2000 Puget Sound update

Puget Sound Water Quality Action Team

Seventh Report of the Puget Sound Ambient Monitoring Program

March 2000

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Summary

This seventh *Puget Sound Update* is based primarily on the findings of the Puget Sound Ambient Monitoring Program (PSAMP). The PSAMP is a long-term effort to investigate environmental trends, improve decision-making and prevent overlaps and duplication in monitoring efforts. The results of the PSAMP are supplemented by the findings of many other efforts to evaluate the condition of Puget Sound's waters, sediments, nearshore habitats and biological resources. Information presented in this report generally reflects conditions through 1998. However, in some cases only older data were available and in other cases results through 1999 were available and included.

Signs of environmental degradation from around Puget Sound suggest that the continuing development in the basin is taking its toll on the Sound. A variety of Puget Sound organisms appear to be in poor condition or their numbers appear to be declining.

Environmental degradation in Puget Sound has been documented for many years. High levels of toxic contaminants in urban bays and waterways and widespread alteration of Puget Sound's estuaries and shorelines can be seen. Puget Sound monitoring provides some signs that conditions may be worsening:

- Levels of fecal contamination have increased in Henderson Inlet and Burley Lagoon—south Puget Sound shellfish growing areas where nearby lands were being developed for residential and commercial uses.
- Incidence of liver lesions in English sole in Elliott Bay (Seattle) has increased, which may reflect increased levels of contamination, especially by PAHs (polynuclear aromatic hydrocarbons), from the Sound's most highly developed urban and industrial lands.

Many measures of the condition of the Puget Sound environment have yet to show a trend. This may, in some cases, reflect stable conditions but in many cases probably results from the difficulty in detecting trends when results vary greatly from year to year and when monitoring records represent only a period of five or six years. A few measures indicate improving conditions. However, on balance, monitoring results suggest that human actions on the developed and developing lands of the Puget Sound basin continue to threaten Puget Sound. The implication is that careful management of Puget Sound's lands and shorelines will be needed to maintain the quality of the Puget Sound environment.

Many species that rely on Puget Sound appear to be declining, including Pacific herring, rockfish, coho salmon, scoters, Western grebes, great blue herons and orca whales. While some species (notably harbor seals) are faring relatively well in recent years, the number and diversity of species in poor or declining condition suggest widespread effects of habitat loss or degradation, harvest pressures cascading through the food web, or natural variations in marine system productivity. More scientific assessment will be needed to understand the causes and implications of declines of marine species in Puget Sound. Key elements of efforts to recover healthy populations of the Sound's organisms will include protection and restoration of habitat and control of harvest.

Environmental indicators reporting

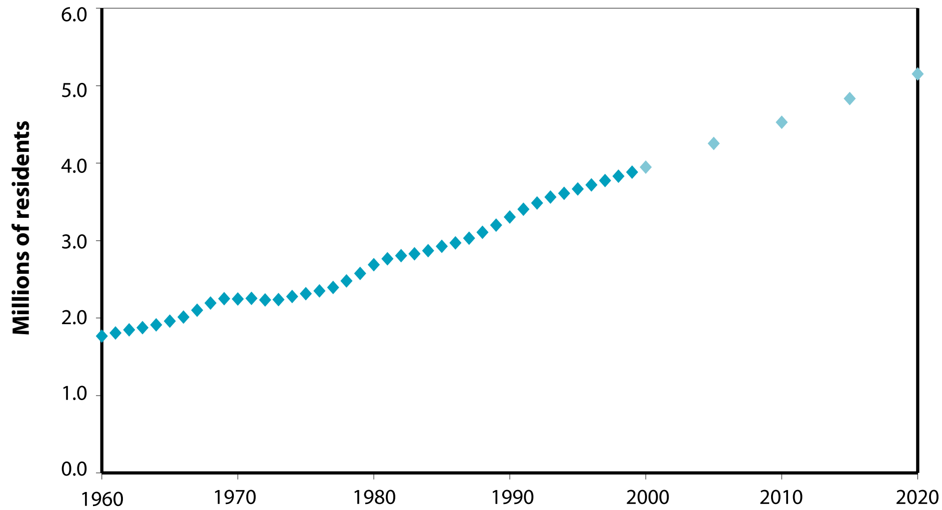
A portion of the information presented in this report is summarized in the Puget Sound Water Quality Action's Team environmental indicators document, *Puget Sound's Health 2000.* The 16-page document provides a brief view of the condition of Puget Sound and its resources. Copies of *Puget Sound's Health 2000* are available from the Action Team and on-line at: http://www.wa.gov/puget_sound.

Other agencies and organizations produce related environmental indicators and status and trends reports. One recent example is "Our Changing Nature," a 1998 report by the Department of Natural Resources, which describes trends in Washington State's forests, grasslands, freshwater systems, marine environments and fish and wildlife.

Increasing development of the Puget Sound basin

In the four most populous counties of central Puget Sound (King, Kitsap, Pierce and Snohomish), land converted to housing and business developments doubled from nearly 150,000 acres in 1970 to 300,000 acres in 1995 (Puget Sound Regional Council as cited in Washington Department of Transportation, 1998). The Washington Department of Transportation (1998) estimates that an additional 200,000 acres of land in the central portion of the basin will be developed for residential, industrial and commercial uses by 2020.

Figure 1. Puget Sound's population, 1960-2020



Source: Washington State Office of Financial Management. 1999.

Summary of Findings

Physical Environment

In recent years, the temperature of many Puget Sound basin streams appeared to be so high that it threatened cold-water organisms, including salmon. Intrusions of Pacific Ocean water carrying very little dissolved oxygen into areas of Puget Sound with limited vertical circulation may lead to low dissolved oxygen levels in some of the Sound's inlets and bays, especially in Hood Canal. This natural occurrence can be aggravated by human influences on water circulation and nutrient input so that dissolved oxygen is depleted over a greater area or for a longer portion of the year. As previously reported, Puget Sound's shoreline has been significantly altered from its original condition. Eighty percent of the eastern shore of Puget Sound's main basin from Mukilteo (south of Everett) to Tacoma is no longer in its natural state due to alteration by bulkheads, docks, piers, or some other type of intertidal or backshore alteration.

Pathogens and Nutrients

Pathogen- and nutrient-related water quality problems are significant concerns in a number of locations around Puget Sound, especially in important shellfish growing areas, near the mouths of major rivers and in bays and inlets where vertical water circulation is limited.

Analyses included in this report indicate that fecal contamination may threaten commercial shellfish harvest in areas of south Puget Sound (Filucy, North and Henderson bays; Burley Lagoon; Nisqually Reach; and Henderson Inlet), some of north Puget Sound's bays and inlets (Drayton Harbor, Saratoga Passage, and south Skagit, Portage and Samish bays) and in Hood Canal at Dosewallips State Park. Conditions at four commercial shellfish growing areas showed two distinct trends over time. Worsening conditions were observed throughout Henderson Inlet and Burley Lagoon, but fecal contamination levels declined in Eld Inlet and Oakland Bay, where concerted efforts by government and citizens identified and addressed contaminant sources.

Monitoring results through the 1990s suggested that some areas of Puget Sound were susceptible to water quality degradation resulting from excess nutrient additions, especially southern Hood Canal, Budd Inlet and Penn Cove.

Toxic Contaminants

Toxic contaminants are present throughout the Puget Sound environment, though the most serious problems occur in urban areas near contaminant sources. Limited trend information suggests that some types of toxic contamination may be decreasing while other problems may be worsening. Studies in Puget Sound also show adverse effects of toxic contaminants in invertebrates and fish.

Consistent with previous evaluations of sediment and fish contamination in Puget Sound, a 1997 survey of sediment contamination in north Puget Sound found that contamination problems occurred primarily near urban areas. Further evidence of this pattern was seen in higher concentrations of PAH (polycyclic aromatic hydrocarbon) metabolites in fish from urban areas than in those from non-urban areas of Puget Sound.

Information on contaminants in the tissue of mussels and harbor seals and the prevalence of liver lesions in English sole indicates that toxic contamination in Puget Sound has changed over time. Concentrations of PCBs, copper, mercury and DDT and its breakdown products in mussels declined at a few of 11 Puget Sound locations monitored from the mid-1980s to the mid-1990s. This indicates that concentrations of these contaminants in Puget Sound waters have decreased over this time period in at least some areas of the Sound. Levels of PCB contamination in south Puget Sound harbor seals declined significantly from the 1970s to the mid-1980s but remained fairly steady from the mid-1980s to the mid-1990s.

Prevalence of liver lesions in English sole from 1989 to 1998 showed no trends at five of six monitoring locations but showed an increasing trend in fish from Elliott Bay. Scientists previously showed that liver lesions in English sole from Puget Sound were associated with PAH contamination in sediment. The increasing incidence of liver lesions in English sole from Elliott Bay suggests that PAH contamination in the bay may be increasing.

Human Health

Conditions in Puget Sound can affect the health of the region's human residents, especially through the consumption of fish and shellfish. Fish and shellfish accumulate toxic contaminants from their food. As they filter large amounts of water, bivalve shellfish can also accumulate pathogenic organisms and naturally-occurring toxic chemicals (biotoxins).

State and local health officials assess conditions at shellfish growing areas to manage pathogen-related risks associated with shellfish consumption. Historically, about 136,000 acres of Puget Sound tidelands have been utilized for commercial shellfish production. As of 1999, about 75 percent of this acreage was approved for direct harvest and marketing of shellfish.

In 1997 and 1998, Puget Sound shellfish accumulated relatively high levels of *Vibrio parahaemolyticus,* a naturally occurring bacterium, which led to more than 100 cases of *Vibrio*-related illness associated with Washington seafood. Concentrations of the bacteria and associated illnesses returned to lower (more normal) levels in 1999.

Puget Sound shellfish sometimes accumulate relatively high concentrations of the naturally occurring biotoxin that causes paralytic shellfish poisoning (PSP). Areas where high concentrations of the PSP biotoxin were measured for extended periods of time (more than 90 days) from 1996 through 1998 include Sequim, Discovery and Mystery bays on the Strait of Juan de Fuca; Miller Bay (Kitsap Peninsula) and Quartermaster Harbor (Vashon Island) in Puget Sound's main basin; and Filucy Bay in south Puget Sound.

Biological Resources

The condition of fish populations in Puget Sound illustrates that many of the Sound's marine populations are declining or in poor condition. In 1999, the National Marine Fisheries Service listed chinook salmon from Puget Sound and summer chum salmon from Hood Canal as threatened under the federal Endangered Species Act. More recently, the National Marine Fisheries Service (NMFS) undertook a review of the status of seven species of Puget Sound marine fish—Pacific herring, Pacific cod, Pacific hake, walleye pollock and quillback, copper and brown rockfish. Based on this review, NMFS may propose listing any or all of these species as threatened or endangered under the Endangered Species Act. Some stocks of Pacific herring, important prey for numerous marine species in Puget Sound, declined dramatically over the past 20 years.

In addition, scientists have documented the presence of more than 50 non-native species in Puget Sound and are monitoring the spread of other non-native species (especially the European green crab and the Chinese mitten crab) along the Pacific coast. Aquatic nuisance species have inflicted large-scale alteration on other ecosystems, including San Francisco Bay and the Great Lakes. By controlling pathways of introduction and responding to introductions that do occur, resource managers hope to avoid similar damage in Puget Sound.

Despite much bad news, a few successes give hope for the future of Puget Sound's biological resources. Under the implementation of the Marine Mammal Protection Act, harbor seal numbers in Puget Sound have increased steadily over the past 20 years. However, the success for seals may be a problem for Puget Sound's fish because harbor seals prey upon some fish populations that are declining. Within Puget Sound, nuisance populations of introduced cordgrasses (*Spartina* species) were controlled, and in some cases eliminated, through the efforts of the Washington Department of Agriculture and a diverse group of partners. In addition, biological resources such as the kelp beds in the Strait of Juan de Fuca and harlequin ducks throughout Puget Sound appeared to be stable through the 1990s.

Conclusions

Findings presented in this *Puget Sound Update* expand the base of knowledge about conditions around Puget Sound and suggest a number of conclusions about further studies and follow up actions. Some of the more important conclusions supported by the new findings include the following:

- Puget Sound's shoreline has been extensively altered by bulkheads, piers and other structures. This alteration affects the availability and function of soft-bottom nearshore habitats. Land owners and resource managers may need to establish protected areas; use alternative, less harmful approaches to protecting shoreline properties; and undertake habitat restoration projects to protect remaining nearshore habitats and to restore functions that have been lost as shorelines have been altered.
- Worsening water quality conditions at some shellfish growing areas reflect the continuing and growing impact of land development on Puget Sound's waters. Continued shellfish harvest in developed and developing areas of Puget Sound will require ongoing attention to appropriate land-use decisions, land management practices and operation and maintenance of septic systems, stormwater management facilities and other pollution control equipment.

- Monitoring results suggest that some areas of Puget Sound, including southern Hood Canal, Budd Inlet, Penn Cove and East Sound are susceptible to water quality degradation if additional nutrients are introduced to the system. Decisions about the discharge of nutrients from point and nonpoint sources to these areas of Puget Sound should take into consideration the potential ecosystem effects of the nutrient additions.
- Additional study of toxic contamination near urban areas and in the vicinity of wastewater discharges is needed to better understand the distribution of problems, to support cleanup activities, and to characterize the effects that toxic contaminants might have on the Puget Sound ecosystem. Information presented in this report suggests a need for further investigations in Everett Harbor, Sinclair Inlet and Elliott Bay.
- Additional information and analysis are needed to characterize the potential human health risks from consumption of Puget Sound shellfish and fish from contaminated areas. Specificially, additional information is needed on water quality conditions at recreational shellfish beaches that have not yet been characterized and classified.
- Widespread evidence of the declining population of Puget Sound marine organisms suggests the importance of new efforts to protect and recover populations. Recovery plans based on an ecosystem perspective will require additional information about the specific relationships among various Puget Sound species and the influences of various natural and human-caused environmental stresses on marine populations.

Introduction

The first *Puget Sound Update* was published in 1990. Then, the Puget Sound Ambient Monitoring Program, or PSAMP, was only two years old and scientists had been collecting information for its initial component studies for about a year. Ten years later, PSAMP scientists continue to collect and evaluate data that make it possible to assess the health of Puget Sound and to prepare the *Puget Sound Update* and other more detailed technical documents.

Even a quick glance around the Sound provides evidence of changes in our environment since the first *Puget Sound Update* was written. New developments along the shore have changed Puget Sound beaches. Many types of fish, including wild chinook salmon, Pacific herring and rockfish, are less abundant in the Sound. Bluffs have eroded onto beaches, sometimes endangering people or their homes. Bigger ships visit our ports. Perhaps most noticeable, many more people live in the Puget Sound region. In fact, there's almost one chance in six that a reader of this report didn't live in the basin when the first *Puget Sound Update* was produced in 1990.

This report, like previous versions of the *Puget Sound Update,* attempts to answer the questions of citizens, lawmakers, resource managers and scientists about the condition of Puget Sound's waters and its biological resources. The goal of the *Puget Sound Update* is to provide information that can help readers evaluate current efforts to protect and restore Puget Sound's water quality and to point out water quality and resource management issues that might require attention now and into the future.

Figure 2. Puget Sound and Georgia basins.

The Puget Sound Ambient Monitoring Program

The 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 composed 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:

- **Washington State Department of Ecology** (sediment, marine water and fresh water)
- **Washington State Department of Fish and Wildlife** (fish contaminants, fish abundance and marine birds and mammals)
- **Washington State Department of Health** (shellfish)
- **Washington State Department of Natural Resources** (nearshore habitat)
- **U.S. Environmental Protection Agency**
- **U.S. Fish and Wildlife Service** (bird contaminants)
- **National Marine Fisheries Service** (fish health)
- **King County Department of Natural Resources** (marine water, sediment and shellfish)

The Puget Sound Water Quality Action Team support staff coordinates the PSAMP activities of these agencies.

Scope of this Document

Ideally, the *Puget Sound Update* would report on the condition of the aquatic ecosystems in the entire Puget Sound/Georgia Basin region shown in Figure 1. This region is bounded on the east by the crest of the Cascade mountains from south of Mt. Rainier into Canada and on the west by the mountains of Vancouver Island and the Olympic Peninsula. The centerpiece of this area is the inland sea of the straits of Georgia and Juan de Fuca and Puget Sound and its many smaller waterways.

In reality, this report focuses only on conditions in the inland marine waters of Washington State. Complementary studies and programs provide greater detail on the freshwater and Canadian portions of the basin. Although the marine waters of Washington and British Columbia mix freely, the international border between Washington State and British Columbia creates an institutional barrier, making it challenging to develop and share information or coordinate management programs concerning the broader ecosystem. Puget Sound scientists have participated in transboundary efforts to coordinate monitoring and to develop joint environmental indicators for the Puget Sound/Georgia Basin, but the data are not yet available to fully represent the Canadian portion of the system in this report. Where possible, information from the Canadian portion of the ecosystem will be included in future editions of the *Update.*

Upcoming products that will provide information about the rivers, streams and watersheds of the Puget Sound basin include the following:

- Reports and other products of the Salmon and Steelhead Habitat Inventory and Assessment Project (SSHIAP) from the Northwest Indian Fisheries Commission. SSHIAP compiles and analyzes information on river and stream habitat throughout most of western Washington.
- The "State of the Salmon" report (due to be completed by the end of 2000) from the Washington State Salmon Recovery Office. This report will include information on the condition of freshwater systems in the Puget Sound basin.
- King County's Sammamish and Washington Analysis and Modeling Project, which compiles and analyzes information on lake, river and stream water quality and habitat throughout the Cedar-Sammamish basin.
- Data sets, model output, reports and visualization interfaces from the University of Washington's Puget Sound Regional Synthesis Model (PRISM), which incorporates the hydrology of the Puget Sound basin in a spatially and temporally dynamic integrated model.

More complete information about conditions in and around the Georgia Basin is available from a number of publications, including:

- "Environmental Trends in British Columbia 1998," a report of the province's Ministry of Environment Lands and Parks (1998); and
- "Review of the Marine Environment and Biota of the Strait of Georgia, Juan de Fuca Strait and Puget Sound: Proceedings of the British Columbia/Washington Symposium on the Marine Environment, January 13 and 14, 1994" (Wilson et al. (Editors), 1994)

Protecting and Restoring Puget Sound

People place great value and, paradoxically, stress on Puget Sound. Results of environmental research and monitoring have pointed out the effects that humans have on the Puget Sound environment (see, for example, prior versions of the *Puget Sound Update*). Recognizing the potential for environmental degradation and the depletion of natural resources, our society has instituted a variety of programs to protect and restore our environment. Many programs to protect and restore Puget Sound are described in the *Puget Sound Water Quality Management Plan.* Activities and funding to implement this plan are described in the biennial Puget Sound Water Quality Work Plan.

The PSAMP and this Update are organized around five monitoring topics (see sidebar) that relate to human activities and management programs. Each of the next five chapters of the Update addresses one monitoring topic, beginning with a summary of the issues addressed by the topic and followed by a presentation and discussion of recent findings from PSAMP and other studies. PSAMP technical reports and monitoring data are available from the agencies implementing the various monitoring studies. Contact information is provided on pages 125 to 127.

PSAMP's monitoring topics and integrated questions

The PSAMP organizes its monitoring and reporting by topics that relate to specific ecosystem characteristics or human-influenced stresses on the environment:

Physical Environment: Are the physical environments of Puget Sound changing and, if so, how do these changes affect Puget Sound's biological resources?

Pathogens and Nutrients: What are the status and trends of pathogen and nutrient contamination in Puget Sound? How do they affect the 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 the humans who consume them?

Human Health: What are the risks to human health from consuming seafood from Puget Sound?

Biological Resources: What are the status and trends of Puget Sound's biological resources?

Toward a comprehensive monitoring program

The ambient monitoring accomplished by the PSAMP is only one aspect of a comprehensive system of scientific study of Puget Sound. PSAMP findings often indicate the need for further investigation in the form of ecosystem research or detailed site investigations.

Action Team agencies rely on the research expertise and facilities of many other entities, especially the National Oceanic and Atmospheric Administration, the research office of the U.S. Environmental Protection Agency, the University of Washington and other colleges and universities located throughout the region.

In addition, resource managers are likely to need additional monitoring and assessment to help evaluate the effectiveness of specific programs or projects. Ambient monitoring is a critical element of the scientific study of Puget Sound, but it cannot be truly effective until it is complemented by research, detailed site investigations and monitoring of program effectiveness.

Monitoring and research results, as presented in this *Puget Sound Update*, help regulatory agencies and the Puget Sound community understand how our ecosystem functions and how it responds to human activities and management programs. Through presentation of its findings, the PSAMP can raise awareness of problems and issues affecting Puget Sound. In some cases, monitoring results from PSAMP and other studies will indicate the need for additional scientific investigation. In other cases, monitoring results may directly indicate the need for new policies, amended strategies or specific measures to protect and restore Puget Sound resources. Each of the remaining chapters of this *Update* concludes with a short list of recommendations for acting on the findings presented in the chapter.

Physical Environment

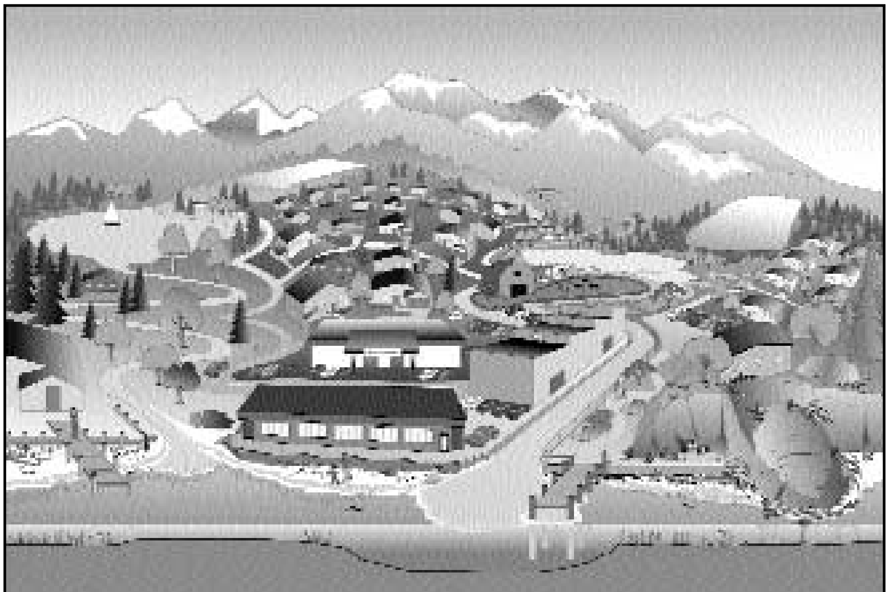
Summary

The physical character of the Puget Sound environment–including its landforms, currents and climate–determine the fundamental character of the Puget Sound ecosystem. The meteorological, hydrologic and geologic processes that form and maintain our rivers and streams, our marine waters and our shorelines provide the essential foundation for the chemical and biological elements of the Puget Sound ecosystem. Many human activities negatively affect Puget Sound's physical environment by altering its natural state. Dynamic changes in the Sound's physical environment also occur in response to winds, rain, currents and geologic processes.

Water delivered to the Puget Sound basin as rain and snow percolates through and runs off the land, gathering in streams, rivers and underground aquifers. This flow of water toward the Sound and the circulation of water within the Sound are the primary vehicles by which sediments, nutrients and woody debris are carried through the environment to support the various components of the Puget Sound ecosystem. Many organisms (e.g., crab and clam larvae and algae) also rely on the flow of water to carry them to, within and beyond Puget Sound. These same processes can transport contaminants to, within and beyond the Puget Sound ecosystem.

The character of the land, river and stream channels, floodways and shorelines of the Puget Sound basin affect the delivery and movement of water, sediments, nutrients, woody debris and contaminants in Puget Sound's watersheds. Figure 3 shows some of the human activities that alter the physical environment of Puget Sound by changing the character of the land, river and stream channels and shorelines.

Figure 3. Physical alterations to the Puget Sound environment.



Source: Visual Communication and EIS Unit, King County Department of Natural Resources.

Examples of effects from these alterations include:

- Development of river, lake and Puget Sound shorelines in the form of residential properties, industrial areas and commercial complexes can affect the delivery of water, sediments, nutrients and contaminants into the adjacent water.
- Development of urban, suburban and rural properties and the associated increase in impervious surfaces (surfaces such as roads, driveways, parking lots and lawns, that cannot be easily penetrated by water) causes increased surface runoff of stormwater. This increased flow can lead to scouring and other alteration of in-water environments.
- Nutrients (e.g., from fertilizers or fecal matter from pets) and contaminants (e.g., toxic chemicals from cars) are often highly concentrated on urban, suburban and rural lands. This can lead to high levels of contamination in stormwater runoff.
- Channelizing streams, filling wetlands and floodplains, and cutting forests adjacent to streams can disrupt the process of water, sediment, nutrient and debris delivery to Puget Sound.
- "Hardening" shorelines with bulkheads, as well as dredging and filling tidal and river delta areas, can alter water circulation and sediment transport processes along shorelines and in estuaries.

Other aspects of Puget Sound's physical environment—such as its climate and geology—*appear* to be beyond the direct influence of humans, but may, in fact, be affected by local or global human activities:

- Temperature, precipitation and other aspects of climate in the Puget Sound region reflect local variations over days, weeks and months. Larger patterns, including El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) affect climate change over years, decades and beyond. ENSO and the PDO are natural cycles, each characterized by shifts between cold, wet weather and warm, dry weather. ENSO operates over the time span of a year, while the PDO appears to span about a 20-year period. ENSO's two extreme conditions, El Niño and La Niña, primarily affect the region's winter weather (warm, dry weather versus cold, wet conditions, respectively). A warm-dry PDO regime appears to be ending; some atmospheric scientists think we already may have shifted to a cold-wet regime. On a global scale, air temperatures have increased through the 20th century. Rising temperatures may be caused by increases in the atmospheric concentration of carbon dioxide (and other greenhouse gases) in response to fossil fuel consumption and deforestation.

- The Puget Sound basin is geologically young and active. Steep slopes slide and bluffs recede as glacial features "mature." Earthquakes and volcanic events can quickly reshape the landscape. These processes will occur without (and in spite of) human intervention, but human development of unstable areas may lead to larger or more rapid changes in the landscape.

Findings

This section presents recent ocean and weather conditions and recent results from relevant studies of the Puget Sound Ambient Monitoring Program (PSAMP). The PSAMP components that help to define the physical conditions of the Puget Sound environment include the Department of Ecology's studies of rivers, streams and Puget Sound marine waters and the Department of Natural Resources' evaluation of Puget Sound's shoreline and nearshore areas.

The Pacific Ocean and Puget Sound Weather Conditions

The Pacific Ocean profoundly affects the character of Puget Sound's marine waters and the region's climate and short-term weather patterns. Waters from the Pacific Ocean enter Puget Sound directly through the Strait of Juan de Fuca and Admiralty Inlet. Changes in ocean conditions in the north Pacific lead to changes in Puget Sound water temperatures and water quality. Changes in oceanic and atmospheric conditions throughout the Pacific Ocean affect regional weather conditions.

The Pacific Ocean's Influence on the Inland Marine Waters. Waters from the Pacific Ocean are drawn into Puget Sound. Upwelling of Pacific Ocean waters draws relatively deep ocean water into the Strait of Juan de Fuca as [primarily summer] winds push surface waters away from the continent. Figure 4 shows the annual pattern of upwelling off the Washington coast: upwelling index values are positive when upwelling draws deep ocean waters toward shore and values are negative when currents push surface waters toward the coast and deep waters are displaced offshore. Upwelling is strongest during late spring, summer and early autumn.

Upwelled Pacific Ocean waters drawn into Puget Sound through estuarine circulation are rich in nutrients, relatively cold and carry low levels of dissolved oxygen (because they have been deep below the ocean surface). The introduction of water from deep in the Pacific Ocean into Puget Sound is a major determinant of marine water conditions in Puget Sound's main basin and in the Sound's many smaller passages, inlets and bays. These waters supply nutrients from the ocean that drive the productivity of the Puget Sound food web. For example, the ocean's supply of nitrogen to the Puget Sound/Georgia Basin has been estimated to be more than 10 times the input from the basin's rivers, streams and sewage discharges (Harrison et al., 1994).

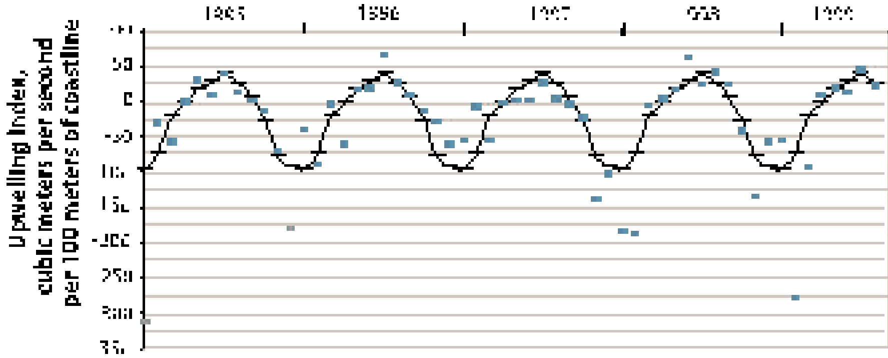
The *Puget Sound Water Quality Management Plan* and threats to Puget Sound's physical environment

The *Puget Sound Water Quality Management Plan* addresses a number of the human-caused stresses to the Puget Sound physical environment. However, some stresses are not addressed by the Puget Sound Plan, including:

- human-induced climate change
- management of freshwater flows (except as flows are affected by stormwater management and wetlands protection and restoration).

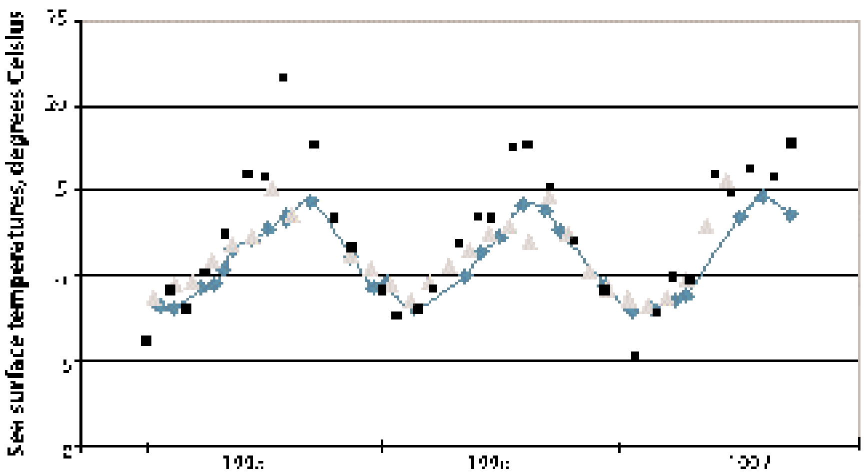
The Puget Sound Water Quality Action Team addresses threats to the Sound's physical environment primarily through its stormwater, habitat and wetlands programs.

Figure 4. Seasonal pattern of upwelling in the Pacific Ocean at 48 degrees North latitude and 125 degrees West longitude.



Source: National Oceanic and Atmospheric Administration's (NOAA) Pacific Fisheries Environmental Group (1999).

Figure 5. Puget Sound and Pacific Ocean sea surface temperatures, 1995-1997.



Source: Department of Ecology and NOAA National Buoy Center data (1999).

Sea-surface temperatures measured in Puget Sound's main basin during the summer are routinely lower than temperatures offshore in the Pacific Ocean or in small, shallow, river-influenced bays and inlets such as south Puget Sound's Budd Inlet (Figure 5). The lower temperatures observed in Puget Sound's main basin compared to the open ocean indicate that colder deep waters are mixed into the surface waters of Puget Sound as a result of turbulent tidal mixing. The much warmer sea-surface temperatures in small, shallow bays such as Budd Inlet probably reflect solar heating of relatively shallow waters that are not well mixed vertically. These two patterns reflect the range of sea-surface temperatures recorded in Puget Sound: small, shallow bays and inlets have seasonally high and low sea-surface temperatures, while the deep, well-mixed basins show less variation and have generally cool temperatures.

Puget Sound's Weather. Weather conditions in the Puget Sound basin in the late 1990s were generally warmer and wetter than normal. Air temperatures (Figure 6) and precipitation (Figure 7) records from Seattle-Tacoma International Airport (Sea-Tac) reflect these warm, wet conditions and show the influences of recent ENSO-related fluctuations on local weather conditions (NCDC, 1999).

Monthly average air temperatures at Sea-Tac from 1995 to 1998 were often higher than the long-term averages. Conversely, temperatures recorded from December 1998 to July 1999 were often lower than the long-term averages. Annual average temperatures indicate that each year from 1995 through 1998 was warmer than the long-term average. In fact, 1995 was the warmest year recorded at Sea-Tac during the period from 1961 through 1998. January and May of 1995 each had record high

What is the El Niño Southern Oscillation (ENSO)?

El Niño (1997-98) and La Niña (ongoing since 1998) are the extremes of the atmosphere-ocean phenomenon ENSO, which is an oscillation of atmospheric pressure and wind patterns in the equatorial Pacific Ocean. Effects from warm (El Niño) and cold (La Niña) ocean conditions off the coast of Peru are transferred through the atmosphere and ocean to the Pacific Northwest.

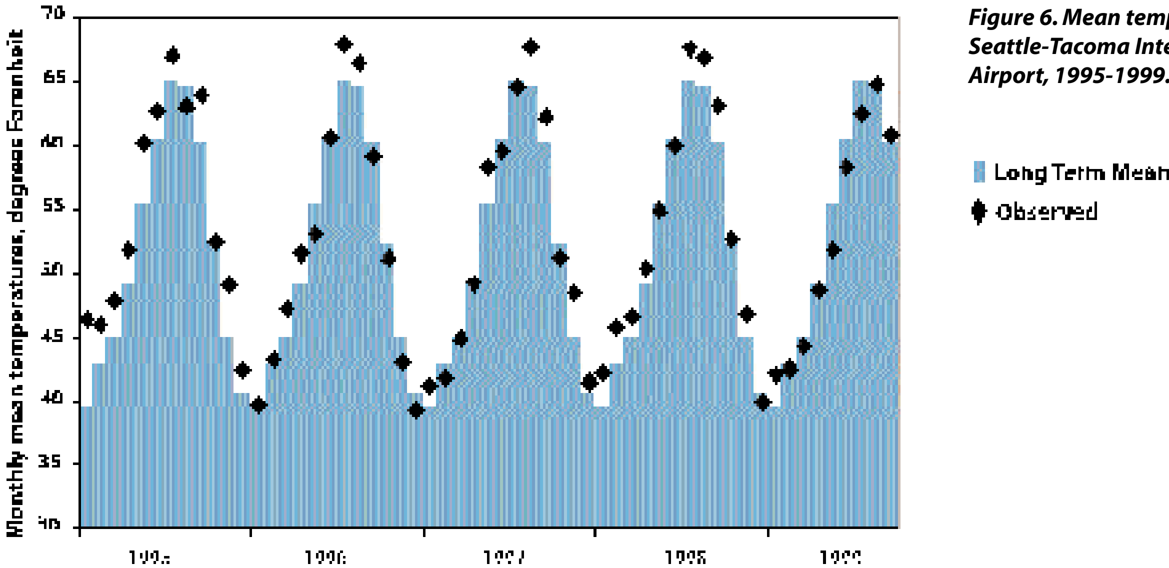


Figure 6. Mean temperatures at Seattle-Tacoma International Airport, 1995-1999.

Source: National Climatic Data Center.

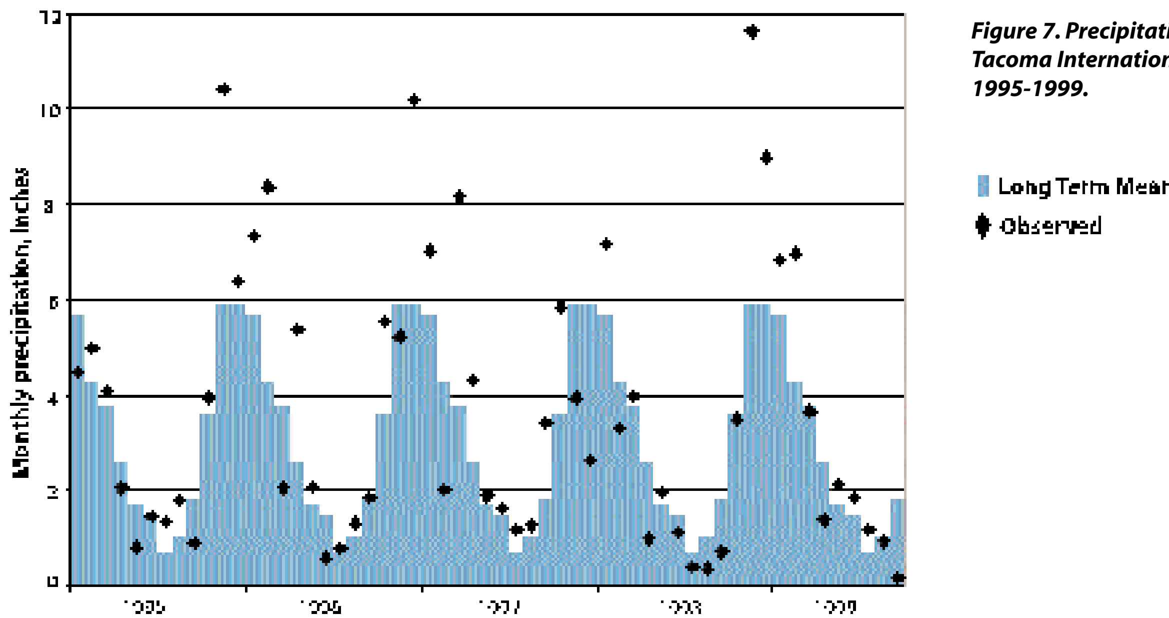


Figure 7. Precipitation at Seattle-Tacoma International Airport, 1995-1999.

Source: National Climatic Data Center.

monthly average temperatures. (No other record high monthly temperatures were set and no record low monthly temperatures were set in the period shown in Figure 6.)

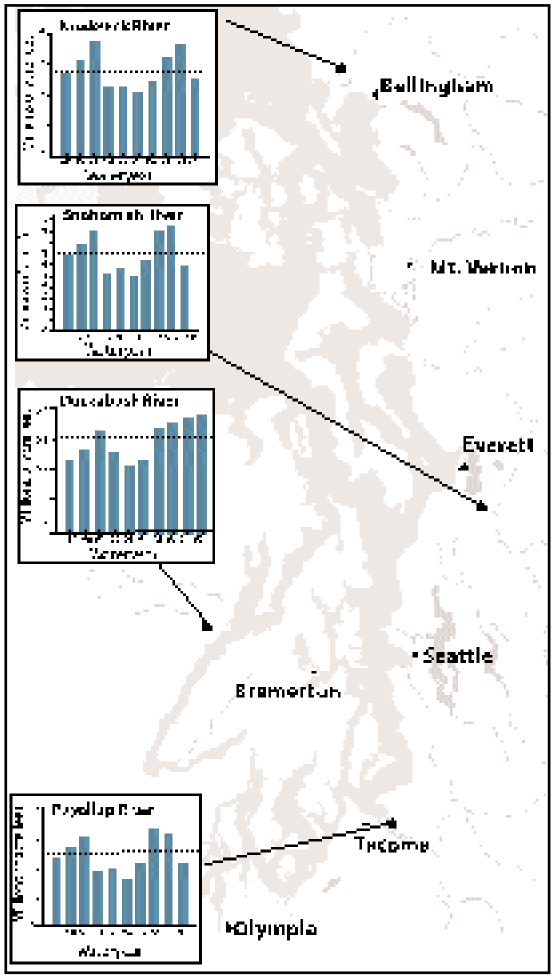
The El Niño conditions of 1997-98 appeared locally as warmer than average temperatures. Higher than average temperatures were measured in all months from November 1997 through April 1998 at Sea-Tac. Conversely, the 1998-99 La Niña conditions appeared locally as cooler than average temperatures from December 1998 through July 1999, except for January 1999.

The higher temperatures of 1995 through 1998 were accompanied by higher than average precipitation. Annual precipitation totals for these four years were all greater than the long-term average of 38.2 inches per year. A record 50.7 inches of precipitation fell at Sea-Tac in 1996. Despite the high annual total, no single month in 1996 set a monthly precipitation record. March 1997 (8.15 inches) and November 1998 (11.6 inches) set monthly records for precipitation at Sea-Tac. (For the period

Figure 8. Recent flow in four major Puget Sound basin rivers.

Observed annual flows

Long-term annual average flows



Source: Department of Ecology analysis of U.S. Geologic survey data.

presented in Figure 7, no low monthly precipitation records were set.)

The El Niño conditions of 1997-98 appeared locally as the driest winter in recent years. Figure 7 shows that peak high precipitation months were lower in 1997-98 than in the preceding two years. November and December 1997 and February 1998 were all drier than average. The La Niña of 1998-99 brought a wet winter to the Puget Sound region. Sea-Tac's record-setting November 1998 was followed by a very wet December (8.98 inches, the third wettest December on record) and a wetter than average January and February 1999. The cool temperatures recorded during this La Niña event persisted much longer into the year (July) than did the high precipitation amounts (February). In summary, the years 1997, 1998 and 1999 were very different in terms of weather conditions.

Weather can influence environmental parameters such as water quality, fish recruitment and river flow. In Puget Sound, analysis of these relationships is just beginning. Part of our current understanding about how weather conditions during El Niño and La Niña affect Puget Sound's marine waters is discussed in the sidebar: Effects of El Niño on Puget Sound water, on page 22.

Rivers and Streams—Freshwater Input to Puget Sound

Streams and rivers deliver the majority of the region's rainfall and snowmelt to Puget Sound. Delivery of water through rivers and streams is an important process that maintains instream habitat (i.e., pools, riffles and large woody debris); controls nutrient, sediment and contaminant transport; and maintains the estuarine character of Puget Sound and its many component estuaries.

Figure 8 compares annual flows for four major rivers of the Puget Sound basin with annual average flows. Total annual flow is presented by wateryear, which runs from October through September. Wateryear 1998, for example, began in October 1997 and ended in September 1998. The three rivers shown in Figure 8 that drain the eastern side of the Puget Sound basin (the Nooksack, Snohomish and Puyallup) experienced above average flows in wateryears 1996 and 1997 and below average flows for all other wateryears from 1992 through 1998. The Duckabush River, on the western side of the basin, showed a different pattern, with high flows occurring consecutively from 1995 through 1998.

Snowpack in the mountains of the Puget Sound basin

Much of the precipitation in the mountains of the Puget Sound region accumulates as snowpack. Melting snowpack through the first half of each year translates to high flows in the basin's rivers and streams that reach into the mountains. Snowpack accumulations and snowmelt are determined by a combination of temperature and precipitation.

Cold, wet conditions are most conducive to large snow accumulations. The La Niña winter of 1998-99 brought record snowfall and accumulations to the Cascade Mountains. Warm, dry conditions contribute to relatively small snow accumulations. During the warm, fairly dry El Niño winter of 1997-98, snow accumulation at Stampede Pass (in the central Cascades) was relatively low, never reaching the equivalent of 40 inches of water (National Water and Climate Center, 1999). The relatively wet years prior to 1998 brought variable snowpack accumulations to Stampede Pass, ranging from less than 40 inches of water in 1995-96 to more than 80 inches of water in 1996-97, depending on winter temperatures (above average for 1995-96 and below average for much of 1996-97).

Spring temperatures and precipitation determine the rate at which the accumulated snowpack melts and flows into rivers, streams and, ultimately, Puget Sound.

WRIA number – Basin name	Number of problem areas based on: Low instream flow	High temperature	Low dissolved oxygen	All parameters *(physical, chemical, biological)*	Total number of areas assessed
1 – Nooksack	3	14	27	63	67
2 – San Juan	0	0	0	1	5
3 – Lower Skagit/Samish	0	18	3	35	42
4 – Upper Skagit	0	3	0	3	6
5 – Stillaguamish	0	8	7	21	34
6 – Island	0	0	1	2	6
7 – Snohomish	0	7	10	24	48
8 – Cedar/Sammamish	0	4	4	47	61
9 – Duwamish/Green	0	11	11	40	51
10 – Puyallup/White	4	10	4	25	33
11 – Nisqually	0	1	1	9	10
12 – Chambers/Clover	0	4	3	12	15
13 – Deschutes	3	4	8	21	27
14 – Kennedy/Goldsborough	0	0	2	18	22
15 – Kitsap	0	4	4	64	73
16 – Skokomish/Dosewallips	1	0	0	7	8
17 – Quilcene/Snow	1	8	1	15	20
18 – Elwha/Dungeness	1	2	1	8	9
19 – Lyre/Hoko	0	7	0	7	8
Total for Puget Sound basin	13	105	87	422	545

Source: Department of Ecology unpublished data.

Table 1. Numbers of waters in various Water Resource Inventory Areas (WRIAs) identified by the Department of Ecology as impaired by poor physical conditions: low instream flow, high temperature and low dissolved oxygen.

"Impaired" indicates the body of water does not meet the applicable state water quality standard.

The 1995 through 1998 flows for the rivers draining the Cascades (the eastern side of the basin) are consistent with the precipitation data for Sea-Tac. The higher precipitation in wateryears 1996 and 1997 is reflected in the higher flows observed during those years. Precipitation at Sea-Tac does not explain the Duckabush River's high flows in wateryears 1995 and 1998. This highlights the importance of understanding meteorological and hydrologic processes on smaller scales across the large expanse of the Puget Sound basin.

The uneven distribution of precipitation through the year in the Puget Sound region combined with modification of watershed, river and stream characteristics can lead to low summer flows in some rivers and streams. River and stream flow is less variable through the year than precipitation because snowmelt and percolation into groundwater delay the runoff of much of the basin's precipitation. Nonetheless, low summer flows of rivers and streams can limit their ability to maintain aquatic life. Table 1 summarizes the distribution of Puget Sound basin waterbodies that the Department of Ecology identified in 1998 as impaired by low instream flows. The table indicates that low instream flows threatened aquatic life in the Puget Sound basin at a limited number of locations; only 13 out of 545 areas assessed were found to have low instream flows.

Instream flow is only one aspect of the physical character of river and stream water that can affect habitat quality. Other physical parameters important for maintaining high quality habitat in streams and rivers include biologically appropriate temperatures and sufficient dissolved oxygen levels. Table 1 shows that high temperatures and low dissolved oxygen concentrations were frequently responsible for water quality problems identified in the Puget Sound basin. Nearly 20 percent of the waters assessed by Ecology (105 of 545) had inappropriately high temperatures for the support of aquatic life. More than 15 percent (87 out of 545) of Puget Sound's

Identifying polluted waters - the 303(d) list

Every two years the Department of Ecology identifies Washington State's polluted waterbodies and submits a list to the U.S. Environmental Protection Agency. This list is commonly referred to as the "303(d) list" because it is required under Section 303(d) of the federal Clean Water Act. The waters enumerated in Table 1 are the "water quality limited" estuaries, lakes and streams identified by the Department of Ecology in 1998. These waters fell short of state surface water quality standards and were not expected to improve within the next two years. State water quality standards include numeric criteria used to make certain that water supports aquatic life and is safe for human uses.

rivers, streams, sloughs and bays that were assessed by Ecology had concentrations of dissolved oxygen low enough to threaten aquatic life. Additional information on marine waters affected by low dissolved oxygen is provided on pages 20 and 21.

Ecology's long-term monitoring of Puget Sound rivers provides additional information about stream temperature problems. In the Puget Sound basin, Ecology scientists collect data monthly at the 24 river monitoring stations indicated in Figure 9. Comparing state water quality standards for temperature to wateryear 1995 through 1998 monitoring results from these stations showed that measurements at these stations frequently exceeded the standard. Figure 10 shows that approximately 10 to 30 percent of the 24 river monitoring stations recorded temperatures above the

Figure 9. Ecology's core river and stream monitoring stations in the Puget Sound basin.

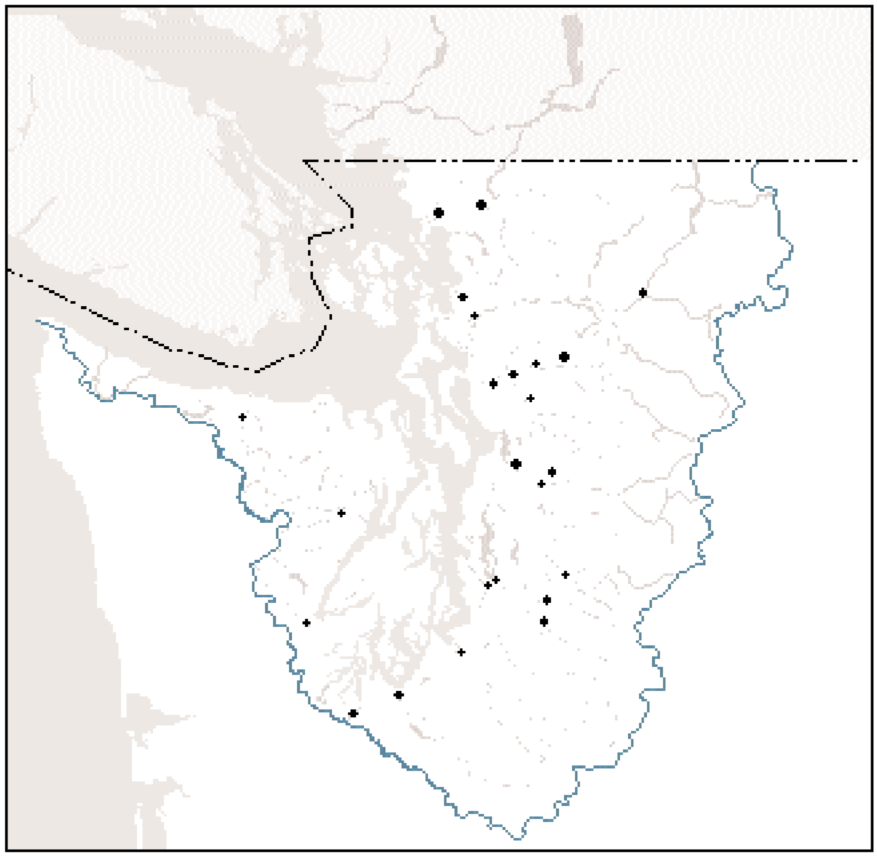
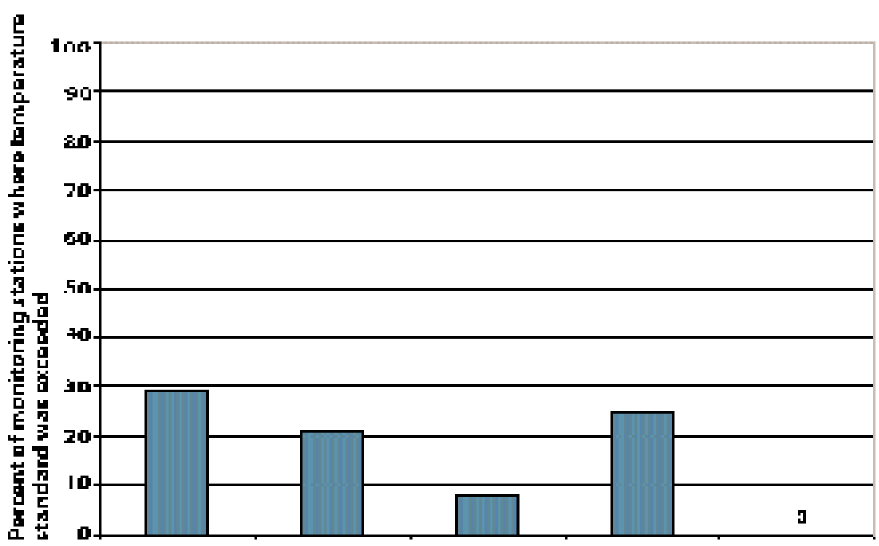


Figure 10. Percent of 24 Puget Sound river and stream monitoring stations exceeding water quality standards for temperature.



standard in wateryears 1995 through 1998. No stations exceeded the temperature standards in wateryear 1999. No trend is evident in these data. Year-to-year variations, probably related to different snowpack and resulting summer flow conditions, are quite large.

Anadromous Fish Habitat Blocked by Culverts. Rivers, streams, lakes and wetlands are all critical to the survival of migratory fish species—providing food, shelter and spawning and rearing habitat. Humans physically alter watersheds and access to these habitats by creating barriers to fish passage, such as culverts, in streams and rivers. These barriers can adversely affect the ability of wild salmon, steelhead and other anadromous salmonids to spawn and grow and can therefore cause healthy fish stocks to decline.

Scientists from the Northwest Indian Fisheries Commission have quantified the effects of known culverts on habitat availability in six Puget Sound river basins—the Cedar/Sammamish, Duwamish/Green, Puyallup/White, Quilcene/Snow, Dungeness/Elwha and Lyre/Hoko. The amount of habitat potentially available for coho salmon and the portion that is blocked by known culverts in each watershed was determined by querying the Salmon and Steelhead Habitat Inventory Assessment Program (SSHIAP) database. Figure 11 summarizes the results.

This analysis is based on coho because this species of salmon can generally penetrate farther up low elevation rivers and streams than other salmon; the analysis therefore provides a good indicator of habitat availability and condition for all salmon. For this evaluation, freshwater coho habitat is divided into two types: stream habitat (measured by length) and lake and wetland habitat (measured by area). This distinction recognizes that lakes and wetlands provide different habitat functions than stream habitat.

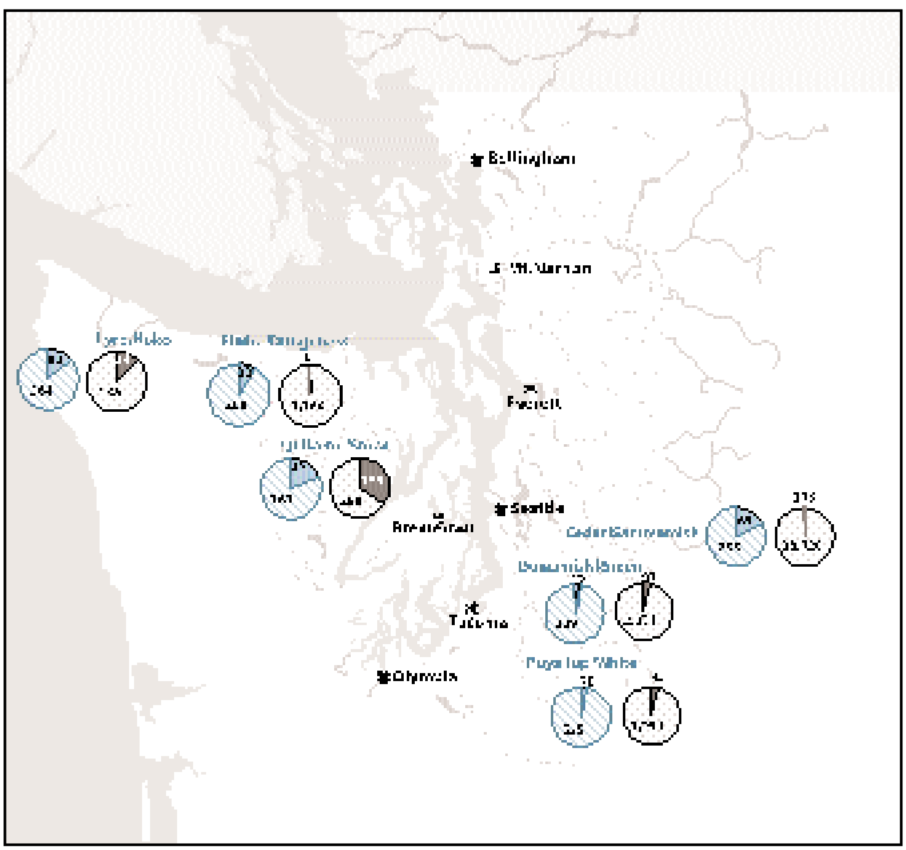
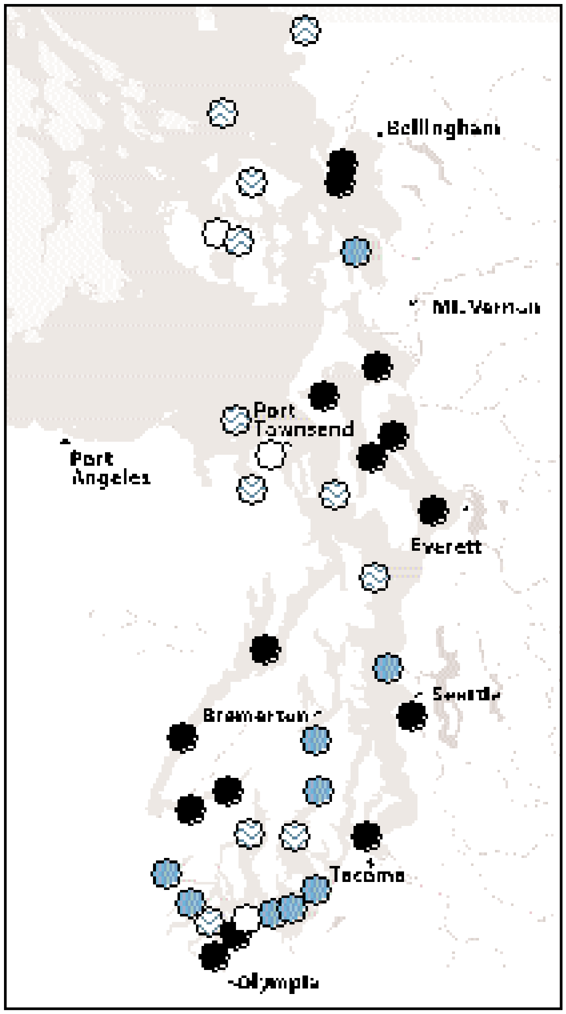


Figure 11. Watershed miles and acreage not accessible to coho due to culverts.

Lake and wetland acres:
Inaccessible
Accessible

Source: Northwest Indian Fisheries Commission unpublished data.

Figure 12. Intensity of water column stratification in Puget Sound.



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.

The six watersheds shown in Figure 11 encompass approximately 2,100 miles of potential stream habitat for coho. Known culvert barriers block approximately 220 miles—11 percent of stream habitat. These watersheds contain nearly 35,000 acres of potential lake and wetland habitat for coho. Known culvert barriers block approximately 650 acres—or two percent—of lake and wetland habitat.

Northwest Indian Fisheries Commission scientists evaluated blockage by culverts based on a review of all available data on culvert location and condition. Dams and other physical alterations were not included in this evaluation. Estimating the total amount of habitat that is inaccessible because of culverts is difficult because a comprehensive culvert inventory does not exist for the state of Washington.

Comprehensive culvert assessments are being done in some watersheds, allowing some limitations to be addressed. For example, the Pierce County Conservation District is currently conducting an extensive culvert inventory in the Puyallup/White watershed. The number of culverts identified as a result of the new inventory is expected to be much higher than the 30 culverts previously known to exist in this watershed. These types of efforts will provide more comprehensive culvert data in the future.

Puget Sound's Marine Waters

The circulation of marine waters is an important process that partially dictates how the Puget Sound ecosystem functions and how well the ecosystem supports various habitats and species. The vertical movement of water from depth to the surface is limited when the water column is stratified, which has implications for water quality.

The Department of Ecology's ambient monitoring of the marine waters of Puget Sound has allowed scientists to describe areas of the Sound that are typically stratified. Figure 12 shows the strength of water column stratification at a number of locations throughout Puget Sound. Ecology scientists classified locations as persistently, seasonally, episodically or weakly stratified based on the types of vertical density profiles observed at sampling stations during monthly sampling from 1990 through 1997. Figure 12 updates a previous version of this map that showed the classification of sites based on data through 1995. This new version of the graphic is consistent with the older version, except in a few cases where additional data has helped to refine the characterizations.

What is stratification?

Stratification refers to the layering of water according to its density. Density is greater in cold, salty waters than in warm, fresh waters. Thus, warmer, fresher coastal waters will overlie cold, salty oceanic waters. Stratification persists when the less dense surface layer is not disrupted by winds, tides or other physical mixing. Since mixing processes and freshwater inputs are diverse in Puget Sound, a variety of stratification patterns are found.

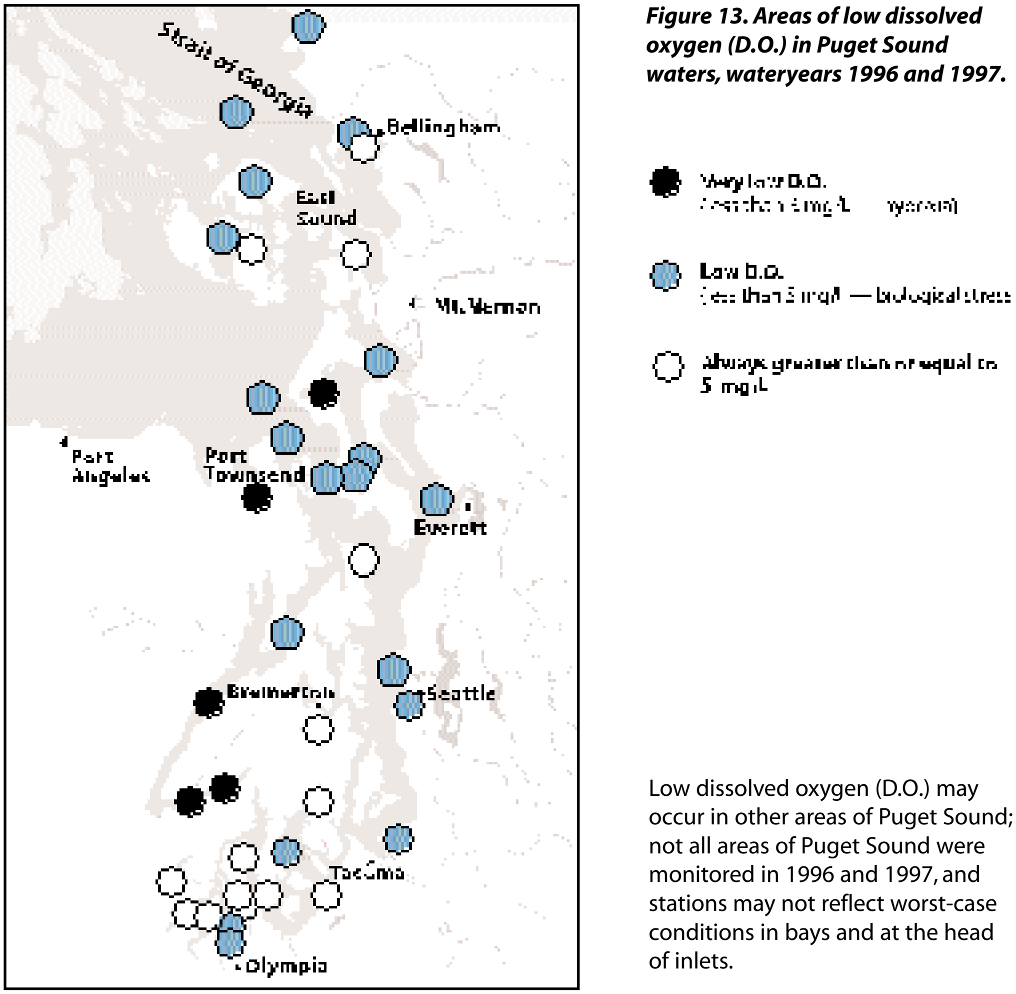


Figure 13. Areas of low dissolved oxygen (D.O.) in Puget Sound waters, wateryears 1996 and 1997.

Low dissolved oxygen (D.O.) may occur in other areas of Puget Sound; not all areas of Puget Sound were monitored in 1996 and 1997, and stations may not reflect worst-case conditions in bays and at the head of inlets.

Persistent and seasonal stratification are the most frequently observed density profile patterns in Puget Sound. Hood Canal and the bays, inlets and passages near the mouths of most large Puget Sound rivers are persistently stratified. Additional locations in south Puget Sound, around Admiralty Inlet, and in the San Juan Islands and Strait of Georgia are seasonally stratified. The widespread occurrence of density stratification and the persistence of stratification observed near river mouths reflect the importance of freshwater input to the character of Puget Sound's marine waters.

Persistent water column stratification can increase the severity of a waterbody's response to actions that degrade water quality. Stratified waters keep substances contained within a smaller area than if the water column was more fully mixed. For instance, chemical or biological contaminants discharged into the surface layer of a stratified water body will stay relatively concentrated instead of being dispersed throughout the entire water column.

Another impact of stratification is that persistent stratification will contribute to the depletion of dissolved oxygen from bottom waters. In areas with strong stratification, phytoplankton populations can grow rapidly—as soon as light levels increase in spring—because the algae cells are not dispersed too rapidly from well-lit surface waters. In the absence of mixing, phytoplankton cells and organic matter will ultimately settle into bottom waters where decomposition of the organic matter consumes dissolved oxygen. In a stratified water column, bottom waters do not circulate to the water surface; therefore, they are not replenished with dissolved oxygen through contact with the atmosphere. If stratification persists, the bottom waters can become depleted of oxygen.

Figure 13 shows locations in Puget Sound where Ecology scientists measured low concentrations of dissolved oxygen in bottom waters during wateryears 1996 and 1997. As designated in the figure, a concentration of 5 mg/L of dissolved oxygen is generally considered the level at which biological stress may begin to occur. Less than 3 mg/L of dissolved oxygen results in hypoxia, a condition marked by low oxygen levels that can have detrimental effects on many marine organisms. The patterns shown in Figure 13 are very similar to those shown for 1990 to 1995 in the 1998 Puget Sound Update. As expected, the areas with very low dissolved oxygen (less than

Effects of El Niño on Puget Sound water

El Niño events in 1991-92 and 1997-98 raised sea-surface temperatures in the Pacific Ocean off the Washington coast. Ecology's marine water monitoring showed that Puget Sound water temperatures were also warmer during these events. Sea-surface temperatures in Puget Sound were one to three degrees Celsius warmer than the average conditions for Puget Sound measured from 1990 through 1998.

In the Pacific Northwest, El Niño winters are typically drier than normal. Reduced precipitation results in lower stream flows, which, in turn, leads to increased salinity in marine waters. Ecology data show that Puget Sound waters were more saline than normal during the 1991-92 El Niño, when precipitation was relatively low. During the relatively dry 1997-98 El Niño, Puget Sound salinity values were at average levels. The reduced precipitation during this latest El Niño apparently caused Puget Sound salinity values to rebound from the fairly low levels recorded during the relatively wet years from 1995 to 1997.

Monitoring data do not indicate how, if at all, shifts in temperature and salinity observed during El Niño events may affect the Puget Sound ecosystem. Further investigation is needed to determine if ENSO-related variations affect marine organisms, alter seawater density sufficiently to affect marine water circulation, or affect the timing or character of phytoplankton blooms.

3 mg/L) have persistent or seasonal stratification and are located towards the end of long, narrow bays (Hood Canal, Penn Cove, Discovery Bay). Other areas with low dissolved oxygen (less than 5 mg/L) include a mix of stratified waters and areas receiving upwelled deep waters that have naturally low dissolved oxygen levels.

The low dissolved oxygen in Admiralty Inlet, Puget Sound's main basin and the waters of nearby San Juan Island reflects the natural input of seasonally upwelled oceanic waters entering Puget Sound. Whether humans are affecting the magnitude of the low dissolved oxygen concentrations in some of the stratified bays such as Hood Canal, Penn Cove and Discovery Bay is not easy to assess. Ecology scientists are currently investigating dissolved oxygen dynamics in Hood Canal.

While the majority of the information in Figure 13 is similar to that presented in the 1998 Update, there are some differences. First, some areas were not previously monitored. Newly monitored areas showing low dissolved oxygen were Discovery Bay, Drayton Harbor and Friday Harbor. Second, some areas show different results than before; interannual variation should be expected because stratification and algae growth are highly dependent on weather. During 1996 and 1997, for instance, dissolved oxygen measurements below 3 mg/L were not measured in Budd Inlet and East Sound (Orcas Island) as they had been earlier in the 1990s. At the Central Hood Canal station, however, more severe conditions (less than 3 mg/L) were observed in 1996 and 1997 than earlier in the 1990s.

New observations of dissolved oxygen concentrations below 5 mg/L were recorded at Bellingham Bay, inner Admiralty Inlet, Commencement Bay, Carr Inlet and West Point off Seattle. In some of the latter cases, the dissolved oxygen concentrations were only slightly below 5 mg/L (<5 percent) and are therefore probably not significant. Longer data records will help to identify whether the observed interannual variation co-varies with weather cycles or whether any trends exist.

Puget Sound's Shoreline

Development has substantially altered Puget Sound's shoreline, leading to losses of natural habitat—especially in nearshore areas—and extensive changes in nearshore circulation and sediment transport processes. Habitat loss is a major threat to biodiversity and ecosystem health; it is the single most common factor associated with the listing of endangered or threatened species nationwide (Wilcove et al., 1998). Habitat loss in Puget Sound's nearshore areas is of particular concern because shallow subtidal and intertidal habitats are some of the most productive components of our ecosystem, and many birds, fish, invertebrates and mammals rely on these habitats during critical life stages. For this reason, the British Columbia/Washington Marine Science Panel made protecting estuarine habitat its highest priority recommendation for ecosystem health (BC/WA Marine Science Panel, 1994).

It is difficult to precisely quantify the extent of nearshore habitat lost due to human activities. However, information is available that highlights the magnitude of these losses:

- Estuarine habitat is generally considered to be the habitat type in the Puget Sound region that is most severely affected by humans. More than 50 percent of tidal flats and intertidal areas in major embayments has been lost since 1850 (Bortleson et al., 1980). Losses have been significantly higher in urbanized areas. For example, Commencement Bay has lost more than 99 percent of its marsh habitat and 95 percent of its intertidal mudflats (U.S. Army Corps of Engineers et al., 1993).

- The quality of remaining estuarine habitat in the Puget Sound region is commonly degraded. As discussed on page 50, approximately 5,700 acres in Puget Sound's urban bays have been identified as having sediment contaminant concentrations that do not meet the state's sediment quality standards. The highest concentrations of contaminants occur in the sediments of urbanized bays, such as Elliott Bay, Commencement Bay, Budd Inlet and Sinclair Inlet. Water quality is impaired in 65 percent of Washington's estuaries (Butkus, 1997).
- Nearshore areas throughout Puget Sound have been altered by development. Humans modify the shoreline and destroy natural habitat directly through construction of bulkheads and other structures and through activities such as filling and dredging. Habitat loss also occurs indirectly through alteration of nearshore processes like wave energy and sediment transport. One common impact of nearshore habitat modification or destruction is beach erosion, which is caused by loss of sediment supply. Another impact is increased runoff. In addition to specific local impacts, the extent of shoreline modification also indicates the intensity of a wide range of human activities affecting nearshore areas. Scientists with the Department of Natural Resources estimate that humans have modified one-third of Puget Sound's shoreline (Puget Sound Water Quality Action Team, 1998). The main basin of Puget Sound is the most intensively modified region of the Sound; more than half of its shoreline has been altered. Other regions are significantly less altered; approximately 20 percent of the shorelines are modified in the region that includes the San Juan Islands and Strait of Juan de Fuca.

Rapid Mapping of Shoreline Using the ShoreZone Inventory. Consistent information about shoreline habitat is needed to characterize the abundance and distribution of different habitats and their general health. To fill this need, staff of the Nearshore Habitat Program at the Department of Natural Resources are completing a rapid statewide inventory of saltwater shorelines using the ShoreZone Mapping System. The ShoreZone inventory provides regional information about spatial patterns in the nearshore environment. It is intended to augment, rather than replace, more detailed habitat studies.

The ShoreZone Mapping System allows scientists to rapidly survey intertidal areas via helicopter. During the fly-over, a video image of the shoreline is recorded with accompanying audio descriptions from a geomorphologist and a biologist. These recordings are then translated to geographic data and maps that describe the physical and biological characteristics of the shoreline. The data include approximately 50 parameters that describe shoreline geomorphology, vegetation and human development features.

Natural Resources will complete data analysis and make the statewide ShoreZone inventory available in late 2000. Preliminary data analysis has been completed for the eastern side of Puget Sound's main basin. This region contains some of the most extensively developed shorelines in Puget Sound, including Seattle and Tacoma. Results for four of the parameters inventoried are shown in Figure 14 (page 24). These examples from the ShoreZone mapping inventory provide the following information:

- Intertidal areas of the eastern side of Puget Sound's main basin have been extensively modified; 79 percent of the shoreline has

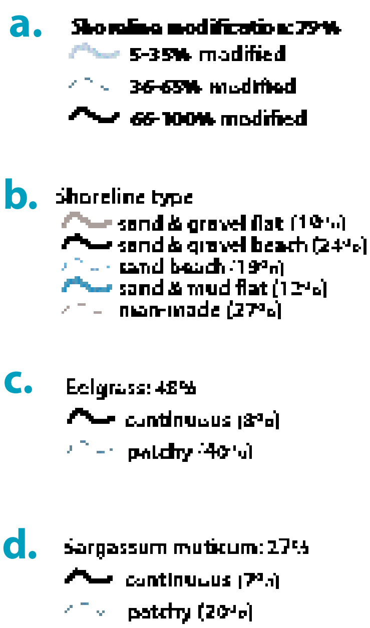
What is nearshore habitat?

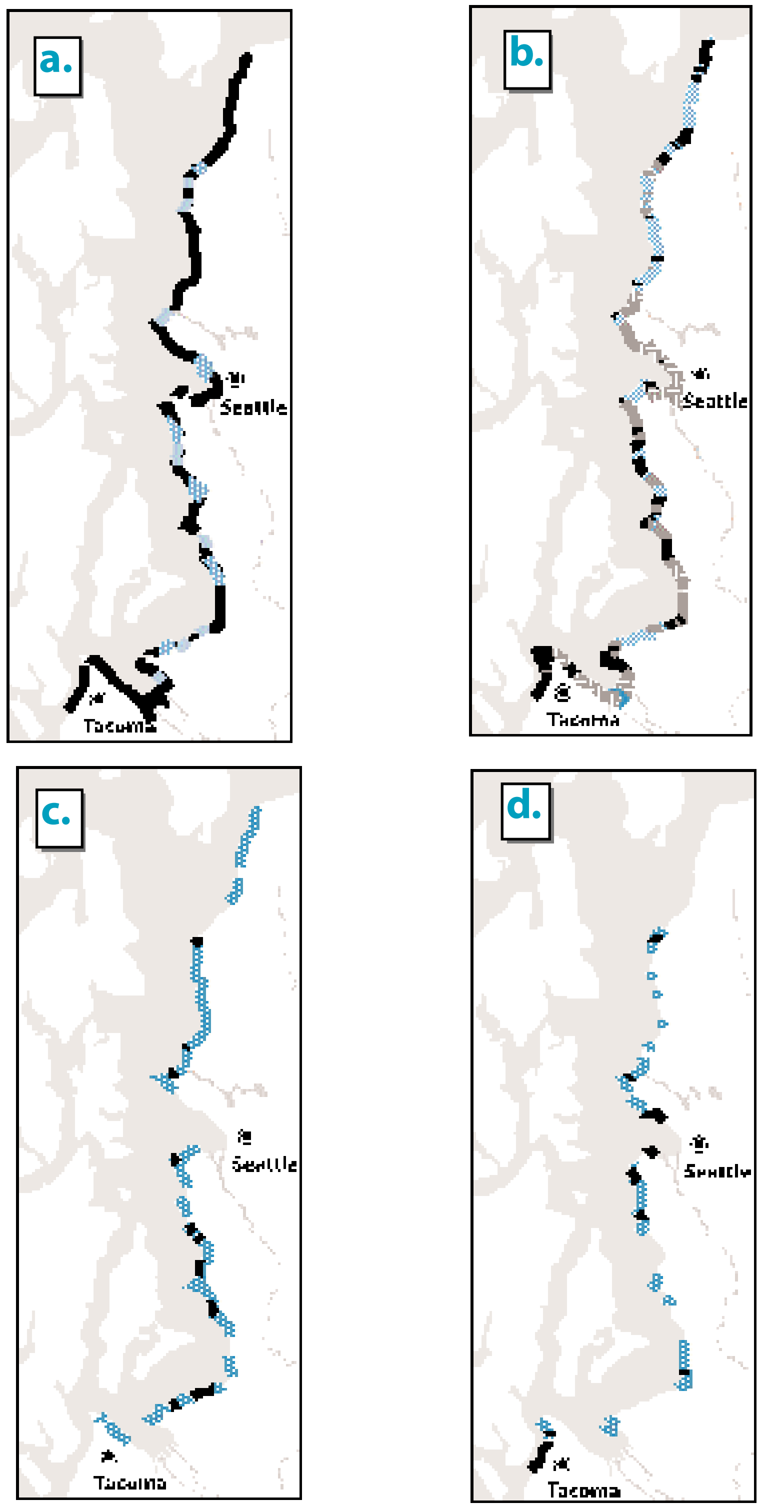
Nearshore habitat includes the area from 65 feet below mean low water to 200 feet upland of the ordinary high water mark. This area generally encompasses several of the following habitats: bluffs, beaches, marshes, riparian vegetation, sandflats, mudflats, rock and gravel habitats, unvegetated subtidal areas, kelp beds, intertidal algae and eelgrass beds.

some type of modification (e.g., bulkheads, docks, piers) in either the intertidal or backshore zones. Along more than one-quarter of the shoreline, the predominant substrate throughout the intertidal zone is man-made.

- The abundance and distribution of different shoreline types in this area reflects both natural patterns in the main basin and historical development trends. The natural shoreline is primarily composed of narrow sand and gravel beaches; rocky intertidal habitat is rare.

Figure 14. ShoreZone inventory of the eastern shore of Puget Sound's central basin.





Analyzing habitat trends across the British Columbia/Washington border

In addition to describing spatial patterns of shoreline characteristics within Puget Sound, the ShoreZone Mapping System will be a useful tool for analyzing trends in habitat across the international border. The system was originally designed in British Columbia and is being used to map provincial shorelines. A joint protocol is being defined by the Washington Department of Natural Resources' Nearshore Habitat Program and the British Columbia Land Use Coordination Office.

Tidal flats comprise only 12 percent of the shoreline today, reflecting the historic loss of estuarine habitat in urbanized embayments.

- Eelgrass *(Zostera marina)* provides important habitat for salmon, marine fish, birds and other wildlife and occurs throughout the study area. Almost one-half of the shoreline has patchy or continuous eelgrass beds. Because of the recognized ecological importance of eelgrass beds, these areas are protected by state policies. It is not known how the distribution of eelgrass has changed along this shoreline over time. Temporal change in the extent of eelgrass is an important topic for future monitoring.
- *Sargassum muticum* is a non-native algae that is established throughout Puget Sound. Its distribution and potential impact on the local ecosystem are not well understood. The ShoreZone inventory provides preliminary information that *Sargassum* beds are extensive along the study area; 27 percent of this shoreline has patchy or continuous beds.

Detailed Inventory of Intertidal Shoreline Characteristics. Department of Natural Resources scientists complete detailed shoreline surveys in focus areas as resources allow. Inventory results are distributed on CD-ROM to assist in land-use planning and to improve understanding of linkages between habitats and species. In 1999, Natural Resources' Nearshore Habitat Program released inventory information for 230 miles of shoreline in Skagit County and northern Island County.

The habitat inventory describes physical characteristics that most strongly affect the distribution of shoreline plants and animals. Intertidal habitats were classified based on substrate, elevation, human modification and energy regime according to *A Marine and Estuarine Habitat Classification System for Washington State* (Dethier, 1990).

Washington State has some of the most diverse shoreline habitats in the world. The inventory illustrates the range in habitat types, from narrow rock ledges along Deception Pass to broad mud and sand flats in Cornet Bay. (See Figure 15 in the color section on page 112.) Mixed fine and sand habitats were the most abundant in terms of acres inventoried (Table 2). These types of habitats support important vegetation communities such as eelgrass meadows and salt marshes. Habitats composed of larger substrates (e.g., gravel, cobble) are less abundant in terms of overall acreage because they tend to be narrower, but they are the most common in terms of total shoreline miles.

A significant portion of natural habitat in the Skagit County study area has been lost through human conversion of upper intertidal and backshore areas to man-made substrate (Figure 16, page 26). The inventory indicates that 34 percent of the shoreline has been modified. Most of this is due to agricultural diking practices in this county.

In addition to describing physical characteristics, the habitat inventory delineates intertidal and canopy-forming vegetation. This data set is discussed in the

Substrate Type	Acres	Percent
artificial	91	< 1
bedrock	220	< 1
boulders	100	< 1
cobble	10	< 0.1
gravel	240	< 1
hardpan	0.3	< 0.1
mixed coarse	880	3.0
mixed fine	10,000	34
mud	4,400	15
organic	410	1.4
sand	13,000	44
Total	**29,351.3**	**100**

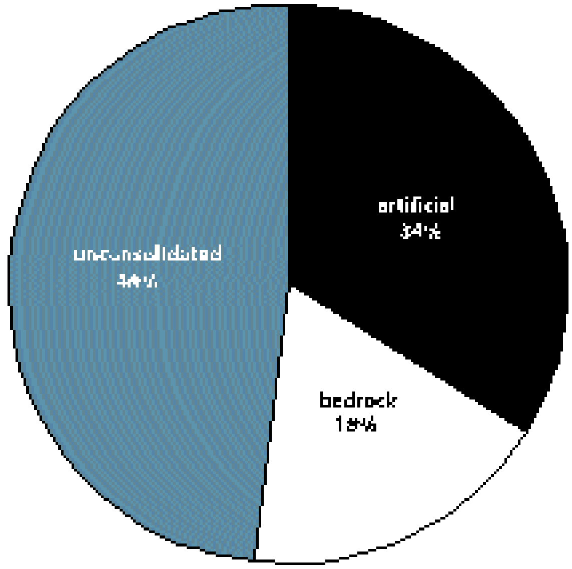
Table 2. Areal extent of intertidal substrate types for Skagit County study area.

ShoreZone Inventory results on Whidbey Island shoreline alteration

Department of Natural Resources scientists queried the ShoreZone inventory data to develop an independent estimate of shoreline modification on Whidbey Island. This analysis showed that just over 20 percent of the island's 155 miles of shoreline are modified in some way. The Beach Watchers' estimate of just over 22 percent for 125 miles of the Whidbey shoreline agrees with this ShoreZone result. The citizen monitoring protocol developed and implemented by Island County/WSU Beach Watchers would provide a direct means of monitoring changes over time in shoreline alteration for selected areas of Puget Sound.

Figure 16. Substrate type at the extreme high water line for Skagit County study area.

Refer to Table 2 (page 25), for examples of unconsolidated substrate, which includes everything but artificial substrate and bedrock. (Unconsolidated means that the substrate moves and does not stay in one large block.)



Biological Resources section of this report (page 81).

Beach Watchers' Assessment of Shoreline Alteration on Whidbey Island. Bulkheads, seawalls, piers, docks, launch ramps, jetties, groins and other structures have hardened over 22 percent of the Whidbey Island shoreline (Island County/Washington State University (WSU) Beach Watchers, 1999). From April to September 1999, volunteers with Island County/WSU Beach Watchers measured the extent of shoreline armoring on approximately 125 miles of Whidbey Island's 155-mile shoreline. The survey used a citizen monitoring protocol that was developed by Beach Watchers and other Puget Sound region citizen monitoring groups (Island County/WSU Beach Watchers 1999). Volunteers measured shoreline structures and unaltered lengths of beach as they walked the high tide line with a measuring wheel. Because surveys were not completed for about 30 miles of Whidbey Island, Beach Watchers' estimate of the proportion of Whidbey Island shoreline that is altered may change slightly when the entire shoreline has been surveyed.

Citizen Shoreline Inventory of King, Pierce and Thurston Counties. The Citizen Shoreline Inventory (CSI) was developed to evaluate the relationship between shoreline development activities and the health of adjacent nearshore habitats in Puget Sound. CSI is a joint effort between People for Puget Sound and Adopt a Beach. Data from CSI are available at http://www.pugetsound.org/csi.

After two years of data collection, scientists at People for Puget Sound analyzed the CSI database to evaluate potential indicators with which to assess the health of Puget Sound's nearshore environment. Data collected in the summer of 1998 from 163 150-foot sections of shoreline in King, Pierce and Thurston counties were analyzed to investigate relationships between habitat characteristics and shoreline alteration (Figure 17).

Shoreline alteration (armoring) was observed at 37 percent of the 163 sections. Eelgrass was more commonly observed in unaltered sections than in altered sections. In addition, fine sediments that provide habitat for many intertidal organisms, including small invertebrates (which are the primary prey for juvenile salmon), were less common in altered areas, with 13 percent of armored sections having cobble as the dominant low intertidal substrate. In contrast, only one percent of unarmored sections had cobble as the dominant substrate. The association between alteration and the presence of cobble substrate may indicate the loss of fine sediment habitat where the shoreline is armored.

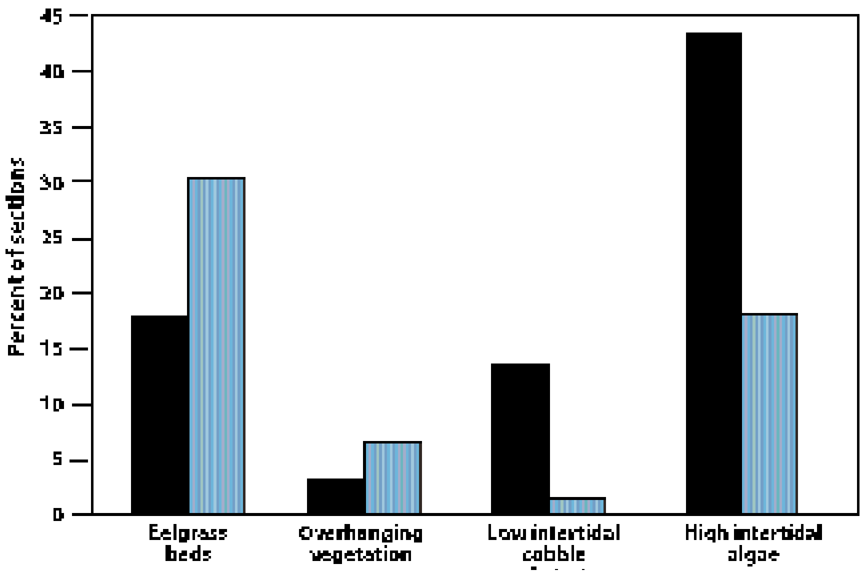


Figure 17. Citizen Shoreline Inventory habitat parameters for armored and unarmored shoreline sections in King, Pierce and Thurston counties, summer 1998.

Source: People for Puget Sound's unpublished analysis of Citizen Shoreline Inventory data.

Acting on the Findings

The information presented in this chapter suggests a number of recommendations for further scientific study and resource management:

- The Department of Ecology should continue (and emphasize) its efforts to develop clean-up plans (also known as total maximum daily loads or TMDLs) for rivers and streams that are impaired by high temperatures and low instream flow. These plans should provide the technical basis for watershed and riparian area improvements that will lead to water quality improvements.
- Local governments and the state should work with land owners to develop more information on culverts and other blockages to salmon habitat. Comprehensive culvert inventories, such as the one currently being conducted by the Pierce County Conservation District for the Puyallup/White watershed, are needed for all watersheds in the Puget Sound basin in order to assess availability of salmon habitat at a time when several salmon species are at risk.
- Local, state and federal agency staff should consider the implications of water column stratification in many of Puget Sound's inlets and bays as they evaluate the effects of discharges to the Sound.
- Ecology should track trends in dissolved oxygen at all of its marine monitoring stations and it should conduct intensive investigative surveys at any locations with decreasing dissolved oxygen levels.
- After Department of Natural Resources scientists complete the ShoreZone inventory, this information should be disseminated to shoreline planners, state agency and tribal staff, and others who should use the inventory in resource management and permitting decisions. Alternatives to beach hardening should be considered.
- State agencies and local governments should make use of nearshore monitoring data collected by citizen monitoring groups to augment data from other sources. Citizen monitoring should be encouraged as a means of developing data needed for shoreline and nearshore resource management decisions.

Pathogens & Nutrients

Summary

Human and animal wastes carry pathogenic organisms, such as bacteria and viruses, and are also rich in nutrients. Although pathogens and nutrients are natural components of the Puget Sound ecosystem, human development, industrialization and population of watersheds and shorelines contributes increased loadings of these materials to the waters of the Puget Sound basin. Where these increased loadings occur, pathogens and nutrients exist in such high concentrations that they effectively become contaminants that can cause significant water quality problems. Pathogens can affect human health when people come in direct contact with them or eat fish or shellfish harvested from contaminated areas.

Pathogen- and nutrient-related water quality problems typically occur in the vicinity of contamination sources. Pathogen and nutrient contamination is a significant concern in a number of locations around Puget Sound, especially in important shellfish growing areas, near the mouths of major rivers and in bays and inlets where circulation is limited.

It is difficult to discern trends in Puget Sound's pathogen and nutrient contamination over time because measurements are quite variable in time and space, but, there is evidence that conditions may be worsening in some locations. For example:

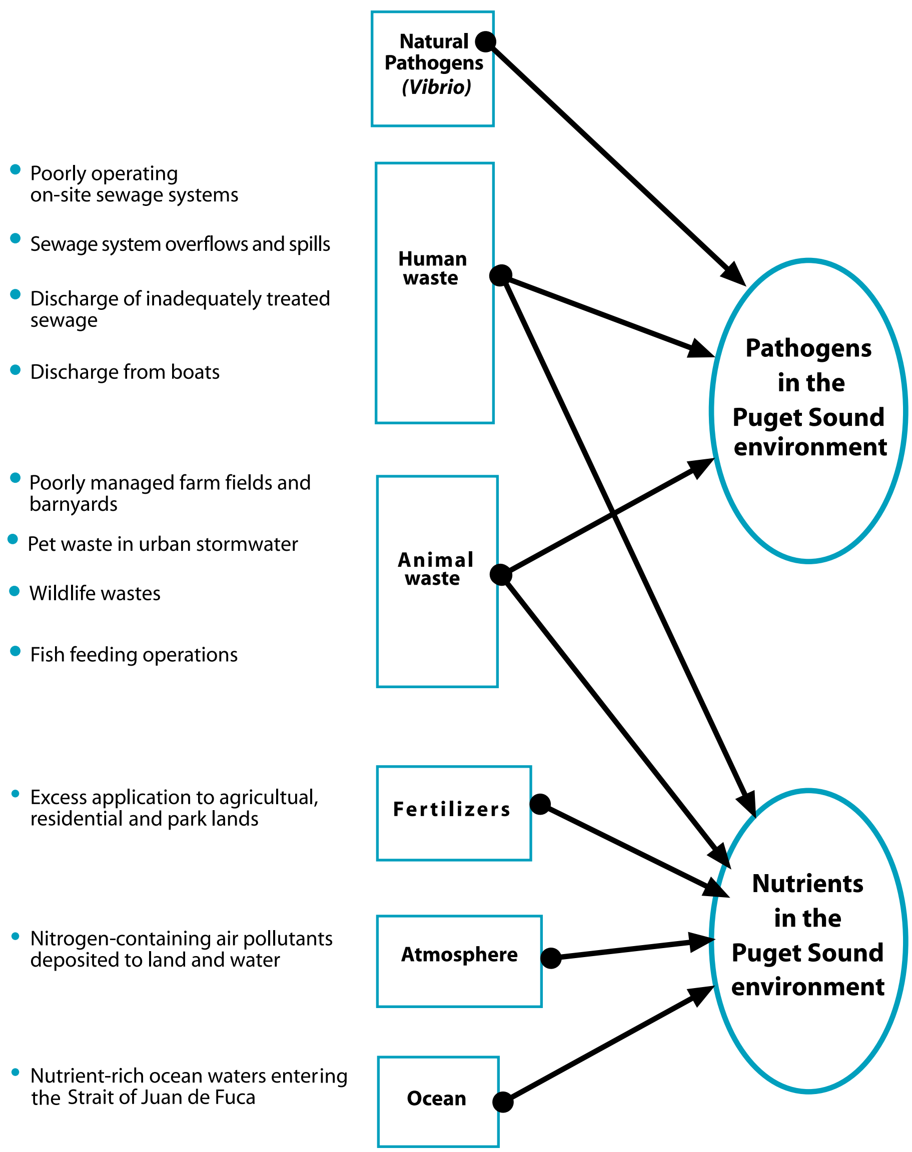
- Fecal contamination at Burley Lagoon (at the head of Carr Inlet) and Henderson Inlet seems to have increased in recent years.

- In Hood Canal, a zone with a low concentration of dissolved oxygen seems to persist through more of the year than it did in years past. Whether this indicates water quality degradation associated with nutrient additions is not known.

At other locations, specifically the shellfish-growing areas in south Puget Sound's Oakland Bay and Eld Inlet, conditions appear to be improving. Fecal contamination in these two areas decreased through the 1990s, probably reflecting considerable public and private work to address point and nonpoint sources of pollution.

Concerns About Pathogen and Nutrient Contamination of Puget Sound. Many human activities in watersheds and on shorelines allow contaminants from human and animal wastes to cause problems in Puget Sound's waters. Figure 18 depicts the major sources of pathogens and nutrients to Puget Sound. Many of these sources are related to human and animal wastes and carry both pathogens and nutrients. Some nutrient sources, particularly lawn fertilizers, atmospheric deposition and the Pacific Ocean, do not carry pathogens.

Figure 18. Sources of nutrients and pathogens to Puget Sound.



Many pathogenic organisms, including bacteria, viruses and protozoans, can survive outside of their animal hosts in aquatic environments. As a consequence, humans and other animals that ingest water or seafood from contaminated areas are at risk of contracting diseases caused by these pathogens. Human diseases associated with waterborne pathogens include typhoid, cholera and hepatitis. Pathogens may also threaten wild and domestic animals in a number of ways.

An excessive loading of nutrients, known as eutrophication, does not typically cause direct harm to a body of water. Instead, when conditions are favorable (i.e., when the water column is stratified, as discussed on pages 20-21, excess nutrients can increase the productivity of algae and plants. Increased productivity can alter the marine ecosystem by shifting the balance in plant and animal communities. Increased productivity can also cause water quality problems when the organic matter decays and depletes dissolved oxygen in the water. Excess nutrient-loading into waters that are stratified or otherwise poorly circulated can lead to nutrient-related water quality problems. Figure 19 summarizes some of the potential effects of eutrophication in Puget Sound.

Control of Pathogen and Nutrient Contamination in Puget Sound. The *Puget Sound Water Quality Management Plan* addresses concerns about pathogen and nutrient contamination through a variety of programs. The plan's attention to on-site sewage systems and shellfish protection is primarily driven by concerns about pathogen contamination from fecal matter. Plan programs related to agricultural and forest practices and municipal and industrial discharges address the spectrum of contaminants associated with these stresses, including both pathogens and nutrients.

Wastewater treatment, proper operation and maintenance of on-site sewage systems, and best management practices for agricultural and forest lands have all contributed

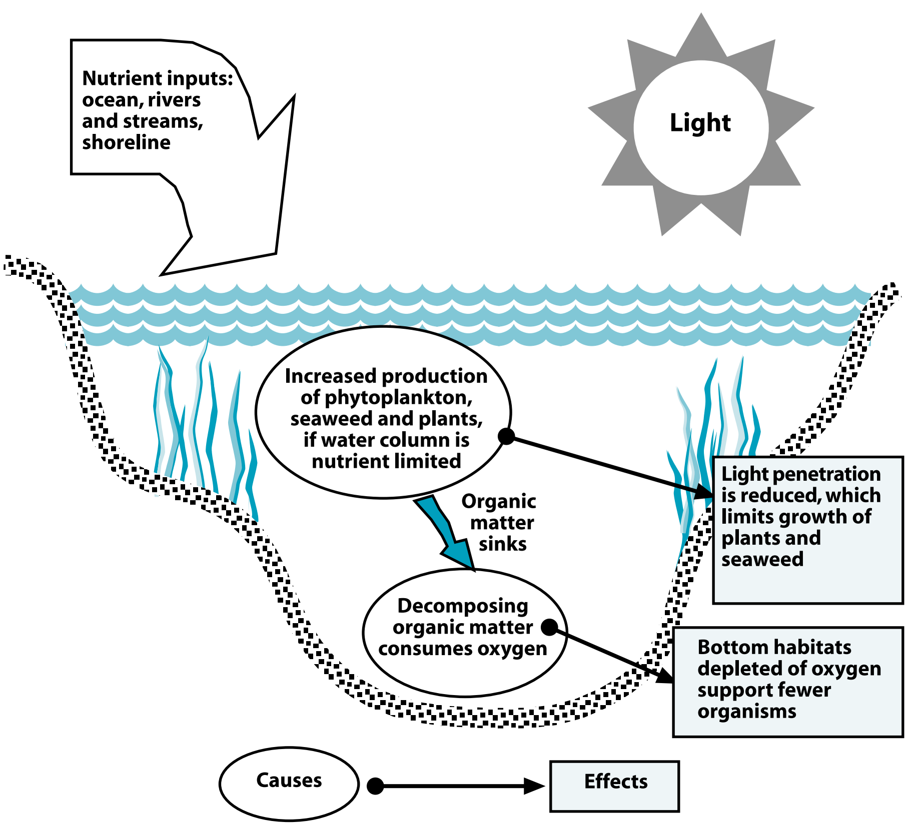


Figure 19. Potential effects of eutrophication in areas of Puget Sound with limited vertical circulation.

to the ongoing control of nutrient and pathogen contamination in Puget Sound. See pages 38-40 for a discussion of water quality improvements (and shellfish growing area upgrades) related to the successful control of fecal contamination at some locations.

Problems persist, however, because sources have not always been effectively controlled and controls (including repair of on-site sewage systems and use of best management practices in barnyards) have not always been adequately maintained. For example, fecal contamination increased recently in the late 1990s at Burley Lagoon, at the north end of Carr Inlet, despite corrective actions along the shoreline and in the watershed. Effective control of fecal contamination at Burley Lagoon will apparently require better controls, broader implementation of controls and continued maintenance of practices that protect water quality. Additional stresses are continually placed on the watershed by human population growth of up to two percent per year in Kitsap and Pierce counties.

In some cases, nutrient loadings can be reduced independently of controls on fecal contamination. For example, nutrient concentrations in the effluent from the Lacey-Olympia-Tumwater-Thurston County wastewater treatment plant were reduced 88 percent following the advent of nitrogen removal treatment processes at the plant (Eisner and Newton, 1997). Landowners and landscapers can control potential nutrient additions to nearby waters by maintaining vegetated buffers, reducing or improving application of fertilizers, or instituting other best management practices on residential, commercial, agricultural and park lands.

Findings on Pathogens

Waters polluted by human and animal wastes may contain a great diversity of pathogenic organisms. Rather than attempt to monitor all the various pathogens (most of which occur in very low concentrations and are costly and difficult to treat), scientists typically look for the presence of waterborne pathogens by measuring concentrations of fecal coliform bacteria. Organisms identified as fecal coliform bacteria occur predominantly in the gut of warm-blooded animals, and are carried into the environment in the fecal matter of these animals. Fecal coliform bacteria are not usually harmful, but they do demonstrate the presence of fecal contamination; thus, fecal coliform bacteria are used to indicate the possibility that other pathogenic organisms are present.

Fecal contamination is a widespread problem in the Puget Sound basin. Rivers, streams, shellfish growing areas and open marine waters are affected by fecal contamination. Table 3 summarizes the number of fresh and marine water areas in the various river basins of the Puget Sound region identified by the Department of Ecology as impaired by fecal contamination (i.e., where water quality does not meet the state's standard for fecal coliform contamination). Fecal contamination is the most common water quality impairment in the Puget Sound basin; nearly one-half of all Puget Sound basin waters that have been assessed are affected. Thirty-two marine areas are among the more than 260 bodies of water in the Puget Sound basin identified as impaired by fecal contamination.

Rivers and Streams

As part of the PSAMP, Ecology monitors conditions monthly at 24 river and stream sampling stations throughout the Puget Sound basin. Figure 20 shows the degree of fecal contamination measured at these stations over the past five years. Specifically, the chart shows that for each year from 1995 through 1999, 40 to 80 percent of the monitoring stations experienced fecal coliform bacteria concentrations above Washington's water quality standard for fecal contamination at least once during the year.

Table 3. Numbers of fresh and marine waters in various Puget Sound basin Water Resource Inventory Areas (WRIAs) identified by the Department of Ecology as impaired by pathogens and nutrients: fecal coliform bacteria, ammonia or total nitrogen, and total phosphorus.

WRIA number – Basin name	Number of fresh waters impaired by fecal coliform bacteria	Number of marine waters impaired by fecal coliform bacteria	Number of fresh waters impaired by ammonia or other forms of nitrogen	Number of marine waters impaired by ammonia or other forms of nitrogen	Number of fresh waters impaired by phosphorus	Total number of water-bodies in basin
1 – Nooksack	37	4	2			67
2 – San Juan		1				5
3 – Lower Skagit/Samish	11	4			2	42
4 – Upper Skagit						6
5 – Stillaguamish	14	1	2		1	34
6 – Island		2				6
7 – Snohomish	17				2	48
8 – Cedar/Sammamish	35				4	61
9 – Duwamish/Green	30	2	1	1	2	51
10 – Puyallup/White	14	1	1			33
11 – Nisqually	3	1			4	10
12 – Chambers/Clover	7				3	15
13 – Deschutes	11	2			1	27
14 – Kennedy/Goldsborough	8	5				22
15 – Kitsap	36	7			1	73
16 – Skokomish/Dosewallips	5	1				8
17 – Quilcene/Snow	3	1				20
18 – Elwha/Dungeness	4					9
19 – Lyre/Hoko						8
Total for Puget Sound basin	**235**	**32**	**6**	**1**	**20**	**545**

"Impaired" indicates that the body of water does not meet the applicable state water quality standard.

Source: Department of Ecology unpublished data.

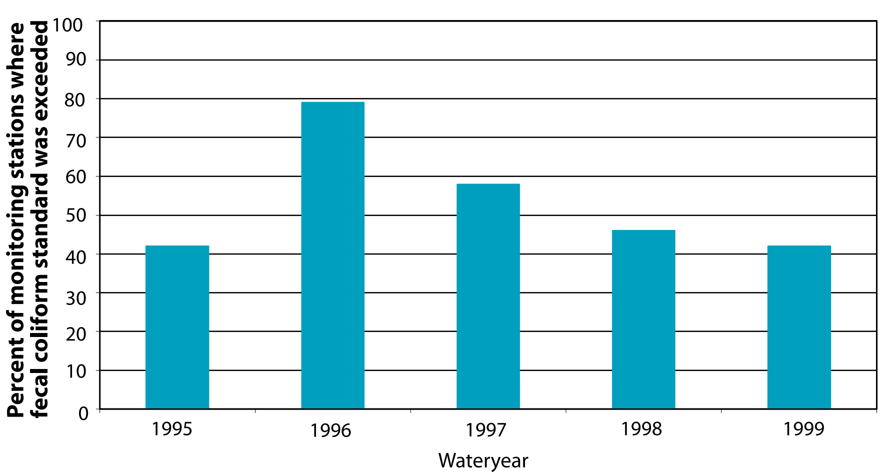


Figure 20. Puget Sound river and stream stations exceeding water quality standards for fecal coliform bacteria.

Because many pathways by which fecal contamination can reach rivers and streams involve rainwater runoff from lands where animal and human wastes are managed, we expect higher levels of fecal contamination when precipitation is higher. In fact, the Department of Health closes eight Puget Sound shellfish-growing areas to harvesting when specified amounts of rainfall occur. Higher than normal precipitation might partly explain the high incidence of fecal contamination observed in wateryears 1996 and 1997, when total precipitation and river flows were higher than average. However, wateryear 1999 was also much wetter than normal but the incidence of fecal contamination was not different from years with average or less than average amounts of precipitation, such as 1998 and 1995, respectively. These results indicate that additional analysis is needed to explain the occurrence of fecal contamination in Puget Sound's rivers and streams.

Department of Ecology Monitoring of Open Marine Waters

Results from Ecology's routine monitoring at 15 marine water stations as part of the PSAMP indicate that seven to 30 percent of stations had fecal coliform bacteria counts higher than the state's water quality standard for marine waters (43 colonies/100 ml). Depending on the year, an additional seven to 40 percent of monitoring stations show moderate levels of contamination—counts above 14 colonies/100 ml, the average level allowed in the standard.

Figure 21 shows the percentage of Ecology's marine water monitoring stations where measurements exceeded these fecal coliform concentrations in each wateryear from 1992 through 1998. Among these years, fecal coliform contamination was worst in 1995 and 1996, when one-third of the monitoring stations recorded concentrations above 43 colonies/100 ml. This data set reveals no trends in fecal contamination of Puget Sound's marine waters and no clear relationship to year-to-year variations in precipitation or stream flow.

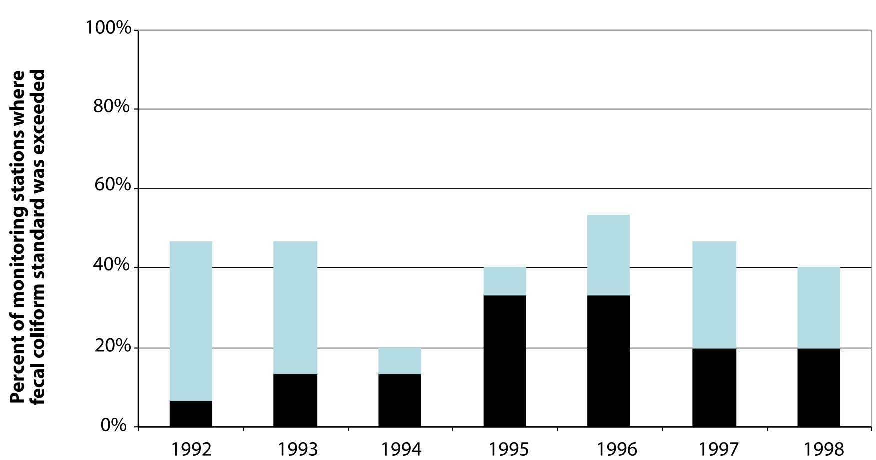
Figure 22 shows the geographic distribution of fecal contamination among the Puget Sound marine water monitoring stations sampled by Ecology in wateryears 1996 and 1997. High fecal coliform bacteria levels were observed at a number of locations:

- Commencement Bay Near Browns Point (Tacoma) had multiple incidents of very high counts. These results are consistent with previous findings at another Commencement Bay station nearer the mouth of the Thea Foss Waterway.

Figure 21. Puget Sound marine monitoring stations exceeding water quality standards for fecal coliform bacteria.

Greater than 43 colonies/100 ml

14 to 43 colonies/100 ml



- Inner Budd Inlet (Olympia) showed consistently high fecal coliform bacteria counts in 1996. This location is not sampled every year by Ecology scientists; conditions there were not monitored in 1997. The station nearer the middle of Budd Inlet had much lower concentrations. This difference in conditions illustrates the short marine lifetime of fecal coliform bacteria, as surface waters move from inner Budd Inlet out toward Puget Sound. It also demonstrates the low probability of detecting fecal coliform bacteria in open-water sites.
- Elliott Bay and the Main Basin of Puget Sound off of West Point (Seattle) occasionally show high counts of fecal coliform bacteria during winter months. These occasional high counts have been observed since 1993 and may be related to fresh water discharges from the Duwamish River and the Lake Washington Ship Canal.

Similar information to that in Figure 22 was presented in the *1998 Puget Sound Update* for wateryears 1990 through 1995. The results show high counts (above 43 colonies/100 ml) at many of the stations previously identified as having high fecal contamination. The two versions of this graphic cannot be directly compared, though, because monitoring is not completely consistent from year to year. Ecology scientists monitor a number of core stations every year and monitor other stations less frequently. The stations that are monitored less than annually are referred to as rotating stations. They are monitored as appropriate based on consideration of previous results, public concerns and a three-year cycle of emphasis between north, central and south Sound stations. A station in Drayton Harbor was first monitored by Ecology's ambient marine monitoring program during 1997 in response to concern over water quality in the inner harbor; high fecal coliform counts were observed. Liberty Bay and Commencement Bay near the Thea Foss Waterway had high counts in the past, but were not monitored in 1996 and 1997.

Moderate contamination (greater than 14 colonies/100 ml but less than 43 colonies/100 ml) was recently identified in the open waters of lower Hood Canal (beyond the Great Bend), where considerable development has occurred in recent years; all measurements at this station prior to 1996 showed low levels of fecal contamination.

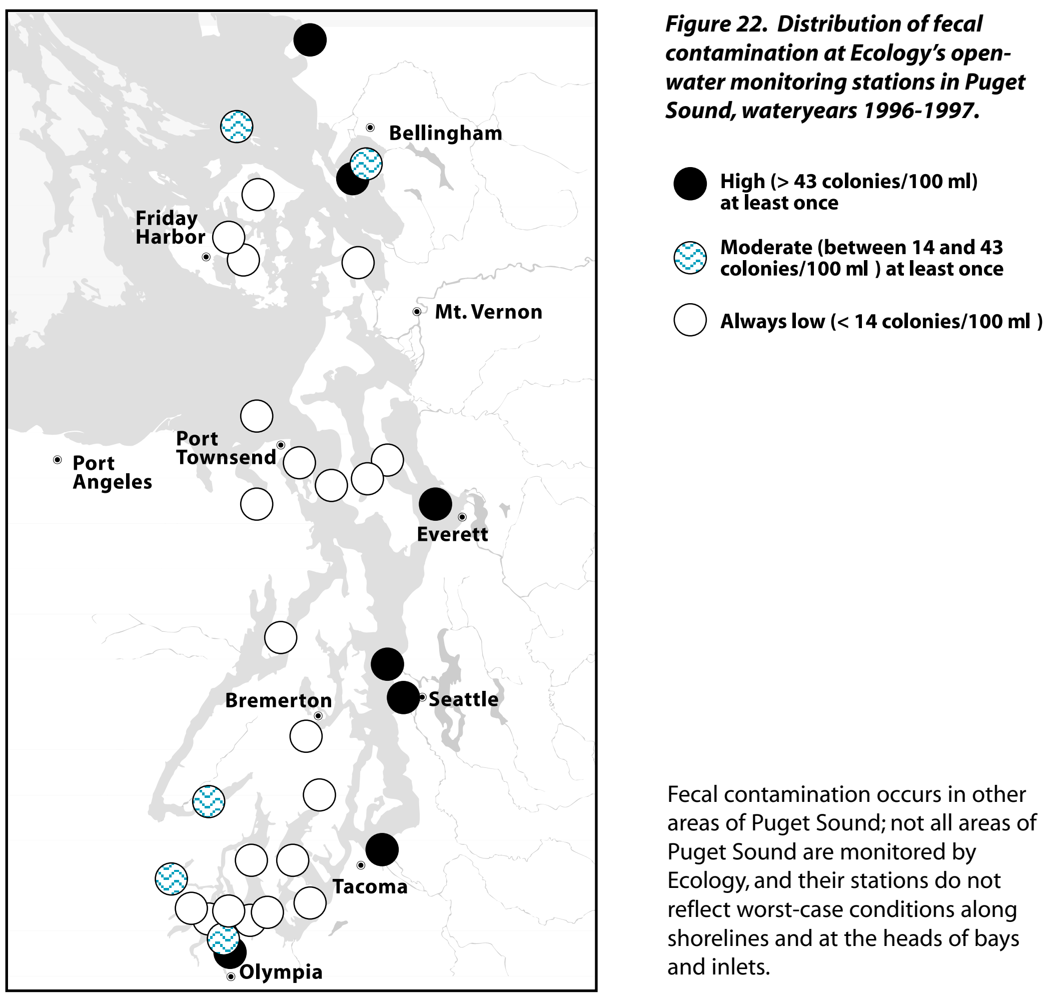


Figure 22. Distribution of fecal contamination at Ecology's open-water monitoring stations in Puget Sound, wateryears 1996-1997.

Fecal contamination occurs in other areas of Puget Sound; not all areas of Puget Sound are monitored by Ecology, and their stations do not reflect worst-case conditions along shorelines and at the heads of bays and inlets.

Fecal coliform counts showing above moderate contamination in the early 1990s at Sinclair Inlet, Oakland Bay and outer Budd Inlet were not repeated during 1996 and 1997 when only low levels of contamination were observed. Previous records of moderate fecal contamination in south Puget Sound at Totten, Eld and Carr inlets were not repeated in samples taken in 1996 and 1997. This variability in observations may represent normal year-to-year variations.

Fecal Contamination at Offshore and Nearshore Areas of King County

The King County Department of Natural Resources monitored 15 nearshore and five offshore sites in central Puget Sound for fecal coliform and *Enterococcus* bacteria in 1997, and 20 nearshore and 10 offshore sites in 1998. The sites were located between Fauntleroy Cove and Richmond Beach, with most sites located on the east side of the Sound's Main Basin. Stations were centered near the county's two main wastewater treatment plant outfalls as well as in areas not influenced by wastewater discharges.

Sampling at offshore stations showed that both fecal coliform and *Enterococcus* bacteria levels were low, if detected at all, throughout the year for all stations with the exception of the station located in inner Elliott Bay. This station has consistently failed the applicable Washington state marine surface water standards for fecal coliform bacteria for the past several years. It is located near a combined sewer overflow (CSO) outfall and high bacteria counts are seen coinciding with high rainfall months (November through January). Currently, there are efforts to reduce the amount of CSO discharge at this site.

Water quality in Puget Sound's nearshore areas is greatly affected by rainwater runoff. Consequently, the highest bacteria counts at nearshore monitoring stations are typically found when there has been a significant amount of rainfall prior to sampling or where the station is in close proximity to a freshwater source—such as the Lake Washington Ship Canal. Stations located in these areas consistently failed fecal coliform bacteria standards. This occurred in both 1997 and 1998, although bacteria levels in 1998 were slightly lower. Stations in areas removed from the strong tidal mixing of the open Sound tend to retain freshwater input longer and also have higher bacteria counts. The station near Fauntleroy Cove is in such an area and this station consistently has high values from year to year.

Fecal Contamination in Commercial Shellfish Growing Waters

The Washington State Department of Health (State Health) classifies commercial shellfish beds according to guidelines set by the U.S. Food and Drug Administration's National Shellfish Sanitation Program (NSSP). As of December 1998, more than 100,000 acres of Puget Sound tidelands in 110 growing areas were classified as "approved" or "conditionally approved." Harvest was restricted or prohibited on an additional 16,000 acres.

The guidelines of the NSSP are designed to ensure thorough surveys of harvest areas in order to keep contaminated shellfish out of the market. To be "approved", a growing area must meet minimum standards for water quality and not be subject to contamination that is hazardous to public health.

Compliance with the National Shellfish Sanitation Program's Standards. Before State Health classifies an area, stations within the proposed area are selected and routinely sampled until a minimum of 30 results per station are available. In the interim, State Health conducts a rigorous shoreline survey to locate and evaluate pollution sources. Sources are reported to appropriate agencies for thorough review and action.

Two statistics are calculated from the 30 water sample results. These are compared to the *NSSP Growing Area Standards.* To classify an area, State Health applies the statistics according to the type of pollution in the area: *point sources* (concentrated sources, such as wastewater discharged through a pipe); or *nonpoint sources* (diffuse sources with non-definable pathways, such as failed on-site sewage systems or drainage from pastures). The standards and their application are described below:

1. The *geometric mean* is not to exceed 14 colonies/100 ml of water (applied in all cases).
2. The *90th percentile value* is not to exceed 43 colonies/100 ml of water (applied to areas where only nonpoint sources are present); OR ten percent of results are not to exceed 43 colonies/100 ml of water (applied when one or more point sources are present).

If both statistics meet the criteria *and* the shoreline survey reveals no significant pollutant sources, the area is classified as "approved." If the criteria are not met, but pollution events can be shown to be episodic and predictable (i.e., rain-related runoff, etc.) the area may qualify as "conditionally approved." Additional evaluations are required to determine the limits of the classification. After initial classification, sampling continues and shoreline surveys are periodically repeated. Water quality is monitored monthly in "conditionally approved" areas and six times a year in "approved" areas.

State Health provides an annual analysis of data for each growing area to shellfish growers and local agencies. State Health issues an "early warning" if 90th percentile values at one or more stations in a growing area exceed 30 colonies/100 ml. The 90th percentile is used as the "early warning" statistic because experience has shown this statistic responds more quickly to change than does the geometric mean.

To focus its activities for the PSAMP, State Health has sorted Puget Sound growing areas into two groups. "Core" areas are assessed annually. These areas were selected based on high shellfish harvest, histories of pollution impacts, active remedial action programs and abundant data, and to ensure wide coverage of Puget Sound. "Rotational" areas have minimal pollution and are assessed every three years. Most core areas are sampled 12 times a year; rotational areas are sampled six times a year. The *2000 Puget Sound Update* presents results for all core growing areas, as well as for rotational growing areas in north Puget Sound, the straits of Juan de Fuca and Georgia and the San Juan Islands. Subsequent reports will discuss status and trends at rotational stations in the remainder of the Sound.

State Health scientists' analyses of water quality conditions at shellfish growing areas address two questions:

1. What is the status of fecal coliform contamination relative to State Health's standards and guidelines?
2. Have levels of fecal coliform bacteria changed over time?

To answer these questions for this report, State Health scientists calculated statistics (geometric means and 90th percentile values) for each sampling date starting from the earliest date with the required minimum number of prior results (i.e., 30 previous samplings) forward to March 1999.

Status of Fecal Coliform Contamination in Puget Sound Growing Areas. Figure 23 shows the water quality status of Puget Sound's core and north Sound rotational

Evaluating fecal coliform data

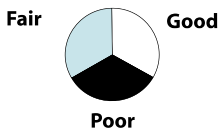
Ecology scientists take a different approach to evaluating fecal coliform data than do scientists at the Washington State Department of Health and the King County Department of Natural Resources. Ecology scientists compare individual measurements to values specified in the state's water quality standards. King County and the Department of Health compare statistical summaries based on 30 consecutive measurements (typically geometric means and 90th percentile values) to relevant shellfish program or water quality standards. This difference means that Ecology scientists are more likely to characterize an area as having "problem" or "high" levels of contamination.

Statistics on the move

The 30-sample statistics used by the Department of Health are "moving" statistics, where each statistic is updated as new data are available (i.e., the oldest result in the 30-sample set is dropped when a new value is added). This technique reduces the effects of temporal variation inherent in fecal coliform data and thus increases the chances of detecting long-term trends. As a result, the statistics of any particular date actually reflect conditions over a substantial period of time. For example, the statistics for a specific date for a "conditionally approved" station (sampled monthly) actually describe conditions over a 30-month period ending at that date. Statistics from a station in an "approved" area (sampled six times a year) reflect conditions prevailing for five years prior to the sampling date.

Figure 23. Status of fecal coliform contamination at selected shellfish growing areas throughout Puget Sound, 1998-1999.

Percent of stations

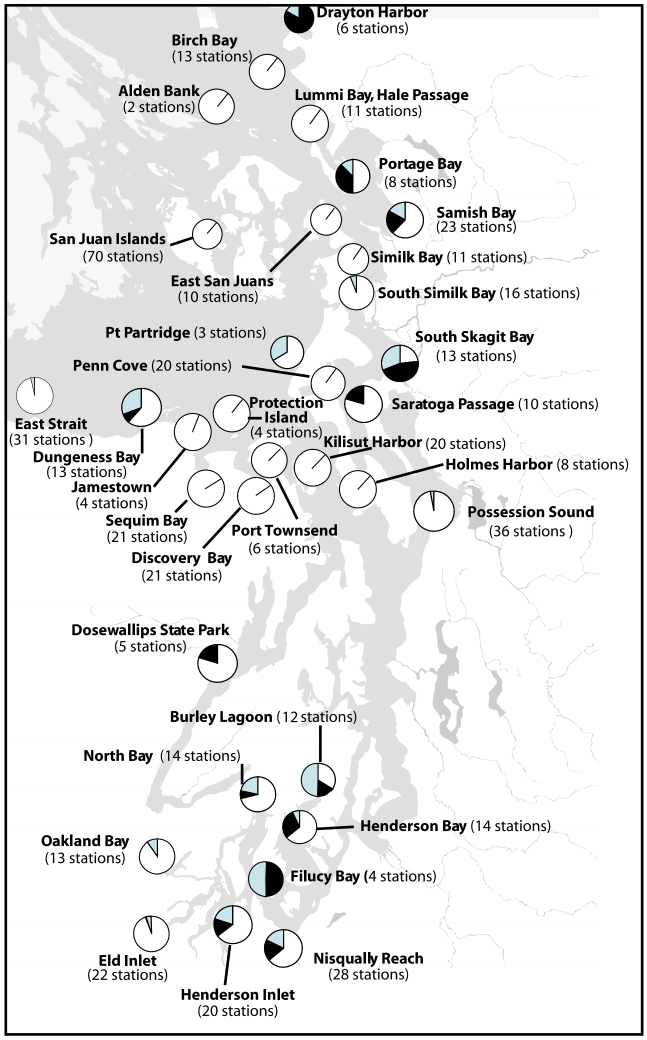


☐ **Good** - All statistics less than 30 MPN/100ml

☐ **Fair** - All statistics less than 43MPN/100 ml, some greater than 30 MPN/100 ml

■ **Poor** - Some statistics less than 43 MPN/100 ml

MPN - most probable number of fecal coliform bacteria.



growing areas. Each pie chart in this figure summarizes the percentage of stations within a growing area that were in good, fair, and poor condition during the period from January 1998 through March 1999. A station was classified as good if no 90th percentile values exceeded the "early-warning" threshold (30 colonies/100ml). A station was termed fair if its maximum 90th percentile value exceeded the "early-warning" threshold, but no 90th percentile values exceeded the NSSP criterion of 43 colonies/100 ml. A station with one or more 90th percentile values above the NSSP criterion was deemed poor.

Among the areas included in this evaluation, the most contaminated areas were Filucy Bay in south Puget Sound (two stations *poor*, two *fair*), Drayton Harbor (five stations *poor;* one *fair*), South Skagit Bay (six stations *poor,* four *fair*, three *good*), and Portage Bay near the mouth of the Nooksack River (three stations *poor*, one *fair,* one *good*). Other areas where one or more stations were identified as poor include Samish Bay, Saratoga Passage, Dungeness Bay, Dosewallips State Park and south Puget Sound's North Bay, Burley Lagoon, Henderson Bay, Nisqually Reach and Henderson Inlet. Other growing areas had stations rated only as good and fair; this includes growing areas in the San Juan Islands, the straits of Juan de Fuca and Georgia, Admiralty Inlet, Penn Cove, Holmes Harbor, Possession Sound, Eld Inlet and Oakland Bay.

The status of any area depends on the magnitude of the sources and the mixing potential of the receiving waters. Certain bathymetric factors (shape of bay, lack of depth, constricted entrance to bay, etc.) and hydrology (ratio of freshwater input to volume of bay, etc.) may limit effective mixing. Frequently, an area's most contaminated stations are located at the head of a poorly flushed inlet (Henderson Inlet, Filucy Bay) or adjacent to a river or stream that carries a fecal load (Dungeness Bay, south Skagit Bay, Samish Bay, Nooksack River). In other areas, it appears that the intensity of human activities within a watershed or along a shoreline threaten water quality and make it increasingly difficult for the waterbody to sustain a safe shellfish harvest.

Have Levels of Fecal Coliform Bacteria Changed Over Time? Temporal trends in fecal

Different measures of fecal contamination in Puget Sound marine waters

Figures 22 and 23 provide slightly different information about fecal contamination of Puget Sound. The distribution of fecal contamination problems presented in Figure 22 reflects the worst conditions observed at open-water stations from October 1995 through September 1997. Figure 23 represents conditions at intertidal shellfish growing areas as indicated by 90th percentile values for sets of 30 samples completed from January 1998 through March 1999. The different time frames may offer a partial explanation. The difference in environment sampled—open water versus intertidal—may also explain some apparent disagreements. For instance, Carr Inlet open waters have low contamination but Filucy Bay, a shellfish growing area along the inlet's southwest shore, is in poor condition. Discrepancies at other areas where assessments do not appear to agree (e.g., Possession Sound and the Strait of Georgia), may be related to different locations of stations within the area, time frames of analyses or approaches used for data analysis (see **Evaluating fecal coliform data** sidebar on page 37).

coliform contamination have been evaluated for four growing areas in south Puget Sound. State Health scientists examined time series of 90th percentile values of fecal coliform counts for these areas and performed tests to determine if apparent trends were statistically significant. Increasing trends mean fecal contamination was getting worse. Decreasing trends in contamination mean conditions were getting better.

Eld Inlet. State Health scientists examined 22 stations in Eld Inlet that were sampled continuously from 1988 to 1999. Generally, conditions at these stations improved over time (Figure 24a, page 40). Eighteen stations showed improvement; one station showed worsening conditions, but the 90th percentile values at this location were too low to be of immediate concern. The data indicate that improvements in water quality began in the mid-1990s; this coincides with efforts by the Thurston County Health Division to find and repair on-site sewage systems in beachfront communities and Thurston Conservation District's work with farmers to implement best management practices on their land. Water quality in Eld Inlet was worst at stations located at the upper end (head) of the inlet where fecal sources are strongest and flushing is weakest. The chief source of fecal contamination in Eld Inlet is most likely pasture runoff.

Henderson Inlet. Twenty stations in Henderson Inlet were sampled continuously from 1988 to 1999. As of March 1999, 18 stations showed increasing contamination, one station appeared to be improving and one station showed no significant change (Figure 24b, page 40). The status of five stations worsened since first reported in the 1998 Puget Sound Update. The stations with the worst water quality were in the innermost parts of the inlet where tidal exchange is minimal and pollutant loading is highest. The improved stations are located in the middle of the bay where tidal mixing is higher. Despite the trend of increasing fecal contamination in Henderson Inlet, most of the inlet remains within acceptable limits for shellfish harvest. However, continuing declines in water quality could lead to a downgrade in shellfish harvest classification.

Oakland Bay. Ten stations at Oakland Bay were sampled continuously from 1988 to 1999. The 1998 Puget Sound Update reported that, as of 1996, the status of eight of 10 stations was good, one was fair, and the station near the sewage treatment plant discharge was poor. Data through March 1999 indicate that the poor station improved to fair. The status of the rest of the stations that were evaluated previously remained the same (Figure 24c, page 40).

Three additional Oakland Bay sites that were not available for analysis in 1998 have now been evaluated. These stations are located in the innermost end (head) of the bay, and have been sampled since 1991. The status of the three sites is *good*. However, contamination at two of the three stations appears to be worsening.

Fecal pollution has declined at most stations in the southwest end of Oakland Bay. This improvement is likely due to the continuing renovation of Shelton's municipal sewage system and the control of stormwater contamination during heavy rains. On the other hand, increasing contamination in the north end of the bay probably results from sources on the adjacent shore or in nearby upland drainages. These sources need to be controlled in order to protect the "approved" classification of the north end of Oakland Bay.

Burley Lagoon. Five stations in Burley Lagoon were sampled continuously from early 1990 to 1999. Sampling began at seven more stations in late 1992. Results from the

Sources of fecal contamination

Likely sources of fecal contamination in all areas include failing on-site sewage systems and pasture drainage. Drayton Harbor and Oakland Bay are affected by contaminated urban stormwater among other nonpoint pollution sources. Drayton Harbor is also likely affected by boat wastes and other activity in the vicinity of the Blaine Marina. Major fecal contamination in Portage Bay appears to be attributed primarily to drainage from livestock operations along the Nooksack River. Dosewallips State Park might be partially affected by harbor seals hauling out in sloughs.

Figure 24. Status and trends in fecal coliform contamination in four South Puget Sound shellfish growing areas.

a. **Eld Inlet**

b. **Henderson Inlet**

c. **Oakland Bay**

d. **Burley Lagoon**

Status - from January 1998 through March 1999

☐ **Good -** All statistics less than 30 MPN/100ml

☐ **Fair -** All statistics less than 43MPN/100 ml, some greater than 30 MPN/100 ml

■ **Poor -** Some statistics less than 43 MPN/100 ml

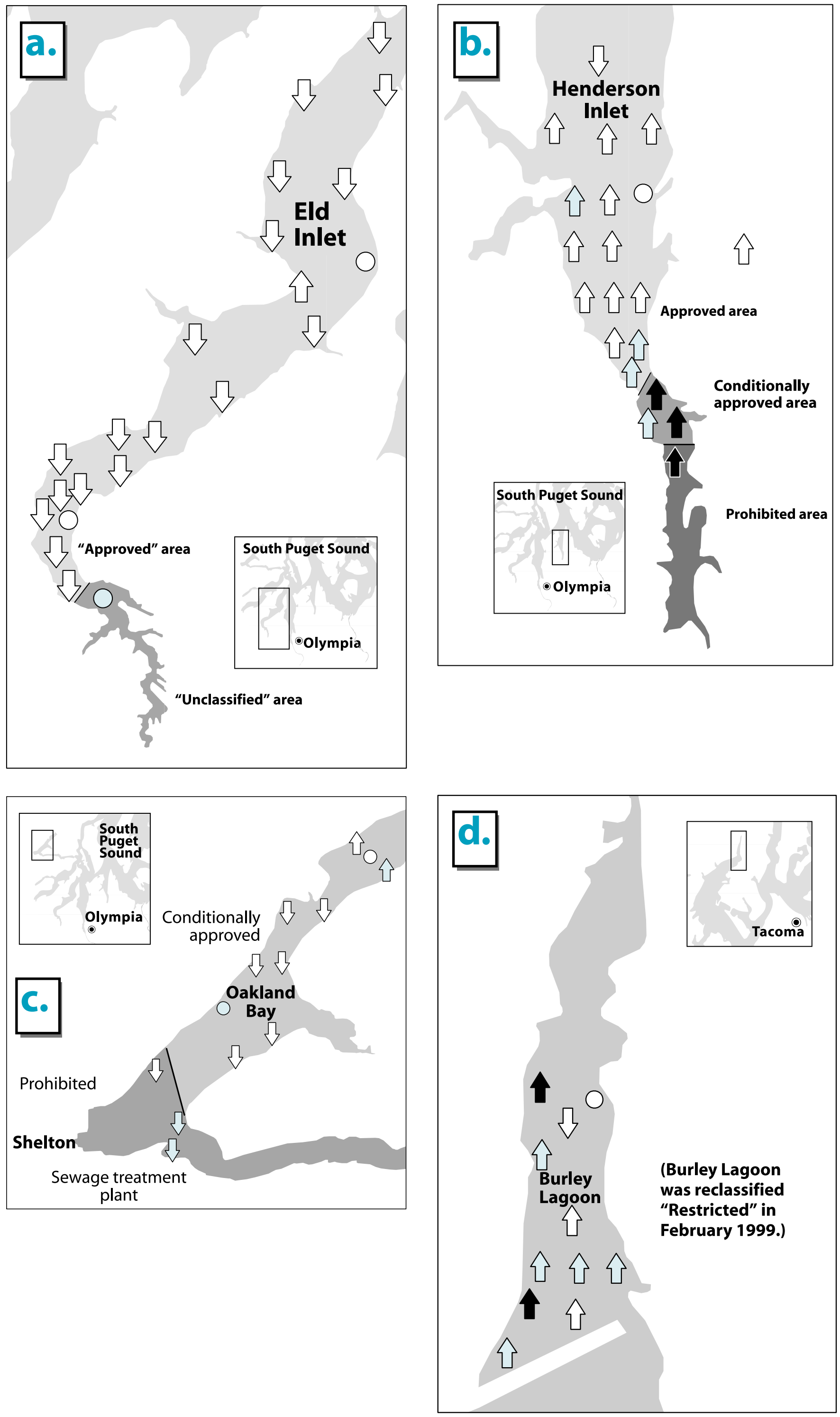
Trends - since January 1995

⇧ **Worse -** Concentrations increasing, conditions getting worse.

◯ **Same -** No change observed.

⇩ **Better -** Concentrations decreasing, conditions improving.

MPN - most probable number of fecal coliform bacteria.



five stations with the longer data record were discussed in the *1998 Puget Sound Update;* two of the five stations were in good condition and three were fair. Trends at three stations appeared to be toward improvement. However, conditions in Burley Lagoon deteriorated after 1996. The status of one of the original five stations fell from fair to poor; another went from good to fair. As of March 1999, two of 12 stations in Burley Lagoon were poor; six were fair, and four were good (Figure 24d). Contamination increased at nine of 12 stations.

Remedial programs have been carried out in the Burley Lagoon watershed since the early 1980s. Initial success resulted in an upgrade of part of Burley Lagoon from "restricted" to "conditionally approved" in 1993. When State Health provided early warning of declining water quality in 1997, local health departments and the conservation district renewed programs to locate and control pollution sources. However, it became necessary to return Burley Lagoon to "restricted" classification in February 1999. Nonpoint pollution control programs will need to be intensified if lost ground is to be regained. Pierce and Kitsap counties have signed a Memorandum of Understanding and formed shellfish protection districts to address the problems affecting the Burley watershed.

Summary. The situation in Eld Inlet and Oakland Bay indicates that fecal contamination in Puget Sound bays can be reduced if local citizens and agencies are committed to focused intensive remedial action (both voluntary and regulatory). The situation in Henderson Inlet and Burley Lagoon points to the need for continuous application of rigorously designed and consistently applied nonpoint programs and land-use policies. Finally, monitoring should be continued to assure that control measures are working to preserve water quality in the face of increasing population growth in Puget Sound watersheds and along the Sound's shorelines.

Findings on Nutrients

High nutrient concentrations are rarely directly associated with water quality impairments in the fresh and marine waters of the Puget Sound basin. Table 3 (page 33) shows that only seven Puget Sound waters have been identified as impaired by ammonia or other forms of nitrogen and 20 fresh waters as impaired by phosphorus. However, as discussed on page 31, excess nutrients can increase plankton production and lead to low dissolved oxygen concentrations if the receiving water is nutrient-limited. Table 1 (page 17) identifies 87 Puget Sound waters that are impaired by low dissolved oxygen.

More specific results about nutrient contamination conditions in Puget Sound's fresh and marine waters are presented in this section. Most of the discussion focuses on nitrate. Although nitrate is not toxic to humans at the concentrations measured in Puget Sound's surface waters, it is very important ecologically. Excessive nitrate in the water can increase the likelihood of algae blooms and may promote the growth of undesirable species of algae and plants.

Rivers and Streams

Rivers and streams deliver approximately 10,000 metric tons of inorganic nitrogen and 1,900 metric tons of phosphorus to Puget Sound each year (Inkpen and Embrey, 1998). The U.S. Geological Survey (Inkpen and Embrey, 1998) synthesized nutrient loading information from 1980 to 1993 for rivers and streams in the Puget Sound basin. This evaluation showed that five rivers—the Snohomish, Skagit, Nooksack, Stillaguamish and Puyallup—account for more than 80 percent of the load of inorganic nitrogen delivered from all Puget Sound basin rivers and streams to Puget

Nutrients in fresh and marine waters

Nutrient dynamics are very different in fresh waters than in marine waters. High concentrations of nitrate in freshwater can be used as an indicator of the likelihood that harmful substances are entering the water, because of nitrates' common association with contaminants. Depending on the source, nitrate can be associated with: (1) fertilizers, herbicides or pesticides (lawns or commercial agriculture); (2) industrial and residential chemicals (stormwater runoff from developed areas); and (3) fecal coliform bacteria (livestock wastes, pet wastes, poorly operating on-site sewage systems).

In marine waters, nitrate is naturally very plentiful. Thus, high concentrations of nitrate cannot be used to indicate that human sources are responsible. In marine waters, the presence of ammonium indicates nutrients regenerated from human sources, zooplankton or other marine organisms. Because marine algae can be limited by the availability of nitrogen, information on nitrate and ammonium distributions and dynamics is important to understanding the condition of marine waters, especially when interpreted along with information about water column stratification, dissolved oxygen concentration and phytoplankton abundance (often measured as chlorophyll concentration).

Nutrients from the Pacific Ocean

Approximately 700,000 metric tons of inorganic nitrogen from the Pacific Ocean enter the Strait of Juan de Fuca each year (Harrison et al., 1994). This oceanic supply of nitrogen to Puget Sound far outweighs the contribution of nutrients from the lands (and rivers) of the Puget Sound basin.

Sound. (This study did not estimate the Pacific Ocean's contribution of nutrients to Puget Sound, which is estimated to be many times greater than the contributions from the basin's rivers, or the atmospheric deposition of nutrients directly to the marine waters of the Sound.)

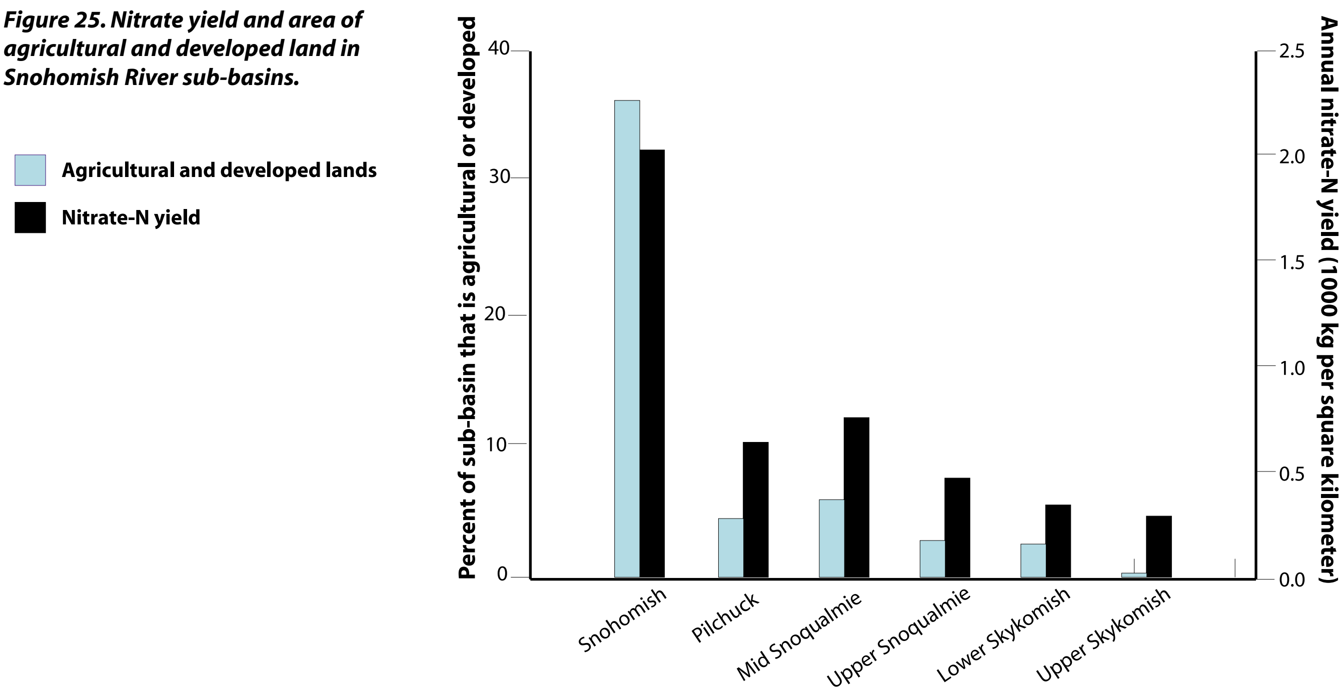
Scientists from the U.S. Geological Survey and elsewhere calculate nutrient contributions not just as loads (i.e., metric tons per year) but also as yields (metric tons/square mile/year) in order to evaluate the intensity of nitrogen contributions independent of river basin size. Using nitrogen yield estimates, scientists from the Geological Survey showed that land use is a major determinant of the nitrogen contributions to Puget Sound watersheds. Of the major rivers that drain to Puget Sound, the Samish River has the highest inorganic nitrogen yield (2.5 metric tons/square mile/year). Other agriculture-dominated basins (Stillaguamish and Nooksack river basins) also have relatively high yields (1.6 to 1.8 metric tons/square mile/year). The Snohomish River basin, with mixed land uses (urban and agriculture), has a relatively high yield (1.6 metric tons/square mile/year).

Department of Ecology scientists have used ambient monitoring data to perform a more focused evaluation of the relationship between land use and nutrient contributions in the Snohomish River basin. As mentioned above, land use in the Snohomish River basin is quite varied; the basin is dominated by forests at higher elevations and a mix of agriculture and urban/suburban development in the lower elevations.

Ecology's analysis provides additional evidence that nitrate yields are higher in sub-basins with a higher proportion of land in agriculture or urban/suburban development (Figure 25). Note that the upper and lower Skykomish and upper Snoqualmie sub-basins, which have lesser degrees of agriculture or other development, have the lowest nitrate yields.

The causes of higher nitrogen yields from agricultural and developed lands are probably a combination of fertilizer application (both residential and commercial)

Figure 25. Nitrate yield and area of agricultural and developed land in Snohomish River sub-basins.



sewage treatment plant effluent, stormwater runoff and animal waste. Animal manure, agricultural fertilizers and atmospheric deposition have been identified as the three largest sources of nitrogen contributing to the lands of the Puget Sound basin (Inkpen and Embrey, 1998).

Marine Waters

Nutrient concentrations measured in Puget Sound represent the balance of nutrients that enter and leave the ecosystem. Nutrients enter Puget Sound from the ocean, fresh water and human-caused sources. A major pathway for their removal is photosynthesis. Phytoplankton, seaweeds, eelgrass and salt marsh plants all use nutrients as they produce new organic matter through photosynthesis.

At the heart of scientists' concerns about nutrient input to Puget Sound is the potential for excessive production by phytoplankton or other photosynthesizers and the effects of this productivity on ecosystem balances. Nutrient inputs to Puget Sound's marine waters can cause a problem when marine water conditions are such that nutrient additions spur additional productivity (i.e., in stratified waters where photosynthesis is nutrient limited).

Existing monitoring is not sufficient to describe areas of excess nutrient loadings to Puget Sound's marine waters. Therefore, the evaluation of nutrients in Puget Sound marine waters focuses on evaluating how the productivity of waters in various portions of Puget Sound might be affected by increased nutrient loading.

Scientists from Ecology's marine water monitoring program have identified a number of areas of Puget Sound where conditions reflect the potential for nutrient-related water quality degradation. Figure 26 summarizes nutrient conditions measured by scientists at stations monitored in wateryears 1996 and 1997. Each station is represented by a two-sided symbol, where the left side describes dissolved inorganic nitrogen (DIN) conditions and the right side describes ammonium conditions.

Low or non-detectable levels of dissolved inorganic nitrogen indicate that nutrient availability may be limiting phytoplankton productivity. Ecology scientists categorize their monitoring stations by the duration of non-detectable levels of dissolved inorganic nitrogen. Longer durations

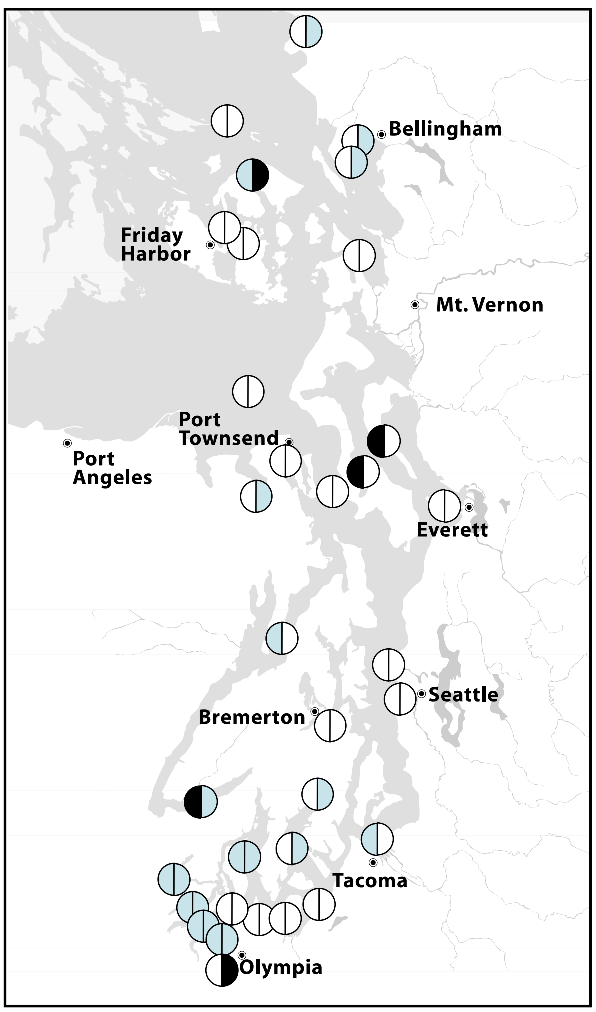


Figure 26. Nutrient conditions at Puget Sound open-water monitoring stations, 1996-1997.

Dissolved inorganic nitrogen (DIN):

DIN not detectable in surface waters for five or more consecutive months.

DIN not detectable in surface waters for three or four consecutive months.

DIN not detectable in surface waters for less than two consecutive months.

Ammonium:

Maximum ammonium greater than 0.14 mg/L

Maximum ammonium 0.07 to 0.14 mg/L

Maximum ammonium no more than 0.07 mg/L

Nutrient-related problems in Puget Sound are poorly characterized

A draw-back to Ecology's approach to indicating nutrient-related problems in Puget Sound's marine waters is that it only identifies areas that are sensitive to excessive nutrient loading, but does not identify areas currently affected by increased loadings of nutrients. Based on nutrient concentrations alone, these latter areas would be indistinguishable from areas with mixed water columns and a steady supply of nitrogen from the ocean. However, such areas could presumably be identified from other indicators presented in this Update (e.g., low dissolved oxygen, as discussed on pages 21-22).

indicate greater evidence of nutrient-limited productivity and, therefore, sensitivity to excessive nutrient loading. For wateryears 1996 and 1997, only lower Hood Canal, Holmes Harbor and Saratoga Passage had less than detectable concentrations of dissolved inorganic nitrogen for five or more consecutive months. A number of other areas, including East Sound (Orcas Island), upper Hood Canal, Oakland Bay and Case, Totten, Eld and Budd inlets, had non-detectable levels for three or four consecutive months.

Dissolved inorganic nitrogen conditions measured in 1996 and 1997 are generally consistent with those seen in the longer record (back to 1993). The largest difference is seen at Possession Sound (near the mouth of the Snohomish River) where recent data indicate that dissolved inorganic nitrogen is prevalent, while the longer data record shows periods of non-detectable levels of five months or more.

The right sides of the symbols in Figure 26 show the occurrence of elevated levels of ammonium, as measured by Ecology scientists during wateryears 1996 and 1997. High ammonium concentrations indicate the presence of an ammonia source, which could be a sewage input or concentrations of zooplankton. Therefore, high ammonium concentrations provide evidence of a human loading of nutrients (eutrophication), a high concentration of phytoplankton upon which zooplankton might be grazing, or the presence of concentrations of fish, seals, whales or other marine life.

During wateryears 1996 and 1997, high ammonium concentrations (greater than 0.14 mg/L) were observed at East Sound and inner Budd Inlet. Moderately high concentrations were more widespread, occurring at Drayton Harbor, Bellingham Bay, Discovery Bay, southern Hood Canal, Commencement Bay, Oakland Bay and Carr, Case, Totten, Eld and outer Budd inlets. The results for 1996 and 1997 are generally consistent with the longer data record, except that recent results show lower concentrations at Possession Sound, Elliott Bay and Sinclair Inlet.

Table 4 summarizes multiple lines of evidence to identify areas of Puget Sound that appear most sensitive to water quality problems associated with eutrophication. This table was constructed based on Ecology scientists' review of their data on dissolved oxygen conditions, stratification intensity and nutrient concentrations from 1993 to 1998 (Newton, personal communication). This analysis indicates that the areas of greatest concern include southern Hood Canal, Budd Inlet and Penn Cove. Nutrient discharges to other areas listed in Table 4 should also be evaluated, though the evidence for the possibility of eutrophication-related problems at these other areas is not quite as great.

This table includes five locations that were not previously identified as potential problem areas: Bellingham Bay, Holmes Harbor, Carr Inlet, Drayton Harbor and Skagit Bay. Ecology's evaluations of Quartermaster Harbor and Discovery Bays are much different than in previous years, reflecting information from new monitoring stations that show different results than the more open-water stations used previously.

King County monitors nutrient concentrations at four offshore stations in King County waters located in the central Puget Sound basin. Monthly samples are collected at depth levels ranging from one meter to 200 meters.

Seasonal patterns of ammonium detection reflect the seasonal pattern of phytoplankton biomass as indicated by chlorophyll-a, with peaks occurring in summer and fall. This may be due to an increase in zooplankton grazing activity. An anomalously high value of ammonium was measured at the West Point Treatment

Location	Dissolved Oxygen (1)	Stratification Intensity	Nutrient Conditions	
			DIN (2)	NH4+ (3)
Southern Hood Canal	Very Low	Persistent	Low	Moderate
Budd Inlet	Very Low	Persistent	Low	Moderate
Penn Cove	Very Low	Persistent	Low	Moderate
East Sound	Very Low	Seasonal	Low	High
Discovery Bay	Very Low	Seasonal		Moderate
Quartermaster Harbor	Very Low	Seasonal		Moderate
Possession Sound	Low	Persistent	Low	Moderate
Bellingham Bay	Low	Persistent	Moderate	Moderate
Commencement Bay	Low	Persistent	Moderate	Moderate
Holmes Harbor	Low	Persistent	Low	
Saratoga Passage	Low	Persistent	Low	
Port Susan	Low	Persistent	Low	
Elliott Bay	Low	Persistent		Moderate
Carr Inlet	Low	Seasonal		Moderate
Drayton Harbor	Low	Seasonal		Moderate
Skagit Bay	Low	Persistent		
Sinclair Inlet		Persistent	Moderate	Moderate
Eld Inlet		Seasonal	Moderate	Moderate
Case Inlet		Seasonal	Moderate	Moderate
Oakland Bay		Episodic	Moderate	Moderate
Totten Inlet		Episodic	Moderate	Moderate
Dyes Inlet		Seasonal	Moderate	
Sequim Bay		Seasonal	Moderate	

Table 4. Areas of Puget Sound where eutrophication may be a concern based on data from 1993-1998.

1. Ecology scientists 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 and kill marine organisms. Dissolved oxygen cells are blank where no measurements below 5 mg/L were recorded.
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 measurement above 0.14 mg/L; "moderate" indicates at least one measurement above 0.07 mgL but none above 0.14 mg/L.

Plant outfall in early October 1998. This may have been due to a temporary shut-down of the treatment facility and a release of untreated sewage on October 12th. Ammonium was rarely detected in samples collected during the winter of 1997-98, including in samples from West Point.

In 1997 and 1998, consistent patterns in nitrite and nitrate concentrations were observed at all stations.

- Nitrite and nitrate concentrations were low when ammonium concentrations were high.
- Minimum concentrations of nitrite and nitrate occurred in summer and fall.
- Nitrite and nitrate concentrations were inversely proportional to chlorophyll-a concentrations.

These relationships all point to the effective removal of nutrients from the water column by phytoplankton.

In 1998 and 1999, nutrient samples were collected at five nearshore stations. There was no apparent difference in nutrient concentrations between nearshore and offshore stations, with the exception of ammonium detected at West Point but not at nearshore stations in the area.

Acting on the Findings

Recent information about pathogen and nutrient problems in Puget Sound's rivers and streams and in its marine waters suggests a number of follow up actions:

- The Department of Ecology should continue (and emphasize) its efforts to develop clean-up plans (also known as total maximum daily loads or TMDLs) for waters that are impaired by fecal coliform contamination. Monitoring program results can be used to set priorities for these efforts. The clean-up plans should provide the technical basis for watershed and shoreline improvements that will lead to water quality improvements.

- Relationships between land use (especially the development of shorelines and watersheds) and water quality in nearby shellfish growing areas should be further analyzed to help resource managers, land use planners and public health officials understand the critical limits that might affect commercial and recreational shellfish harvest in Puget Sound.

- Increasing fecal contamination in Henderson Inlet in south Puget Sound should be investigated and pollution sources controlled in an effort to prevent a downgrade of the area's shellfish harvest classification.

- Decisions about the discharge of nutrients to Puget Sound from point and nonpoint sources should incorporate an understanding of the local marine area's sensitivity to nutrient-related water quality degradation. Areas of Puget Sound shown to be sensitive to eutrophication should be managed accordingly.

- Areas of Puget Sound that are sensitive to nutrient-related water quality degradation should be investigated further to characterize nutrient loading and cycling.

Toxic Contaminants

Summary

Toxic contaminants are present throughout the Puget Sound environment, though serious problems occur in urban areas near contaminant sources. Limited trend information suggests that some aspects of toxic contamination are decreasing (e.g., concentrations of metals in the waters of Commencement Bay) while other problems may be worsening (e.g., an increasing trend in the occurrence of liver lesions in English sole from Elliott Bay). Studies in some Puget Sound locations show toxic effects in invertebrates and fish. Levels of contamination in harbor seals may be high enough to cause adverse effects to these animals.

Toxic Contamination Concerns in Puget Sound

Human activities introduce toxic contaminants, including organic compounds and metals, to the Puget Sound environment. Some toxic substances, notably metals and hydrocarbons, occur naturally but become concentrated in the environment through human activities. Some of the sources of toxic contaminant input to Puget Sound include: stormwater runoff from urban areas; discharges of municipal and industrial wastewater; spills from vessels and shoreline and upland properties; pesticide runoff from agricultural, residential and park lands; aquacultural applications of pesticides; leaching of contaminants from shoreline structures (e.g., preservatives from pilings) and vessels (e.g., antifouling agents); channel dredging and dredged material disposal; and atmospheric deposition of air pollutants.

Humans have synthesized a variety of compounds that have been released to the environment. Some of these compounds have been specifically designed to be toxic

Oil spills in Puget Sound

Oil spills release toxic contaminants to the Puget Sound environment. Four spills released 10,000 or more gallons of petroleum or petroleum products to the waters and land of the Puget Sound basin between 1992 and 1999. A June 1999 spill from the Olympic pipeline in Bellingham was the basin's largest spill since 1991. In the Puget Sound basin, 120 oil spills of 25 to 10,000 gallons were reported to the Department of Ecology from July 1992 to June 1999.

(e.g., pesticides such as DDT and anti-fouling agents such as tributyltin). These compounds are often purposefully applied to the environment; they can also enter the environment through spills or improper disposal.

A variety of other compounds are designed and used for other purposes but happen to be toxic due to their chemical structure (e.g., polychlorinated biphenyls, or PCBs, used in a variety of industrial applications; and phthalates, used as plasticizers). These compounds typically enter the environment through incidental or accidental releases during their use or disposal.

A final group of toxic organic compounds are not purposefully generated but are toxic byproducts of society's activities (e.g., chlorinated dioxins and furans formed during some pulp bleaching processes; and polycyclic aromatic hydrocarbons, or PAHs, formed during the combustion of fossil fuels). These compounds often form in wastewater and combustion gases, which are released to the environment as part of discharges permitted by regulatory authorities. They can also be released to the environment through improper waste management and unpermitted discharges.

Human-made and naturally occurring chemicals can affect biological resources and humans in a number of ways. Concern over many chemicals relates to their ability to cause or promote the development of cancer in humans and other animals. Chemicals that are known or suspected causes of cancer include dioxins, PCBs, chlorinated organic pesticides and some PAHs. Organic compounds and metals can also cause ill effects to specific biological systems. For example, lead and mercury can cause neurological problems in humans, especially during fetal and childhood development, and in other animals as well. In recent years, scientists have found that some environmental contaminants interfere with normal hormone functioning and can cause reproductive problems. For example, a variety of organic compounds, including dioxins, PCBs and phthalates, have been shown to have estrogen-like activity. In addition, scientists have begun to show that environmental contamination (e.g., by PCBs) can cause immune function problems that can increase one's susceptibility to disease.

Many toxic contaminants cause additional problems because they accumulate in the tissues of organisms. Concentrations of some toxic chemicals become magnified through the food web when predators eat contaminated prey. This means that high-level predators can be exposed to much higher concentrations of contaminants than organisms that feed lower in the food web.

Toxic contaminant issues in Puget Sound are managed through a variety of programs. Ongoing release of toxic contaminants to the environment is addressed by controls on the discharge of wastewater from municipal and industrial facilities and by the implementation of best management practices for the management of stormwater and the prevention and clean up of spills. Toxic contaminants present in Puget Sound's sediments are addressed by sediment clean-up actions (page 50) and the management of dredged materials. In some cases, contamination can occur from atmospheric transport of pollutants both locally and globally (from nations where sources are not well regulated).

Findings

Toxic contaminants are pervasive throughout the Puget Sound ecosystem and there are many possible approaches to monitoring and reporting on the status and trends in Puget Sound's toxic contamination. This chapter presents information from PSAMP and other studies of toxic contaminants in Puget Sound, moving from sediment and

Table 5. Puget Sound waters identified as impaired by toxic contaminants

Water Resource Inventory Area (WRIA) – Basin Name	Waters Listed as Impaired by Toxic Contaminants: Marine Waters (reason for listing)	Fresh Waters (reason for listing)
1 – Nooksack	Bellingham Bay; Strait of Georgia (various)	
3 – Lower Skagit	Padilla & Fidalgo bays & Guemes Channel (PCBs)	
5 – Stillaguamish		Stillaguamish River (arsenic, copper, lead, nickel)
7 – Snohomish	Port Gardner & Inner Everett Harbor (various); Ebey Slough (bioassay)	Skykomish River (copper, lead, silver); Snohomish River (PAHs)
8 – Cedar/Sammamish		Lake Union & Ship Canal (dieldrin, bioassay); Lake Washington (bioassay); multiple areas of May Creek (lead, zinc); Kelsey Creek (DDT, dieldrin, heptaclor epoxide); Bear-Evans Creek (mercury)
9 – Green/Duwamish	Elliott Bay; Duwamish Waterway (various)	Springbook (Mill) Creek (various metals, bioassay)
10 – White/Puyallup	Inner & Outer Commencement Bay (various); Thea Foss Waterway (dieldrin, PCBs)	White River (mercury, copper); Wilkenson Creek (copper); Puyallup River (arsenic)
12 – Chambers Creek		Lake Steilacoom (sediment bioassay); Chambers Creek (copper, PCBs)
13 – Deschutes	Inner Budd Inlet (various)	Ward Lake (PCBs)
15 – Kitsap	Dyes Inlet & Port Washington Narrows; Eagle Harbor; Port Gamble Bay; Sinclair Inlet; Port Orchard, Agate and Rich passages; Quartermaster Harbor (various)	
18 – Dungeness/Elwha		Elwha River (PCBs)

Source: Department of Ecology.

the water column through the food web to invertebrates, fish, birds and mammals. The various ecosystem components provide a robust set of information about the status of contamination in Puget Sound, its geographic distribution and evidence of trends over time.

Based on evidence available through 1998 from sediments, surface waters and biological resources, Department of Ecology staff labeled 42 fresh and marine waters in the Puget Sound basin as “water-quality limited” because of toxic contaminants. Table 5 identifies these 23 marine water and 19 fresh water areas.

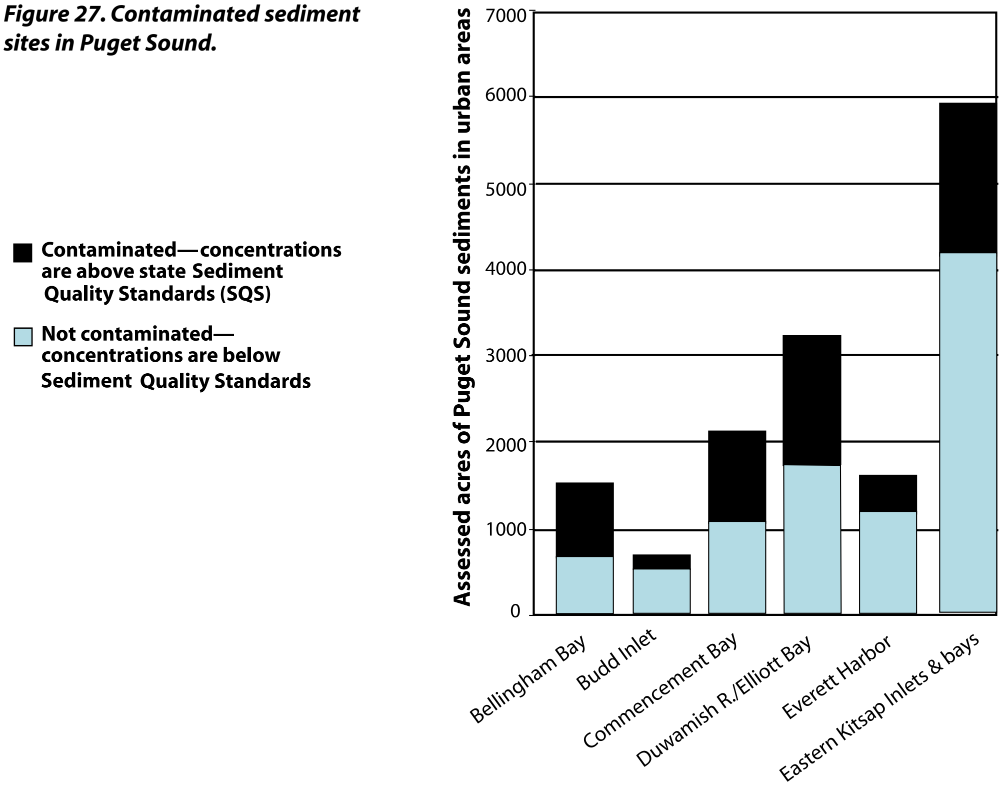
Sediment Contamination

Sediments are widely considered to be the major repository for toxic contaminants of concern in Puget Sound. They are also the primary source of contaminants in biota. The PSAMP therefore emphasizes sediment monitoring as a critical element in its characterization of toxic contamination in Puget Sound.

The 303(d) list and impaired waters

A discussion of the 303d list and how it identifies polluted estuaries, lakes and streams in Washington state appears in the Physical Environment chapter of this document on page 17.

Figure 27. Contaminated sediment sites in Puget Sound.



Source: Department of Ecology.

As of 1999, Department of Ecology staff had compiled sufficient data in their sediment quality database (SEDQUAL) to characterize more than 15,000 acres of Puget Sound's urban embayments (Department of Ecology, unpublished data). Thirty-eight percent of this area, 5,750 acres, was identified as contaminated above the state's sediment quality standards (Figure 27). Eighty-six of the most highly contaminated, discrete areas (estimated at 3,200 acres) within these urban embayments were identified as contaminated sediment sites, requiring cleanup directed by either state or federal cleanup laws. These sites are currently in various stages of cleanup: 15 have been cleaned up since 1996 and the remaining sites are being investigated to support the planning and design of cleanup activities.

Ecology staff used data newly available in January 1996 to characterize almost 1,400 acres of Puget Sound sediment (of the 15,000 acre total) that were not previously evaluated. Nearly 48 percent of this area, 660 acres, was identified as contaminated above state sediment quality standards. The high rate at which contaminated areas continue to be identified indicates that evaluations of urban bays remain incomplete. Consequently, larger areas of Puget Sound's urban embayments may be identified as contaminated when additional data become available.

Ecology's 1997 Evaluation of Sediment Contamination in North Puget Sound. In 1997 Ecology scientists altered the design of their study of marine sediment contamination to take advantage of an opportunity to partner with the National Oceanic and Atmospheric Administration's (NOAA's) National Status and Trends Program and to improve their characterization of the more contaminated areas of Puget Sound (the original design primarily targeted areas of Puget Sound with little contamination).

The overall goal of the 1997 Ecology-NOAA project was to estimate the percentage of north Puget Sound in which sediment quality is significantly degraded. This study used a stratified-random sampling approach, allowing the data to be extrapolated from sampling stations to a larger, defined surrounding area (i.e., a stratum). These data could then be used to estimate the spatial extent of chemical contamination and toxicity within a specified geographic area with a quantifiable degree of confidence (Long et al., 1999).

One hundred samples were collected during June and July 1997 at locations selected randomly within 33 geographic strata. The strata covered the area from Port Gardner, near Everett, to the U.S./Canadian border. Strata were selected to represent

Sediment contaminant monitoring in Puget Sound – a collaboration between the Department of Ecology and NOAA

In 1997, the goals and schedules of NOAA's National Status and Trends Program and Ecology's PSAMP sediment component aligned well and a three-year collaborative project was developed. Through this joint effort, approximately one-third of the area of Puget Sound was characterized each year from 1997 to 1999. The collaborating scientists have completed a report on the 1997 effort to characterize north Puget Sound (Long et al., 1999). The accompanying paragraphs summarize the results presented in the Ecology-NOAA report. The 1998 and 1999 results for central and south Puget Sound, respectively, are presently being analyzed. Reports on these areas are expected later in 2000 and in 2001.

conditions near Everett, Anacortes, Bellingham and Blaine, and the marine environments between these cities. Sediments from each of the 100 locations were analyzed for toxic contaminants and physical sediment characteristics, subjected to four toxicity tests and characterized by the organisms dwelling within them.

Figure 28. Sampling stations in north Puget Sound with trace metal concentrations exceeding Washington state criteria.

Metals occur at concentrations above state Sediment Quality Standards (SQS).

Metals occur at concentrations above the state Cleanup Screening Level (CSL)

PCBs occur at concentrations above state's SQS and NOAA's Effects-Range Median screening values

The highest chemical concentrations in north Puget Sound were seen in sediments from the two most urbanized embayments, Everett Harbor and Bellingham Bay. The pattern was most evident for several metals and PAHs. PAH concentrations were also relatively high in sediments near Anacortes (and nearby March Point), another urbanized area with significant petroleum refining and transport facilities. In contrast to these patterns, a sample from southern Boundary Bay, far from obvious sources of contamination, had a very high mercury concentration.

Results of chemical analyses indicated that relatively wide ranges in concentrations of some contaminants occurred among the 100 samples. However, only a small proportion of the samples had elevated concentrations of most contaminants.

- In samples from five stations, at least one metal occurred at a concentration at or above the state's sediment quality standards (SQS). Four of these stations were from inner Bellingham Bay and Everett Harbor, both urbanized bays, and one station was in Boundary Bay. Based on the program's random sampling design, these stations (Figure 28) represented about 3,200 acres (13 square km), equivalent to approximately 1.7 percent of the north Puget Sound study area.
- PAH concentrations did not exceed the state's SQS, but samples from eight stations in Everett Harbor had levels above NOAA's Effects Range Median (ERM) screening value for the sum of seven low molecular weight PAH compounds (Figure 29, page 52). One of these stations also had a total concentration for six high molecular weight PAH compounds above NOAA's ERM screening value.
- A sample from one location in inner Everett Harbor had total PCB concentrations above the state's SQS and NOAA's ERM screening value (Figure 28). This station represents less than 0.1 percent of the north Puget Sound study area.

Toxicity tests indicated that less than five percent of the north Puget Sound survey area was highly toxic. North Puget Sound sediments are among the least toxic that NOAA has evaluated in its surveys of the nation's estuaries. An amphipod survival test failed to identify any highly toxic samples, but three other tests indicated that samples

Measuring sediment quality

Chemical contaminants measured in sediments collected from Puget Sound are compared with critical values that have been set and adopted into law by the state of Washington. They are also compared with critical values that have been generated by federal researchers at NOAA based on sediment monitoring work conducted in more than 30 estuaries nationwide.

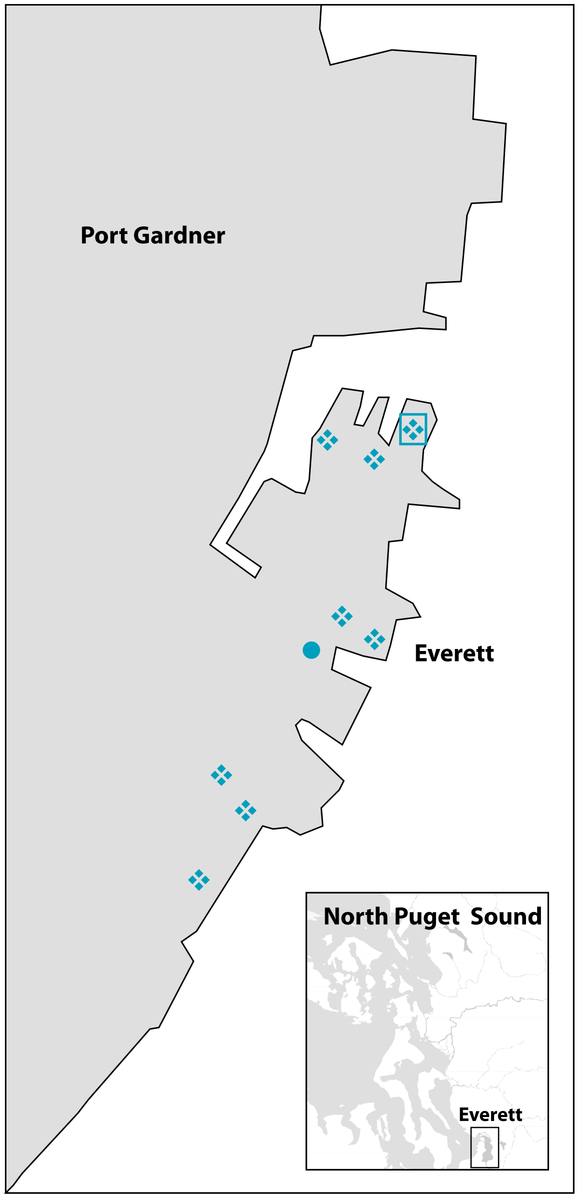
The "Washington State Sediment Management Standards" include two tiers of criteria against which sediment quality data are evaluated: (1) Sediment Quality Standards (SQS)—sediment concentrations above which adverse biological effects are expected and (2) Cleanup Screening Levels (CSL)—sediment contaminant concentrations higher than SQS above which active cleanup is required.

NOAA standards developed by Long et al. (1995) also include two tiers of criteria against which sediment quality data are evaluated: (1) Effects Range Low (ERL)—sediment concentrations below which toxic effects are not expected and (2) Effects Range Median (ERM)—sediment contaminant concentrations above which higher probabilities of toxic effects would occur.

Figure 29. Sampling stations in Everett Harbor with concentrations of PAHs above screening guidelines.

- Total concentration of seven low molecular weight PAHs exceed NOAA's Effects Range Median guidelines
- Total concentration of six high molecular weight PAHs exceed NOAA's Effects Range Median guidelines
- Sum of PAHs below NOAA's guidelines

No stations in the remainder of the north Puget Sound study area had PAH concentrations above these guidelines.



from Everett Harbor were the most toxic in the study area. Two tests (Cytochrome P450 RGS and Microtox™) demonstrated a gradient of increasing toxicity from the entrance to the head of Everett Harbor. Less severe toxicity was observed in the remainder of the study area. Other locations that showed toxicity included Drayton Harbor, Whatcom Waterway and other portions of Bellingham Bay, inner Padilla Bay, March Point, Fidalgo Bay, Port Susan and parts of Port Gardner. Sediments from Saratoga Passage, Possession Sound and most of Port Gardner were among the least toxic in these tests.

Ecology scientists intend that the results of the 1997 collaboration with NOAA will provide the basis for quantifying changes in sediment quality in north Puget Sound in future years. By repeating sediment quality measurements in future years using a study design comparable to the 1997 study, they can measure improvement or degradation in sediment quality. Data from north Puget Sound will be combined with those from central Puget Sound (sampled in 1998) and south Puget Sound (sampled in 1999) to assess the quality of sediments across the entire Puget Sound basin.

Evidence of toxic contaminant-induced degradation in north Puget Sound

Among the 100 stations evaluated by Ecology-NOAA in 1997, 18 stations had at least one chemical concentration above a guideline value, at least one toxicity test that indicated highly toxic conditions, and some degree of reduced diversity and abundance of the sediment-dwelling community. These stations were located in Everett Harbor, Port Gardner, Drayton Harbor, Bellingham Bay, Padilla Bay and Fidalgo Bay. Only the Everett Harbor stations, and possibly Port Gardner, had sediment-dwelling communities that suggested "strong evidence of pollution-induced degradation."

Streambed Sediment Contamination in the Puget Sound Basin. Concentrations of many metals, including arsenic, cadmium, chromium, lead, mercury, nickel and zinc, have been detected at higher concentrations in Puget Sound basin streambed sediments from agricultural and urban sites than in sediments from forest and reference sites (MacCoy and Black, 1998). A 1995 study by the U.S. Geological Survey (USGS) evaluated concentrations of toxic contaminants in streambed sediment and aquatic organisms and their relation to land use. The study detected pesticides in streambed sediments at three of 18 sampling locations in the Puget Sound basin. The highest pesticide concentrations were measured at the urban site. PAHs were detected frequently in streambed sediment samples from urban streams. USGS scientists concluded that developed land uses may have led to increased levels of contaminants, though the generally low levels observed do not necessarily suggest negative impacts in the environment (MacCoy and Black, 1998).

Toxic Contaminants in Water

Due to the rapid dilution in the surface waters of Puget Sound, the PSAMP does not emphasize analysis of water samples for toxic contaminants. Many toxic contaminants accumulate in sediments or in biological tissues, making toxic chemicals easier to measure in these other media than in water.

Metals in Rivers and Streams. The waters of Puget Sound's rivers and streams appear to be free of appreciable contamination from metals. Six times per year, Ecology scientists analyze water samples from selected Puget Sound rivers for metals. Samples collected since late 1996 have not contained metals at concentrations above the applicable water quality standards.

Pesticides in Urban Streams. A variety of frequently purchased pesticides are present at levels of concern in urban streams in the Puget Sound basin. The USGS, the Department of Ecology and King County collaborated on a study of pesticides in streams in 10 urban watersheds in King County. Water samples were collected from streams during storms and analyzed for 98 pesticides (or their breakdown products). The USGS (1999) reported that 23 pesticides were detected and concentrations of five pesticides exceeded limits set to protect aquatic life. Another part of the study evaluated retail sales of pesticides in King and south Snohomish counties. Many of the most frequently purchased pesticide ingredients, including 2,4-D, MCPP and Diazinon, were detected in all stream samples. This suggests a link between residential use of pesticides and water quality degradation. Many of the routinely detected pesticides (e.g., pentachlorophenol, atrazine, simazine) were not reported in the retail sales data, which suggests that these pesticides are being applied to non-residential areas in the urban watersheds (USGS, 1999).

Metals in Commencement Bay. Metals concentrations in Commencement Bay appear to have declined by almost one-half over the past 15 years, but patterns of contamination are still apparent (Johnson and Summers, 1999). Although Ecology scientists do not routinely evaluate toxic contaminants in marine waters, they conducted a special study of metals in Commencement Bay in 1997 and 1998. Ten stations were sampled, including one in the center of Commencement Bay and three each in the Thea Foss, Blair and Hylebos waterways. All measured metals concentrations were lower than water quality criteria for the protection of marine life. Based on study results, Ecology staff (Johnson and Summers, 1999) concluded that:

- Bay-wide levels of arsenic had declined by almost one-half from levels measured in the early to mid-1980s.
- Zinc, copper and mercury concentrations in Commencement Bay and its waterways were approximately five times as high as levels seen in deep inflowing seawater. Lead, arsenic and nickel concentrations were also elevated but to a lesser degree (approximately twice the values seen in seawater).
- Patterns of contamination within Commencement Bay were apparent: arsenic was relatively high in the Hylebos Waterway and lead was relatively high in the Thea Foss Waterway.

Ecological Risks from Tributyltin in the Surface Waters of Puget Sound. Tributyltin concentrations appear to be declining in Puget Sound and other marine waters of the United States (Cardwell et al., 1999). Scientists from Parametrix, a Kirkland-based consulting firm, recently published an assessment of the ecological risks presented by tributyltin in the nation's coastal waters, including Puget Sound. Using data from U.S. Environmental Protection Agency and Navy monitoring programs, the authors demonstrated that, for saltwater environments, tributyltin concentrations are

Sediment monitoring by NPDES dischargers

Ecology scientists have completed a preliminary review of sediment monitoring data received from entities permitted to discharge wastewater to Puget Sound and other Washington waters (Ecology, unpublished data). Dischargers reporting results to Ecology included aluminum smelters, pulp and paper mills, petroleum refineries, shipyards and municipal wastewater treatment plants.

Some level of sediment contamination was observed at 35 of 50 discharge sites statewide (the majority of the 50 discharge sites are in Puget Sound). Contamination ranged from concentrations of single chemicals slightly above the state's SQS to concentrations of multiple contaminants above the higher CSL. Phthalates were commonly observed in the vicinity of sewage discharges. Metals contamination was commonly observed at shipyards.

The observed levels of sediment contaminants in the vicinity of discharges do not necessarily indicate that a discharge is currently causing sediment contamination. In some cases contamination may have resulted from a facility's historic discharge or from another source.

Commonly used pesticides

2,4-D—an herbicide sold in products such as Weedone and Weed-b-gone.

MCPP—an herbicide also known as Mecoprop and a variety of other trade names.

Diazinon— an insecticide.

Pentachlorophenol— a fungicide sometimes known as penta.

Atrazine—an herbicide also known as Atrex and a variety of other trade names.

Simazine—an herbicide also known as Princep and a variety of other trade names.

significantly higher at marinas than in other environments, including commercial harbors, shipyards and fish and shellfish habitats. The Parametrix analysis showed that tributyltin concentrations in various Puget Sound settings were in the range of concentrations seen elsewhere around the country. For instance, tributyltin in Puget Sound waters was found to pose considerably less risk to aquatic life than contamination in Galveston Bay, Texas but more risk than contamination in Narragansett Bay, Rhode Island.

Data from 1992 to 1996 provide evidence of declining concentrations and ecological risks of tributyltin at marinas in Puget Sound and other coastal waters. This decline may be associated with 1988 restrictions on the uses of tributyltin-containing paints that were enacted because of concerns about the effects of this chemical on aquatic organisms (Cardwell et al., 1999).

Toxic Contaminants in Shellfish

King County Monitoring. In 1998, King County scientists monitored toxic contaminants in shellfish (using butter clams) at four stations located from Richmond Beach south to Normandy Park. Metals concentrations were all well below U.S Food and Drug Administration guidance values for arsenic, cadmium, chromium, lead, nickel and mercury in shellfish. Except for benzoic acid, no organic compounds were detected in any of the shellfish samples. Benzoic acid is used as a food preservative and anti-fungal agent, but it is also produced by metabolic processes and is always detected in shellfish samples. Monitoring results also showed that a concentration gradient does not exist from north to south—arsenic, cadmium, chromium, mercury and nickel concentrations were similar in samples from all four stations. Silver was also detected in samples from all four stations and was slightly higher at the station located just north of the lighthouse at West Point, near the West Point wastewater treatment plant (Table 6).

NOAA Mussel Watch Results for Puget Sound. NOAA's national Mussel Watch monitoring program includes 14 long-term monitoring stations in Puget Sound (Figure 30). An analysis of Mussel Watch data from 1990 to 1996 (NOAA, 1998) showed that 10 of the 14 Puget Sound stations had concentrations of one or more contaminants that were high relative to concentrations seen elsewhere along the nation's coast (Table 7). High concentrations of PAHs were frequently measured at seven of 14 Puget Sound stations. Concentrations of four other contaminants were frequently high at one or more Puget Sound stations: zinc (four stations), nickel (three stations), and lead and butyl tins (one station each).

Eleven of 14 Mussel Watch stations in Puget Sound have a sufficient data record to support analysis of trends over time (i.e., they were sampled during at least six years) from 1986 to 1996 (Figure 30). Decreasing trends in concentrations of one or more contaminants were observed at six of these 11 stations (NOAA, 1998). No increasing trends were observed for any contaminant at any of the Puget Sound Mussel Watch stations. Contaminants that showed declining concentrations include:

- PCBs, which declined at three Puget Sound stations. The most recent measurements at these stations represent 23 to 87 percent reductions from early Mussel Watch measurements.
- Copper, which declined at three Puget Sound stations. The most recent measurements represent 14 to 47 percent reductions from early measurements.
- DDT and its breakdown products, which declined at two Puget Sound stations. One of these stations showed a 57 percent

	Concentration (mg/kg dry weight)								
	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Silver	Zinc
Richmond Beach	15.7	0.83	2.05	12.9	1.55	0.082	5.67	5.04	89.4
West Point	20.7	0.37	1.93	12.7	0.74	0.081	5.89	7.22	94.2
Alki Point	18.9	0.31	1.61	10.8	0.7	0.042	4.95	5.86	90.3
Normandy Park	17.7	0.37	1.67	8.1	0.63	0.04	4.22	5.82	80.2

Table 6. Metals concentrations in butter clams from King County, 1998.

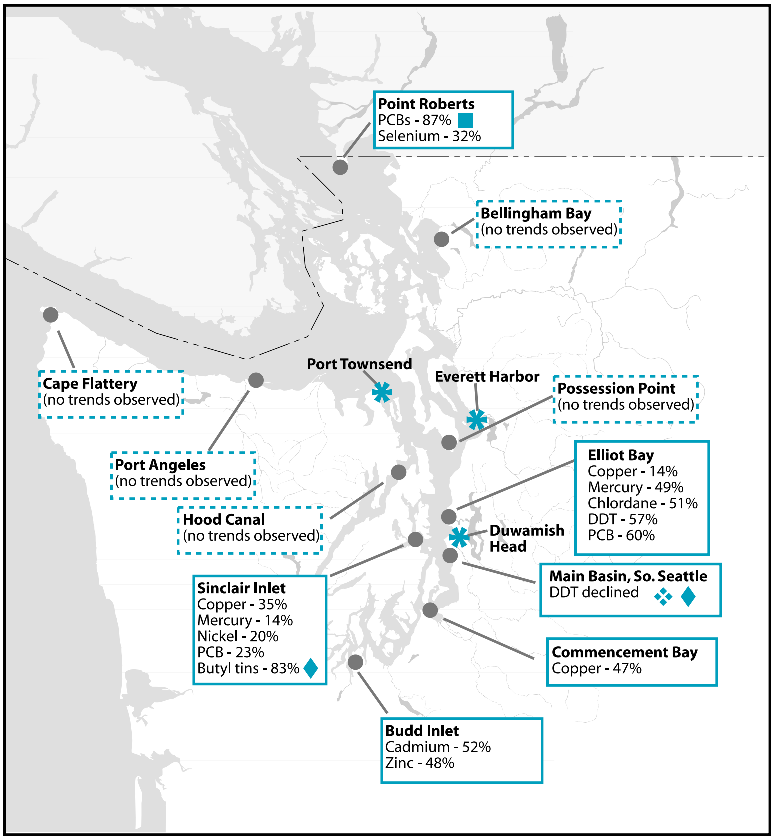


Figure 30. Declining contaminant concentrations in mussel tissue in Puget Sound, 1986-1996.

Values indicate the percent decline observed from 1986 to 1996, unless otherwise noted. No increasing trends were observed at Puget Sound monitoring locations.

Declining trend observed but most recent value is relatively high

Data available for 1989 to 1996 only

Data available for 1986 to 1994 only

Three long-term Puget Sound monitoring stations are not shown because of an insufficient data record to support analysis of trends over time:

- Port Townsend
- Everett Harbor
- Elliott Bay-Duwamish Head

Station (years sampled)	Contaminants present at "high" concentrations in at least one-half of Mussel Watch samples from 1990 to 1996				
	PAHs	Zinc	Nickel	Lead	Butyl tins
Point Roberts (5)			*		
Bellingham Bay (5)	*	*	*		
Everett Harbor (2)	*	*		*	
Possession Sound (5)			*		
Elliott Bay – 4-Mile Rock (5)	*	*			
Elliott Bay – Duwamish Head (2)	*				*
Sinclair Inlet (5)		*			
Main Basin, south Seattle (5)	*				
Commencement Bay (5)	*				
Port Townsend (5)	*				

Source: NOAA, 1998

Table 7. Frequent occurrence of "high" contaminant concentrations in Puget Sound Mussel Watch samples.

"High" concentrations are those greater than the mean plus one standard deviation of the lognormal distribution of concentrations among sites evaluated in the Mussel Watch program in 1989.

reduction in concentrations. The other station showed a declining trend despite a relatively high concentration measured in 1996.

- Mercury, which declined at two stations. The most recent measurements reflected 14 and 49 percent reductions from earlier measurements.
- Six other contaminants, which showed declines at only one station. Reductions from 1986 to 1996 ranged from 20 to 50 percent for nickel, selenium, zinc, cadmium and chlordane to over 80 percent for butyl tins.

Nationwide evidence of decreasing concentrations was seen for chlordane, DDT, PCBs, dieldrin, butyl tins and cadmium (NOAA, 1998). With the exception of dieldrin, decreasing concentrations of each of these contaminants were also evident in Puget Sound. Puget Sound observations of decreasing concentrations of copper and mercury appear to differ from the trends for the entire nation. Increasing trends in concentrations of these and other metals were occasionally observed elsewhere in the Mussel Watch program but never at Puget Sound stations.

Toxic Contaminants in Fish

Scientists at the Washington Department of Fish and Wildlife assess the status and the spatial and temporal trends of contaminant accumulation in Puget Sound fishes and the effects of contamination on fish health. In previous versions of the *Puget Sound Update,* PSAMP monitoring data have shown that:

- English sole and rockfish from urban bays accumulated higher PCB levels than fish in near- and non-urban bays. Exposure to PCB-contaminated sediments was believed to be the main factor associated with PCB accumulation in English sole.
- Pacific salmon from all areas of Puget Sound also accumulated PCBs, with central and south Puget Sound stocks accumulating higher levels than north Puget Sound stocks. Unlike English sole, PCB accumulation in salmon, a pelagic migratory fish, was not directly linked to contaminated sediments but was more likely related to the presence of PCBs throughout the food web.
- Mercury accumulation was detected in all fish species sampled by the PSAMP, but the highest levels accumulated in quillback and brown rockfish, two long-lived species. Rockfish from Sinclair Inlet contained especially high levels of mercury.
- Analysis of data from annual sampling at fixed sites showed no temporal trends in contaminant accumulation. Despite attempts to control sources of variation that can mask trends, data were too variable for most species to demonstrate temporal trends in contaminant accumulation.
- The prevalence of liver disease in English sole was elevated at four urbanized areas in Puget Sound: the Duwamish River, Eagle Harbor, Elliott Bay and Commencement Bay. When compared with the risks for similarly aged English sole from non-urban areas, the likelihood of fish developing liver lesions (tumors) in the Duwamish River was 32 times higher, in Eagle Harbor 11 times higher, and in Elliott Bay and Commencement Bay about six times higher. At most near-urban areas, the likelihood of fish developing liver lesions was two to four times higher than the likelihood of fish from non-urban areas. Although English sole may naturally develop liver lesions as they age, researchers with the National Marine Fisheries Service and Washington Department of

> Fish and Wildlife have shown that exposure to contaminated sediments, particularly high molecular weight PAHs, is the main risk factor associated with increased lesion prevalence in English sole.

Since 1997, a substantial portion of the Department of Fish and Wildlife's existing sampling effort has been directed to better defining smaller-scale spatial patterns in contaminant accumulation for English sole and rockfish at selected contaminated areas of Puget Sound. In addition to providing additional geographic coverage for evaluations of English sole and rockfish, Department of Fish and Wildlife scientists have begun monitoring contaminants in Pacific herring because of the fish's importance in the Puget Sound marine food web.

Pilot Study Results for Pacific Herring. In a 1995 pilot study, Department of Fish and Wildlife scientists concluded that Pacific herring were sufficiently exposed to Puget Sound's commonly occurring toxic contaminants (primarily mercury, PCBs and PAHs) to be useful as a monitoring sentinel for these pollutants. Pacific herring are particularly suitable for monitoring temporal trends in contaminant accumulation because they are short-lived, ubiquitous and occupy a low position in the food web. In addition, they comprise a large portion of the diet of many carnivores in the Puget Sound food web, including Pacific salmon, marine birds and marine mammals.

In February 1995, 38 Pacific herring were collected from Fidalgo Bay for chemical analyses (Figure 31). Nineteen whole fish samples were analyzed for mercury, arsenic, copper and lead and another 19 were analyzed for PCBs and chlorinated pesticides. In addition, bile samples from these fish were tested for the presence of PAH metabolites, measured as fluorescing aromatic compounds (FACs).

Results from the Fidalgo Bay pilot study showed that Pacific herring accumulated the same group of contaminants that have been observed in other species from Puget Sound. PCBs were detected in all herring samples, ranging from 38 to 195 µg/kg (micrograms/kilogram), with a mean of 102 µg/kg. Whole body lipid (fat) levels in Fidalgo Bay herring (mean of four percent) were similar to chinook and coho salmon muscle tissue, and were about 10 times greater than muscle from English sole and rockfish. Because PCB concentration can increase with lipid content, the high lipid content of herring may contribute to their PCB levels. The pesticides DDD, DDE and gamma-chlordane were also detected consistently, although at low levels; mean concentrations were 3.4, 17.7 and 4.5 µg/kg,

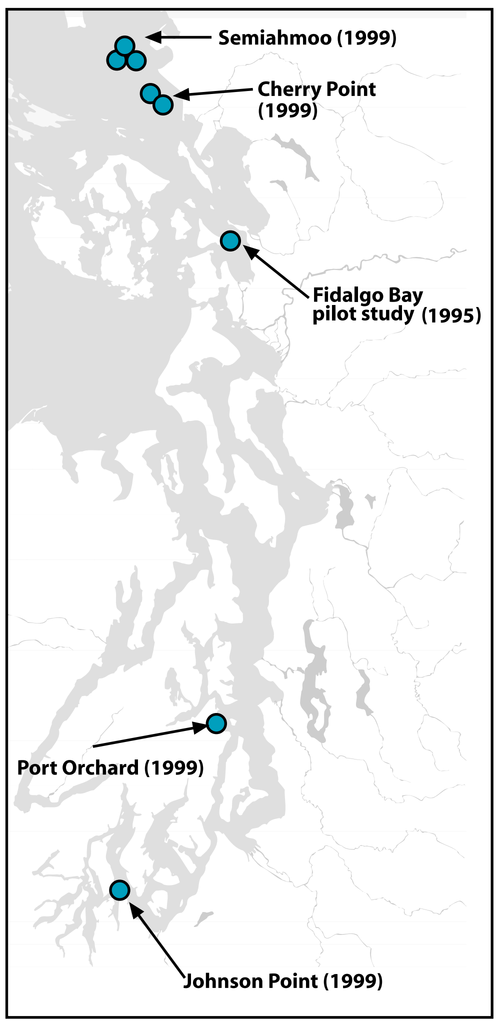


Figure 31. Pacific herring sampling stations.

Table 8. Summary of contaminant results for the PSAMP Pacific herring pilot study, February, 1995.

Parameter (units)	Mean	Minimum	Maximum
Age (years)	3.7	2	5
Whole Body			
Lipids (%)	4.0	0.8	7.8
PCBs (sum of Aroclors µg/kg)	102.3	38.0	195.0
DDD (µg/kg)	3.4	1.2	7.8
DDE (µg/kg)	17.7	3.9	38.4
Total DDTs (µg/kg)	21.1	6.4	44.8
gamma Chlordane (µg/kg)	4.5	0.5	10.6
Mercury (mg/kg)	0.06	0.02	0.10
Arsenic (mg/kg)	1.6	0.9	2.2
Copper (mg/kg)	0.6	0.4	1.0
Lead (mg/kg)	0.0	0.0	0.0
PAH metabolites in bile (FACs ng/g)			
Naphthalene equivalents	227,000	6,850	545,000
Benzo(a)pyrene equivalents	977	53	2,600
Phenanthrene equivalents	65,700	5,200	211,000

respectively (Table 8). Mercury was detected in low levels in all samples; the maximum concentration was 0.10 mg/kg. Arsenic and copper were detected at low levels in all samples and lead was not detected in any sample. PAH metabolites were also detected in Pacific herring. Overall, the concentrations of PCBs, pesticides and metals in whole body samples of Pacific herring from Fidalgo Bay generally fell within the range observed in skin-off fillets of other Puget Sound fish species.

Lead Accumulation in English Sole from Sinclair Inlet. Results of PSAMP monitoring suggest that English sole from the Sinclair Inlet area are exposed to significantly higher lead levels than are sole from any other area of Puget Sound. Between 1989 and 1996 Department of Fish and Wildlife scientists collected 324 composite muscle tissue samples of English sole from 43 different Puget Sound locations. Lead was detected in only 18 of these samples and levels measured were low (0.03 - 0.06 mg/kg). Sixteen of these 18 samples were from Sinclair Inlet and the surrounding bays of Dyes Inlet, Liberty Bay and Port Orchard. Higher lead concentrations were measured in liver tissue than muscle tissue and the same geographic pattern was observed. Lead concentrations in liver tissue of English sole from Sinclair Inlet ranged from 1.8 to 4.7 mg/kg, concentrations significantly higher than those observed at any other location.

Department of Fish and Wildlife scientists evaluated lead accumulation in English sole from six fixed sampling locations throughout Puget Sound and found that of all the urban stations, only lead levels in the fish from Sinclair Inlet were not correlated with their age (Figure 32). At four other fixed sites—two urban stations (Elliott Bay and Commencement Bay) and two non-urban stations (the Strait of Georgia and Hood Canal)—lead concentrations in liver tissue samples were much lower and decreased with fish age (Figure 32). The lowest lead levels were observed at Port Gardner, a near-urban station, where concentrations did not vary with fish age.

The most obvious explanation for the higher concentration of lead in liver and muscle tissue of English sole from Sinclair Inlet is exposure to sediments highly contaminated with lead. Lead levels measured in sediments between 1989 and 1996 at sampling stations near the fish collection locations were also significantly higher at Sinclair Inlet than at the other urban- or near-urban locations. Average sediment lead

New baseline monitoring for Pacific herring

In 1999, the Department of Fish and Wildlife initiated baseline contaminant monitoring of Pacific herring at one Strait of Georgia station and four Puget Sound stations. Results from the 1999 baseline monitoring will show if contaminant levels in herring vary among the north, central and south Puget Sound stations and between Puget Sound and the Strait of Georgia. This information is of interest to PSAMP scientists because the scientists have shown that adult coho salmon from south and central Puget Sound have higher PCB levels than coho from north Puget Sound. Likewise, harbor seals from south Puget Sound have been shown to accumulate higher PCB levels than those from the Strait of Georgia. Future PSAMP efforts will attempt to monitor PCB accumulation in Puget Sound food webs.

levels (dry weight) were 77.2 mg/kg at Sinclair Inlet, 62.6 mg/kg at Elliott Bay, 27.2 mg/kg at Commencement Bay and less than 10 mg/kg at Port Gardner, the Strait of Georgia and Hood Canal. These data were based on one sampling location in each bay. Preliminary results from the 1998 Ecology-NOAA evaluation of contaminated sediments at Sinclair Inlet and Elliott Bay also revealed that most areas in Sinclair Inlet have higher lead levels than Elliott Bay (Figures 33 and 34). The uniformly high lead levels in sediments throughout Sinclair Inlet may expose English sole to higher lead levels than they can effectively metabolize and excrete. Additionally, it is possible that lead is more easily available to English sole from Sinclair Inlet due to the unique mixture of heavy metals present in those sediments.

Liver Disease in English Sole

With their ongoing monitoring of liver condition in English sole from six fixed stations, Department of Fish and Wildlife and National Marine Fisheries Service scientists showed that English sole from three urban locations (Elliott Bay, Commencement Bay and Sinclair Inlet) and one near-urban location (Port Gardner) were significantly more likely (8.7 to 1.8 times) to develop toxicopathic (related to exposure to toxins) liver lesions than English sole from clean reference areas (Figure 35, page 61). The likelihood of English sole from the Strait of Georgia and Hood Canal developing liver disease was statistically indistinguishable from the likelihood of English sole from the other clean reference areas developing liver disease. In addition, the risk of English sole developing liver disease in Elliott Bay increased significantly from 1989 to 1998 (Figure 36, page 61); in 1998, English sole from Elliot Bay were more than twice as likely to develop toxicopathic liver lesions as in 1989. No trends in risk were observed in risk from the other five fixed stations.

Elliott Bay and Sinclair Inlet Focus Studies. Baseline sampling at three urban fixed stations (Elliott Bay, Sinclair Inlet and Commencement Bay) showed that fish from these bays were exposed to and accumulated higher levels of contaminants than fish from near- and non-urban locations. Consequently, the Department of Fish and Wildlife initiated a series of focus studies to better define the extent of contamination in these urban bays. Elliott Bay was sampled in 1997, Sinclair Inlet in 1998, and Commencement Bay in 1999 (Figure 37, page 62).

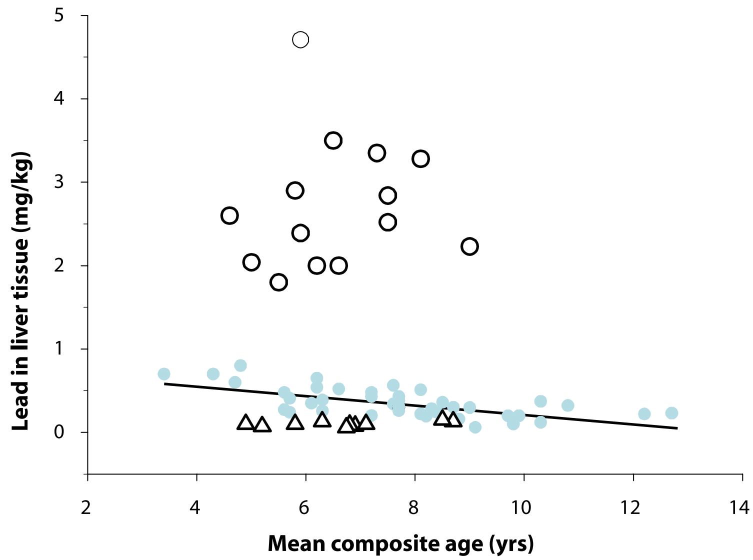
Statistical analysis was used to compute the risk of developing toxicopathic liver lesions for English sole from five Elliott Bay and five Sinclair Inlet locations relative to English sole from clean reference areas. The analysis accounts for the effects of fish age (Figures 38 and 39, page 62). English sole from the Duwamish Waterway (Elliott Bay) were 24 times more likely than those from clean areas to develop lesions; those from the three other inner harbor locations (Harbor Island, Seattle Waterfront and Myrtle Edwards Park) were two to 10 times more likely to develop lesions. The risk to English sole from Alki Point (Elliott Bay) was indistinguishable from the risk to fish from clean reference areas. The risk for English sole from Sinclair Inlet and four surrounding areas was indistinguishable from the risk for English sole from clean reference areas; risks from these five locations were equal to or less than those from clean areas.

Exposure to PAH-contaminated sediments has been shown to be the major risk-factor affecting the development of liver lesions in English sole (Puget Sound Water Quality Acton Team, 1998). Collectively, these data suggest that most of the English sole from Elliott Bay (but not Sinclair Inlet) are exposed to high levels of PAH-contaminated sediments and are developing liver lesions and possibly other health problems as a result (see sidebar). Moreover, the increasing trend in liver lesions in fish from Elliott Bay (Figure 36, page 61) suggests that PAH exposure in these fish is increasing. Inputs of PAHs to Elliott Bay from combined sewer overflows have

Effect of lead on Puget Sound fish

Lead is a non-nutritive, naturally occurring element that is absorbed by the epithelium of a fishes' gills and intestines. It is rapidly metabolized by the liver and accumulates in muscle tissue only when exposures are too high for the fish to effectively metabolize it. At monitoring stations outside of the Sinclair Inlet area, it appears that lead exposures are low enough to be regulated by fish. However, observations of decreasing lead levels in older fish from Elliott Bay, Commencement Bay, the Strait of Georgia and Hood Canal may indicate that older fish are better able to metabolize and excrete lead than younger fish. Alternatively, shifting food habits and habitat may expose older fish to lower lead levels.

Figure 32. Lead concentration in English sole liver tissue from six Puget Sound locations.



Sinclair Inlet

Elliott Bay, Hood Canal, Strait of Georgia and Commencement Bay (with regression line)

Port Gardner

Data and statistical analysis from Fish and Wildlife's monitoring of contaminants in Puget Sound fish.

Figure 33. Average lead concentrations in Sinclair Inlet. 1998 Sediment Sampling Strata.

Average lead (ppm) in 1998

1 - 25

26-50

51-75

76-100

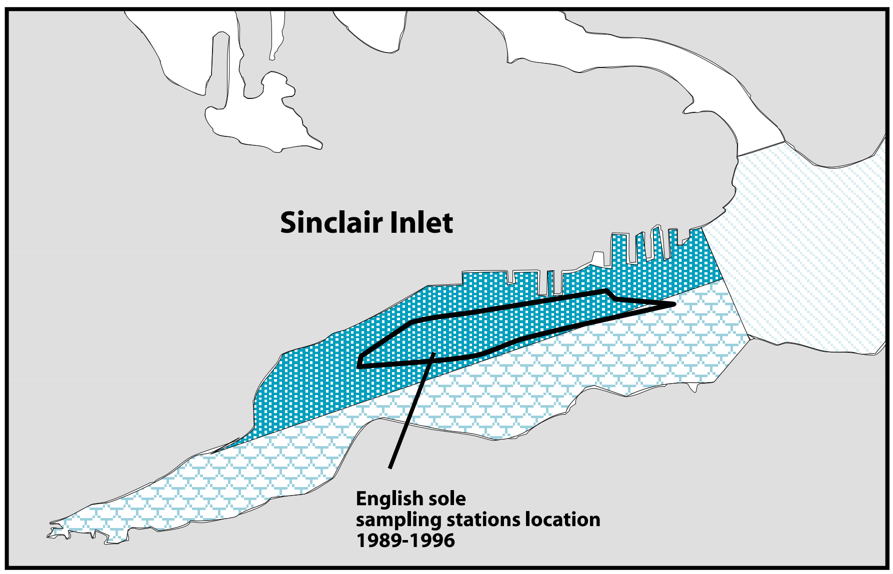


Figure 34. Average lead concentrations in Elliott Bay. 1998 Sediment Sampling Strata.

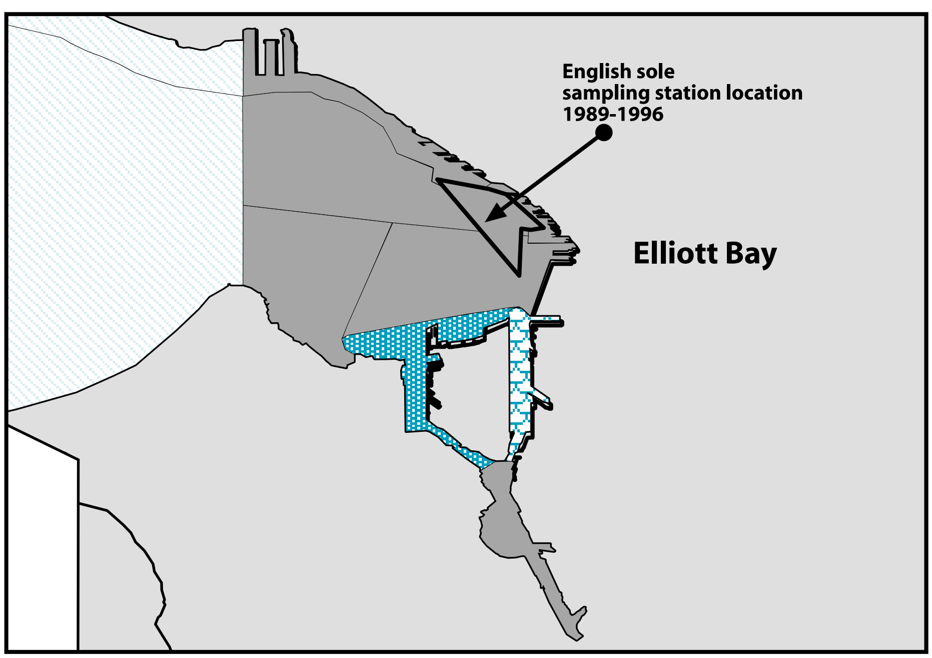
Average lead (ppm) in 1998

1 - 25

26-50

51-75

76-100



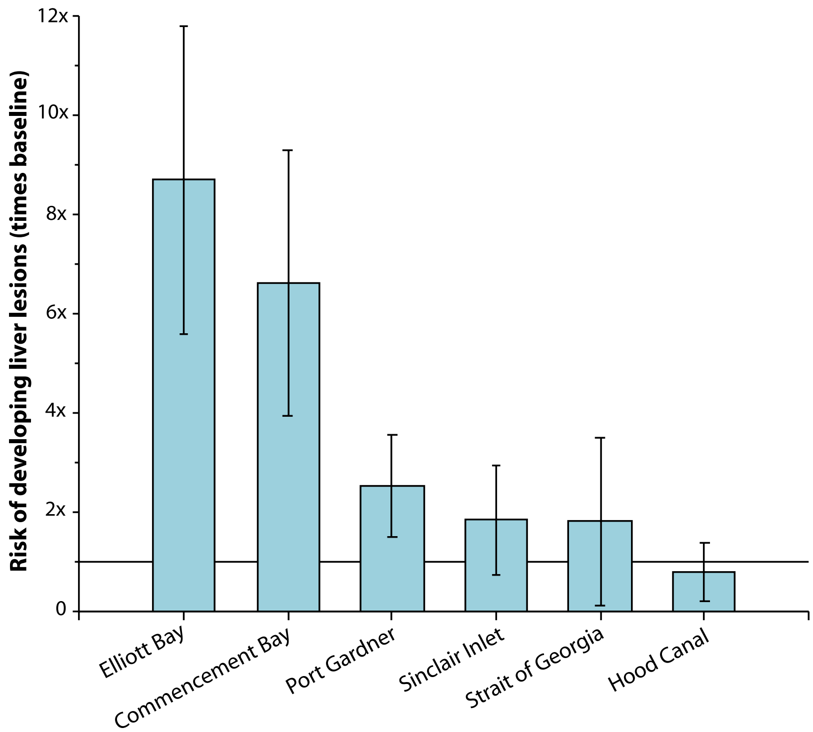


Figure 35. Risk of English sole developing liver disease relative to English sole from clean reference areas, 1989-1998.

Shown here are risks by station averaged over 10 years, ±95% confidence interval. The horizontal line indicates the baseline from which increased risk was estimated.

Risk observed in fish from Elliott Bay, Commencement Bay, Port Gardner and Sinclair Inlet was significantly greater than risk to fish from reference areas. The analysis for the two other locations was inconclusive.

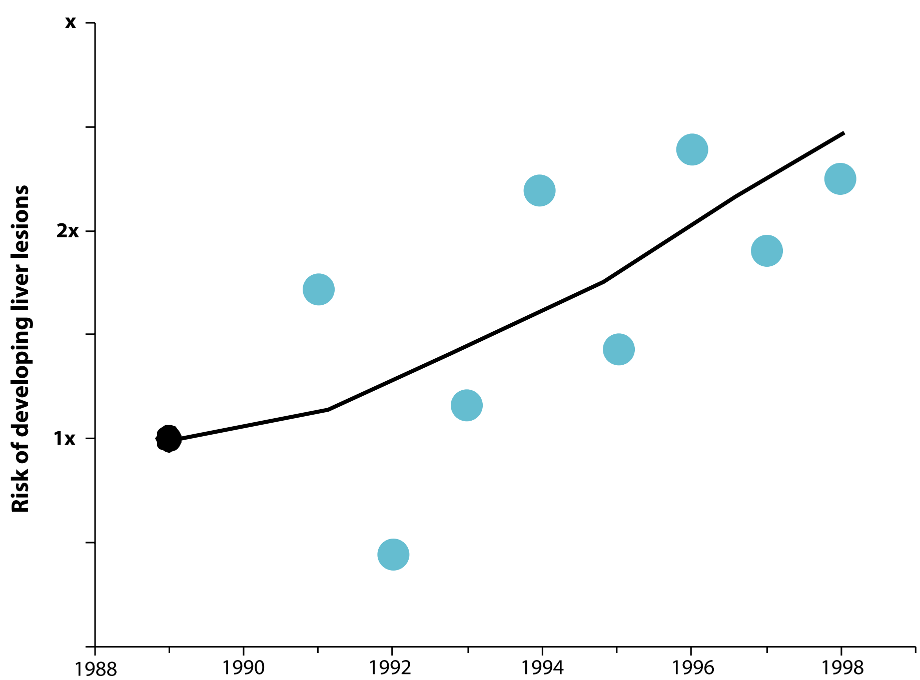


Figure 36. Trend in risk of liver disease in English sole from Elliott Bay.

Logistic regression of odds ratios while controlling for fish age (a covariate), using 1989 as the baseline year (p=0.005). No samples were taken in 1990. From 1989 through 1998, the risk of developing liver lesions increased on average by 1.119 each year.

Figure 37. English sole focus study sampling areas.

▲ Sampling station

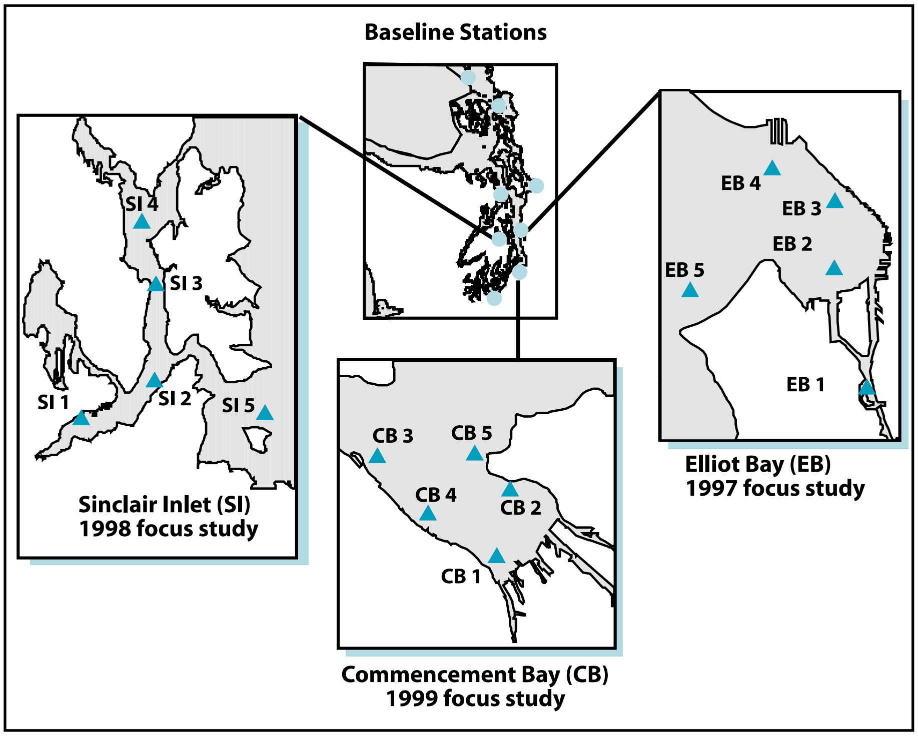


Figure 38. Risk of English sole developing liver lesions in Elliott Bay.

Values:
Greater than 1x indicates elevated risk relative to clean reference areas.

▲ Sampling station

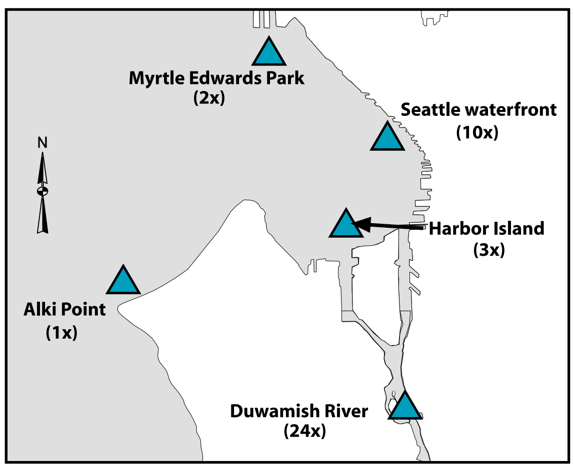
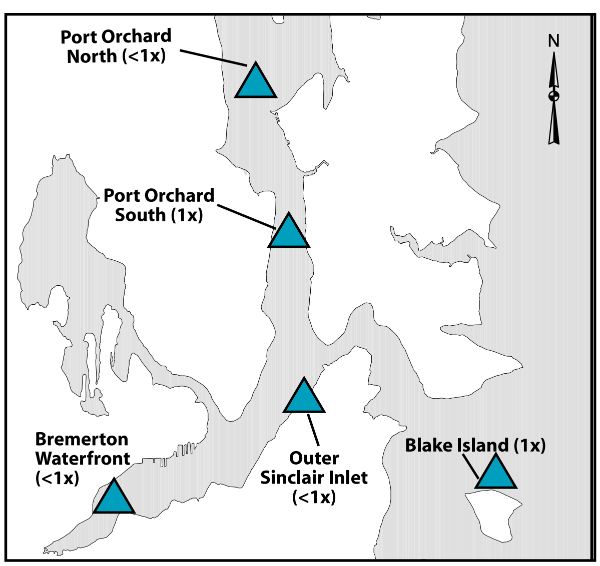


Figure 39. Risk of English sole developing liver lesions from various locations around Sinclair Inlet.

▲ Sampling station



All risks were statistically indistinguishable from clean reference areas (1x or <1x) declined in recent years (King County DNR, 1998) but the status and trends in inputs from stormwater are unknown.

Fish Exposure to PAHs. Exposure to PAHs, especially high molecular weight PAHs, has been associated with increased liver disease and reproductive damage in Puget Sound fishes. Consequently, Department of Fish and Wildlife scientists have started to monitor PAH exposure in Pacific herring, English sole and rockfish by estimating the amount of PAH metabolites in bile, measured as fluorescent aromatic compounds (FACs). PAH metabolites in bile were first measured by the PSAMP for the 1995 Pacific herring pilot study. Since 1997, PAH metabolites in bile samples have been measured in all rockfish and English sole collected for Department of Fish and Wildlife PSAMP monitoring.

Department of Fish and Wildlife scientists performed a preliminary analysis to compare Pacific herring results with recent FAC concentrations measured in English sole and quillback rockfish. Concentrations of FACs were greatest in English sole and rockfish from urban stations, followed by Pacific herring, English sole and rockfish from near-urban stations (Figure 40). The lowest levels of FACs were observed in English sole and rockfish from non-urban stations. More detailed spatial analysis of PAH metabolites in English sole showed that fish from most urban stations were exposed to PAHs levels comparable to those associated with reproductive impairment and liver disease in earlier studies. (Figure 41, page 64).

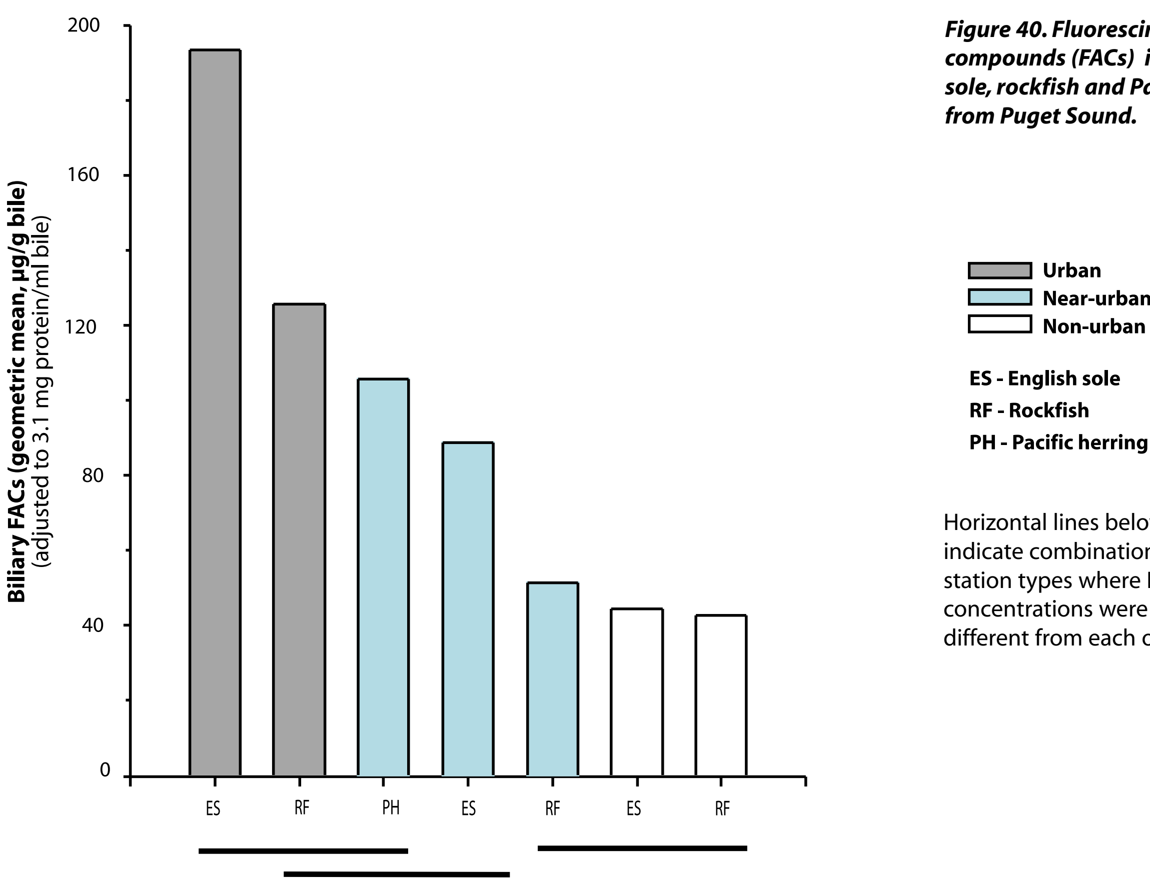
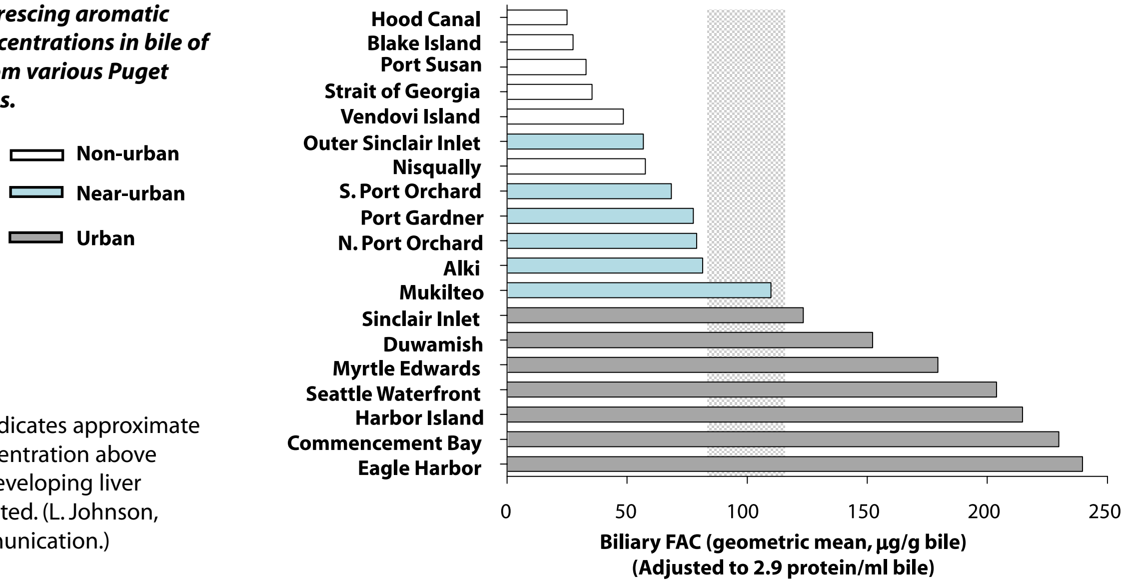


Figure 40. Fluorescing aromatic compounds (FACs) in bile of English sole, rockfish and Pacific herring from Puget Sound.

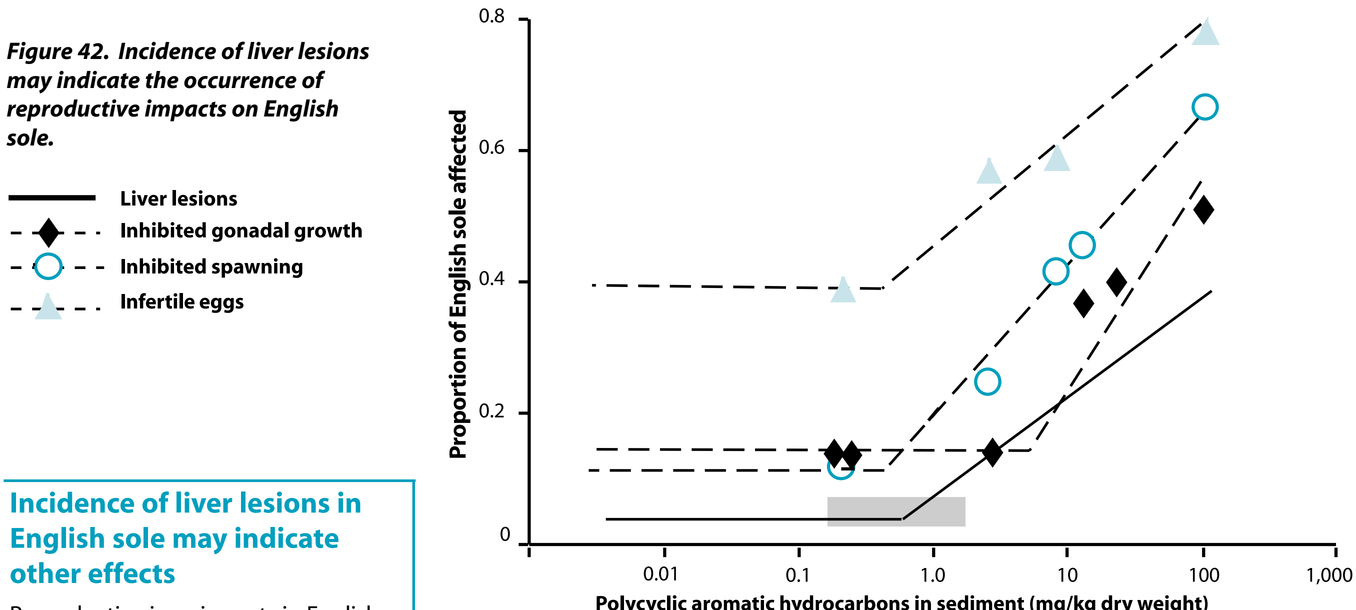
Horizontal lines below the graph indicate combinations of species and station types where FAC concentrations were not significantly different from each other.

Figure 41. Fluorescing aromatic compound concentrations in bile of English sole from various Puget Sound locations.



Shaded area indicates approximate threshold concentration above which risk of developing liver disease is elevated. (L. Johnson, personal communication.)

Figure 42. Incidence of liver lesions may indicate the occurrence of reproductive impacts on English sole.



Source: L. Johnson, personal communication.

Incidence of liver lesions in English sole may indicate other effects

Reproductive impairments in English sole from Puget Sound appear to occur at levels of PAH contamination similar to those associated with increased incidence of liver disease (lesions) (Johnson et al., 1988; Casillas et al., 1991; Johnson et al., 1999; Horness et al., 1998). Studies by National Marine Fisheries Service researchers suggest that the prevalence of reproductive impairments, such as inhibited gonadal growth, inhibited spawning, and infertility of eggs, increases from baseline values at PAH sediment concentrations of about one to five mg/kg. This is approximately the same range at which increases in the incidence of liver lesions have been observed (Figure 42).

Toxic Contaminants in Birds and Mammals

Contaminant Monitoring of Surf Scoters. In 1995, U.S. Fish and Wildlife Service scientists began monitoring contaminants in surf scoters in the Commencement Bay area as part of the PSAMP to determine whether changes in contaminant concentrations in the birds occurred during their wintering period in Puget Sound. Scoters were also collected for contaminant monitoring from Bellingham Bay in 1996 and Hood Canal, near Union, in 1997.

Surf scoters were chosen as a monitoring species because they meet three necessary criteria: 1) they are relatively abundant in Puget Sound, 2) they forage in the marine system, and 3) they spend a substantial portion of their lives in Puget Sound, either as year-round or winter residents. Surf scoters are abundant winter residents of Puget Sound, arriving in September and October and remaining throughout the winter. Scoters begin departing Puget Sound in mid-March to April to return to their northern nesting areas. Surf scoters typically use the low intertidal and subtidal zones.

Location	Average Fall Concentration	Average Winter Concentration
Bellingham Bay	0.91 mg/kg (0.40 to 1.72)	2.82 mg/kg (0.97 to 5.45)
Commencement Bay	2.10 mg/kg (0.82 to 14.09)	2.59 mg/kg (1.24 to 6.87)
Hood Canal	0.85 mg/kg (0.40 to 2.04)	1.85 mg/kg (0.35 to 4.22)

Table 9. Mercury concentrations in scoters at three Puget Sound locations.

Numbers in parentheses indicate ranges of concentrations. The data are reported on a dry-weight basis.

They feed entirely in the marine waters of Puget Sound in the winter. In this study, mussels and clams were their main source of food.

Scientists collected 20 adult male surf scoters from the Commencement Bay area in October when the scoters first arrived in the area and then again in February before they departed. Fifteen adult male scoters were collected from Bellingham Bay and Hood Canal during each sampling period. The purpose of collecting scoters in both the fall and late winter was to document any changes in contaminant concentrations in the scoters during their wintering period in Puget Sound. Liver samples were analyzed for trace metals, organochlorine pesticides and total PCBs. Kidneys were analyzed for selected trace metals. Possible exposure to hydrocarbons was evaluated using bile samples.

Overall, surf scoters collected in this study appeared to be healthy. Concentrations of all the trace metals and organics measured in the scoters' livers and kidneys were well below those known to cause negative impacts to birds. Mercury was the only trace element that increased between the fall and winter sampling periods at all three locations, with the greatest increase occurring in Bellingham Bay (Table 9). Based on this limited sample, it appears that mercury levels have increased during the birds' time in Puget Sound.

Low concentrations of PCBs were recorded in most of the samples from Commencement Bay and in a few samples from Bellingham Bay. PCBs were not detected in the samples from Hood Canal. Low concentrations of DDE were recorded at all three locations. Results of the study indicated that the surf scoters did not have a significant exposure to PAHs during their winter residency at any of the three locations.

Based on results of this study, environmental contaminant exposure does not appear to be negatively affecting surf scoters wintering in Puget Sound. For this reason, collecting surf scoters for contaminant monitoring will not be continued at this time. However, data collected in this study provide baseline information on concentrations of contaminants in surf scoters wintering in Puget Sound. If warranted, contaminant monitoring could be started again in the future. The final report of this study will be available from the U.S. Fish and Wildlife Service in spring 2000.

Scoter abundance on the West Coast appears to be declining (see page 91). Scientists must gain a better understanding of surf scoters' ecology and the environmental stresses they encounter while on nesting grounds, migration routes and wintering grounds in Puget Sound. Additional monitoring of spatial and seasonal patterns of abundance and distribution, and of scoters' use of decreasing resources such as herring stocks or nearshore habitat would provide further knowledge of potential reasons for their decline.

Monitoring Contaminants in Pigeon Guillemot Eggs. Pigeon guillemots are common year-round residents in Washington, nesting along the Strait of Juan de Fuca, Hood Canal, the San Juan Islands and Puget Sound. Pigeon guillemots typically nest in natural cavities in a variety of habitats, including bluffs, rock crevices, driftwood and the undersides of piers. They lay one or two eggs each year.

Studies of estrogen-like compounds in the Puget Sound environment

During the past few years, scientists have become concerned about potential exposure of aquatic organisms to estrogen-like (estrogenic) substances (e.g., natural and synthetic hormones and industrial chemicals) in sewage and industrial effluents. Recent studies indicate that marine flatfish residing in estuaries where large sewage treatment plants are located are exposed to estrogenic compounds (Lye et al., 1998; Mattheison et al., 1998). To determine if exposure to environmental estrogens also occurs in Puget Sound, National Marine Fisheries Service scientists, in collaboration with Washington Department of Fish and Wildlife scientists, are surveying Puget Sound flatfish. Male English sole are being monitored for production of vitellogenin, an estrogen-induced yolk protein that is normally only found in female fish with developing eggs. Their gonadal tissues are also being examined for signs of feminization or other types of abnormal development. Results of the survey should be available later in 2000.

Table 10. Concentrations of PCBs, an organochlorine pesticide and three trace elements in pigeon guillemots at two Puget Sound locations.

Numbers in parentheses indicate ranges in concentration. The data are reported on a wet-weight basis.

Location	Contaminant concentration				
	PCBs	p,p'-DDE	Mercury	Selenium	Arsenic
Protection Island NWR	0.3 mg/kg (0.1 to .7)	0.2 mg/kg (0.04 to 0.20)	0.9 mg/kg (0.5 to 1.3)	0.5 mg/kg (0.3 to 1.2)	0.2 mg/kg (Not detected to 0.6)
Elliott Bay	12.1 mg/kg (11.6 to 13.0)	0.5 mg/kg (0.4 to 0.6)	1.1 mg/kg (0.7 to 1.3)	0.7 mg/kg (0.4 to 1.0)	0.3 mg/kg (0.3 to 0.4)

In 1994, three addled (not hatchable) pigeon guillemot eggs were collected from two nests in conduit holes in a pier in Elliott Bay. In 1996 and 1998, a total of seven addled pigeon guillemot eggs were collected from wooden nest boxes on Protection Island National Wildlife Refuge (NWR). The nest boxes were originally placed on Protection Island NWR to use as part of the PSAMP.

The eggs were analyzed for total PCBs, organochlorine pesticides, mercury, selenium and arsenic (Table 10). To compensate for moisture loss in the addled eggs, a correction factor was used when evaluating the contaminant concentrations.

Total PCBs and p,p'-DDE are the only organochlorine contaminants discussed, as concentrations of the other organochlorine pesticides were either not detected or were present at very low levels. Total PCB concentrations were low in the addled guillemot eggs from Protection Island NWR, while the eggs collected from Elliott Bay had higher levels of total PCBs. The Elliott Bay levels were similar to those in an egg collected in 1982 near Seattle with PCB concentrations of 11.3 mg/kg (Riley et al., 1983). The concentrations of total PCBs in the eggs collected on Protection Island NWR were below levels known to affect hatchability. The concentrations of total PCBs in the eggs collected from Elliott Bay were above levels known to affect hatchability in eggs of some bird species.

Average concentrations of p,p'-DDE in the eggs from Elliott Bay and those from Protection Island were similar and at levels below those known to cause negative impacts to birds. The concentrations of mercury, selenium and arsenic in the guillemot eggs from both locations were also below levels known to negatively affect birds.

Contamination in Harbor Seals. A group of scientists at Cascadia Research Cooperative, Canada's Department of Fisheries and Oceans and the Washington Department of Fish and Wildlife have recently updated analyses of trends in PCB and DDT contamination of harbor seals from south Puget Sound (Calambokidis et al., 1999). Data from earlier studies were evaluated by analyzing archived samples using today's analytical methods. The results of older methods were found to be comparable to results of currently available methods. This finding suggested that data from the earlier studies could be pooled with data from the 1990s to describe changes in contamination in harbor seals from the 1970s through 1997. PCB concentrations in seals declined significantly between the 1970s and 1980s (Figure 43). This decline slowed and became less pronounced in the 1990s. The collaborating scientists hope to collect samples in 2001 or 2002 to extend this analysis of temporal trends.

As discussed in the *1998 Puget Sound Update,* recent work on the contamination of harbor seals also provides detailed information about the specific contaminant compounds (i.e., congeners of PCBs, dioxins and furans) that are present in Puget Sound and Strait of Georgia harbor seals. As reported previously, south Puget Sound seals have a much greater burden of PCBs and related chemicals than do animals from the Strait of Georgia.

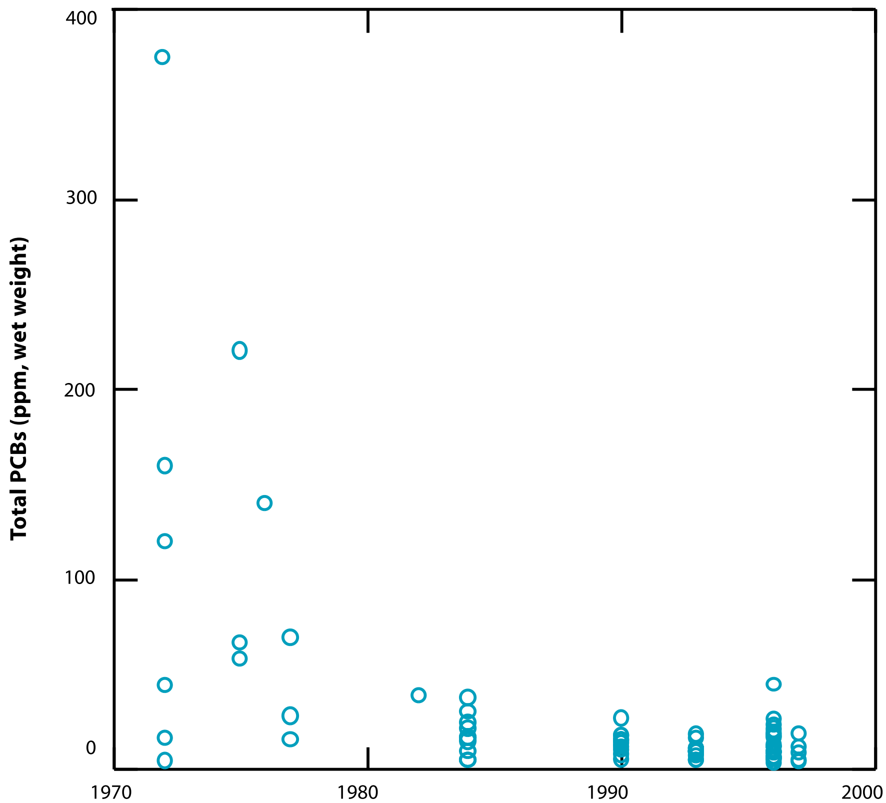


Figure 43. Total PCBs in south Puget Sound harbor seals.

Source: Calambokidis et al., 1999

Acting on the Findings

The information presented in this chapter suggests a number of recommendations for further scientific study or resource management:

- Data from the characterization of sediments in Everett Harbor suggest the need for further investigations of the presence and distribution of dioxins in Puget Sound, especially in areas near potential ongoing and historic sources of these contaminants.
- The Department of Ecology and permitted dischargers should continue to investigate and respond to findings of sediment contamination in the vicinity of discharges. Appropriate actions might include identifying sediments in the vicinity of discharges as part of sediment cleanup sites, evaluating discharges to determine if current discharge levels might cause contamination and continuing to monitor sediment quality in the vicinity of the discharge.
- Environmental managers at the departments of Ecology and Health, the U.S. EPA, the U.S. Navy, the Suquamish tribe and the city of Bremerton should further investigate elevated lead levels in Sinclair Inlet.
- State, local and federal agencies should coordinate to evaluate and respond to the continuing indications from monitoring data that liver lesions in English sole are increasing in Elliott Bay.

- The Department of Fish and Wildlife and the National Marine Fisheries Service should continue investigations of the effects of toxic contaminants and other stressors on fish health. Information on fish abundance should also be collected as an indicator of overall fish health.

Human Health

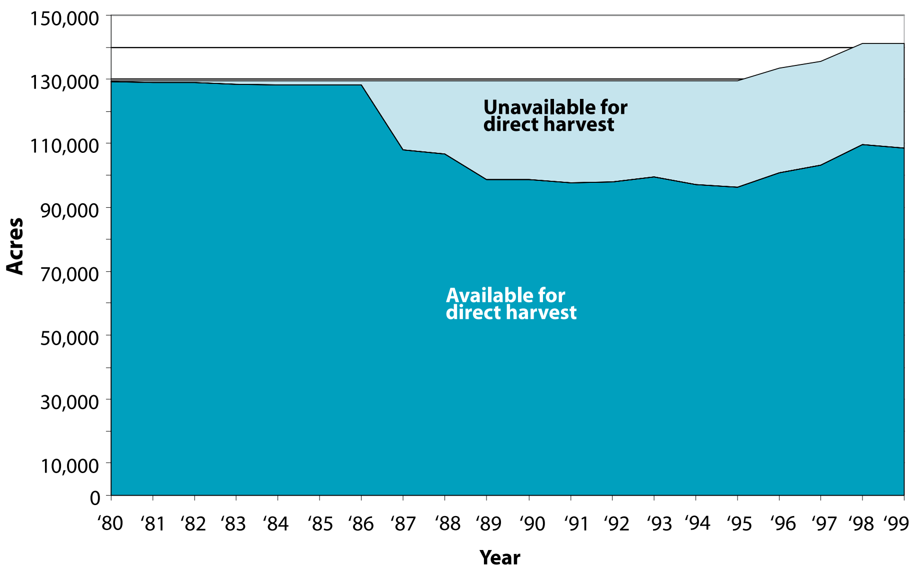
Summary

Conditions in Puget Sound can affect the health of the region's human residents. Contaminants that harm the Sound's biological resources can also threaten human health. Much of our society's concern for clean water is directed at making sure we can fish, swim and safely eat shellfish harvested in our waters. Our society addresses these concerns by developing programs and institutions to control biological and chemical contamination of our waterways from human-caused or human-controlled sources.

Contamination of Puget Sound by pathogens, nutrients and toxic substances was discussed in earlier chapters of this report. This chapter summarizes some of the human health implications of pathogen and toxic substance contamination in the Sound. It also summarizes information on naturally occurring toxic substances, such as the toxin that causes paralytic shellfish poisoning, and pathogens, such as *Vibrio parahaemolyticus*, that affect the safety of Puget Sound's shellfish as a food source.

Human health threats from Puget Sound occur primarily through consumption of shellfish and fish, rather than through contact with the water during wading, swimming or other activities. Because pathogens and toxic chemicals accumulate in shellfish and other organisms, they become more concentrated in these organisms than in the surrounding water, and therefore pose a greater risk of causing sickness. For this reason, this chapter addresses only health risks from consumption of shellfish and fish. Local health authorities may be able to provide information on human health risks related to wading, swimming and diving in contaminated areas.

Figure 44. Trend in commercial shellfish growing area in Puget Sound available for direct harvest.



Source: Department of Health.

This chapter specifically addresses: (1) the management of pathogen-related risks associated with shellfish growing and harvest, (2) the occurrence of natural toxins that threaten human health due to their concentration in shellfish, and (3) the threats posed to human health by toxic contaminants in fish.

Findings

Managing Pathogen-Related Risks from Shellfish Consumption

The Washington State Department of Health (State Health) and local health jurisdictions routinely assess water quality at commercial shellfish growing areas and at recreational shellfish harvesting areas. Health professionals use this water quality data and information from surveys of potential pollution sources to identify or "certify" areas from which shellfish can be harvested and areas where harvest must be restricted or prohibited.

Commercial Growing Areas. State Health classifies commercial shellfish growing areas throughout Puget Sound according to each area's ability to produce shellfish that are safe for human consumption. Historically, about 136,000 acres of Puget Sound tidelands have been utilized for commercial shellfish production. Approximately 75 percent of this area is currently approved for direct harvest and marketing of shellfish. Figure 44 shows how much commercial shellfish growing acreage in Puget Sound was available in 1998 for direct harvest of shellfish (i.e., the acreage classified as "approved" or "conditionally approved" by State Health's shellfish program).

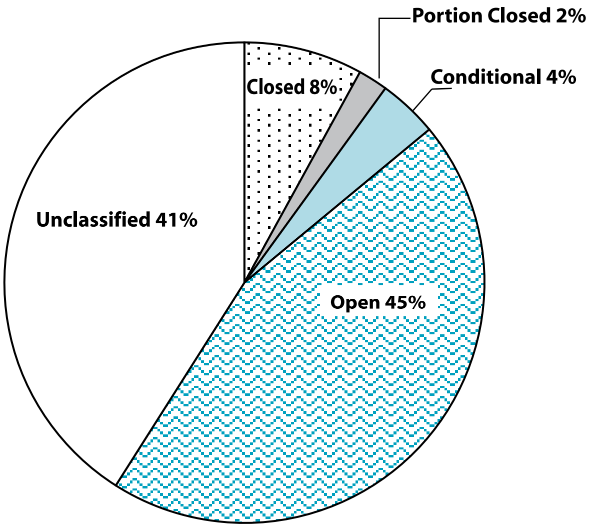
Recreational Shellfish Harvest at Public Beaches. Local health jurisdictions and State Health shellfish programs work together to evaluate public beaches to determine which areas should be opened to recreational harvest and which areas should be closed. Department of Fish and Wildlife staff estimate that nearly 250,000 residents and visitors harvested shellfish from Puget Sound public beaches in 1998. Figure 45 shows that approximately 50 percent of recreational harvest in 1998 occurred in areas that were classified as open or conditionally open for harvest. Unfortunately, eight percent of the harvest occurred at beaches classified as closed. Just over 40 percent of the harvest occurred at beaches that have not been evaluated and classified. State Health will classify the remaining recreational beaches as time and resources allow.

Safeguards on human health

Our society has developed safeguards to limit risks to human health from exposures to harmful agents in the environment. Laws and government programs have been developed to ensure the safety of food and to protect against environmental contamination. In many cases, these laws and programs work by restricting or curtailing human uses of resources from waterways, such as Puget Sound, for food supply or recreational opportunity. Many of the results presented in this chapter focus on these restrictions.

Figure 45. Recreational shellfish beach classifications.

Percent of harvesters observed in 1998 at beaches in each classification.



Source: Department of Health

Vibrio parahaemolyticus **in Puget Sound.** The Department of Health began regular monitoring of shellfish meat for *Vibrio* bacteria after an outbreak of illnesses in 1997. The department closes growing areas to shellfish harvest when *Vibrio* levels exceed 10,000 micrograms of *V. parahaemolyticus* bacteria per gram of shellfish meat. Lower levels of contamination and outbreaks of *Vibrio*-related illness have led State Health to recommend that industry voluntarily restrict harvest and include "cook thoroughly" labels on shellfish products.

Over 30 species of *Vibrio* bacteria occur naturally in marine waters, estuaries, lakes and ponds worldwide. Ten of these species are known to cause gastrointestinal illness. *Vibrio* infection has been directly related to eating raw or partially cooked seafood that has accumulated the bacteria, particularly during warm summer months. The species of greatest concern in Puget Sound is *Vibrio parahaemolyticus*.

The highest levels of *V. parahaemolyticus* occur in shellfish that are exposed during mid-summer low tides when water and air temperatures are highest. Not surprisingly, this period coincides with the greatest number of *Vibrio*-related illnesses (vibriosis). The largest local vibriosis outbreak on record occurred in the summer of 1997, when 58 confirmed cases that were strongly linked to Washington molluscan shellfish were reported by the end of September. Prior to 1997, confirmed cases ranged from two to 32 per year.

During the summer of 1998, 48 shellfish-related *Vibrio* illnesses were reported to the Department of Health, only slightly fewer than the year before.

- Two-thirds of these cases were from commercial products and the remaining one-third were from recreationally harvested shellfish.
- Two-thirds of the cases were linked to shellfish harvested from various parts of Hood Canal, including Quilcene and Dabob bays. Four cases were linked to Samish Bay. The remaining 12 cases were linked to areas in south Puget Sound, Birch Bay (Strait of Georgia) and Willapa Bay (Coast).
- Nearly three-quarters of the cases were linked to consumption of raw oysters (30 to shellstock oysters and five to shucked oysters). The remaining cases were linked to consumption of cooked shellstock oysters (five cases), steamed clams one case) and multiple shellfish and seafood products (seven cases).

In 1999, only 14 confirmed cases of vibriosis linked to Washington shellfish occurred through September. All were linked to oysters. An additional eight confirmed cases were linked to oysters served in restaurants that serve shellfish from numerous areas, including Washington.

Pollution sources limit areas suitable for shellfish harvest

The information presented on the previous page about Puget Sound's shellfish growing areas does not address the Sound's east shore from Everett to Tacoma. Potential harvest areas in this portion of central Puget Sound, and in other heavily urbanized areas, cannot be certified because commercial shellfish harvesting is prohibited near potential pollution sources. Authorities recommend against recreational harvest in this area because of the presence of many potential sources of pollution.

Table 11. Peak counts of* Vibrio parahaemolyticus *as measured in 1998 at five Washington shellfish growing areas.

Date in 1998	Growing Area	Maximum *Vibrio* Concentration (µg/g shellfish tissue)
June 29	Samish Bay (north Puget Sound)	1,100
July 27-September 8	Totten Inlet (south Puget Sound)	24,000 (seen several times)
August 4	Rocky Bay (Case Inlet—central Puget Sound)	2,400
August 4	Quilcene Bay (Hood Canal)	24,000
August 8	Willapa Bay (coast)	43

After the 1997 outbreak, State Health staff began year-round monitoring of *V. parahaemolyticus* in five growing areas implicated as sources of contaminated shellfish. These areas were: Samish Bay (north Puget Sound), Quilcene Bay (Hood Canal), Totten Inlet and Rocky Bay (both in south Puget Sound), and Willapa Bay (on the coast). Monitoring was suspended for the season in November 1999 after *V. parahaemolyticus* dropped to undetectable levels.

Oyster samples collected from late 1997 through the spring of 1998 had non-detectable or extremely low levels of V. parahaemolyticus. Except for a few sporadic samples collected in May and June 1998, levels remained low (below 100 micrograms (µg) of bacteria per gram (g) of oyster tissue) until July of 1998. The levels increased rapidly in July but dropped again to non-detectable or extremely low levels by the end of September. The highest levels of bacteria found in each monitoring area during 1998 are shown in Table 11.

In 1999, monitoring from commercial shellfish growing areas indicated that summertime levels of *V. parahaemolyticus* were low compared to those in 1998. Only Hood Canal had *Vibrio* levels above 100 micrograms per gram of oyster tissue. The highest level of *Vibrio parahaemolyticus* detected in 1999 (1,100 µg/g) was in a sample from Quilcene Bay in July.

Biotoxins in Shellfish

Since 1957, the Department of Health has regularly monitored paralytic shellfish poison (PSP) and other biotoxins that accumulate in shellfish. The department closes an area to shellfish harvest when PSP levels in the local shellfish equal or exceed 80 µg of toxin per 100 g of shellfish meat—the safety level set by the U.S. Food and Drug Administration (FDA).

In Washington, PSP is produced by the dinoflagellate *Alexandrium catenella.* In other parts of the world, different species produce PSP. Blooms of *Alexandrium* are seasonal, tending to begin in spring and often extending well into fall.

To protect shellfish consumers, scientists from State Health monitor PSP in a number of shellfish species at many locations in Washington's marine waters. A portion of this monitoring effort, called the "Sentinel Biotoxins Program," provides early warning of the onset of toxic events based on the sampling of mussels every two weeks at over 40 sites.

In 1999, Department of Health scientists examined monitoring results from 33 sites in Puget Sound, the Strait of Juan de Fuca and the Strait of Georgia. Using these data, they calculated the duration (in days) that PSP concentrations in shellfish samples from each site exceeded the FDA standard.

Vibrio-induced illness

Vibrio bacteria have been isolated from virtually every geographic area in the United States; the most frequently observed species include *V. cholerae, V. vulnificus*, and *V. parahaemolyticus*. The first two species can cause life-threatening illness or death. Historically, *Vibrio cholerae* (cholera) has been particularly devastating, especially in the third world. Although morbidity can run quite high in areas affected by cholera, the fatality rate can be less than one percent with proper diagnosis and treatment. Both *V. cholerae* and *V. vulnificus* can cause septicemia and ulcerating sores in persons with pre-existing health problems such as liver impairment or a suppressed immune system. Gastroenteritis is the chief complaint associated with *V. parahaemolyticus* infection. Symptoms include diarrhea, abdominal cramps, nausea and vomiting. Rarely, *V. parahaemolyticus* may be involved with infections outside the gastrointestinal tract at the site of a recent injury.

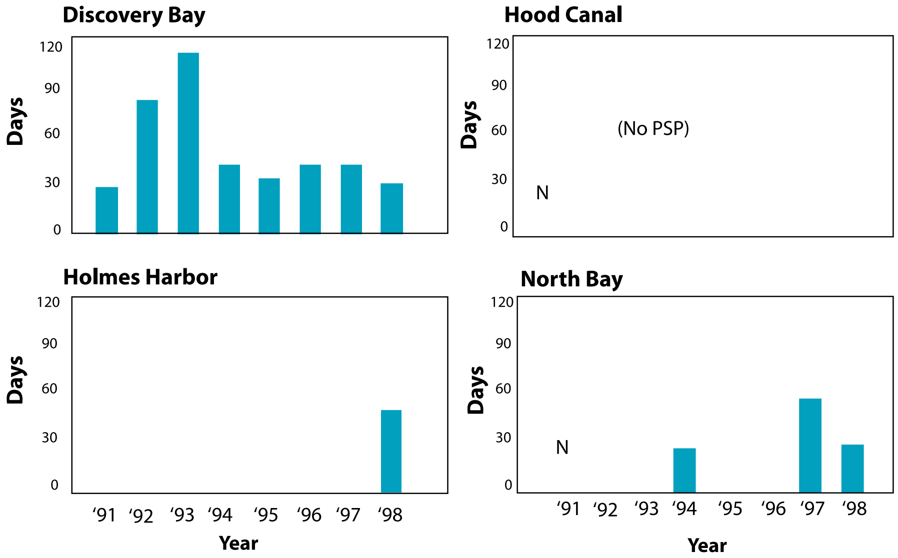


Figure 46. Year-to-year patterns of paralytic shellfish poisoning (PSP) toxic impact at selected locations in Puget Sound.

"N" indicates that insufficient data were available to calculate PSP toxic impact for that year.

Figure 46 shows four patterns of year-to-year variability in the annual duration of PSP concentrations above the FDA standard. From 1991 to 1998, a number of stations showed consistently high impacts from PSP as shown in Figure 46 for Discovery Bay. Other locations exhibiting this pattern of PSP toxic impact include Sequim Bay, Mystery Bay (Marrowstone Island), Quartermaster Harbor (Vashon Island) and Miller Bay (Kitsap Peninsula). Stations in southern Hood Canal had no PSP problems from 1991 to 1998, while stations farther north in the canal showed rare, limited PSP impacts. Stations at Holmes Harbor and Penn Cove (on the east shore of Whidbey Island) showed no PSP problems from the 1970s until 1998. A number of south Puget Sound stations showed sporadic impacts in the early 1990s followed by a sustained toxic event from late 1997 to early 1998, as shown in Figure 46 for North Bay (Case Inlet). This pattern was also observed at other south Sound locations including Jarrell Cove, Johnson Point, Filucy Bay and Steilacoom.

Year-to-year variations at all 33 stations evaluated by Department of Health staff showed that nearly one-half of stations experienced shorter periods of toxicity in 1998 than in 1997, and only one-fifth of stations had longer toxic periods. The remaining nine stations had no PSP problems in either year. This indicates that PSP toxicity in Puget Sound in 1998 was less severe than it was in 1997.

Figure 47 (page 74) shows the total duration of PSP toxic impacts observed from 1996 through 1998. Four categories of PSP impact for the period from 1996 to 1998 were defined as follows:

- **high-impact:** where the total duration was greater than 90 days;
- **moderate-impact:** where the total duration was between 31 and 80 days;
- **low-impact:** where the total duration was one to 30 days; and
- **no-impact:** where no PSP measurements above the FDA standard were recorded.

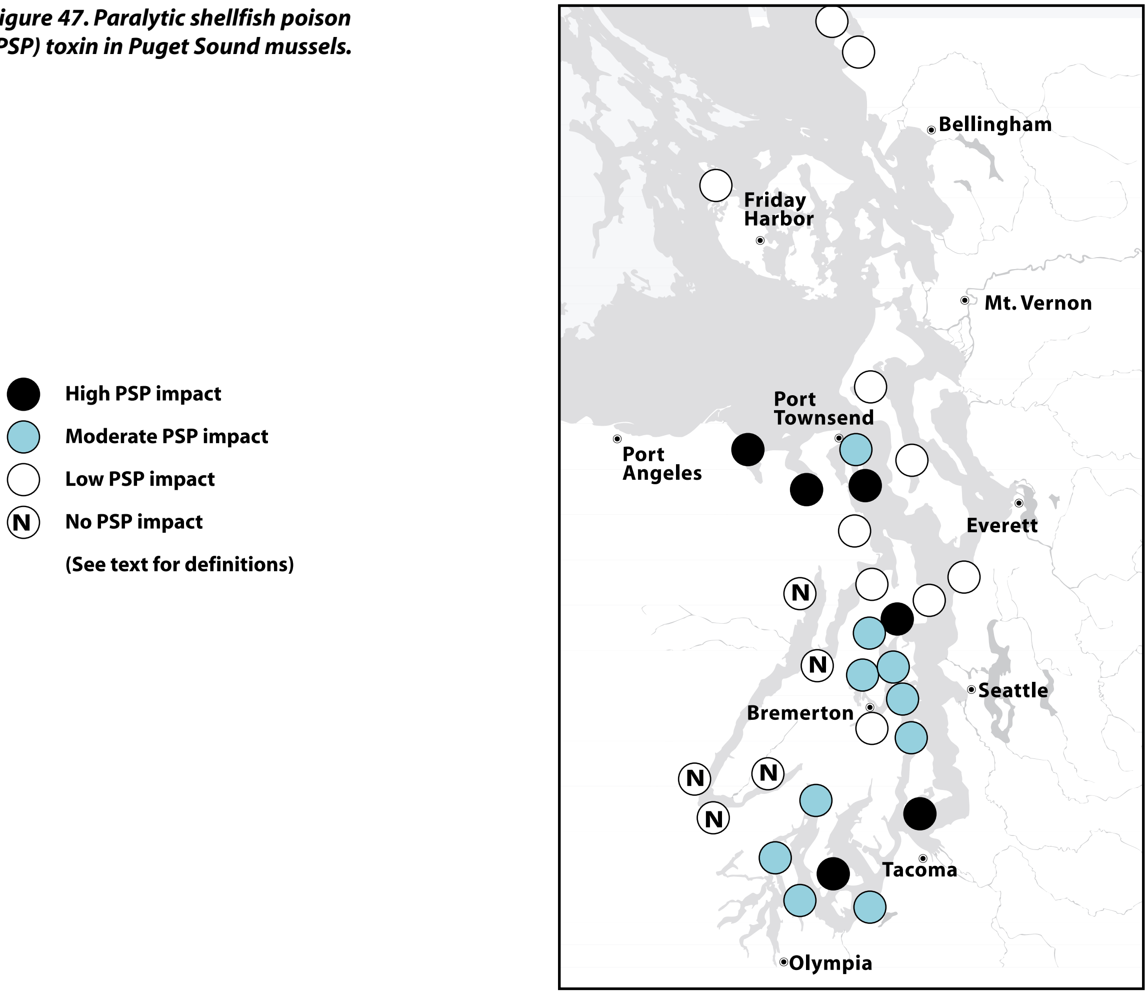
Hunter and Shoal bays in the San Juan Islands were sampled inconsistently in 1998 and could not be assigned a PSP impact category.

Figure 47 indicates that six locations in Puget Sound registered high PSP impact from 1996 to 1998: Sequim, Discovery and Mystery bays on the Strait of Juan de Fuca;

Paralytic Shellfish Poison

PSP is actually a family of related chemicals called saxitoxins that interfere 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 and swallowing; loss of muscular coordination; and paralysis. PSP can lead to death if it paralyzes the respiratory system. Symptoms develop quickly, usually within an hour or two after eating PSP-contaminated shellfish. There is no known antidote.

Figure 47. Paralytic shellfish poison (PSP) toxin in Puget Sound mussels.



Source: Department of Health

Miller Bay (Kitsap Peninsula) and Quartermaster Harbor (Vashon Island) in Puget Sound's main basin; and Filucy Bay in south Puget Sound. The observed geographic pattern of PSP impact in Puget Sound has not been explained, but, factors being considered include:

- Land use—the watersheds of the six "high-impact" locations are mainly rural in character. This observation argues against the theory that increased nutrient loadings from developed lands might be an important factor contributing to toxic algae blooms.
- Hydrographic characteristics-an interaction of physical characteristics including narrow entrances, distance from entrance, shallowness, etc. that might limit flushing and induce water column stratification appears to partially describe the bays with high PSP impact. However, hydrographic features alone do not explain PSP impact; some bays with high PSP impact share similar features to those with lower PSP impact (e.g., Lynch Cove, Quilcene Bay, Drayton Harbor, Liberty Bay and Penn Cove).

Even in areas with similar characteristics, PSP impacts were different. For example, Westcott and Hunter bays are near each other in the San Juan Islands and are similar in form and upland activity; yet, PSP impact was very different at these locations.

A PSP toxic event that occurred in late 1997 and early 1998 illustrates some of the complexities that affect PSP events in Puget Sound. The impact of this event was far

Shellfish physiology and PSP

Shellfish physiology may have affected the length of the late 1997 toxic event in south Puget Sound. Mussels generally had higher levels of PSP than any other shellfish species at the same location, probably due to higher filtration rates. Dropping water temperatures late in the event probably reduced the rates at which shellfish could purge PSP from their tissues. This may have caused the duration of shellfish PSP impact to extend well beyond the time of the *Alexandrium* bloom.

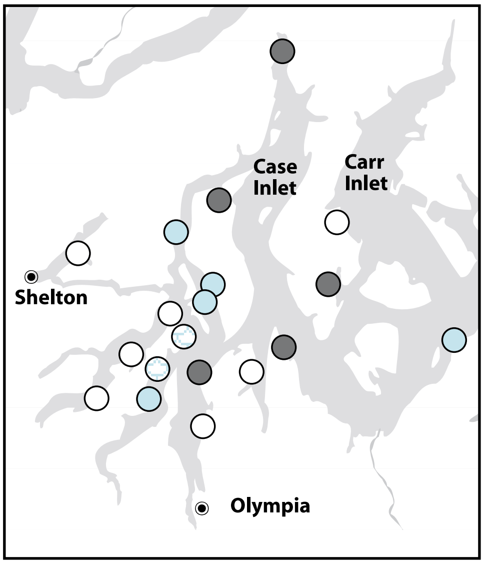


Figure 48. Maximum paralytic shellfish poisoning (PSP) levels in mussels collected at various sites in south Puget Sound from October 1997 - January 1998.

Below 80 micrograms PSP per 100 grams.

80 - 500 micrograms PSP per 100 grams.

500-1,000 micrograms PSP per 100 grams.

Above 1,000 micrograms PSP per 100 grams.

greater in south Puget Sound and the coastal bays (Willapa Bay and Grays Harbor) than anywhere north of this general latitude. Localized heavy rainfall in south Puget Sound followed by region-wide fair weather in late 1997 may have promoted a late-season bloom. Shellfish from the western inlets (Totten, Skookum and Hammersley inlets and Oakland Bay) of south Puget Sound remained free of PSP impacts while levels were consistently high elsewhere in south Puget Sound (Figure 48). This pattern suggests that water circulation patterns may have influenced the distribution of the *Alexandrium* bloom and the resulting PSP toxin. This event also mirrored the 1996-1998 region-wide pattern of high impacts in rural areas (North Bay) and lesser impacts in urban areas (Budd Inlet at Olympia).

Toxic Contaminants in Fish and Shellfish

Health Risk Assessments and Consumption Advisories for Puget Sound Fish. Data on toxic chemical contamination in fish and shellfish allow Puget Sound scientists to document spatial and temporal trends in contamination (see pages 54 to 64). These data can also be used to evaluate the safety of Puget Sound seafood for human consumption. The PSAMP's fish contaminant data, collected by the Department of Fish and Wildlife, have been used as the basis for a consumption advisory for rockfish from Sinclair Inlet, to develop a model for sediment quality standards protective of human health, and to provide data for risk assessment of consuming seafood from various Puget Sound locations.

Department of Health scientists are currently evaluating fish contaminant data from the PSAMP to assess human health risks from the consumption of Puget Sound fish contaminated with mercury and PCBs. These assessments will incorporate information on the toxicity of the contaminants and estimates of fish consumption by various segments of the population. It will also consider duration of exposure to the contaminants. Reports on State Health's assessments should be available in 2000.

As shown in Table 12, scientists from State Health have identified seven fish and shellfish consumption advisories related to toxic chemical contamination in various locations around Puget Sound.

Consumption of Seafood from the Duwamish River and Elliott Bay. King County scientists assessed human health risks from the consumption of seafood as part of King County's February 1999 Combined Sewer Overflow Water Quality Assessment for the Duwamish River and Elliott Bay. Scientists estimated the potential risks incurred from the consumption of Duwamish River and Elliott Bay seafood, which is contaminated with high levels of PCBs and arsenic, among other chemicals. Estimated risks from human exposure to arsenic from consumption of Duwamish River and Elliot Bay fish were about the same as risks from exposure to arsenic in seafood from Puget Sound reference sites.

Table 12. 1998 Puget Sound fish and shellfish consumption advisories due to toxic chemical contamination.

Location of advisory	Agency that issued advisory	Fish and shellfish affected	Contaminants identified
Budd Inlet, Olympia	Thurston County Health Department	Shellfish	Creosote, volatile organic compounds, pentachlorophenol and dioxins
Commencement Bay waterways, Tacoma	Tacoma-Pierce County Health Department	Bottom fish and crab	PCBs, a phthalate and tetrachloroethylene
Dogfish Bay, Keyport	Bremerton-Kitsap County Health District	Shellfish and bottom fish	Metals and vinyl chloride
Dyes and Sinclair inlets, Bremerton	Bremerton-Kitsap County Health District	Rockfish, crab, shellfish and bottom fish	PAHs and mercury
Eagle Harbor, Winslow (Bainbridge Island)	Bremerton-Kitsap County Health District	Shellfish, crab and bottom fish	PAHs and mercury
Indian Island, Jefferson County	U.S. Navy	Shellfish	Pesticides, PCBs and metals
King County marine waters, Seattle and vicinity	Seattle-King County Department of Public Health	Bottom fish, crab and shellfish	Contamination associated with historic industrial discharges

Source: G. Patrick, personal communication

Table 13. Summary of predicted cancer risks from exposure to PCBs and arsenic in seafood from the Duwamish River and Elliott Bay.

Consumption Frequency	Range of Predicted Cancer Risks
Every day (365 meals/year)	1 in 10,000 to 2 in 100
Twice per month (24 meals/year)	2 in 1,000,000 to 2 in 10,000
Once every 6 weeks (8 meals/year)	Less than 1 in 1,000,000 to 1 in 100,000

Source: King County Department of Natural Resources

A King County fishing survey identified 450 people who have eaten seafood from the Duwamish River or Elliot Bay. Seven of these people reported that they eat seafood from this area every day of the year. About one-fourth of these 450 people eat seafood from the area more than 24 times per year. About one-half of the 450 people consume seafood from the river or bay eight or fewer times per year.

Relatively high lifetime risks of developing cancer from exposure to arsenic and PCBs were predicted for people who eat seafood every day from the Duwamish River or Elliott Bay (Table 13). Lower risks were predicted for people who eat seafood from the river or bay twice per month or once every six weeks. Cancer risks from consumption of PCBs in English sole are about 20 times higher in the Duwamish River than in Elliott Bay and nearly 10 times higher in Elliott Bay than in reference Puget Sound sites. In general, predicted risks from eating salmon were lower than risks from eating other fish species.

Other types of health concerns from exposure to PCBs and arsenic were also predicted for people who eat seafood from the Duwamish River and Elliott Bay every day. Examples include effects on the neurological system, immune system and skin.

Acting on the Findings

The information presented in this chapter suggests a number of recommendations for further scientific study and/or public health management:

- Efforts to monitor water quality conditions at beaches where recreational shellfish harvest occurs should be stepped up to ensure that residents and visitors can make informed decisions about where they might harvest shellfish that is safe for consumption.

- Additional informational and educational materials should be made available to the public to increase awareness of health professionals' advice about the recreational harvest of shellfish from public beaches and the preparation of shellfish from areas that may be affected by *Vibrio parahaemolyticus*.
- Additional research and analysis are needed to improve the understanding of environmental factors that influence the distribution and timing of PSP and *Vibrio parahaemolyticus* contamination events.
- Efforts to develop consumption advice for Puget Sound fish should be completed and a system developed to ensure that advice is available to the public.

Biological Resources

Summary

Over time, Puget Sound has become a less hospitable place for many of the organisms that reside within it. As discussed in the previous chapters of the *Update*, a variety of stressors affect Puget Sound's biological resources. From the Sound's water to the land of the entire Puget Sound basin, impacts to the Sound's biological resources (species and habitats) are manifested in many ways. These and other items are discussed in more detail later in the chapter:

- The Puget Sound basin has experienced extensive loss of tree cover in the last 25 years.
- Seven species of Puget Sound marine fish are currently being considered for possible protection under the federal Endangered Species Act.
- Three of the five species of diving birds discussed in this chapter appear to be declining in abundance.
- A rapid inventory of non-indigenous species in Puget Sound reported 10 of these species that had not previously been found. This brings the total number of known non-indigenous species in Puget Sound to 52.

Populations of many important species in the Puget Sound ecosystem have declined substantially in recent years, causing concern among natural resource managers. These declines have probably resulted from a number of human-induced stressors including overharvest, habitat loss and pollution, as well as natural processes such as cyclical

changes in temperature. Especially worrisome is the steady decline in abundance of adult Pacific herring that has occurred since the mid-1970s (see page 84). Pacific herring comprises a large part of the food base for Puget Sound carnivores (e.g., rockfish, codfishes, dogfish, lingcod, common murre, marbled murrelet, tufted puffin and harbor porpoise), many of which are also in decline (West, 1997). Harbor seals and California sea lions, protected from harvest since 1972 by the Marine Mammal Protection Act, are notable exceptions to this trend.

Findings

PSAMP investigators and other cooperating scientists monitor the abundance and health of key species or groups of organisms (such as harbor seals, salmon, herring, surf scoters and phytoplankton) as indicators of ecosystem health. Scientists monitor not only the abundance and distribution of organisms, but also their exposure to pollutants and changes in their habitats. This section presents the findings of investigations about the health of the plants, algae, invertebrates, fish and wildlife that call Puget Sound home.

Loss of Tree Cover in the Puget Sound Basin

Human impacts to the vegetation of the Puget Sound basin were revealed by a recent analysis of local tree cover over a 25-year period. American Forests, a Washington, D.C.-based non-profit organization, analyzed satellite imagery of 3.9 million acres of land in the east side of the Puget Sound basin to determine how forest cover in the basin changed between 1972 and 1996. The analysis showed that the landscape of the basin changed dramatically:

- Areas with dense vegetation and tree canopy coverage (50 percent tree cover or more) declined by 37 percent—from 1.6 million acres to 1.0 million acres.
- Areas with sparse tree cover (less than 20 percent) more than doubled—from 25 percent of the region to 57 percent of the region.

American Forests (1999) estimated that the loss of trees resulted in a 35 percent increase in stormwater runoff from the study area. Replacing this lost stormwater retention capacity with reservoirs and other engineered systems would cost $2.4 billion. American Forests also estimated that the lost tree canopy would have removed approximately 35 million pounds of air pollutants annually, at a cost to society of approximately $95 million.

Nearshore Vegetation

Aquatic vegetation provides structural habitat for many organisms and supports the food web through primary production. Because of their recognized ecological importance, many types of aquatic vegetation (e.g., algae, eelgrass and kelp) are protected by law.

The amount of aquatic vegetation nationwide has decreased dramatically over the last 70 to 100 years (Tiner, 1984). Substantial losses have occurred in Puget Sound, especially near urban centers (Bortelson et al., 1980). Tidal marshes and swamps in Puget Sound have declined more than 70 percent from their historic extent (Thom and Hallum, 1991). Loss of other types of aquatic vegetation due to human activities has probably occurred, but the extent of these losses is not well documented. Eelgrass beds are thought to be decreasing due to human impacts on the physical environment and water quality. Canopy-forming kelp is believed to have increased Sound-wide during this century, perhaps due to increased coarse sediment habitat associated with

Table 14. Areal extent of nearshore vegetation types for Skagit County study area.

Vegetation Type	Acres	Percent
Eelgrass	14,000	84
Green algae	1,200	7
Salt marsh	950	6
Mixed algae	240	1
Kelp	200	1
Red algae	0.1	< 1
Brown algae	69	< 1
Spit or berm vegetation	39	< 1
Total	**17,000.1**	**100**

shoreline modification (Thom and Hallum, 1991). Local losses of historic kelp beds have also been reported (see, for example, page 82).

Nearshore vegetation losses are attributed primarily to changes in the physical environment. Loss of vegetation beds frequently occurs as a direct result of habitat conversion, such as dredging and filling. Historically, extensive vegetation bed losses occurred in estuaries due to conversion to uplands. Changes in the physical environment have also lead to indirect loss of vegetation through degradation of water quality, eutrophication, changes in sediment supply and changes in wave energy.

Inventory of Nearshore Vegetation. In 1999, the Department of Natural Resources released nearshore vegetation inventory information for 230 miles of shoreline in Skagit County and northern Island County. Inventory results are available on CD-ROM to assist in land-use planning and to facilitate a better understanding of linkages between habitats and species.

Using multispectral imagery, Natural Resources classified vegetation into one of eight categories: eelgrass, brown algae, kelp, green algae, mixed algae, salt marsh, spit and berm vegetation and red algae. Eelgrass was the most abundant vegetation type in the area (see Table 14), followed by green algae and salt marsh. These vegetation types were found predominantly in broad embayments in the study area, including Padilla Bay, Samish Bay and Skagit Bay.

The inventory illustrates the wide range of intertidal environments found in Puget Sound. Along rocky shores such as Deception Pass, canopy forming kelps and mixed algae beds alternated with pocket beaches containing green algae and eelgrass (see Figure 49, Color Section, page 113). Other more protected shores, such as Cornet Bay, contained extensive eelgrass beds on large tidal flats and high intertidal marshes (see Figure 49, Color Section, page 113).

Temporal Trends in Canopy-Forming Kelp along the Strait of Juan de Fuca. In the Puget Sound region, the canopy layer of a floating kelp bed is formed by two species—giant kelp *(Macrocystis integrifolia)* and bull kelp *(Nereocystis luetkeana)*—that have float-like structures to hold the upper portion of the plant at the surface. Other kelp species dominate the understory level, providing a dense layer of vegetation used as shelter for small invertebrates and larval fishes. This habitat has one of the highest primary productivities of any ecosystem on earth. Kelp beds extend along approximately 12 percent of the Puget Sound shoreline (Thom and Hallum, 1991). Some of the richest beds are along the Strait of Juan de Fuca.

Natural Resources' scientists mapped floating kelp beds on the Strait of Juan de Fuca from 1989 to 1998. These data suggest that the size of the kelp population was highly variable from year to year, yet stable over the long-term. Despite large year-to-year fluctuations as high as 57 percent in the total area of floating kelp beds in the Strait, the total area has not changed significantly over the last 10 years. During the study period, the total kelp bed area along the Strait of Juan de Fuca ranged from a minimum of 4,700 acres in 1989 to a maximum of 7,700 acres in 1998 (see Figure 50).

Shoreline physical characteristics

In addition to delineating nearshore vegetation, Natural Resources' nearshore inventory describes a set of physical shoreline characteristics that are known to affect the distribution of plants and animals. This data set is discussed on pages 25 to 26 in the Physical Environment chapter.

Figure 50. Kelp bed areas in the Strait of Juan de Fuca.

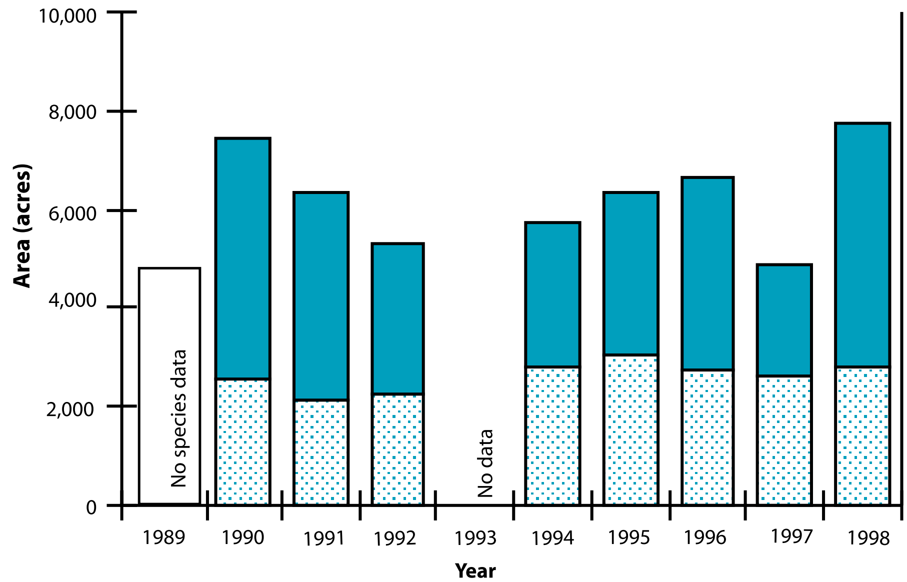
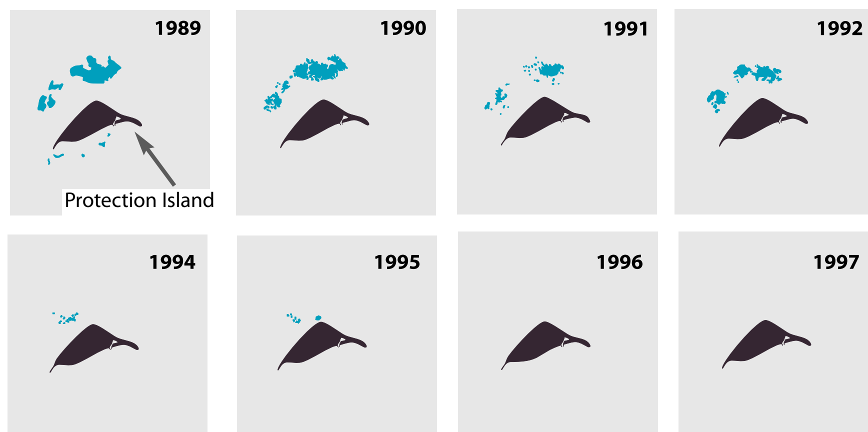


Figure 51. Changes in canopy-forming kelp around Protection Island.



Factors that endanger kelp beds

Many factors, both natural and human, affect the extent and composition of kelp beds. Elevated water temperature and intense sea urchin grazing can wipe out entire kelp beds. El Niño events stress kelp by producing severe winter storms and reducing upwelling events, which normally replenish the nutrients in the water column. Human influences on kelp beds include sewage and other runoff, which decrease water quality by changing nutrient levels and reducing light in the water column. Kelp plants can also be physically damaged by boat propellers and fishing gear. Commercial harvest of kelp is prohibited in Washington; consequently, this practice is not a significant factor in determining the extent and composition of kelp beds. Recreational harvest is permitted but Natural Resources does not have data on how this affects the kelp population.

The species composition of the floating kelp beds varied greatly from year to year, reflecting the two species' different responses to environmental conditions. Species dominance shifted during the study: bull kelp dominated from 1990 to 1992 and again in 1998; giant kelp was the dominant species in the other years.

Other differences between species of floating kelp were evident. Bull kelp populations consistently occurred in lower densities. Bull kelp also showed much higher year-to-year variation: the population decreased in area by 55 percent from 1994 to 1995 and increased by 250 percent from 1997 to 1998. The higher density and relative year-to-year stability of the giant kelp population is attributed in part to life cycle differences. Giant kelp is a perennial and can regrow new vegetative stipes from its base or holdfast. Bull kelp, on the other hand, is an annual and is usually removed by winter storms.

Some local losses of kelp have occurred. For example, the kelp bed north of Protection Island National Wildlife Refuge near Port Townsend began dwindling from 181 acres in 1989 until it completely disappeared in 1997 (see Figure 51). Human impacts to Protection Island are thought to be minimal because it is approximately four kilometers offshore and because of its status as a wildlife refuge. More research would be needed to understand the cause of this local trend.

Phytoplankton

Department of Ecology scientists monitor concentrations of chlorophyll as an indicator of the abundance of phytoplankton in Puget Sound's open waters. This monitoring, which relies on monthly sampling, allows scientists to quantify phytoplankton density but does not provide information on phytoplankton populations, communities or growth rates.

The *1998 Puget Sound Update* reported on Ecology's characterization of two seasonal patterns of chlorophyll concentrations in Puget Sound. The first pattern, the typical temperate condition, shows spring and fall blooms of phytoplankton (actually measured as elevations of chlorophyll-*a* concentrations). Ecology's 1996 to 1997 monitoring showed that Burley Lagoon (at the head of Carr Inlet) and Bellingham Bay exhibited this pattern.

The second seasonal pattern shows elevated chlorophyll-*a* concentrations in the summer as well as in the spring and fall. This pattern of summer blooms indicates that nutrient supplies are not depleted by growth of phytoplankton during spring blooms. The supply of nutrients can be natural (e.g., ocean input) or from human sources (e.g., on-site septic systems or agricultural wastes). Locations that exhibited summer blooms during 1996 and 1997 include Budd Inlet, East Sound (Orcas Island), lower Hood Canal and Holmes Harbor. The occurrence of summer phytoplankton blooms at these locations is consistent with the identification of these areas as sensitive to eutrophication (see page 45).

King County Department of Natural Resources scientists monitor chlorophyll-*a* and another pigment called phaeophytin monthly at several depths at nine open water stations in the central Puget Sound basin. Data collected in 1997 and 1998 show seasonal blooms occurring in late April (1998 only) and mid- to late-July. This pattern is consistent with previous years' findings.

Stations where there are potential sources of nutrient inputs (such as wastewater outfalls and industry) do not have higher chlorophyll-*a* levels than stations without nutrient inputs. The highest levels (greater than 30 µg/L) sampled during this two-year period were from the central basin in July 1998. Although the highest levels detected in 1998 were higher than in 1997, no trend is evident over the longer term.

Alternative approaches to monitoring chlorophyll concentrations

Monthly monitoring of chlorophyll concentrations at a few fixed depths is far from ideal and severely limits the ability of Ecology and King County scientists to draw conclusions about the spatial and temporal dynamics of phytoplankton growth in Puget Sound. Puget Sound scientists are actively investigating alternative monitoring approaches, including: moored sensors to increase temporal resolution; remote sensing to improve spatial coverage; and depth profiling to improve vertical resolution and support estimates of phytoplankton biomass.

Sediment-Dwelling Organisms

As part of the PSAMP's investigations of the condition of Puget Sound's sediments, Department of Ecology scientists collect information about the community of organisms that dwell in and on the sediment in open-water areas of the Sound. Measurements taken at Ecology's long term monitoring stations did not indicate that either species richness or total abundance of organisms was affected by contamination, probably because there were generally low levels of contaminants at the monitoring stations (Llansó et al., 1998). Nonetheless, Ecology scientists identified a few other indications of pollution effects in the composition of the sediment-dwelling communities at these stations. The primary example of such an effect was the community dominance by the polychaete worm *Aphelochaeta sp.* at locations where the sediments were enriched with organic pollution and/or showed moderate toxic contamination (Llansó et al., 1998).

However, the community of sediment-dwelling organisms is affected by a variety of stressors, not just organic enrichment and toxic contamination. The community responds to habitat changes, including sediment grain size alteration and seasonal reductions in dissolved oxygen concentrations. Ecology is continuing its long-term monitoring of the sediment-dwelling community to provide information about subtle shifts occurring in the soft habitats at the bottom of Puget Sound.

Ecology's baseline monitoring of sediment-dwelling organisms was conducted from 1989 to 1993 (Llansó et al., 1998). In 1997, Ecology scientists sampled a subset of the original monitoring network, focusing on 10 stations that represent the diversity of soft-bottom environments observed in Puget Sound.

Samples from 1997 have been analyzed and compared to the community parameters observed in the baseline samples taken from 1989 to 1993. Table 15 summarizes the community characteristics at these 10 stations and any differences observed in 1997. For three stations (Bellingham Bay, Port Gardner and Anderson Island), results from 1997 were generally consistent with the baseline findings. The other seven stations showed somewhat different conditions in 1997 than were observed previously. Changes at two stations (Point Pully and Strait of Georgia) indicated worsening conditions. Changes at one station (Commencement Bay) reflected improving conditions. Additional analysis is needed to understand whether the observed differences might reflect natural variability over the course of a few years or might point to other changes in the environment.

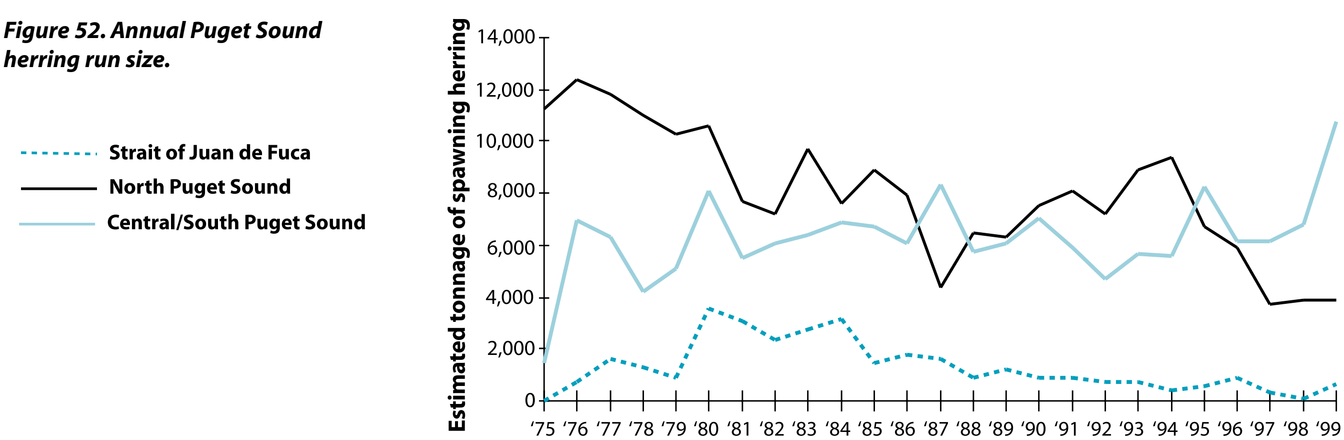
Fish

The condition or status of the various fish resources in Puget Sound exemplify why scientists who track the health of Puget Sound are concerned about the state of the estuary. Fish species in every grouping discussed in this section—forage fish, bottomfish and wild salmon—seem to be in serious decline in terms of population size, some enough to warrant review for possible listing as federally threatened or endangered species.

Pacific Herring. In June 1999, the National Marine Fisheries Service announced that it would conduct a "status review" of seven species of marine fish in Puget Sound to determine if they need protection under the federal Endangered Species Act. Pacific herring is among these seven species. Pacific herring is a vitally important forage fish species in Puget Sound and it is a significant resource for commercial and subsistence fisheries.

Figure 52 shows the estimated tonnage of spawning herring in north and south Puget Sound and the Strait of Juan de Fuca over the last 25 years. Stocks of herring in the north Sound and the Strait of Juan de Fuca have experienced a gradual, but fairly steady decline over the past 25 years. The status of the north Sound and Strait of Juan de Fuca stocks is currently depressed and critical. Stocks in south and central Puget Sound, on the other hand, do not show the same downward trends, and estimated herring run size has been increasing since 1996. Stock status for south/central Puget Sound is currently categorized as healthy.

Figure 52. Annual Puget Sound herring run size.



Source: Department of Fish and Wildlife.

Table 15. Summary of sediment-dwelling community characteristics at Ecology's long-term monitoring stations.

Station location (Station number)	Conditions represented by station	Summary of community character as observed from 1989-1993	Changes observed in 1997
Strait of Georgia (3)	Deep, mixed sand-silt-clay	Community unlike those at other monitoring locations; low abundance and numbers of species.	Symptoms of stress related to low dissolved oxygen —low abundance, diversity and species richness. Similar conditions observed in 1990, although diversity was not so low.
Bellingham Bay (4)	North Puget Sound clay	Relatively high numbers of species and diversity; community not dominated by any species.	Same as 1989-1993 baseline, except polychaete *Aricidea lopezi* now among the most abundant species.
North Hood Canal (13)	Sand	High abundance, moderate species numbers very low diversity. Dominated by the bivalve *Psephidia lordi.*	Large increase in abundance; small increase in number of species. *Phoronida* more abundant.
Port Gardner (21)	Mixed sand-silt-clay	Relatively high numbers of species and diversity; community not dominated by any species though most abundant species is an opportunistic bivalve.	Same as 1989-1993 baseline.
Shilshole (29)	Deep clay	Large cycles in abundance and species dominance. Dominated by the bivalve *Macoma carlottens*is and the ostracod *Euphilomedes producta.*	Abundance values below levels seen in 1992 and 1993; community appears to be less dominated by the most abundant species.
Point Pully (38)	Deep clay	Abundance is low, but numbers are increasing; community not dominated by any species.	Bivalve *Axinopsida,* which can indicate organic enrichment, now most abundant.
Sinclair Inlet (34)	Clay	High degree of dominance by two polychaetes, *Phyllochaetopterus prolifica* and *Aphelochaeta* sp.	Higher abundance but lower species numbers; no change in dominance.
Commencement Bay (40)	Silty sand or sand	Relatively high number of species and diversity; community not dominated by any species.	Higher abundance but no change in dominance. Community indicates improving conditions: *Aphelochaeta* disappeared, *Amphioda* now among most abundant species.
E. Anderson Island (44)	Sand	Relatively high numbers of species and diversity; community not dominated by any species.	Same as 1989-1993 baseline. Some shift in most abundant species, possibly resulting from the very evenly distributed community.
Inner Budd Inlet (49)	South Puget Sound inlet end, mud	Low abundance, number of species and diversity; in 1993, abundance spiked and the diversity was unusually low.	Community may be structured by episodes of low dissolved oxygen. Abundance and diversity returned to pre-1993 levels.

Source: Roberto Llansó, unpublished analysis of Department of Ecology data.

The combined herring run size for all stocks in Puget Sound was 15,300 tons in 1999. This was the largest total weight measured since 1995. The increase occurred mainly in south and central Puget Sound. Though the total Puget Sound estimate for 1999 was a substantial increase from 1998 numbers, it was still considerably lower than the 1980 peak estimate for herring run size of 22,200 tons. Further, overall status for all Puget Sound stocks was depressed in 1999. Department of Fish and Wildlife classified the 18 known stocks of herring in Puget Sound in 1999 as follows: seven stocks in healthy condition, three in moderately healthy condition, five depressed, two critical and one in unknown condition. The number of stocks in the depressed and critical categories more than tripled between 1994 and 1998.

Historically the largest of the 18 known herring stocks in Puget Sound, the Cherry Point stock of Pacific herring has declined a dramatic 91 percent over the last 25 years. This decline, coupled with a proposed pier extension at ARCO oil refinery facilities at Cherry Point led the Washington Department of Natural Resources to commission an ecological risk assessment of the project. This assessment revealed some interesting findings about the decline of the Cherry Point herring:

- Increasing mortality in the adult age classes accounts for much of the overall decline in the biomass of the stock.
- Because harvest pressures have declined over time, adult mortality must be due to other factors. Possibilities include increased predation and a variety of stressors linked to changing oceanographic conditions.
- The number of two and three year old spawners does not appear to have declined, further supporting the idea that the overall decline in the stock results from mortality in the older, rather than the younger, age classes.
- There is evidence that in contrast to the other Puget Sound stocks that appear to be resident, the Cherry Point stock is a migratory population that spends its summers and winters off the coast of Vancouver Island, making it subject to local conditions there as well.

The study concluded that local stressors do not seem to be the primary cause for the decline in the Cherry Point herring stock. Further, the study's review of individual stressors at Cherry Point found that their contribution to the decline in the stock would likely be negligible to low. The potential cumulative effect of stressors was difficult to assess due to a lack of available data.

Although the ecological risk assessment did not find habitat loss and toxicity to be among the primary causes of the historic decline in the abundance of Cherry Point herring, these factors have been identified as important to preventing further stock declines and to facilitating stock recovery. Agencies are now completing additional studies of potential stressors on herring in the Cherry Point area. Habitat loss due to development is a concern because the proposed pier extension affects one of the few remaining stretches of habitat that is currently being used by herring for spawning. Exposure to contaminants is also being evaluated because environmental contaminants from nearby industrial activities may affect critical life stages and impair the reproductive success of the Cherry Point stock.

Sand Lance and Surf Smelt. Sand lance and surf smelt are a significant part of the forage base for seabirds, marine mammals and a variety of fish in Puget Sound, including salmon. However, despite the critical role these forage fish play in the Puget Sound ecosystem, data are insufficient to support assessments of the status of these fish or to determine if stocks have been growing or declining in recent years.

Information regarding the biology and life history of both sand lance and surf smelt stocks within Washington is limited. Data collection has focused on the identification and documentation of spawning habitat, which occurs within the upper intertidal zone and is very susceptible to degradation from development. Department of Fish and Wildlife scientists have surveyed 75 percent of Puget Sound beaches for the two species, recording 135 miles of sand lance spawning habitat and 205 miles of surf smelt spawning habitat (Bargmann, personal communication). The spawning grounds for both species appear to be widely distributed throughout the shorelines of Puget Sound.

In 1998, in response to the important role of sand lance as forage and the lack of information on their abundance, the Washington Fish and Wildlife Commission ended all commercial fishing for the species. They also cut the daily limit for sport fishing of sand lance. Though the commercial fishery for surf smelt continues, the Fish and Wildlife Commission has reduced the sport fishing limit on this species. The Fish and Wildlife Commission took these actions in order to preserve the forage role of sand lance and surf smelt in the marine waters of Washington State.

Bottomfish. Bottomfish are marine fish species that live near or on the bottom of marine waters for most of their adult lives. Puget Sound once supported thriving commercial and recreational fisheries for bottomfish. However, many of these fish populations have recently declined to alarming levels. Some of these species have declined so much that the National Marine Fisheries Service received a petition asking that 17 species of Puget Sound bottomfish (in addition to Pacific herring) be considered as threatened or endangered under the federal Endangered Species Act. In June of 1999, the agency concluded that there was sufficient evidence to conduct a status review of six of the 17 bottomfish species included in the petition: Pacific cod, walleye pollock, Pacific whiting, copper, quillback and brown rockfishes. The National Marine Fisheries Service concluded that information was insufficient to support a status review for the other 11 species, all of which were rockfish.

The *1998 Puget Sound Update* included a summary of the findings of the Department of Fish and Wildlife's "1995 Status of Puget Sound Bottomfish Stocks" (revised as Palsson et al., 1997), which described the status and trends of 18 species or species groups of bottomfish. In their assessment of conditions in 1995, Fish and Wildlife scientists reported that the majority of bottomfish stocks were in below average or worse condition and that Pacific cod, walleye pollock and Pacific whiting were in critical condition.

Department of Fish and Wildlife scientists are currently updating their evaluation of the status of bottomfish in Puget Sound. Their assessment so far finds that the majority of bottomfish stocks are still in poor condition; accordingly, their status is below average, depressed or critical (Table 16, page 88). As with the 1995 assessments, most of the ongoing evaluation is based on information supplied by recreational or commercial fishers. The success of fishers over time provides an indication of the relative population strength for many bottomfish species. Assessments are conducted separately for fish in the northern part of Puget Sound (the straits of Juan de Fuca and Georgia and the San Juan Archipelago) and those in the southern part of the Sound (all of Puget Sound proper, the Whidbey basin and Hood Canal). At the time this document was prepared, scientists had only enough information to assess the status of 21 of the 39 species-stock combinations. The status of the remaining stocks was unknown. Eleven of the 21 stocks for which sufficient information was available (52 percent) were in poor condition. Seven of these stocks were identified as depressed and four were in critical condition. Three of the four stocks in critical condition were from the southern part of the region. Nine stocks, mostly in the northern area, were in average or above average condition. Scientists had the least information about stocks from south Puget Sound, where the status of 12 stocks is unknown.

Reasons for declines in bottomfish stocks

There is no single reason to explain the decline that has been observed in key bottomfish species in Puget Sound. A variety of potential stressors have been identified as likely contributors to depressed bottomfish species, including fishing, marine mammal predation, changes in regional climate and possibly toxic contamination, hatchery practices and nearshore land-use practices (West, 1997). For Pacific cod and walleye pollock, warm oceanic conditions most likely caused a natural decline in these cold water species. As with other species, additional stressors may have acted to further hasten their declines. In the case of cod and pollock, marine mammal predation and relatively intense fishing likely furthered the population decline. For Pacific whiting, the population was subjected to heavy fishing for a number of years before fishing was ended. However, the population continued to decline after the fishing ban as predation by sea lions appears to have intensified. For nearshore rockfish species, fishing appears to be the primary factor controlling population numbers and the sizes of individual fish (Palsson and Pacunksi, 1995).

Table 16. 1998 status of Puget Sound bottomfish stocks.

Species	North Sound	South Sound
Spiny dogfish	Depressed	Average
Skates	Above Average	Unknown
Spotted ratfish	Unknown	Unknown
Pacific cod	Depressed	Critical
Walleye pollock	Critical	Critical
Pacific whiting	Depressed	Critical
Rockfishes	Depressed	Depressed
Lingcod	Depressed	Above Average
Sablefish	Above Average	Unknown
Greenlings	Unknown	Unknown
Sculpins	Unknown	Unknown
Wolf-eel	Unknown	Unknown
Surfperches	Unknown	Average
English sole	Above Average	Unknown
Rock sole	Depressed	Unknown
Starry flounder	Above Average	Unknown
Dover sole	Above Average	Unknown
Sand sole	Above Average	Unknown
Pacific halibut	Above Average	Above Average
Other groundfish	Unknown	Unknown

Source: Washington Department of Fish and Wildlife (in preparation).

Several assessments have changed since 1995. Dover sole in the northern part of the Sound and surfperch in the southern part of the region have been upgraded from depressed or critical condition in the 1995 assessment to average or above average condition in the new assessment (Table 16). Spiny dogfish populations in the northern part of the region have shifted from average to depressed status since the 1995 assessment. The assessment for Pacific halibut in Puget Sound (part of the southern management region of the International Pacific Halibut Commission) changed from below average to above average.

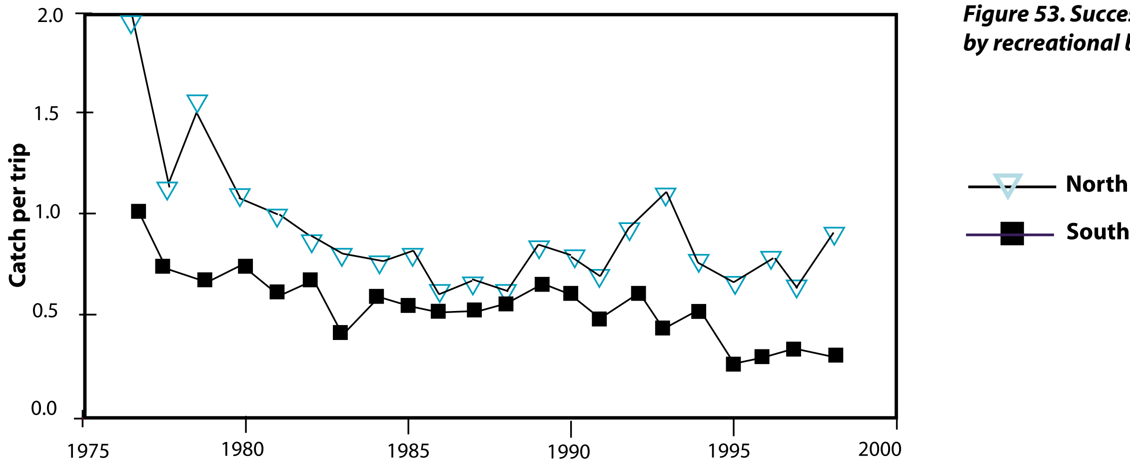
Rockfish assessments have been expanded to incorporate information on changes in size and estimated reproductive output for the most prevalent species. In both north and south Puget Sound, rockfish populations are now characterized as depressed. Rockfish stocks that were previously listed as average or below average have been downgraded to depressed based on a long-term decline in the success of rockfish catch by recreational fishers targeting bottomfish (see Figure 53) and by a decline in the proportion of large copper rockfish, a commonly harvested species, in the recreational catch (see Figure 54). Fish size is important because smaller fish are not able to produce as many eggs as larger fish. The smaller number of fish, which is indicated by the decline of the rockfish catch, and the smaller number of eggs per fish, which is indicated by the reduced size of individual fish, have combined to substantially reduce the estimated spawning potential of copper rockfish. Across the region, spawning potential has declined approximately 75 percent since the historic peak levels observed during the 1970s. Many management authorities consider declines of more than 60 percent of the natural spawning potential as a sign of a population under stress.

Fish and Wildlife's current assessment lists more stocks as unknown than did their 1995 assessment. This has happened primarily because the recreational fisheries are not providing sufficient data about some of the more uncommon species. Additional surveys and other sources of information will be needed to provide a means to evaluate the status of some of these poorly understood stocks.

Survey of fish species on the Washington/British Columbia border

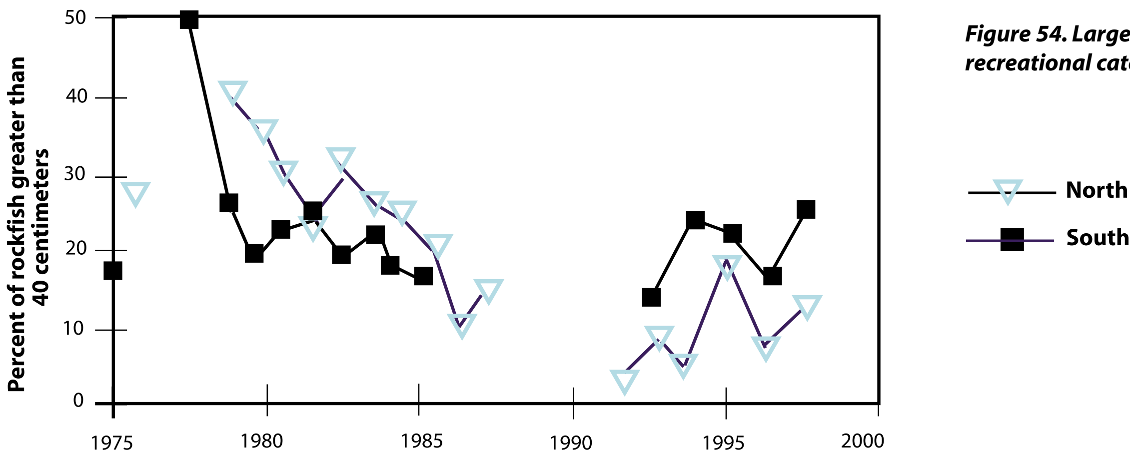
In 1997, Department of Fish and Wildlife scientists conducted a trawl survey in the transboundary waters of Washington and British Columbia in the southern Strait of Georgia. The survey had four broad goals: to estimate the abundance of key benthic (bottom-dwelling) fish species; to identify population trends; to quantify the impact of fisheries on fish stocks; and to determine the distribution of key commercial fishes that likely move across the international boundary. The study revealed several findings:

- British Columbia has a greater number of fish species and individuals in the area sampled, which reflects the distribution of habitat between the province and Washington State. The spotted ratfish is dominant in both regions.
- Key shallow-water fish species are restricted by the deep waters of the central basin and are less likely to make transboundary movements. This forces Washington and British Columbia to fish particular stocks in their own waters. The deepwater species, on the other hand, are more likely to move across the international border. This subjects them to both Washington's and British Columbia's fisheries.
- Washington fisheries have a greater impact overall on fish stocks in the Strait of Georgia than do British Columbia fisheries. Washington fisheries harvest a greater proportion of the stock of key commercial species. Further, Washington fisheries appear to be benefiting from the transboundary movements of deepwater species, especially spiny dogfish. For the shallow-water species, both British Columbia and Washington fisheries may be significantly impacting localized stocks.



Source: Department of Fish and Wildlife.

Figure 53. Success of rockfish catch by recreational bottomfish fishers.



Source: Department of Fish and Wildlife.

Figure 54. Large copper rockfish in recreational catch.

Coho Smolt Production and Marine Survival. Since the 1970s, the Department of Fish and Wildlife has measured wild coho smolt production from a number of Puget Sound watersheds. Results of this long-term monitoring project explain inter-annual variation in production. A number of factors, such as flow conditions during critical periods throughout the year, spawner escapement, habitat damage and interactions with other species, affect smolt production. Variations in coho smolt production for three Puget Sound rivers are summarized in Table 17. Over the years measured, coho smolt production in Big Beef Creek, a small stream on Hood Canal, varied by a factor of four and smolt production in the Skagit River varied by a factor of three. Coho smolt production in the Deschutes River (the southernmost tributary to Puget Sound) varied by a factor of more than 20.

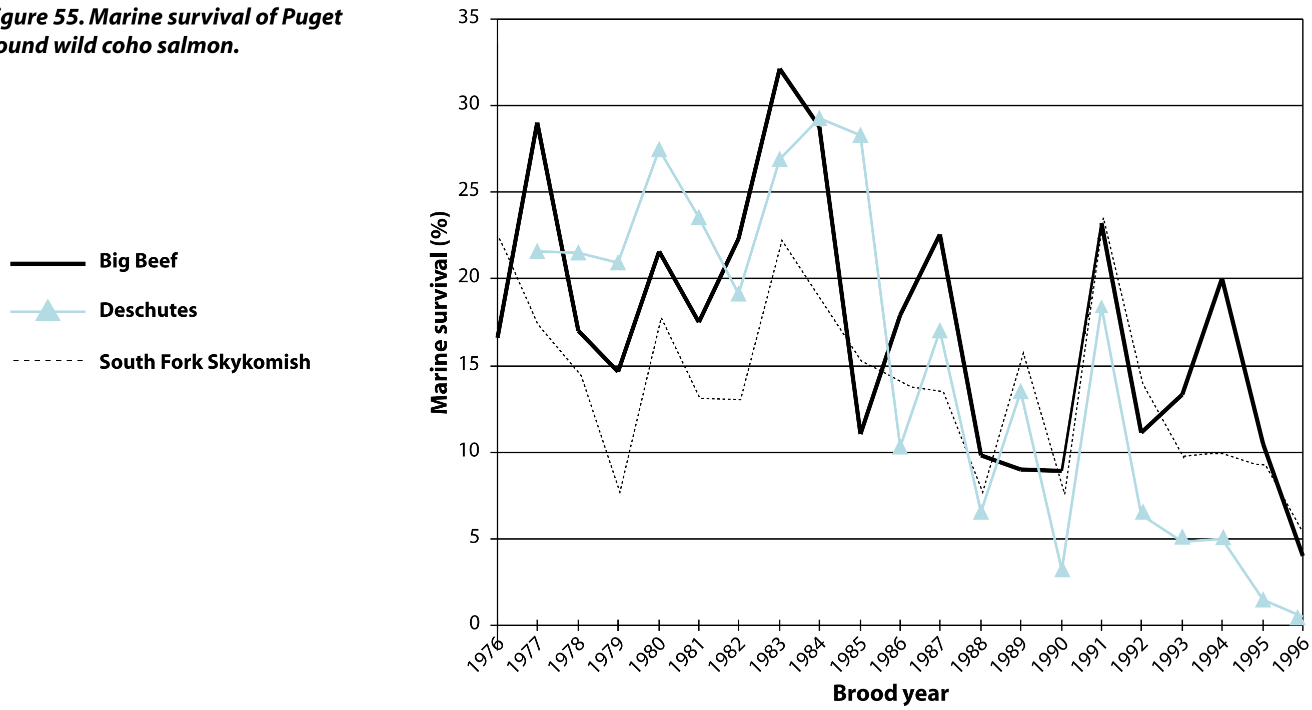
The Deschutes River system once produced an average of 70,000 wild coho smolts. As recently as 1990, the river produced as many as 133,000 smolts. More recently, however, production in the Deschutes River has declined to less than 10,000 wild coho smolts. Habitat damage in the upper watershed, small body-size of returning adults, high flows during egg incubation and most importantly, extremely low marine survival throughout most of the 1990s, appear to be responsible for this decline. Department of Fish and Wildlife scientists measured marine survival rates for wild coho stocks at several stations in Puget Sound beginning as early as 1979. For more than 12 brood years from 1976 through 1987, wild coho smolts survived to become

Table 17. Puget Sound coho smolt production.

Stream (period of record)	Low Production	High Production	Average Production	1998 Production
Big Beef Creek (21 years)	11,500	45,634	24,614	22,000
Deschutes River (19 years)	6,000	133,198	66,000	6,000
Skagit River (9 years)	617,600	1,760,000	1,002,000	1,760,000

Source: Department of Fish and Wildlife.

Figure 55. Marine survival of Puget Sound wild coho salmon.



Source: Department of Fish and Wildlife.

adults at rates that averaged in excess of 20 percent. Marine survival declined in the early 1990s; over the eight broods from 1988 through 1995 (adults returning in 1991 through 1998, respectively), marine survival declined to an average of around 10 percent (Figure 55).

In recent years, coho stocks entering the south Puget Sound have experienced the lowest survival rates ever measured. Marine survival of Deschutes River wild coho, which enter Budd Inlet at Olympia, has declined more than any of the other stocks measured. Hatchery coho in the south Sound have also experienced extremely poor survival in recent years. For example, two million smolts released from Squaxin Island net pens in 1998 returned at just a fraction of one percent in 1999. The low survival rate affecting south Sound stocks appears to be occurring inside Puget Sound rather than in the ocean, based on survival trends for the other production areas.

Marine Birds and Waterfowl

Department of Fish and Wildlife scientists conducted PSAMP aerial surveys for marine birds from 1992 to 1999. These surveys covered 13 to 15 percent of Puget Sound's nearshore habitat (waters less than 20 meters deep) and three to five percent

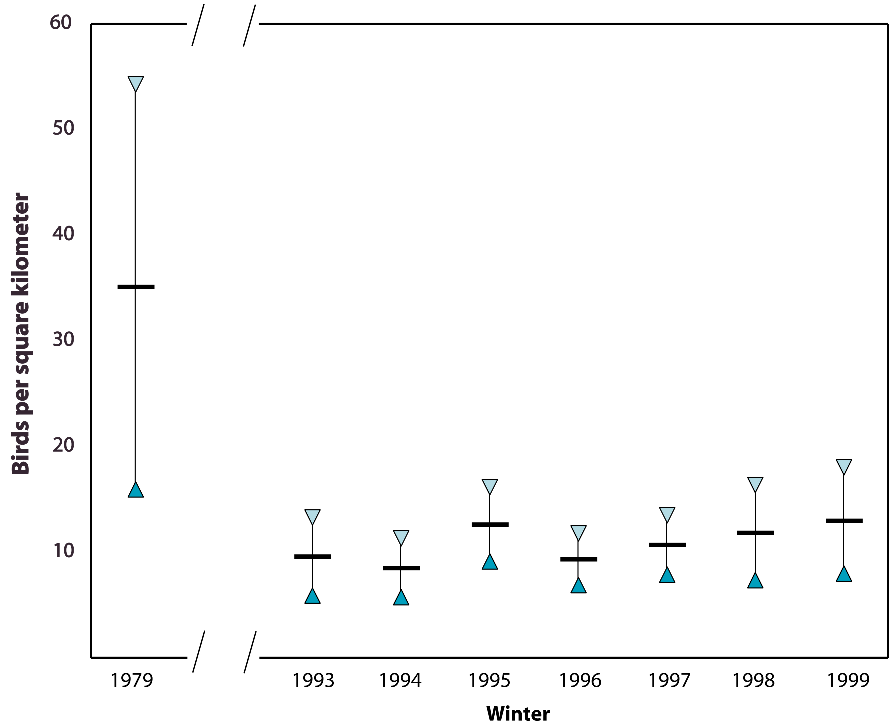


Figure 56. Scoter density indices—northern study area.

95% upper confidence limit
95% lower confidence limit
Mean

Data for 1993 to 1999 from Fish and Wildlife monitoring of Puget Sound marine birds in winter. Data for 1979 from Puget Sound Marine Ecosystem Analysis (MESA).

of the Sound's offshore habitat (waters more than 20 meters deep) annually. The surveys were designed for monitoring the abundance and distribution of medium to large diving marine birds or waterfowl that use greater Puget Sound for some key portion of either the summer (July) or the winter (December-February). As a result of the surveys, habitat and geographic usage patterns have been well-documented for a variety of species. The surveys also provided information on changes and trends in abundance over time. This *Update* presents survey results through winter 1999 for scoters (primarily surf and white-winged scoters) and western grebes. These two species groups were selected for reporting because survey results for these birds, more than most other species, indicated that densities observed in the 1990s were lower than those observed in the late 1970s. Results from an intensive boat-based survey of pigeon guillemots in 1999 are also provided. In addition, the status and trends in the numbers of American widgeons and Harlequin ducks are discussed based on studies conducted outside of the PSAMP.

Scoters. Fish and Wildlife scientists have previously presented data that showed that wintering scoter numbers in greater Puget Sound have declined by between 40 and 70 percent over the last 20 years (Nysewander and Evenson, 1998). Figure 56 presents scoter densities observed in various years for the Strait of Juan de Fuca, the San Juan Islands and the marine waters north to British Columbia. During the PSAMP monitoring effort from 1992 to 1999, which focused on all of the inland marine waters of Washington, scoter densities were either relatively stable or decreasing slowly. Year-to-year variations in density were consistent in the north and south portions of the survey area except during winter 1996-97 (Figure 57, page 92). That winter, the scoter density decreased in the southern part of the survey area but increased in the northern part. Results from the next two winters were consistent with the 1996-97 findings, indicating a slight shift in scoter densities from south to north compared to earlier years. Even after this increase in scoter densities in the north, the southern portion of the survey area (which includes south and central Puget Sound) contained both higher densities and higher overall numbers of scoters than those areas supporting scoters in the north.

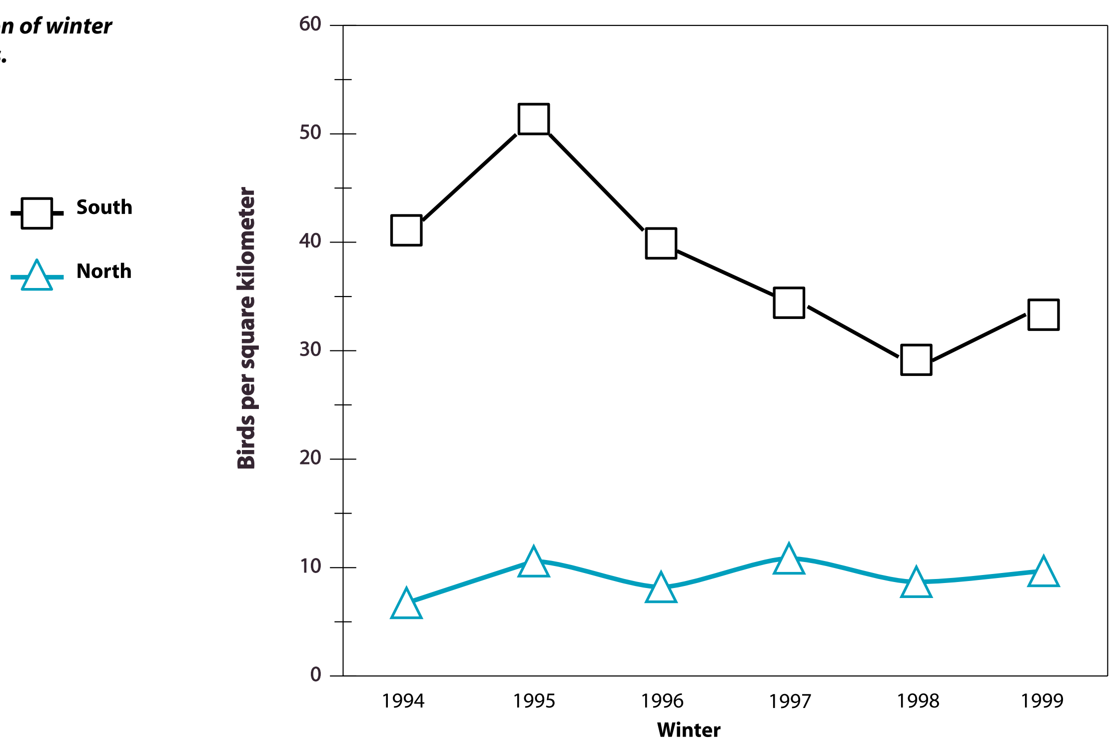
Because changes in annual density indices can vary by degree and direction in any one year between different portions of Puget Sound, it is useful to revisit whether scoters are moving to some other portion of their wintering range rather than disappearing. Nysewander and Evenson (1998) reviewed conditions at all other wintering areas on the west coast from which data were available and observed that all had declining numbers of scoters over the last 20 years. The data did not suggest that disappearing scoters were moving from one wintering area to another. However, British Columbia marine waters are not monitored in the winter for sea ducks. It is possible that scoter densities may have increased in British Columbia while they have decreased elsewhere.

Western Grebes. Western grebe populations appear to have declined even more over the last 20 years than scoter populations. Wahl et al. (1981) reported that 38,000 western grebes were present in greater Bellingham Bay in 1978-79. PSAMP aerial surveys have never recorded more than 5,700 birds in that area between 1993 and 1999.

Estimates of western grebe numbers in Puget Sound are imprecise because the clumped distribution of these birds introduces considerable uncertainty in numbers derived from any given survey. Note, for example, the large variability seen in the winter of 1996-97 (see Figure 58). Nevertheless, survey data shown in Figure 58 suggest that western grebe populations have declined at least 50 percent or more over the last 20 years. Figure 59 shows that the southern portion of the survey area (south and central Puget Sound) had both higher densities and higher overall numbers of western grebes than the areas to the north in recent years. As with scoters, the lack of winter monitoring in the more protected marine waters of British Columbia limits the ability of scientists to evaluate possible movement of grebes over the years and to estimate the overall size of the wintering population in the region's marine waters.

Pigeon Guillemots. Pigeon guillemots are numerous, well-distributed, year-round residents of Washington's inland marine waters. Two sets of historical data exist regarding pigeon guillemots in Puget Sound: 1) northern Puget Sound summer aerial surveys taken during the winter of 1978-79, and 2) June and July colony counts

Figure 57. Comparison of winter scoter density indices.



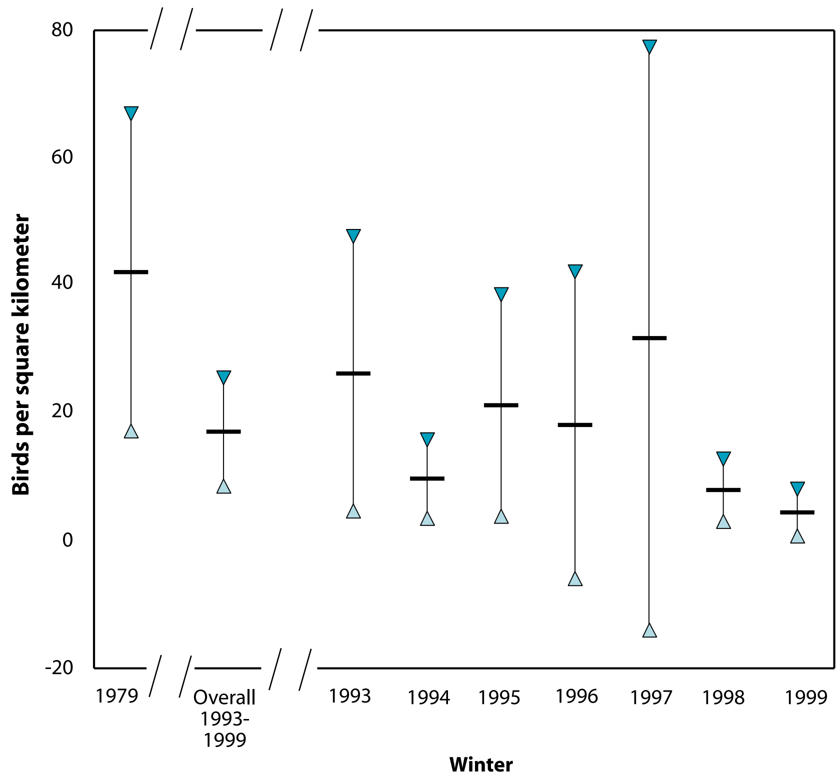


Figure 58. Western grebe density indices—northern Puget Sound study area, winter.

95% upper confidence limit
95% lower confidence limit
Mean

Data from 1993 to 1999 from Fish and Wildlife monitoring of Puget Sound marine birds in winter. Data for 1979 from Puget Sound Marine Ecosystem Analysis (MESA).

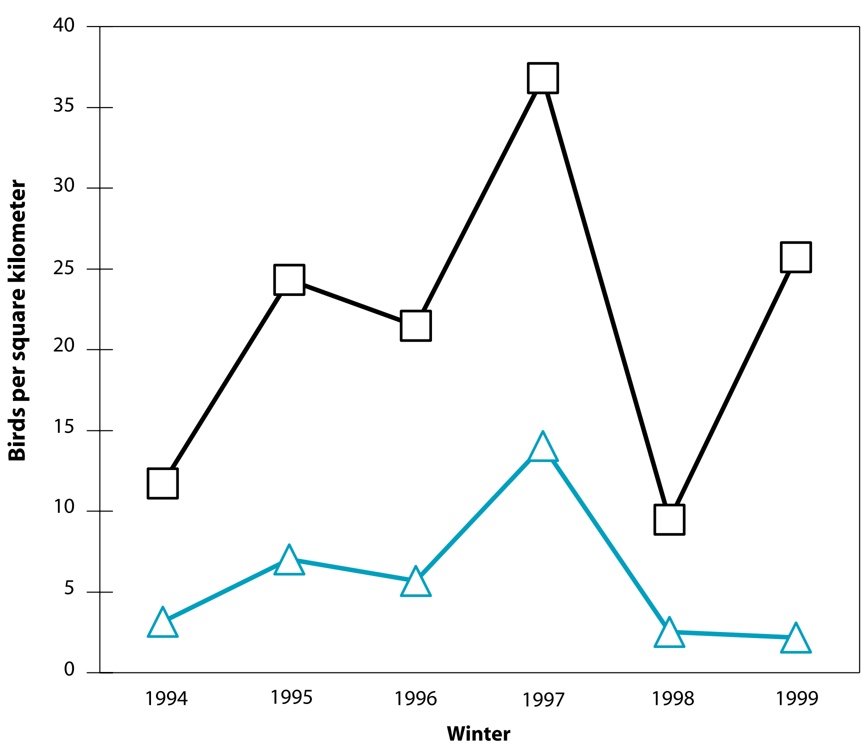
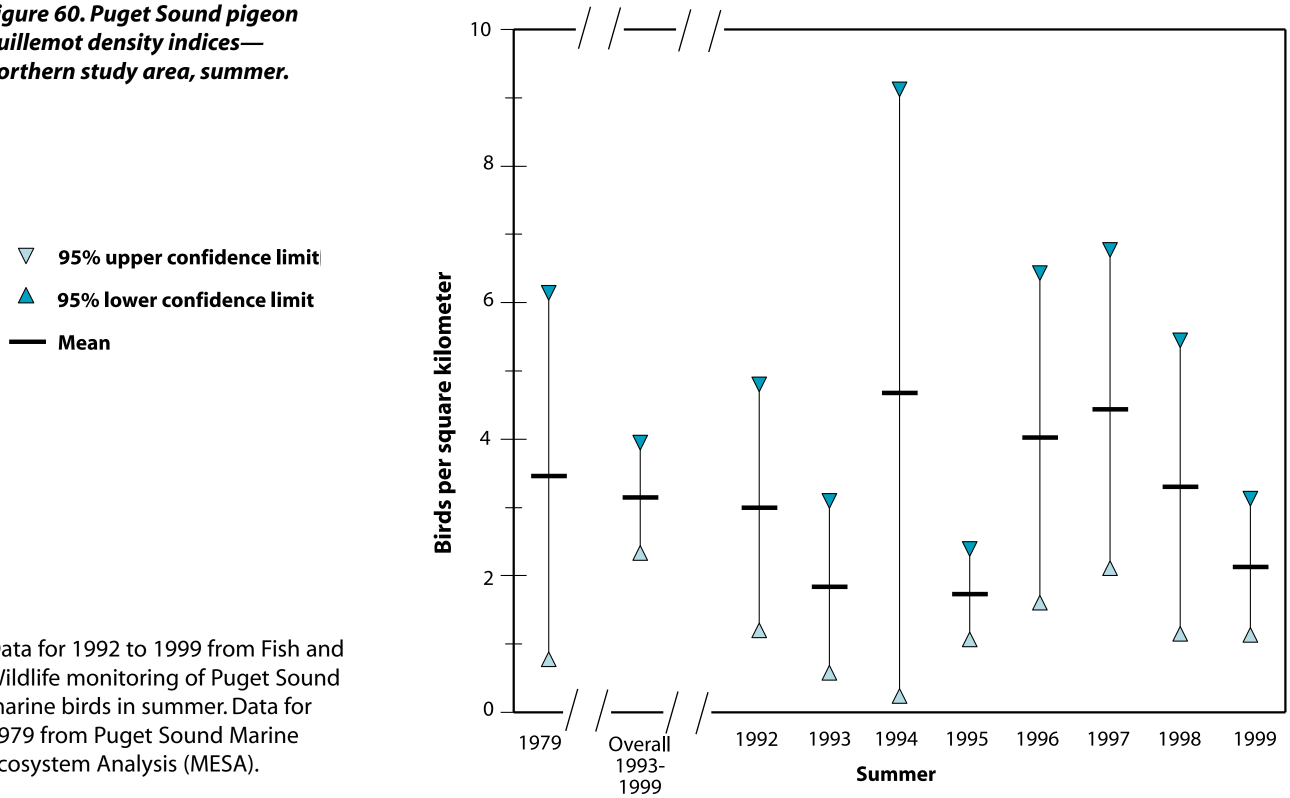


Figure 59. Comparison of western grebe density indices.

South
North

Data from Fish and Wildlife monitoring of Puget Sound marine birds.

Figure 60. Puget Sound pigeon guillemot density indices—northern study area, summer.



Data for 1992 to 1999 from Fish and Wildlife monitoring of Puget Sound marine birds in summer. Data for 1979 from Puget Sound Marine Ecosystem Analysis (MESA).

conducted prior to 1983 (Speich and Wahl, 1989). More recently, Fish and Wildlife scientists monitored pigeon guillemots in Puget Sound during the PSAMP summer aerial surveys from 1992 to 1999. It is difficult to compare guillemot densities derived from the PSAMP surveys with estimates from the 1978-79 northern Puget Sound surveys because of the large uncertainty associated with each density estimate (see Figure 60).

To obtain a clearer picture of the pigeon guillemot population in Puget Sound, a breeding colony census was coordinated by PSAMP program staff working at the Washington Department of Fish and Wildlife and staff from the U.S. Fish and Wildlife Service's western Washington office in May and June 1999. The participants in the surveys included staff from these coordinating groups, staff from the National Wildlife Refuges and the Whale Museum, and regional staff from state Fish and Wildlife. The 1999 pigeon guillemot colony census resulted in counts of guillemots at 367 colonies within Puget Sound, 120 of which were previously catalogued colonies and 247 of which were identified in the 1999 search effort but had not been previously catalogued (see Table 18). A total of 10,600 breeding pigeon guillemots were counted in 1999 from all colonies. Table 18 shows that the biggest gaps in the historical data were in the southern half of Puget Sound, where the 1999 census counted four times as many breeding birds as were counted in the previous listing.

The 1999 colony census data, based on early morning counts, are not directly comparable to the historical data from 1978 to 1982, which were based on counts conducted at various times throughout the day. One would expect that the difference in methodology would result in higher counts in 1999 (because more birds are typically present at their colonies in early morning). Comparisons of counts at 58 colonies surveyed from 1978 through 1982 and again in 1999 showed relatively small differences. Eleven percent more birds were counted at 45 colonies in the northern half of Puget Sound. Two percent more birds were counted at 13 colonies in the southern half of Puget Sound. These results suggest that numbers of pigeon

	Colonies Previously Listed		Colonies Not Previously Listed		All Colonies	
Region	Number of Colonies	Count of Guillemots	Number of Colonies	Count of Guillemots	Number of Colonies	Count of Guillemots
North >Lat 48°N	91	6,262	121	2,429	212	8,691
South <Lat 48°N	29	478	126	1,464	155	1,942
Total	**120**	**6,740**	**247**	**3,893**	**367**	**10,633**

Table 18. Pigeon Guillemot colony counts from the inland marine waters of Washington State.

Counts at colonies previously listed in the *Catalog of Washington Seabird Colonies* were conducted during May 1999. Counts at colonies not previously listed in the catalog were conducted during May and June 1999.

guillemots have not declined as have scoters and western grebes. However, future surveys using the standardized methodology implemented in 1999 will be needed to better evaluate trends in pigeon guillemot numbers in Puget Sound.

American Widgeons at the Nisqually National Wildlife Refuge. The Nisqually Delta, located at the southern end of Puget Sound, is a major non-coastal resting and feeding area for migrating waterfowl and shorebirds within the Pacific flyway. Nisqually National Wildlife Refuge (U.S. Fish and Wildlife Service) staff have conducted fall and winter aerial surveys (October through March) over the Nisqually Delta to monitor waterfowl populations since 1975.

Dabbling ducks accounted for more than 90 percent of all waterfowl sightings in these surveys. American widgeon, the most abundant dabbling duck species observed on the refuge, made up 71 percent of all dabbling ducks sighted. The American widgeon spends more time in marine waters than other dabbling ducks; American widgeons that winter locally spend an average of eight months of the year in Puget Sound. Approximately 20,000 widgeons were observed on two occasions (October 1979 and November 1982). All other counts from 1975 to 1998 were below 15,000. Between 1995 and 1998, peak numbers of widgeons ranged from only 870 to 9,110, representing a drop of 55 percent or more since the peak observed in 1982. (The lowest count, 870 birds, occurred in 1997, when only one survey was conducted for the entire season. A peak count very well may have been missed for that year.)

Figure 61 presents annual peak observations and suggests a downward trend in widgeon numbers at the Nisqually Delta. However, there is high variability in peak counts, the trend is not statistically significant. Nonetheless, the dramatic decline in the number of widgeons observed to be using the Nisqually Delta over the last five

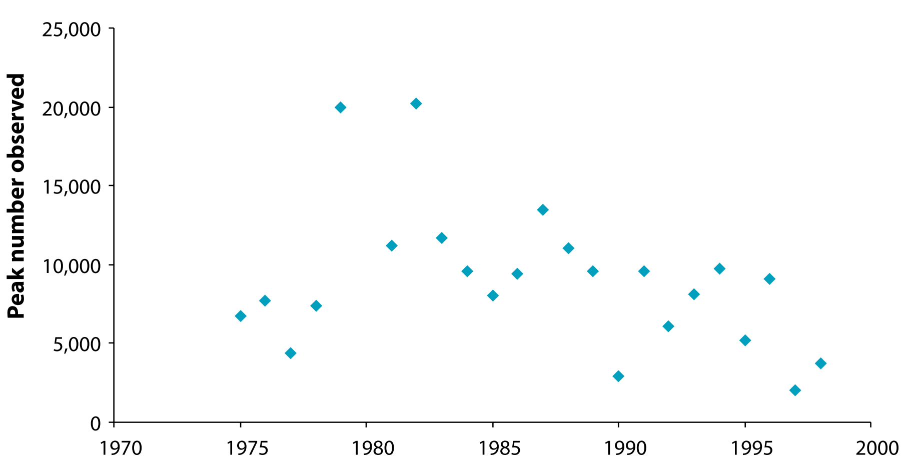
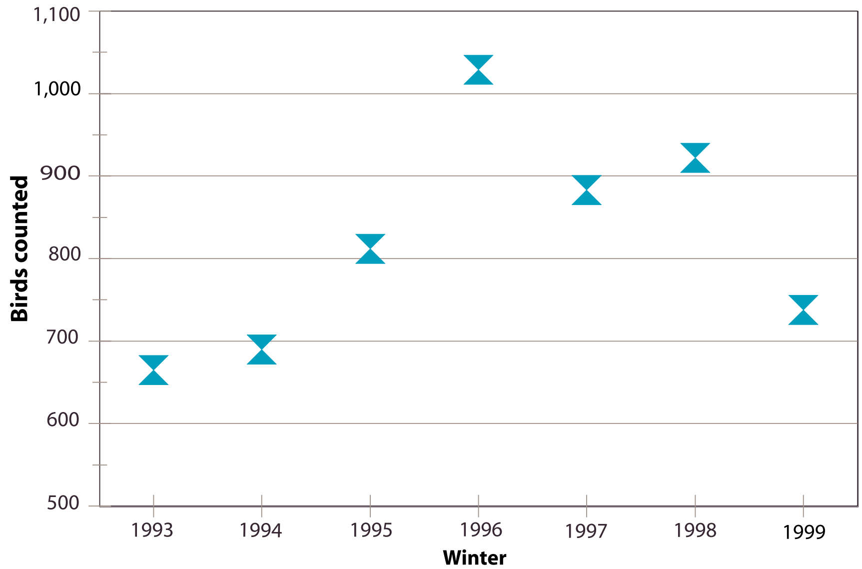


Figure 61. Annual peak American widgeon counts, Nisqually Delta. 1975-1998.

Source: Nisqually National Wildlife Refuge, U.S. Fish and Wildlife Service.

Figure 62. Harlequin duck trends for Puget Sound, PSAMP winter surveys.



years warrants further investigation. In addition, waterfowl surveys conducted throughout Puget Sound might be evaluated to investigate trends in American widgeon numbers elsewhere in the Sound.

Harlequin Ducks. Department of Fish and Wildlife biologists have worked with scientists from other states and provinces to gain a better understanding of the ecology and status of harlequin ducks. Harlequin ducks nest along fast moving mountain streams throughout the mountainous West. They return to the saltwater to molt, select a mate and forage for the winter. They concentrate primarily in exposed rock, cobble and kelp habitats throughout the Strait of Juan de Fuca and the Georgia Basin. Department of Fish and Wildlife winter aerial surveys were conducted throughout Puget Sound and the outer coast from 1991 to 1997 to track population trends. Analysis of data from selected areas within these surveys suggest that Washington's harlequin duck population increased from 1991 to 1997. Total counts of harlequin ducks from the 1993 to 1999 PSAMP winter aerial surveys in greater Puget Sound show this increase, but also show subsequent decreases in numbers from 1996 to 1999 (Figure 62). This Sound-wide decrease was largely attributable to decreases in harlequin numbers at Protection Island, which recently lost the considerable kelp beds that were present there earlier in the decade (see page 82).

With the help of volunteers who observed marked harlequins (see sidebar), Department of Fish and Wildlife biologists estimated the overall peak population in Washington waters during the late summer to fall of 1997 at 2,384 +/- 282 ducks. The survival and recruitment rates for males were calculated at 0.78 and 0.39, respectively. These numbers suggest a stable population of harlequin ducks wintering in the marine waters of Washington State.

Although the Washington State population of harlequin ducks appears to be stable, it is relatively small. Because most of the harlequin molting areas in Washington are in the straits near tanker routes, this relatively small population is vulnerable to oil spill impacts and should be carefully monitored.

Harlequin ducks that winter in Puget Sound

Department of Fish and Wildlife studies of harlequin ducks have focused on five major molting sites in Puget Sound where the birds replace their worn flight feathers. During August and September, when the birds return to Puget Sound, they undergo a molt and are flightless for a period of time. Department of Fish and Wildlife scientists have captured and marked 805 harlequin ducks at the molting sites to study their movements to breeding grounds and to examine population demographics. The marked birds have been observed on nesting streams in Jasper, Banff and Grand Teton national parks, in northern Idaho and as far away as Hudson Bay. There appears to be little or no interchange with the large Alaskan population of harlequin ducks. Washington breeding harlequins have been observed wintering in the Strait of Georgia at Hornby Island.

Hood Canal Bald Eagles

The Department of Fish and Wildlife and the U.S. Fish and Wildlife Service continue to evaluate the status of bald eagles on Hood Canal, as reported in the *1998 Puget Sound Update.* It has been proposed that bald eagles be taken off the federal

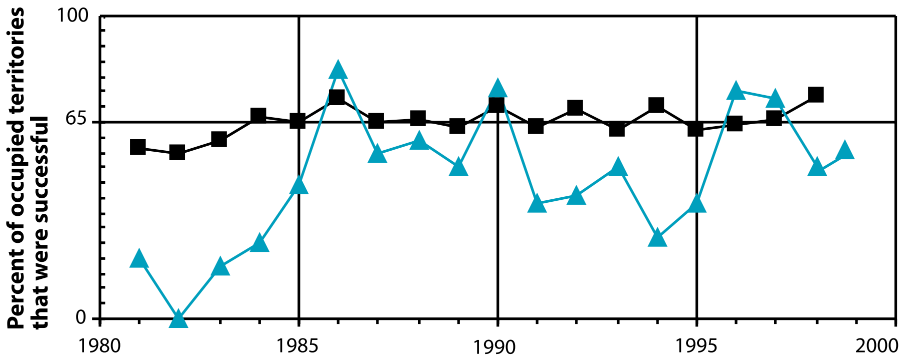


Figure 63. Nesting success of bald eagles in Hood Canal and statewide.

Source: Department of Fish and Wildlife.

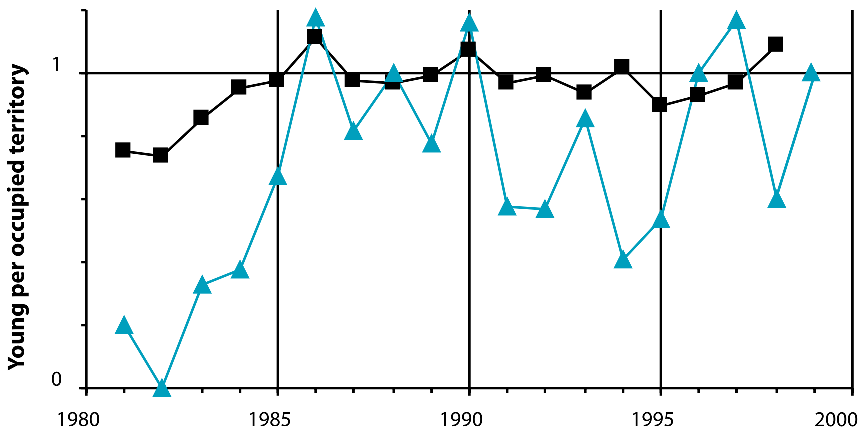


Figure 64. Young bald eagles per nest in Hood Canal and statewide.

Source: Department of Fish and Wildlife.

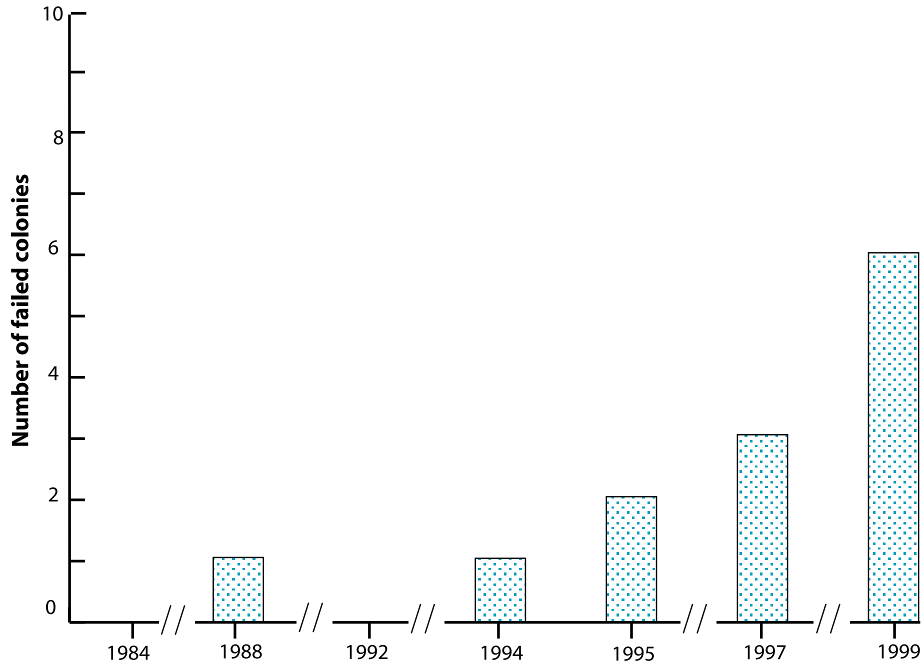
Endangered Species List. However, until the proposal is finalized, the bald eagle retains its federal status as a threatened species in Washington State. The Hood Canal population of bald eagles has at times exhibited very low productivity.

The Pacific State Bald Eagle Recovery Plan recommends that there be a five-year average of 1.0 fledgling per occupied nest and an average nesting success of 65 percent for the species to be removed from the Endangered Species List. Hood Canal eagles showed short-term positive trends and met both of these criteria in 1996 and 1997—better than bald eagles statewide. However, Figures 63 and 64 show that in 1998 neither of the criteria were met and, in 1999, only one of the criteria was met. Further, 1998 statewide bald eagle population and productivity numbers were better than Hood Canal numbers for the first time since 1995. The statewide data are not yet complete for 1999.

It is difficult to explain the variable success of Hood Canal bald eagles in recent years. Though toxic contaminants were cited as the primary reason for the decline of bald eagles at the time of listing, more study of contaminants in the Hood Canal food web would be needed in order to document whether contaminants currently threaten eagle production in Hood Canal. Other possible impacts on productivity of Hood Canal bald eagles include adverse weather conditions during critical incubation, human disturbance during the breeding and nesting season, predation of eggs or chicks and inadequate food supply.

Figure 65. Number of 10 major great blue heron colonies on Puget Sound abandoned by year.

No data available for years not shown (1985-1987; 1989-1991; 1993; 1996; 1998)



Source: D. Norman.

Great Blue Heron Colonies

The Audubon Society's Christmas Bird Count and data collected for the U.S. Fish and Wildlife Service show that great blue heron populations in Puget Sound began dramatically increasing in the 1960s. As of 1995, heron populations in the Sound were reported as stable (Norman, 1995). Recent data, however, show a negative trend in population size (Norman, personal communication).

A significant contribution to the recent decline in heron productivity is attributed to disturbance by bald eagles (Norman, personal communication). Eagle incursions into heron colonies have become commonplace, threatening the productivity of all heron colonies in western Washington. When eagles harass incubating herons, the herons temporarily abandon the nest, allowing crows to scavenge the eggs. After several such events, the herons abandon the colony.

In 1999 only a few colonies were spared harassment by eagles. Six of 10 colonies that had been monitored for more than 15 years were abandoned in 1999 (Figure 65). In addition, colonies at Port Orchard and Duckabush were abandoned. This pattern of colony abandonment puts the Washington heron population in an unstable condition.

Other factors that potentially threaten the heron population in Puget Sound include colder than normal winter conditions; exposure to toxic contaminants through food; and development that destroys foraging areas, alternate nesting sites and upland wintering areas.

Great blue herons and contaminated areas

In 1997, U.S. Fish and Wildlife Service scientists conducted a study to better understand the link between great blue heron productivity and foraging in potentially contaminated areas of Commencement Bay. Based on observations in the spring and summer of 1997, a Fish and Wildlife scientist (Krausmann, 1999) concluded that:

- Substantial numbers of herons' forage trips from Dumas Bay and Hylebos Waterway colonies (47 percent and 44 to 71 percent , respectively) were to Commencement Bay sites;
- The Dumas Bay colony failed, most probably the result of continuous harassment by bald eagles from February through May; and
- The Hylebos colony provided no evidence of a correlation between nest failure and selection of foraging locations; very few nests failed and most birds foraged in Commencement Bay.

Marine Mammals

Harbor Seal Populations. Surveys of harbor seal populations in Puget Sound began in 1978 and have continued as part of the PSAMP since 1985. Systematic surveys of Washington's inland marine waters have documented an increasing harbor seal population, with an estimated 16,000 seals present in 1997 (Washington Department of Fish and Wildlife (WDFW) and Northwest Marine Mammal Lab (NMML), unpublished data).

Overall growth of the harbor seal population in Washington's inland waters is estimated at 6.6 percent annually since 1978 (WDFW and NMML, unpublished data). Counts of seals hauled out at selected monitoring sites within Washington's inland waters reflect varying population growth rates (Figure 66, page 100) and indicate an apparent slowing of population growth in some regions. This slowing population growth suggests that the harbor seal population may have reached the limits of what Puget Sound can support.

Food Habits of Harbor Seals in Hood Canal

Fish and Wildlife scientists analyzed the food habits of harbor seals in Hood Canal by collecting and examining fecal samples (scats). Scats were examined for evidence of prey based on the occurrence of hard parts (i.e., otoliths, bones, teeth, squid beaks, etc.). Scats were collected at harbor seal haul-out areas near Quilcene Bay and the Dosewallips, Duckabush, Hamma Hamma and Skokomish rivers from September through November 1998. Based on the frequency of occurrence in scats (Table 19, page 100), Hood Canal harbor seals appear to eat a variety of prey. The most important species in their diet are Pacific hake, Pacific herring and salmon (WDFW, unpublished data).

Orcas (Killer Whales). Until 1995, the population of resident orcas (killer whales) in Puget Sound was increasing. Since 1995, however, this population of orcas, known as the "southern residents" of the inland marine waters of Washington and British Columbia, has decreased from 96 to 84 animals (Balcomb, personal communication). Scientists have recently reported highly elevated levels of PCBs in the whales (Ross et al., in press); some scientists suspect that these compounds may play a role in the observed population decline. A diminished food supply in the form of dwindling salmon populations and stress inflicted by heavy boat traffic are among the other possible contributors to declining orca numbers. As a result of the apparent decline and instability of the southern resident orca population, Washington biologists are preparing a petition to list the southern resident orcas as threatened or endangered under the federal Endangered Species Act.

Canadian biologists at the Pacific Biological Station, Department of Fisheries and Oceans Canada, have been collecting orca data since 1972. In contrast to the southern residents, the northern resident orcas, which live near the northern end of Vancouver Island, appear to be faring well overall. Their total population is approximately 210 individuals. Canadian scientists developed a population model in 1990 that showed that the northern resident population of orcas had been increasing at a steady rate of two to three percent per year. Another version of this model, based on data collected since 1990, is currently under development.

Aquatic Nuisance Species

Exotic species have been introduced to marine waters through shipping, aquaculture and other human activities. While awareness of the threat of exotic species is becoming widespread, current research has focused on tracking and controlling several species of concern, including the cordgrasses, *Spartina* spp., and the green crab, *Carcinus maenus.* These species and their undesirable effects on the ecosystem are comparatively well understood. In contrast, most other non-indigenous (exotic) species in Puget Sound are little recognized and poorly known.

The impacts of an exotic species moving into and becoming established into a new ecosystem are difficult to predict; while the effects of many non-indigenous species can go unnoticed, others can be catastrophic. For example, an introduced Atlantic shipworm bored its way through the entire maritime infrastructure—wharves, piers and ferry slips—causing more than $2 billion in damage in northern San Francisco

Harbor seals in the Pacific Northwest

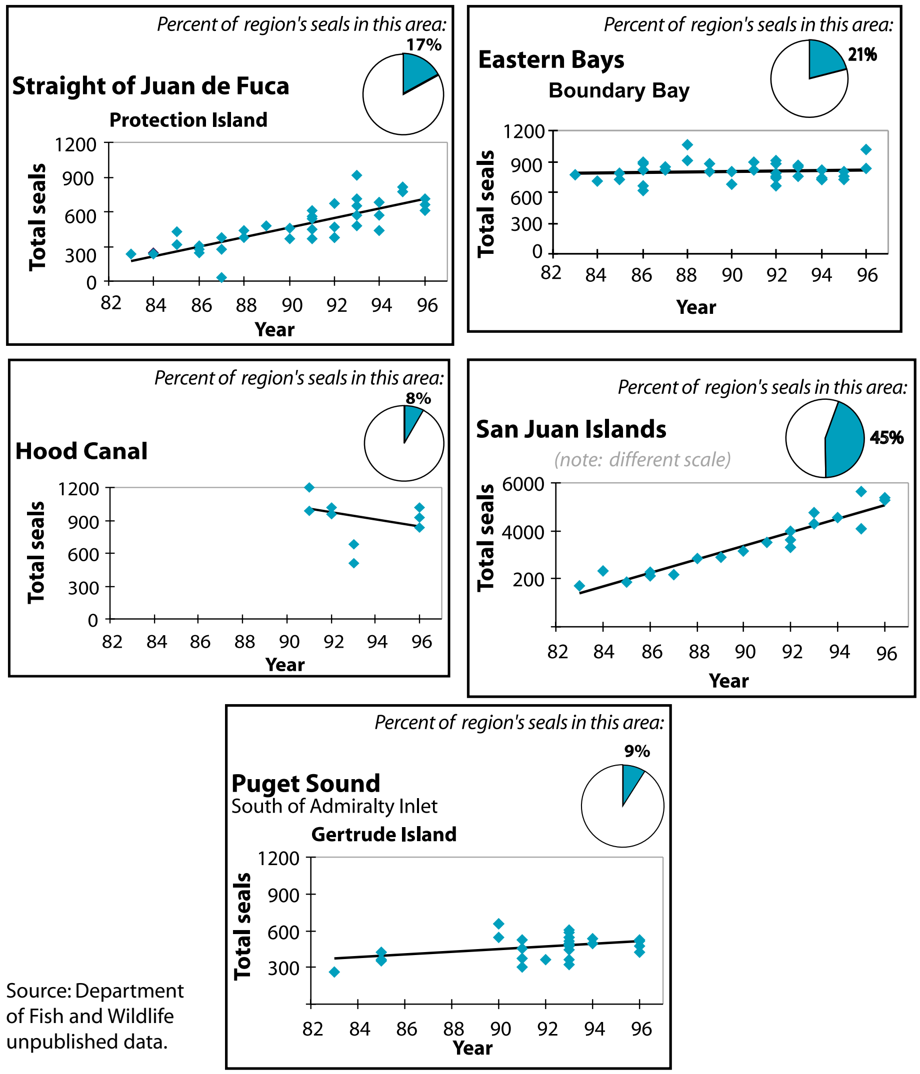
Harbor seals are the most abundant marine mammal in the Pacific Northwest, with approximately 35,000 resident in Washington. Historical levels of their abundance are unknown, but numbers were severely reduced in prior years by bounty and other control programs that aimed to reduce competition between seals and commercial and sport fishermen. The Washington State harbor seal population was estimated at 2,000 to 3,000 animals in the early 1970s. Since the Marine Mammal Protection Act (MMPA) was passed in 1972, harbor seal numbers in the Pacific Northwest have shown significant increases.

Impacts of harbor seals and California sea lions on West Coast ecosystems

In February 1999, the National Marine Fisheries Service issued a report entitled "Impacts of California Sea Lions and Pacific Harbor Seals on Salmonids and West Coast Ecosystems." This report addresses the potential impact of abundant and increasing seal and sea lion populations and resulting predation on salmonid species that are on the decline or are listed under the federal Endangered Species Act (ESA). It also addresses impacts to other ecosystem components and to human activities. While seals and sea lions are protected under the Marine Mammal Protection Act of 1972, the report recommends that declining or ESA-listed salmonid species should be given precedence over seals and sea lions (on a site-specific basis) when conflicts between the protected species arise.

Figure 66. Numbers of harbor seals in Puget Sound. Percent of seals by region in 1996 and at representative survey locations, 1983-1996.

Note: Trend lines indicate a best-fit linear relationship, but do not indicate statistical significance.



Source: Department of Fish and Wildlife unpublished data.

Table 19. Frequency of occurrence of prey species in harbor seal scats collected in Hood Canal, Fall 1998.

Prey species	**Percent occurrence of prey species in scat samples**
Pacific hake *(Merluccius productus)*	84.8
Pacific herring *(Clupea harengus)*	43.7
Salmon *(Oncorhynchus* species)	25.4
Shiner surfperch *(Cymatogaster aggregata)*	6.6
Squid *(Loligo* species)	3.4
Pacific staghorn sculpin *(Leptocottus armatus)*	2.7
Pacific tomcod *(Microgadus proximus)*	2.5
Plainfin midshipman *(Porichthys notatus)*	2.4
Northern anchovy *(Engraulis mordax mordax)*	2.4
Juvenile crab (infraorder Brachyura)	1.7
Threespine stickleback *(Gasterosteus aculeatus)*	1.2
Other species*	3.2
Unidentified fish	4.9

Based on analysis of 591 scats from Quilcene Bay and the Dosewallips, Duckabush, Hamma Hamma and Skokomish rivers.

**Other prey species (less than 1.0 percent) include pile perch* (Rhacochilus vacca)*, English sole* (Parophrys vetulus)*, rockfish* (Sebastes spp.)*, walleye pollock* (Theragra chalcogramma)*, Berryteuthis species, roughback sculpin* (Chitonotus pugetensis)*, surf smelt* (Hypomesus pretiosus pretiosus) *and skate (Family Rajidae)*

Bay in 1919 and 1920 (after it was first noticed in the bay in 1913). Although they are often more difficult to assess, the ecological impacts of exotic species can be severe.

The Puget Sound Expedition: A Systematic Survey for Exotic Species. To provide improved baseline information on non-indigenous species in Puget Sound, Department of Natural Resources scientists jointly organized the Puget Sound Expedition, a systematic survey of exotic species, with scientists from the University of Washington and the San Francisco Estuary Institute. The cooperative project brought together 19 experts from a variety of institutions and disciplines to sample 25 sites in Puget Sound between Blaine and Shelton. The sampled sites represented a range of environmental and anthropogenic conditions. The expedition adopted methods used by previous San Francisco expeditions (Cohen and Carlton, 1995) that focused primarily on sampling floating docks and associated benthic habitats. These areas were chosen because they could be easily accessed and provided an obvious pathway for introduction and a protected location for larval settlement and survival.

The Puget Sound Expedition collected and identified 39 non-indigenous invertebrates, algae and vascular plant species in six days of sampling. Much analysis remains to be completed, including genetic analysis of mussels and identification of plankton samples. Some highlights of the study's findings to date include the following:

- Ten non-indigenous species were found that had not been previously reported in Puget Sound. These discoveries increased the number of known non-indigenous species in Puget Sound salt and brackish waters to 52.
- Puget Sound appears to have far fewer exotics than San Francisco Bay, which is known to have over 150 species in habitats similar to those of Puget Sound. This comparison should not put us at ease, however, because even a single exotic species has the potential to greatly change the Puget Sound ecosystem.
- Approximately one-half of Puget Sound's non-indigenous species whose native range is known are from the North Atlantic and the other half are from the Western Pacific. The importance of the two source regions appears to have shifted over time. The majority of species discovered before 1950 are from the North Atlantic, while the majority of species discovered after 1950 are from the Western Pacific (Table 20, 102).
- Initial analysis of the distribution of non-indigenous species collected by the expedition reveals no obvious trends in the distribution of exotic species throughout the Sound with regard to salinity, temperature or region. The highest number of introductions was found at Shelton, Des Moines, Seabeck and Blaine, which represent the northern and southern sampling endpoints and two midpoints in the study area.

Non-Native Copepods in Elliott Bay. In the summer of 1998 several examples of an introduced Asian copepod, *Pseudodiaptomus marinus,* were observed in samples of epibenthos (animals living attached to the sea bottom or moving freely over it) collected from Seattle's Elliott Bay. This was the first observation of this genus of copepod in Puget Sound.

In the spring of 1999, researchers at the University of Washington repeated sampling for *P. marinus* in order to determine its status in Elliott Bay. They did not find *P. marinus* or any of the other new Asian copepods found the previous spring. It appears

Exotic copepods in coastal estuaries

Scientists at the University of Washington are currently conducting research on another non-native Asian copepod, *Pseudodiaptomus inopinus,* a crustacean likely introduced into Pacific Northwest coastal estuaries via ballast water. One phase of the study includes a survey of estuaries between southern British Columbia and northern California to be conducted during the summer of 2000. The purpose of the survey is to determine whether or not *P. inopinus* has invaded new estuaries and increased its geographic range and to verify that it has persisted in estuaries in which it has been recorded before. *P. inopinus* has not been recorded in Puget Sound.

Table 20. Origins, first records and mechanisms of introduction of non-indigenous species collected by the Puget Sound Expedition.

General Taxon	Species	Native Range	First Pacific Coast Record	First Puget Sound Record	Possible Mechanism of Introduction
Seaweeds	*Sargassum muticum*	Japan	1944	?	OJ
Anthophyta	*Spartina anglica*	England	1961-62	1961-62	MR
	Zostera japonica	W Pacific	1957	?	OJ
Foraminifera	*Trochammina hadai*	Japan	1983	1997	BW,SF,OJ
Cnidaria	*Cordylophora caspia*	Black/Caspian Seas	ca. 1920	ca. 1920	BW,SF
	Diadumene lineata	Asia	1906	<1939	OA,SF
Annelida	*Hobsonia florida*	NW Atlantic	1940	1940	?
	Pseudopolydora sp.	?	?	?	?
Mollusca	*Batillaria attramentaria*	Japan	1924	1924	OJ
	Crepidula fornicata	NW Atlantic	1905	1905	OA
	Myosotella myosotis	Europe?	1871	1927	OA(SB,SF)
	Crassostrea gigas	Japan	1875	1875	OJ
	Mya arenaria	NW Atlantic	1874	1888-89	OA
	Nuttallia obscurata	Japan, Korea (China?)	1989	1991-96	BW
	Venerupis philippinarum	NW Pacific	1924	1924	OJ
Copepoda	*Choniostomatid copepod*	?	?	1998	?
Cumacea	*Nippoleucon hinumensis*	Japan	1979	1998	BW
Isopoda	*Limnoria tripunctata*	not known	1871 or 1875	?	SF
Amphipoda	*Ampithoe valida*	NW Atlantic	1941	?	BW,OA,SF
	Caprella mutica	Japan to Vladivostok	1973-77	1998	BW,OJ
	Corophium acherusicum	not known	1905	1974-75	OA,SF
	Corophium insidiosum	N Atlantic	1915	1930	OA,SF
	Eochelidium sp.	Japan or Korea	early 1990s?	1997	BW
	Grandidierella japonica	Japan	1966	?	BW,OJ,SF
	Jassa marmorata	NW Atlantic	1941	?	BW, SF
	Melita nitida	NW Atlantic	1938	1966	BW,OA,SB,SF
	Parapleustes derzhavini	W Pacific?	1904	1998	SF
Entoprocta	*Barentsia benedeni*	Europe	1929	<1998	OJ,SF
Bryozoa	*Bowerbankia gracilis*	NW Atlantic?	<1923	<1953	OA,SF
	Bugula sp. 1	?	?	1993	?
	Bugula sp. 2	?	?	1998	?
	Bugula stolonifera	NW Atlantic	<1978	1998	SF
	Cryptosula pallasiana	N Atlantic	1943-44	1998	OA,SF
	Schizoporella unicornis	NW Pacific	1927	1927	OJ,SF
Urochordata	*Botrylloides violaceus*	Japan	1973	1977	OJ,SF
	Botryllus schlosseri	NE Atlantic	1944-47	?	OA,SF
	Ciona savignyi	Japan?	1985	1998	BW,SF
	Molgula manhattensis	NW Atlantic	1949	1998	BW,OA,SF
	Styela clava	China to Okhotsk Sea	1932-33	1998	BW,OJ,SF

This list of species is provisional pending further taxonomic work and review by expedition members and associates.

Native ranges, dates of first record (planting, collection, observation or report) in Puget Sound and on the Pacific Coast of North America, and possible initial mechanisms of introduction to the Pacific Coast are given. First records consisting of written accounts that do not state the date of planting, collection or observation are preceded by the symbol "<". Mechanisms given in parentheses indicate less likely mechanisms. Mechanisms are listed as:

OA-with shipments of Atlantic oysters
SF-in ship fouling or boring
BW-in ship ballast water or seawater system
OJ-with shipments of Japanese oysters
SB-in solid ballast
MR-planted for marsh restoration or erosion control

that the non-native species observed in 1998, which had probably been introduced from ballast water releases, may not have successfully reproduced in Elliott Bay.

As far as is known by scientists, the only copepod introductions that are established in Elliott Bay are two species of Stephos, *S. pacificus* and another unidentified and possibly undescribed species. These species co-occur in shallow subtidal sediments around the bay and can be quite abundant (J. Cordell, personal communication).

European Green Crab. The European green crab *(Carcinus maenus)*, a non-native species, made its appearance on the outer coast of Washington in June 1998. The European green crab is a federally recognized nuisance species and has been declared an aquatic nuisance species by the Washington Department of Fish and Wildlife.

The European green crab is an introduced species of particular concern for many reasons. It is a relatively small crab, but a voracious predator for its size. It preys upon a wide variety of plants and animals, but prefers small bivalves, including commercially and recreationally important clams, oysters and mussels. An adult green crab can consume large quantities of these organisms. The crab has also been known to prey upon Dungeness crab (*Cancer magister*) of equal or lesser size. The European green crab is an accomplished burrower, and the possible effects of its digging activities on the benthic environment and integrity of shore banks is unknown. The crab is found along the shoreline in water up to, and sometimes exceeding, 30 feet deep, in the high intertidal zone and in salt marshes.

In preparation for the potential spread of the green crab into Puget Sound, a monitoring program was launched to increase the probability of detecting green crabs in Puget Sound, the Strait of Juan de Fuca and the San Juan Islands. Fish and Wildlife and other government agency staff, volunteer groups, tribes, shellfish growers, schools and individual citizens have been monitoring for the presence of C. maenus, primarily by setting baited traps in the intertidal zone. In addition, the Department of Fish and Wildlife and the U.S. Fish and Wildlife Service have contracted with Adopt a Beach, a non-profit volunteer group, to train and coordinate volunteers to monitor for the European green crab in Puget Sound. With its large volunteer base and membership from throughout the Puget Sound region, Adopt a Beach has been able to provide broad geographical monitoring coverage in a very short period of time. Between July and September 1999, Adopt a Beach trained approximately 35 volunteers, establishing 32 monitoring sites ranging from south Puget Sound to the San Juan Islands to the U.S./Canadian border. Through the cooperation and combined efforts of all participating groups and individuals, approximately 80 European green crab monitoring sites were established in 1999 (Figure 67, page 104). As of February 2000, no European green crabs have been found in Puget Sound.

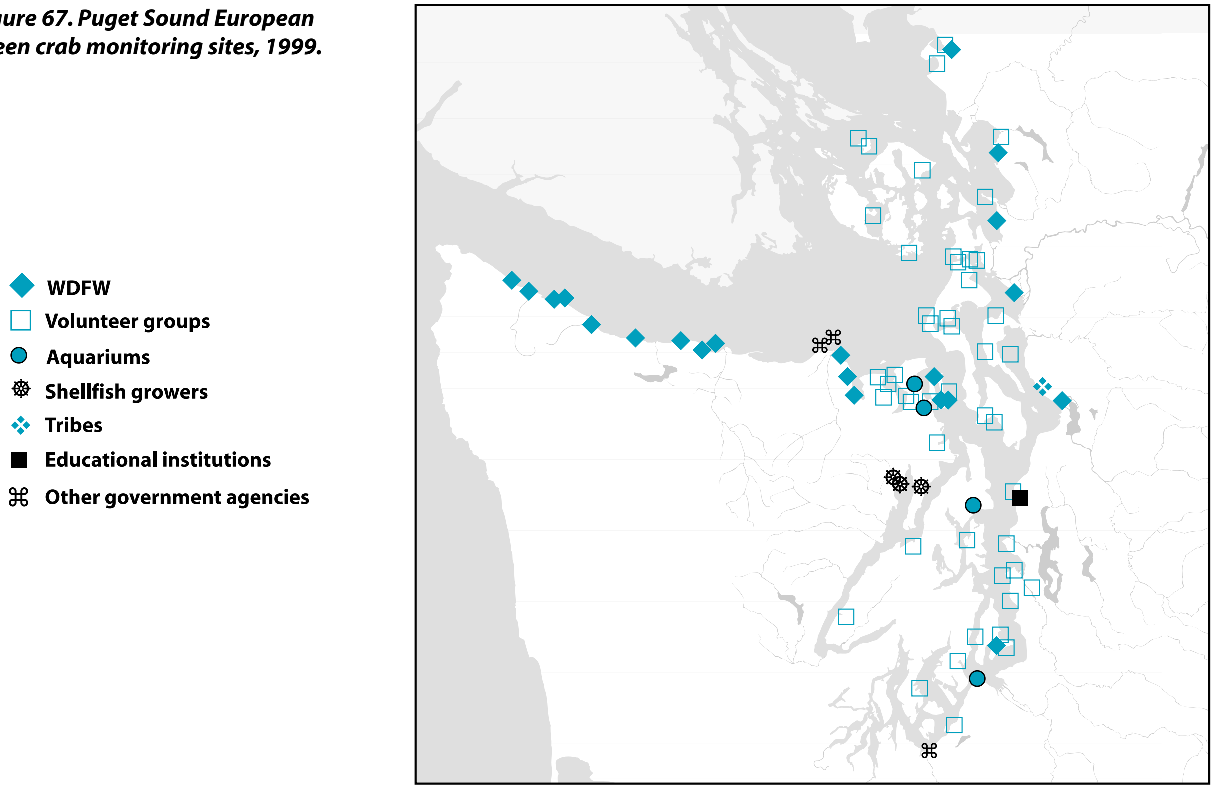
In June 1999, an adult female green crab was discovered in Useless Inlet, an area of commercial oyster leases on the west coast of Vancouver Island. During the course of the summer, four more adults were found in the same location. In August 1999, four additional adult green crabs were found in the Strait of Juan de Fuca in the vicinity of Victoria. It is believed that because the crabs found in British Columbia were adult size, they must have arrived in 1997 or 1998—likely as a result of coastal current transport of larvae. The Department of Fisheries and Oceans Canada is currently planning to begin green crab monitoring in British Columbia.

***Spartina* (Cordgrass).** *Spartina,* commonly known as cordgrass, is a noxious weed that severely disrupts native saltwater ecosystems, alters fish, shellfish and bird habitat, and increases the threat of floods. Three species of *Spartina* have been introduced to and have become established in nearshore environments in western Washington.

The European green crab in Washington's coastal estuaries

The Department of Fish and Wildlife, with assistance from shellfish growers, the Shoalwater Tribe and students from The Evergreen State College, have been monitoring the green crab in Willapa Bay and Grays Harbor (estuaries outside of Puget Sound) since 1998. Based on data about the "catch per unit effort" of fishing for green crabs, Fish and Wildlife scientists estimate that the number of green crabs in Willapa Bay actually decreased from 1998 to 1999. Although it is too soon in the monitoring effort to draw conclusions, there are many possible explanations for the observed decrease: the summer 1998 fishing effort by Fish and Wildlife scientists and shellfish growers may have reduced the population; the crabs may have spread throughout the bay away from the trapping areas around the mouth of the bay where they were concentrated in 1998; as they grew larger, the crabs may have been subject to predation by native species. Only after continued long-term monitoring and directed research studies will the reasons for the changes in numbers of green crabs trapped become more clear.

Figure 67. Puget Sound European green crab monitoring sites, 1999.



Source: Department of Fish and Wildlife.

Previous introductions of the European green crab to Washington

Between Pacific Tides (Ricketts and Calvin, 1968) notes the appearance of the European green crab in Willapa Bay in 1961. It is the consensus that Ricketts and Calvin would not have included this report in their book unless it was substantiated. However, no other details about the sighting are available. Documentation in the form of a specimen, photograph or detailed written description has apparently been lost. In any case, it is unlikely that a population of European green crabs became established in Willapa Bay after that initial sighting.

In Puget Sound, known Spartina infestations occur at a few locations along the Strait of Juan de Fuca and into Hood Canal, at three locations in San Juan County (one each at San Juan, Orcas and Lopez islands), 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 (see Figure 68). Spartina has not been found south of the Tacoma Narrows in Puget Sound.

The Washington Department of Agriculture (Agriculture) coordinates a *Spartina* Eradication and Control Program. As part of this program, Agriculture conducts all control work in San Juan, Clallam, Jefferson, Kitsap and King counties and also coordinates the entire Puget Sound/Hood Canal effort. The agency allocates funding and other support to Island, Snohomish and Skagit counties, Adopt a Beach, private landowners and the Swinomish and Suquamish tribal communities. In addition, Department of Fish and Wildlife staff conduct substantial control work on their property throughout northern Puget Sound and assist county control efforts as time and funding permit.

As of the beginning of the 1999 control season, the control efforts of Agriculture and its partners have resulted in significant progress in reducing the size of Puget Sound *Spartina* infestations (and in some cases, eliminating them). As Agriculture and collaborators such as Fish and Wildlife succeed at reducing or eliminating smaller, outlying populations of *Spartina* that have the potential to greatly increase in area, larger areas of infestation, such as South Skagit Bay, will become a bigger priority and the focus of additional funding.

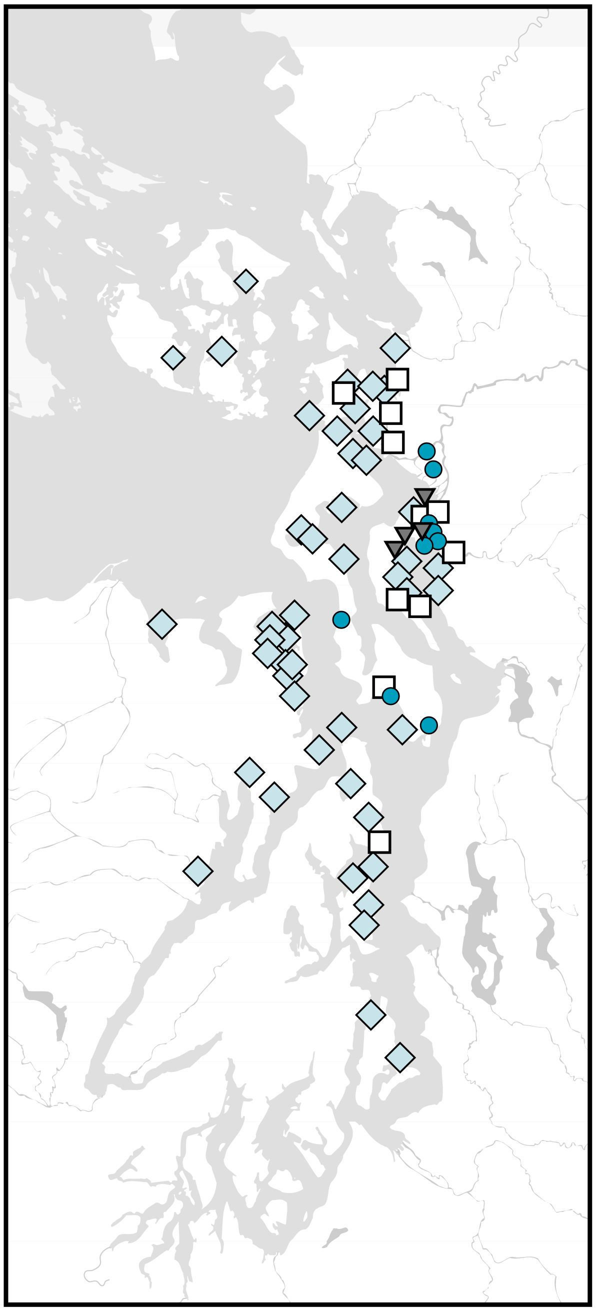


Figure 68. Approximate 1999 locations and sizes of known Spartina infestations in Puget Sound and Hood Canal.

◇ < 1 acre
□ 1-5 acres
● 6-100 acres
▼ >100 acres

Acreage values are for estimated acres totally covered by *Spartina.*

Data from Washington State Department of Agriculture.

Acting on the Findings

Information presented in this chapter suggests a number of follow up actions to improve the understanding and management of Puget Sound's biological resources. One suggestion sprinkled throughout the preceding pages is that agencies should continue and expand efforts to monitor the abundance, as well as the condition, of Puget Sound organisms and habitats. Information from abundance monitoring should be used to manage species harvests, where applicable, and to shape and direct other resource management actions. Recommended actions related to specific biological resources include the following:

- Nearshore vegetation monitoring should be expanded to include evaluation of trends in the extent of eelgrass beds in Puget Sound.

The Department of Natural Resources is currently developing a program to monitor temporal trends in intertidal and subtidal eelgrass beds. Information from this effort will increase knowledge about trends over time in the distribution and abundance of eelgrass beds along Puget Sound's shoreline.

- State agencies such as the Department of Ecology, local governments, etc. should use Natural Resources' data on kelp resources in the Strait of Juan de Fuca and the agency's nearshore inventory data for Whatcom, Skagit and the northern portion of Island counties to help with nearshore resource management, including oil spill response planning and land-use planning.
- Scientists should continue to develop improved approaches to characterizing phytoplankton biomass in Puget Sound, possibly including the use of remote sensing and/or sensors deployed on moorings.
- The Department of Fish and Wildlife should expand fishery-independent monitoring of marine fish abundance to provide consistent data on stock status.
- Scientists from the region should study ecosystem relationships in south Puget Sound to develop information about the causes of the declines in marine survival in salmon from south Puget Sound, as well as possible remedies to this problem.
- Resource managers should evaluate ways to restore and recover fish populations in Puget Sound (such as those found on pages 84 to 90).
- U.S. and Canadian scientists should collaborate to expand winter aerial surveys of bird abundance and distribution into the inland coastal waters of British Columbia in order to better define habitat use and population size for more of the Puget Sound/Georgia Basin ecosystem.
- Scientists should evaluate harbor seal diets in other areas of Puget Sound to provide information about the predation pressures that seals exert on various fish species.
- Scientists in the region should conduct additional surveys of exotic species in habitats not assessed during the Puget Sound Expedition to develop a more comprehensive list of exotic species in Puget Sound.
- Resource management agencies should support basic research to improve our understanding of exotic species that may be introduced to Puget Sound as well as those that are already established in the estuary. Agencies should also develop response plans that can be implemented in the event of exotic species introductions to Puget Sound.

Conclusion

The seventh *Puget Sound Update* expands the base of knowledge about environmental conditions around Puget Sound. Monitoring of these conditions for the last 10 years has also helped us to understand how Puget Sound has changed over time. In the interest of continuing to increase our understanding of the Puget Sound environment, the *Update* supports recommendations for a number of further studies and follow up actions.

Status. Puget Sound environmental monitoring continues to provide evidence of environmental degradation in a number of areas of Puget Sound. Nearly 80 percent of the Puget Sound shoreline from Mukilteo to Tacoma has been altered. Water quality at a number of shellfish growing areas is poor enough to require restrictions on commercial harvest of shellfish. The degradation in these areas is a result of failing on-site sewage systems, poorly managed agricultural lands and other contaminant sources. Recent (1997) findings about sediment contamination in north Puget Sound further confirm the long-recognized pattern of contamination in Puget Sound's urban bays.

On the other hand, monitoring continues to show that most types of environmental degradation are not pervasive throughout Puget Sound. Many areas of the Sound do not show evidence of fecal or toxic contamination problems. Fecal contamination does not appear to threaten commercial shellfish harvest at many growing areas scattered throughout the Sound, including areas in the San Juan Islands, the straits of Juan de Fuca and Georgia, Admiralty Inlet, Penn Cove, Holmes Harbor, Possession Sound, Eld Inlet and Oakland Bay.

Monitoring and surveys have identified a number of Puget Sound organisms, especially marine fish (groundfish and forage fish), salmon and some birds, whose populations are in poor condition. These populations may be affected by environmental degradation in Puget Sound or by other factors, including harvest, changing predation pressures, or varying ocean and climatic conditions. One additional factor that may be affecting the Puget Sound ecosystem is the introduction and establishment of marine invasive species. As of 1998, scientists had documented the presence of more than 50 non-native species in Puget Sound.

Trends. Puget Sound monitoring indicates that environmental conditions and natural resource abundance continue to change. Some measures show improvements over time and others point to worsening conditions.

Improving trends are seen in declining levels of some contaminants and in the increasing numbers of harbor seals living in Puget Sound. Fecal contamination is declining at two shellfish growing areas where agencies and local citizens have committed to ongoing remedial actions. Toxic contamination in mussels from a number of locations around Puget Sound is declining, probably as a result of improved pollution control. The population of harbor seals living in Puget Sound has grown steadily over the past 20 years, though it appears to be stabilizing in many areas of the Sound.

Other measures provide evidence that continuing development and other environmental stressors are contributing to declining conditions. Fecal contamination is worsening at two commercial shellfish growing areas (only four were studied in detail for this report), probably the result of increased development of nearby lands for residential and commercial uses. The incidence of liver lesions in English sole from most Puget Sound locations did not change from 1989 to 1998, but the risk of liver lesions in fish from Elliott Bay increased. Liver lesions in English sole have been associated with PAH contamination in sediments. An increase in the incidence of liver lesions in English sole from Elliott Bay indicates that PAH contamination in that area may be increasing.

Monitoring data and stock assessments indicate that populations, productivity and survival of a number of organisms that live in Puget Sound have declined in recent years. The size of the spawning run for all stocks of Pacific herring in Puget Sound has declined from a peak of more than 22,000 tons in 1980 to just over 10,000 tons in 1997 and 1998, though the spawning run recovered to just over 15,000 tons in 1999. Rockfish stocks in Puget Sound appear to have been declining over the past few decades, based on evidence of declines in the recreational catch and a 75 percent decline in spawning potential. As recently as the late 1980s, 20 percent of Puget Sound coho salmon survived the marine portion of their life cycle. For the 1995 brood, only 10 percent survived the marine environment to return to their spawning streams. Numbers of scoters and grebes over-wintering in northern Puget Sound have declined by 50 percent or more since the late 1970s.

Recommendations for Further Actions. The findings presented in this document suggest a number of further studies and follow-up actions. Actions are listed in the last section of each of the preceding chapters. Some of the more important recommendations include the following:

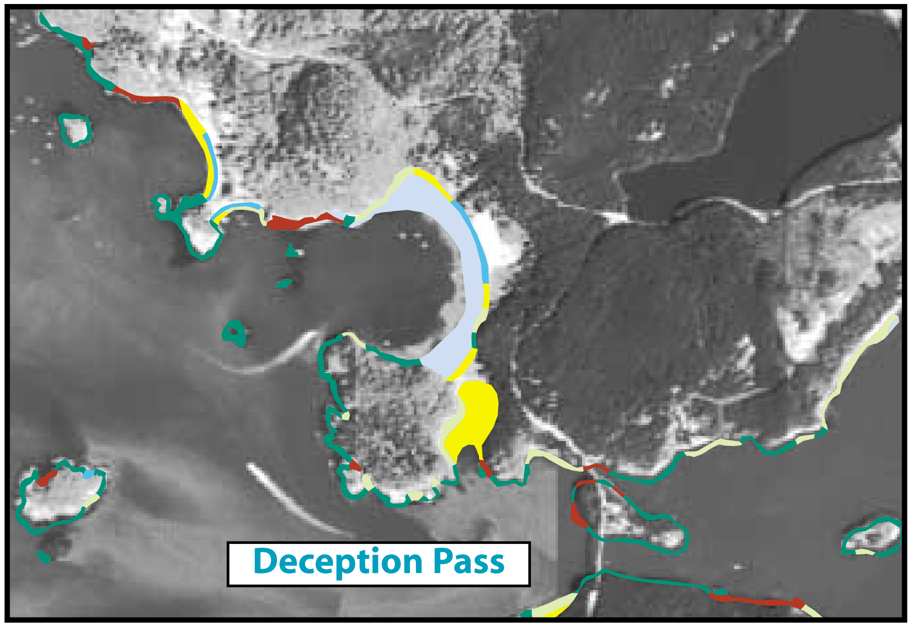
- Puget Sound's shoreline has been extensively altered by bulkheads, piers and other structures. This alteration affects the availability and function of soft-bottom nearshore habitats. Land owners and resource managers may need to establish protected areas; use alternative, less harmful approaches to protecting shoreline properties; and undertake habitat restoration projects to protect remaining nearshore habitats and to restore functions that have been lost as shorelines have been altered.
- Worsening water quality conditions at some shellfish growing areas reflect the continuing and growing impact of land development on Puget Sound's waters. Continued shellfish harvest in developed and developing areas of Puget Sound will require ongoing attention to appropriate land-use decisions, land management practices and operation and maintenance of septic systems, stormwater management facilities and other pollution control equipment.
- Monitoring results suggest that some areas of Puget Sound, including southern Hood Canal, Budd Inlet, Penn Cove and East Sound, are susceptible to water quality degradation if additional nutrients are introduced to the system. Decisions about the discharge of nutrients from point and nonpoint sources to these areas of Puget Sound should take into consideration the potential effects of the nutrient additions on the ecosystem.
- Additional study of toxic contamination near urban areas and in the vicinity of wastewater discharges is needed to better understand the distribution of problems, to support cleanup activities, and to understand the effects that toxic contaminants might have on the Puget Sound ecosystem. Information presented in this report suggests a need for further investigations in Everett Harbor, Sinclair Inlet and Elliott Bay.

- Additional information and analysis are needed to characterize the potential human health risks from consumption of Puget Sound shellfish and fish from contaminated areas. Specifically, additional information is needed on water quality conditions at recreational shellfish beaches that have not yet been characterized and classified.
- Widespread evidence of the declining population of Puget Sound marine organisms suggests the importance of new efforts to protect and recover populations. Recovery plans based on an ecosystem perspective will require additional information about the specific relationships among various Puget Sound species and the influences of various natural and human-caused environmental stresses on marine populations.

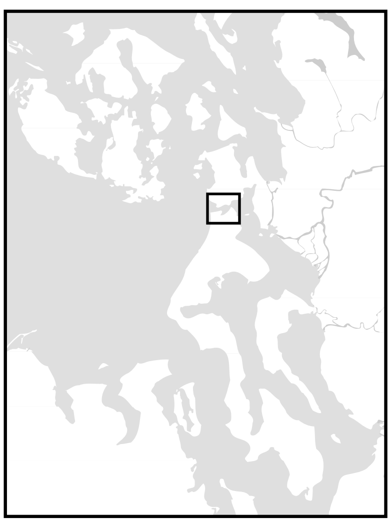
Color Section

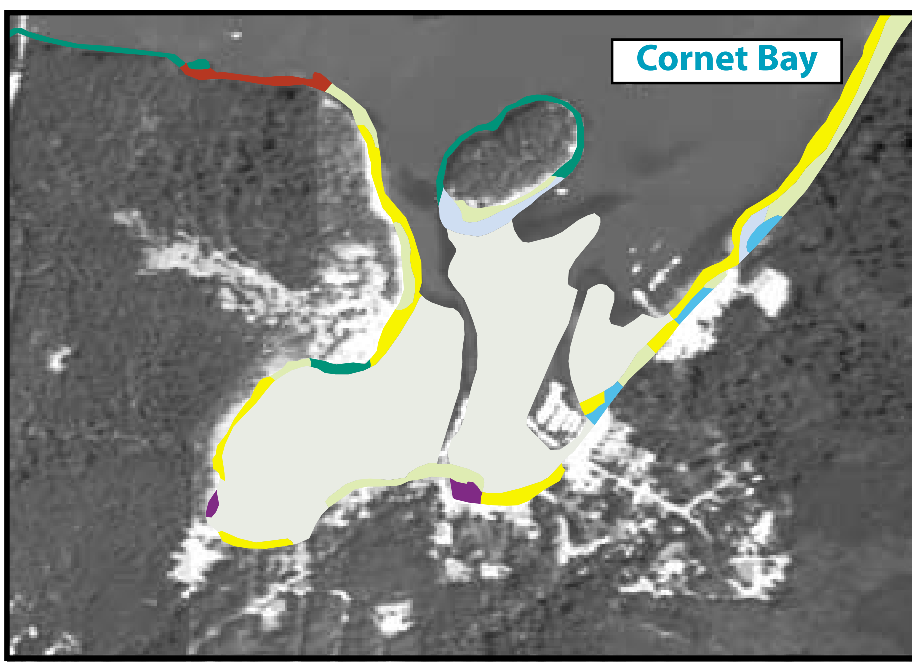
Figure 15. Intertidal substrate inventory at Deception Pass and Cornet Bay.

Artificial
Bedrock
Boulder
Cobble
Gravel
Hardpan
Mixed coarse
Mixed fine
Mud
Organic
Sand



Approximate scale: 1 inch = 2,200 feet





Approximate scale: 1 inch = 1,400 feet

Source: Department of Natural Resources

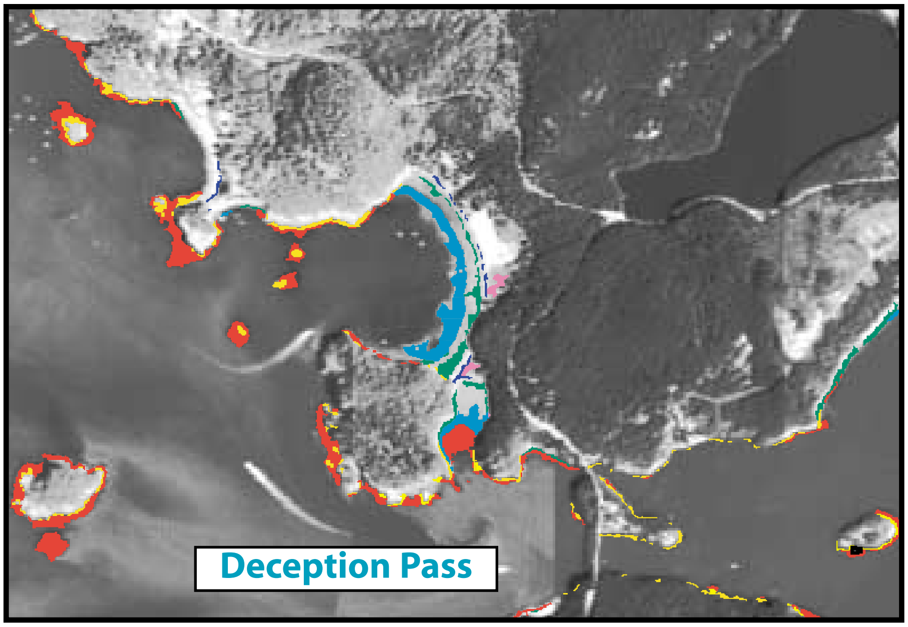
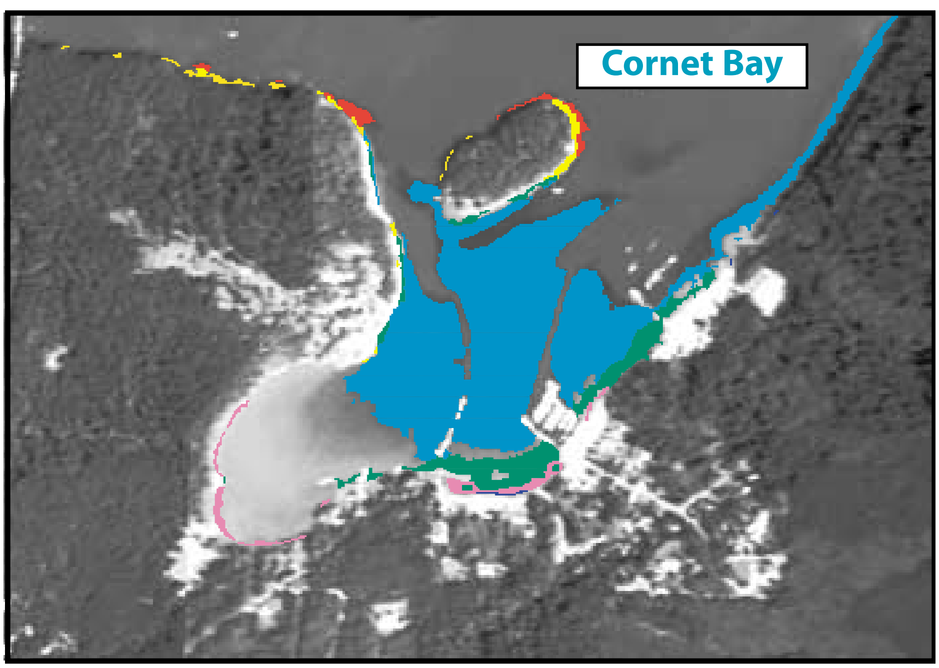
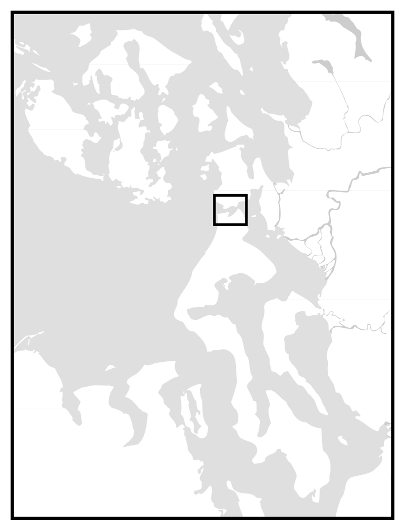


Figure 49. Intertidal and canopy-forming vegetation inventory at Deception Pass and Cornet Bay.

Brown Algae
Green Algae
Mixed Algae
Red Algae
Eelgrass
Kelp
Salt Marsh
Spit or Berm vegetation

Approximate scale: 1 inch = 2,200 feet





Approximate scale: 1 inch = 1,400 feet

Source: Department of Natural Resources

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PSAMP Reports

General/Overview

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Floating Kelp Resources in the Strait of Juan de Fuca and the Pacific Coast of Washington (Mumford et al.)

Mapping Shorelines in Puget Sound I. A Spatially Nested Geophysical Shoreline Partitioning Model (Schoch and Dethier)

Mapping Shorelines in Puget Sound II. Linking Biota with Physical Habitats (Dethier and Schoch)

Mapping Shorelines in Puget Sound III. Management Applications for Inventory and Monitoring (Berry et al.)

Marine Benthic Invertebrate Communities near King County's Wastewater Outfalls (Laetz)

Probability-based Estimation of Nearshore Habitat Characteristics (Bailey et al.)

Puget Sound Intertidal Habitat Inventory: Vegetation Mapping (Ritter and Bailey)

Status and Trends for Selected Diving Duck Species Examined by the Marine Bird Component of the PSAMP (Nysewander and Evenson)

Variation in Primary Productivity of Budd Inlet (Newton et al.)

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