Puget Sound's 18 stocks of Pacific herring were at least moderately healthy. However, this evaluation also revealed some concerns:

- The Port Orchard, Port Susan/Port Madison and Cherry Point stocks were depressed. The abundance of herring in these locations was somewhat low, though not low enough to anticipate permanent damage.
- The Discovery Bay herring stock was in critical condition due to very low abundance. Permanent damage to this stock has occurred or is likely.
- The status of seven stocks was unknown.

Herring in Puget Sound

In 1997 Jim West, a scientist with the Department of Fish and Wildlife, prepared a report for the Puget Sound/Georgia Basin Interational Task Force that further explains our concerns about the status of herring and also recommends actions to address these concerns.

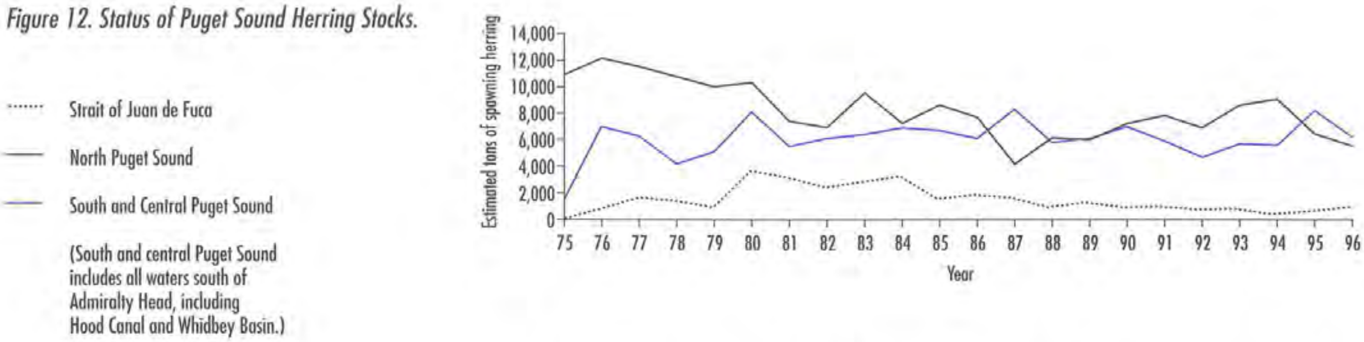
Major stressors and other factors contributing to stress among herring include:

- Climactic trends (higher than long-term average temperatures) have created environmental conditions unfavorable to herring propagation and favorable to their predators.
- An apparent increase in potential predation of herring by seals and sea lions, spiny dogfish, and Pacific salmon.
- Other factors that may contribute to stress of Pacific herring include loss of vegetated, nearshore habitat for spawning, contamination of nearshore nursery areas, and accumulation of contaminants.

Recommendations for managing herring:

- Continue monitoring abundance and mortality.
- Coordinate with the PSAMP to evaluate the effects of climactic and environmental variables on herring abundance.
- Continue and expand research on contaminant accumulation and effects.
- Continue and enhance protection of vegetated nearshore habitats.
- Investigate the relative contributions of various predators to the natural mortality of Pacific herring, especially focusing on predators whose populations have changed substantially in recent years (for example, harbor seals).

Figure 12. Status of Puget Sound Herring Stocks.



- Natural mortality of adult herring from the Cherry Point stock was steadily increasing. The reasons are not fully known, but possible stressors include predation or habitat loss. Current populations are sustained by average or above average numbers of young fish. This condition leaves the herring stock vulnerable; a loss of a single-year's offspring could result in a dramatic downturn.

The Threat of Non-native Species in Puget Sound

In 1994, a Marine Science Panel convened by the Environmental Cooperation Council of Washington and British Columbia identified preventing the introduction of non-native species as a high priority in the shared waters of Puget Sound the Georgia Basin. Non-native species may damage both the environment and economy. Environmental damages may occur when native species are forced to cope with the predation, competition, diseases/or parasites associated with non-native species. Other environmental damages may occur when non-native species modify habitats to the detriment of native species. In extreme situations, native species may be eliminated from a waterbody. Economic damages may arise as non-native species displace recreationally or commercially important species, including shellfish.

A recent report (Elston, 1997) for the Puget Sound/Georgia Basin International Task Force presents information on this issue and provides a basis for actions to minimize the introductions of non-native—often called exotic—species to the area. The report discusses ways that non-native species may enter Puget Sound or the Georgia Basin and existing programs to manage these pathways. It also highlights management programs from around the world, summarizes non-native species currently found in or near the shared waters, and presents recommendations for improving management of non-native species.

Non-native species enter the Puget Sound basin through intentional and accidental releases by the aquaculture industry, accidental releases from the aquarium trade and public aquaria, importations of seafood, research and teaching institutions, and the release of ballast water by the shipping industry.

The report specifically addresses a number of exotic species in or near Puget Sound, including an Asian copepod, Atlantic salmon, Sargassum (a brown algae), *Spartina*, the European shore or green crab, the Japanese oyster drill, Japanese eelgrass, the Mahogany clam, the Manila clam, and the Pacific oyster.

Spartina (Cordgrass) in Puget Sound. Most nearshore vegetation provides valuable habitat. *Spartina*, however, threatens tideflats in Puget Sound and coastal Washington because it alters natural fish and shellfish habitat and dominates native vegetation. Commonly known as cordgrass, *Spartina* grows in dense colonies that trap sediments, changing the elevation of tideflats. Three species of *Spartina* have been introduced to western Washington and are on the Washington State Noxious Weed List.

In Puget Sound, known *Spartina* infestations occur at a few locations along the Strait of Juan de Fuca and into Hood Canal, at one location on San Juan Island, in numerous areas along the shorelines of Skagit, Island and Snohomish counties, and at a few locations along the shorelines of King and Kitsap counties. *Spartina* has not been found south of Tacoma Narrows in Puget Sound. The Washington State Department of Agriculture (Agriculture) runs a *Spartina* Eradication and Control Program. As part of this program, Agriculture funds control crews in Skagit, Island and Snohomish counties. In addition, Agriculture staff, Adopt a Beach volunteers, tribal members, landowners and others participate in efforts to control cordgrass in Clallam, Jefferson, San Juan, Kitsap and King counties. A focus of this effort is to identify colonies and halt the spread of *Spartina*.

The Value of Citizen Monitoring – Spartina Watch. Since June 1994, Adopt a Beach—a private non-profit organization—has coordinated "*Spartina* Watch," a program in which community members hunt for new infestations of *Spartina* in Puget Sound. This monitoring program is a vital part of Agriculture's efforts to control and eradicate *Spartina* in Puget Sound. It is also an example of a monitoring effort that might only be accomplished through citizen actions.

Since the program's inception, *Spartina* Watch volunteers have surveyed more than 740 miles of Puget Sound shoreline. This represents almost one-third of the entire shoreline of the Sound. *Spartina* Watch surveyors discovered 30 new infestations of *Spartina*. Follow-up work has begun to control 18 of these infestations.

From July 1995 to July 1997, Adopt a Beach and the Washington Water Trails Association jointly coordinated *Spartina* Watch under a contract with the Department of Agriculture. (Earlier *Spartina* Watch efforts were supported by the Puget Sound Water Quality Authority.) Over this two-year period, 192 people attended *Spartina* Watch training events. Nearly 140 of these people adopted portions of shorelines totaling 400 to 500 miles. In nearly 400 miles of shoreline surveyed, *Spartina* Watch volunteers reported 15 sightings of *Spartina*, all of which were confirmed. Adopt a Beach entered data from volunteer surveys into its database and provided data to interested state agencies, appropriate county Noxious Weed Control Boards, and tribes.

USING MONITORING DATA TO SUPPORT MANAGEMENT DECISIONS

Marine Bird Surveys and Gillnet Fisheries

Resource managers and public groups have used data from the Department of Fish and Wildlife's aerial surveys of marine birds to evaluate the threats posed to birds by gillnet fishing. The aerial surveys conducted over the past six years provide useful information on the relative numbers of common murres and rhinoceros auklets that might migrate into locations within Puget Sound where gillnets for sockeye salmon could entangle or kill these birds. Resource managers are using these long-term data and additional information from targeted aerial surveys to decide how to regulate the areas and timing of gillnet fishing to minimize entanglement threats to marine birds.

Nearshore Vegetation Mapping

The Department of Natural Resources has distributed the Whatcom County nearshore vegetation inventory to planners, managers and scientists to assist analysis and management of nearshore habitat in the county. Some examples of how these data are being used include:

- The U.S. Fish and Wildlife Service used the eelgrass mapping data for the area around the Nooksack River and Portage Island in a review of a proposed road-building project.
- Planners for a multi-party project to cleanup sediments and restore habitat in Bellingham Bay are using vegetation (and shoreline characteristics) information from the nearshore survey.
- The Department of Natural Resources uses the vegetation information in conjunction with land ownership information and other data to review boundaries for harbor areas and for land use decisions in the Cherry Point region.

Kelp Bed Surveys

State and federal agencies are using the results of kelp resource studies conducted by the Department of Natural Resources in the Strait of Juan de Fuca to assess the potential damages from the Tenyo Maru oil spill in 1991 and to plan responses to future oil spills. Clallam and Jefferson counties are using the studies to map critical habitats as they plan for growth management. Results from these surveys have also been used in the past to locate sites for harvest of giant kelp for the herring roe-on-kelp fishery.

PHYSICAL ENVIRONMENT

SUMMARY

It appears that the character of Puget Sound's physical environment has been, and continues to be, degraded by human influences. This is especially true of the nearshore areas, which bear the brunt of our desire to live, work and play along our sheltered coastline. In this chapter, we present information that supports conclusions about changes in Puget Sound's physical environment. Biological aspects of habitat, specifically the patterns of and changes in vegetated habitats, are discussed in the chapter on biological resources (page 13).

A Changing Environment – The Role of Humans

Puget Sound's great diversity of environments sets it apart from other estuaries. Rocky shores, mud flats, deep waters of straits and basins, shallow inlets and estuaries, and subtidal areas of mud, sand and rock define the basin. The dramatic erosion of many Puget Sound bluffs in early 1997 and the explosive eruption of Mt. St. Helens in 1980 remind us that the physical environment in which we live is not static. Our Puget Sound environment changes naturally, but we also see evidence that human interventions may cause changes or accelerate and exaggerate changes that might occur naturally. A visible example from Puget Sound is the increased "hardening" of the shoreline caused by construction of seawalls and bulkheads.

Influences on Puget Sound's Environment

The diversity and character of the physical environment of Puget Sound are functions of:

- The relatively recent origin of Puget Sound and the characteristic land forms of recently glaciated areas, including steep U-shaped valleys and deposits of glacial rubble and till.

- A climate driven by weather systems originating over the North Pacific and altered and affected by the topography of the Olympic and Cascade mountain ranges.

- The freshwater runoff from the mountains and lowlands of the Puget Sound basin.

- The continuous supply of ocean waters that play a large part in determining the circulation and mixing of the Sound's waters.

- The direct actions of humans on terrestrial, shoreline and deep-water areas to physically alter the environment or cause indirect changes by degrading water quality.

Human developments over the past century have brought changes to the physical environment of Puget Sound. These changes are echoed through the ecosystem causing or influencing shifts and changes in the types of communities and species of marine organisms that can live and thrive here. Following are some examples of how human activities can affect habitat characteristics.

- Modern human development has extensively altered the shoreline of Puget Sound. (See the 1992 *Puget Sound Update* and the 1988 State of the Sound report for descriptions of the extent of estuarine habitat lost to harbor development.) This has affected the quantity and distribution of nearshore vegetation, with repercussions on biological resources that rely on various vegetated habitats for food and shelter.

- Human activities alter the timing and amount of freshwater that enters Puget Sound in many ways, including constructing and operating dams and destroying or disrupting wetlands. They also affect sediment loads in streams and rivers through, for example, improper land management. Fresh water is an important driver of circulation in Puget Sound. It also delineates habitat for estuarine organisms. Sediment loads carried by streams and from eroding bluffs affect how much light is able to penetrate the water, carry nutrients and contaminants, and build or modify nearshore or benthic habitat.

Changes in the quality of habitat can have far-reaching effects on the ecosystem. Managing Puget Sound and its resources requires an understanding of the Sound's physical environment, the effects of human activities on the environment, and the transmission of these effects through the Puget Sound ecosystem.

Some scientists' investigations have related the distribution and extent of nearshore vegetation to changes in the physical environment (for example, eelgrass beds might be altered by construction of shoreline or in-water structures). However, these and other effects of changes in the physical environment are difficult to quantify and additional investigations are necessary.

FINDINGS

This section presents recent results of a few studies from the Puget Sound Ambient Monitoring Program (PSAMP), including the Department of Natural Resources' (Natural Resources) evaluation of shoreline modifications and characteristics and the Department of Ecology's (Ecology) monitoring of marine and fresh water.

Shoreline Modification

Shoreline modifications, such as construction of bulkheads and filling and dredging, can lead to direct habitat loss by destroying upper intertidal habitat used by fish. Indirectly, they can change sediments and wave energy on a beach and in adjacent subtidal areas. For these reasons, shoreline modification is recognized as a significant stress on intertidal and nearshore habitats and on the organisms that rely on these habitats.

Table 4. Modification of Shoreline in Puget Sound.

Basin	Modified in Intertidal Zone		Modified Above Normal Tide Range		Natural (Not Modified)	
	Miles	Percent of Region's Total	Miles	Percent of Region's Total	Miles	Percent of Region's Total
Central Puget Sound	227	45%	36	7%	241	48%
Hood Canal	57	24%	21	9%	163	68%
Whidbey	71	24%	36	12%	192	64%
San Juan Islands & Straits	85	11%	78	10%	646	80%
South Puget Sound	142	31%	14	3%	298	66%
Overall	**582**	**25%**	**185**	**8%**	**1,541**	**67%**

Source: Department of Natural Resources, unpublished data and analysis

Using a 1995 survey of 325 randomly selected sites along Puget Sound's shoreline, scientists with Natural Resources estimated that humans have modified one-third of Puget Sound's shoreline, approximately 800 miles (H. Berry, pers. comm., 1997). Details of this estimate are shown in Table 4. Twenty-five percent of the Sound's shoreline has been modified in the intertidal zone—areas that are regularly covered and uncovered by tides. People have modified another eight percent of the shoreline above the normal extent of tides. Modifications above the normal tidal range characteristically affect the shoreline character and processes less severely than modifications in the intertidal zone, though they can adversely affect the supply of sediment needed to maintain beach habitat.

The distribution of modified shorelines around the Puget Sound basin reflects historical development patterns and natural environmental effects. The central Puget Sound region, with the basin's highest historical and current population levels, showed the highest level of modification overall (52 percent) and the highest percentage of shoreline with intertidal modification (45 percent). Human activities have modified approximately one third of the shorelines in the Whidbey Island, Hood Canal, and south Puget Sound regions. The most striking difference among these regions is that south Puget Sound had much more intertidal alteration, reflecting the relative ease of development of its low bank environments and a long history of shellfish farming and settlement along the water.

The San Juan Islands, the Strait of Juan de Fuca to Port Angeles, and regions north of Guemes Channel have the highest proportion of natural (unmodified) shoreline, almost 80 percent. Within this area, most modifications are likely to be along the strait and the northern mainland, with the islands comprising the smallest percentage. This northern part of the Sound has more bedrock shorelines, which are less likely to erode (a primary reason that landowners modify their shorelines by constructing bulkheads).

Shoreline modification can have significant, long-term effects on Puget Sound's habitat (Thom and Shreffler, 1994). The effects of a specific

Human Activities that Change Puget Sound's Physical Environment

Properly managing human activities is important in ensuring that Puget Sound's physical character continues to provide the foundation for a productive, biologically diverse and aesthetically pleasing Puget Sound. The following activities alter the physical environment of Puget Sound:

Shoreline development and uses

- Use and repair of existing structures (homes, piers, marinas)
- Construction of new structures
- Operations of shoreline or on-water facilities (power plants, refineries)
- Habitat restoration
- Log booming and storage
- Shoreline recreation

Spills and discharges

- Wastewater
- Stormwater
- Toxic materials
- Oil
- Bilge or ballast water
- Septic system effluent

Watershed activities

- Upland construction
- Agriculture practices
- Forest practices
- Impoundment and channeling of streams and rivers
- Removal and diversion of fresh waters

Biological resource harvest and culture

- Harvest of finfish, invertebrates, plants, birds, mammals
- Aquaculture operations
- Introduction and control of exotic species
- Planting vegetation
- Managing marine mammals

Miscellaneous activities in the marine environment

- Boating
- Dredging and disposing of dredged materials

An Example of Shoreline Modification in the Georgia Basin

A report for Canada's Department of Fisheries and Oceans (Frith, in prep.) compares shoreline characteristics (and vegetation) from the 1950s and the 1990s in two estuaries in the Georgia Basin. Interpretation of aerial photographs of the Goldstream estuary "showed little change since the 1950s due to the lack of any development in this estuary." Conversely, the Squamish estuary has "undergone substantial change over the same time period due mainly to industrial development." The report estimates that186 acres of sand and mud flats and 131 acres of intertidal marsh were lost to development from 1957 to 1994. This represents a 47 percent decrease in the intertidal area of the Squamish estuary since 1957.

modification depend on the type of change, the marine life that uses the shoreline habitat, and environmental factors such as sediment supply and wave energy. The modification of one-third of all Puget Sound shorelines probably has profoundly affected the basin's habitat and biological resources. Limiting shoreline modification is one way to preserve the health of nearshore habitat. Where modification is necessary, methods that minimize impacts should be used.

Shoreline Characteristics

As part of its Nearshore Habitat Program, the Department of Natural Resources surveyed shoreline characteristics in intertidal areas according to a system described in *A Marine and Estuarine Habitat Classification System for Washington State* (Dethier, 1990). In 1995, Natural Resources conducted aerial and ground surveys along much of the Whatcom County shoreline. An example of the substrate-type information developed through these surveys is shown in Figure 13 (in the color section at the end of this report). These surveys also evaluated exposure of the nearshore area to waves and wind. This type of map (and geographically referenced data) is available from Natural Resources for the Whatcom County shoreline as far north as Point Whitehorn. Data collected in 1996 for Skagit County and northern Island County shorelines will be available soon.

The Habitat Characteristics of Puget Sound's Marine Waters

The Department of Ecology characterizes the habitat quality of Puget Sound's marine waters by evaluating stratification of the water column (the layering of water based on salinity and temperature differences) and measuring dissolved oxygen, turbidity, and the availability of sunlight below the water surface. Areas of the water column with persistent or seasonal density stratification are more susceptible to water quality problems than well-mixed areas, where nutrients, contaminants and oxygen are more readily dispersed and distributed.

Areas of Puget Sound that Ecology sampled and found to be sensitive to degradation of marine water habitat are shown in Figure 14. This figure depicts the strength (or intensity) of stratification of the water column. A highly stratified water column is susceptible to oxygen depletion because oxygen-rich surface waters are not mixed with deeper waters. In addition, decaying organic matter settling to the bottom of the water column can deplete dissolved oxygen in the near-bottom waters. Stratification intensity was most persistent in semi-enclosed areas most directly influenced by freshwater inflows, including Bellingham Bay (Nooksack River), Skagit Bay and Saratoga Passage (Skagit River), Port Susan (Stillaguamish River), Possession Sound and Port Gardner (Snohomish River), Elliott Bay (Duwamish River), Commencement Bay (Puyallup River), Budd Inlet (Deschutes River), and Hood Canal (Skokomish, Duckabush, and Dosewallips rivers). One area of persistent stratification not associated with a major river discharge was Sinclair Inlet; it is fed by several minor streams.

Ecology measures dissolved oxygen near the bottom of the water column to identify areas with potential water quality problems. If the dissolved oxygen in a body of water is depleted (by the respiration of organisms and the decay of organic matter), marine organisms will avoid the area, suffer

stress or die. Biological stress typically occurs when dissolved oxygen concentrations approach 5 mg/l. Dissolved oxygen concentrations of 2 mg/l can be fatal to some organisms. The mixing of waters in much of Puget Sound sufficiently oxygenates the water and there is no oxygen-related stress on marine organisms in those areas. Puget Sound is somewhat unique compared to other estuaries. Its source waters come from the Pacific Ocean entering through the Strait of Juan de Fuca. During late summer, much of the entering water has upwelled from deeper coastal sources and has a naturally low dissolved oxygen content. As a consequence, Puget Sound waters naturally can have relatively low concentrations of dissolved oxygen (5.5 to 6.0 mg/l). This means that any reduction in the dissolved oxygen concentration due to human impacts could be significant.

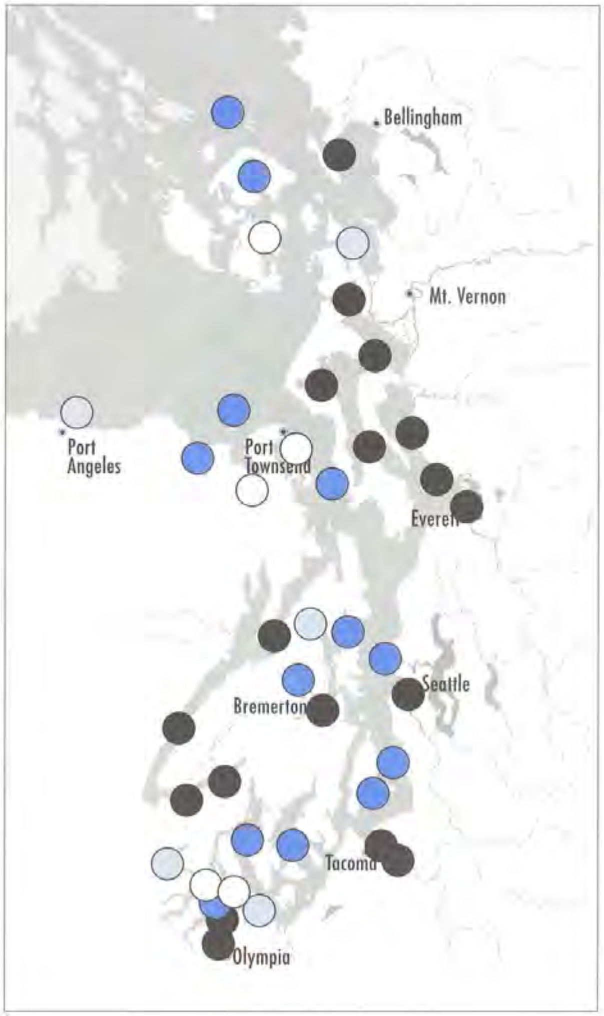


Figure 14. Intensity of Water Column Stratification in Puget Sound.

Persistent

Seasonal

Episodic

Weak

Stratified waters are sensitive to water quality degradation. This assessment is based on data collected by Ecology's Marine Waters Monitoring Program from wateryear 1990–1995. Stratification may occur in other areas of Puget Sound; not all areas of Puget Sound are monitored and stations may not reflect worst-case conditions in bays and at the heads of inlets.

Figure 15 shows areas around Puget Sound sampled by Ecology where a deficiency of oxygen was limiting the quality of habitat in marine water. Areas of greatest concern included Budd Inlet, southern Hood Canal, Penn Cove and East Sound. Areas of lesser concern were distributed throughout greater Puget Sound, with a cluster of sensitive stations in Saratoga Passage, Skagit Bay and Port Susan. Ecology's sampling locations were selected to provide many other types of information in addition to dissolved oxygen. A sampling design that better focuses on susceptible areas, such the heads of bays and inlets, could reveal oxygen stress in additional areas of the Sound.

Many of the areas of known low dissolved oxygen showed persistent stratification—the layering of water based on temperature and salinity—and are associated with freshwater inputs. Some such as East Sound and the Strait of Georgia, showed only seasonal stratification. These two locations, which are closer to the Strait of Juan de Fuca and incoming Pacific Ocean waters than other sites, may reflect a combination of the

Characteristics of Deeper Subtidal Areas

The Department of Natural Resources is investigating the physical character of Puget Sound's shoreline. Similar characterization might also be done for the entire bottom of Puget Sound. Scientists and resource managers working on Puget Sound issues recognize the importance of the habitat represented by subtidal sediments. It may be important to characterize and inventory the types of subtidal sediment habitats present in Puget Sound. Some information is collected through ongoing sampling of sediments and associated organisms or by larger-scale (typically remote-sensing) approaches to characterizing the bathymetry and bottom materials of the Sound.

Figure 15. Areas of Known Low Dissolved Oxygen in Puget Sound Waters.

Very low dissolved oxygen (<2 mg/l — hypoxia)

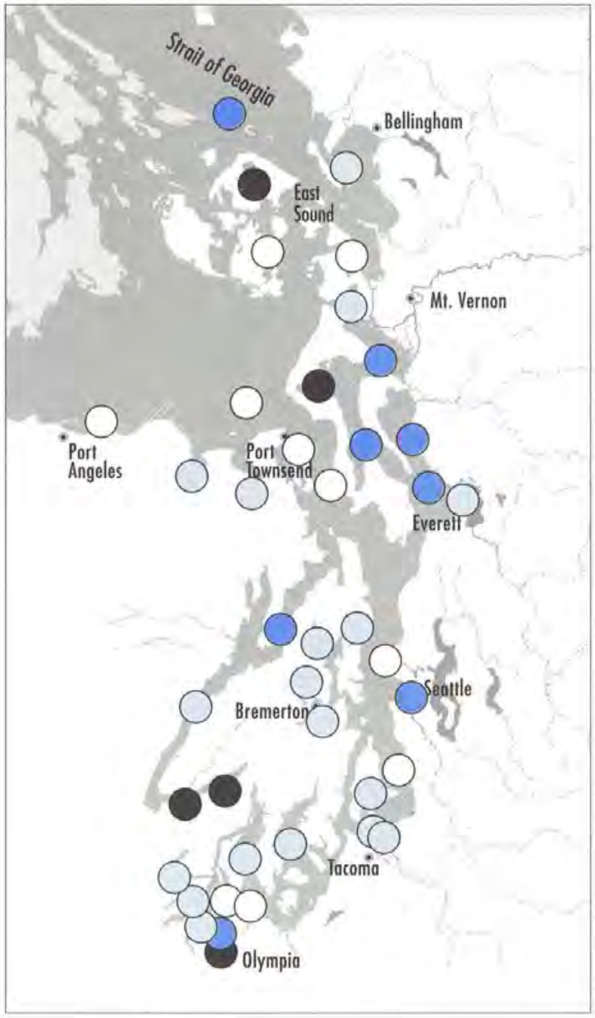
Low dissolved oxygen (<5 mg/l — biological stress)

Susceptible* to low dissolved oxygen

No measurements of low dissolved oxygen and not susceptible

*Susceptibility to low dissolved oxygen was evaluated by the presence of persistent or seasonal stratification and three or more months of non-detectable inorganic nitrogen.

Assessment based on wateryear 1990–1995 data from Ecology's Marine Waters Monitoring Program. Low dissolved oxygen may occur in other areas of Puget Sound; not all areas of Puget Sound are monitored and stations may not reflect worst-case conditions in bays and at the heads of inlets.



relatively low oxygen content of upwelled ocean waters and local influences (such as stratification from the Fraser River plume in the Strait of Georgia).

Bellingham Bay, Port Gardner, Commencement Bay and Sinclair Inlet were persistently stratified, but did not show low levels of dissolved oxygen based on the one monitoring station in each area. Other, less well-mixed locales within these areas may be experiencing low levels of oxygen. Alternatively, basin geometry and other characteristics of these areas may maintain circulation and oxygenation of the deeper waters. More study may be needed in these areas.

Monitoring of marine water by King County confirms Ecology's assessment that the main stem of central Puget Sound was not persistently stratified and did not appear susceptible to habitat degradation through depletion of dissolved oxygen. King County's recent data for two main stem sampling locations indicated only weak stratification in the summer months and adequate concentrations of dissolved oxygen (above 5.0 mg/l) at all sampling depths.

The chapter on pathogens and nutrients (page 61) provides additional information and analysis on the effects of nutrient pollution on marine water quality in Puget Sound.

Freshwater and Physical Character

Flows. Freshwater flows from October 1995 through September 1996 were exceptionally high throughout western Washington. Figure 16 shows the average annual flows of some of the major rivers in Puget Sound. Flows in wateryear 1996 were the highest recorded in the past 10 years. The dashed line in each plot represents that station's average flow for the entire period of record.

Flow can be important for human domestic, industrial and agricultural uses. Maintaining the instream flow is important to support and protect fish. In addition, water flow carries a wide variety of suspended and dissolved substances, of both natural and man-made origin, and flow in freshwater streams and rivers can dramatically affect the loading of these materials to Puget Sound. Knowing the relationship between flow and the concentration of various substances is critical if one is to detect changes in water quality early (e.g., while corrections or cleanups are still feasible).

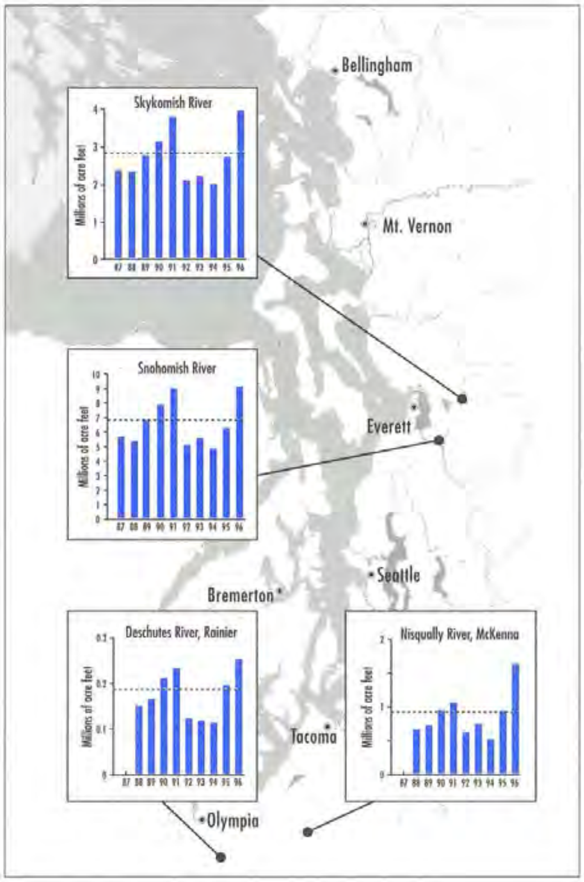


Figure 16. Recent Flow in Some Major Rivers Compared to Long-Term Average Annual Flows (shown as dashed lines).

Snohomish Basin Rivers. High water temperatures and low dissolved oxygen concentrations were measured in 1995 and 1996 in the Snohomish, Snoqualmie, Pilchuck and Skykomish rivers. Temperature data did not show any trend over ten years. Dissolved oxygen concentrations (and percent saturation) showed a decreasing trend at all Snohomish basin stations except for the station at Monroe (which has been monitored only since 1992).

Concentrations of suspended solids and total phosphorus, which are commonly associated with siltation increased over the past ten years in both the Snoqualmie and Skykomish rivers, but not in the Snohomish River.

South Puget Sound Rivers. Monitoring data for the Nisqually and Puyallup rivers for the past ten years showed a trend of slightly decreasing dissolved oxygen concentrations (and oxygen saturation) and no trend in temperatures. As in the Snohomish River basin, suspended solids increased over the past ten years in the Puyallup and Nisqually rivers.

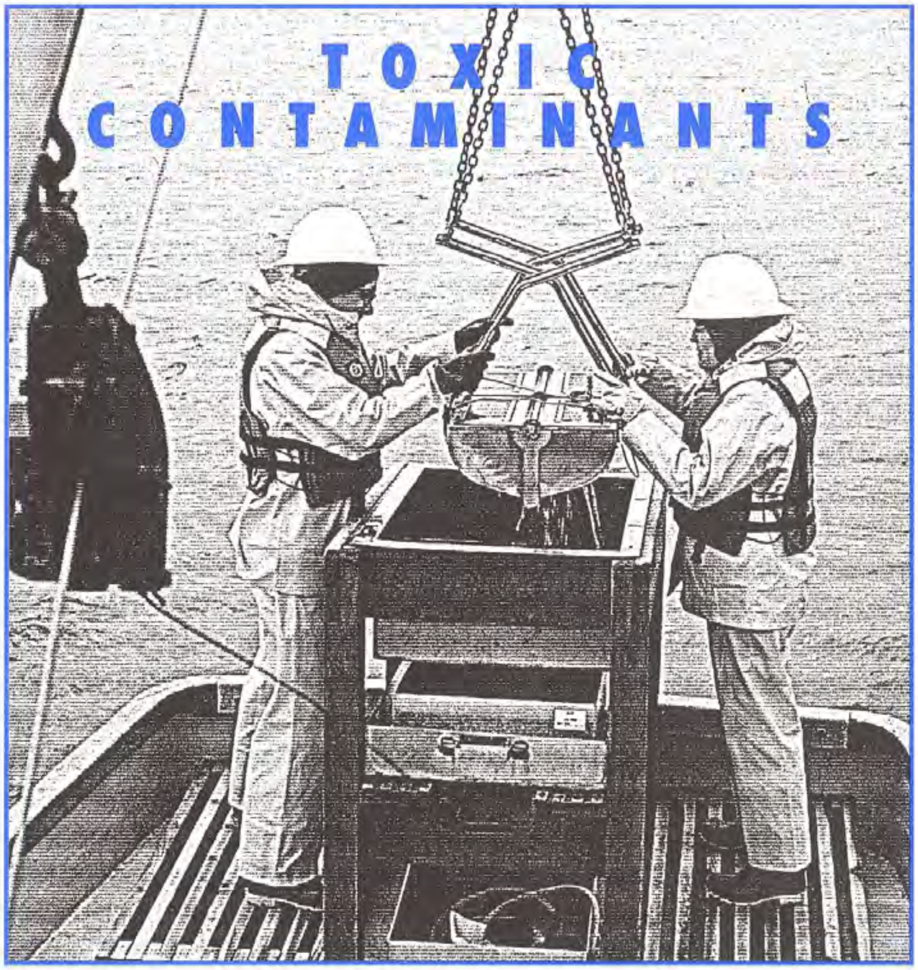
Ecology's Basin Monitoring Cycle

In order to equitably distribute its limited resources to monitor the quality of fresh water throughout the state, the Department of Ecology evaluates various basins around the state on a five-year cycle. In implementing this cycle, Ecology has focused recent monitoring on the Island-Snohomish and south Puget Sound areas. The major rivers that drain these sub-basins include the Snohomish, Snoqualmie, Skykomish and Pilchuck rivers and the Puyallup and Nisqually rivers in the south Sound area. The results presented in this section (and in other chapters) focus on these rivers and the Deschutes River, which flows to Budd Inlet at Olympia.

USING MONITORING DATA TO SUPPORT MANAGEMENT DECISIONS

In 1996, King County began efforts to evaluate the mixing and circulation of water in the Duwamish estuary and Elliott Bay as part of a risk assessment that will support management decisions concerning the control of combined sewer overflows. Understanding the physical character of the waters in the Duwamish River and Elliott Bay will help scientists better estimate the effects of toxic contaminants introduced to the estuarine system when stormwater overloads municipal treatment plants causing untreated wastewater to flow into Puget Sound.

In another example, scientists from the Department of Fish and Wildlife evaluated threats to Pacific cod from thermal pollution originating from an oil refinery at Cherry Point in Whatcom County. The scientists relied on the Department of Ecology's data and expertise in this evaluation.



SUMMARY

Results from the Puget Sound Ambient Monitoring Program (PSAMP) and other studies indicate that toxic contaminants are present throughout Puget Sound, though their distribution is determined by proximity to pollution sources. Measurable effects of toxic contaminants seem to be restricted to fairly small, but highly contaminated areas of the Sound. Information from some studies indicates that concentrations of some toxic contaminants in the Sound may be decreasing slightly over time.

Similar to problems related to the physical environment and water quality, sediment degradation is a human-caused stress on the Puget Sound system. Toxic contaminants in Puget Sound can threaten the health of fish, shellfish, birds and biological resources. Toxic contaminants can also threaten human health, as is discussed in the chapter on human health (page 77).

Scientists and resource managers with the PSAMP and other programs study the distribution of toxic contaminants and how they might be affecting biological resources and human health in Puget Sound. This chapter presents results from some of these studies.

Toxics in Puget Sound—The Role of Humans

Toxic contaminants in Puget Sound originate predominantly from human activities, although some toxic substances—especially metals and some organic compounds—occur naturally in the environment. Humans have released excessive amounts of some naturally occurring toxic contaminants into the environment through activities such as mining and mineral processing (metals) and combustion and spills of fossil fuels (complex organic compounds called PAHs or polycyclic aromatic hydrocarbons). Modern industrial processes have created other toxic contaminants, such as chlorinated organic compounds and pesticides. These substances enter Puget Sound through discharges of industrial and municipal wastewater, stormwater runoff, spills, bilgewater and bottom paint from vessels, on-site sewage systems, and the use and misuse of toxic substances along the developed shoreline of Puget Sound. Some toxic contaminants are released purposely—during the application of pesticides or the discharge of wastewater, for example. Many toxic substances enter Puget Sound indirectly—from water that runs off roofs, parking areas and roads, for example. The accidental release of toxic contaminants in Puget Sound usually occurs when oil or toxic chemicals are spilled.

FINDINGS

As part of the PSAMP's studies of toxic contaminants and their effects, the Department of Ecology (Ecology) investigates Puget Sound's marine sediments, the Department of Fish and Wildlife (Fish and Wildlife) evaluates fish and harbor seals, the U.S. Fish and Wildlife Service investigates birds, and the King County Department of Natural Resources studies contaminants in water and sediment. This section presents the results of these studies and results of studies conducted by National Oceanic and Atmospheric Administration (NOAA) and Ecology on contaminants in mussel tissue.

Marine Sediments

The marine sediments of Puget Sound are repositories for many toxic pollutants, including heavy metals and organic compounds. It is here that the transfer of contaminants up the food chain often begins, to the detriment of benthic communities and other biological resources. Ecology's sediment management program has identified 49 contaminated sediment sites in Puget Sound (Ecology, 1996). These sites are almost entirely in urban areas—near Bellingham, Everett, Seattle, Tacoma, Bremerton and Olympia. As of 1996, cleanup was under way at 30 of these 49 sites. These sites and the additional area of Puget Sound found to have concentrations of sediment contaminants above the state's cleanup screening levels cover nearly 3,200 acres (Figure 17). This represents 0.3 percent of the total submerged surface area of Puget Sound.

From 1989—when Ecology initiated its marine sediment monitoring as a component of the PSAMP—through 1995, the agency sampled 76 ambient monitoring stations throughout Puget Sound. (Thirty-four stations were sampled each year and 42 stations were sampled once every three years—14 each year on a rotating basis). Ecology intentionally located the sampling

Two Contaminants of Special Concern

Mercury. Mercury occurs naturally throughout the marine environment, at least in low levels. Methylmercury, which typically forms when elemental mercury enters the food chain, is the most toxic form of mercury. It concentrates in muscle, brain and other tissues, from where it is released slowly. Analyzing methylmercury is prohibitively expensive and, as a result, most monitoring efforts measure total mercury.

PCBs. Polychlorinated biphenyls (PCBs) are synthetic organic compounds shown to be highly toxic in aquatic environments. PCBs preferentially associate with lipids or fats in biological tissues. The PSAMP measures mixtures of PCBs identified by their tradenames, Aroclors.

In addition to accumulating in tissues, methylmercury and PCB also progressively increase up the food chain, or biomagnify, as contaminated organisms low in the food chain are consumed by organisms higher in the food chain.

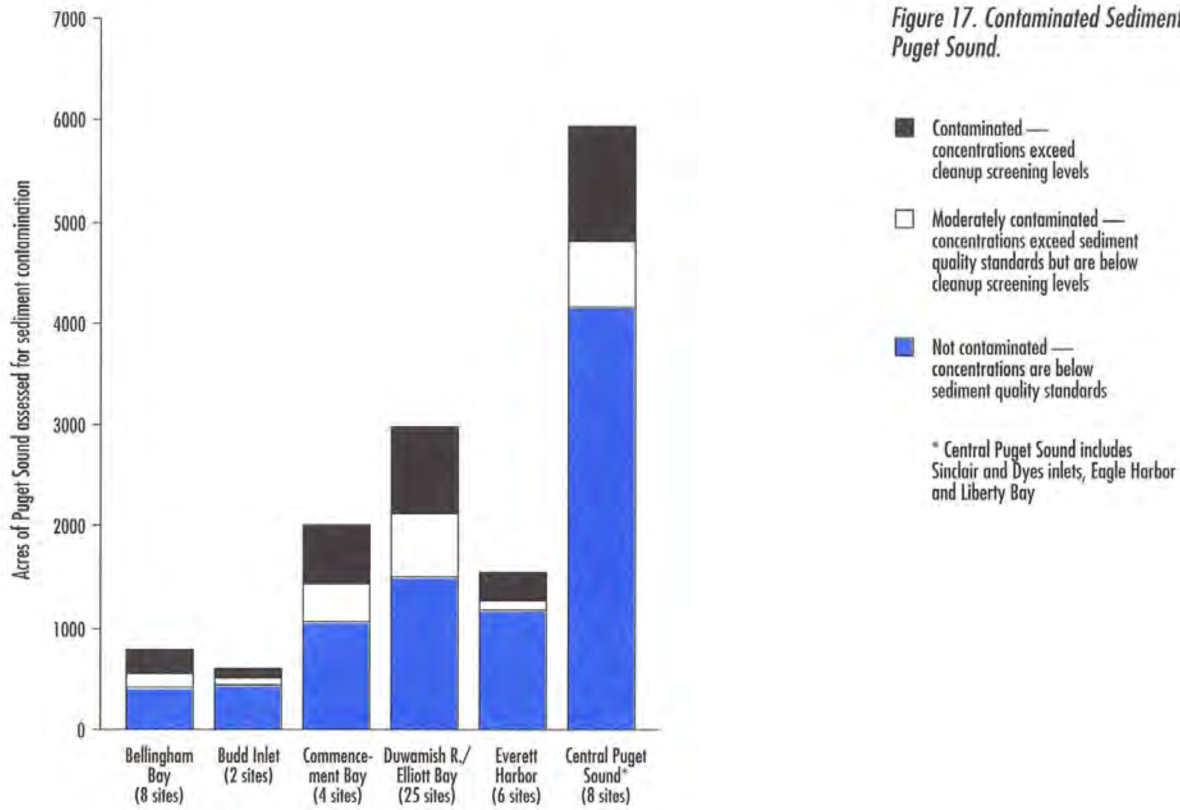


Figure 17. Contaminated Sediment Sites in Puget Sound.

stations away from the most highly polluted areas of the Sound (generally outside of the contaminated sediment sites). The following information is based on Ecology's ambient monitoring network for marine sediments.

Chemical analysis of sediments from Ecology's ambient monitoring locations indicated a relatively low degree and extent of sediment contamination in Puget Sound. The agency did not detect contaminants in 70 percent of the PSAMP sediment analyses. Contaminants were detected primarily in urban or industrial areas. Ambient monitoring locations with relatively high concentrations of mercury, lead, PAHs or PCBs included Port Angeles Harbor, Eagle Harbor (Bainbridge Island), Elliott Bay (Seattle), Sinclair and Dyes inlets (Bremerton), East Passage near Point Pully (south King County), Commencement Bay's Thea Foss (or City) Waterway (Tacoma), and Budd Inlet (Olympia). Figures 18 through 21 show the highest concentrations of mercury, PAHs and PCBs observed in Ecology's samples. These figures show data points only for stations that have relatively high concentrations of these contaminants. Data for many other PSAMP stations are available, but all measured concentrations at these stations lie within the shaded regions of Figures 18 to 21. No statistically significant trends were observed in these data, except for increasing concentrations of PCBs in Dyes Inlet from 1989 to 1995.

A number of the sediment samples collected by Ecology exceeded the state's sediment quality standards for mercury (Figure 18). Very few samples exceeded the sediment quality standards or Apparent Effects Thresholds for other contaminants.

Measuring Sediment Quality

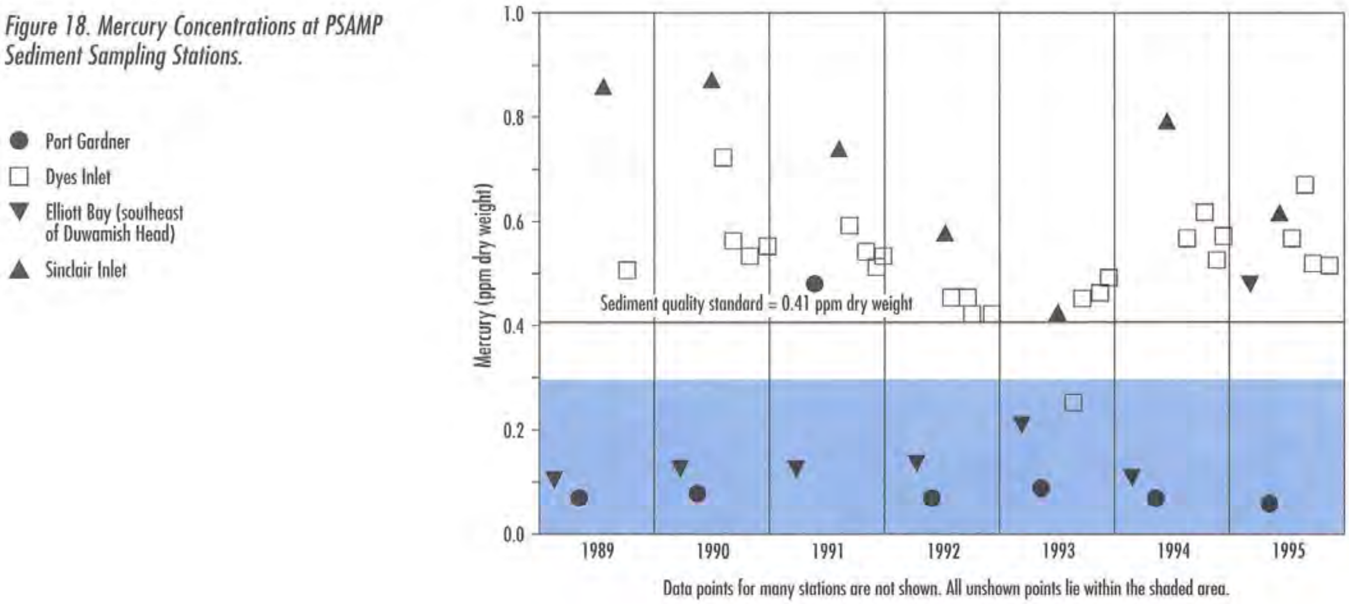
The Department of Ecology has developed Sediment Management Standards that include two tiers of criteria against which sediment quality data are evaluated:

Sediment quality standards – sediment contaminant concentrations above which adverse biological effects are expected.

Cleanup screening levels – sediment contaminant concentrations higher than sediment quality standards above which active cleanup is required.

Washington state's sediment management standards and the Apparent Effects Thresholds, upon which the standards are based, identify concentrations at and above which scientists expect adverse biological effects from toxic contaminants. Levels above these concentrations are referred to as "exceeding" the standard or threshold.

Figure 18. Mercury Concentrations at PSAMP Sediment Sampling Stations.



From 1994 to 1996, the King County Department of Natural Resources analyzed toxic contaminants in sediments at 15 subtidal and 40 intertidal locations. As with Ecology's monitoring, King County did not detect contaminants except for some naturally occurring metals in most subtidal sediment samples. Of all subtidal sediment analyses conducted from 1994 to 1996 by King County, only mercury at a station located along the Seattle waterfront (in Elliott Bay) exceeded the state sediment quality standards. PAHs were commonly detected in King County's analyses of subtidal sediments. The specific PAH compounds present in some samples from inner Elliott Bay were characteristic of creosote, commonly used as a wood preservative on pilings. Pesticides and, generally, PCBs were not detected in King County's evaluation of subtidal sediments.

Intertidal (or nearshore) sediments at King County's monitoring locations—including stations at Richmond Beach, West Point and just south of Alki Point—generally had low or non-detectable concentrations of toxic contaminants. PCBs and pesticides typically were not detected. PAHs frequently appeared at low levels (just above detection limits). Metals were routinely detected but never at concentrations above the state sediment quality standards.

Fish

English Sole. A number of researchers in Puget Sound, especially scientists from the National Marine Fisheries Service, have documented the links between exposure to toxic contaminants and the resulting effects on the health of bottom-dwelling fish like English sole. Building on the results of these studies, Department of Fish and Wildlife scientists designed and implemented PSAMP monitoring studies to identify geographic patterns in exposure of fish to contamination (as measured by tissue contaminant levels) and effects of contaminants on fish health (as measured by prevalence of liver tumors, or lesions).

Between 1989 and 1996, Fish and Wildlife sampled English sole from 43 locations throughout Puget Sound. Liver lesions were sometimes

Fish Tissue Contamination and Fish Health in the Fraser River Estuary

In 1994, part of the Fraser River Estuary Management Program (FREMP), Canadian scientists studied resident fish in the Fraser River estuary. As summarized in the program's 1996 Environmental Quality Report, this study showed few spatial differences in contamination throughout the estuary. Scientists did show higher PAH concentrations in the north and main arms of the river, which are downstream, than in the main stem, which is upstream.

When compared to historic data, the 1994 results led scientists to conclude that concentrations of chlorinated pesticides remained fairly constant over the past 10 years, PCB concentrations dropped slightly and concentrations of metals (arsenic, mercury and lead) decreased measurably.

Both contaminant analyses and enzymatic assays suggested that organic contaminants did not adversely affect resident fish in the lower Fraser River. Similar to English sole from Puget Sound, examination of tissue from Fraser River fish revealed a number of apparent tissue and organ abnormalities. Additional studies of these observed abnormalities are under way.

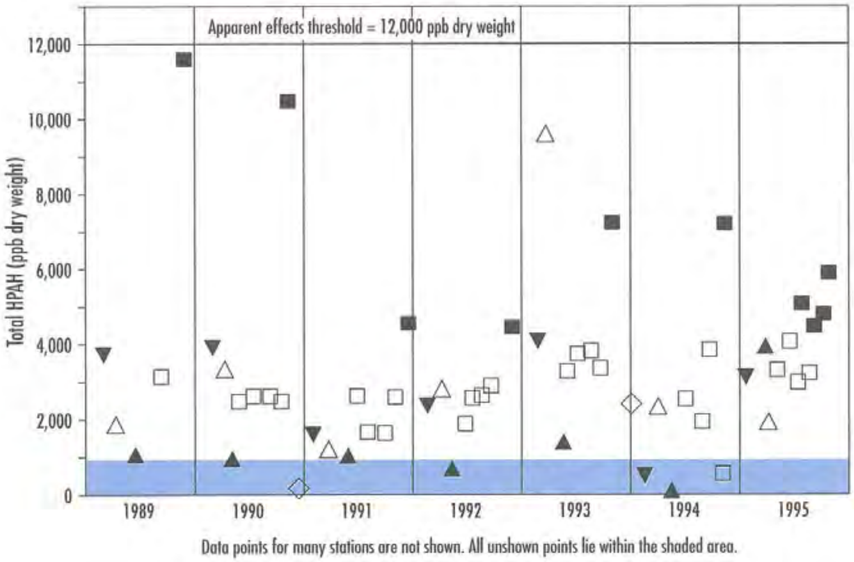


Figure 19. High Molecular Weight PAH (HPAH) Concentrations at PSAMP Sediment Sampling Stations.

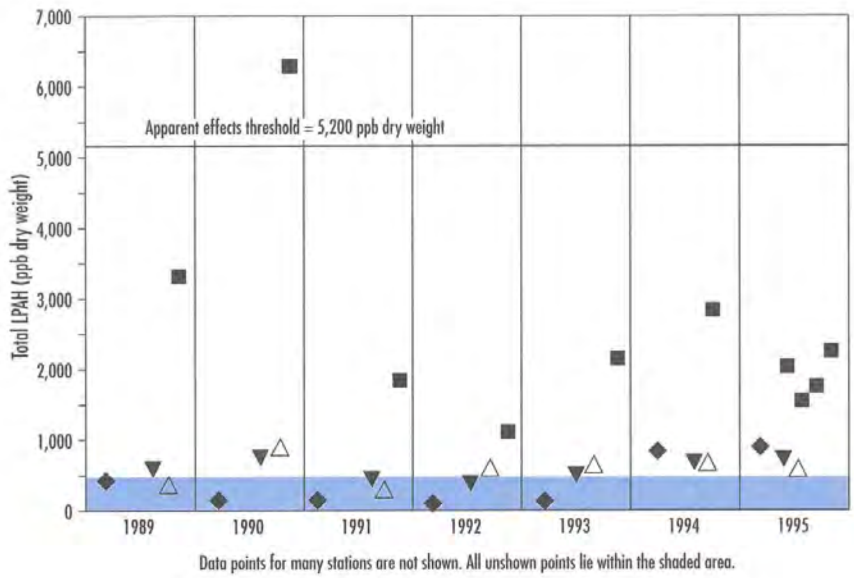


Figure 20. Low Molecular Weight PAH (LPAH) Concentrations at PSAMP Sediment Sampling Stations.

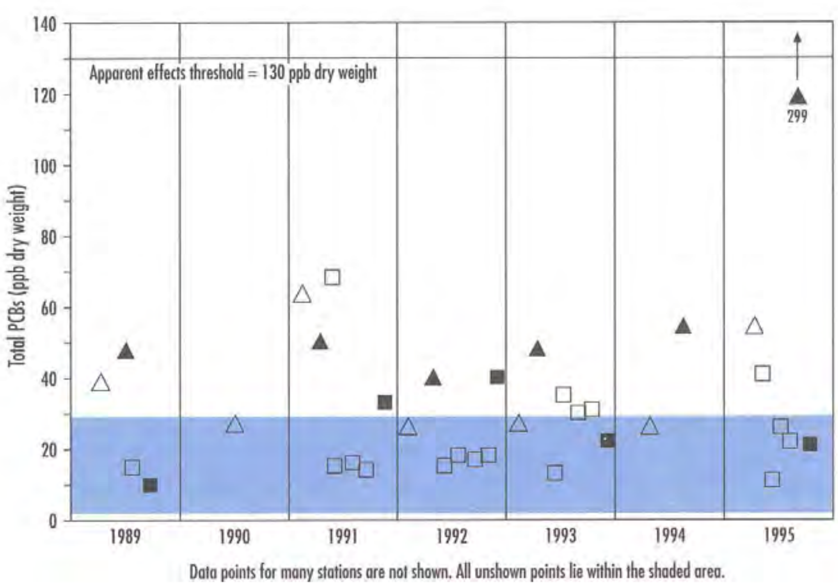
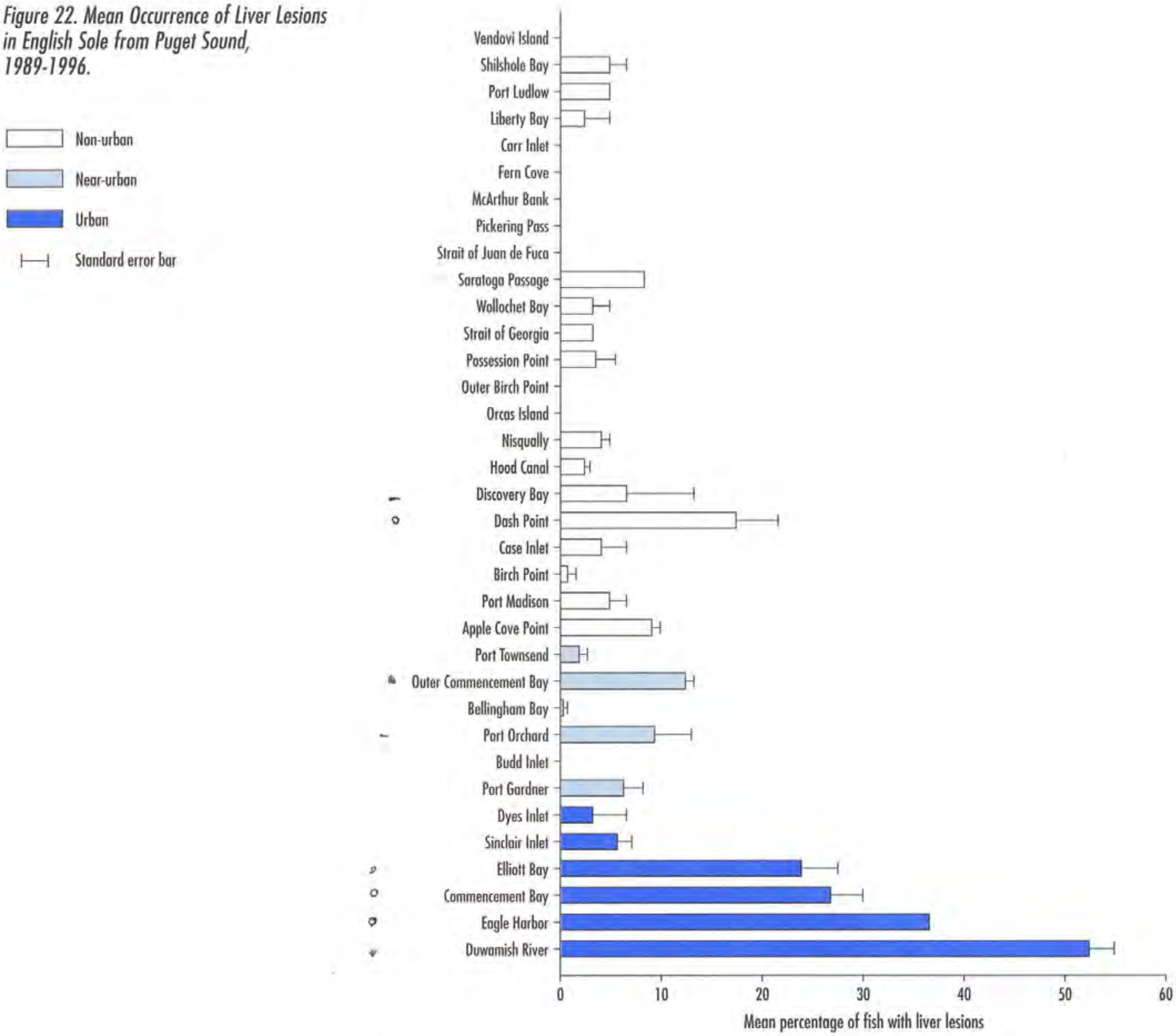


Figure 21. Total PCB Concentrations at PSAMP Sediment Sampling Stations.

Figure 22. Mean Occurrence of Liver Lesions in English Sole from Puget Sound, 1989-1996.



observed in fish from relatively uncontaminated reference areas. However, significantly higher occurrences of liver lesions were observed in English sole from four urban locations within Puget Sound: the Duwamish River, Eagle Harbor, Elliott Bay and Commencement Bay (Figure 22).

Although fish age accounts for some differences in the frequency of liver lesions (see discussion on page 44), the chance of English sole from these four urban locations developing liver lesions was significantly greater than could be accounted for by fish age. When compared with English sole from non-urban areas, the likelihood of fish developing liver lesions in the Duwamish River was 32 times higher, in Eagle Harbor 11 times higher, and in Elliott and Commencement bays about six times higher.

Although fewer liver lesions were detected in English sole from near-urban locations like outer Commencement Bay, Port Gardner and Port Orchard and from two non-urban locations—Dash Point and Case Inlet, the occurence was still significantly higher than most non-urban locations. The

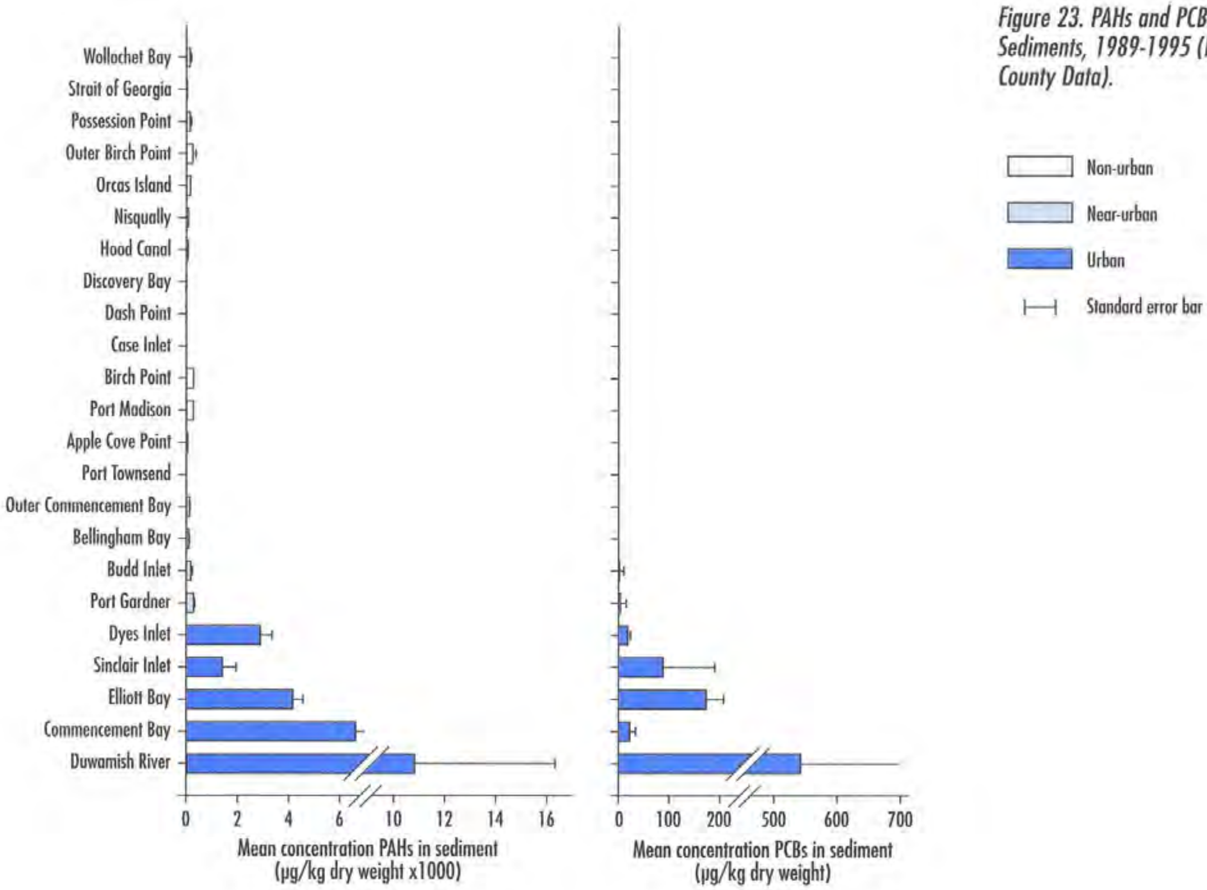


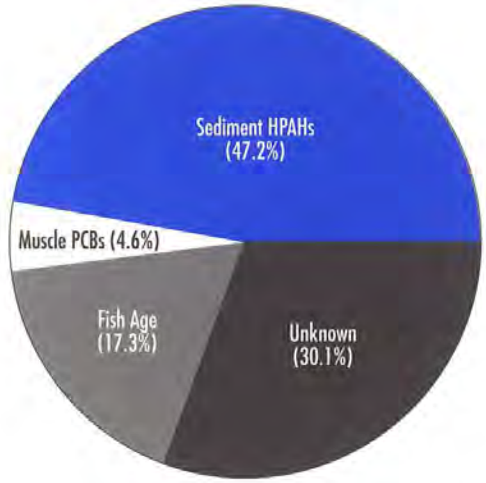
Figure 23. PAHs and PCBs in Puget Sound Sediments, 1989-1995 (PSAMP and King County Data).

chance of English sole developing liver lesions at these locations was two to four times greater than fish in non-urban areas, even after accounting for differences in fish ages among sampling locations.

By reviewing the concentrations of PAHs and PCBs in sediments in the vicinity of locations where English sole were sampled (Figure 23), scientists with Fish and Wildlife found that the prevalence of liver lesions in the fish appeared to reflect the degree of sediment contamination. No sediment data for Eagle Harbor are shown in Figure 23 because Fish and Wildlife's and Ecology's sampling stations were located in different areas of Eagle Harbor. A collaborative study by the Department of Fish and Wildlife and the National Marine Fisheries Service quantitatively documented the link between exposure to contaminants and the development of liver lesions. This study positively correlated liver lesions in English sole with exposure to high molecular weight PAHs (HPAHs) and PCBs, and with fish age (Figure 24). Other factors, including exposure to low molecular weight PAHs, were not significantly correlated with observances of liver lesions. This means that fish from locations contaminated with PCBs and PAHs had a greater risk of developing lesions, and older fish from all locations had a greater risk of developing liver lesions than younger fish.

Although PCBs were a significant risk factor associated with developing liver lesions, a more detailed analysis indicated that fish exposed to high concentrations of PCBs without exposure to high concentrations of PAHs did not develop liver lesions at a rate greater than the fish in less

Figure 24. Attributing the Occurrence of Liver Lesions in Puget Sound English sole.



Percentages indicate the variability in the observed occurrence of liver lesions that can be attributed to each factor.

contaminated reference areas. For example, PCB contamination in the sediments of Sinclair and Dyes inlets was similar to that in other urban bays in Puget Sound, but these inlets had lower concentrations of PAHs than other urban areas (Figure 23). English sole from Sinclair and Dyes inlets did not show an increased risk of developing liver lesions, whereas fish from the other urban locations were more likely to develop lesions.

Neither contamination by PAHs or PCBs nor fish age could account for the elevated occurrences of liver lesions in fish from Case Inlet and Dash Point. The sediment chemistry from these locations did not suggest high levels of contamination; however the tissue chemistry data indicated that the fish had been exposed to PCBs. This disparity suggests that sediment contamination in Case Inlet and Dash Point was not adequately assessed, or that fish collected at these locations had a home range that included more highly contaminated locations.

The sediment-to-fish link is further illustrated by the relationship between PCB levels in tissues and sediments. The levels of PCBs in muscle tissue from English sole that the Department of Fish and Wildlife sampled from Puget Sound showed an association with PCBs in sediments, especially from those locations with the greatest sediment PCB levels (Figure 25). Highest PCB concentrations were observed in both fish tissues and sediments from four urban locations: the Duwamish River, Elliott Bay, Sinclair Inlet and Commencement Bay. Moderate to low concentrations of PCBs were observed in the muscle tissue of English sole from the remaining 32 stations, including a mix of urban, near-urban and non-urban locations. PCB concentrations were low to moderate in sediments of the near-urban stations, but were never detected in sediments at non-urban locations.

Although Fish and Wildlife's monitoring program does not optimally identify trends in contaminants or contaminant effects in fish, the agency has attempted to evaluate changes in PCB concentrations in tissue and the occurrence of liver lesions in English sole over time. Figure 26 shows mean PCB concentrations in tissue samples from English sole at six sites sampled annually from 1991 through 1996. Variability in the data (represented in the figure by standard error bars) is too great to allow any inferences about trends. The apparent increases in PCB concentrations at the three urban locations—Commencement Bay, Elliott Bay and Sinclair Inlet—from the first three years of sampling to the last three years may be explained partly by the age of fish sampled in each year (also shown in Figure 26). Except

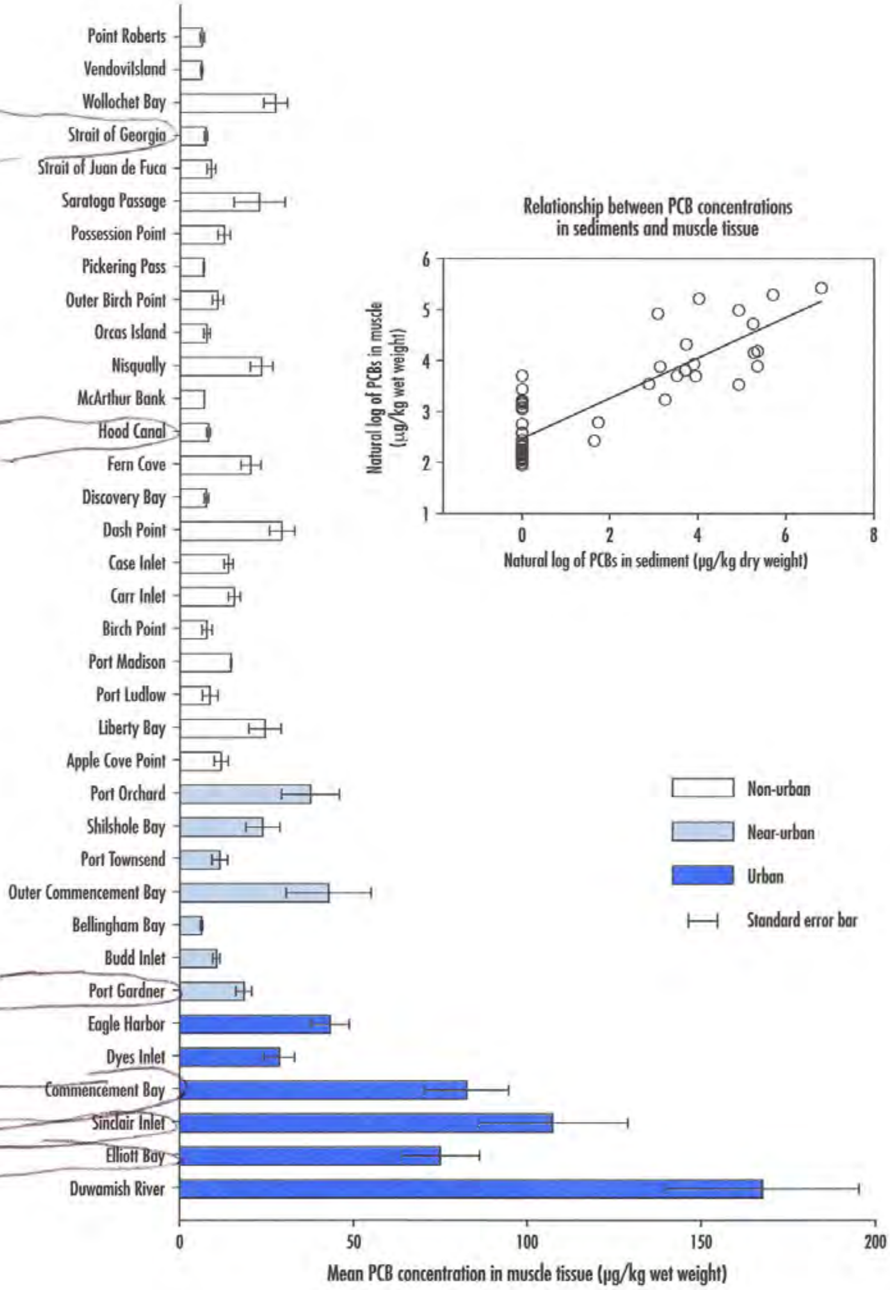


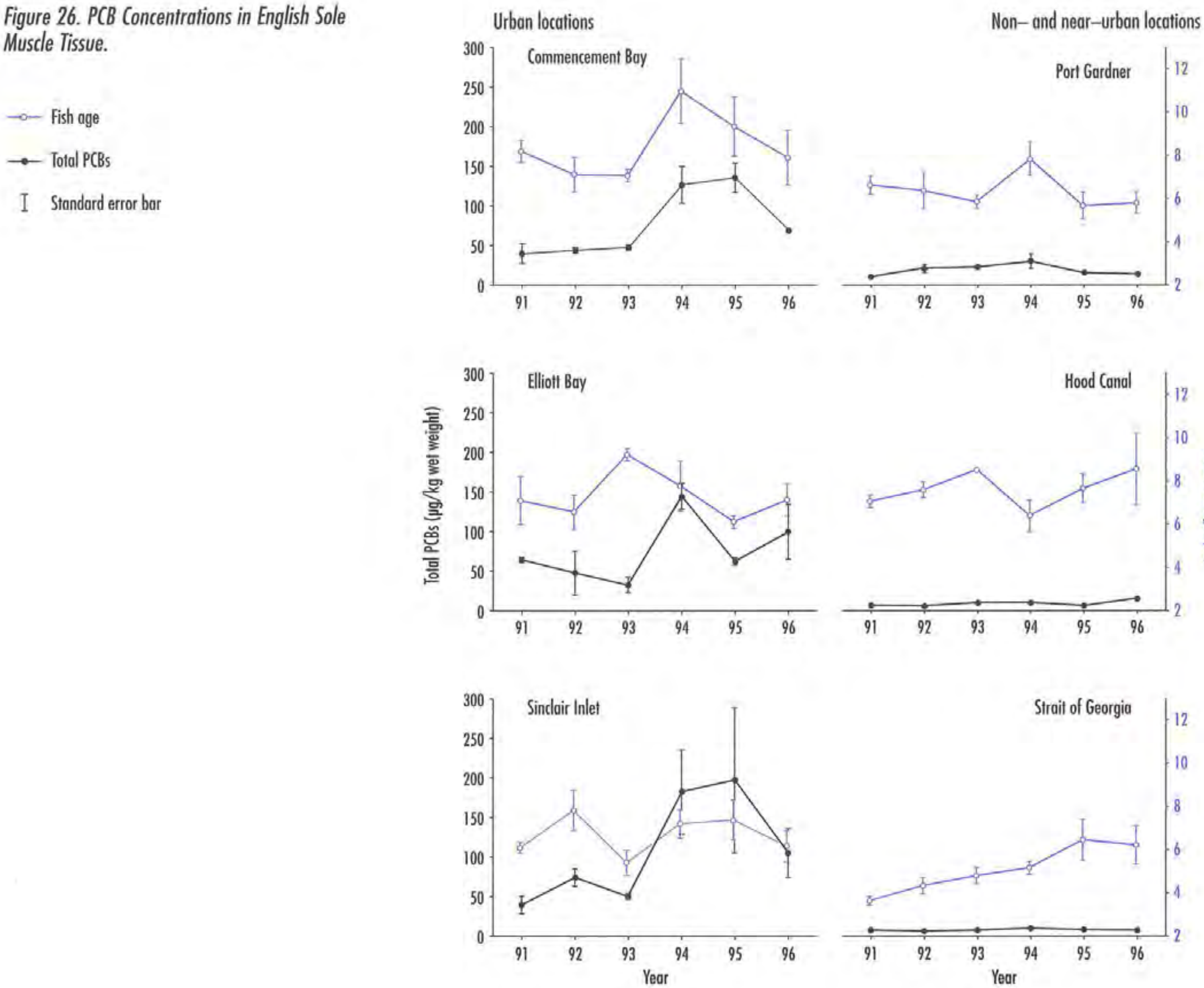
Figure 25. PCBs in Muscle Tissue of English Sole from Puget Sound Locations Sampled by the PSAMP, 1991-1996.

Non-urban
Near-urban
Urban
Standard error bar

for the Elliott Bay measurement in 1993, PCB trends generally followed those of fish age, with older fish having higher levels of PCBs in their tissues.

Figure 27 shows the occurrence of liver lesions in English sole from Fish and Wildlife's six fixed monitoring stations. At four of these stations—Commencement Bay, Sinclair Inlet, Port Gardner and Hood Canal—variations in fish age account for year-to-year changes in lesions. At Elliott Bay and the Strait of Georgia, liver lesions increased significantly but increases in fish age were not great enough to completely account for this trend. Fish and Wildlife is evaluating these data and apparent increasing trends further.

Figure 26. PCB Concentrations in English Sole Muscle Tissue.



Quillback Rockfish. From 1989 to 1996, the Department of Fish and Wildlife sampled quillback rockfish from 11 locations in Puget Sound, including Hood Canal, the San Juan Islands and two urban sites (Elliott Bay and Sinclair Inlet) in central Puget Sound. Fish and Wildlife began analyzing individual quillback rockfish in 1995 (instead of samples comprised of composites of multiple fish) to more accurately estimate the full range of contaminant concentrations in fish tissues. Fish and Wildlife focused on PCBs and mercury, contaminants of most concern in this species.

Mercury concentrations increased with fish age at all locations where sample size allowed analyses. For simplicity, Fish and Wildlife compared the accumulation of mercury in quillback rockfish from one urban location (Elliott Bay) and one near-urban location (Blakely Rocks near Bainbridge Island). Mercury concentrations in Elliott Bay rockfish were substantially higher than concentrations in same-aged fish from Blakely Rocks (Figure 28). The slope of the lines in Figure 28 indicates that Elliott Bay rockfish accumulated mercury at a greater rate than rockfish from Blakely Rocks.

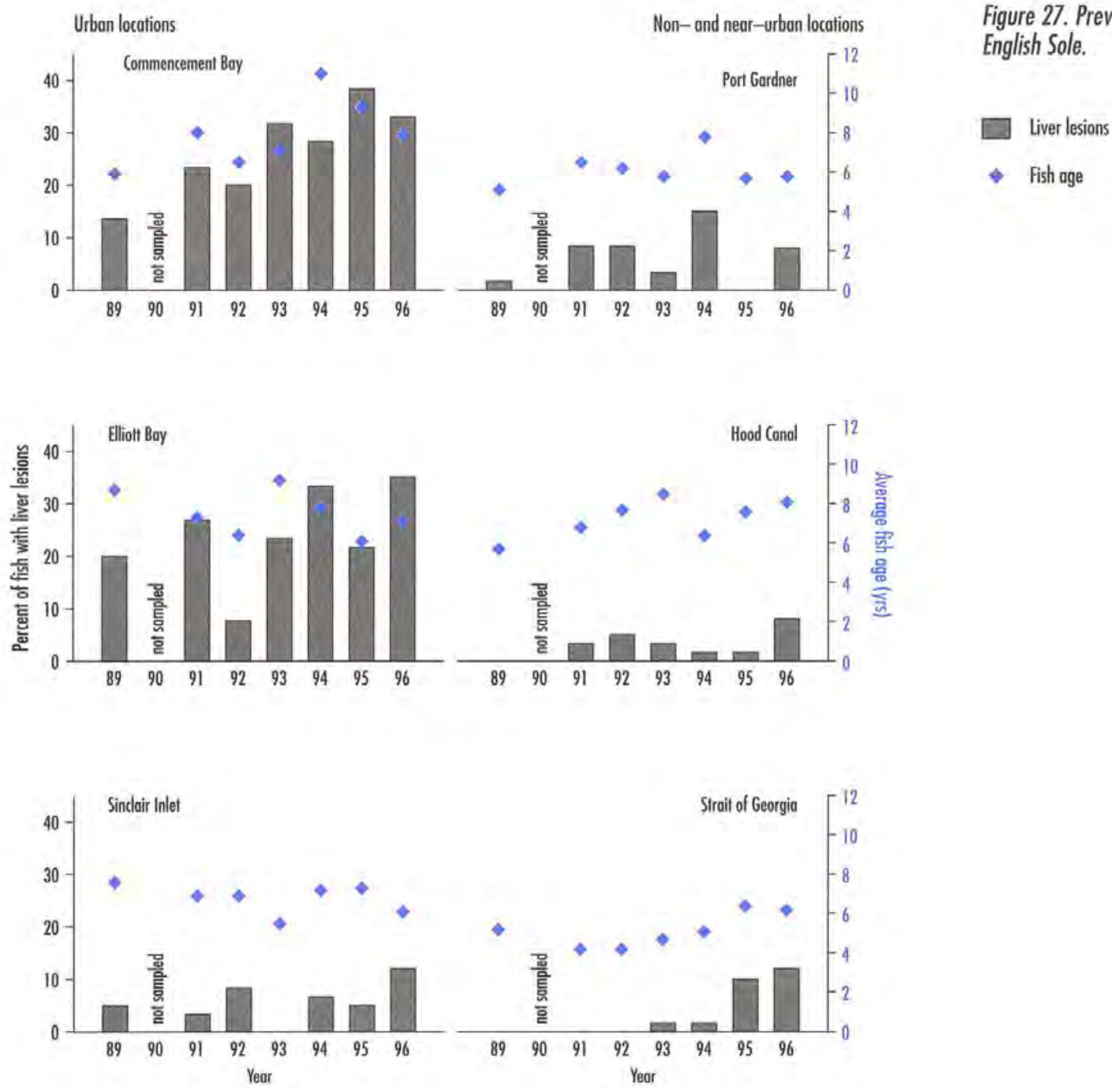


Figure 27. Prevalence of Liver Lesions in English Sole.

In addition, the graph shows that accumulation of mercury appeared to level off in older fish from Blakely Rocks. Other researchers have observed similar accumulation patterns in a number of other long-lived species, especially carnivorous species high in the food web. Evaluating risks associated with human consumption of rockfish from Puget Sound requires careful consideration of such location-specific accumulation patterns.

Mercury levels in quillback rockfish from Elliott Bay (Figure 28) and Sinclair Inlet (not shown) ranged from near zero in young fish, to greater than 1.0 mg/kg in a 22-year-old fish. The life span of this species is generally more than 80 years. Scientists from Fish and Wildlife were unable to sample fish older than 26 years from urban locations. Consequently, mercury levels in rockfish 26 years and older from Elliott Bay and Sinclair Inlet remain unknown. Older fish from these areas likely contain mercury concentrations greater than 1.0 mg/kg.

Quillback rockfish from Elliott Bay and Blakely Rocks also contained consistently detectable levels of PCBs. However, in Elliott Bay Fish and Wildlife scientists observed accumulation of PCBs only in male quillback

Ongoing Studies of Effects

Biologists from the Department of Fish and Wildlife, University of Washington and National Marine Fisheries Service are investigating potential effects of maternal transfer of PCBs to larvae, as well as effects of PCBs on the reproductive health of male rockfish.

Larvae were sampled from female quillback rockfish in urban and non-urban locations in 1997 to compare abnormalities in development. In addition, blood samples were taken from male and female rockfish to investigate the possibility that PCBs can act as estrogen-like hormones, causing changes in reproductive condition.

Figure 28. Mercury in Quillback Rockfish Tissue as Predicted by Fish Age.

● Elliott Bay

○ Blakely Rocks

Data shown include male and female rockfish at both locations.

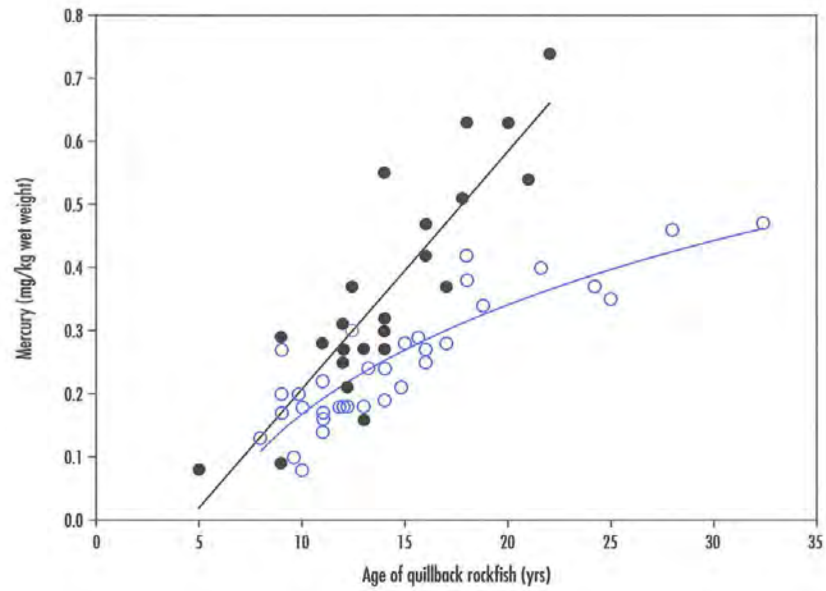
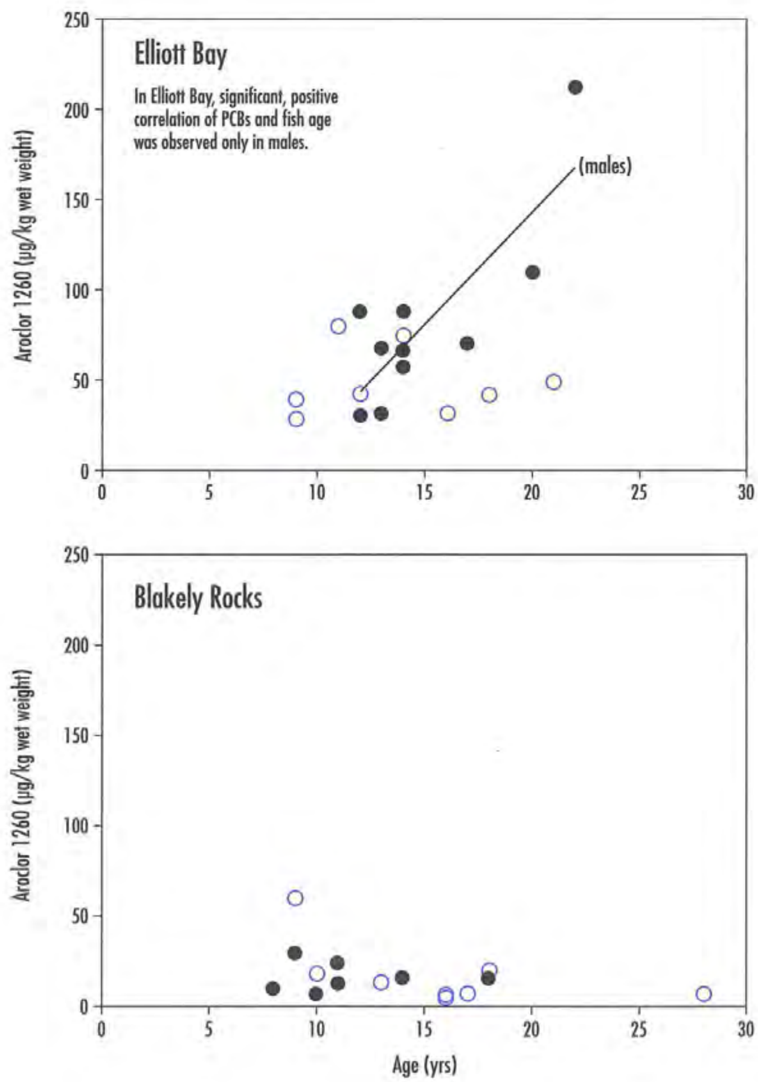


Figure 29. PCBs in Quillback Rockfish Tissue Related to Fish Age.

● Male

○ Female



rockfish (Figure 29). PCBs (as Aroclor 1260) in quillback rockfish from Elliott Bay ranged from near 30 $\mu g/kg$ for 10-year-old males and females to 212 $\mu g/kg$ in a 22-year-old male. The greatest concentration of Aroclor 1260 in females (80 $\mu g/kg$) was observed in an 11-year-old fish from Elliott Bay.

Scientists have reported or predicted sex-specific accumulation rates of compounds that accumulate in lipids (oils or fats), as shown in Figure 29 for PCBs in rockfish, in other long-lived species. The most plausible explanation for the phenomenon is that females lose PCBs when maternal lipids are transferred to eggs or larvae. Quillback rockfish are livebearers, giving birth to well-developed, free-swimming larvae that depend on maternal lipids (as yolk) for nutrition before and after birth.

Pacific Salmon. The Department of Fish and Wildlife monitors contaminant concentrations in muscle tissue of adult chinook and coho salmon because of their importance in recreational and commercial fisheries. From 1992 to 1995, Fish and Wildlife collected samples from five terminal stock fisheries (river locations to which salmon were returning to spawn) and four offshore marine mixed stock areas where the origins of the fish were unknown. Average concentrations of PCBs were higher in chinook salmon than coho salmon (Figure 30), probably because of differences in diet, age, migration patterns or the amount of time each species spends in estuarine and marine habitats. For both species, samples from mixed stocks had higher PCB levels than terminal stocks. Differences in lipid content (fats and oils) between terminal and mixed stock fishes may account for this result. Salmon sampled from terminal areas were closer to spawning and had fewer lipids in their muscle tissue than fish from mixed stock areas. Consistent with the association of PCBs with lipids, fish from these terminal areas had lower concentrations of PCBs.

Among same-aged fish, PCB concentrations in both salmon species increased as levels of lipids increased (Figures 31 and 32). A more detailed analysis of coho salmon data indicated that the fish's river of origin also influenced PCB accumulation—coho salmon from central and southern

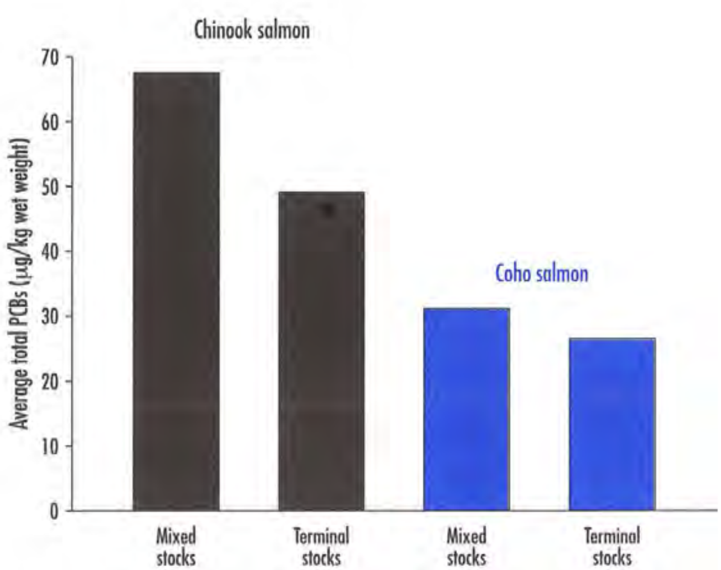


Figure 30. PCBs in Coho and Chinook Salmon, 1992-1995.

Figure 31. PCBs in Coho Salmon Related to Lipid Content—Differences Between North and South Sound Stocks.

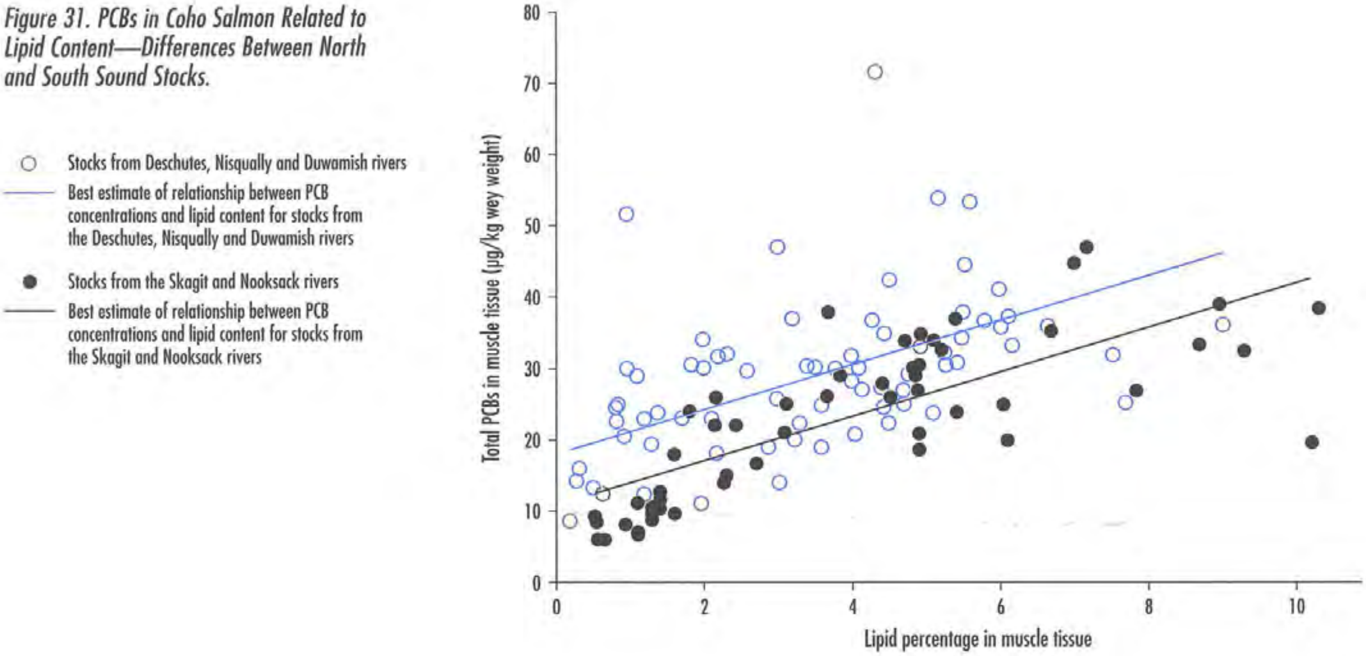
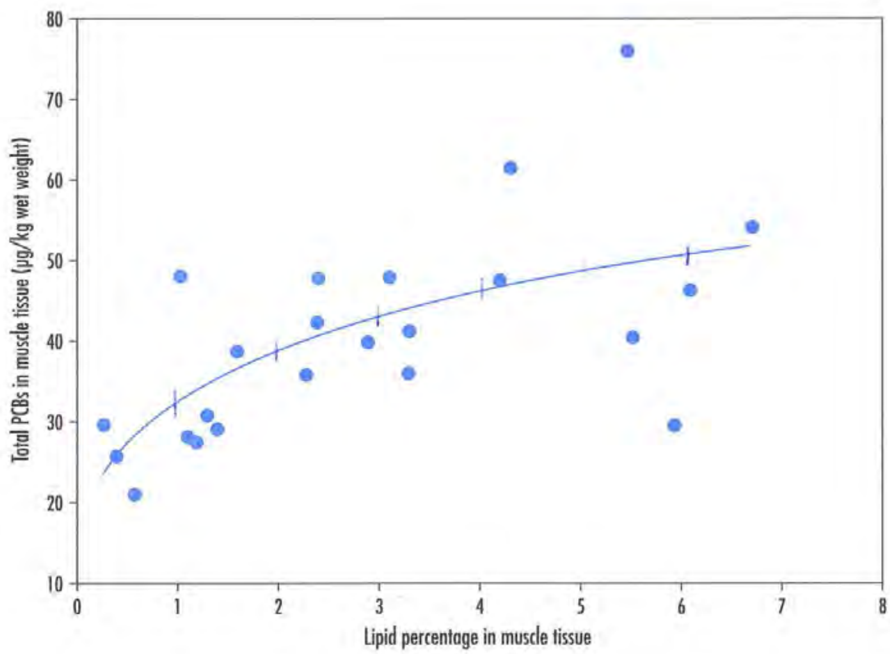


Figure 32. PCBs in Chinook Salmon Related to Lipid Content.



Puget Sound rivers (the Duwamish, Nisqually and Deschutes rivers) had significantly higher PCB concentrations than fish from northern Puget Sound (the Nooksack and Skagit rivers) for a given tissue lipid level. This regional difference in coho salmon may result from variations in migration patterns or differences in the amount of time fish from each region reside in Puget Sound or other marine areas. Based on other studies, scientists from Fish and Wildlife have concluded that most PCB accumulation in Puget Sound salmon occurs after the fish enter marine waters (S. O'Neill, pers. comm., 1997).

Total PCB concentrations in four-year-old chinook salmon also increased with increasing lipid content in muscle tissue (Figure 32). Unlike coho salmon, the river of origin was not correlated with PCB accumulation in these chinook salmon. The similar PCB burden observed in four-year-old chinook salmon from various Puget Sound rivers suggests that these fish receive similar exposures to PCBs.

Shellfish

Bivalves can be good indicators of toxic contaminants in the water because they filter large quantities of water as they feed. Toxic substances can accumulate in tissues, where they may harm the shellfish themselves or organisms, including humans, that eat the bivalves. Of particular concern are PAHs because shellfish do not rapidly metabolize these complex organic compounds. Consequently, PAHs can accumulate in shellfish tissues and can indicate that contamination by these pollutants is available for uptake by marine organisms. The following pages discuss monitoring of mussel tissue for toxic contaminants (the mussel monitored was *Mytilus trossulus*, formerly classified as *Mytilus edulis*).

NOAA's Mussel Watch Program. Concentrations of many toxic contaminants in mussel tissue have decreased in numerous areas around Puget Sound. The National Oceanic and Atmospheric Administration's (NOAA's) Mussel Watch Program indicates that concentrations of at least one toxic chemical decreased at six of the seven Puget Sound stations sampled routinely by these agencies from 1986 to 1993 (O'Connor and Beliaeff, 1996). Although NOAA did not show declines for all chemicals at all sites, there was no evidence of increasing toxic contamination in mussel tissue at any of NOAA's sampling locations in Puget Sound.

Where NOAA observed decreasing contamination trends, declines in tissue concentrations from 1986 to 1993 ranged from 20 percent to as much as 96 percent (Figure 33). Concentrations of seven contaminants decreased at NOAA's sampling location in Elliott Bay (Seattle). Decreasing concentrations of more than one contaminant

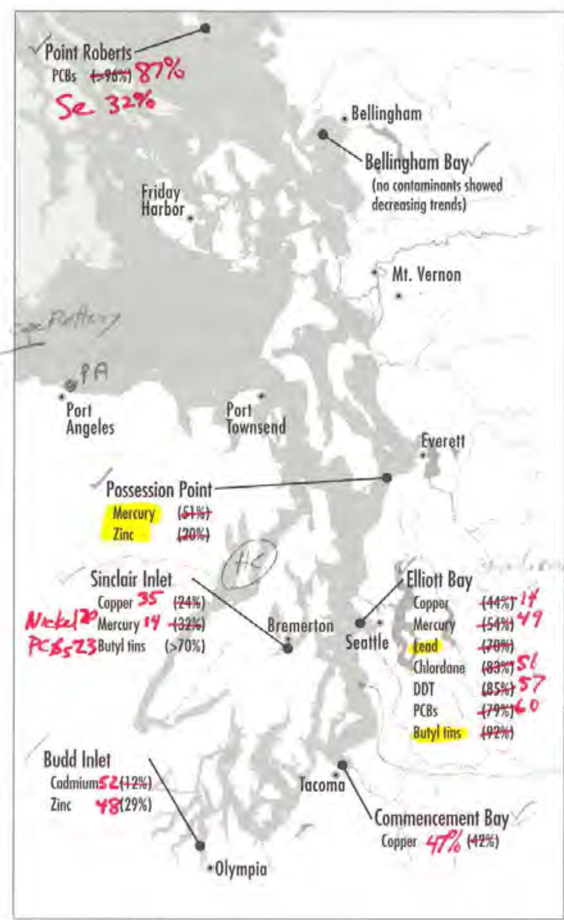


Figure 33. Percentage of Contaminant Reduction in Mussel Tissue from 1986-1993 (NOAA's Mussel Watch Program).

Numbers for butyl tins represent reductions from 1989 to 1993.

Monitoring Toxics in Shellfish—The Department of Health

As reported in the *1994 Puget Sound Update*, the Department of Health (Health) evaluated toxic contaminants in native littleneck clams from 1989 to 1993 as part of the Puget Sound Ambient Monitoring Program (PSAMP). Health detected few contaminants in clams from the sampled locations. Nine organic chemicals were detected in some samples but measured valves were relatively low. Six trace metals showed up consistently in all samples from all locations (Patrick, 1996).

The results of this effort led Health to conclude contamination generally was not high enough to affect human health. One exception was Eagle Harbor near Poulsbo. Clams from Eagle Harbor had the highest mean concentrations of copper, lead, mercury and three PAH compounds observed at any of Health's monitoring sites. The agency issued a public health advisory, which remains in effect.

In 1993, Health discontinued monitoring toxic contaminants in native littleneck clams under the PSAMP. This action was in response to budget reductions and altered priorities. The collection of these data was important in that it provided a baseline against which to compare future littleneck clam data.

Although native littleneck clams did not appear to be a sensitive indicator of contamination by organic chemicals, other species of bivalve shellfish are proving useful in monitoring environmental contamination. As the PSAMP continues to evaluate monitoring needs and opportunities, the collection and analysis of other kinds of shellfish, such as Dungeness crab or squid, may be considered.

were also observed at Sinclair Inlet in Bremerton, Budd Inlet in Olympia, and Possession Sound near Everett.

Among the contaminants in mussel tissue evaluated by NOAA, concentrations of mercury, copper, zinc, PCBs and butyl tins decreased at multiple locations. Concentrations of four other contaminants (lead, chlordane, DDT and cadmium) each decreased at only one Puget Sound station.

In addition to identifying trends, the Mussel Watch Program provides information on how contamination in Puget Sound compares to other coastal areas of the U.S. (O'Connor and Beliaeff, 1996). NOAA's data show that, with the exception of PAHs, contaminant concentrations in mussels from Puget Sound generally were not high compared to concentrations in other parts of the country. PAH concentrations at eight Puget Sound locations sampled by NOAA were high relative to concentrations seen elsewhere in the country. (PAH concentrations showed no decreasing or increasing trends at NOAA's Puget Sound sampling locations). Concentrations of zinc, nickel, copper and PCBs were relatively high at several Puget Sound locations.

Puget Sound locations sampled by NOAA that show relatively high concentrations of at least two contaminants in mussel tissue include:

- Bellingham Bay—PAHs, zinc, nickel and copper
- Commencement Bay—PAHs, zinc and nickel
- Port Townsend—PAHs and PCBs
- Elliott Bay—PAHs and zinc
- Point Roberts—zinc and nickel

Locations that had only one contaminant at relatively high concentrations include:

- Budd Inlet, Hood Canal, south Seattle and Everett Harbor—PAHs
- Sinclair Inlet—zinc
- Possession Point—nickel

Ecology's Monitoring of Pesticides and PCBs in Puget Sound Mussels. In 1995, the Department of Ecology began to sample and analyze mussels for the presence of pesticides (or their breakdown products) and PCBs at five sites in Puget Sound. This effort expanded an ongoing pesticide monitoring program (Johnson and Davis, 1996). Ecology took samples at Padilla Bay near Mount Vernon, Duwamish Waterway in Seattle, Hylebos Waterway in Tacoma's Commencement Bay, Chambers Creek at Nisqually Reach, and Budd Inlet near Olympia. The agency detected PCBs and 20 pesticide compounds in Puget Sound mussels.

The largest number of compounds and highest concentrations were observed in Hylebos Waterway. The least contaminated site was Padilla Bay. Several currently used pesticides were detected, including the insecticides endosulfan and lindane, and a breakdown product of the fungicide pentachlorophenol. These are among the most heavily used pesticides in the Puget Sound basin. PCBs and other banned or severely restricted chemicals were present largely due to the environmental persistence of historical contamination.

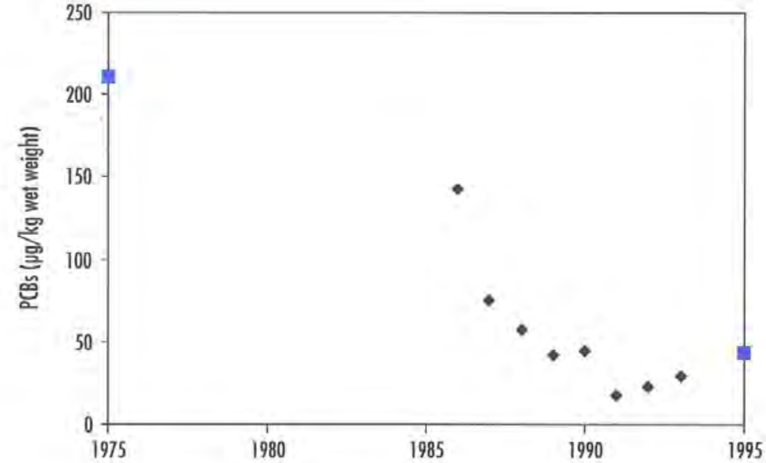


Figure 34. Total PCBs in Mussels from the Duwamish Waterway and Elliott Bay.

- Four-Mile Rock–Elliott Bay (NOAA)
- W. Duwamish Waterway (Mowrer et al., Ecology)

Observed concentrations of pesticides were well within U.S. Environmental Protection Agency (EPA) guidelines, which are based on a lifetime cancer risk of one-in-100,000 (EPA, 1995). However, total PCB concentrations exceeded the guideline at three of the five Puget Sound stations—Budd Inlet, Duwamish Waterway and Hylebos Waterway—where levels ranged from 21 to 70 parts per billion compared to an EPA guideline of 10 parts per billion.

Comparison of Ecology's measurement of PCBs in mussels from the Duwamish Waterway to historical data from that location and to NOAA's Mussel Watch data for Four-Mile Rock in Elliott Bay suggest that PCB concentrations decreased markedly in these areas from 1975 to 1995 (Figure 34).

Harbor Seals

Because of their high position in the marine food chain, harbor seals provide a good focus for studies of chlorinated organic contaminants such as PCBs and dioxins in Puget Sound and the Georgia Basin. Scientists from Washington's Department of Fish and Wildlife and Canada's Department of Fisheries and Oceans are collaborating on studies of geographic patterns of dioxin, furan and PCB contamination in harbor seals. These studies also are evaluating trends in contamination over time, though results are not yet available.

Dioxins and Furans

Chlorinated dioxins and furans are impurities in industrial chemicals and byproducts of the chlorination of organic materials. These compounds are not readily broken down and can accumulate in the environment. They are among the most potent cancer–causing environmental contaminants.

Researchers evaluate dioxins, furans and PCBs together because they behave similarly in the environment and pose similar threats to marine organisms and humans. Measured concentrations of these contaminants are mathematically combined to estimate the "equivalents" of 2, 3, 7, 8-tetra-chlorinated dibenzo-p-dioxin (TCDD), the single most toxic compound of this type. Monitoring results are expressed as equivalent to nanograms of TCDD, but the contaminants present could include any combination of dioxins, furans and PCBs.

Preliminary analysis of contaminant levels from nine blubber samples collected from seals at Gertrude Island (located in south Puget Sound, near McNeil Island) in 1996 suggest that Puget Sound seals were more

contaminated than seals from British Columbia. The contaminant burden of seal blubber collected from Gertrude Island in 1996 was equivalent to 178 nanograms of TCDD per kilogram of seal lipid, approximately three times the mean measured in seals from the Georgia Strait (P. Ross, Department of Fisheries and Oceans, pers. comm.). The concentrations of PCBs in the 1996 samples from Gertrude Island seals were in the range shown to cause adverse biological effects, including damaging effects on the immune system, in studies of captive harbor seals in the Netherlands (P. Ross, Department of Fisheries and Oceans, pers. comm.).

While seals from British Columbia appeared to be exposed to a fairly constant level of contamination, seals from Puget Sound appeared to reflect exposure to a broad range of environmental contamination. Contaminant levels in Puget Sound seals ranged from 73 to 358 nanograms of TCDD per kilogram of seal lipid. This wide range suggests more diverse migration and feeding patterns among seals in Puget Sound, more variation in prey selection and widely varying patterns of contamination throughout the Sound's sediments.

In seals sampled from south Puget Sound, PCBs accounted for 94 percent of the TCDD equivalents, while dioxins and furans accounted for only five and one percent, respectively. This dominance by PCBs is not seen in British Columbia seals, which show a greater contribution from dioxins. The relative importance of PCBs and dioxins probably relates to the seals' proximity to ongoing and historic sources of contamination. Present-day PCB contamination in Puget Sound most likely originated from historic discharges and spills from a variety of industrial sources. Dioxins in marine and aquatic environments have been associated with discharges from pulp mills. Data on trends in concentrations of PCBs, dioxins and furans measured over time, which will be available soon, should allow scientists to draw conclusions about how the environment is responding to efforts to stop discharges of these contaminants and to clean up areas of contaminated sediments.

Birds

Scoters. The U.S. Fish and Wildlife Service (USFWS) studies contaminants in surf scoters, a sea duck that winters in large numbers in Puget Sound. Studies in the Commencement Bay / Vashon Island area began in 1992 and final samples were collected in February 1996. Prior to initiating contaminant monitoring, the USFWS performed a study to determine whether surf scoters remain in the same local areas throughout the winter. This study showed strong site-fidelity, which allows scientists to study the difference in contaminant concentrations among scoters collected at the beginning and end of winter. The differences provide information about the birds' exposure to contaminants in the Puget Sound study location over the course of the winter.

Scientists collected 20 adult male surf scoters from the Commencement Bay / Vashon Island area in October 1995 and again in February 1996. These scoters primarily fed on mussels, clams, tube worms and snails. The same analyses of toxic chemicals were conducted on samples of birds from the October and February collections. Livers were analyzed for chlorinated

Monitoring Contaminants in Pigeon Guillemots

The U.S. Fish and Wildlife Service (USFWS) is evaluating the use of pigeon guillemots to monitor contaminants in Puget Sound birds. Studies of pigeon guillemots would involve collecting eggs and non-lethal sampling of birds on nests. Since most pigeon guillemot nests are inaccessible, scientists are attempting to facilitate sampling using nest boxes. Pigeon guillemots have used nest boxes in Budd Inlet and Elliott Bay very little, allowing collection of only a few samples. Boxes at Port Townsend and Grays Harbor have been sparsely occupied. Nest boxes have been a success at the Protection Island National Wildlife Refuge. Scientists from the USFWS are comparing results from a few samples from Elliott Bay to samples from Protection Island. In light of the limited use of nest boxes, the USFWS continues to evaluate the potential for monitoring contaminants in guillemots and to consider alternative monitoring approaches.

organic contaminants and trace metals. Kidneys were analyzed for selected trace metals. Possible exposures to hydrocarbons were evaluated using bile samples. Scientists evaluated the general condition of the birds by examining a variety of tissue samples for lesions and conducting blood cell counts and serum chemistry analyses.

Overall, surf scoters collected in the Commencement Bay / Vashon Island area appeared to be healthy. Metals in the scoters' livers and kidneys were lower than those measured by scientists in 1984 and 1985 (Henny et al., 1991). In the 1984-1985 study, scientists collected scoters at the mouth of waterways in Commencement Bay. In 1995 and 1996, the USFWS collected scoters from further out in Commencement Bay. Concentrations of mercury and chromium, which increased slightly from October to February, were below those known to negatively affect birds. Concentrations of cadmium, copper and zinc appeared to decrease while the scoters wintered in the Commencement Bay area.

In October 1996 and February 1997, USFWS scientists collected surf scoters for a similar study in Bellingham Bay. Scoters in this area were consuming mussels and / or clams. When scientists complete their analysis of contaminant data, the USFWS will release the results in a report. The USFWS is continuing this monitoring approach, collecting scoters from

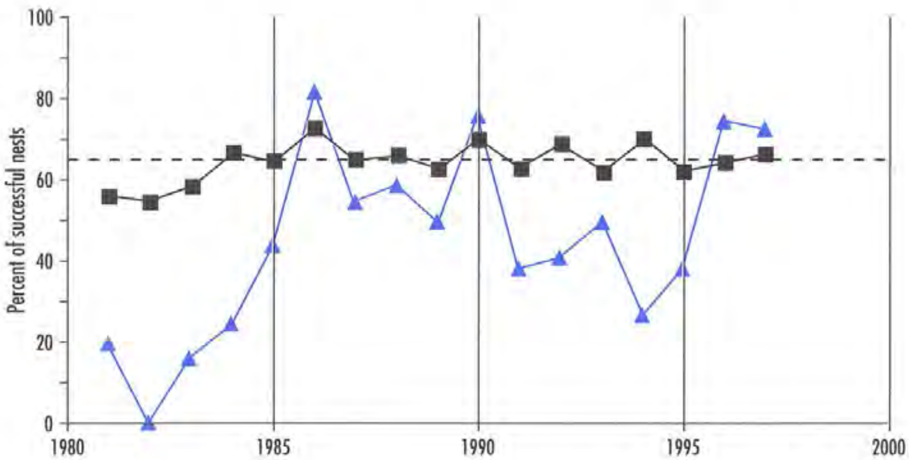


Figure 35. Nesting Success of Bald Eagles in Hood Canal and Statewide.

One criteria for removing Washington's bald eagles from listed status is a 5-year average of 65 percent nesting success.

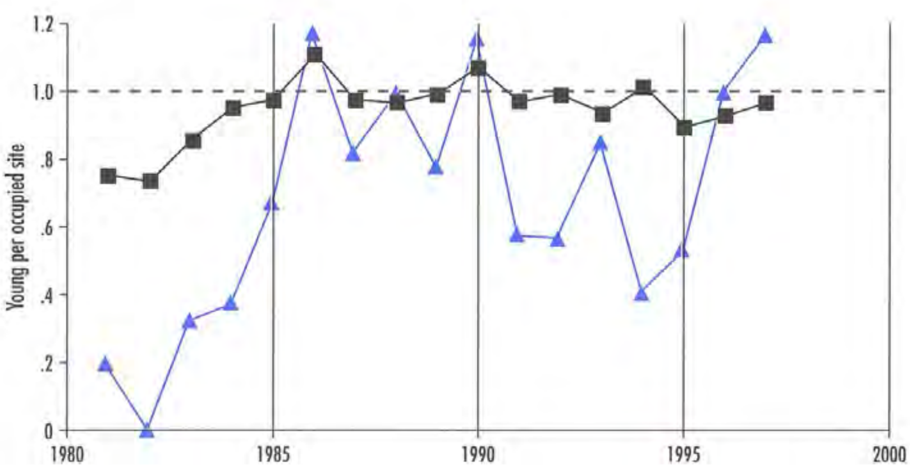


Figure 36. Young Bald Eagles per Nest in Hood Canal and Statewide.

One criterion for removing Washington's bald eagles from listed status is a 5-year average of 1.0 fledged young per occupied site.

lower Hood Canal in October 1997 and February 1998.

Hood Canal Bald Eagles. As reported in the *1994 Puget Sound Update*, the U.S. Fish and Wildlife Service and the Department of Fish and Wildlife have been evaluating the status of bald eagles on Hood Canal. Bald eagles in Washington state are listed as a federally threatened species. At the time of listing, toxic contaminants were cited as the primary reason for the decline of bald eagles. One of the criteria for removing Washington's bald eagles from listed status is a five-year average of 1.0 fledgling per occupied site and an average nesting success of 65 percent. In 1996, the statewide five-year average fledgling success stood at 0.96 young per occupied site (Fish and Wildlife, unpublished data). Areas, including Hood Canal, with depressed bald eagle productivity are part of the reason that the statewide recovery goals have not been reached.

Figures 35 and 36 show nesting success and young per occupied nest for bald eagles from Hood Canal and statewide for each year since 1981. Bald eagle territories in Hood Canal reached the goal of 1.0 young per occupied nest with at least 65 percent nesting success at active nests only twice from 1980 to 1995 (in 1986 and 1990). Hood Canal eagles met both of these criteria in 1996 and 1997. Bald eagles in the Hood Canal territories were more successful, by both measures, than those from other areas of the state in 1996 and 1997. It is not yet clear whether the 1996 and 1997 productivity results represent a long-term improvement in the condition of Hood Canal bald eagles. These results, however, indicate that contamination by environmentally persistent organic chemicals likely is not causing widespread negative impacts to Hood Canal bald eagles at this time.

Washington State's Water Quality Criteria

Washington state's water quality standards include criteria to protect aquatic life. For each chemical, two criteria are identified:

Acute criteria – relatively high values which indicate concentrations that can harm aquatic life even if the concentration persists only for a brief time.

Chronic criteria – relatively low values which indicate concentrations that can harm aquatic life only if the concentrations persist for a long period of time.

Marine and Fresh Water

Much of the toxic contamination in Puget Sound probably enters the marine system through fresh water flowing from rivers and streams or from direct wastewater discharges. However, the PSAMP does not focus monitoring on analyzing contaminants in the fresh and marine waters of the Puget Sound basin because concentrations in water are generally too low to measure effectively and because many persistent toxic contaminants are measured better in sediments or in the tissue of organisms where they tend to accumulate. Nonetheless, some limited information on toxic contamination of the water is available from PSAMP studies conducted by the Department of Ecology (metals in fresh water) and the King County Department of Natural Resources (toxic contaminants in central Puget Sound's marine waters).

Metals in Fresh Water. As part of the PSAMP, Ecology monitors metals six times a year at selected rivers and streams draining into Puget Sound. Data from this monitoring helps determine if concentrations of metals are adversely affecting aquatic life in fresh waters. Once in Puget Sound, metals can accumulate in sediments and organisms, potentially harming marine life.

The concentration of metals generally is quite low at seven Puget Sound basin sites monitored from 1994 to 1997. During nearly four years of monitoring rivers and streams with new low detection-level methods,

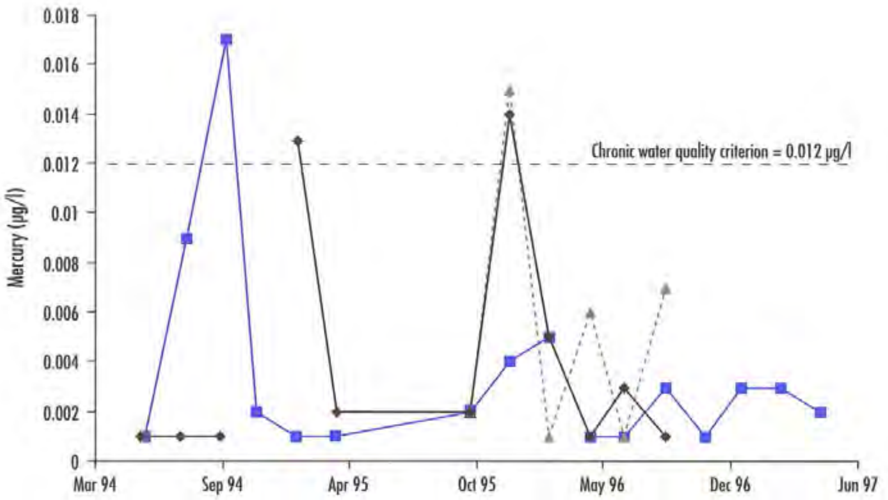


Figure 37. Highest Levels of Mercury Measured in Puget Sound Rivers and Streams.

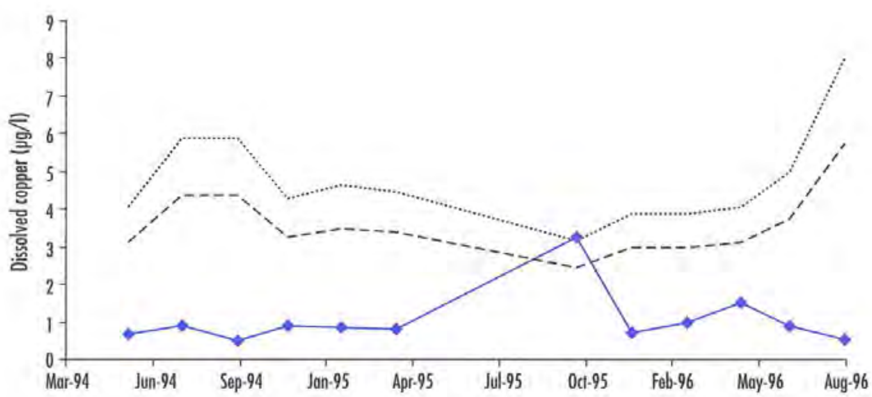


Figure 38. Concentrations of Copper in the Stillaguamish River.

Ecology measured concentrations of metals approaching or exceeding the concentration specified in state criteria for water quality on only four occasions (three for mercury, one for dissolved copper). Figure 37 shows how measured mercury concentrations changed over time and how these values compared to the water quality criteria for mercury. The chronic water quality criterion for mercury in fresh water is 0.012 $\mu g/l$. Measured values for the Stillaguamish River, Puyallup River and Clover Creek are above this level, indicating that concentrations in these waters may approach the level where long-term impacts to biota are probable. More intensive monitoring of mercury in these waters may be justified.

The hardness of water affects the toxicity of many metals (not including mercury) in fresh water. Consequently, the chronic and acute water quality criteria for dissolved copper are based upon hardness values measured at the time of sample collection. Figure 38 shows the calculated criteria for copper in the Stillaguamish River, as well as concentrations measured over time. One measured value exceeded applicable acute and chronic criteria.

Figures 37 and 38 show the only times that Ecology's new low detection-level monitoring of metal concentrations in Puget Sound's rivers and streams has found metals near or above potentially harmful levels. As shown from this relatively small data set, metals concentrations are not

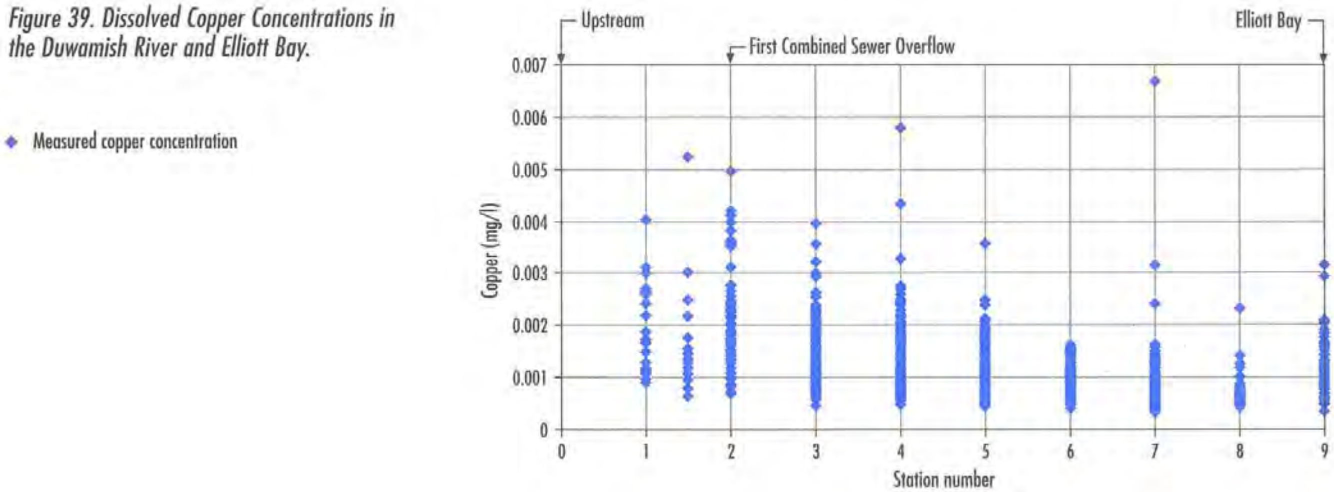
British Columbia's Water Quality Monitoring Network

The quality of fresh water in portions of the Georgia Basin are monitored by British Columbia's Water Quality Monitoring Network. Among other parameters, this program evaluates concentrations of metals and absorbable organic halides (a measure of contamination from pulp mill discharges). The monitoring network includes five stations in the Georgia Basin. The data record for some stations goes back to 1984; data collection at two of the Georgia Basin stations began in 1997. Results for the following two stations provide examples of conditions in the rivers and streams of the Canadian portion of the Puget Sound/Georgia Basin.

Elevated levels of sulfate, strontium, copper and chromium at a monitoring station on the Quansam River, near Campbell River on the east side of Vancouver Island, indicates declining water quality. The pollutants probably originate from a coal mine located upstream.

Water quality appears to be improving at a monitoring station on the Fraser River at Hope (100 km upstream of the river's mouth). Reduced discharges from a pulp mill have lowered levels of chloride and absorbable organic halides.

Figure 39. Dissolved Copper Concentrations in the Duwamish River and Elliott Bay.



generally a concern in the streams and rivers sampled. Ecology's low detection-level methods can help identify problems and focus attention on contaminants and locations that might require further analysis.

King County's Evaluation of Toxic Contaminants in the Waters and Sediments of the Duwamish River and Elliott Bay. The King County Department of Natural Resources has undertaken an extensive study of the effects of combined sewer overflows (CSOs) on the Duwamish River and Elliott Bay. As part of this study, King County measured organic contaminants and metals in the water, sediments and tissues of fish and invertebrates from the river and bay. Because of the low concentrations of toxic contaminants in the water, these measurements are technically challenging and are not typically part of routine ambient monitoring.

Organic Contaminants. Traditional sampling techniques yielded little or no information on the occurrence and concentration of organic contaminants in the waters of the Duwamish River and Elliott Bay. For the Water Quality Assessment study, King County scientists are using samplers called semi-permeable membrane devices that can be left in the water for up to several weeks. Data from these samplers allow scientists to calculate average concentrations of organic contaminants in the water during the time the samplers were deployed. The compounds most readily sampled by these devices include PAHs and PCBs. Low levels of PAHs were detected in these samplers, including benzo(k)fluoranthene, which was present at less than 1 nanogram per liter.

Metals. King County took samples at nine locations, starting in the freshwater section of the Duwamish River near Tukwila and moving down the river into the estuarine area of the lower river to saltwater stations in Elliott Bay. Figure 39 shows dissolved concentrations of copper for stations from the freshwater zone of the river to the marine area of Elliott Bay. Samples collected from locations of downstream of King County's CSOs had slightly higher copper concentrations than those measured upstream.

USING MONITORING DATA TO SUPPORT MANAGEMENT DECISIONS

Information on fish contaminants gathered by the Department of Fish and Wildlife led the state Department of Health and the Bremerton-Kitsap Health District in 1996 to advise people to avoid consuming rockfish from Sinclair Inlet. Data collected by Fish and Wildlife in 1995 showed that fish from Sinclair Inlet accumulated mercury to levels above 1.0 mg/kg. Standards set by the U.S. Food and Drug Administration state that mercury levels above 1.0 mg/kg make fish unsafe for human consumption.

PATHOGENS AND NUTRIENTS

SUMMARY

Pathogens (disease-causing bacteria and viruses) and excessive nutrients are causing or threatening to cause localized problems in Puget Sound. Although these problems usually are reversible and tend not to be widespread throughout Puget Sound, they can severely affect the environment and economy of individual waterbodies and communities.

Generally, the areas of Puget Sound most susceptible to the effects of excess nutrients are also vulnerable to pathogens. These areas include warm, shallow, stratified (see page 33) waters with high biological productivity, which also makes them ideal for growing shellfish. The very conditions that make these waterbodies productive for shellfish can also lead to high concentrations of nutrients and elevated levels of pathogens.

Concerns About Pathogens and Nutrients in Puget Sound

Pathogenic microorganisms and nutrients are natural components of the Puget Sound ecosystem. However, a number of human activities can send more nutrients or pathogens into Puget Sound than the ecosystem can handle. Contributors to these excess loadings of pathogens and nutrients include failing on-site sewage systems, runoff from improperly managed farms, combined sewer overflows, and stormwater discharges.

Beyond Measurements of Fecal Contamination

As discussed on this page, fecal bacteria contamination is measured to indicate the potential presence of disease-causing organisms. Scientists are continuing to design and implement improved measures of pathogens in the environment. In the future we may be able to present information on the occurrence of *E. coli* (a specific type of fecal coliform bacteria), enteric viruses and other specific measures of the health threats posed by pathogens in Puget Sound.

Pathogens

Scientists measure fecal coliform bacteria in the environment to protect humans from contracting illnesses from pathogenic microorganisms in nearshore waters, sediments, shellfish or other Puget Sound organisms. Because most pathogenic microorganisms originate in human and animal wastes, fecal coliform bacteria, which grow in the digestive tract and fecal material of warm-blooded animals, serve as an indicator of the potential presence of pathogens in the environment.

Monitoring to assure the safety of shellfish for consumption is focused on measuring of fecal coliform bacteria in seawater from shellfish growing areas. Fecal contamination of shellfish beds seriously threatens the economy of rural areas around Puget Sound because it leads to restrictions on harvesting of commercial and recreational shellfish.

Nutrients and Eutrophication

The quality of some bodies of water, including portions of Puget Sound, can be degraded by excessive amounts of nutrients. Improperly treated sewage and runoff from property where animal wastes and fertilizers are not properly managed are a few sources of nutrients in Puget Sound's watersheds. Referred to as eutrophication, excess nutrient loadings can lead to an overabundance of phytoplankton (algae) and high levels of ecosystem productivity. Heightened productivity can cause water quality problems when blooms of algae die and the microorganisms that decompose the algae consume all or much of the available oxygen dissolved in the water. As a consequence of excess nutrient loading (eutrophication) and the subsequent degradation of water quality, sensitive species can become stressed (and, in severe conditions, lost from some environments), biological communities can lose diversity and become dominated by pollution-tolerant species, and the aesthetic quality of the water body can be degraded.

FINDINGS — FECAL CONTAMINATION IN PUGET SOUND

The Puget Sound Ambient Monitoring Program (PSAMP) measures fecal contamination in marine and freshwater environments. The Department of Health (Health) monitors fecal coliform bacteria in seawater at shellfish growing areas. The King County Department of Natural Resources investigates fecal coliform contamination near recreational beaches and other areas along the Sound's shore. The Department of Ecology (Ecology) and King County Department of Natural Resources measure fecal coliform bacteria in the open marine waters of the Sound. Ecology investigates fecal coliform bacteria in fresh waters flowing into Puget Sound.

Fecal Contamination in Commercial Shellfish Growing Waters

The Department of Health classifies commercial shellfish beds according to guidelines set by the National Shellfish Sanitation Program. As of 1996, 86,000 acres of tidelands in Puget Sound were unconditionally approved for commercial shellfish harvest. Health conditionally approved the commercial harvest of shellfish from an additional 11,000 acres (generally meaning the areas are subject to closures based on temporary changes in

local pollution or climate). Commercial shellfish harvest was prohibited or restricted on the remaining 35,000 acres of Puget Sound's tidelands that have been classified for commercial harvest. (The east shore of Puget Sound from Possession Sound to the Tacoma Narrows is not classified for commercial harvest). See page 80 for further discussion of Health's classifications of shellfish growing areas.

The National Shellfish Sanitation Program ensures the uniform survey of shellfish growing areas so that contaminated shellfish do not reach the seafood market. To be approved for commercial shellfish harvest under this program, a growing area must meet minimum standards for water quality. Health regularly evaluates the quality of water through an intensive sampling program at 110 commercial shellfish growing areas in Washington state.

Through the PSAMP Health thoroughly analyzed monitoring results for three shellfish growing areas in south Puget Sound: Henderson Inlet (northeast of Olympia), Oakland Bay (near Shelton) and Burley Lagoon (at the north end of Carr Inlet between Bremerton and Tacoma). These areas were selected for detailed study because they are threatened by known sources of pollution, they are conditionally approved for commercial shellfish harvest, and each has been the focus of major cleanup or restoration efforts since downgrades for shellfish harvest in the early 1980s.

For each of the three areas, Health analyzed conditions to answer two questions.

- Do fecal coliform levels comply with the National Shellfish Sanitation Program's standards?
- Have levels of fecal coliform bacteria changed over time?

Compliance with the National Shellfish Sanitation Program's standards. Evaluating compliance with the standards is fairly complicated. The National Shellfish Sanitation Program has slightly different standards for areas affected by point sources of pollution (direct, identifiable sources, such as wastewater that discharges from a pipe) and areas affected solely by nonpoint sources of pollution (disperse pollution from sources that are difficult to identify, such as surface water runoff or failing on-site sewage systems).

The standards include two criteria for water quality. Compliance with the criteria is determined by evaluating the fecal coliform measurements of the 30 most recent samples.

1. The first criterion is the same for areas affected by point and nonpoint sources: the geometric mean of the 30 most recent samples cannot to exceed 14 fecal coliform colonies per 100 milliliters (ml) of water.

2. The second criterion differs for areas subject to point and nonpoint pollution. In areas affected by point sources of pollution, no more than 10 percent of measured values can exceed 43 fecal coliform colonies per 100 ml of water. In areas affected only by nonpoint

Beyond Trends and Compliance

How do human activities contribute to increases or decreases in fecal coliform bacteria in Puget Sound? This is not an easy question to answer. Human activities can reduce fecal contamination by, for example, better controlling existing sources of bacteria. They can also increase contamination by, for example, adding new sources or releasing improperly treated sewage.

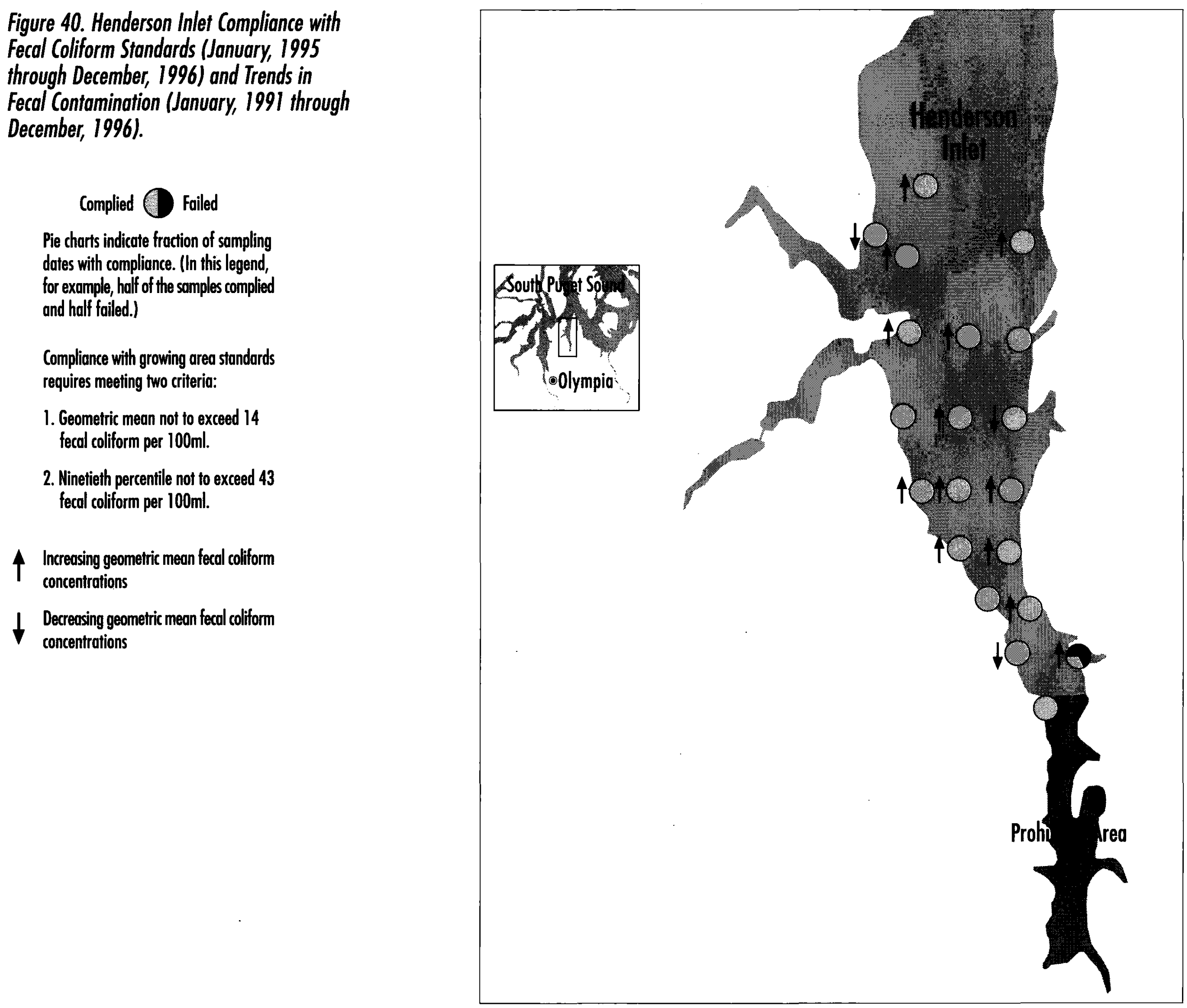
Determining the effects of nonpoint pollution from human activities may be elusive for many reasons—the potential sources can be diffuse, intermittent and difficult to identify and sample. There are legal and political constraints, for example, on parcel-by-parcel inspections of on-site sewage systems. Natural factors, such as fecal bacteria from marine mammals or birds, may mask influences from human activities. The question of human effects on environmental conditions is important for the management of Puget Sound, but it is beyond the scope of this Update.

sources, calculations must show that less than 10 percent of the samples are likely to have concentrations as high as 43 fecal coliform colonies per 100 ml of water.

Regardless of the standard used, both criteria must be met at all sampling stations. The discussion on the following pages describes the percent of sampling in 1995 and 1996 in which both criteria were met at each sampling station in the growing areas studied by Health. Because Health must use the 30 most recent samples to judge compliance for each sampling date and because the agency samples conditionally approved areas approximately once a month, compliance or non-compliance in 1995 and 1996 actually reflects conditions beginning as early as mid-1992 (for the 30 samples ending in January 1995) or as late as mid-1994 (for the 30 samples ending in December 1996).

Have levels of fecal coliform bacteria changed over time? Health's evaluation of trends in fecal contamination is largely consistent with the evaluation of compliance. Scientists at Health calculated the geometric mean of the 30 most recent fecal coliform measurements at each sampling date to

Figure 40. Henderson Inlet Compliance with Fecal Coliform Standards (January, 1995 through December, 1996) and Trends in Fecal Contamination (January, 1991 through December, 1996).



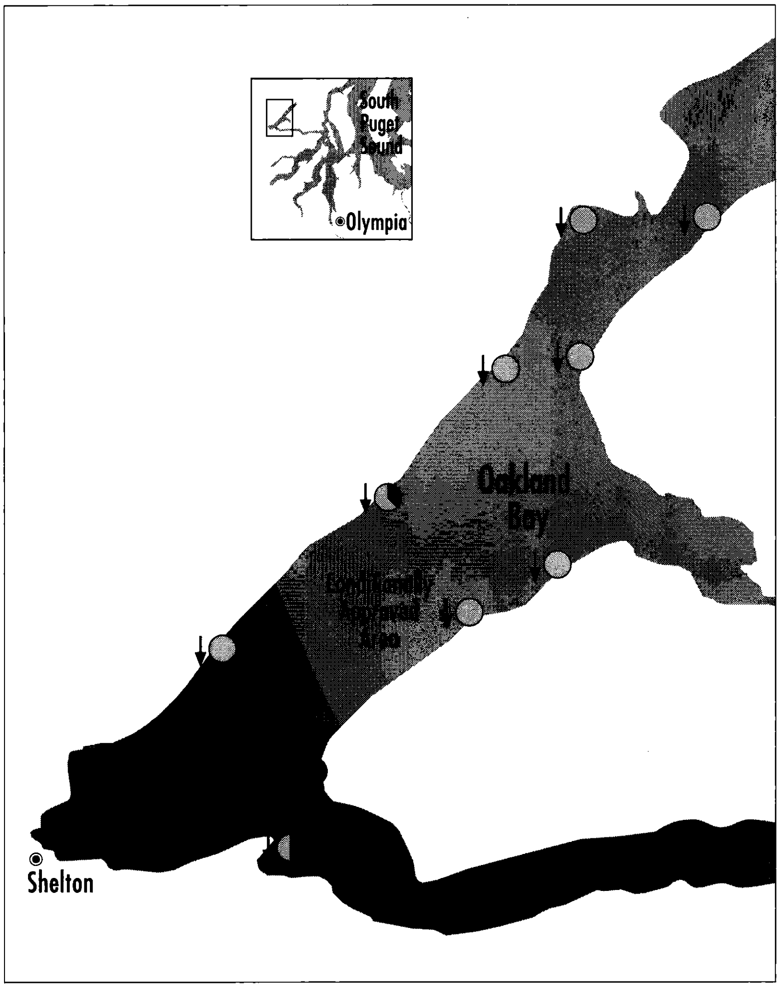


Figure 41. Oakland Bay Compliance with Shellfish Fecal Coliform Standards (January, 1995 through December, 1996) and Trends in Fecal Contamination (January, 1991 through December, 1996).

Complied ◐ Failed

Pie charts indicate fraction of sampling dates with compliance. (In this legend, for example, half of the samples complied and half failed.)

Compliance with growing area standards requires meeting two criteria:

1. Geometric mean not to exceed 14 fecal coliform per 100ml.
2. Ninetieth percentile not to exceed 43 fecal coliform per 100ml.

↑ Increasing geometric mean fecal coliform concentrations

↓ Decreasing geometric mean fecal coliform concentrations

characterize each sampling station. This 30-sample geometric mean was updated each month (or whenever a new sample was analyzed). The series of 30-sample averages for each sampling station was evaluated statistically to identify whether the contamination trends were increasing or decreasing.

Henderson Inlet. Health has monitored water quality at 20 stations in Henderson Inlet since 1988. Figure 40 shows that only one of these stations failed to comply with the applicable National Shellfish Sanitation Program standard from January 1995 through December 1996. This station, along the southeast shore of Henderson Inlet, failed the standard on 16 of 20 occasions. This figure also shows that fecal contamination was increasing at 13 of 20 stations. The upward trends were gradual though, and geometric mean concentrations remain well below 14 fecal coliform colonies per 100 ml of water.

These results suggest that conditions in Henderson Inlet were generally good, considering the growing population and the extent of development in the watershed. However, the slow but steady trend of increasing fecal coliform bacteria is a reminder that pollution control efforts must be intensified.

Oakland Bay. Oakland Bay receives discharges from a wastewater treatment plant operated by the city of Shelton. Consequently, this area is subject to the National Shellfish Sanitation Program standard for areas

Combining Results for Accuracy

The Department of Ecology's marine waters monitoring program is not particularly sensitive to fecal coliform problems. First, the agency samples stations located away from likely problem areas as opposed to sites along the shore where fecal concentrations may be higher. Second, sampling events may not capture conditions during storms in which fecal contamination might be especially high—samples cannot be collected from a float plane in stormy weather.

Consequently, these monitoring results are best used to complement the efforts of the Department of Health, local health districts and monitoring by dischargers to assess fecal contamination problems in Puget Sound.

affected by point sources. Seven of 10 sampling stations in Oakland Bay complied with this standard from January 1995 to December 1996 (Figure 41). Most violations at the other three stations occurred during the last six months of 1996.

The two southernmost stations that did not comply with the national standard lie in a zone where commercial shellfish harvest is prohibited due to nearby discharges from the wastewater treatment plant. The third non-complying station lies on the northwest shore in the conditionally approved zone. The station in the prohibited zone that is furthest north of the treatment plant discharges violated the water quality standard more often than the station closer to the discharge point. This suggests the station at the edge of the prohibited zone (as well as the site on the northwest shore) may be affected more by a nearby onshore source than the distant discharge. Site-specific investigations may reveal an explanation.

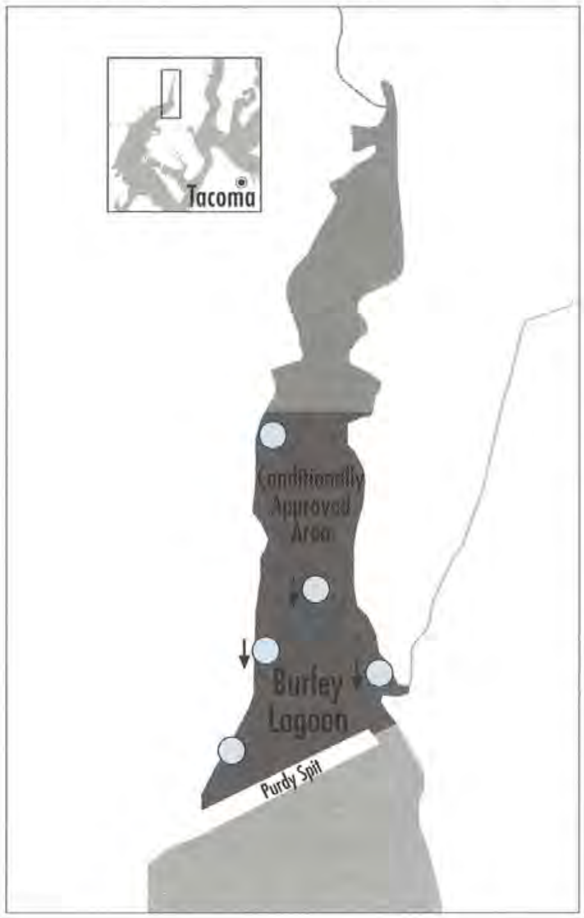


Figure 42. Burley Lagoon Compliance with Fecal Coliform Standards (January 1995, through December, 1996) and Trends in Fecal Contamination (January, 1995 through December, 1996).

Complied ◐ Failed

Pie charts indicate fraction of sampling dates with compliance. (In this legend, for example, half of the samples complied and half failed.)

Compliance with growing area standards requires meeting two criteria:

1. Geometric mean not to exceed 14 fecal coliform per 100ml.
2. Ninetieth percentile not to exceed 43 fecal coliform per 100ml.

↑ Increasing geometric mean fecal coliform concentrations

↓ Decreasing geometric mean fecal coliform concentrations

Figure 41 also shows that fecal coliform levels at all 10 sampling sites in Oakland Bay have decreased since 1991. The observed decrease may be explained, in part, by the partial renovation of the city's sewer system.

Burley Lagoon. The Department of Health monitored five stations in Burley Lagoon from January 1991 to December 1996. Water quality at all five stations complied with the applicable National Shellfish Sanitation Program standard from January 1995 to December 1996 (Figure 42). An analysis of trends (also shown in Figure 42) since January 1995 showed decreasing levels of fecal coliform at three mid-bay sites. Two other stations (one at the northern boundary of the conditionally approved zone and one in the southwest corner) showed no significant change.

Summary. The Department of Health's detailed analysis of monitoring data from these three areas suggests that fecal coliform contamination can be held in check through targeted, local actions to find and fix pollution problems. Henderson Inlet and Oakland Bay highlight another point as

well: continued evaluation is needed to maintain and improve water quality in the face of increasing development of Puget Sound's watersheds and shoreline.

Fecal Contamination in Nearshore Areas of King County

Nearshore Waters. The King County Department of Natural Resources monitors fecal coliform bacteria in nearshore waters at 24 King County beaches. Levels of fecal contamination measured at 13 beaches from 1994 to 1996 were often higher than the state's marine water quality standards. Freshwater runoff from watersheds surrounding Puget Sound influences the condition of these intertidal areas. Consequently, levels at stations tended to be higher than state standards during the winter months with high rainfall, particularly near streams and other sources of freshwater runoff.

Semi-enclosed bays and shorelines away from the strong tidal mixing of the open Sound retain fresh water for a longer period of time. As a result, these areas also tend to have high counts of fecal coliform bacteria. The Tramp Harbor fishing pier on Vashon Island, for example, tended to have elevated bacteria counts, whereas a Department of Health sampling site further offshore complied with the applicable National Shellfish Sanitation Program standard. Intertidal stations with the lowest fecal coliform levels were those near Richmond Beach, West Point, Seahurst Park, the north side of Alki Point, and Fay Bainbridge State Park. Stations that consistently exceeded the standards between 1994 and 1996 were in the Carkeek Park area, Golden Gardens, inner Shilshole Bay and the Seattle waterfront.

Shellfish. From 1994 to 1996, King County scientists collected and analyzed shellfish from 13 beaches in King County for fecal contamination in shellfish tissue. Samples were collected from eight beaches between May and September and from the other five beaches in July only. Scientists collected the most prevalent edible species of shellfish at each beach. In contrast to water samples, shellfish tissue collected in July and August had higher fecal contamination levels than samples collected in the other months. Higher levels in July and August may be due to increased filter feeding by bivalves during optimal summer growing conditions.

Fecal Contamination in Puget Sound's Open Marine Waters

Department of Ecology Monitoring. The Department of Ecology analyzes the geographic distribution of fecal contamination in the open marine waters of Puget Sound. Relatively high levels of fecal contamination were measured throughout Puget Sound: including Bellingham Bay, Possession Sound, Elliott Bay, Commencement Bay, Sinclair Inlet, Liberty Bay, Budd Inlet and Hammersly Inlet/Oakland Bay (Figure 43).

Many of the stations with measurements of greater than 43 fecal coliform colonies per 100 ml of water are associated with major river discharges to Puget Sound. These rivers, including the Nooksack, Snohomish, Duwamish, Puyallup and Deschutes rivers, may be significant sources of pathogens into Puget Sound.

Other areas with relatively high levels of fecal contamination include inlets and bays where water circulation and mixing is limited. Hammersly

Pollution Controls at the Three Growing Areas

State and local government agencies investigated the shellfish growing areas discussed in this section to locate and correct problems that led to shellfish harvest restrictions. Failing on-site sewage systems and stormwater runoff were polluting each area. Poor animal-keeping practices at farms were contributing to pollution in Henderson Inlet and Burley Lagoon. Stormwater contaminated by sewage (from Shelton's aging sewer system) was a major problem in Oakland Bay.

Each area is taking corrective actions, including:

- Conservation districts helped rural landowners keep animal waste out of the water.
- Local health departments searched for failing on-site sewage systems and monitored their repair or replacement.
- In Oakland Bay, Shelton is renovating the sewer system to reduce the intrusion of groundwater into sewer pipes and eliminate rain-related sewer overflows.
- Several enterprises in Purdy repaired their on-site sewage systems.

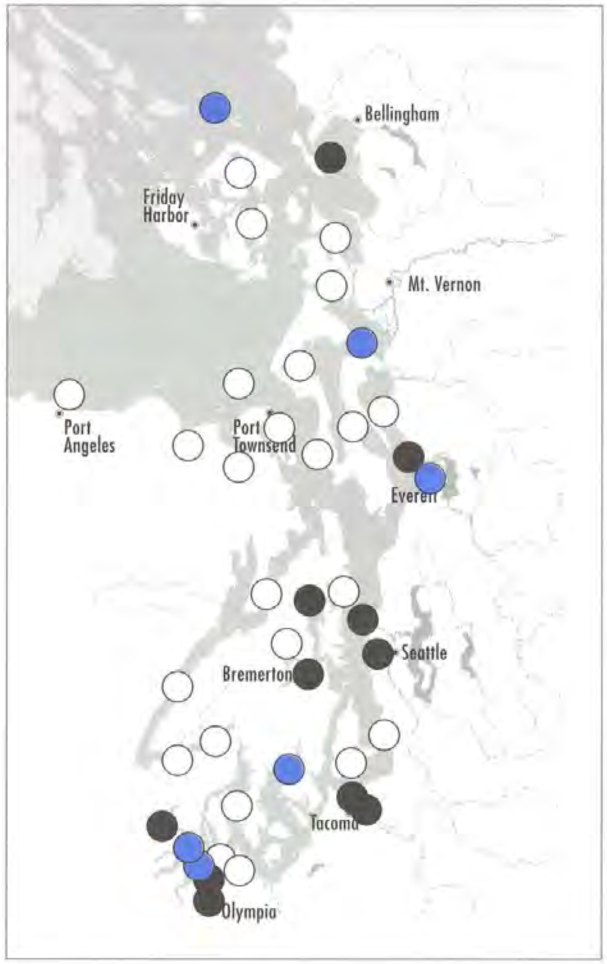
Although many existing pollution sources were cleaned up, it is unclear how increasing population will affect these areas. Population in the Henderson Inlet watershed increased from 20,000 to over 50,000 between 1984 and 1994. In the Oakland Bay watershed, a population increase from 18,000 in 1990 to nearly 25,000 in 2000 is projected. The city of Shelton proposes to expand its sewer system to accommodate an increase from 7,000 people to 17,000 by 2014. Population in south Kitsap County (which contains most of the Burley Lagoon watershed) is projected to grow at at rate of 1.8 percent per year from 1992 through 2012.

Figure 43. Distribution of Fecal Contamination Problems in Puget Sound's Open Waters, 1990-1995.

High (>43 org/100ml) at least once

Moderate (between 14 and 43 org/100ml) at least once

Always low (<14 org/100ml)



Inlet/Oakland Bay, Sinclair Inlet and Liberty Bay are among these areas. The limited mixing of waters in such areas allows fecal contamination from shoreline sources to be detected in open-water areas.

Ecology measured high levels of fecal contamination at one station that is not close to a river discharge and does not have limited circulation and mixing: the station in the main stem of Puget Sound's central basin near Seattle. Conditions at this station might indicate contamination by treated wastewater from King County's West Point treatment plant; fresh water from the Cedar River and Lake Washington watershed via the Lake Washington Ship Canal, or fresh water flowing from the Green/Duwamish River watershed into nearby Elliott Bay.

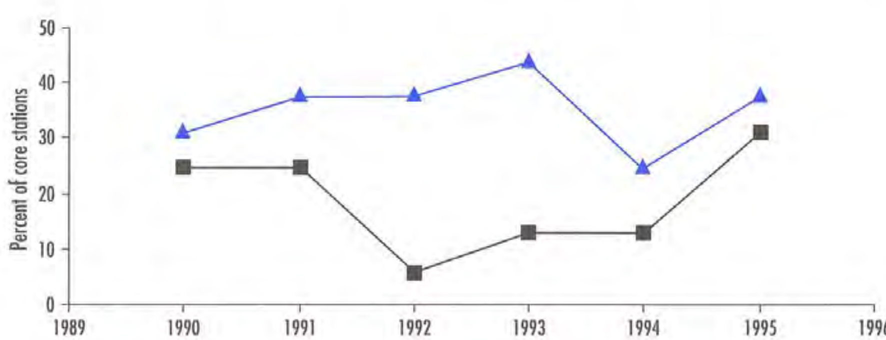
Figure 44 shows how fecal contamination at Ecology's long-term sampling stations in open marine waters of Puget Sound has varied.This sampling indicates no apparent improving or declining trends over time.

King County Monitoring. The King County Department of Natural Resources monitors offshore marine waters at 19 sites throughout King County. Some stations are located away from known discharges to assess baseline conditions, others are placed near sewer outfall pipes to assess

Figure 44. Percentage of the 16 Long-Term Puget Sound Marine Water Sampling Stations with Fecal Coliform Above Standard.

Measured concentrations >14 org/100 ml

Measured concentrations >43 org/100 ml



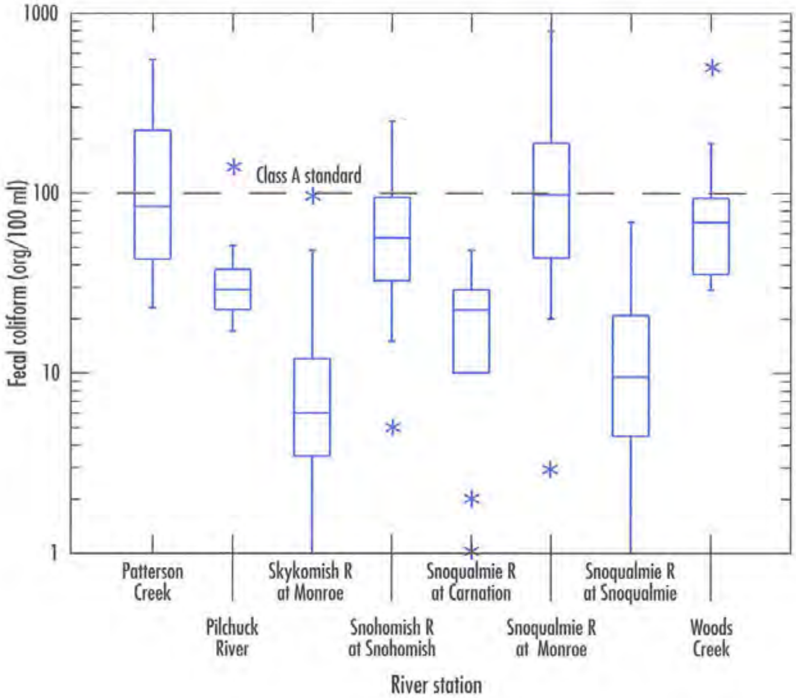


Figure 45. Distribution of Fecal Contamination at Snohomish River Basin Stations.

Box Plots

Scientists use box plots to summarize distributions of data. Read a box plot as follows:

- An extreme measured value that fell outside the expected distribution of measurements.
- Upper end of measured range
- 75th percentile
- Median
- 25th percentile
- Lower end of measured range

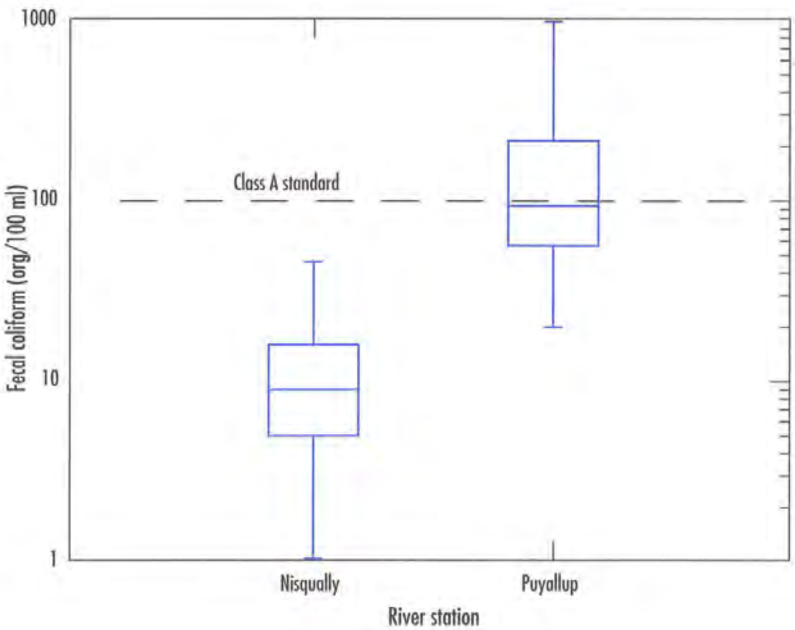


Figure 46. Distribution of Fecal Contamination at Puyallup and Nisqually River Stations.

effects from point source pollution. Monitoring results from 1994 to 1996 showed low or nondetectable levels of fecal coliform bacteria at most sampling stations. Measured concentrations fell well below the state's standards for marine water quality at all sites except a station near the mouth of the Lake Washington Ship Canal. This station consistently had elevated fecal coliform levels that may be attributed to higher levels in the Lake Washington-Lake Union system, the major source of fresh water into Shilshole Bay.

What are Conditions near West Point?

The Department of Ecology and the King County Department of Natural Resources independently characterize water near West Point in the vicinity of the discharge from the county's wastewater treatment plant. Ecology's data from 1990 to 1995 identify the West Point location as having high fecal contamination. Conversely, King County's data from 1994 through 1996 identify this location as one of many that meet state standards for water quality.

Upon closer inspection of the data, we see that both monitoring programs have measured sporadic, high concentrations of fecal coliform bacteria at this location. Similar to high values Ecology measured in 1991, a King County measurement in January 1996 exceeded 50 fecal coliform colonies per 100 ml of water.

King County's approach to data analysis is similar to that used by the Department of Health in its application of the National Shellfish Sanitation Program standards: it combines the results of 30 consecutive measurements to develop values that are compared to appropriate water quality criteria. By this method of evaluation, the West Point station was identified as meeting the applicable standard.

To provide an environmental assessment, Ecology takes a different approach to analyzing the data, comparing individual measurements of fecal contamination to the values in the water quality criteria. Using this approach, Ecology identifies any station with at least one measurement of fecal coliform above 43 fecal coliform colonies per 100 ml of water (including the West Point station) as having a "relatively high" level of fecal contamination.

This example highlights a difficulty in presenting data summaries throughout the *Puget Sound Update*. One must evaluate the underlying data, and the methods of data analysis to understand conclusions. In this case, by looking at data from the perspectives of both Ecology and King County, we can conclude that the open marine waters at West Point are subject to sporadic, high levels of fecal contamination. Uncertainty exists as to the correct scientific and management interpretation of these sporadically high levels.

Fecal Contamination in Puget Sound Basin Rivers and Streams

Fecal contamination is common and fairly widespread in the rivers and streams in the Puget Sound basin (Hallock et al., 1996) as is illustrated by the Department of Ecology's results from freshwater monitoring for the Snohomish River basin and south Puget Sound drainages.

Figure 45 shows the range of contamination by fecal coliform bacteria in samples collected in the Snohomish River basin from October 1993 through September 1996. Ecology scientists identified fecal coliform contamination as the primary water quality problem in this basin during these three years. Trend analysis of data collected from the long-term monitoring stations in this basin since September 1987 showed no significant improvement, even with adjustments for differences in flow among years.

Samples from the Puyallup River and Chambers and Clover creeks regularly exceeded fecal coliform standards. Figure 46 shows the range of fecal coliform contamination in the Nisqually and Puyallup rivers. Analysis of trends indicated no significant changes in fecal coliform numbers measured at the long-term monitoring stations on the Nisqually and Puyallup rivers.

Half or more of all Puget Sound river and stream stations monitored by Ecology from 1984 to 1996 had measured concentrations of fecal coliform bacteria above 100 fecal coliform colonies per 100 ml of water (Figure 47). The percent of stations with these relatively high values varied considerably from year to year. As with the examples discussed earlier for individual river basins, no long-term trend was evident for all Puget Sound basin stations.

FINDINGS — NUTRIENTS AND EUTROPHICATION IN PUGET SOUND

The Department of Ecology evaluates nutrient-related problems and eutrophication in Puget Sound through its marine and freshwater monitoring programs. The King County Department of Natural Resources also investigates potential eutrophication problems in the marine waters of central Puget Sound.

Nutrients in Puget Sound's Marine Waters

Assessing nutrient contamination in marine waters is complicated. A given concentration of a nutrient, such as nitrate or ammonium, in Puget Sound represents the balance of nutrients that enter the ecosystem and nutrients that are consumed by the phytoplankton community. Despite excess loadings caused by human activities, marine waters may not have elevated concentrations of nutrients if phytoplankton consume the nutrients at a high rate. Because of the relationships among nutrient concentrations and the use and cycling of nutrients by phytoplankton, scientists cannot simply use the occurrence of high concentrations to identify nutrient-related water quality problems. Instead, scientists study the availability of nutrients to identify areas where low concentrations indicate that nutrients may be limiting phytoplankton productivity. These areas might be sensitive to water quality degradation because additional nutrients supplied to the system could increase productivity.

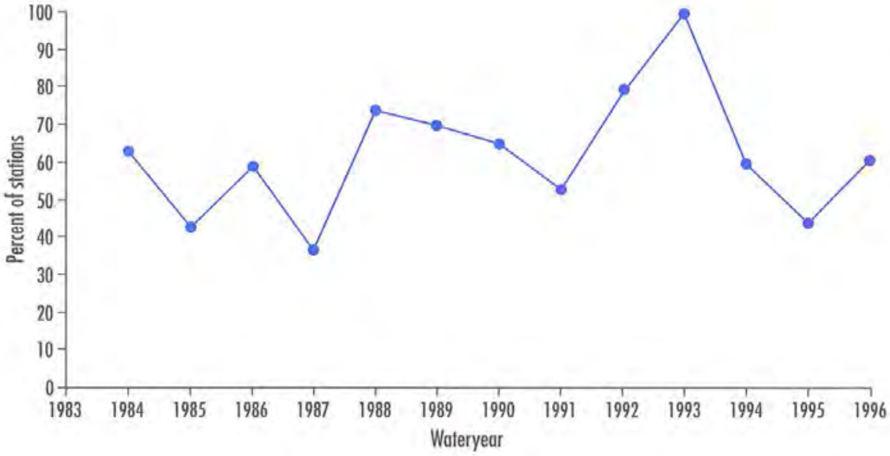


Figure 47. Percentage of long-term Puget Sound basin river and stream sampling stations with fecal coliform above standard.

In marine systems, nitrogen, rather than phosphorus, is typically the nutrient that limits productivity. Consequently, Puget Sound scientists review monitoring results for evidence of low or undetectable levels of nitrogen. Ecology scientists, for example, interpret three or more consecutive months of dissolved inorganic nitrogen concentrations below the level of detection as an indication that an area might be nutrient-limited and is sensitive to human-induced eutrophication.

In addition to identifying areas of nutrient sensitivity due to characteristics of the marine system, scientists also attempt to identify areas where major human-caused loadings may be occurring. High ammonium concentrations often, though not always, indicate human-influenced sources of nitrogen nutrients to Puget Sound.

Ecology's Marine Water Monitoring. Figure 48 shows the geographic distribution of areas monitored by Ecology where nutrient loadings may be of concern in Puget Sound. Among Ecology's

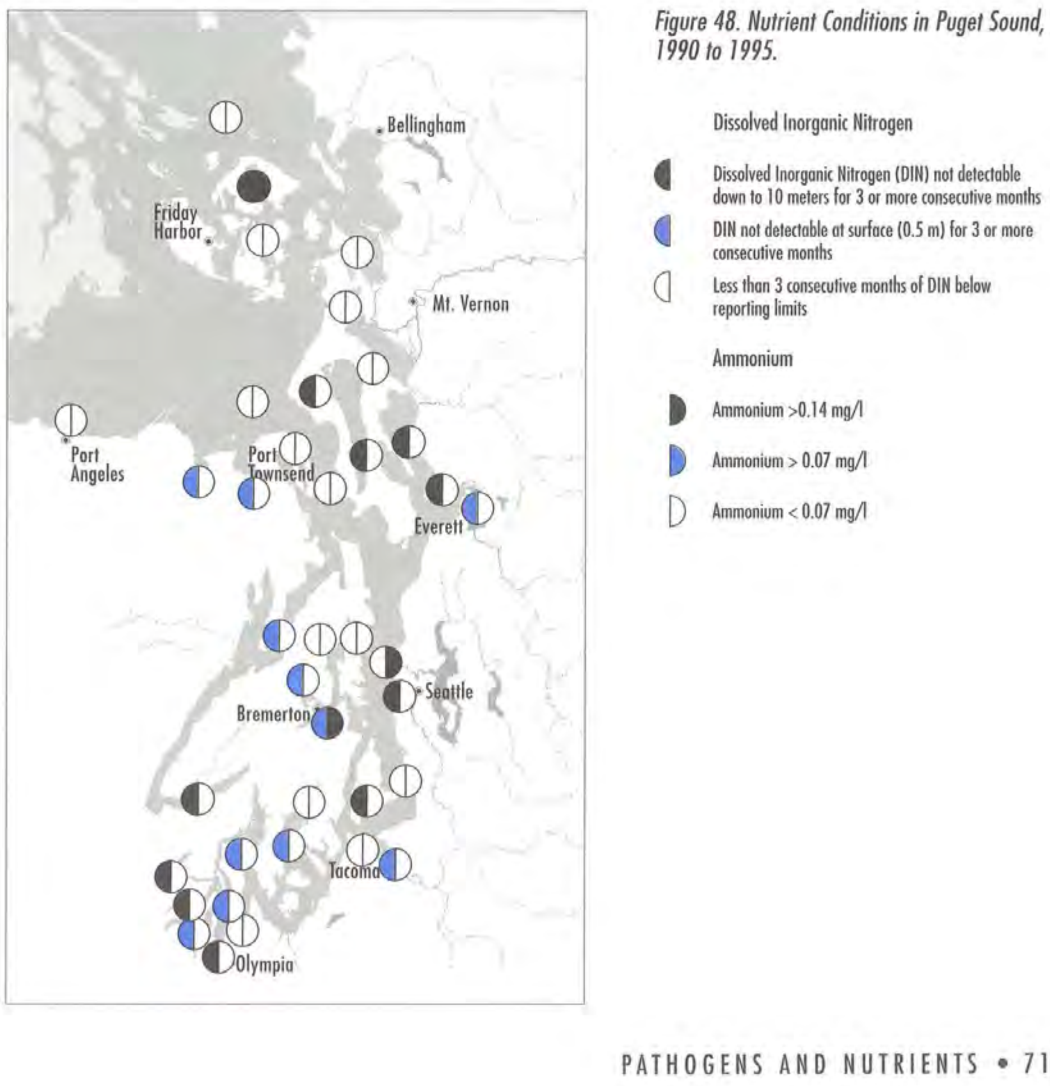


Figure 48. Nutrient Conditions in Puget Sound, 1990 to 1995.

Table 5. Areas of Puget Sound Where Eutrophication May be a Concern.

Location	Dissolved Oxygen(1)	Stratification Intensity	Nutrient Conditions(2,3)
Budd Inlet	Very low	Persistent	Low DIN & Moderate NH_4^+
Penn Cove	Very low	Persistent	Low DIN & Moderate NH_4^+
Southern Hood Canal	Very low	Persistent	Low DIN
East Sound	Very low	Seasonal	Low DIN & High NH_4^+
Possession Sound	Low	Persistent	Low DIN & Moderate NH_4^+
Port Susan	Low	Persistent	Low DIN
Saratoga Passage	Low	Persistent	Low DIN
Elliott Bay	Low	Persistent	Low DIN
Sinclair Inlet		Persistent	Moderate DIN & High NH_4^+
Commencement Bay		Persistent	Moderate DIN & High NH_4^+
Hammersly Inlet		Episodic	Low DIN & Moderate NH_4^+
Totten Inlet		Weak	Low DIN & Moderate NH_4^+
Eld Inlet		Seasonal	Moderate DIN & NH_4^+
Case Inlet		Seasonal	Moderate DIN & NH_4^+
Quartermaster Harbor		Seasonal	Low DIN
Dyes Inlet		Seasonal	Moderate DIN
Sequim Bay		Seasonal	Moderate DIN
Discovery Bay		Weak	Moderate DIN

(1) Ecology noted dissolved oxygen as "very low" if any measurement was below 2 mg/l; as "low" if any measurement was below 5 mg/l (but none were below 2 mg/l). Low and very low dissolved oxygen can stress marine organisms.

(2) DIN = dissolved inorganic nitrogen; "low" indicates DIN was not detectable down to 10 m for three or more consecutive months; "moderate" indicates that DIN was not detectable at the surface for three or more consecutive months.

(3) NH_4^+ = ammonium; "high" indicates at least one Ecology measurement above 0.14 mg/l; "moderate" indicates at least one Ecology measurement from 0.07 to 0.14 mg/l.

Budd Inlet—Evaluating Nitrogen Removal and its Effects on Puget Sound

Through its program for monitoring marine waters, the Department of Ecology conducted a focused study of Budd Inlet during 1992, 1993 and 1994. The goal was to assess whether the efforts by the regional sewage treatment plant to reduce nutrient loading in early 1994 would immediately change concentrations of nutrients, phytoplankton and dissolved oxygen in Budd Inlet.

Low concentrations of dissolved oxygen in the bottom waters of the inner bay are a persistent problem for Budd Inlet. This condition is the result of the decay of large phytoplankton blooms and strongly stratified water. Adding nutrients that may stimulate phytoplankton can worsen the situation greatly.

Concentrations of nitrate and ammonium in the water were consistently lower in 1994 than in the previous years. However, no change was apparent for concentrations of chlorophyll and near-bottom dissolved oxygen. Weather conditions that were conducive to phytoplankton appeared to have an overriding influence on stratification and phytoplankton abundance, and hence on near-bottom dissolved oxygen in 1994. Evidence that nutrients were limiting phytoplankton growth in 1994 indicates that growth would have likely been higher had the sewage treatment plant not implemented nitrogen removal.

sampling locations, concentrations of nitrogen are low for a number of months each year in most inlets and bays with poor water mixing. Some of these bays also have relatively high concentrations of ammonium. This combination indicates an area's sensitivity to human-caused eutrophication. Where these two factors coincide—especially in south Puget Sound west of Nisqually Reach, and in Commencement Bay, Sinclair Inlet, Possession Sound, Penn Cove and East Sound—algae blooms and degraded water quality might be seen.

Table 5 combines the information on areas that are sensitive to problems with the characterization of stratification intensity and low concentrations of dissolved oxygen from the earlier discussion of the Sound's physical environment (page 34). The locations listed in Table 5 may require additional investigation to help us to better understand eutrophication processes and problems in Puget Sound.

King County's Marine Water Monitoring. From 1994 to 1996, King County monitored nutrient conditions at five marine water stations. A King County open-water sampling station (off Point Jefferson) showed seasonal patterns of nitrate depletion, particularly at the surface (Figure 49). Concentrations occasionally fell below the detection limit, though not for three or more

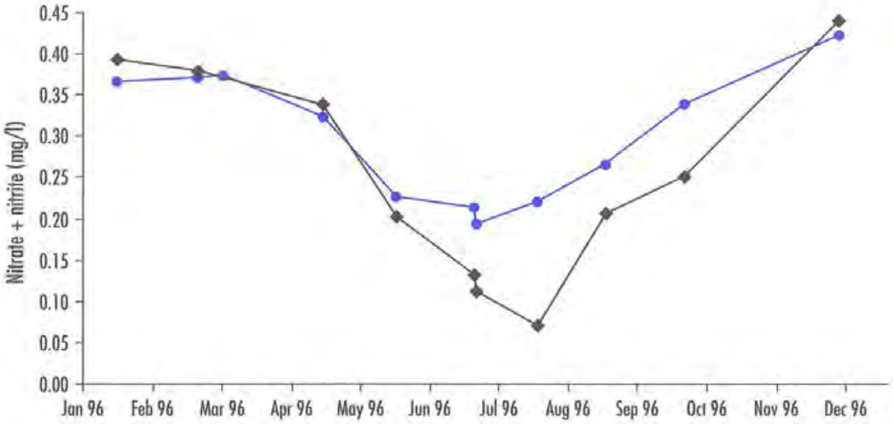


Figure 49. Nitrate Conditions in Central Puget Sound 1994 to 1996—King County DNR Monitoring.

consecutive months (the criteria used by Ecology scientists to assess sensitivity to human-caused eutrophication). Nitrate concentrations were generally greatest in winter when less nutrients are consumed by the relatively scarce phytoplankton and when freshwater runoff is highest. Phytoplankton consumption is restricted to the depths which get enough light for photosynthesis. This is one reason why nitrate concentrations are greater in deeper water (Figure 49).

Ammonium concentrations measured at all five King County monitoring stations and depths were below the detection limit except between June and August. King County measured one concentration above 0.14 mg/l and a few above 0.07 mg/l. These summer concentrations of ammonium tended to increase with depth. King County scientists believe that this profile of elevated levels of ammonium was associated with the decay of phytoplankton settling out of the water column. (Higher ammonium concentrations were measured in 1994 when high chlorophyll-*a* levels were also noted).

Nutrients in Puget Sound's Rivers and Streams

Elevated concentrations of nutrients in Puget Sound streams and rivers can cause problems related to eutrophication in the fresh waters of the basin and in the receiving bays and inlets of Puget Sound. As an example of the type of data available from the Department of Ecology, this section discusses some monitoring results from the Snohomish River basin and south Puget Sound rivers.

Ecology's long-term monitoring data from the Snohomish River basin showed no apparent trends over time in nitrate concentrations for the Skykomish and Snoqualmie rivers, although concentrations in the Snoqualmie River appeared to be somewhat elevated (Figure 50). Concentrations downstream in the Snohomish River appeared to be rising. This increase probably resulted from growing nitrate loadings occurring between the Snoqualmie and Skykomish stations and the Snohomish River station. The nitrate load at upstream monitoring stations (Skykomish, Snoqualmie and Pilchuck rivers) does not account for the downstream measurements in the Snohomish river (Figure 51). The difference between upstream and downstream measurements indicates that a substantial

USGS Estimates of Nutrient Loadings to Puget Sound

The U.S. Geological Service (USGS) will publish estimates of the transport of nutrients from rivers to Puget Sound in a report and related fact sheet in 1998. Part of the U.S. Geological Survey National Water Quality Assessment Program estimates were based on data collected by the USGS and other agencies from 1980 to 1993.

Figure 50. Nitrate Concentrations in the Snoqualmie and Skykomish Rivers.

■ Snoqualmie

● Skykomish

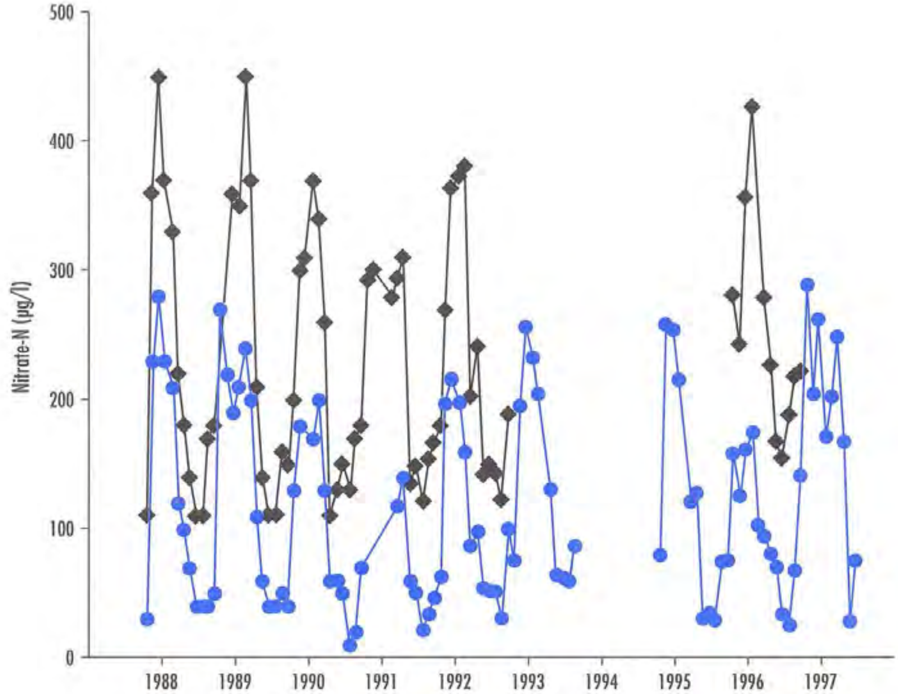
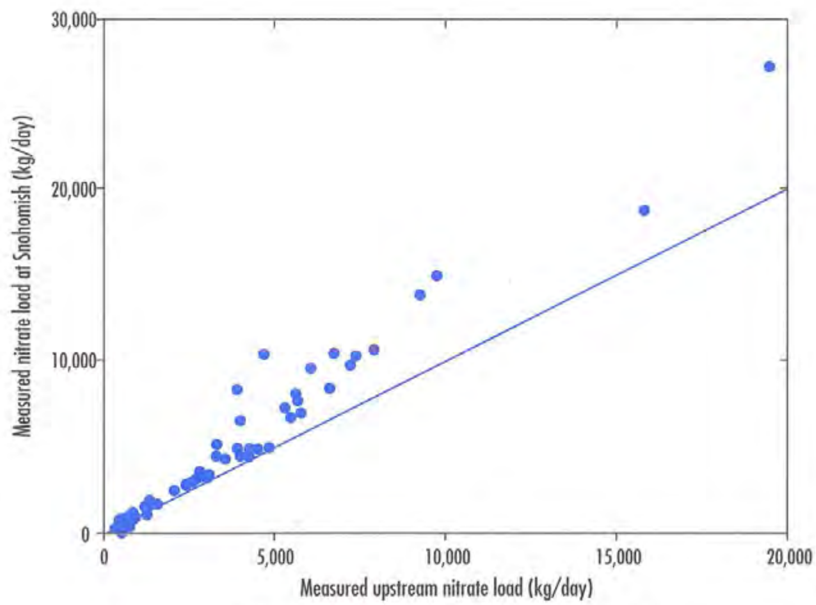


Figure 51. Flux of Nutrients in the Snohomish River Compared to Flux Measured Upstream.



The diagonal line indicates equivalent loads measured upstream and at Snohomish. The data values above the line reflect a greater load at Snohomish than is accounted for by upstream measurements.

nitrate load enters the river between the sampling stations. The difference between upstream and downstream loads increased with water flow, suggesting that the mid-basin source was associated with runoff rather than a steady input.

Total phosphorus concentrations in the Snoqualmie and Skykomish rivers increased over time, but no significant change was observed in concentrations in the Snohomish River. Phosphorus tends to be physically associated with sediment river particles. As expected, concentrations of suspended solids increased at the two stations where Ecology observed increasing levels of phosphorus.

Concentrations of total phosphorus and suspended solids in the Nisqually and Puyallup rivers were much higher than in most Puget Sound rivers. These higher concentrations might reflect the rivers' glacial origins rather than human-caused impacts. Among nutrients monitored in these rivers, only concentrations of ammonia changed significantly over time, declining over the period of record at the Puyallup River station.

USING MONITORING DATA TO SUPPORT MANAGEMENT DECISIONS

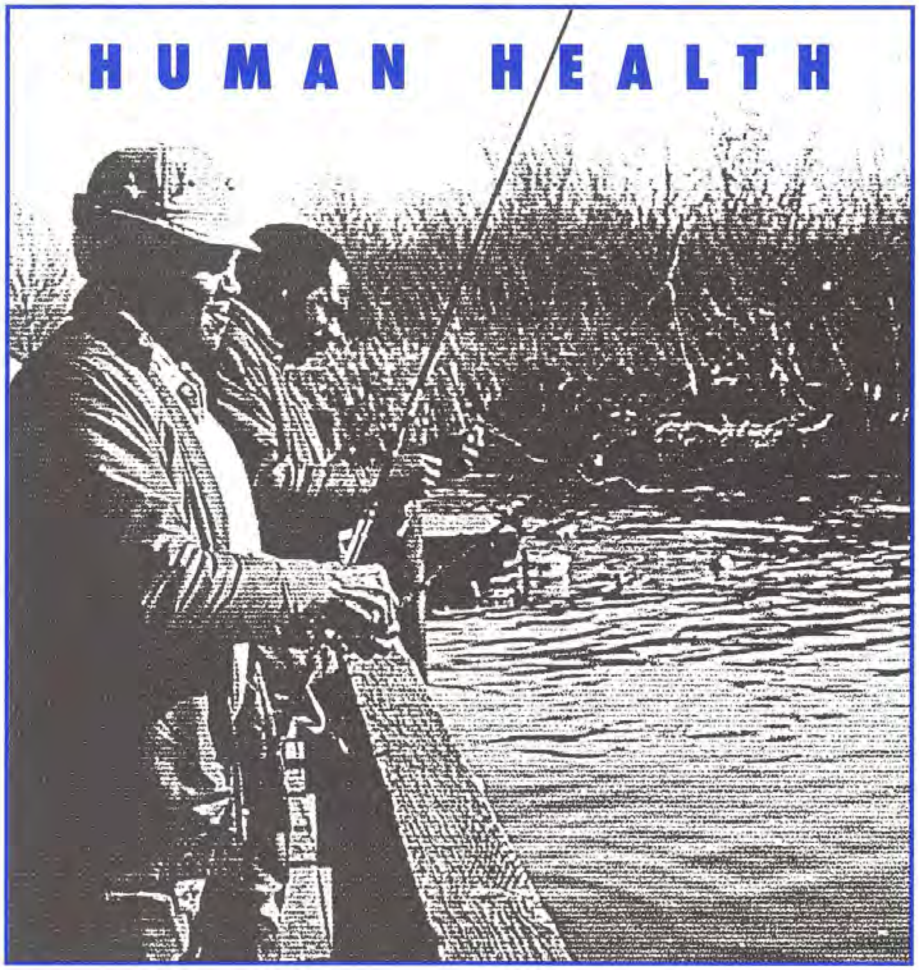
Classifying Shellfish Growing Areas

The chapter on human health (beginning on the next page) explains how the Department of Health uses fecal coliform monitoring data to classify shellfish growing areas. These data and information about known sources of contamination in the vicinity of growing areas are crucial to protecting the safety of shellfish harvested from Puget Sound.

Discharges of Treated Wastewater to Budd Inlet

The Lacey, Olympia, Tumwater, Thurston County (LOTT) wastewater management partnership is assessing the effects of wastewater discharges on the waters and sediments of Budd Inlet. Consultants to the LOTT partnership are using the Department of Ecology's long-term monitoring of Budd Inlet and the agency's 1992 to 1994 focused study along with intensive investigation and modeling to develop an understanding of how Budd Inlet might respond to increased nutrient discharges in the future. This information is helping the LOTT partnership develop a long-term plan to manage wastewater. It will also help regulatory agencies decide on appropriate conditions and restrictions to place on permits to discharge wastewater to Budd Inlet.

HUMAN HEALTH



This report examines many of the stresses that threaten Puget Sound resources and the effects of these stresses on marine organisms, biological communities and habitats. This chapter's focus on threats to human health rounds out the picture of how conditions in Puget Sound affect all of the region's inhabitants.

Conceivably, toxic contaminants in Puget Sound put humans at risk of cancer and other illnesses when concentrations accumulate and biomagnify in fish, shellfish and other resources that humans consume. Pathogenic microorganisms and natural biotoxins in the environment—especially in shellfish—also threaten human health. The threats from toxic contaminants, pathogens and biotoxins share a common characteristic: eating shellfish and finfish appears to be the most significant pathway by which humans can be exposed to harmful contaminants.

Our society has developed safeguards to limit human-health risks from exposures to harmful agents in the environment. Laws and government programs exist to ensure the safety of food and to protect against environmental contamination. These laws and programs sometimes work by restricting or curtailing human uses of Puget Sound's resources for food supply or recreational opportunity. Some of the discussions that follow focus on these restrictions.

Toxic Contaminants

The most significant threat to human health from contaminated resources in Puget Sound is thought to be associated with consuming fish which have accumulated contaminants from water, sediments or prey. As discussed in the chapter on toxic contamination (page 37), the Department of Fish and Wildlife (Fish and Wildlife) monitors contaminants in several fish species, including English sole, quillback and copper rockfish, and chinook and coho salmon—all species that are routinely consumed by Puget Sound residents.

Risk assessments and health analyses have not been performed to assess the risks associated with consuming Puget Sound seafood. Such assessments are beyond the scope of this *Puget Sound Update*. However, scientists with Fish and Wildlife have compared concentrations of contaminants in fish collected from Puget Sound between 1989 and 1993 with concentrations in fish from the lower Columbia River. A risk assessment (TetraTech, 1996) and health analysis (Laflamme and Duncan, 1996) of the lower Columbia River identified potential human-health concerns from consuming fish from that river. Scientists assume that fish consumption patterns and other exposure characteristics for Puget Sound are similar to those used in the lower Columbia River analyses. This allows a direct comparison of contaminant concentrations observed in Puget Sound fish to levels shown to pose a health concern in the lower Columbia River.

In the lower Columbia River risk assessment, Tetra Tech (1996) concluded that concentrations of PCBs, mercury, arsenic and DDE (a product of the environmental breakdown of the pesticide DDT) in fillets of some fish were potentially harmful to human health. The Washington Department of Health and the Oregon Health Division completed a health analysis for the same set of fish tissue samples. Their analysis, using different assumptions about consumption rates and different toxicity assessments than Tetra Tech (1996), concluded that PCB concentrations in many lower Columbia River fishes and DDT/DDE concentrations in carp exceed criteria considered safe for human health, but concentrations of arsenic and mercury were not a health concern (Laflamme and Duncan, 1996).

Scientists with Fish and Wildlife documented concentrations of PCBs, mercury, arsenic and DDE in Puget Sound fish from 1989 through 1993 that were similar to or higher than concentrations in fish from the lower Columbia River. This suggests that consuming fish from Puget Sound at rates similar to those assumed in the Columbia River studies may also be harmful to human health. Additional comparisons of PCB and mercury levels in fish from Puget Sound and the lower Columbia River follow to provide perspective. These comparisons are not meant to substitute for a risk assessment or health analysis. Fish and Wildlife recommends conducting species and location-specific risk assessments or health analyses to better estimate the effects of eating Puget Sound fish on human health.

PCBs. From 1989 to 1993, mean concentrations of PCBs observed in the fillets of English sole caught in urban and industrialized bays of Puget Sound ranged from 32 to 111 micrograms per kilogram ($\mu g/kg$). These concentrations are similar to the highest PCB concentrations detected in fillets of carp, white sturgeon and largescale sucker from the lower Columbia River. For the same time period, average PCB concentrations in Puget Sound chinook and coho salmon were 50 $\mu g/kg$ and 27 $\mu g/kg$, respectively. These concentrations are also higher than those measured in Columbia River fish.

Starting in 1995, the Puget Sound Ambient Monitoring Program (PSAMP) sampled rockfish from two urbanized locations, Elliott Bay and Sinclair Inlet. Average concentrations of total PCBs in rockfish from these areas were significantly higher than rockfish sampled from non-urban areas of Puget Sound between 1991 and 1996. Furthermore, average concentrations of total PCBs in rockfish from urbanized areas were higher than levels observed for English sole from the same locations.

Based on direct application of the results of the lower Columbia River risk assessment (TetraTech, 1996) to average PCB concentrations in Puget Sound fishes, people consuming English sole from urban areas of Puget Sound or salmon from any Puget Sound location at a rate of 54 grams of fish per day (an average consumption rate for recreational fishers) face an estimated risk of increased incidence of cancer between 1-in-1,000 and 1-in-100,000. At higher consumption rates (for example, 176 grams of fish per day, the average amount consumed by Columbia River Native Americans), PCB exposure would be high enough to potentially cause other (non-cancer) types of health effects. Similarly, the health protective value for PCBs used in the lower Columbia River health analyses (Laflamme and Duncan, 1996), which assumes that people consume 140 grams of fish per day, is exceeded by average PCB concentrations in chinook salmon from any Puget Sound location, English sole from urban areas like the Duwamish River and Sinclair Inlet, and rockfish from urban areas like Elliott Bay and Sinclair Inlet.

Mercury. The mean concentration of mercury in fillets from quillback rockfish collected at non-urban Puget Sound locations between 1991 and 1993 was 0.22 mg/kg. This is higher than concentrations in fish from the lower Columbia River (mean concentrations in white sturgeon and largescale sucker were 0.170 mg/kg and 0.153 mg/kg, respectively). Based on direct application of the risk assessment for the lower Columbia River study (TetraTech, 1996), estimated mercury exposures from consuming Puget Sound rockfish would be high enough to cause adverse, non-cancer effects in humans. However, mercury in rockfish at non-urban Puget Sound locations did not exceed the protective criteria for health used in the health analyses for the lower Columbia River study (Laflamme and Duncan, 1996). Mercury concentrations in rockfish collected from other Puget Sound locations in 1995 and 1996 were higher (Fish and Wildlife, unpublished data) and may exceed these protective criteria for health.

Public Health Advisories Based on Toxic Contamination. Public health agencies, including the state Department of Health and local health districts, can issue public health advisories if they find that environmental

conditions, such as contamination of fish by toxic chemicals, pose a human health threat. No comprehensive, up-to-date listing of public health advisories throughout Puget Sound is available.

The Bremerton-Kitsap Health District maintains a list of closure advisories it has issued for areas with known sources of chemical or biological pollution. As of late 1997, the health district advised that eating any species of shellfish, crab, bottomfish and rockfish from the following areas may pose a threat to human health:

- Sinclair Inlet, from Port Washington Narrows west to Gorst
- The west side of Ostrich Bay in Dyes Inlet near Jackson Park
- The head of Dogfish Bay near Keyport
- Eagle Harbor, out to Wing Point

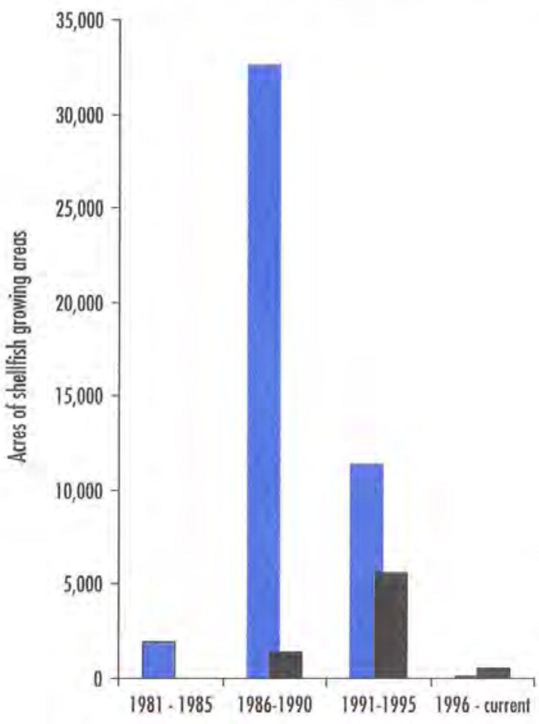
The Bremerton-Kitsap Health District provides this information on its web site (http://www.wa.gov/kitsaphealth). Similar information may be available from other local health districts throughout the Sound.

Pathogens

Commercial Shellfish Beds. The *1994 Puget Sound Update* reported promising trends in the classification of commercial shellfish acreage, which is primarily determined by fecal contamination and exposure to pathogens. From 1994 to 1996 upgrades in classifications continued due to improved water quality, but the Department of Health also issued two major downgrades during this period. Based on improvements in water quality or shoreline conditions at four growing areas, Health upgraded the classifications of a total of 1,150 acres from 1994 to 1996. Upgrades exceeded downgrades in 1996, only the second year in which this has happened. (The other year was 1993). Classifications were downgraded in large areas of Samish Bay in 1994 and in Drayton Harbor in 1995.

Figure 52 depicts the changes in classification of Puget Sound shellfish growing areas from 1981 through 1996. This figure shows that downgrades in recent years have affected much less area than the downgrades in the late 1980s. Upgrades have begun to recover some of the area lost in prior downgrades.

Figure 52. Shellfish Harvest Areas Available for Unrestricted Harvest.



Classification	1994	1996
Open	29	52
Conditionally Open*	4	5
Closed	37	41
Not Yet Classified	72	44

Table 6. Classifications of Recreational Shellfish Beaches in Puget Sound.

*Conditionally open means the areas are closed to harvest after heavy rains, during boating season, or during other events that may elevate fecal coliform levels.

Recreational Shellfish Beach Classifications.
In 1996, Health classified 28 recreational shellfish beaches in Puget Sound, bringing the total number of classified public beaches to 98. Table 6 summarizes the status of these beaches in 1994, when initial classifications were made, and in 1996.

Twenty-three of the 28 newly classified beaches were open to harvest. As of 1996, restrictions (conditionally open or closed) were in place for 47 percent of the classified recreational shellfish beaches. Maps showing the locations and classifications of identified recreational shellfish beds are provided in Health's *1996 Annual Inventory of Commercial and Recreational Shellfish Areas in Puget Sound.*

Biotoxins

Since 1950 the Department of Health has monitored the toxin that causes paralytic shellfish poisoning (PSP) and other biotoxins in shellfish throughout Puget Sound and coastal waters. The agency closes harvest of all shellfish species from an area when PSP biotoxin levels equal or exceed the U.S. Food and Drug Administration (FDA) standard (80 mg toxin/100g shellfish tissue). The PSP biotoxin is produced by naturally occurring phytoplankton. The species that causes PSP in Washington is *Alexandrium catanella*. The PSP biotoxin interferes with nerve function in warm-blooded animals. The primary symptoms of PSP are numbness and tingling of the lips, tongue, face and extremities; difficulty talking, breathing, swallowing and coordinating muscles; and paralysis. Death can occur if the respiratory system becomes paralyzed. Symptoms develop quickly, usually within one to two hours of consumption. There is no known antidote.

PSP blooms are often cyclical, tending to begin in summer and often extending well into fall. The length and intensity of the PSP bloom varies among sites and over years. So it is hard to make comparisons among sites or to detect changes over time.

Blue mussels have been sampled year-round at 24 stations as part of the PSAMP since the late 1980s. Scientists estimated the impact of PSP for each site, shown in Figure 53, by counting the number of days of all PSP blooms that occurred from January 1995 through December 1997. This count of days represents the total PSP impact. A PSP bloom is defined as the time during which PSP levels in shellfish samples were continuously above the FDA standard.

Three sites rated a high PSP impact from 1995 to 1997, meaning that the total duration of PSP blooms ranged from 100 to 120 days. Two sites are on

Pathogenic Organisms from Puget Sound

In the summer of 1997, shellfish growers and consumers were confronted with an especially severe case of contamination by a pathogenic organism that does not originate in human or animal wastes. *Vibrio parahaemolyticus* is a marine bacteria that occurs naturally, typically in low numbers, in the waters of Puget Sound. In the warm months of summer, this bacteria can multiply and accumulate to problem levels in the tissue of shellfish, which, if not fully cooked, can cause sickness in humans. With its natural marine origin, this pathogen shares some characteristics with the plankton species that cause paralytic shellfish poisoning (PSP).

Figure 53. Paralytic Shellfish Poison (PSP) Toxin in Puget Sound Mussels.

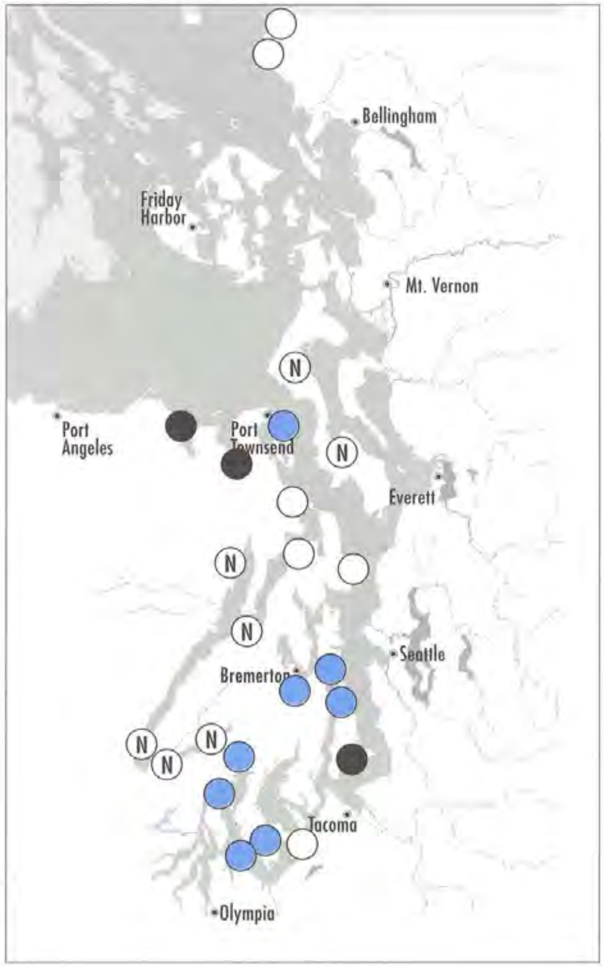
High PSP impact

Moderate PSP impact

Low PSP impact

(N) No PSP impact

(See text for definitions)



the Strait of Juan de Fuca (Sequim and Discovery bays) and a third is in the main basin of Puget Sound (Quartermaster Harbor). These sites typically had summer blooms of varying intensity and duration followed by a die-off in winter.

Eight sites showed a moderate PSP impact for 1995 to 1997, meaning that the total duration of PSP blooms ranged from 30 to 60 days. PSP bloom patterns at Fort Flagler State Park (on Kilisut Harbor near the Strait of Juan de Fuca) and three other stations (Port Orchard in Sinclair Inlet, Manchester, and Southworth in the main basin of Puget Sound) were fairly typical of past years, with occasional summer blooms of low to moderate intensity. However, four sites in south Puget Sound (North Bay, Jarrell Cove, Johnson Point on Nisqually Reach, and Filucy Bay) were placed in the moderate group due to very high levels of the PSP biotoxin during November and December of 1997. In previous years, several south Puget Sound stations experienced only occasional PSP blooms of low intensity and short duration.

Six stations showed a low level of PSP from 1995 through 1997. The total duration of PSP blooms at these stations ranged from 1 to 15 days. Two sites are in or near upper Hood Canal, one in the main basin, one in south Puget Sound, and two in the Strait of Georgia.

The remaining seven stations showed no PSP impact from 1995 through 1997. Five of these stations are in Hood Canal and two (Penn Cove and Holmes Harbor) are in Saratoga Passage. Although Penn Cove has been free of the PSP biotoxin in recent years, intensive blooms occurred there in the late 1970s.

Health's monitoring shows no clear link between frequent occurrence of high concentrations of the PSP biotoxin and urban or industrial development. Sinclair Inlet is the only urbanized area monitored for PSP by the PSAMP. There were fewer instances of high concentrations of the

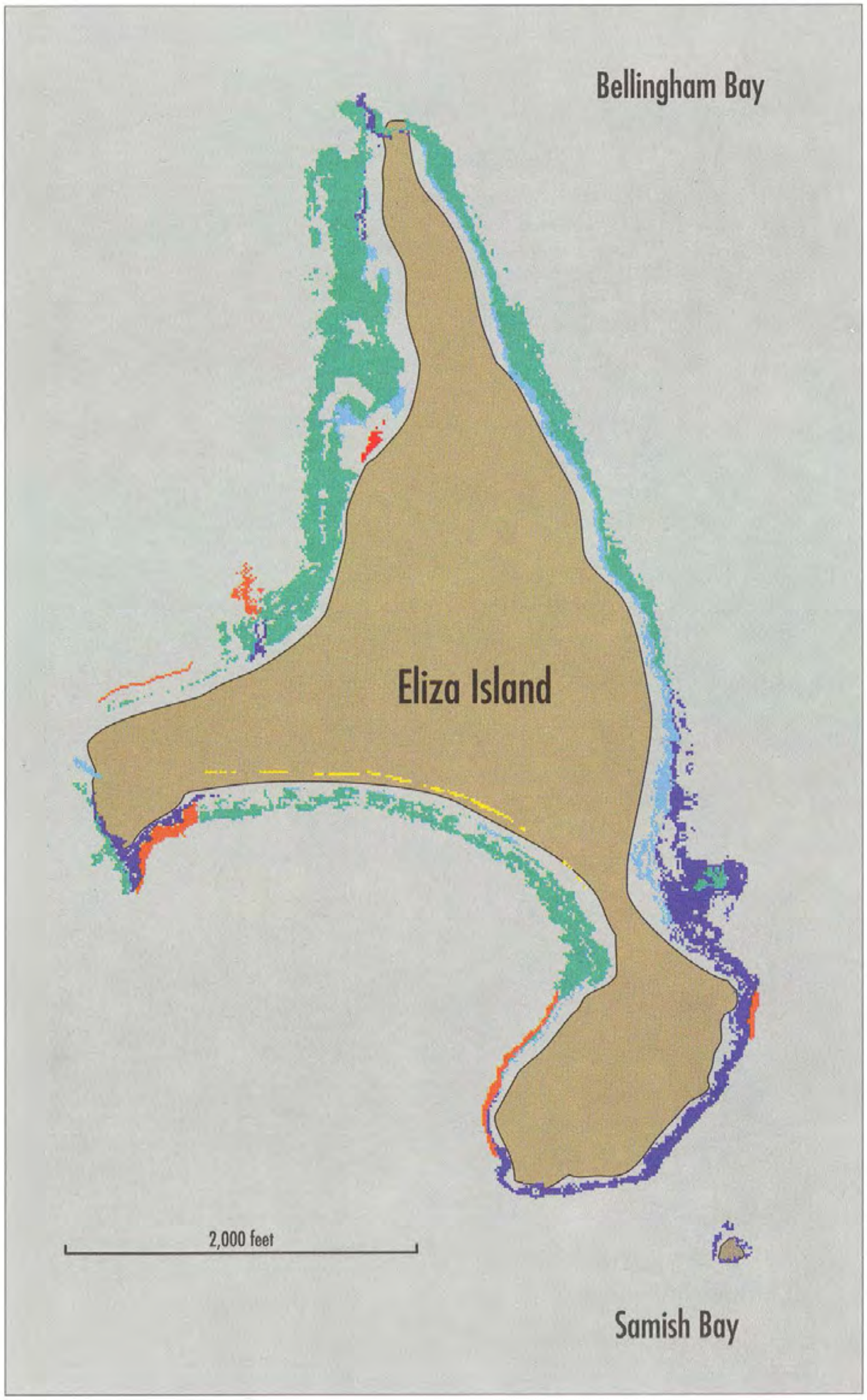
PSP biotoxin in Sinclair Inlet than in other, far less developed areas, including along the Strait of Juan de Fuca and the open coast. In addition, several PSAMP sites in the San Juan Islands showed very high levels of PSP during the summer despite isolation from strong urban influences. (The San Juan sites were not included in Figure 53 because samples are taken only in summer).

Several PSAMP sites with frequent high concentrations of the PSP biotoxins are in semi-enclosed bays (Sequim, Discovery and Filucy bays, and Quartermaster and Kilisut harbors). Conditions in these bays may promote PSP blooms by providing necessary combinations of physical stability, temperature, salinity and nutrients. Other factors are probably also important—PSP blooms also occur frequently in locations where conditions are unlike those of a semi-enclosed bay (for example, along the Strait of Juan de Fuca).

COLOR SECTION

Figure 9. Nearshore Vegetation of Eliza Island in 1995 as Mapped by the Department of Natural Resources. (See page 19).

- Green algae
- Mixed algae
- Eelgrass
- Kelp
- Salt marsh
- Spit or berm



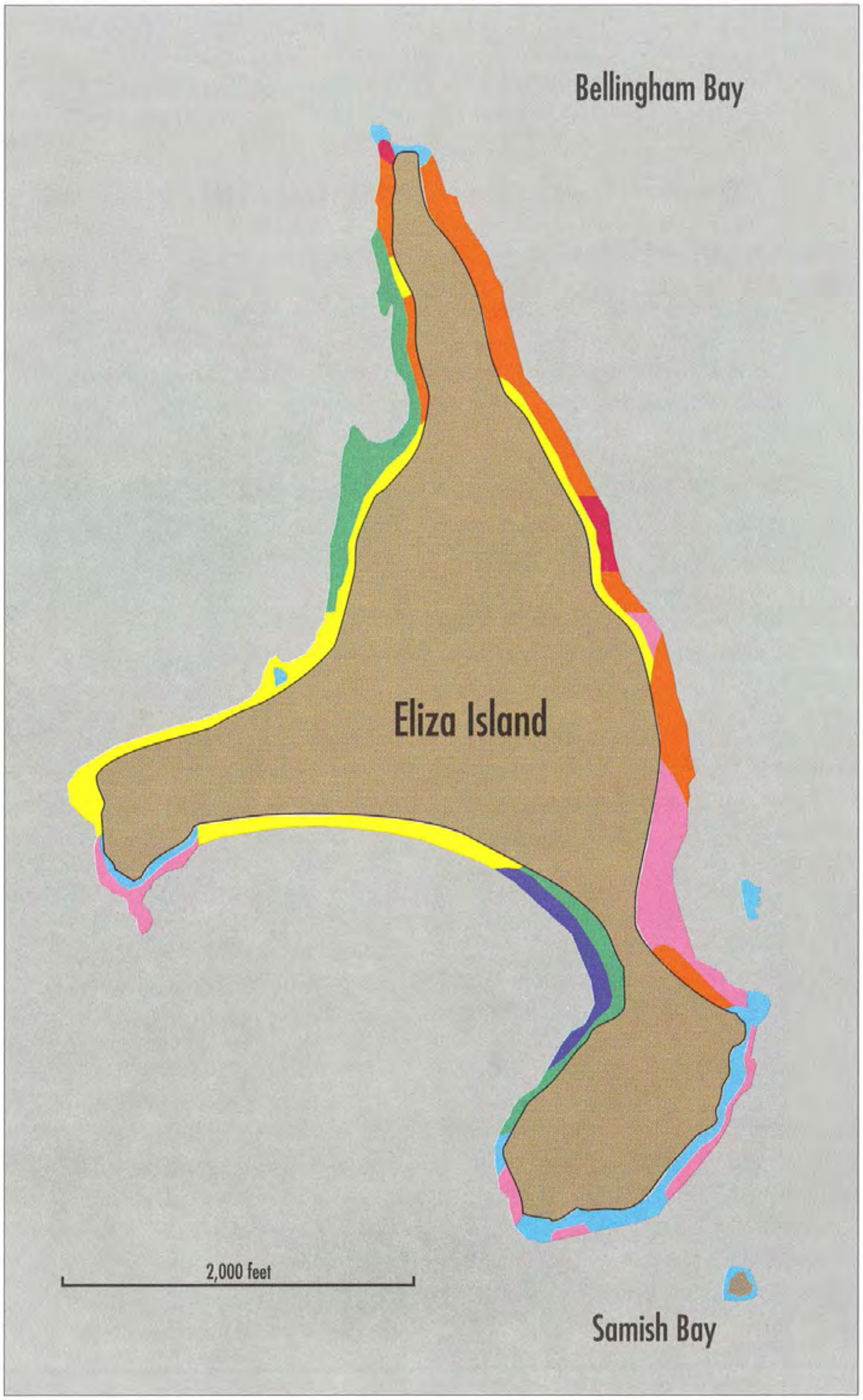


Figure 13. Example of Whatcom County Intertidal Substrate Mapping. (See page 32).

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"Overview of the Marine Bird, Waterfowl, and Marine Mammal Monitoring Task within the Puget Sound Ambient Monitoring Program, July 1994 to March 1995," pp. 57-67.

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"Remote Sensing of Nearshore Vegetation in Washington State's Puget Sound," pp. 527-536.

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"Field Survey and Classification of Puget Sound Nearshore Habitats," pp. 333-339.

"Inventory of Eelgrass (*Zostera* spp.) in Washington State," pp. 508-515.

"The Puget Sound Ambient Monitoring Program: Nearshore Habitats," pp. 68-74.

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Budd Inlet Focused Monitoring Report for 1992, 1993, and 1994 (Washington State Department of Ecology, Environmental Investigations and Laboratory Services Program, 1997)

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"Dissolved Oxygen Concentrations in Hood Canal: Are Current Conditions Different from Those of 40 Years Ago?" pp. 1002-1008.

"El Niño Weather Conditions Reflected in Puget Sound Temperatures and Salinities," pp. 979-991.

"Principal Component Analysis of Hydrographic Data in Sinclair and Budd Inlets: Or, How to Sample the Greatest Amounts of Variability (with the Least Effort)," pp. 992-1001.

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River and Stream Ambient Monitoring Report for Wateryear 1995 (Washington State Department of Ecology, Environmental Investigations and Laboratory Services Program, Publication No. 96-355, December 1996.)

Toxic Contaminants in Fish

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Proceedings of Puget Sound Research '95 (Puget Sound Water Quality Authority, 1995)

"Accumulation of Mercury and Polychlorinated Biphenyls in Quillback Rockfish *(Sebastes maliger)* from Puget Sound, Washington," pp. 666-677.

"Contaminant Monitoring in Fish: Overview of the Puget Sound Ambient Monitoring Program Fish Task," pp. 35-50.

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Contaminant Monitoring of Surf Scoters in the Tacoma, Washington Area, 1995 to 1996 (U.S. Fish and Wildlife Service, Report 97-1: Puget Sound Program, 1997)

Proceedings of Puget Sound Research '95 (Puget Sound Water Quality Authority, 1995)

"Puget Sound Waterbirds as Contaminant Monitors," pp. 927-933.

Fecal and PSP Contamination of Shellfish Beds

1995 Annual Inventory of Commercial and Recreational Shellfish Areas in Puget Sound (Washington State Department of Health, Office of Shellfish Programs, December 1995)

1996 Annual Inventory of Commercial and Recreational Shellfish Areas in Puget Sound (Washington State Department of Health, Office of Shellfish Programs, December 1996)

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