PUGET SOUND UPDATE 2002

Eighth Report of the Puget Sound Ambient Monitoring Program

PUGET SOUND WATER QUALITY ACTION TEAM

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September 2002

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Summary

This *Puget Sound Update* is the eighth report of the Puget Sound Ambient Monitoring Program (PSAMP) since the program was initiated in 1988 by the State of Washington. The program encompasses the greater Puget Sound region with a broad, interdisciplinary approach.

The *Puget Sound Update* is a technical document that integrates results from all of the PSAMP components and serves as an overall program report issued every two years. 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 biological resources and to point out water quality and resource management issues that might require attention now and into the future.

PSAMP uses the *Puget Sound Update* to report on its own results but also to summarize the related work of other researchers in Puget Sound. This report is organized around five monitoring topics that relate to human activities and management programs. Highlights from the chapters dedicated to each of the topics are given below.

Physical Environment

- The region experienced the second worst drought on record in late 2000 and early 2001.
- La Niña conditions were interspersed with neutral conditions with respect to the El Niño—Southern Oscillation (ENSO) over the Pacific Ocean. Based on previous return intervals and ocean conditions in early 2002, scientists anticipate that El Niño conditions may emerge in 2002 and 2003.
- The Washington State Department of Ecology developed a new water quality index (WQI) for rivers and streams designed to measure general watershed conditions. The index shows generally good conditions throughout the basin with fair conditions in south Sound and the lower Stillaguamish and poor conditions at three stations in Skagit County.
- Department of Ecology scientists have developed a ranking of marine water quality concern based on five variables. In this ranking, Budd Inlet, south Hood Canal and Penn Cove showed the poorest water quality but for differing reasons.
- Scientists with the Washington State Department of Natural Resources have determined that 33 percent of Puget Sound shorelines have been modified with bulkheads and half of this amount is associated with single-family residences.

Pathogens and Nutrients

Pathogens

- A new water quality index (WQI) was developed by the Department of Ecology for detecting chronic problems with freshwater fecal coliform bacteria. The fecal WQI showed the lowest level of concern at most ambient freshwater stations within the Puget Sound basin for wateryear 2000 (24 of 33). No ambient monitoring stations were placed in the highest concern category (the remaining stations were in the moderate concern category).

- Trend analyses at 20 of the Department of Ecology's freshwater stations for 1991-2000 showed seven stations had decreasing fecal contamination, one station at Cedar Run in Renton had an increasing contamination and the remainder had no discernable trends.
- The Washington State Department of Health evaluated fecal pollution in 89 shellfish harvest areas for the period from March 2000 through March 2001. According to its Fecal Pollution Index, 29 areas had significant impact from fecal pollution. The following areas ranked highest in fecal impact: South Skagit Bay, Drayton Harbor, Chico Bay (Dyes Inlet) and Portage Bay. Sixty other harvest areas had minimal pollution.
- The state Department of Health analyzed five-year trends at 302 monitoring stations in Puget Sound that had sufficient data records and evidence of pollution. Fecal pollution increased significantly at 40 percent of the stations. Pollution decreased at a third of the sites and remained unchanged at 27 percent of stations.
- Results from 15 core marine water stations in Puget Sound by the Department of Ecology in 2000 showed the lowest occurrence of high fecal coliform counts since 1994.
- The highest marine fecal coliform counts observed by the Department of Ecology at ambient monitoring stations in 2000 were seen in Commencement, Elliott and Oakland bays. Oakland Bay, however, had only moderate fecal impact in statistics calculated by the state Department of Health using data from commercial shellfish growing areas.
- Several years of analysis of water samples from King County beaches have shown several stations that
    - Consistently have fecal coliform levels that exceed standards: Tramp Harbor, inner Elliott Bay, Fauntleroy Cove, Golden Gardens, Lake Washington Ship Canal, Piper's Creek
    - Consistently have low fecal coliform levels: Seacrest Park, Duwamish Head, north side of Alki Point, Fay Bainbridge State Park.
    - Have highly variable results from year to year: Richmond Beach, Seahurst Park, southern West Point.

Nutrients

- The Department of Ecology's WQI for total nitrogen indicated that the majority of ambient freshwater sampling stations (20 of 33 stations) were in the lowest concern category in water year 2000. The remaining stations were split between moderate concern (7) and highest concern (6). The highest concern stations were in the lower Skagit valley and on the Deschutes River.
- A trend analysis of 1991-2000 data at the Department of Ecology's freshwater monitoring stations indicated decreasing trends or no trends for nitrogen throughout the Puget Sound basin. Slight increasing trends for phosphorus were identified at a number of stations.

- The Department of Ecology scientists identified three areas as having exceptional sensitivity to eutrophication due to a combination of low dissolved oxygen (DO), low dissolved inorganic nitrogen (DIN), and strong, persistent stratification in a 1994-2000 dataset. These areas are Budd Inlet, south Hood Canal and Penn Cove.

Toxics

Sediment

- Comparing surface sediment samples collected in 2000 to results from 1989-1996 at 10 long-term Puget Sound sites showed:
  - Decreases in metal concentrations, particularly mercury and copper.
  - Increases in concentrations of polycyclic aromatic hydrocarbons (PAHs).
  - Substantial increase in benzoic acid at all sites.
  - Particularly high PAH concentrations at the Thea Foss Waterway (Commencement Bay) relative to the other sites.
  - Particularly high metal concentrations—including copper, lead, mercury, silver and zinc—at Sinclair Inlet relative to the other sites.
- Analysis of sediment samples from 300 randomized sites collected in 1997-1999 in Puget Sound showed:
  - The majority of observed sediment contamination was located in urban waters including Bellingham Bay, around March Point, Sinclair Inlet, Everett Harbor, Elliott Bay and Commencement Bay.
  - Greatest toxicity in Everett Harbor, Elliott Bay, Commencement Bay and the Port of Olympia based on a series of four toxicity tests designed to gauge impacts on biota.
  - Greatest percent area of degraded sediments in central Puget Sound, followed by Whidbey Basin and south Puget Sound and Hood Canal regions, based on the weight of evidence developed through a triad of sediment quality information.
  - A portion of each study region, including the majority of Hood Canal, showed no signs of sediment degradation.

Shellfish

- Dungeness crab in Puget Sound accumulate PAHs, with the greatest exposure occurring in crab in urban areas, suggesting that they are suitable as indicator species to quantify PAH exposure in marine biota.
- Analysis of butter clams from six sites in central Puget Sound showed metal concentrations below U.S. Food and Drug Administration (FDA) standards and no detectable organic compounds except benzoic acid, which was prevalent in all samples.

Acronyms

Acronyms are frequently used in this report, especially for compounds such as polychlorinated biphenyls (PCBs) or polycyclic aromatic hydrocarbons (PAHs). A list of acronyms used can be found in the Resources chapter at the end of the report.

Fish

- Concentrations of polychlorinated biphenyls (PCBs) in Pacific herring were higher in fish from central and southern Puget Sound relative to fish from the northern Sound and the Strait of Georgia. These PCB concentrations were generally below values suggested by the National Marine Fisheries Service (NMFS) as thresholds for possible adverse effects in salmonids, although there is a potential for adverse effects in herring stocks in central Puget Sound.

- At long-term sampling stations, English sole in two urban bays (Elliott and Commencement) were observed to have significantly higher risk of liver disease than the intermediate risk measured at Sinclair Inlet and Port Gardner and the lower risk observed in the Strait of Georgia and Hood Canal.

- Monitoring of English sole, rock sole and starry flounder at a site where highly contaminated sediment was capped with clean sediment, showed reduced risk of liver disease associated with reduced exposure to PAHs.

Birds and Mammals

- A study of PCB contaminants in orcas based on samples from 1993-1996 showed very high levels of contamination with clear relationships to food source. Transient orcas that feed from higher trophic levels (marine mammals) were the most highly contaminated of the whales studied. Southern residents were four to six times more contaminated than northern residents, presumably because their food source comes from more contaminated areas of Puget Sound and the Strait of Georgia.

- A study of contaminants in Hood Canal bald eagles concluded that while the population was growing, PCBs were negatively affecting the eagles and causing lower productivity rates relative to populations elsewhere in Washington State.

Human Health

- The state Department of Health reclassified four commercial shellfish growing areas in Puget Sound in 1999, five areas in 2000 and six in 2001. A total of 1,580 acres were upgraded and 2,069 acres were downgraded over these three years.

- The number of confirmed cases of human *Vibrio parahaemalyticus* infection continued the declining trend with each consecutive year since a major outbreak occurred in 1997. There were six cases in 2001 compared to 66 in 1997.

- The state Department of Health observed the greatest concentration of Paralytic Shellfish Poisoning (PSP) toxin in shellfish along the Strait of Juan de Fuca and scattered sites in the Main Basin and south Puget Sound. Areas free of PSP in 2000 included Hood Canal south of Lofall, south Puget Sound west of Anderson Island, Saratoga Passage, and Westcott Bay on San Juan Island.

Biological Resources

Vegetation, Phytoplankton and Macro-Invertebrates

- A statewide inventory of the shoreline called the ShoreZone Inventory was completed in 2000. It characterizes shoreline geomorphology, vegetation, and anthropogenic development along the 3,000 miles of saltwater shoreline in Washington State.
- Eelgrass beds were sampled at 67 sites throughout Puget Sound as part of a new Submerged Vegetation Monitoring Program. This study provides the first estimate of the amount of eelgrass in Puget Sound, and other information on eelgrass bed characteristics. It also serves as a baseline for a long-term monitoring program.
- Kelp canopy area in the Strait of Juan de Fuca increased in both 1999 and 2000 following a strong decrease in 1997 associated with the most recent El Niño episode. In spite of high yearly variability, no long-term trend is apparent in kelp area between 1989 and 2000, suggesting that the population is stable over this time period.
- Phytoplankton blooms in central basin of Puget Sound in 1999 and 2000 were not as consistent as previous years in terms of spatial extent and timing.
- Species diversity in intertidal macro-invertebrates is three times higher in northern Puget Sound relative to the southern Sound with a smooth gradient in between.

Fish

- The Washington State Department of Fish and Wildlife found in their 2000 trawl survey of groundfish in the eastern Strait of Juan de Fuca that most populations were less abundant than previously observed. Some numerically depressed species showed no population growth in response to the recent reduction of fisheries pressure.
- The total amount of spawning herring increased modestly in Puget Sound in 2000 and 2001 although some stocks, particularly the Cherry Point stock, have shown tremendous declines and the reasons for this decline remain unknown.
- Isotopic and genetic studies of Puget Sound herring stocks, including the Cherry Point stock, were not conclusive but did not provide strong evidence in support of treating individual stocks as distinct units under the Endangered Species Act (ESA).
- The state Department of Fish and Wildlife observed an increase in marine survival of juvenile coho and other salmon in the Strait of Georgia in 2000. Other data suggest that this increase is associated with shifts in the food web and a decrease in predation on these species.

Birds

- Baseline data on the pigeon guillemot population, collected in 1999-2000 as part of a new study, showed highest concentrations in the northern and southern areas with fewer numbers in central Puget Sound.

- A new trend analysis of populations of wintering nearshore waterbirds in Puget Sound showed significant decrease in most species studied (grebes, cormorants, loons, pigeon guillemot, marbled murrelets, scoters, scaup, long-tailed ducks and brant), but an increase in harlequin ducks and stable numbers in other species.
- The bald eagle population in Hood Canal is increasing but still trails behind other populations in productivity.

Marine Mammals

- The sharp decline in the southern resident orca whale population continued in 2000 and 2001. This Puget Sound population has declined from a recent maximum of 97 in 1996 to 78 in 2001. High contaminant levels, including PCBs, are a possible factor because they are greater than levels that have been shown to have a negative impact on other marine species. Declining food sources and artificial underwater sounds are other possible negative factors.
- In 2001, a consortium submitted a petition to NMFS to list the southern resident population of orcas, which reside for most of the year in Puget Sound/Georgia Basin, as threatened or endangered under ESA. NMFS completed a biological review and determined that protection under ESA is not warranted because of limitations on how the Act can be applied, not based on the prognosis for the southern resident population.
- The state Department of Fish and Wildlife released a new trend analysis of the harbor seal population in Washington State (1978-1999) that shows an overall threefold increase since enforcement began of the Marine Mammal Protection Act in 1978. The greatest growth has been in the San Juan Islands and the Strait of Juan de Fuca. Model analysis suggests the population is near the current carrying capacity of the inland marine ecosystem in Washington.

Exotic Species

- The Department of Natural Resources conducted a seven-day expedition in 2000 to survey exotic organisms in selected marine areas and documented a total of 40 exotic species. Fewer exotic species were found in Elliott Bay and the Totten/Eld Inlet region (15 species each) compared to Willapa Bay on the outer coast (34 species).
- Coordinated efforts to control the spread of exotic *Spartina*, an invasive aquatic grass, has led to a reduction in the size of the Puget Sound infestation as a whole and the elimination in some areas.

1. Introduction

This *Puget Sound Update* is the eighth report of the Puget Sound Ambient Monitoring Program (PSAMP). Since the first report was published in 1990, the results of the monitoring work reported here have become increasingly vital as pressures on the natural resources in Puget Sound rise and our understanding of the interrelated nature of the ecosystem grows. Both of these trends argue for increasingly sophisticated management of Puget Sound's resources—management based on scientific data and evaluated by achievement of objectives as reflected in this scientific data.

The increasing use of Puget Sound's natural resources is directly tied to the area's continuing high rate of population growth (OFM 2002). This growth leads to land conversion for new development and associated changes to watershed hydrology and contaminant transport to the marine environment. The increasing population may also be associated with an increase in recreational fishing harvest, recreational boating and residential and commercial shoreline development. All of these activities represent uses of Puget Sound's natural resources that must be carefully managed to sustain the integrity of these resources and ultimately the overall health of the ecosystem.

Many governments (tribal, local, state and federal) and non-governmental organizations in Puget Sound are engaged in monitoring activities designed to contribute to the management of the region's natural resources. Most of these efforts focus on particular areas of Puget Sound, for example, within a government's jurisdiction, or on a particular facet of the ecosystem within an agency's responsibility. In 1988, the State of Washington initiated PSAMP as a monitoring program to encompass the greater Puget Sound region with a broad, interdisciplinary approach.

The Puget Sound Ambient Monitoring Program

The *1987 Puget Sound Water Quality Management Plan* identified the lack of a long-term comprehensive program to monitor Puget Sound and its resources. PSAMP was designed to fill this need by bringing a number of existing monitoring efforts under one management structure and initiating new efforts where needed. Under the authority of the Puget Sound Water Quality Action Team (Action Team) and the *Puget Sound Water Quality Management Plan*, two committees direct and oversee the design and implementation of PSAMP. These committees are composed of scientists and managers from government agencies that help implement the program.

Government agencies that participate in PSAMP and the focus of their monitoring activities include:

- Washington State Department of Ecology
  Marine sediment, marine water and fresh water.
- Washington State Department of Fish and Wildlife
  Contaminant burdens and abundance of fish, marine birds and marine mammals.
- Washington State Department of Natural Resources
  Nearshore habitat.
- Washington State Department of Health
  Nearshore marine water (shellfish growing areas).
- King County Department of Natural Resources and Parks
  Marine water, sediment and shellfish.
- U.S. Fish and Wildlife Service
  Bird contaminants.
- National Marine Fisheries Service
  Contaminant burdens and associated health effects in fish.
- U.S. Environmental Protection Agency
  Technical and programmatic support. Sponsorship of targeted studies.
- Puget Sound Water Quality Action Team
  Coordination of PSAMP activities and management.

PSAMP reports its results and analyses through individual agency technical reports, scientific meetings and various briefings and documents prepared for managers, legislators and regional working groups. The *Puget Sound Update* is a technical document that integrates results from all of the PSAMP components and serves as an overall program report issued every two years.

Scope and Structure of this Report

This report includes results from the breadth of the PSAMP monitoring activities conducted by all the participating agencies. This is a technical report, but it does not include the methodological and analytical detail found in individual agency technical reports. This report attempts to answer the questions of citizens, lawmakers, resource managers and scientists about the condition of Puget Sound's waters, sediments 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.

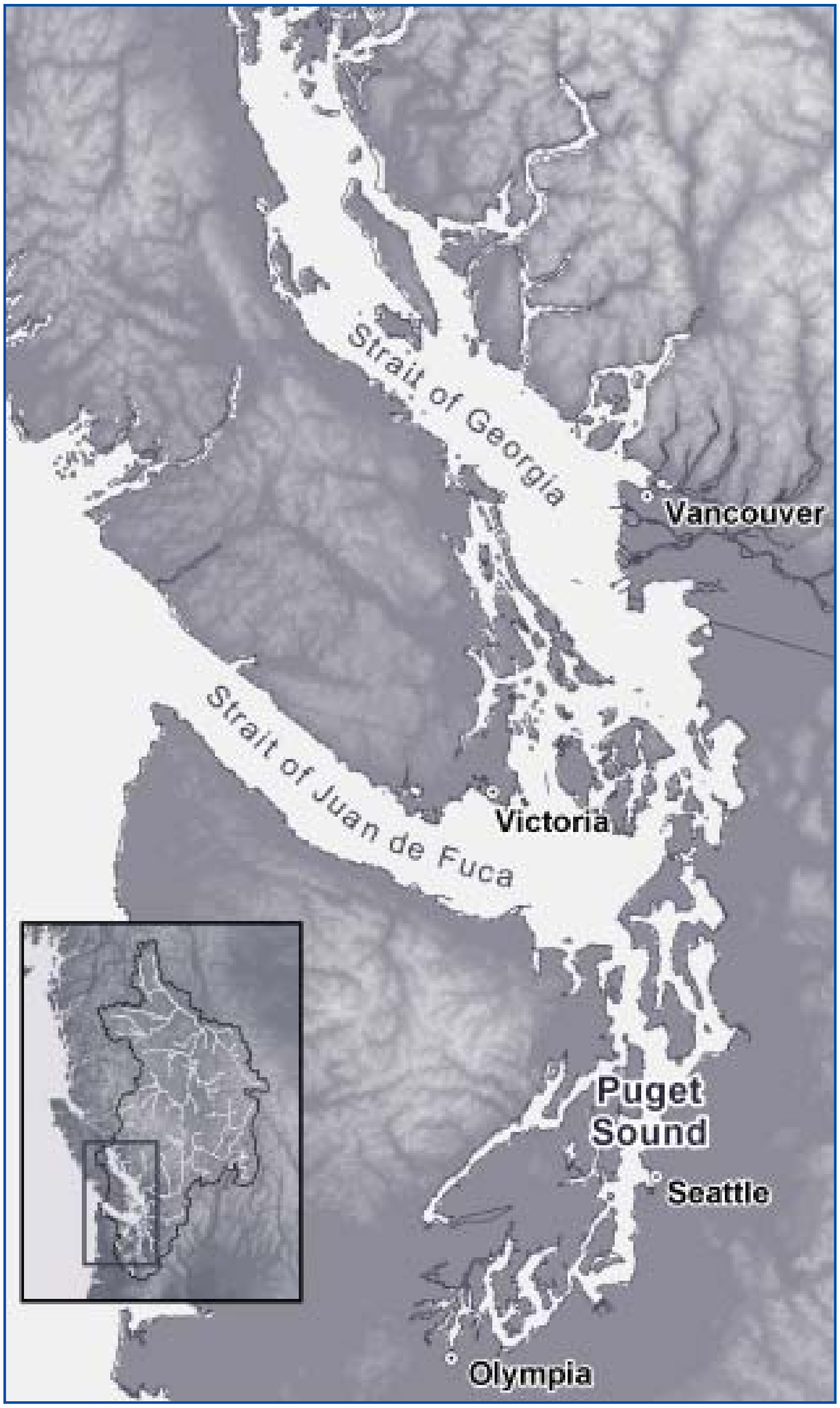


Figure 1-1. Puget Sound, the straits of Georgia and Juan de Fuca and the associated drainage basin.

Data source: HYDRO 1K dataset, U.S. Geological Survey

PSAMP uses the *Puget Sound Update* to report on its own results but also to summarize the related work of other researchers in Puget Sound as well as the larger region. The geographic scope of PSAMP is formally the inland marine waters of the State of Washington, including Puget Sound proper, part of the Strait of Juan de Fuca and the southern portion of the Strait of Georgia. In this report, the term Puget Sound is used in a broad sense to represent all these inland marine waters of Washington. In many respects, however, these marine waters of Washington are part of a single larger ecosystem that includes the entire Strait of Georgia in British Columbia (Figure 1-1). This is reflected in this report through a number of monitoring activities that are either transboundary in nature or focus on the Strait of Georgia.

PSAMP's monitoring topics and integrated questions

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 contamination in Puget Sound? How does toxic contamination affect the Sound's biological resources?

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?

Although the marine waters of Washington and British Columbia mix freely, the international border creates an institutional barrier, making it challenging to develop and share information or coordinate management programs concerning the broader ecosystem. To address this, the governor of Washington State and the premier of British Columbia entered into an Environmental Cooperation Agreement in 1992 to foster cooperation and collaboration. The joint publication of the Georgia Basin – Puget Sound Environmental Indicators Report (GBEI 2002) released earlier this year is evidence of this increasing cooperation. Also, next year's biennial research conference will be an international effort, with joint sponsorship from both sides of the border. The 2003 Georgia Basin–Puget Sound Research Conference will be in Vancouver, British Columbia. Future editions of the *Puget Sound Update* will no doubt further reflect this growing cooperation.

This report is 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. A number of monitoring activities fall into more than one category. Cross-references between chapters are provided where this occurs.

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, 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 the *Update* concludes with a short list of recommendations for acting on the findings presented in the chapter.

2. Physical Environment

Overview

The physical environment determines the extent of the Puget Sound basin and provides the atmospheric and oceanic influences that shape the dynamics of the ecosystem. The physical environment also includes the patterns and processes that create the basic habitat for all organisms. From an ecosystem perspective, the physical environment and the region's biological resources form a single interacting system.

A wealth of ecological literature characterizes the effects of organisms on their immediate environment, and scientific opinion increasingly agrees about human effects at the global scale. For example, in 2001, the Intergovernmental Panel on Climate Change (IPCC) stated that "most of the observed warming [of the atmosphere] over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations" (IPCC 2001). Closer to home, a modeling analysis of potential impacts of global climate change suggests that by 2050 the Pacific Northwest will experience greater annual precipitation but with greater seasonality (Mote et al. 1999). These studies emphasize the interaction between the physical environment and living organisms at a range of scales.

This chapter highlights climatic patterns, streamflows and monitoring results from fresh and marine waters from the last two years in the Puget Sound basin. It also addresses two important components of aquatic habitat in the basin: physical changes to the marine shoreline resulting from development, and disconnection of upper watershed fish habitat from lower freshwater and marine habitats due to fish-barrier culverts. Specific highlights from this chapter include:

- The region experienced the second worst drought on record in late 2000 and early 2001.
- La Niña conditions were interspersed with neutral conditions with respect to the El Niño-Southern Oscillation (ENSO) over the Pacific Ocean. Based on previous return intervals and ocean conditions in early 2002, scientists anticipate that El Niño conditions may emerge in 2002 and 2003.
- The Washington State Department of Ecology developed a new water quality index for rivers and streams designed to measure general watershed conditions. The index shows generally good conditions throughout the basin with fair conditions in south Sound and the lower Stillaguamish and poor conditions at three stations in Skagit County.
- Department of Ecology scientists have developed a ranking of marine water quality concern based on five variables. In this ranking, Budd Inlet, south Hood Canal and Penn Cove showed the poorest water quality but for differing reasons.
- Scientists with the Washington State Department of Natural Resources have determined that 33 percent of Puget Sound shorelines have been modified with bulkheads and half of this amount is associated with single family residences.

El Niño, La Niña and the Southern Oscillation

El Niño and La Niña refer to large-scale perturbations in the pattern of surface temperature in the equatorial Pacific Ocean. El Niño is a warming of the central and eastern equatorial Pacific and La Niña is an anomalous cooling of this area. El Niño events typically persist from 6 to 18 months and recur every 2 to 7 years. They are associated with profound perturbations on weather patterns in many areas of the world.

El Niño typically brings warmer than normal winter and spring weather to the Pacific Northwest but the impact on rainfall is less predictable. The last major event occurred in 1997-98 (see Figure 2-1).

The oceans and atmosphere are part of a coupled system, and as the equatorial Pacific Ocean experiences these large-scale patterns in surface temperature, the overlying atmosphere experiences similarly large-scale oscillations in surface pressure known as the Southern Oscillation. The Southern Oscillation Index (SOI) is calculated from surface pressure at Tahiti and Darwin, Australia and is used to monitor the state of the **El Niño–Southern Oscillation** (ENSO) system.

FINDINGS

Overview of Ocean and Weather Conditions

During 2000 and 2001, the most significant occurrence in the physical environment of Puget Sound was the second-most extreme drought in the 107-year meteorological record. During much of this period, La Niña conditions persisted in the equatorial Pacific with some temporary weakening during the summer of 2000 and a shift to neutral ENSO conditions in the spring of 2001 (Figure 2-1).

Weather Highlights

During the fall, winter and spring of 1999 through 2000, large-scale patterns over the eastern Pacific continued to be consistent with a moderate to strong La Niña over the tropical Pacific (Figure 2-1). For Western Washington, weather conditions are usually cooler and wetter than normal under these conditions (Werth 2001).

During October 1999 through February 2000, precipitation totals were near normal in all areas of Western Washington but well below the record amounts of this period in 1999 (Figure 2-2). The winter snowpack in the Cascade Mountains was above normal levels by mid-December. La Niña conditions weakened in the summer of 2000 and most of Western Washington experienced below normal temperatures and near normal precipitation. A number of areas were exceptions to this pattern, including the northeast Olympic peninsula and other areas (e.g. SeaTac, see Figure 2-2) that experienced an exceptionally dry summer. It was the second summer in a row when the temperature at SeaTac Airport never exceeded 90 degrees (Werth 2001).

Extremely dry conditions during November 2000 through March 2001 resulted in the second driest rainy season in the last 107 years for the Pacific Northwest. Only the 1976 through 1977 period was drier. Many rivers reached record low streamflow levels and reservoirs were depleted to meet water demand. This drought followed a

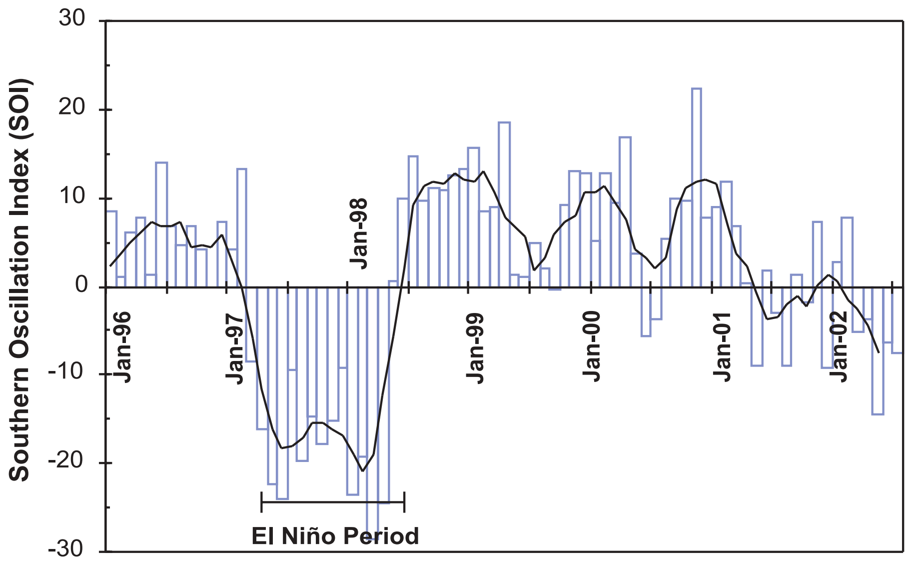


Figure 2-1. Monthly Southern Oscillation Index (SOI) and the 5-month running mean. Persistent negative values are indicative of an El Niño Event.

Monthly SOI

5-month running mean SOI

Data source: Bureau of Meteorology, Australia.

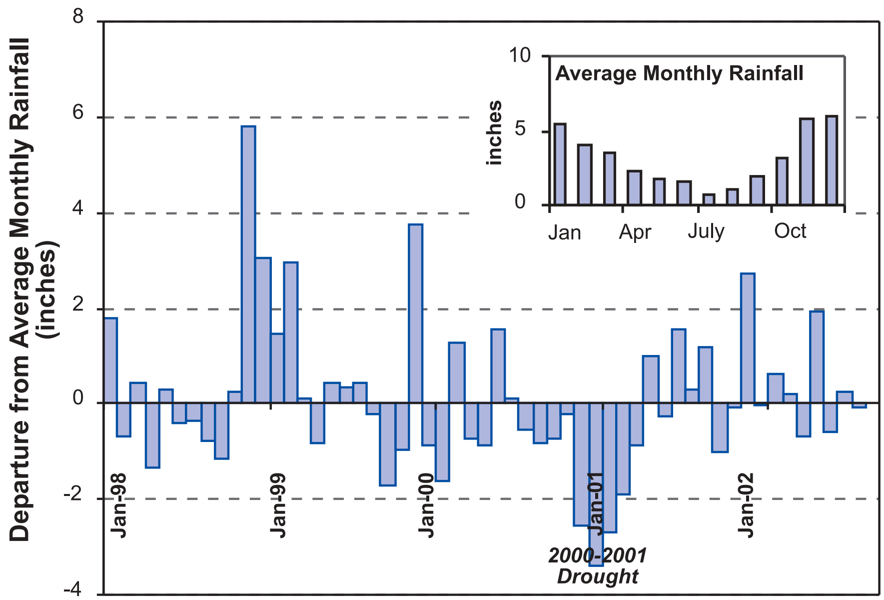


Figure 2-2. Departures of monthly rainfall from average at SeaTac Airport, January 1998 through December 2001. Inset chart shows 30-year monthly mean rainfall.

Data source: National Climatic Data Center (NCDC)

summer that was exceptionally dry in some areas, which resulted in low soil moisture before the onset of the drought. A number of private wells were reported to run dry in the Puget Sound basin. Washington, as well as Oregon and Idaho, declared drought emergencies. A series of Pacific storms near the end of autumn brought a beneficial snowpack to the mountains and a wet start to the 2001-2002 rainy season (NCDC 2001).

Ocean Highlights

The Pacific Ocean influences the physical conditions in Puget Sound directly through exchange of marine waters through the Strait of Juan de Fuca. This exchange is one of the major factors, together with stream water inflow, that control water temperature, salinity and nutrient levels. Upwelling of deeper ocean water is a process that varies over time and has a significant impact on the conditions of coastal ocean water as well as Puget Sound marine water. Upwelled water is cooler, saltier and more nutrient rich than surface water with higher levels of nitrogen, phosphate and silica. The intensity and extent of upwelling influence marine primary production, which affects the productivity and abundance of organisms higher in the food web. Upwelling varies on time scales of days and weeks but can also display patterns over seasonal to interannual periods.

The NOAA Pacific Fisheries Environmental Laboratory (National Marine Fisheries Service) has developed an upwelling index that represents the intensity of upwelling at a number of sites along the Pacific Coast. The index is derived from six hourly and monthly mean surface atmospheric pressure fields. Figure 2-3 shows the recent pattern in the monthly upwelling index for a point off the northwest coast of the Olympic peninsula. The long-term mean pattern shown in Figure 2-3 reflects increased upwelling in the summer months. During 2000 and 2001, no strong periods of suppressed upwelling occurred as in the early months of 1998 and 1999. Increased upwelling did occur in the fall (and late summer of 2001) but well within the level of variation seen in recent years.

Patterns of sea-surface temperature over the Pacific Ocean that change in space and time have also been shown to have important impacts on the Pacific Northwest environment. As noted earlier, El Niño events in the tropical Pacific are linked to climate anomalies in many areas of the world—including the Pacific Northwest—that can affect all components of an ecosystem. A more recent discovery is a pattern in sea-surface temperature in the temperate Pacific Ocean that varies at the scale of decades. This pattern is known as the Pacific Decadal Oscillation (PDO) and has been shown to be closely associated with variations in some fish populations (Hare et al. 1999).

The PDO varies irregularly but is characterized by periods of relative stability that can last for 20 to 30 years with sharp periods of transition, or regime shifts, between these stable states. The index used to track the PDO is based on a multivariate analysis of sea-surface temperatures over the northern Pacific Ocean (Mantua et al. 1997). Statistical analysis of the index time series indicates regime shifts around 1925, 1947 and 1977 (Figure 2-4).

The 1947 and 1977 regime shifts correspond with dramatic shifts in salmon production in the Pacific Northwest and in Alaska. It has been shown that Pacific salmon catches in Alaska have varied inversely with catches from the Pacific Northwest during the past 70 years, and this pattern is associated with the PDO (Hare et al. 1999). For instance, from 1977 to the early 1990s, ocean conditions favored Alaskan salmon stocks and disfavored Pacific Northwest stocks while in the previous period, Alaskan stocks were low and some Northwest stocks were very productive (Hare et al. 1999).

An analysis of western North American tree-ring records shows evidence of the PDO back to AD 1700 (D'Arrigo et al. 2001). It is clear that both the PDO and ENSO are persistent, large-scale oscillations in sea-surface temperature patterns in the Pacific Ocean. It is not clear at this point how the two are related. Mantua et al. (1997) suggest that ENSO operates within the constraints of the PDO, i.e., the PDO regime dictates the amplitude of the ENSO signal.

Rivers and Streams—Freshwater Input to Puget Sound

Freshwater inputs from rivers and streams are an important part of the Puget Sound hydrologic cycle and a major factor controlling the estuarine environment. These inputs have a direct impact on water temperature, salinity and the pattern of these variables both vertically and horizontally within the Sound. Rivers and streams also serve to link the marine environment with the upper watersheds. Human activities in the watersheds affect river nutrient and sediment loadings and the presence of pathogens, which in turn influence the Puget Sound marine environment.

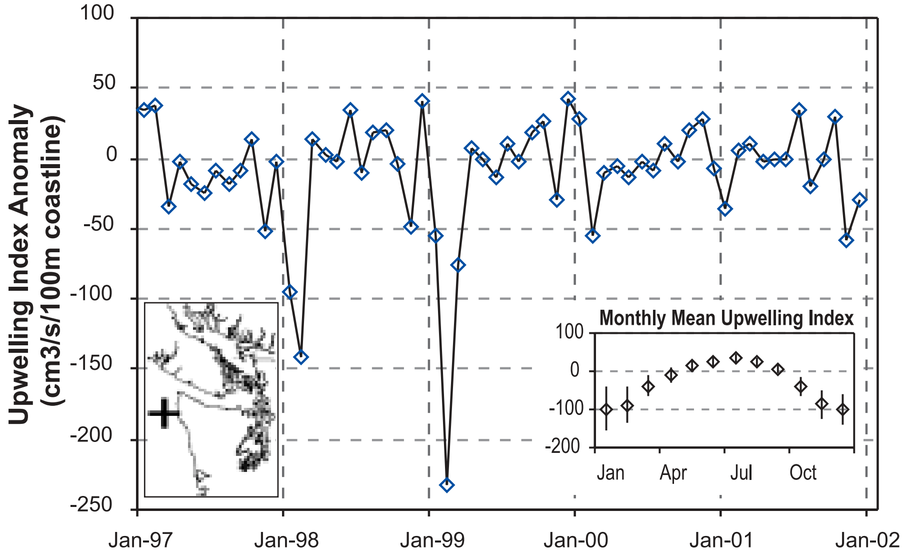


Figure 2-3. Monthly upwelling index anomaly relative to the long-term monthly mean (1967-1991) for the location indicated in the map, 48° North, 125° West. The inset graph shows the long-term monthly mean with error bars indicating +/- one standard deviation. Positive values are associated with increased upwelling.

Data source: NOAA Pacific Fisheries Environmental Laboratory.

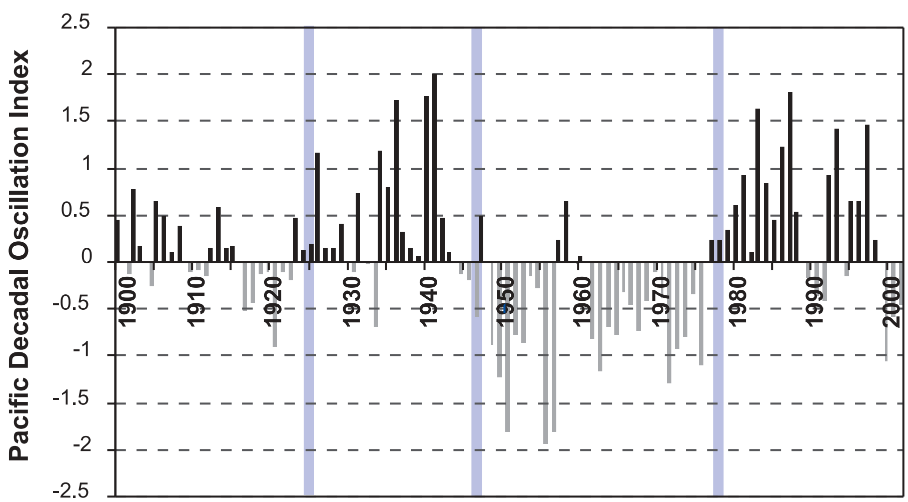


Figure 2-4. Annual Pacific Decadal Oscillation (PDO) index derived from an analysis of sea-surface temperatures over the Pacific Ocean (Mantua et al. 1997). The vertical blue lines indicate regime shifts between different states of the PDO. The data suggest a regime shift may also have occurred in 1998 through 1999, although data from several more years will be necessary to confirm this.

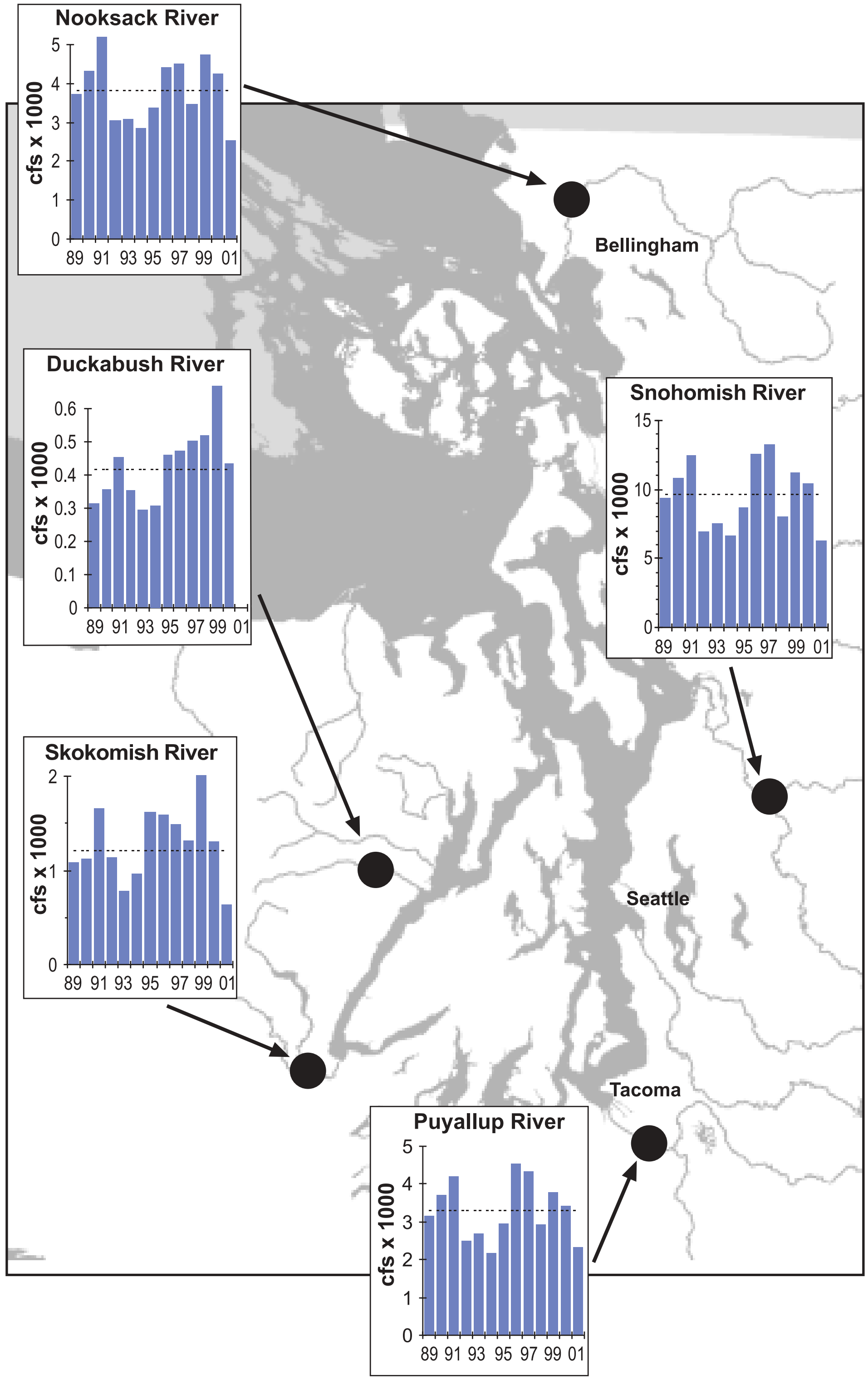
Data source: University of Washington

All streamflow is ultimately derived from precipitation, but it reaches rivers and streams through different mechanisms. Runoff of rainfall is generally the greatest contributor to streamflow but in the spring and particularly in the drier months of summer, snowmelt in the higher elevations becomes a very important source. Groundwater intrusion to stream channels also can be a major contributor to streamflow.

Figure 2-5 shows mean annual flow rate for five major rivers of the Puget Sound basin relative to the long-term averages. These data are calculated on a wateryear basis that runs from October through September of the following year. Wateryear 2001, for example, began October 1, 2000 and ended September 30, 2001. There are local variations in precipitation that are reflected in the different patterns seen in the five rivers over the 13-year record (only 12 years were available for the Duckabush River). Strong climatic signals, however, are generally not localized and these can be seen in data from all the rivers. For example, the 3-year period of below average rainfall from 1992 to 1994 is reflected in all five river flows. Likewise, the recent drought of wateryear 2001 is reflected in data from each river where these data are available. More subtle climatic signals can be seen in the data that are not pervasive over the entire Puget Sound basin but are consistent within smaller geographic areas of the basin. For instance, the three rivers draining the eastern side of Puget Sound (Nooksack, Snohomish and Puyallup) each had above average flows in the years

Figure 2-5. Annual mean flow in five major Puget Sound rivers on a wateryear basis (October through September), expressed as cubic feet per second (cfs) x 1000.

Data Source: U.S. Geological Survey



between 1996 and 2000 and below average flows in 1998. In contrast, the two rivers to the west of Puget Sound that drain parts of the Olympic peninsula had above average flows throughout the 1995 through 2000 period. This reflects the strong geographic patterns that exist within the Puget Sound basin and highlights the importance of understanding basic landscape processes, both physical and biological, at smaller scales.

In addition to the magnitude and timing of freshwater discharge, water quality characteristics of the freshwater inputs are important controlling factors on the Puget Sound marine environment. The Department of Ecology regularly monitors water quality at a number of rivers and streams in the Puget Sound basin as part of the Puget Sound Ambient Monitoring Program (PSAMP). The department initiated its freshwater sampling program in 1970 and currently samples 14 water quality parameters on a monthly basis. The Department of Ecology recently started reporting freshwater conditions using a Water Quality Index (WQI) for eight parameters in addition to a single overall WQI for each sampling station (Ecology 2001). The overall WQI aggregates results from one year of sampling of the eight parameters. These eight parameters include measures of nutrients (total nitrogen, total phosphorus), pathogens (fecal coliform bacteria) and other physical parameters (water temperature, dissolved oxygen, pH, total suspended solids, turbidity) (Butkus et al. 2001). The Department of Ecology also monitors biological conditions (benthic invertebrates) and the spread of invasive, nonnative aquatic plant species.

Figure 2-6 shows the overall WQI analysis for the long-term freshwater monitoring stations in the Puget Sound basin for wateryear 2000. This analysis categorizes just over half of the stations (17 of 33) as being of lowest concern. Some stations in the South Sound area and the lower Stillaguamish were categorized as being of moderate concern. Three stations were of highest concern in Skagit County, two on the Skagit River and one on Joe Leary Slough.

The temperature WQI is shown in Figure 2-7. Temperature is an important parameter influencing habitat quality for a number of aquatic organisms. The results show that there were no chronic water temperature problems at the long-term monitoring stations in wateryear 2000. A trend analysis based on data collected from 1991 through 2000 showed either no detectable trend or decreasing temperatures at all of the monitoring stations (Butkus et al. 2001). These analyses do not imply that there are no temperature problems in the rivers and streams in the Puget Sound basin. In 1998, the Department of Ecology listed 105 fresh water bodies under the federal Clean Water Act—the **303(d) list**—with water quality problems associated with high temperatures. The long-term monitoring stations (Figure 2-7) do not reflect these largely localized problems because the sample design targets sites that are representative of general watershed conditions, e.g., mainstem sampling sites rather than smaller tributaries.

Culverts as Barriers to Migrating Fish

Culverts are pipes or arches made of concrete or metal, that permit water to flow beneath roads where they cross streams. When these streams are bearing fish, culverts are required to be designed to allow for the passage of migrating fish. Many existing culverts, however, present a barrier to fish passage either by improper design, because of changes in watershed hydrology or because of deterioration and the need for maintenance. These culverts may have openings that are too high above the streams for fish to jump into or the culverts may be positioned so that they are too steep. In other cases the culverts are undersized for a particular drainage and may become clogged with debris. These culverts result in habitat loss, as the upstream aquatic areas are made unavailable for spawning and rearing. Fortunately this habitat loss is reversible with maintenance or replacement of these barrier culverts.

The Clean Water Act—303(d) and 305(b) lists

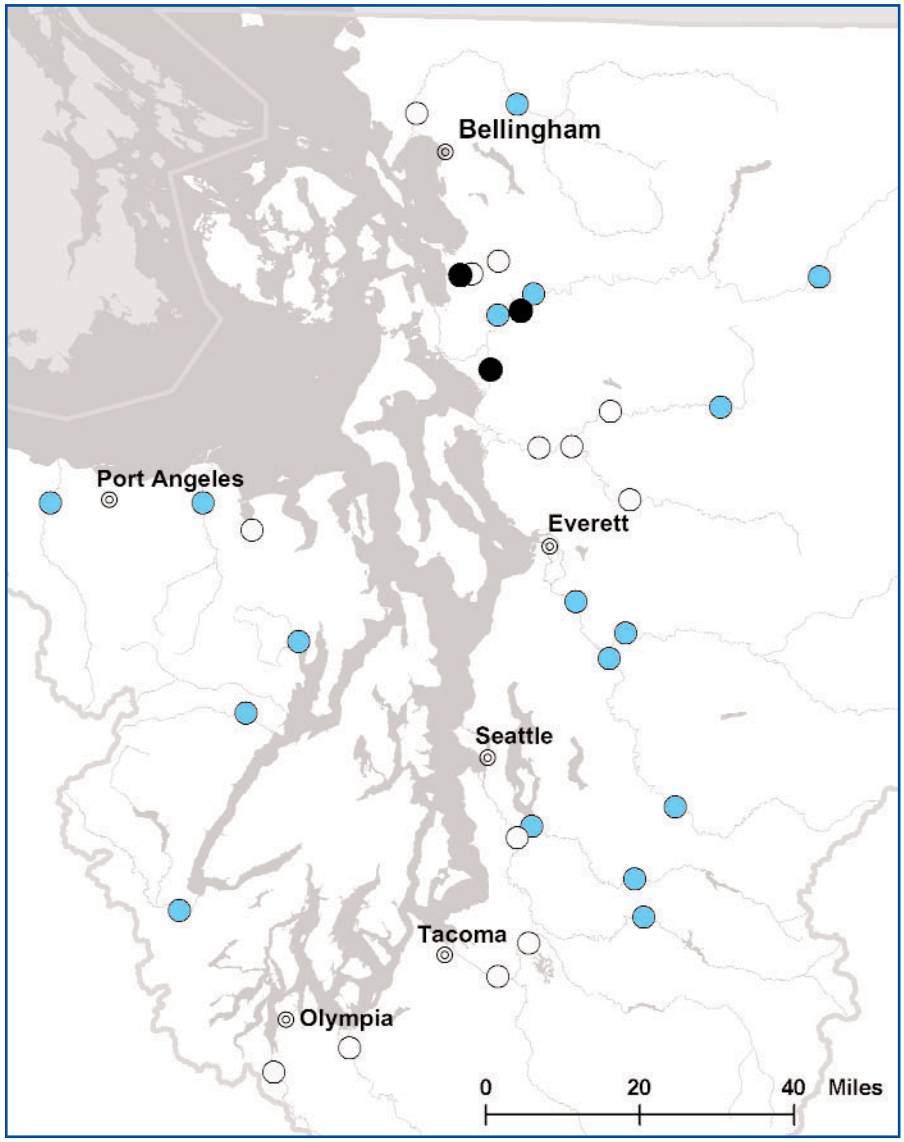
The Washington State Department of Ecology's Water Quality Program uses monitoring data to meet requirements of sections 303(d) and 305(b) of the federal Clean Water Act, pertaining to the status of Washington's water quality. Section 303(d) of the Act requires each state to identify degraded water bodies and submit this list, called the **303(d) list**, to the EPA every two years. The purpose of Section 305(b) is to provide a more general statewide assessment of the state's waters and report the results, called the **305(b) report**, to EPA every two years. In the past, the two reporting requirements were on different timelines. EPA has recently developed guidance for states to merge the two processes, and has set a new transitional deadline of October 2002 to submit both the 303(d) list and the 305(b)report.

When a waterbody is placed on the 303(d) list, the Clean Water Act requires a management effort to restore water quality. This is done through the Total Maximum Daily Load (TMDL) process for individual pollutants. The current list, completed in 1998, was summarized in the *2000 Puget Sound Update.* The Department of Ecology is now in the process of revising the policy guidelines for listing waterbodies that will be reflected in the next 303(d) list.

Figure 2-6. Overall water quality in rivers and streams as measured by the Department of Ecology's Water Quality Index for wateryear 2000.

● Highest Concern
○ Moderate Concern
● Lowest Concern

Source: Washington State Department of Ecology.



No comprehensive inventory exists of culverts along the 170,000 miles of public and private roads in Washington State (WSDOT 2000). Consequently, the Washington State Department of Transportation (WSDOT) has identified inventory and assessment of culverts as a priority (WSDOT 2000). The Washington State Department of Fish and Wildlife and WSDOT jointly maintain the most complete inventory of culverts. This is the Salmonid Screening, Habitat Enhancement and Restoration (SSHEAR) Fish Passage database. In addition to a simple inventory of culverts, the database includes assessments based on state Department of Fish and Wildlife guidelines, on whether the culverts represent barriers to fish passage. The database also forms part of a broader database that characterizes freshwater and estuary habitat conditions and salmonid stocks in Washington. This is the Salmon and Steelhead Habitat Inventory and Assessment Program (SSHIAP), a joint effort of the Northwest Indian Fisheries Commission and the state Department of Fish and Wildlife. The SSHEAR database is continually improving as new inventories are submitted by tribes, local jurisdictions, state agencies and other entities (Figure 2-8). These new additions to the database include recent as well as older culvert assessments. During 2000 and 2001, several agencies led efforts to expand the SSHEAR database with new culvert assessments: state Department of Fish and Wildlife (934 culvert assessments); Pierce County Conservation District (164 culvert assessments); and Skagit Systems Cooperative (111 culvert assessments). The new

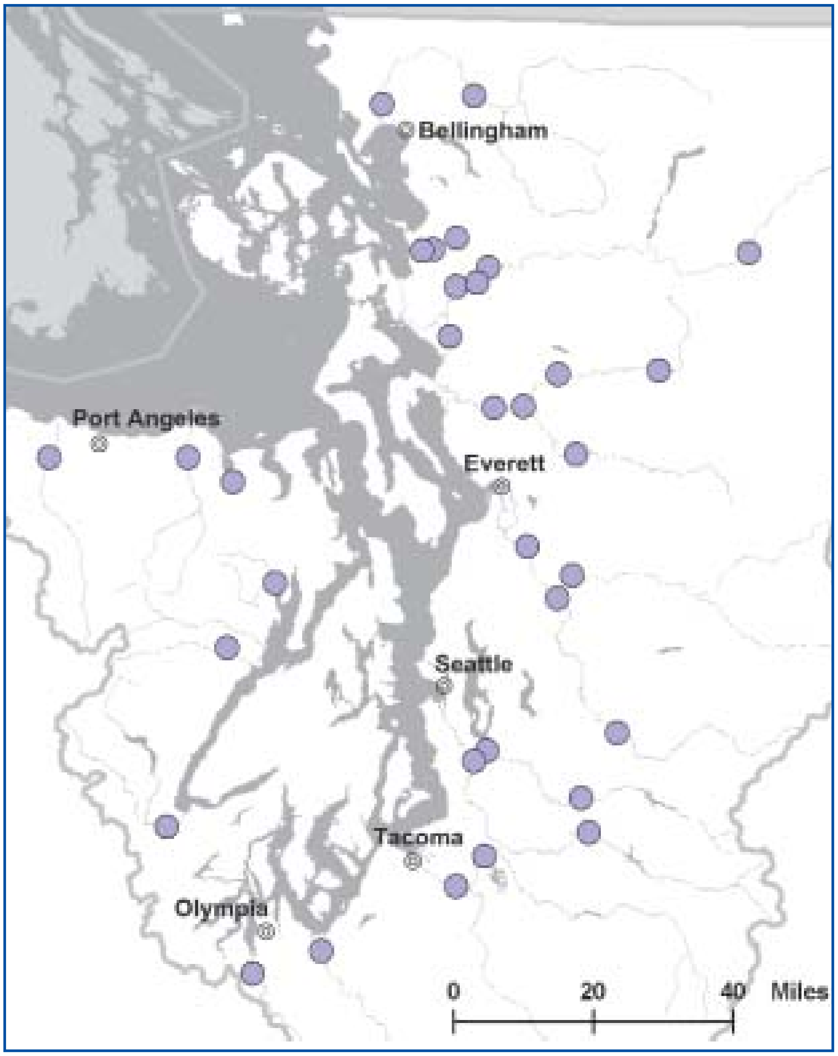
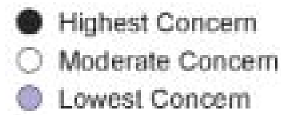


Figure 2-7. Water temperature conditions in rivers and streams as measured by the Department of Ecology's temperature Water Quality Index (WQI) for wateryear 2000.



Source: Washington State Department of Ecology.

assessments from Pierce County were primarily in the southern Kitsap peninsula and appear in the Kitsap Water Resources Inventory Area (WRIA) 15 in Figure 2-8.

Currently the SSHEAR inventory contains 4,619 culverts in the Puget Sound basin, but 1,093 of these are located in non fish-bearing streams and therefore do not impact migrating fish. Of the culverts on fish-bearing streams and streams of unknown fish-bearing status, 1,828 (52 percent) have been assessed to be either partial or total fish passage barriers.

The 2000 and 2001 additions increased the SSHEAR database by 37 percent. This reflects a substantial effort to inventory and assess Washington culverts, but the state Department of Fish and Wildlife estimates that the SSHEAR database represents only 10 to 15 percent of the culverts in Washington State.

Repair or replacement of fish barrier culverts is a priority for protecting salmon populations within the Puget Sound basin. During 1998 through 2000, WSDOT funded the repair or replacement of 84 culverts. During this period many more barriers were eliminated using federal funds, primarily by the U.S. Fish and Wildlife Service through the Jobs in the Woods program (GAO 2001).

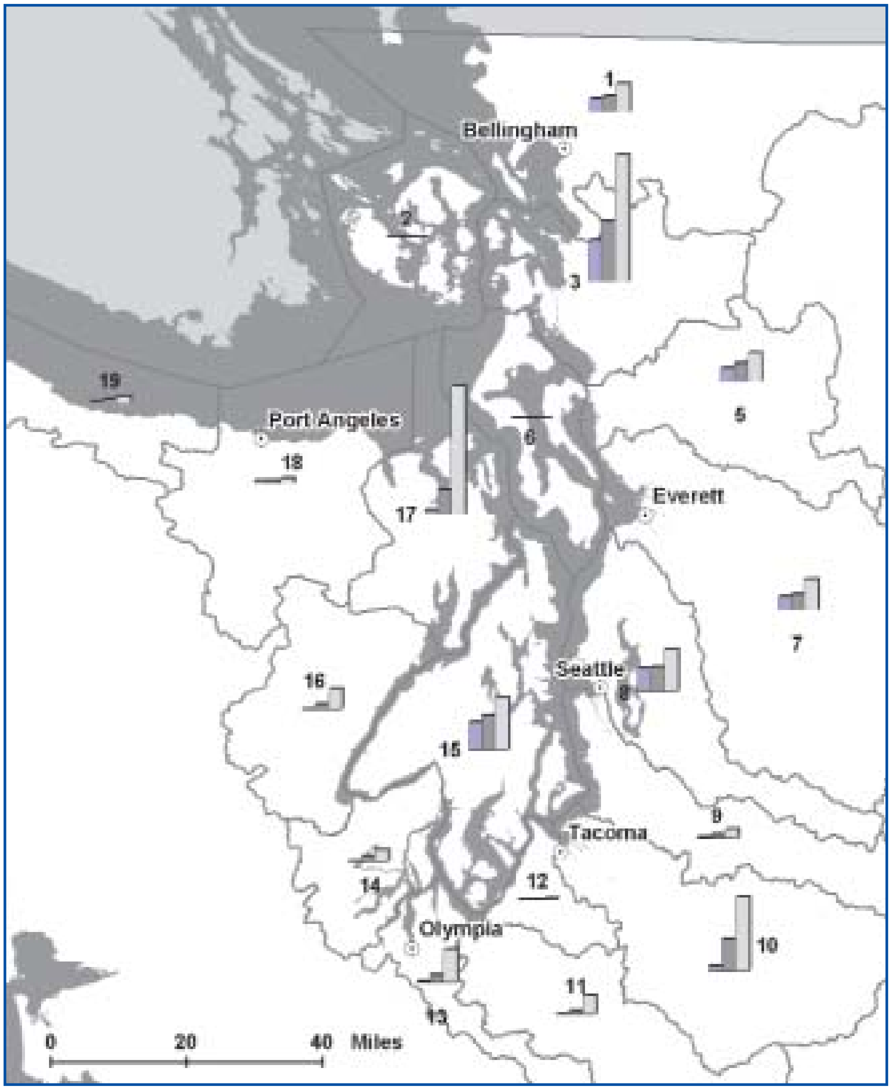


Figure 2-8. Culvert inventory for each Puget Sound WRIA as represented in the SSHEAR fish barrier database. The graphs indicate total number of culverts in the database and those that are known fish migration barriers. The number of new culvert assessments indicates the progress made during 2000-01 in reaching a full inventory of Puget Sound culverts.

The Puget Sound basin is composed of Water Resource Inventory Areas (WRIAs) 1-19 as shown.

Data source: Washington State Department of Fish and Wildlife

Culverts on Federal Lands

A recent report by the U.S. General Accounting Office (GAO 2001) reviews the status of culverts and efforts to remove fish passage barriers on federal lands in Washington and Oregon. The report acknowledges that the total number of fish barrier culverts on these federal lands is not known. Based on current assessments, however, federal agencies estimate that restoration of fish passage to barrier culverts may ultimately cost more than $375 million and take decades. Between one to two years is required for each barrier removal project. The Forest Service and the Bureau of Land Management completed 141 culvert projects between July 1998 and August 2001 on federal lands in Washington and Oregon. This effort opened approximately 171 miles of fish habitat to anadromous fish, but most of this was outside the Puget Sound basin.

Puget Sound's Marine Waters

Water properties in Puget Sound are affected by many things, including river flow, air temperature, winds, sunlight and ocean properties. Cold seawater temperatures can either be from an influx of cold, recently upwelled ocean water or from local cool weather. High salinity can be from upwelled ocean water or from a lack of river flow. Department of Ecology scientists are studying how weather and climate influence water properties in Puget Sound.

An important water property for water quality is the degree and persistence of density stratification in the water column. Warm, fresh water is lighter (less dense) than cold, salty water. If there is a strong density gradient, the water column is **stratified.** Whereas if mixing processes, such as tides and winds, disrupt this, then the water column becomes **well-mixed.** The stable layers in a stratified water column are more susceptible to developing water quality problems, e.g. depleted oxygen. For example, the addition of nutrients from human activities to the surface layer of a stratified water column can lead to high nutrient concentrations (since mixing is suppressed) supporting algal blooms. As the algae settles and decays, zones of low oxygen can develop at depth, which can be deleterious to organisms. Thus, stratification has important implications for water quality.

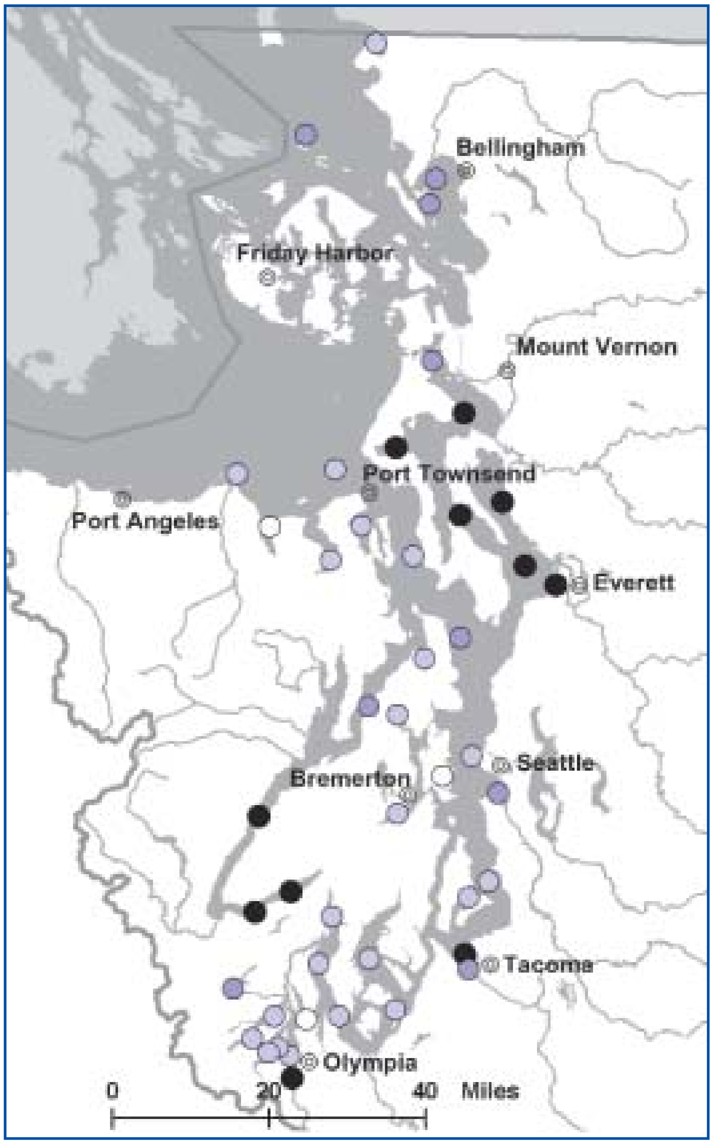


Figure 2-9. Intensity of water column stratification in Puget Sound during wateryears 1998-2000.

- Strong and Persistent
- Strong and Intermittent
- Moderate and Infrequent
- Weak and Infrequent

Source: Washington State Department of Ecology

Department of Ecology scientists classify marine water stratification based on both the intensity of the stratification and its persistence. All Puget Sound waters were compared for the strength of density stratification (3 levels) as well as the amount of time it remains stratified (3 levels). Though seven categories were actually possible in the 3x3 analysis, only four were observed in Puget Sound: strong, persistent stratification; strong intermittent stratification; moderate infrequent stratification; and weak infrequent stratification.

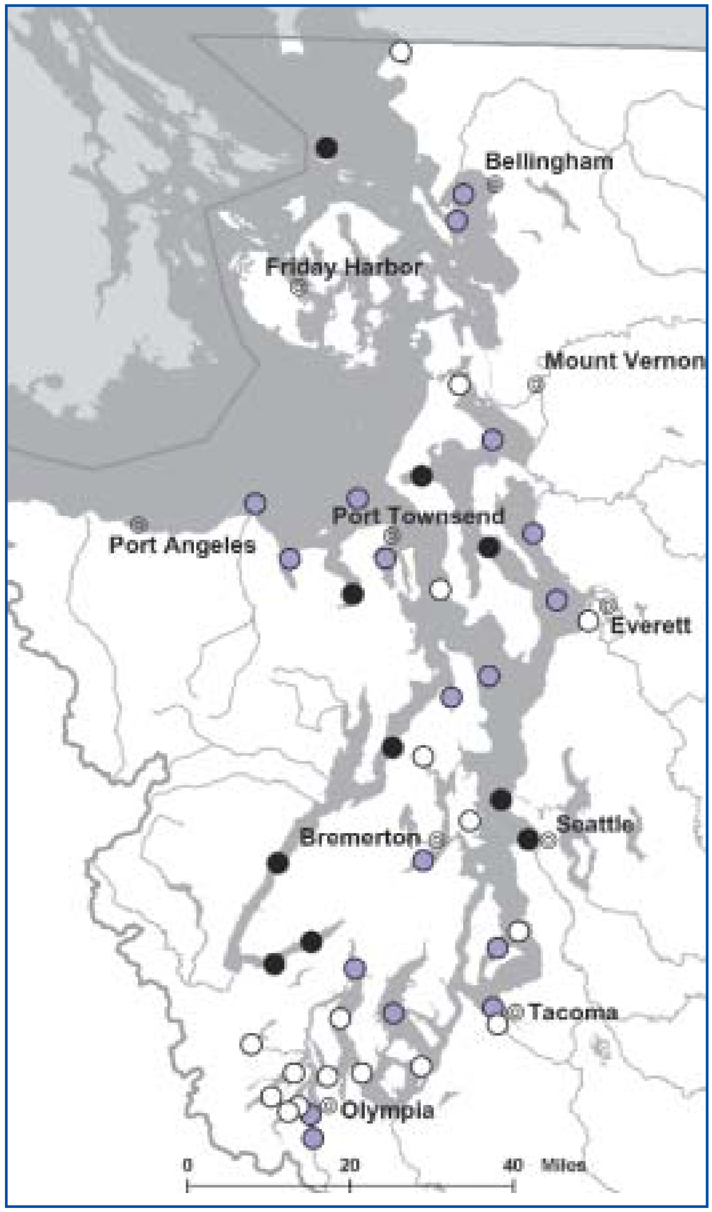
The distribution of stratification properties at various monitoring stations throughout Puget Sound is shown in Figure 2-9. As expected, the strongest stratification is found near river drainages.

Figure 2-10 shows locations in Puget Sound where Department of Ecology scientists measured low concentrations of dissolved oxygen from 1998 through 2000. These results represent the minimum dissolved oxygen measured in the entire water column. 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.

Figure 2-10. Areas of low dissolved oxygen (DO) in Puget Sound waters, wateryears 1998 to 2000. These are the lowest values measured through the entire water column.

- Very low DO (<3mg/L)
- Low DO (<5mg/L)
- High DO (>5mg/L)

Source: Washington State Department of Ecology



While much of the information in Figure 2-10 is similar to that presented previously, there are some differences. In general, dissolved oxygen concentrations seem to be lower in many areas than was found during 1996 and 1997. Observations below 3 milligrams per liter (mg/L) occurred in the Strait of Georgia near Patos Island, Saratoga Passage, north Hood Canal, Elliott Bay, and off West Point, whereas previous observations at these stations were above 3 mg/L. The strong upwelling and shallow thermocline in the Pacific during the 1999 La Niña may have contributed to this signal. Department of Ecology scientists are working to differentiate what part of the signal is from changing ocean conditions and what part, if any, might be due to human effects.

Water Quality Concern

The monitoring of marine waters in PSAMP conducted by the Department of Ecology is focused on assessing temperature, salinity, density, dissolved oxygen, nutrients, chlorophyll, and fecal coliform bacteria. These variables can be used to help assess eutrophication (dissolved oxygen, nutrients, chlorophyll, stratification), sewage waste (fecal coliform, ammonium), food available to secondary producers

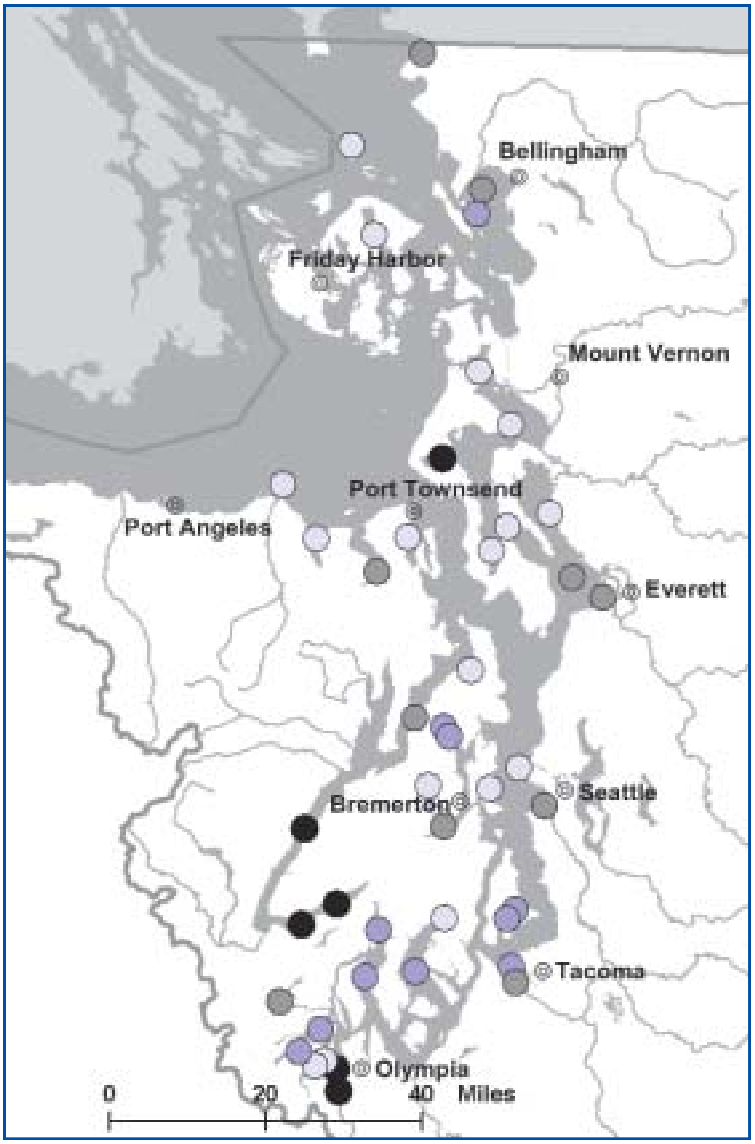


Figure 2-11. Integrated assessment of marine water quality for wateryears 1994-2000. The assessment is based on parameters shown in Table 2-1.

Source: Washington State Department of Ecology

(chlorophyll), and pelagic habitat quality (temperature, salinity), as well as to determine compliance with federal and Washington State water quality standards for temperature, dissolved oxygen, and fecal coliform bacteria. Fecal coliform and nutrient data are presented in more detail in Chapter 3. The determination of water quality concern is based on all these variables and is discussed in this section.

Using these variables, the Department of Ecology scientists have developed five indicators designed to assess overall water quality: strength/persistence of stratification; lack of nitrogenous nutrients for several months; low dissolved oxygen concentrations; high ammonium concentrations; and high fecal coliform bacteria counts. To rank these attributes, the Department of Ecology identified two thresholds for each of the indicators. These indicators are discussed individually in the coming chapters, but collectively these can be viewed to point out general patterns of overall water quality concern.

Figure 2-11 shows the level of water quality concern estimated for various locations in greater Puget Sound using data from 1994 through 2000. Table 2-1 depicts factors responsible for the level of concern. Budd Inlet showed the poorest water quality because it showed high fecal and ammonium concentrations, as well as having strong, persistent stratification with accompanying low oxygen and depleted nutrients. These

Table 2-1. Results for each parameter used to derive the water quality concern index, by waterbody. The indicator attributes of most concern to water quality are shown in blue:

- **DO** = dissolved oxygen
- **FCB** = fecal coliform bacteria
- **DIN** = dissolved inorganic nitrogen
- **NH4** = ammonium
- **Stratif** =stratification

For stratification, results are indicated as:

- **SP** = strong persistent
- **SI** = strong intermittent
- **MI** = moderate infrequent
- **WI** = weak infrequent

Colors in the last column correspond to data in Figure 2-11.

- Highest Concern
- High Concern
- Moderate Concern
- Lower Concern

Source: Washington State Department of Ecology

Station	DO	FCB	DIN	NH4	Stratif	WQ Concern Index
Budd Inlet	**Very Low**	High	**Low**	High	**SP**	
S. Hood Canal	**Very Low**		**Low**		**SP**	
Penn Cove	**Very Low**		**Low**		**SP**	
Upper Willapa Bay		**Very High**	**Low**	Moderate	SI	
Possession Sound	Low	High	Moderate	**High**	**SP**	
Grays Harbor		**Very High**		Moderate	**SP**-MI	
Commencement Bay	Low	**Very High**			**SP**	
Bellingham Bay	Low	Moderate	**Low**	Moderate	SI	
Oakland Bay		**Very High**	Moderate	Moderate	SI	
Sinclair Inlet	Low	High	**Low**	Moderate	MI	
Elliott Bay	Low	**Very High**			SI	
Discovery Bay	**Very Low**		Moderate	Moderate	MI	
N. Hood Canal	Low		**Low**		SI	
Carr Inlet	Low		**Low**	Moderate	MI	
Drayton Harbor		Moderate	**Low**		MI	
Saratoga Passage	Low		Moderate		**SP**	
Case Inlet	Low	Moderate	Moderate	Moderate	MI	
Port Orchard		High		Moderate	MI	
Quartermaster Hbr	Low			Moderate	MI	
Totten Inlet			Moderate	Moderate	MI	
Outer Willapa Bay			**Low**		MI-WI	
Holmes Harbor	Low				**SP**	
Skagit	Low				**SP**	
Port Susan	Low				**SP**	
East Sound	Low			Moderate	MI	
West Point		High			MI	
Dungeness	Low				MI	
Port Gamble	Low				MI	
Sequim Bay	Low				MI-WI	
Dyes Inlet			Moderate		WI	
Eld Inlet			Moderate		MI	
Burley-Minter				Moderate	MI	
Port Townsend	Low				MI	
Strait of Georgia	Low				SI	

waters have received less nutrient input in the late 1990s due to wastewater treatment plant incorporation of nitrogen removal. The bay may be improving, but it is too soon to evaluate with certainty. South Hood Canal continues to have very low dissolved oxygen concentrations and strong nutrient limitation. Oxygen levels appear to be decreasing, though the cause is not easy to evaluate. Other possibilities include eutrophication, changes in circulation due to freshwater diversion, interannual variation, and climate forcing. Penn Cove falls in the highest concern category because of low dissolved oxygen, low dissolved inorganic nitrogen and strong, persistent stratification. The highest fecal contamination is seen in Commencement Bay, Elliott Bay, and Oakland Bay. It is clear from this analysis that water quality is quite varied in Puget Sound and water quality is impaired for a variety of reasons, including natural causes.

More detailed results of dissolved inorganic nitrogen, ammonium and sensitivity to eutrophication are given in Chapter 3.

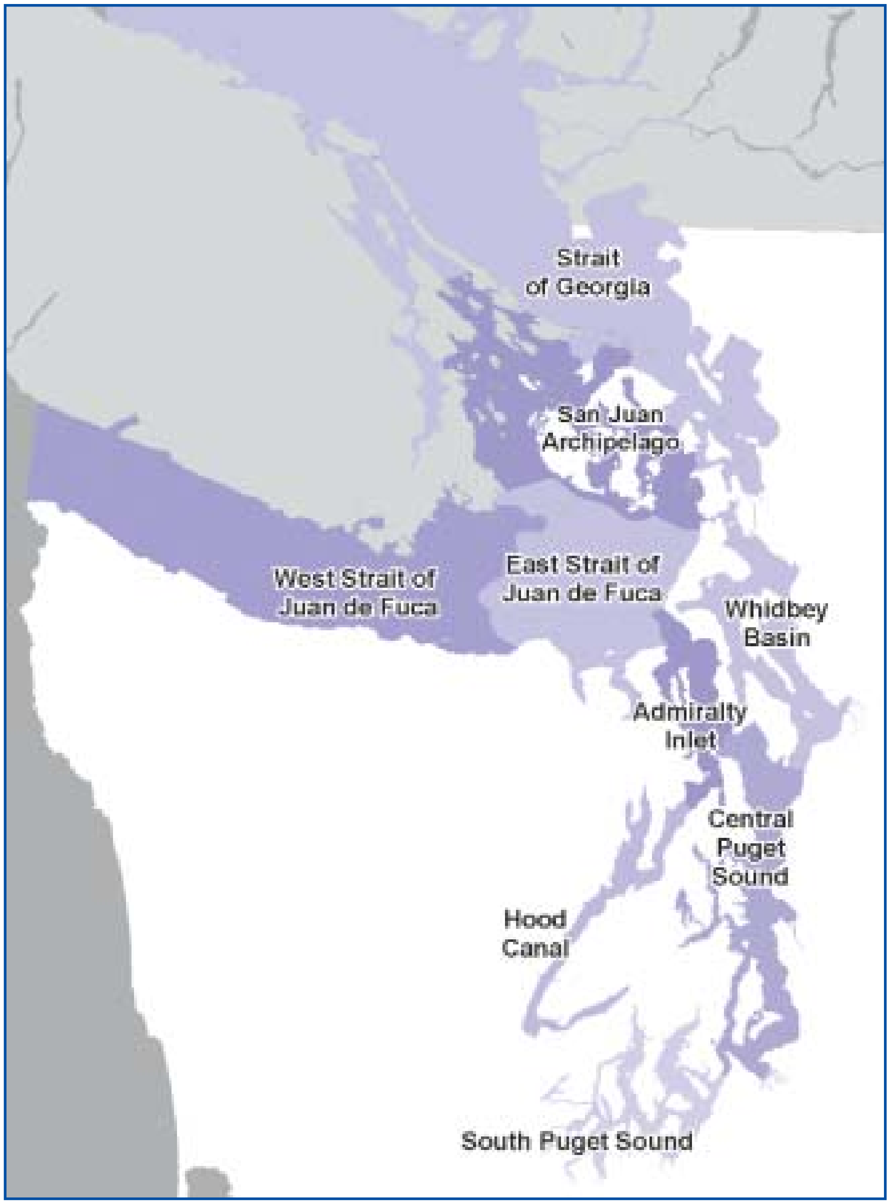


Figure 2-12. Sub-basins delineated by PSAMP. Boundaries largely follow those of Ebbesmeyer et al. (1984).

Source: PSAMP Steering Committee

Delineation of Sub-basins

Puget Sound and the straits of Georgia and Juan de Fuca form a complex network of inland waters. Glacial action scoured several basins, leaving them separated by sills. Denser ocean water enters these basins and circulates at depth while fresher waters from river inputs circulate and move toward the ocean near the surface. Strong mixing and refluxing of water masses occurs at the sills, which form natural boundaries to the basins.

PSAMP has delineated major basins of greater Puget Sound based primarily on the work of Ebbesmeyer et al. (1984) (Figure 2-12). Boundaries coincide with sills where they occur, but some demarcations are arbitrary with no clear physiographic basis. The purpose of this delineation is to provide a basis for common reporting of monitoring results at a sub-basin scale for future editions of *Puget Sound Update* and other reports.

Sills

In Puget Sound sills occur as linear features. They are elevated areas of the bottom of the Sound that partially separate basins. A sill restricts the movement of bottom water masses and can result in partial isolation of the basins.

Puget Sound's Shoreline

Shoreline Modification

Humans have modified Washington State's shorelines extensively. Shoreline modification, such as bulkheads and seawalls, directly converts areas of intertidal habitat to uplands, and indirectly affects habitat through altering nearshore processes. The amount of modified shoreline in an area can be a useful indicator of the extent of human impact on the nearshore environment.

Scientists with the Nearshore Habitat Program at the Department of Natural Resources inventoried the extent of shoreline modification as part of a statewide inventory of saltwater shorelines. The shoreline modification results are discussed here. Other data in the statewide ShoreZone Inventory are discussed in Chapter 6.

The inventory results show that approximately one-third of all saltwater shorelines in Washington State have some of kind shoreline modification structure, such as a bulkhead (Table 2-2).

Shoreline modification is not evenly distributed geographically (Figure 2-13). The outer coast has relatively little modification, while Puget Sound is more extensively modified. The large river deltas in Puget Sound are some of the most extensively modified areas, including the Commencement Bay/Puyallup River areas and the Elliott Bay/Duwamish River areas. These urban embayments were once highly productive estuarine deltas. At the county level, Snohomish County and King County have the most highly modified shorelines. These areas have relatively high population densities and a high proportion of unconsolidated shorelines. Much of the shoreline has been modified (historically and recently) for agricultural, industrial and residential uses. San Juan County has the lowest modification overall. This county is less heavily developed, and many of the shorelines are rocky, which do not tend to erode. In addition to structures such as bulkheads, the ShoreZone Inventory summarizes other types of shoreline modification. For example, it estimates that the state has approximately 1,200 boat ramps, 3,600 piers and docks, and 30,000 recreational boat slips.

Shoreline Modification Associated with Single-Family Residences

Shoreline modifications, such as bulkheads, are known to degrade shoreline habitats by interrupting natural shoreline processes. For this reason, a variety of state and federal statutes regulate shoreline modification projects. State statutes exempt projects associated with single-family residences or subject them to less stringent criteria. In the past, resource managers have suggested that existing policies might be altered to address the cumulative impacts of shoreline modification due to single-family residences. However, the relative proportion of shoreline modification associated with single-family residences was not known.

To determine the relative significance of single-family residences in overall shoreline modification, Department of Natural Resources scientists collected data on the proportion of shoreline modification along state saltwater shorelines associated with single-family residences. They found that approximately half of all shoreline modification in Washington State is associated with single-family residences (55 percent ±9 percent). This finding suggests that shoreline modification associated with single-family residences is a major component of total shoreline modification.

County	Total Miles	Miles Modified	Percent Modified
Snohomish	133	99	75%
King	123	84	68%
Pierce	239	129	54%
Thurston	118	54	46%
Kitsap	254	110	43%
Mason	231	92	40%
Skagit	229	81	35%
Whatcom	147	49	34%
Grays Harbor	187	45	24%
Island	214	49	23%
Pacific	276	57	21%
Clallam	254	27	11%
Jefferson	254	22	9%
San Juan	408	19	5%
Puget Sound	2469	813	33%
Outer coast	598	104	17%
TOTAL	**3067**	**917**	**30%**

Table 2-2. Shoreline modification by county.

Source: Washington State Department of Natural Resources

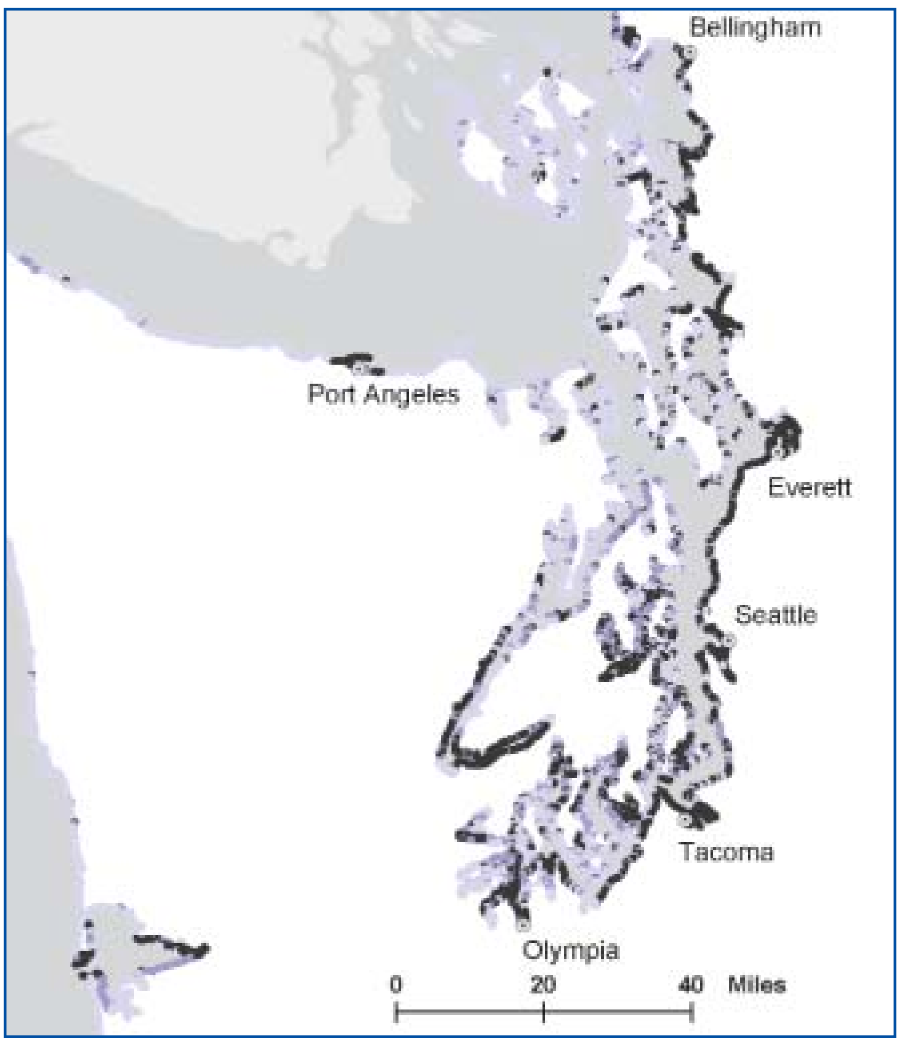


Figure 2-13. Shoreline modification.

Source: Washington State Department of Natural Resources.

Acting on the Findings

The findings presented in this chapter suggest specific actions for the region's resource managers, including:

- Resource managers and planners should investigate opportunities to integrate our developing understanding of climatic cycles into ecosystem-based management of the region's habitats and species.
- Shoreline modification associated with single-family residences is a major component of total shoreline modification. State and local governments should review policies that regulate shoreline modification for single-family residences to ensure patterns of modification are balanced with the protection of Puget Sound.
- Scientists need to better understand the role of groundwater in Puget Sound's freshwater budget.

3. Pathogens and Nutrients

Department of Ecology, Environmental Assessment Program

OVERVIEW

The interaction of higher organisms with their environment involves the exchange of pathogens and nutrients between organisms and the environment. Pathogens consist of microorganisms (bacteria, protozoa and fungi) or viruses that cause disease. The monitoring of pathogens in the environment and the management of pathogenic waste streams from livestock, domestic animals and human wastewater are basic aspects of modern sanitation.

Where pathogens enter rivers and streams and drain to marine waters, they pose risks to humans through direct exposure or by entering the food stream supply through fish or shellfish. There is also an enormous economic incentive to maintain water quality because of the fisheries industries that rely on aquatic resources. This chapter addresses the monitoring of pathogens within the Puget Sound basin. The impacts of pathogens on human health are discussed in Chapter 5. Fecal coliform bacteria, a generally benign group of bacteria, are used as an indicator for the potential presence of pathogens that originate in the digestive tracts of warm-blooded animals. Major sources of fecal contamination include failed on-site septic systems, livestock grazing along streams, malfunctioning municipal sewage systems, boat waste and contaminated stormwater.

Nutrients are required by organisms for basic metabolic and growth processes. Two nutrients are discussed in this chapter: **nitrogen**—including ammonium—and **phosphorus**. Nutrient availability is frequently a limiting factor and therefore key to biological processes. Humans have massively altered the nitrogen cycle, in particular, through the capture of atmospheric nitrogen for the manufacture of fertilizers. The alteration of nutrient availability can have a major impact on ecosystems by improving conditions for some species to the detriment of others. In aquatic ecosystems an increase in nutrient availability—eutrophication—often provides favorable conditions for growth of macro-algae, phytoplankton and aquatic vegetation. The subsequent increase in organic matter leads to increased microbial decomposition and increased demand for oxygen. The resultant oxygen depletion can create a harmful environment for fish and other organisms.

This chapter discusses results from recent monitoring of pathogens and nutrients in fresh and marine waters. Some of the new findings and accomplishments that are highlighted in this chapter are summarized below.

Pathogens

- The Washington State Department of Ecology developed a new water quality index (WQI) to detect chronic problems with freshwater fecal coliform bacteria. The fecal WQI showed the lowest level of concern at most ambient freshwater stations within the Puget Sound basin for water year 2000 (24 of 33). No ambient monitoring stations were placed in the highest concern category (the remaining stations were in the moderate concern category).
- Trend analyses at 20 of the Department of Ecology's freshwater stations for 1991 through 2000 showed seven stations had decreasing fecal contamination. One station at Cedar Run in Renton had an increasing contamination and the remainder had no discernable trends.
- The Washington State Department of Health evaluated fecal pollution in 89 shellfish harvest areas for the period from March 2000 through March 2001. According to its Fecal Pollution Index, 29 areas had significant impact from fecal pollution. The following areas ranked highest in fecal impact: South Skagit Bay, Drayton Harbor, Chico Bay (Dyes Inlet) and Portage Bay. Sixty other harvest areas had minimal pollution.
- The state Department of Health analyzed five-year trends at 302 monitoring stations in Puget Sound that had sufficient data records and evidence of pollution. Fecal pollution increased significantly at 40 percent of the stations. Pollution decreased at one third of the sites and remained unchanged at 27 percent of stations.
- Results from 15 core marine water stations in Puget Sound monitored by the Department of Ecology in 2000 showed the lowest occurrence of high fecal coliform counts since 1994.
- In 2000, the Department of Ecology's ambient monitoring stations recorded the highest marine fecal coliform counts in Commencement, Elliott and Oakland bays. Oakland Bay, however, had only moderate fecal impact in statistics calculated by the state Department of Health using data from commercial shellfish growing areas.
- Subtidal marine water samples collected in central Puget Sound by King County in 1999 through 2000 all met national standards for fecal coliform except for two stations in Elliott Bay.
- Several years of analysis of water samples from King County beaches have shown several stations that:
    - Consistently have fecal coliform levels that exceed standards: Tramp Harbor, inner Elliott Bay, Fauntleroy Cove, Golden Gardens, Lake Washington Ship Canal and Piper's Creek.

   - Consistently have low fecal coliform levels: Seacrest Park, Duwamish Head, north side of Alki Point and Fay Bainbridge State Park.
   - Have highly variable results from year to year: Richmond Beach, Seahurst Park and southern West Point.
- A concerted multi-agency effort to control fecal coliform contamination from dairy farms and septic systems in the Whatcom County has led to dramatic improvements in contaminant levels in the Nooksack River.

Nutrients

- The Department of Ecology's WQI for total nitrogen indicated that the majority of ambient freshwater sampling stations (20 of 33 stations) were in the lowest concern category in wateryear 2000. The remaining stations were split between moderate concern (7) and highest concern (6). The highest concern stations were in the lower Skagit Valley and on the Deschutes River.
- The Department of Ecology's WQI for total phosphorus indicated three highest concern freshwater ambient monitoring stations—one in the Skagit Valley (Joe Leary Slough) and two in the lower Puyallup River drainage.
- A trend analysis of 1991 through 2000 data at the Department of Ecology's freshwater monitoring stations indicated decreasing trends or no trends for nitrogen throughout the Puget Sound basin. Slight increasing trends for phosphorus were identified at a number of stations.
- The Department of Ecology scientists identified three areas as having exceptional sensitivity to eutrophication due to a combination of low dissolved oxygen (DO), low dissolved inorganic nitrogen (DIN), and strong, persistent stratification in a 1994 through 2000 dataset. These areas are Budd Inlet, south Hood Canal and Penn Cove.

Findings on Pathogens

Rivers and Streams

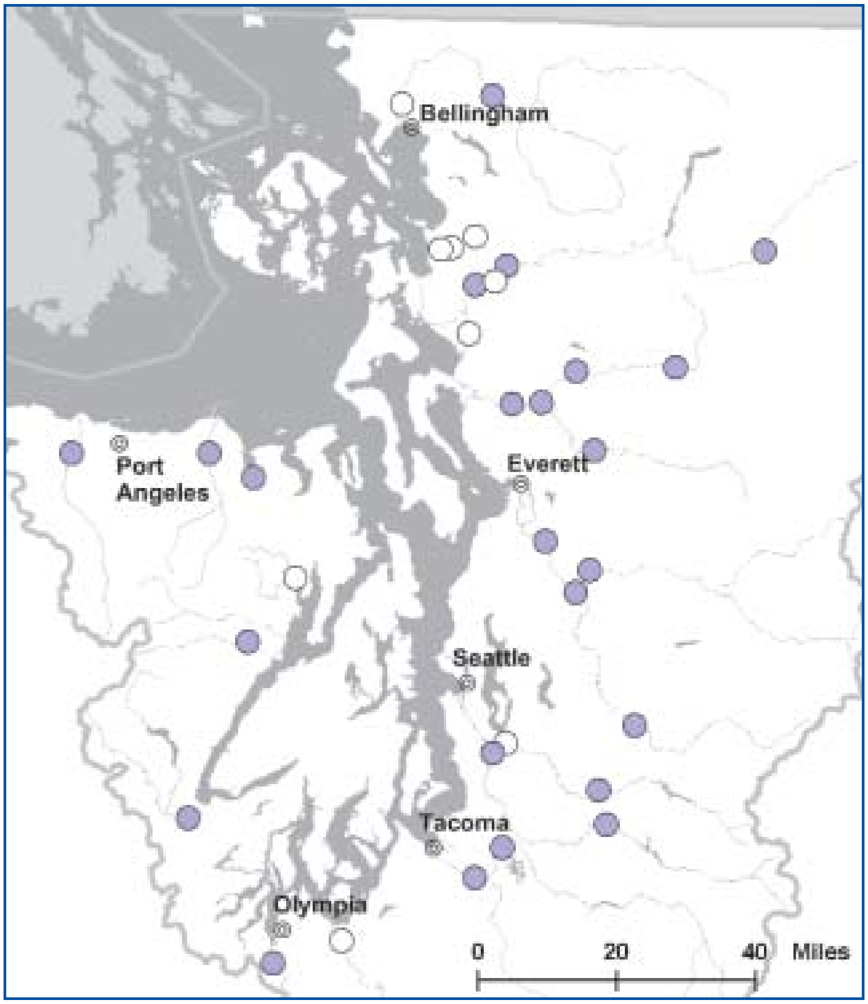
As part of PSAMP, the Department of Ecology monitors ambient water quality parameters monthly at 33 river and stream sampling stations in the Puget Sound basin. The Department of Ecology recently started reporting freshwater conditions using a WQI for eight individual parameters in addition to a single overall WQI for each sampling station (Ecology 2001; see Chapter 2). The WQI is designed to detect chronic water quality problems rather than isolated spikes in conditions. Fecal coliform concentration is one of the parameters analyzed with an individual WQI (Butkus et al. 2001). While fecal coliform bacteria are not pathogens themselves, they are used as indicators of the presence of pathogens.

Figure 3-1 shows the fecal coliform WQI at the ambient sampling stations for wateryear 2000, the latest year available. The majority of the stations had fecal coliform conditions in the lowest concern category (24 of 33 stations). The other stations were placed in the moderate concern category. There were no ambient monitoring stations in the highest concern category for fecal coliform contamination. Department of Ecology scientists performed trend analyses on data from 20 of these ambient monitoring stations using data spanning 1991 to 2000.

Figure 3-1. Fecal coliform conditions in rivers and streams as measured by the Department of Ecology's fecal coliform Water Quality Index (WQI) for wateryear 2000.

Highest Concern
Moderate Concern
Lowest Concern

Source: Washington State Department of Ecology



Most stations had no significant trend, but seven had decreasing trends in fecal coliform concentrations and one had an increasing trend. The seven stations with decreasing trends are: Nooksack River at Brennan; Stillaguamish River near Silvana; South Fork Stillaguamish at Arlington; North Fork Stillaguamish at Cicero; Snohomish River at Snohomish; Green River at Tukwila; and Puyallup River in Puyallup. The single increasing trend was seen in the Cedar River station at Renton.

Controlling Fecal Coliform Contamination in the Nooksack Watershed

Whatcom County has the most dairies in the state. Poor manure management practices used by Whatcom County dairy farmers in the early 1990s contributed the largest loading of bacterial pollution to the Nooksack River, resulting in the closure of the Portage Bay shellfish beds and declining water quality throughout the county. Since 1998, however, dairy farmers have worked with federal, state and local agencies to improve water quality in many Whatcom County streams.

Whatcom County Conservation District and Natural Resources Conservation Service staff have provided technical assistance to many dairy farmers and have developed 150 dairy nutrient management plans. These plans provide farmers with specific practices to control manure from entering streams. Two Department of Ecology inspectors have completed 600 dairy inspections in Whatcom County and have issued 36 enforcement actions to stop or correct discharges of manure into streams. Whatcom County Health and Planning departments have, respectively, repaired failing septic

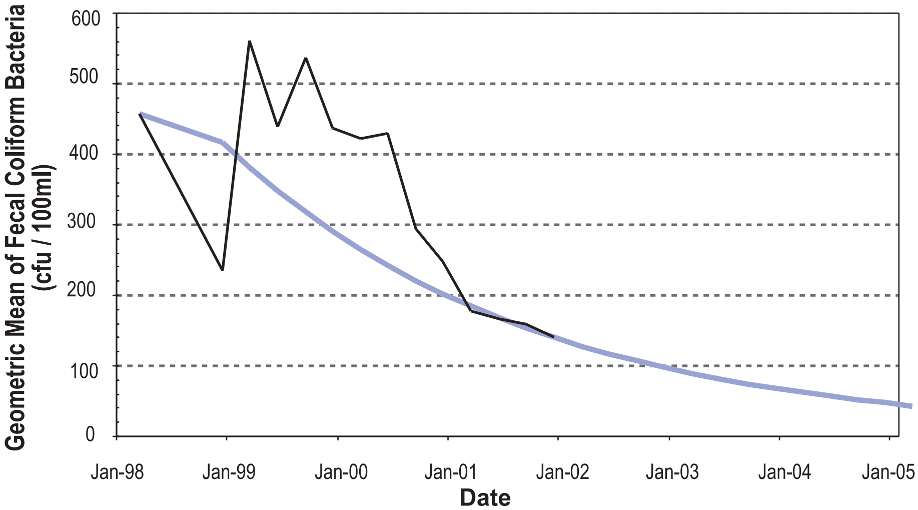


Figure 3-2. Observed and target fecal coliform levels (geometric mean) called for in the Total Maximum Daily Load (TMDL) cleanup plan for Fishtrap Creek in the Nooksack watershed. Similar patterns have been documented elsewhere in the Nooksack watershed.

Source: Washington State Department of Ecology

systems or issued enforcement actions to remove animals from entering streams. Many farmers have changed their farm practices voluntarily to meet the goal of keeping streams clean. Some have even installed tree and shrub buffers along streams flowing through their farm property.

Water quality monitoring since 1998 by the Northwest Indian College has measured the results of these individual efforts. Data for the 2001 year show fecal coliform bacteria levels in the Nooksack River and in Portage Bay are substantially improved from 1997 through 1998 levels (Figure 3-2).

Fecal Contamination in Commercial Shellfish Growing Waters

The state Department of Health classifies commercial shellfish beds according the guidelines set by the U.S. Food and Drug Administration's National Shellfish Sanitation Program (NSSP) based largely on sampling of fecal coliform bacteria in marine waters in shellfish growing areas. As of May 2001, the state Department of Health has classified nearly 200,000 acres in nearly 100 growing areas statewide as Approved or Conditionally Approved for shellfish harvest. In the 1980s the state Department of Health downgraded almost 33,000 acres; only 1,000 acres were upgraded. However, in the 1990s, upgraded acreage nearly equaled downgraded acreage.

The PSAMP analysis of state Department of Health data addresses two broad questions:

- What is the status of fecal coliform contamination relative to Department of Health's growing area standards?
- Has fecal pollution changed significantly over time?

State Department of Health scientists calculated growing area statistics (geometric means and ninetieth percentiles) for more than 1,114 stations in 89 shellfish growing areas using monitoring data collected through March 2001.

Growing Area Status

The status of each growing area was determined for the period from March 2000 through March 2001. Each station within a growing area was categorized according to the highest 90th percentile occurring at the sampling station during the period:

Water Quality Index and the 303(d) List

The results from The Department of Ecology's Water Quality Index (WQI) analysis for fecal coliform shows a different picture than the contents of the most recent 303(d) list (1998) for impairment due to fecal coliform contamination. The two approaches involve different data sources as well as different analyses. The WQI is based on data from ambient monitoring stations that are selected to represent overall watershed conditions. The WQI analysis itself is designed to detect chronic water quality problems rather than short-term spikes in contaminants. In contrast, the 303(d) list is based on data from multiple sources that focuses on localized water quality problems and includes cases where contaminants appear only briefly in addition to cases with chronic impairment.

Most Probable Number and Colony Forming Units

Concentrations of fecal coliform bacteria are reported either in units of Most Probable Number (MPN) or Colony Forming Units (cfu). These units are generally considered to be equivalent, but they indicate which of two different techniques was used to measure the concentration. Values reported in cfu are derived from counting the number of colonies grown in a culture. Values reported in MPN are derived from the measurement of carbon dioxide given off by cultured colonies.

GOOD (0-30 MPN per 100 ml)

FAIR (31-43 MPN per 100 ml)

BAD (above 43 MPN per 100 ml)

The fraction of sampling stations within each category was used to produce a pie chart for each growing area. These pie charts provide a means to visually compare 89 growing areas in Puget Sound and the straits of Georgia and Juan de Fuca (Figure 3-3). South Skagit Bay, Drayton Harbor, and Chico Bay (Dyes Inlet) appear to be the most affected by fecal pollution.

Ranking of Fecal Impact in Growing Areas and Regions

Each growing area was ranked according to fecal pollution impact by calculating a "Fecal Pollution Index" or FPI. First, the fraction of stations within each category was multiplied by a corresponding weighting factor (good: 1.0; fair: 2.0; or bad: 3.0). Next, the resulting weighted fractional values are added to produce the FPI. If all stations in the growing area are good, the index is 1.0 (1.00 x 1.0). On the other hand an index of 3.0 means all stations are bad (1.00 x 3.0). A growing area with a mixture of categories would fall between the extremes. Figure 3-4 shows the indices of 29 growing areas (one third of the total) with values greater than 1.0. The data in Figure 3-4 confirms our visual impressions from Figure 3-3. South Skagit Bay has been affected the most (FPI = 2.8), followed by Drayton Harbor (FPI = 2.6) and Chico Bay (FPI = 2.3).

The concept of calculating FPI was extended to the level of the region. The 89 growing areas are divided into six regions:

1. North Puget Sound and Georgia Strait (areas 1-17)
2. Admiralty Inlet and the Puget Sound Main Basin (areas 18-31)
3. South Puget Sound (areas 32-61)
4. San Juan Islands (areas 62-67)
5. Strait of Juan de Fuca (areas 68-76)
6. Hood Canal (areas 77-89)

For each region the total number of stations within each category (good, fair, bad) was calculated. Next, the count of stations in each category was weighted by a value of 1.0, 2.0 or 3.0 as described above. The weighted proportions were summed to produce an FPI for each of the regions: The FPI for North Puget Sound/Georgia Strait was nearly identical to that of South Puget Sound (FPI =1.28 and 1.25, respectively). Next in order came the Strait of Juan de Fuca (FPI = 1.12), Admiralty Inlet and the Main Basin (FPI =1.08), Hood Canal (FPI = 1.06), and the San Juan Islands (FPI = 1.0).

Trends in Fecal Coliform Contamination

The period of record for many growing areas extends back for over a decade. However, the time period for this year's PSAMP trends analysis was limited to a maximum of five years prior to March 2001 to detect recent changes. Trends in 90^{th} percentiles were analyzed for stations that had: (1) 90^{th} percentiles greater than 10 MPN per 100 ml, or (2) a length of record longer than three years. The 302 "trend" stations (27 percent of total stations) were located in nearly half of the 89 growing areas discussed above. About 40 percent of the trend stations showed significant worsening conditions. One-third showed improving conditions, and the remaining 27 percent had not changed significantly.

Scientists at the state Department of Health have also assessed trends in fecal contamination by examining the number of sampling stations within each shellfish growing area that have increasing contamination. Henderson Inlet in south Puget Sound had the largest fraction of worsening stations (15 of 26 stations). Other areas

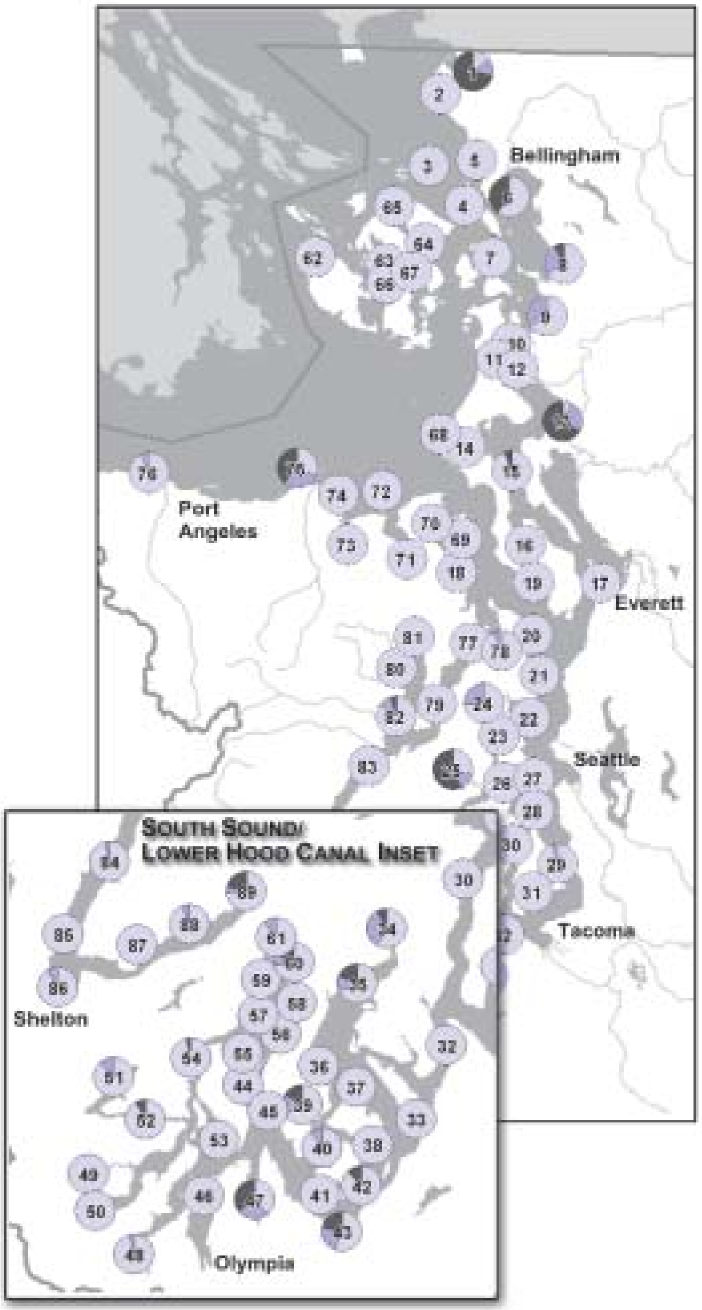


Figure 3-3. Fecal pollution of shellfish beds in Puget Sound and the straits of Georgia and Juan de Fuca, 2000.

Pie charts show proportion of sampling stations in three categories based on 90th percentiles. Based on data from January 2000 through March 2001.

Good: Statistic <=30 MPN/100 ml

Fair: Statistic >30 MPN/100 ml, but <= 43 MPN/100ml

Bad: Statistic > 43 MPN/100 ml

Source: Washington State Department of Health

▶ (Growing areas listed in **BOLD** have stations that are categorized as FAIR or BAD.)

NORTH PUGET SOUND AND GEORGIA STRAIT

1. Drayton Harbor
2. Birch Bay
3. Alden Banks
4. Lummi Island
5. Lummi Bay
6. Portage Bay
7. East San Juan Islands
8. Samish Bay
9. Padilla Bay
10. Similk Bay
11. North Whidbey Island
12. Swinomish
13. South Skagit Bay
14. Penn Cove
15. Saratoga Passage
16. Holmes Harbor
17. Possession Sound

ADMIRALTY INLET AND MAIN BASIN PUGET SOUND

18. Oak Bay
19. SW Whidbey Island
20. Eglon
21. Kingston
22. Port Madison
23. Agate Passage
24. Lemolo (Liberty Bay)
25. Chico Bay (Dyes Inlet)
26. Port Orchard Passage
27. Port Blakely
28. Blake Island
29. East Passage
30. Colvos Passage
31. Quartermaster Harbor

SOUTH PUGET SOUND

32. Tacoma Narrows
33. Fox Island
34. Burley Lagoon
35. Henderson Bay
36. Penrose Point SP
37. Wyckoff Shoals
38. Balch Passage
39. Filucy Bay
40. Drayton Passage
41. Thompson Cove
42. Oro Bay (Anderson Island)
43. Nisqually Reach
44. McMicken Island
45. Whiteman Cove
46. Budd Inlet
47. Henderson Inlet
48. Eld Inlet
49. Skookum Inlet
50. Totten Inlet
51. Oakland Bay
52. Hammersley Inlet
53. Peale Passage
54. Pickering Passage
55. Spencer Cove
56. Dutcher Cove
57. Stretch Island
58. Vaughn Bay
59. Reach Island
60. Rocky Bay
61. North Bay

SAN JUAN ISLANDS

62. Westcott Bay
63. Blind Bay
64. Buck Bay
65. East Sound
66. Upright Channel
67. Shoal Bay

STRAIT OF JUAN DE FUCA

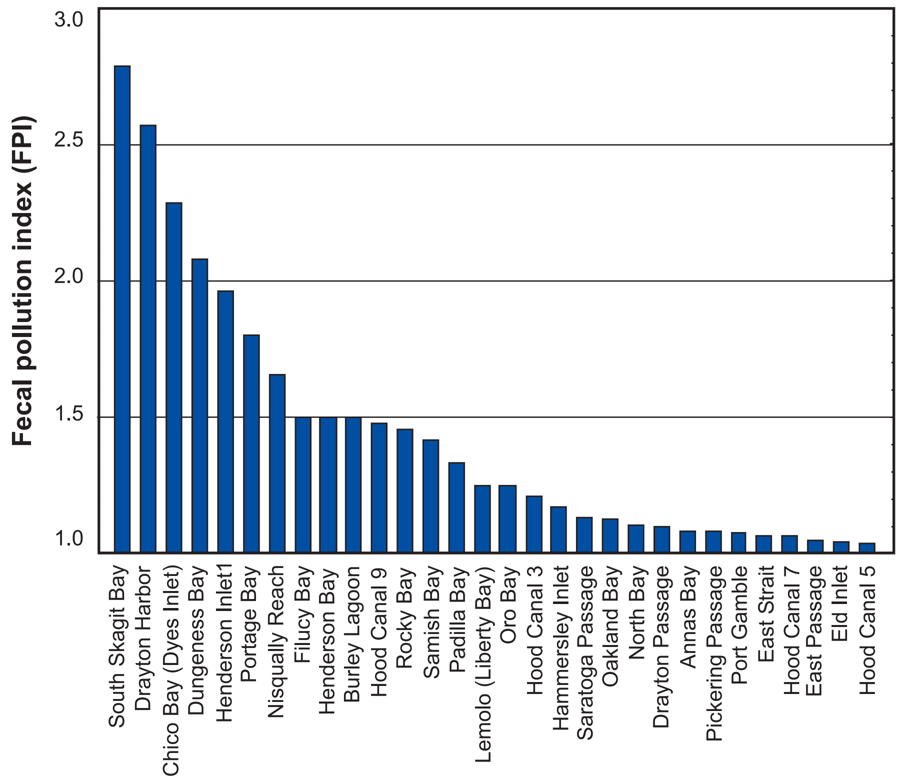
68. Pt. Partridge
69. Kilisut Harbor/ Mystery Bay
70. Port Townsend
71. Discovery Bay
72. Protection Island
73. Sequim Bay
74. Jamestown
75. Dungeness Bay
76. East Strait

HOOD CANAL AND APPROACHES

77. Hood Canal #1
78. Port Gamble
79. Hood Canal #2
80. Quilcene Bay
81. Dabob Bay
82. Hood Canal #3 (incl. Dosewallips)
83. Hood Canal #4
84. Hood Canal #5 (incl. Lilliwaup)
85. Hood Canal #6
86. Annas Bay
87. Hood Canal #7
88. Hood Canal #8
89. Hood Canal #9 (Lynch Cove)

Figure 3-4. Shellfish growing areas ranked by fecal coliform impact.

Source: Washington State Department of Health



with noteworthy worsening trends included South Skagit Bay in North Puget Sound (9 of 14 worsening stations) and Dungeness Bay on the Strait of Juan de Fuca (11 of 13 worsening stations). Generalized worsening trends might seem to be a feature of heavily impacted areas, but this isn't always the case. Buck Bay in the San Juan Islands (4 worsening stations out of 5) and Port Blakely on Bainbridge Island (6 of 8 stations getting worse) are currently good (i.e., FPI=1.0). However, their overall worsening trends suggest vigilance is in order.

Sources of Fecal Pollution

Table 3-1 summarizes fecal pollution sources that were historically identified for some growing areas selected from Figure 3-4. Actions have been taken to minimize the impacts of many of these sources. The sources of fecal pollution emanating from rural watersheds have tended to be similar regardless of their location in Western Washington. Major sources contributing to most growing areas are livestock grazing along streams and drainages, and failed on-site sewage systems along the marine shoreline. In Oakland Bay, Henderson Inlet and Drayton Harbor, sewage and contaminated stormwater from towns were important sources. Boat waste and marine wildlife have generally been shown to be seasonal, or highly localized in their effect.

Remedial Action

Local governments and citizens have conducted remedial action programs in most Puget Sound watersheds for more than a decade. The degree of effort has varied among programs, and outcomes have been mixed. An intensive program conducted by the Thurston County Health Department in the mid-1990s in Eld Inlet focused on locating and repairing on-site sewage systems. The effort significantly reduced fecal pollution and allowed the state Department of Health to upgrade the growing area. Likewise, fecal pollution in Oakland Bay was significantly reduced during a decade-long program by the City of Shelton to upgrade and repair its municipal sewage system. On the other hand, major efforts to eliminate raw sewage discharges in Bow, Edison and Blanchard have not yet significantly reduced fecal pollution loading into Samish Bay, possibly because reductions in fecal coliform from these discharges were overshadowed by inputs from the extensive pasture lands on the Samish River floodplain.

Fecal Contamination at Offshore and Nearshore Areas of King County

King County monitored bacteria (fecal coliform and *Enterococcus*) at 21 and 29 beach stations and 14 and 17 subtidal stations in 1999 and 2000, respectively. *E. coli* was also monitored at 8 subtidal stations in 1999 and at 8 subtidal and 14 beach stations in 2000 (Figure 3-5).

Water Column

All water column stations (including those near wastewater treatment plant discharges) met Class AA fecal coliform surface water standards in both 1999 and 2000 with the exception of two stations located in inner Elliott Bay. Fecal coliform

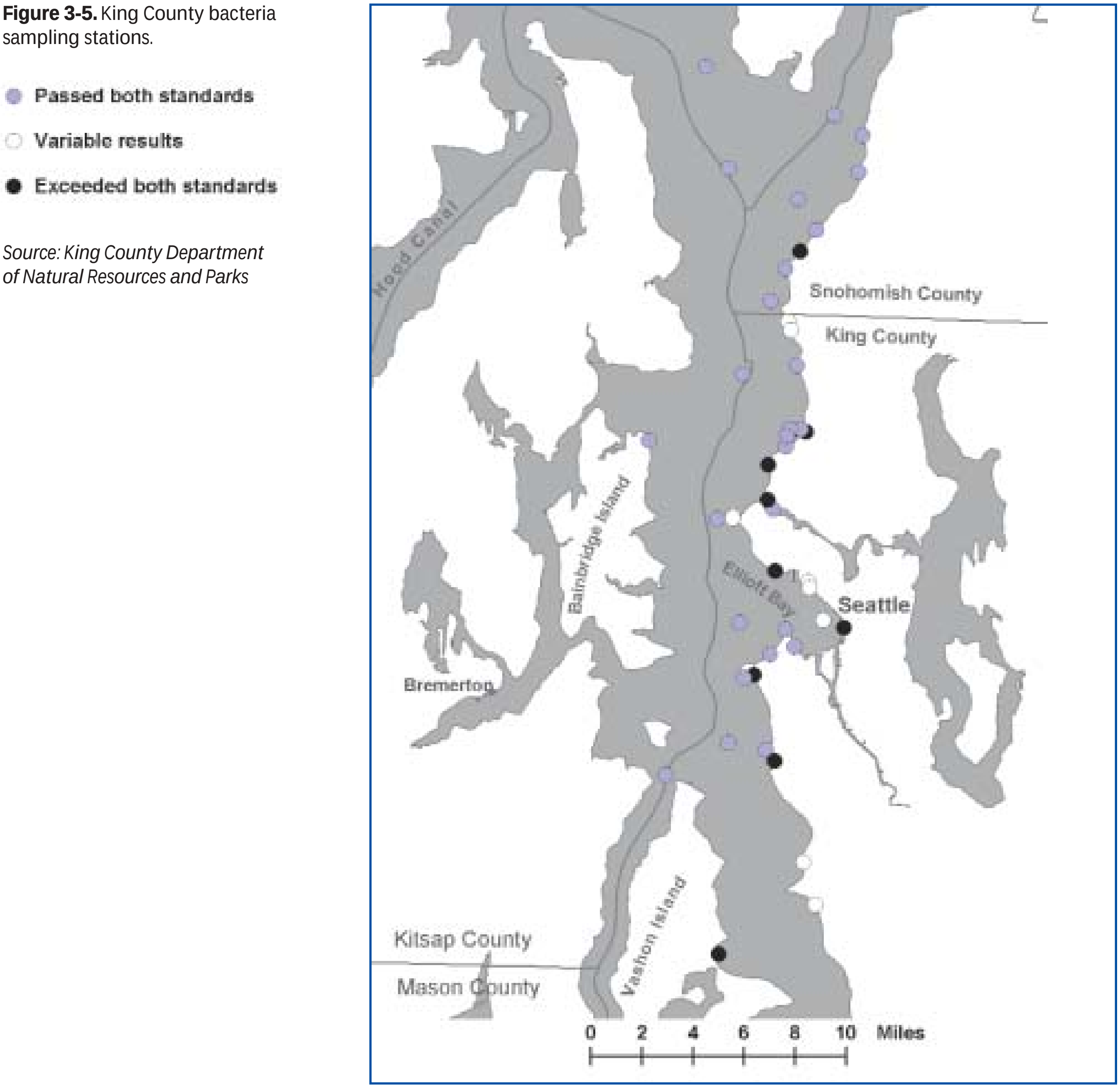
Map#	Growing Area	FPI	Description of historical fecal sources. (Note: Remedial action is underway in all growing areas.)
13	South Skagit Bay	2.79	1. Livestock herds in Skagit River delta. 2. On-site sewage from failed sewage systems in uplands and along marine shorelines. 3. Sewage treatment plants and stormwater from nearby towns. 4. Food processor discharges in nearby towns. 5. Seasonally migrating birds in lowland pastures
1	Drayton Harbor	2.57	1. Livestock along upland streams. 2. Bypasses and leaks in Blaine sewer system. 3. Contaminated stormwater runoff from streets, roads. 4. Boat waste from two marinas. 5. Waste discharge from fish canneries. 6. Marine mammals and birds
75	Dungeness Bay	2.00	1. Livestock along upland streams. 2. On-site sewage systems along marine shorelines and along upland streams. 3. Marine mammals and migrating birds.
47	Henderson Inlet	1.96	1. Livestock along upland streams. 2. On-site sewage systems along marine shorelines and along upland streams. 3. Contaminated stormwater runoff from streets, roads. 4. Marine mammals.
6	Portage Bay	1.80	1. Dairy herds along the Nooksack River. 2. Contaminated stormwater runoff from streets, roads. 3. Marine mammals.
34	Burley Lagoon	1.50	1. Livestock along upland streams. 2. On-site sewage systems along marine shorelines and upland streams.
8	Samish Bay	1.42	1. Livestock herds along lower Samish River. 2. Direct sewage discharge from Bow, Edison villages. 3. On-site sewage systems in Blanchard and along marine shorelines. 4. Seasonally migrating birds in lowland pastures.
51	Oakland Bay	1.13	1. Bypasses and leaks in Shelton sewer system. 2. Livestock along upland streams. 3. On-site sewage systems along marine shorelines.
48	Eld Inlet	1.04	1. On-site sewage systems along marine shorelines. 2. Livestock along upland streams.

Table 3-1. Sources of fecal pollution affecting selected shellfish growing areas in Puget Sound and the straits of Georgia and Juan de Fuca.

For each growing area the Fecal Pollution Index (FPI) and the area number corresponding to Figure 3-3 are shown.

Source: Washington State Department of Health

Figure 3-5. King County bacteria sampling stations.



Source: King County Department of Natural Resources and Parks

counts at these stations have met the geometric mean but exceeded the peak standard for the past several years. Both these stations receive higher freshwater input than other water column stations sampled due to their proximity to the Duwamish River and exceedences of the peak standard occurred most frequently when rain fell prior to sampling.

As with fecal coliform bacteria, *Enterococcus* bacteria in water column samples were low, if detected at all, in both 1999 and 2000. There was no spatial trend detected and levels at the treatment plants outfalls were similar to ambient stations.

E. coli was monitored at eight subtidal stations in 1999 and 2000. As with both fecal coliform and *Enterococcus* bacteria, *E. coli* levels in subtidal waters were detected at low levels, if at all. Of all the samples analyzed, 94 percent were at or below one colony forming unit per 100ml (cfu/100ml).

Beaches
Fecal coliform concentrations in water samples from beaches can be influenced by freshwater runoff and waterfowl congregating in these areas. As a result, the number of stations exceeding standards increased during high rainfall months and at stations close to streams and other sources of freshwater runoff. Stations in areas with restricted water movement tend to retain freshwater input for a longer period of time and also frequently exceed standards. Stations in Tramp Harbor, inner Elliott Bay, Fauntleroy Cove; Golden Gardens, near the Lake Washington Ship Canal; and Piper's Creek have consistently failed both the geometric and peak standards for the last five years. Although sampling has been limited (less than two years of data) at a station located at Brackett's Landing in Edmonds, 11 of 19 samples had fecal coliform values over 43 cfu/100 ml.

In contrast to the above-mentioned beaches, stations near Seacrest Park, Duwamish Head, the north side of Alki Point, and the exposed beach at Fay Bainbridge State Park have consistently had low bacteria concentrations over the past several years and have met both water quality standards. Some stations, including Richmond Beach, Seahurst Park, and the southern West Point station, have variable results from year to year and do not show a consistent pattern.

Enterococcus bacteria counts at beach stations varied from station to station and from month to month. Values tended to be higher in the higher rainfall months for both years, but did not show a consistent pattern with rainfall. Generally, *Enterococcus* bacteria counts were not elevated when fecal coliform results were high and overall did not correspond with fecal coliform results.

E. coli was monitored at 14 beach stations in 2000. *E. coli* values for beach stations varied with month and station with the highest proportion of values between 10 to 50 cfu/100 ml. Boeing Creek, Meadowdale Beach Park, and the Carkeek stations had the lowest *E. coli* counts throughout the year. As with fecal coliform bacteria, the Brackett's Landing station had the highest *E. coli* values throughout the year with counts ranging from 3 to 920 cfu/100 ml. Bacteria concentrations at this station were not associated with rainfall.

While *Enterococcus* and fecal coliform bacteria values do not appear to be related, *E. coli* and fecal coliform bacteria for the beach stations sampled in 2000 do show a similarity when sampled concurrently. Figure 3-6 shows the fecal coliform, *Enterococcus*, and *E. coli* bacteria levels measured at the Brackett's Landing station.

Department of Ecology Monitoring of Open Marine Waters

Department of Ecology scientists analyzed marine water at 45 stations in Puget Sound for fecal coliform bacteria in 1998 through 2000. Results for 15 core stations that have been sampled monthly since 1992 are shown in Figure 3-7. Fecal coliform results are shown separated into two groups: those that exceed 14 colony forming units per 100ml (cfu/100ml) and those that exceed 43 cfu/100ml. These thresholds are state standards when applied to geometric mean values. In this analysis, the Department of Ecology uses this threshold to categorize stations based on individual samples. The results from these 15 core stations show a decrease in the 14 to 43 cfu/100ml group in 1999 relative to the previous year and a decrease in both categories in 2000. Results from 2000 reflected the second lowest frequency of high fecal counts in this data record, after 1994. These results reflect changes in the sources of fecal coliform contamination as well as transport of the contamination throughout the basin to the marine waters in Puget Sound. Both 1999 and especially 2000 were years of below-average rainfall which may be at least partially explain the decreasing trend over these two years.

Pathogen Indicators

Fecal coliform, *E. coli* and *Enterococcus* are all bacteria used to test for the likely presence of other pathogens. Fecal coliform refers to a sub-group of bacteria in the coliform group that is a normally in the intestines of warm-blooded animals. *E. coli* is one species of bacteria in the fecal coliform group. The presence of *E. coli* has been shown to be better correlated with the occurrence of swimming-related illnesses than the test for more general fecal coliform bacteria. *Enterococcus* is a group of bacteria unrelated to the coliforms that also lives in the intestines of warm-blooded animals. This group is also more highly correlated with swimming-related illnesses than is fecal coliform.

Marine Fecal Coliform Standards

Washington State marine Class AA fecal coliform standards for surface waters state that organism counts shall not exceed a geometric mean value of 14 colony forming units per 100 ml (cfu/100ml) and not more than 10 percent of the samples used to calculate the geometric mean may exceed 43 cfu/100 ml. King County and the state Department of Health use results from the 30 most recent samples (surface samples only) to obtain geometric mean values as per the guidelines in the National Shellfish Sanitation Program (NSSP 1999). Surface samples are used, as these tend to be the highest values and represent the area where most contact occurs with people and intertidal organisms. The Department of Ecology uses these numeric thresholds somewhat differently by comparing individual measurements rather than the geometric mean.

The NSSP guidelines are also discussed in Chapter 5, "Human Health."

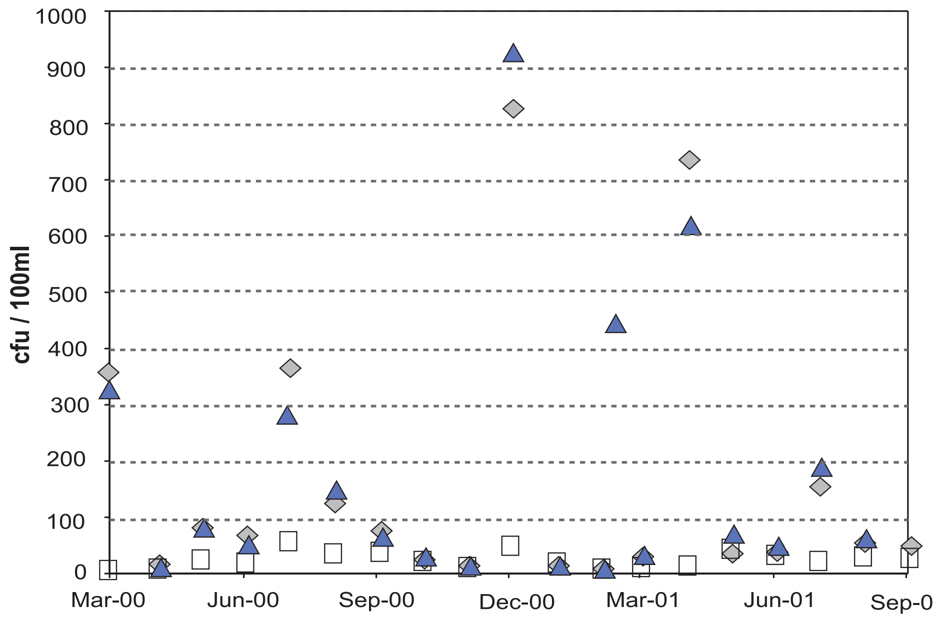


Figure 3-6. Bacteria concentrations at Brackett's Landing station, 2000-2001.

◇ Fecal Coliform
□ *Enterococcus*
▲ *E. coli*

Source: King County Department of Natural Resources and Parks

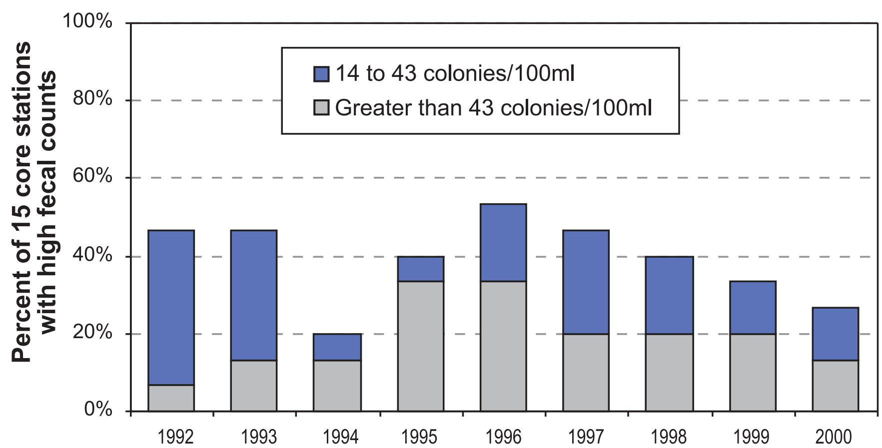


Figure 3-7. Puget Sound marine monitoring stations in two categories based on maximum observed fecal coliform contamination.

Source: Washington State Department of Ecology

Results from all 45 stations sampled in 1998 through 2000 are shown in Figure 3-8 and are grouped into low, moderate and high concentration categories. These categories are delineated using the same thresholds as above, i.e. 14 cfu/100ml and 43 cfu/100ml. The highest fecal contamination is seen in Commencement Bay, Elliott Bay, and Oakland Bay. High levels of contamination were also seen on the outer coast. This result for Oakland Bay contrasts with the results of the state Department of Health analysis where Oakland Bay has only modest contamination (see Figure 3-4). This difference is likely due to the location of the ambient station used by the Department of Ecology relative to the area of the shellfish growing area used by Department of Health as well as differences in the analysis of the data. The Department of Ecology identifies high fecal concentrations in individual monthly samples while the state Department of Health analysis is based on the geometric mean of 30 samples.

Findings on Nutrients

Rivers and Streams

As part of PSAMP, the Department of Ecology monitors water quality parameters monthly at 33 river and stream sampling stations in the Puget Sound basin. The

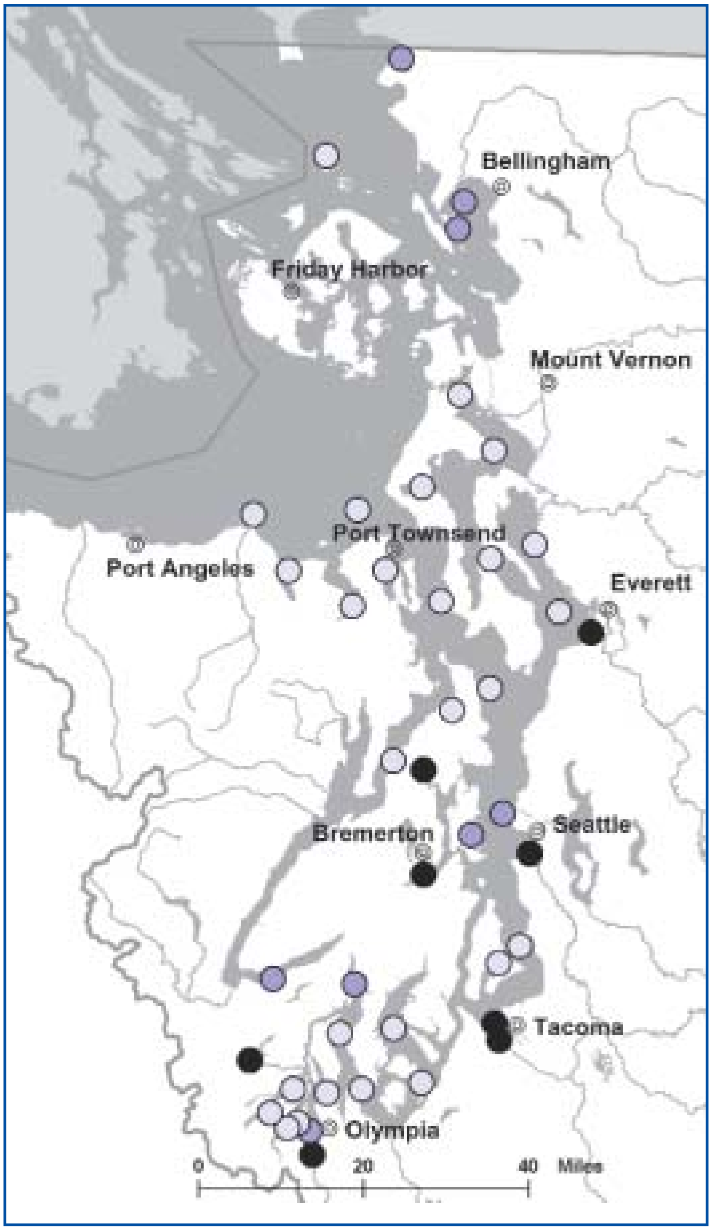
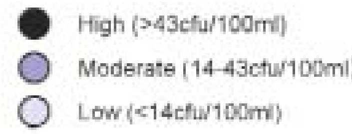


Figure 3-8. Distribution of maximum-observed fecal contamination at the Department of Ecology's open water monitoring stations in Puget Sound, 1998-2000.



Source: Washington State Department of Ecology

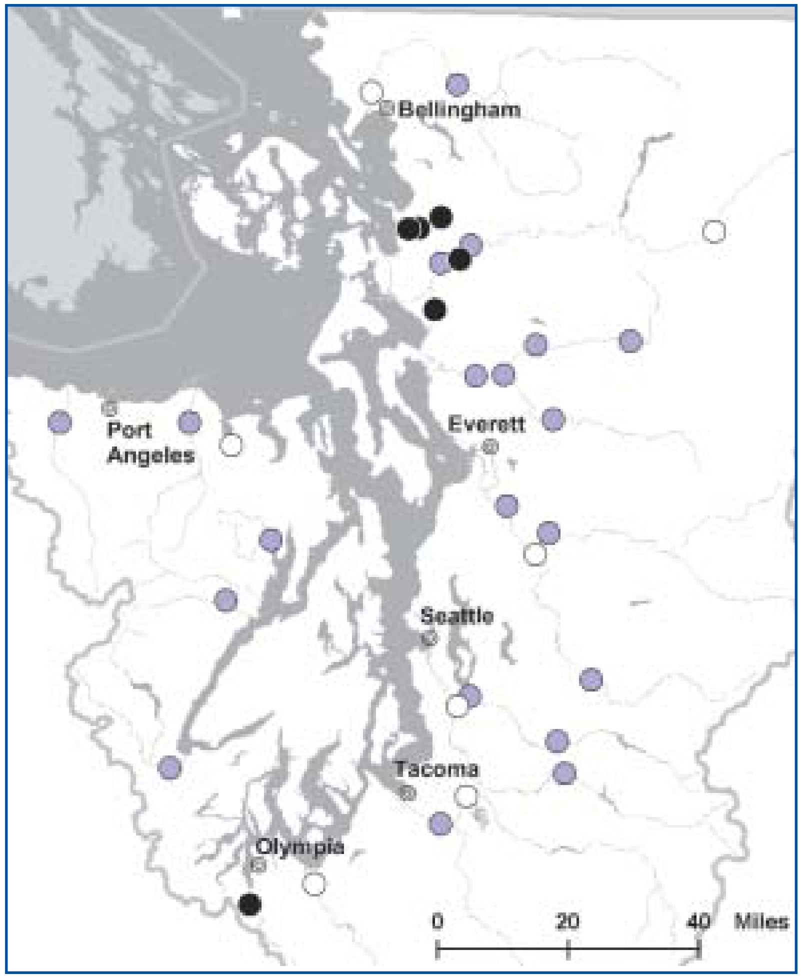
Department of Ecology recently started reporting freshwater conditions using a water quality index (WQI) for eight individual parameters in addition to a single overall WQI for each sampling station (Ecology 2001; see also Chapter 2). Two of these parameters assess the nutrient status of rivers and streams and are based on measured total concentrations of nitrogen and phosphorus (Butkus et al. 2001). When concentrations of nitrogen and phosphorus are elevated significantly over background levels this may indicate the presence of some pollutant source. A common source is runoff from agricultural or residential areas where fertilizers are used.

Figure 3-9 shows the total nitrogen WQI for the 33 sampling stations within the Puget Sound basin. The results indicate good conditions with respect to nitrogen for the majority of the stations (20 out of 33 stations). The remaining stations are almost equally split between the fair (7 stations) and poor (6 stations) classes. The poor stations are clustered in the lower Skagit valley but include a station on the Deschutes River in the southern area of the basin.

Figure 3-9. Total nitrogen conditions in rivers and streams as measured by the Department of Ecology's total nitrogen water quality index (WQI) for wateryear 2000.

● Highest Concern
○ Moderate Concern
● Lowest Concern

Source: Washington State Department of Ecology



The total phosphorus WQI (Figure 3-10) shows a different pattern than the nitrogen WQI (Figure 3-9). Only three stations were rated poor with the others equally split between good and fair (15 stations each). The stations rated poor include Joe Leary Slough in the Skagit Valley, and two stations in the lower Puyallup River drainage.

Department of Ecology scientists performed a trend analysis on 20 of the 33 stations within the Puget Sound basin using data spanning 1991 to 2000. In the case of total nitrogen, they found that data from most of these stations had no significant trend; but in three cases, scientists detected downward trends in total nitrogen concentration. These three stations are: Snoqualmie River near Monroe; Nisqually River near Nisqually; and Skokomish River near Potlatch.

In contrast, Department of Ecology scientists found increasing trends in total phosphorus concentrations at five monitoring stations during the 1991 to 2000 data record. Data from the other 15 stations showed no significant trend. The five stations with increasing trends are: Cedar River near Landsburg; Green River at Kanaskat; Nisqually River at Nisqually; Deschutes River at Tumwater; and Skokomish River near Potlatch.

Marine Waters

Nutrient concentrations in Puget Sound marine waters are the result of a balance of inputs from rivers, streams, and the Pacific Ocean and removal of nutrients by

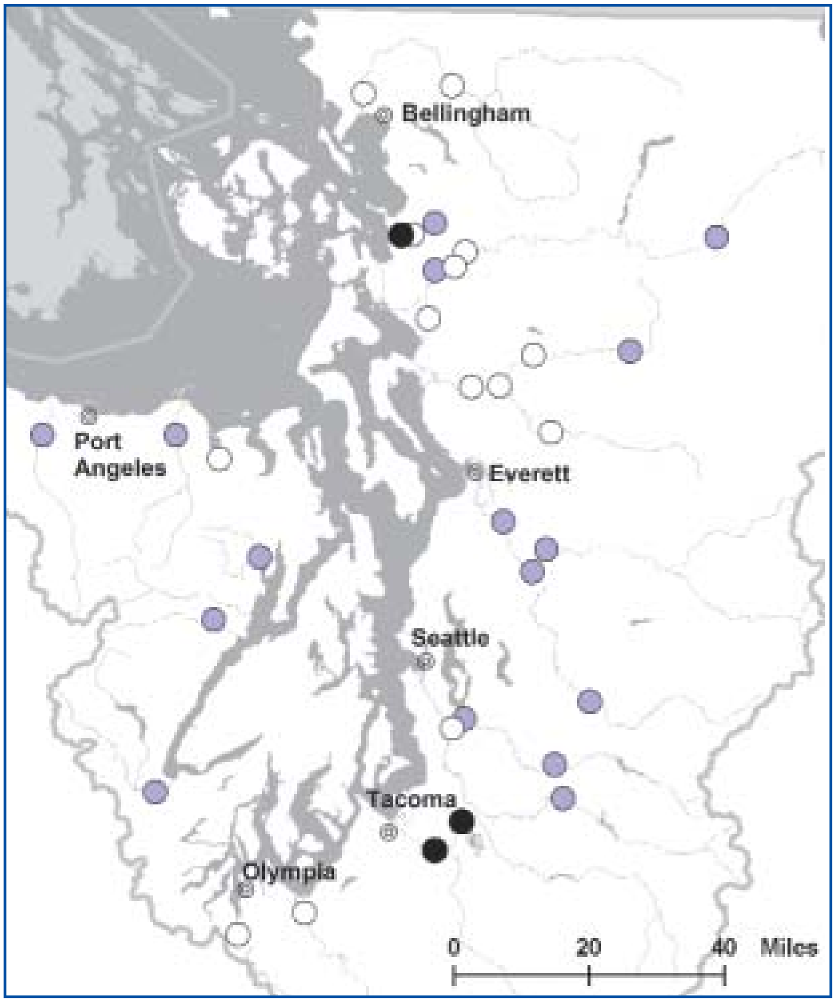


Figure 3-10. Total phosphorus conditions in rivers and streams as measured by the Department of Ecology's total phosphorus WQI for wateryear 2000.

Highest Concern
Moderate Concern
Lowest Concern

Source: Washington State Department of Ecology

phytoplankton and aquatic vegetation. Scientists from the Department of Ecology analyze marine water samples for dissolved inorganic nitrogen (DIN) and ammonium. Results summarized for 1998 through 2000 are shown in Figure 3-11 (DIN) and Figure 3-12 (ammonium). These parameters were also used to determine an overall marine water quality concern index that also incorporated physical and pathogen parameters (see Chapter 2).

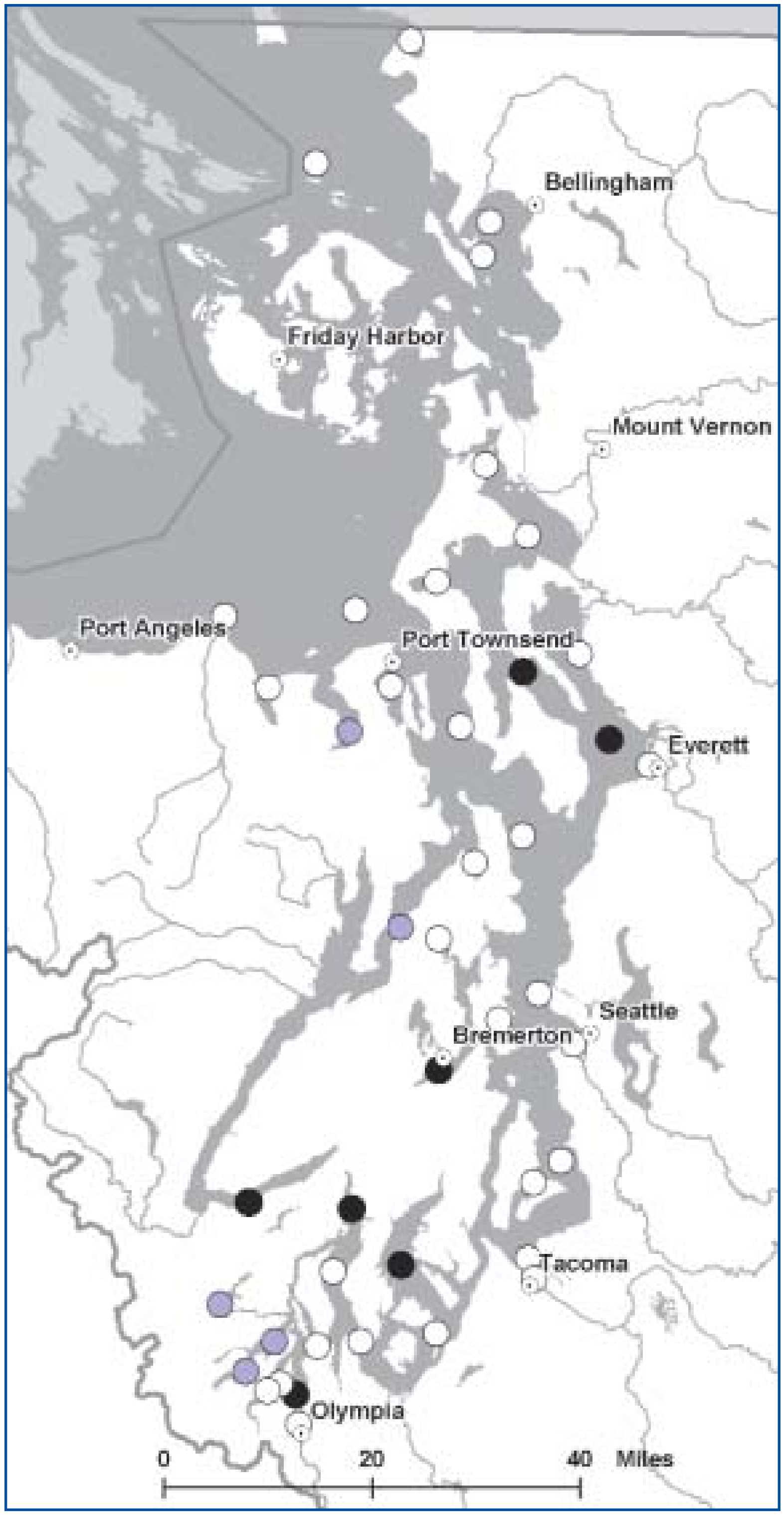
Figure 3-11 categorizes the monitoring stations by the number of months that DIN is not detectable over 1998 through 2000. Non-detectable levels indicate that nutrient availability may be limiting phytoplankton productivity and making the water body more susceptible to eutrophication if nutrients are added as a result of human activities. During the 1998 through 2000 time period, seven stations had no detectable DIN for five months or more. Two of the seven stations, Saratoga Passage and lower Hood Canal, had similar results in the 1996 to 97 data reported in the *2000 Puget Sound Update*. Data from three of the seven stations reflect increased nutrient limitation relative to 1996 through 1997: Possession Sound near Gedney Island, Sinclair Inlet and Budd Inlet. The remaining two stations of the seven were not sampled in 1996 and 1997.

Figure 3-12 shows the occurrence of elevated levels of ammonium as measured by the Department of Ecology in 1998 to 2000. High ammonium concentrations indicate the presence of an ammonia source and a potential water quality problem. Five stations had maximum ammonium concentrations greater than 10.0 mM (micromolar). These were Bellingham Bay, Port Gardner, Sinclair Inlet and Budd Inlet. This

Figure 3-11. Dissolved inorganic nitrogen (DIN) at Puget Sound open-water monitoring stations, 1998-2000. Stations are ranked by the number of months in which no DIN is detectable. Nitrogen can be a significant limiting factor for primary production.

- not detectable 5 months or more
- not detectable 3-4 months
- not detectable 0-2 months

Source: Washington State Department of Ecology



reflects increased ammonium concentrations at Sinclair Inlet and Possession Sound when compared to the results from 1996 through 1997. Data from the East Sound station at Orcas Island had high ammonium in 1996 through 1997 but this station was not sampled in 1998-2000. Stations with moderate levels of ammonium tended to be clustered in the south Sound area, while the northern Sound stations had low levels, except for the two urban water stations noted above.

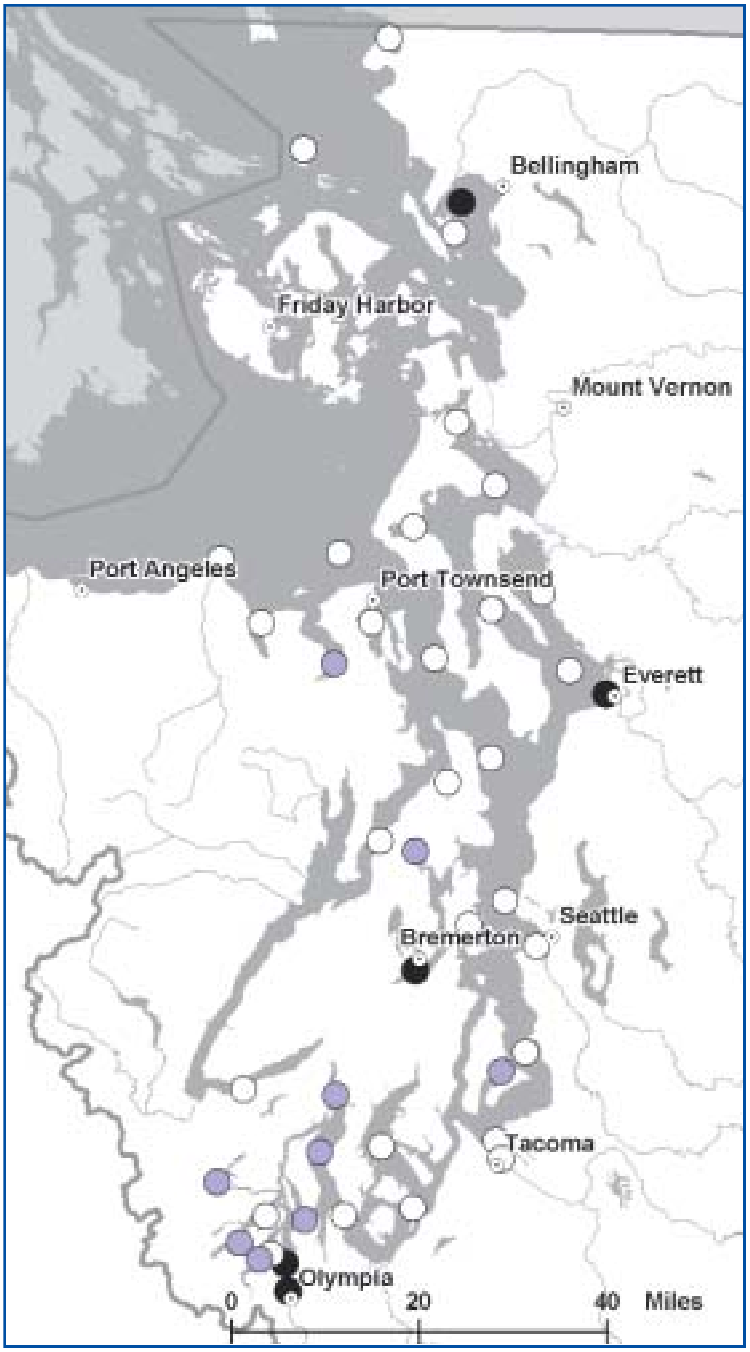
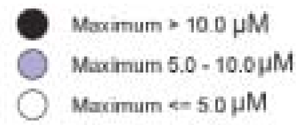


Figure 3-12. Maximum ammonium concentrations at the Department of Ecology's open water stations for 1998-2000. Threshold concentrations used to derive classes are in micromolar (μM) units.



Source: Washington State Department of Ecology

Scientists from the Department of Ecology analyzed data from 1994 through 2000 to determine sensitivity to eutrophication (Table 3-2). This analysis incorporates data on DO and stratification intensity as well as DIN. The stratification and DO data are presented in more detail in Chapter 2. In a stratified water column, zones of depleted nutrients can develop in the surface, which can result in large blooms of algae if humans add nutrients. The rotting bloom can result in zones of low oxygen at depth, which can be deleterious to organisms. Thus, stratification has important implications for water quality because it regulates whether things will mix or stay in layers. Scientists identified three areas as having exceptional sensitivity to eutrophication due to a combination of low DO, low DIN and strong, persistent stratification. These areas are Budd Inlet, south Hood Canal and Penn Cove. Low DO measurements also provide evidence of direct water quality limitations that may be caused by eutrophication or may be natural.

Table 3-2. Washington State marine waters where eutrophication may be a concern based on data from 1994-2000.

DO=dissolved oxygen
DIN=dissolved inorganic nitrogen

SP = Strong and Persistent
SI = Strong and Intermittent
MI = Moderate and Intermittent
WI = Weak and Intermittent

Attributes of most concern for sensitivity to eutrophication are shown in blue.

Source: Washington State Department of Ecology

Station	DO	DIN	Stratification	Sensitivity to eutrophication
Budd Inlet	Very Low	Low	SP	exceptional
S. Hood Canal	Very Low	Low	SP	exceptional
Penn Cove	Very Low	Low	SP	exceptional
Possession Sound	Low	Moderate	SP	high
Bellingham Bay	Low	Low	SI	high
N. Hood Canal	Low	Low	SI	high
Saratoga Passage	Low	Moderate	SP	high
Sinclair Inlet	Low	Low	MI	high
Discovery Bay	Very Low	Moderate	MI	high
Carr Inlet	Low	Low	MI	high
upper Willapa Bay		Low	SI	high
Commencement Bay	Low		SP	high
Holmes Harbor	Low		SP	high
Skagit	Low		SP	high
Port Susan	Low		SP	high
Case Inlet	Low	Moderate	MI	high
Oakland Bay		Moderate	SI	moderate
Elliott Bay	Low		SI	moderate
Strait of Georgia	Low		SI	moderate
Drayton Harbor		Low	MI	moderate
outer Willapa Bay		Low	MI-WI	moderate
Totten Inlet		Moderate	MI	moderate
Eld Inlet		Moderate	MI	moderate
Quartermaster Hrbr	Low		MI	moderate
East Sound	Low		MI	moderate
Dungeness	Low		MI	moderate
Port Gamble	Low		MI	moderate
Sequim Bay	Low		MI-WI	moderate
Port Townsend	Low		MI	moderate
Grays Harbor			SP-MI	low
Dyes Inlet		Moderate	WI	low
Port Orchard			MI	low
West Point			MI	low
Burley-Minter			MI	low

Acting on the Findings

This chapter presented recent findings on levels of pathogens and nutrients in fresh and marine waters within the Puget Sound basin. This is clearly a critical component of the monitoring effort in Puget Sound because of the implications for human health and the potential effects on an important segment of the local economy that is adversely affected by high pathogen levels.

Several recommendations can be made based on the studies presented in this chapter:

- Intensive and coordinated local efforts can reduce fecal pollution problems as evidenced by successes in the Nooksack basin as well as seen in previous results for Eld Inlet and Oakland Bay presented in the *2000 Puget Sound Update.*

- Such efforts should be initiated at all areas where the state Department of Health's analysis indicates worsening trends, especially those areas where currently open shellfish harvest areas would be threatened with downgrades if the trend were to continue. These include Henderson Inlet, Dungeness Bay, south Skagit Bay and others.
- Monitoring should, wherever possible, adopt an interdisciplinary approach that integrates sampling of pathogens and nutrients with physical parameters of the receiving waterbody and the nature of the sources. Areas of Puget Sound that are sensitive to nutrient-related water quality degradation should be investigated further to characterize nutrient loading and cycling.
- 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.

4. Toxic Contaminants

Mohsen Kourendar, Washington State Department of Ecology

OVERVIEW

As our society became more industrialized over the last century, we came to rely on a number of chemicals, some naturally occurring and others newly synthesized, for various industrial and agricultural purposes. These chemicals, and others that occur in a variety of waste streams (e.g., exhaust from internal combustion engines, air pollution from coal burned to generate electricity, waste waters from numerous industrial operations), are released to the environment, sometimes intentionally and sometimes inadvertently or accidentally. With time it has become clear that many of these chemicals are very persistent with extremely low rates of decomposition in the environment, allowing them to linger in sediments and water and accumulate in food webs. It has also become clear, first with DDT[1] and then with other compounds, that some of these compounds have disastrous effects on living organisms.

Concentrations of many contaminants increase as contaminants pass through food webs. A consumer at one trophic level may consume, and accumulate contaminants from, a relatively large number of organisms at lower trophic levels. Organisms at the top of their food webs have the greatest risk of adverse effects since they accumulate the highest concentrations of toxic contaminants in their tissue.

Since DDT in bald eagles was found in the early 1970s to result in thin eggshells and lowered productivity rates, the study of toxic contaminants in the ecosystem has received increasing attention both within the science community and the general public (see a recent report from People for Puget Sound: Schmidt and Johnson 2001).

[1] A number of chemical abbreviations, or acronyms, are used throughout this chapter. An acronym list is given in the Resources section at the end of the report.

Definitions

Bioaccumulation: general term referring to the increase in the concentration of a chemical in a biological organism over time relative to the concentration in the environment.

Bioconcentration: a specific bioaccumulation process by which the concentration of a chemical in an organism becomes higher than its concentration in the air or water around the organism; for example, the concentration of chemicals by filter-feeding bivalves or by fish (through gills) relative to the surrounding water.

Biomagnification: a specific bioaccumulation process by which the concentration of a chemical in an organism reaches higher levels than are found in its food. This leads to higher concentrations of contaminants at higher trophic levels of a food chain.

Persistent, bioaccumulative and toxic pollutants (PBTs): long-lasting substances that can build up in the food chain to levels that are harmful to human and ecosystem health.

This chapter discusses results from recent monitoring activities focusing on a wide range of toxic contaminants in Puget Sound sediments and water as well as shellfish, fish, birds and mammals. The new findings and accomplishments in this chapter include the following highlights.

Sediment

Comparing surface sediment samples collected in 2000 to results from 1989 through 1996 at 10 long-term Puget Sound sites showed:

- Decreases in metal concentrations, particularly mercury and copper
- Increases in polycyclic aromatic hydrocarbon (PAH) concentrations
- Substantial increase in benzoic acid at all sites
- Particularly high PAH concentrations at the Thea Foss Waterway (Commencement Bay) relative to the other sites
- Particularly high metal concentrations at Sinclair Inlet relative to the other sites.

Analysis of sediment samples from 300 randomized sites collected in 1997 through 1999 in Puget Sound showed:

- The majority of observed sediment contamination was located in urban waters including Bellingham Bay, around March Point, Sinclair Inlet, Everett Harbor, Elliott Bay and Commencement Bay.
- Greatest toxicity was found in Everett Harbor, Elliott Bay, Commencement Bay and the Port of Olympia based on a series of four toxicity tests designed to gauge impacts on biota.
- Greatest degree of degraded sediments was found in central Puget Sound, followed by Whidbey Basin, south Puget Sound and Hood Canal regions, based on the weight of evidence developed through a triad of sediment quality information.
- A portion of each study region, including the majority of Hood Canal, showed no signs of sediment degradation.

Shellfish

- Dungeness crab in Puget Sound accumulate PAHs, with the greatest exposure occurring in crab in urban areas, suggesting that they are suitable as indicator species to quantify PAH exposure in marine biota.
- Analysis of butter clams from six sites in central Puget Sound showed metal concentrations below Food and Drug Administration (FDA) standards and no detectable organic compounds except benzoic acid, which was prevalent in all samples.

Fish

- Polychlorinated biphenyl (PCB) concentrations in Pacific herring were higher in fish from central and southern Puget Sound relative to fish from the northern Sound and the Strait of Georgia. These PCB concentrations were generally below values suggested by the National Marine Fisheries Service (NMFS) as thresholds for possible adverse effects in salmonids, although there is a potential for adverse effects in herring stocks in central Puget Sound.

- At long-term sampling stations, English sole in two urban bays (Elliott and Commencement) were observed to have significantly higher risk of liver disease than the intermediate risk measured at Sinclair Inlet and Port Gardner and the lower risk observed in the Strait of Georgia and Hood Canal.
- Monitoring of English sole, rock sole and starry flounder at a site where highly contaminated sediment was capped with clean sediment, showed reduced risk of liver disease associated with reduced exposure to PAHs.

Birds and Mammals

- A study of PCB contaminants in orcas based on samples from 1993 through 1996 showed very high levels of contamination with clear relationships to food source. Transient orcas that feed from higher trophic levels (marine mammals) were the most highly contaminated of the whales studied. Southern residents were four to six times more contaminated than northern residents presumably because their food source comes from more contaminated areas of Puget Sound and the Strait of Georgia.
- A study of contaminants in Hood Canal bald eagles concluded that while the population was growing, PCBs were negatively affecting the eagles and causing lower productivity rates relative to populations elsewhere in Washington State.

Clopyralid: A new concern

As new compounds are regularly synthesized by the chemical industry, there is an ongoing need to monitor for these compounds in the environment and their toxicity to living organisms. A recent example is the compound clopyralid, which is not currently known to have impact on the marine environment but has introduced a serious problem to the compost industry. Clopyralid is an herbicide produced by Dow Agrosciences that is persistent and toxic to some plants at very low concentrations. The compound was introduced into commercial compost through trimmings and agricultural waste and was later found to be responsible for killing plants in gardens and nurseries where the compost was used. This problem, first observed in Spokane (Bezdicek et al. 2000), is the subject of intense debate and sends a clear message about the need for the continuing study of toxic compounds in the environment.

Findings

Sediment Contamination

All sediments in Puget Sound (and areas of net deposition out to the ocean) have concentrations of chemicals that are elevated over pre-industrial levels as a result of human activities. The pattern of this elevated concentration has two components: discrete hot spots around sources and a general smog representing contamination carried far from sources by currents or as airborne contaminants.

There are many different tools for measuring levels of contamination and biological harm in sediments. The State of Washington has adopted sediment management standards that use a combination of tests to pass or fail sediments for the purposes of state sediment management. Because animals have access to buried contamination, the state applies the sediment standards to samples from the top 10 cm to determine level of degradation for regulatory purposes.

The PSAMP sediment monitoring program samples recently deposited sediments (0-3 cm) to better focus on trends in contamination. Past studies have shown the rates of change in sediment contaminant concentration to be generally low in Puget Sound. By limiting the sampling to recent sediments only, PSAMP is more likely to reveal temporal patterns rather than lumping the record of deposited sediment represented by a 10 cm sample.

PSAMP scientists in the Washington State Department of Ecology use the state sediment management standards to evaluate measurements from these 0-3 cm samples, but it is important to note that the results are not meant to be used for regulatory purposes (which require application of standards to 0-10 cm samples). PSAMP results may differ from analysis of 0-10 cm samples that would be used for regulatory purposes. Furthermore, PSAMP scientists have assessed degraded sediments based on their analysis, and this is distinct from the legal definition of contaminated sediments used for regulatory purposes in Washington State.

Long-term Trends in Sediment Condition

As one element of the PSAMP sediment component, Department of Ecology scientists collected surficial sediments in 2000 from 10 of the original PSAMP sediment component sampling stations (Llansó et al. 1998a, 1998b; PSWQAT 1998; see Figure 4-1) and analyzed these samples for 121 toxic chemicals (including metals, PAHs, PCBs, pesticides, and other organic contaminants). The 10 stations are located in or near the Strait of Georgia, Bellingham Bay, North Hood Canal, Port Gardner, Shilshole, Sinclair Inlet, Point Pully, Thea Foss Waterway, East Anderson Island, and Budd Inlet and are sampled at five-year intervals. These stations were chosen for their widespread geographic distribution throughout the Sound, their co-occurrence with other PSAMP component (i.e., fish, water column) sampling locations, the pre-existence of long-term (30-year) data sets for some locations, and for the occurrence of differing benthic community assemblages at each location. Results for 2000 were summarized and compared with the historical PSAMP (1989-1996) data set to determine whether any significant changes occurred in the levels of chemical contaminants at these 10 "sentinel" PSAMP sediment stations over time.

Overall, target compound concentrations were above detection limits in 32.5 percent of the analyses conducted on sediment samples collected in 2000, similar to that for the data from 1989 through 1996 (32.2 percent). Sediment quality problems, represented by concentrations above state sediment quality standards, observed in 2000 were generally consistent with the evidence from previous years (e.g., mercury contamination in Sinclair Inlet and PAH contamination in the Thea Foss Waterway). But the 2000 results also indicated a problem level of benzoic acid in inner Budd Inlet. Results were compared to state sediment quality standards (SQS and CSL values—Washington State Sediment Management Standards, Chapter 173 204WAC) and sediment guidelines (ERM values—Long et al. 1995) derived from data collected nationally.

Sediment contaminant levels at each station were compared over time for the 53 compounds that were measured at detectable levels. Data that qualified as "undetected" (i.e., measured in quantities at or below the analytical laboratory equipment's ability to detect a compound) were excluded from these analyses. Significant increase or decrease in sediment contaminant levels between the historical and the most recent samples was determined for each compound by comparing the median and 95 percent confidence limits for the data from 1989 through 1996 with the value measured in 2000 at each station. In addition, analyses were conducted to determine, for each compound, the predominant change in concentration value (i.e., increasing, decreasing, no change) for all 10 stations combined. These changes are described, in part, below.

- Of the 121 compounds reexamined in 2000, 68 were undetected at the quantitation limits of the laboratory instrumentation.
- Measurements for 37 of the 53 detected compounds in 2000 were statistically significantly different from the median values from 1989-1996 at one or more of the 10 locations sampled.
- Overall, there were more increases (75) than decreases (52) in the levels of individual compounds at individual stations (530 possible). Closer examination showed that metals concentrations

Figure 4-1. PSAMP long-term sediment monitoring stations.

Source: Washington State Department of Ecology

decreased substantially (41 decreases versus five increases), while PAHs increased in similar proportion (45 increases versus nine decreases). Other organic compounds accounted for 26 increases and four decreases.

- Point Pully (station 38) sediments were remarkable in that the levels of 17 compounds (10 metals, six PAHs, and one other organic, β-coprostanol) decreased, while only three organic compounds (benzoic acid, cholesterol, and cymene) increased.

Benzoic Acid

Benzoic acid is a naturally occurring compound in many plants and animals, such as berries and shellfish. This compound is the degradation product of hippuric acid, present in the urine of herbivores and also, to a small extent, in humans (Wibbertmann et al. 2000). It is always found in tissues of marine bivalves and other marine herbivores, as it is part of the metabolic pathway for these organisms. Anthropogenic sources of benzoic acid into the aquatic environment are primarily from its use as an anti-microbial food preservative. Benzoic acid is also produced as an intermediary byproduct in the reduction of aromatic compounds, such as phenol and cresol (dimethyl phenol).

Benzoic acid toxicity to humans is low, although it can cause allergic reactions in some people. Benzoic acid is thought to exhibit low toxicity to various aquatic organisms. Most toxicity studies have been conducted with freshwater organisms, and the toxicity to marine organisms is not well known. Benzoic acid is rapidly biodegradable, has low bioaccumulation potential, is rapidly metabolized by biota, and does not adsorb to sediments (Wibbertmann et al. 2000).

Benzoic acid is often measured in sediments when organic pollutants are a concern. Results for this compound are often difficult to interpret as high levels may indicate anthropogenic input but may also indicate an abundance of benthic organisms and a healthy environment. When sampling sites are located in riparian or vegetated areas, high benzoic acid levels may be found due to the nearby plant material. For example, high benzoic acid levels detected at one location in the Duwamish River appear to derive from overhanging blackberry shrubbery along the riverbank (S. Mickelson, pers. comm.). Therefore, when interpreting benzoic acid results it is necessary to evaluate many factors, including site characteristics and benthic community data, to determine if the source of this compound might be natural or anthropogenic.

- The concentrations of eight metals decreased at Budd Inlet (station 49).
- The locations with the most numerous increases in PAH levels were East Anderson Island (station 44), with 11 compounds increasing (none decreasing), Bellingham Bay (station 4), with 8 compounds increasing (none decreasing), and Thea Foss Waterway (Commencement Bay, station 40), with 8 compounds increasing and one decreasing.
- Benzoic acid levels were measured an order of magnitude higher in samples collected in 2000 than they were historically. These results were strongly statistically significant. There was no evidence of an increasing trend in the early 1990s, and no data for the intervening years are available.
- Cholesterol and β-sitosterol levels were both significantly higher in samples collected in 2000 than they were historically at five of the 10 stations. At the Strait of Georgia (station 3), North Hood Canal (station 13R), and at Shilshole (station 29) concentrations of both compounds increased.
- Copper levels were significantly lower in samples collected in 2000 than they were historically at seven of the 10 stations.
- Mercury concentrations were significantly lower in samples collected in 2000 than they were historically at five of the 10 stations.
- Naphthalene and total LPAH were significantly higher in samples collected in 2000 than they were historically at five of the 10 stations.
- Total HPAH levels in 2000 were, on average, 1.5 times higher than they were historically, while total LPAH levels were 2.5 times higher.
- At Thea Foss Waterway (station 40) the LPAH and HPAH concentrations were about 25 times as high as at the other stations.
- Over all years, Sinclair Inlet (station 34) had higher levels of metals, particularly copper, lead, mercury, silver, and zinc, than any of the other locations.

Other trend analyses were conducted on these data that are not reported in this document. A publication describing the full set of PSAMP sediment temporal trend analyses is in preparation (Marine Sediment Monitoring Team, in prep.), and will be released at a later date.

Ecology's 1997-1999 Evaluation of Sediment Quality throughout Puget Sound

As described in the *2000 Puget Sound Update,* Department of Ecology scientists refocused the PSAMP Sediment Component's spatial monitoring element to form a three-year partnership with the National Oceanic and Atmospheric Administration's (NOAA's) National Status and Trends Program. This study used a stratified-random sampling approach to estimate the percentage of the Puget Sound study area in which sediment quality is significantly degraded based on a variety of evaluation approaches.

Three hundred samples of recently deposited sediment were collected during June and July of 1997, 1998, and 1999, at locations extending from the U.S./Canadian border, south to Olympia, and west to Hood Canal. Sediments from each location

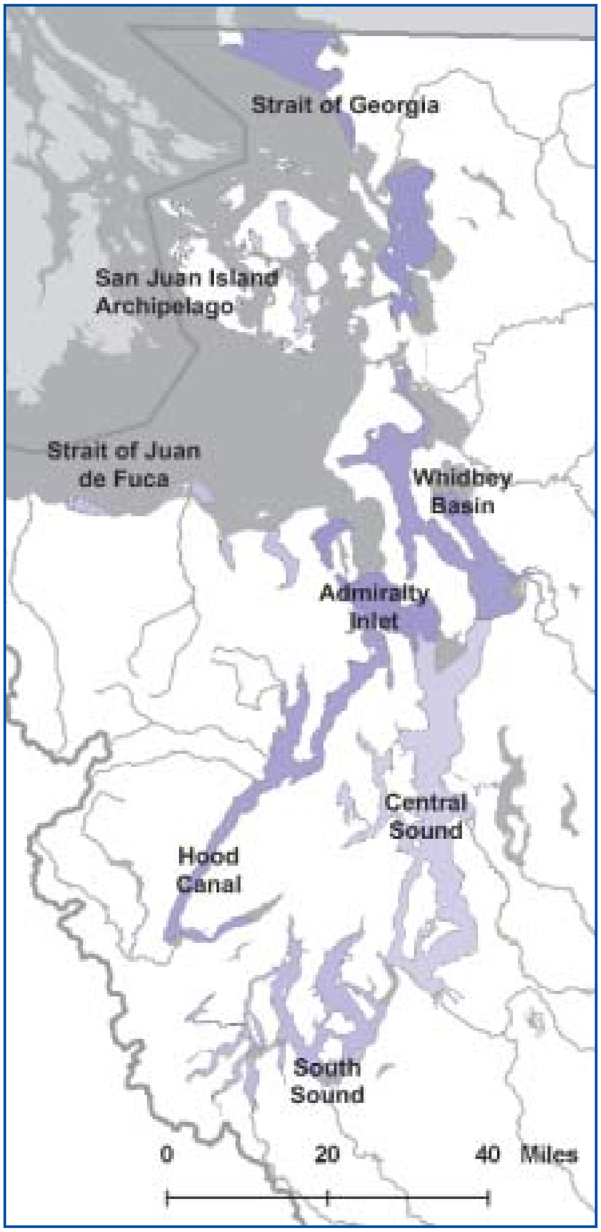


Figure 4-2. The six regions used for the 1997-1999 Ecology-NOAA sediment monitoring study. Two additional regions are shown that are used by the Department of Ecology in continuing PSAMP sediment monitoring—the Strait of Juan de Fuca and San Juan Island Archipelago regions.

Source: Washington State Department of Ecology

were analyzed for more than 160 toxic contaminants and physical sediment characteristics, tested for toxicity in four laboratory tests, and characterized by the benthic infaunal organisms dwelling within them. The results were summarized in three separate reports (Long et al. 1999, 2000, 2002) and characterize six geographic regions including the Strait of Georgia, Whidbey Basin, Admiralty Inlet, central Sound, south Sound, and Hood Canal (Figure 4-2). The distribution and spatial extent of sediment chemical contamination, toxicity, and benthic infaunal distribution was determined for all regions, along with a Sediment Quality Triad "weight-of-evidence" to characterize sediments throughout the Puget Sound study region. The triad includes three tests (sediment contaminants, sediment toxicity, and infaunal invertebrate community structure) that were examined simultaneously at each station.

Distribution and Spatial Extent of Chemical Concentrations in Puget Sound Sediments

The Ecology-NOAA study tested sediments to determine the concentration of more than 160 chemical contaminants.

Contaminants exceeding various state standards in 1997-99 sampling

Arsenic
Copper
Mercury
Lead
Silver
Zinc
Individual LPAHs & HPAHs
Total LPAH
Total HPAH
Total PCB congeners
Total Aroclor
Phthalate esters (3)
Phenol
Phenolic compounds (3)
Chlorinated aromatic compounds (3)
Benzoic Acid
Benzyl Alcohol
Dibenzofuran

Throughout Puget Sound, 22 compounds or compound groups were measured in concentrations exceeding state sediment criteria (Sediment Quality Standards, SQS; or Cleanup Screening Levels, CSL) and/or national sediment guidelines (Effects Range Median, ERM values). These include six priority pollutant metals (arsenic, copper, mercury, lead, silver, and zinc), individual LPAH and HPAH compounds (low and high molecular weight PAHs, respectively) and total LPAH and HPAH sums, total PCB congener and Aroclor sums, three phthalate esters, phenol and three substituted phenolic compounds, two chlorinated aromatic compounds, and three miscellaneous extractable compounds (benzoic acid, benzyl alcohol, and dibenzofuran).

The average concentration, spatial extent of contamination (i.e., the number of stations and proportion of study area represented), and locations in which each of the 22 chemical contaminants or contaminant groups exceed state sediment criteria and/or national sediment guidelines for the different regions examined are summarized in Long et al. (in prep). As expected, the majority of the contaminated locations are urban/industrialized areas, including Bellingham Bay, March Point, Sinclair Inlet, Everett Harbor, Elliott Bay, and Commencement Bay.

The spatial extent of chemical contamination relative to three different guidelines or standards is summarized in Figure 4-3 for the six geographic regions of Puget Sound. The bar charts shown represent the percent of stations in which at least one compound was measured at levels above one or more of the three sediment guidelines and standards, and the proportion of each study region that these stations represent. The central Puget Sound region had the greatest percent of stations exceeding ERM, SQS, and CSL values (located primarily in the urban/industrial embayments of Elliott Bay, Commencement Bay, and Sinclair Inlet). The Whidbey Basin had the next greatest number of ERM and CSL exceedances (with contaminant problems primarily in Everett Harbor). The total percent area of each region contaminated above criteria was largest in the Strait of Georgia for ERM and SQS values, and largest in the Whidbey Basin for CSL values. No chemical contaminant values exceeded guidelines in the Admiralty Inlet region.

Spatial Extent of Toxicity in Puget Sound Sediments

In a second part of the Ecology-NOAA study, scientists subjected sediments from the six Puget Sound study regions to a battery of four toxicity tests that tested different phases of the sediment, different types of organisms, or were sensitive to different suites of contaminants that might be present in the sediments. These tests included the 10-day amphipod survival test conducted with bulk sediment samples on an amphipod, *Ampelisca abdita*. This test is a measure of the survival rate of adult amphipods in bulk sediments. A second test, the sea urchin fertilization test, was conducted with sediment pore water samples on *Strongylocentrotus purpuratus* gametes to test the reproductive sensitivity of echinoderms to the presence of toxicants in the sediments. The third and fourth tests, the microbial bioluminescence (Microtox™) and cytochrome P450 HRGS tests, were conducted with organic solvent extracts of sediment samples. The Microtox™ test is a measure of the toxicity

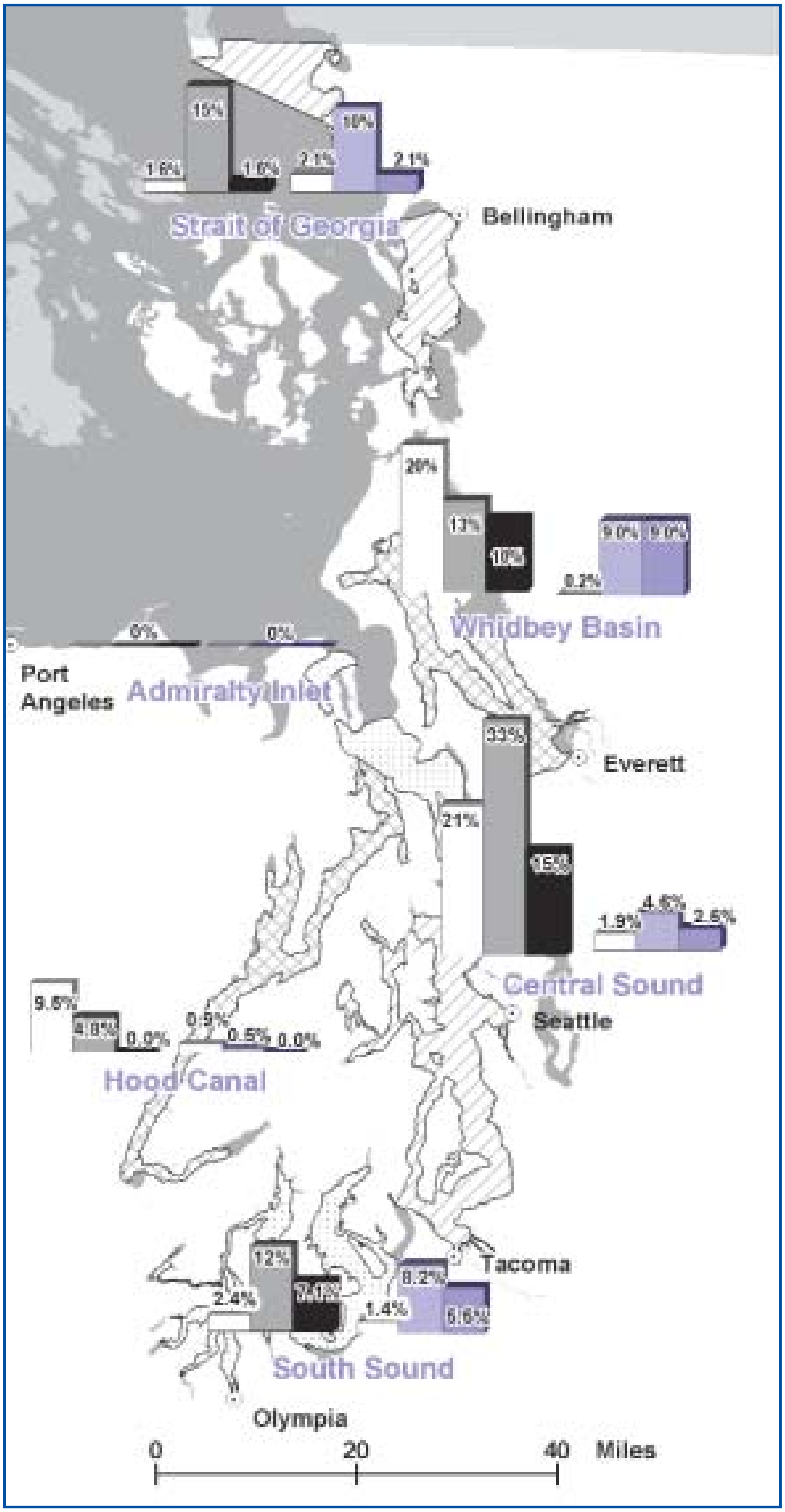
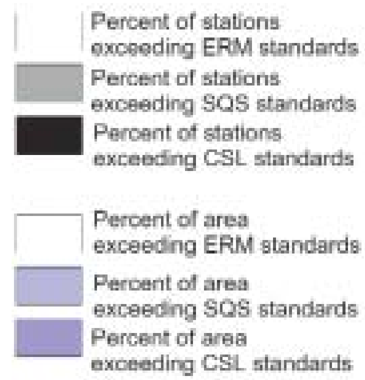


Figure 4-3. Chemical contamination by study region relative to three standards. For each region, one chart shows the proportion of stations exceeding each set of standards for at least one contaminant. The other chart shows an estimate of the proportional area that exceeds the standards.



Source: Washington State Department of Ecology

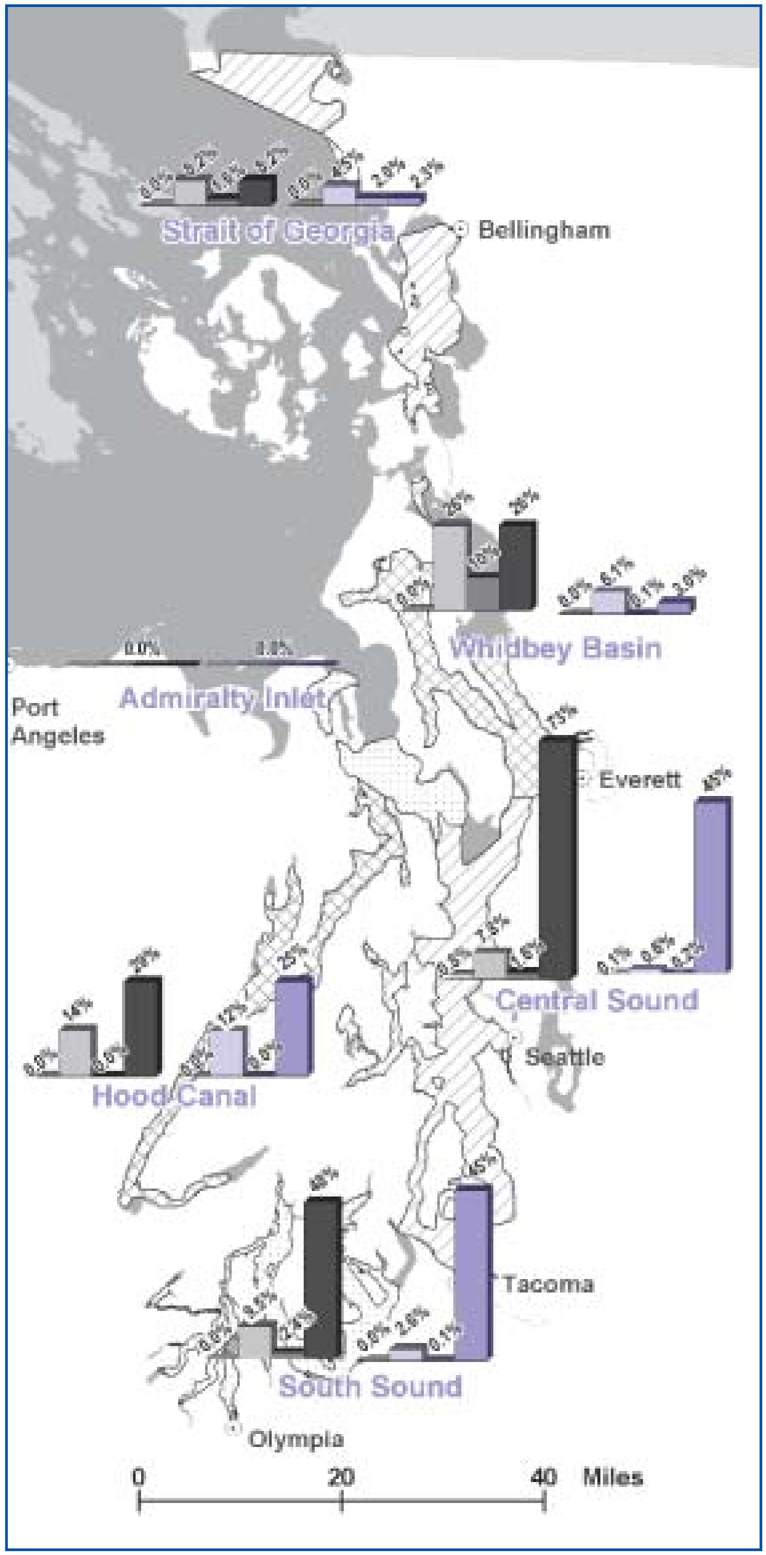
Figure 4-4. Results of four toxicity tests by study region. For each region, one chart shows the proportion of stations exceeding each test criteria. The other chart shows an estimate of the proportional area that exceeds the test criteria.

Percent of stations exceeding toxicity test

- Amphipod survival
- Urchin fertilization
- Microbial bioluminescence
- Cytochrome P450 HRGS

Percent of study region area exceeding toxicity test

- Amphipod survival
- Urchin fertilization
- Microbial bioluminescence
- Cytochrome P450 HRGS



Source: Washington State Department of Ecology

of an organic solvent extract of the sediments (i.e., all bioavailable and bound contaminants in the sediments). The cytochrome P450 HRGS assay is an indicator of the presence of PAHs, PCBs, dioxins and furans.

Estimates of the spatial extent of toxicity for the six geographic regions of Puget Sound are summarized in Figure 4-4. The highest levels of toxicity and greatest concurrence among toxicity measures occurred in the urban/industrialized embayments, including Everett Harbor, Elliott Bay, Commencement Bay, and the Port of Olympia, while significant, single test responses occurred in other urban and rural locations. In central and south Sound and Hood Canal, stations displayed the greatest percent of stations and percent area with the cytochrome P450 HRGS assay, an indicator of the presence of PAHs, PCBs, dioxins, and furans, with the majority of these responses occurring in the urban bays of the central Sound region. The urchin fertilization porewater test, representing the reproductive sensitivity of echinoderms to the presence of toxicants in the sediments, displayed the next greatest percent number of stations and area of responses in the Whidbey Basin. Microtox™ test response, representing the toxicity of an organic solvent extract of the sediments (i.e., all bioavailable and bound contaminants in the sediments), was much lower throughout the total study area, the greatest number of responses were in the Whidbey Basin (Everett Harbor). Toxicity was observed in only one of the 300 amphipod tests (Port Washington Narrows) which test the survival rate of adult amphipods in bulk sediments.

Benthic Infaunal Communities

The types and quantities of chemical compounds deposited in the estuarine sediments of Puget Sound play a role in determining the toxicity of these sediments and, ultimately, the composition of the invertebrate communities that can inhabit them. Organisms living within the surface sediments were collected, identified, and counted for each of the 300 stations sampled. Sixty-one of the 300 stations appeared to have impaired invertebrate communities, based on a comparison of benthic indices including total organism abundance, taxa richness, the evenness of the distribution of individuals, and the number and composition of the dominant organisms found at each station (Long et al. 1999, 2000, 2002). Stations that appear to have impaired communities were all found in harbors, embayments, and inlets including Bellingham Bay, Oak Harbor, Everett Harbor, Port Gardner, Sinclair and Dyes Inlets, an inlet off Port Washington Narrows, Elliott Bay and the Duwamish River, Commencement Bay waterways, Gig Harbor, Budd Inlet and the Port of Olympia, Oakland Bay at Shelton, Port Ludlow, and Port Gamble.

Sediment Quality Triad "Weight-of-Evidence"

To determine the overall quality of the recently deposited sediments sampled throughout Puget Sound, all three elements of the Sediment Quality Triad (i.e., sediment contaminant levels above critical values, sediment toxicity, and impaired infaunal invertebrate communities) were examined simultaneously to determine the extent to which they co-occurred at each station. Sediment quality for each station was ranked based on a "weight-of-evidence" approach, and four categories of sediment quality were generated to define each station, based on the sum of the number of impaired parameters measured at each station.

These four categories of sediment quality include:

- **High Quality** (no degradation detected)
- **Intermediate/High Quality** (degradation detected in one test)
- **Intermediate/Degraded Quality** (degradation detected in two tests)
- **Degraded Quality** (degradation detected in three tests)

The percent of stations in each of these four sediment quality categories, and the percent area in each category were summed for each of the six Puget Sound sediment study regions. These spatial extent results are displayed in Figure 4-5. Based on this index, the central Sound region displayed the greatest percent area with degradation in all three sediment tests, followed by the Whidbey Basin, Hood Canal and then the south Sound regions. Hood Canal had the greatest percent area with no degradation detected in the three tests, followed by south Puget Sound, Whidbey Island, Admiralty Inlet, the Strait of Georgia and the central Sound region.

Toxic Contaminants in Water

Contamination of the Sea Surface Microlayer in Burrard Inlet, Vancouver, B.C.
Scientists from British Columbia's Ministry of Environment Land and Parks (now the Ministry of Water, Land and Air Protection) studied contamination in the surface microlayer of Burrard Inlet, an embayment of the Strait of Georgia at Vancouver, in 1999 and 2000 (Moore and Freyman 2001).

Results indicated elevated levels of contaminants in the Burrard Inlet microlayer, at levels similar to those reported elsewhere, e.g., Puget Sound (Batelle 1988) and Chesapeake Bay (PTI 1990). Copper and other metals occur in the microlayer in concentrations up to 20 times the relevant B.C. water quality criteria. Some PAHs, such as benzo(a)pyrene and chrysene, occur at concentrations almost 400 times their criteria.

The observed levels of contamination of the microlayer are significantly greater than the concentrations measured in the underlying surface waters, which have traditionally been monitored to determine water quality conditions. Thus, a lack of microlayer monitoring may downplay the actual impacts of contaminants to water quality and marine life forms.

The limited sampling accomplished by B.C. scientists suggests that microlayer contamination may be restricted to areas immediately surrounding point source discharges or to embayments (adjacent to developed lands) affected by non-point sources of pollution (including atmospheric deposition and runoff). While they do not expect that significant microlayer contamination extends over large areas of Georgia Strait, the B.C. scientists recommend further monitoring to accurately characterize the extent and environmental significance of microlayer contamination.

Surface Microlayer

The surface microlayer is approximately 50 microns thick. It has significant value for the eggs and larvae of numerous marine organisms utilize this area as a "nursery". However, the same factors that allow eggs and larvae to collect in this region also allow contaminants to be concentrated at this interface between the marine water and the atmosphere. Contaminants from sources such as stormwater, effluent discharges, spills, and atmospheric deposition can accumulate in the surface microlayer.

The microlayer also has significant contact with habitats in the intertidal zone. As water levels fluctuate, organisms are repeatedly exposed to these elevated concentrations of contaminants.

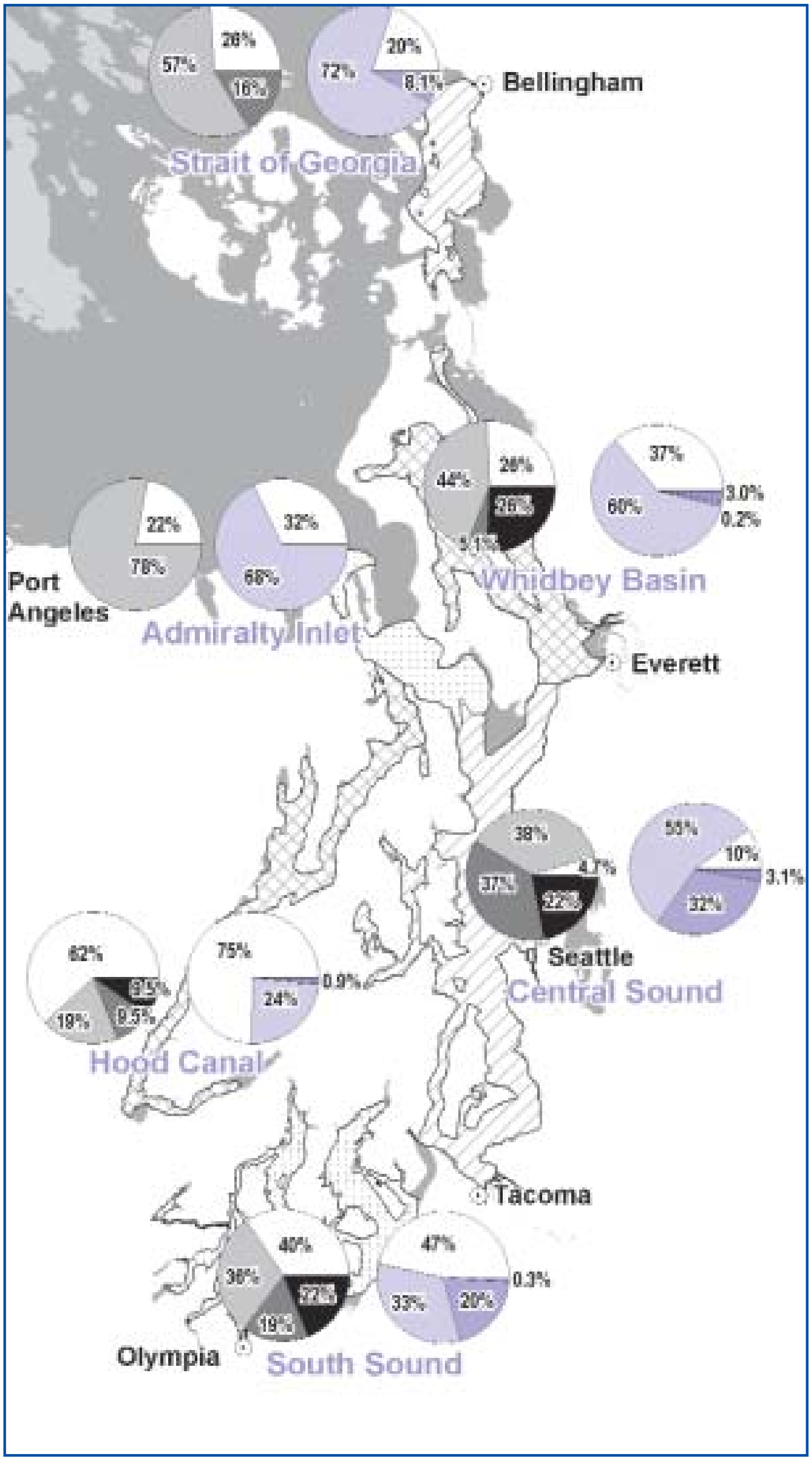
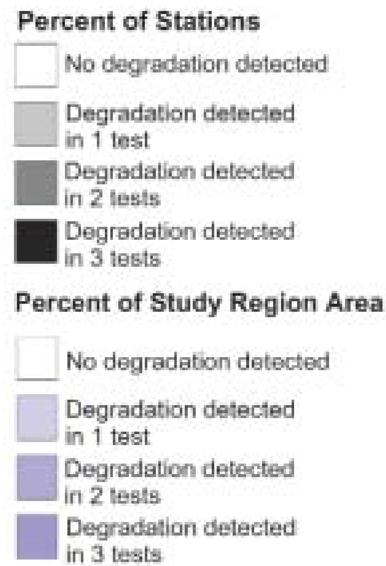


Figure 4-5 Sediment triad results by study region. For each region, one pie chart shows the percentage of the stations in four categories based on results from the three sediment tests. The other pie chart shows an estimate of the proportional area of the region that falls into the four categories.



Source: Washington State Department of Ecology

Metal Contaminants in Shellfish

State and federal criteria do not exist for acceptable levels of metals in shellfish tissues. The U.S. Food and Drug Administration (FDA), however, has established guidance values termed Levels of Concern for mollusks for five metals: arsenic, cadmium, chromium, lead and nickel. Additionally, the FDA has established an Action Level in fish and shellfish tissues of 1.0 mg/kg for mercury. Food products that exceed the Action Level cannot be commercially traded, an important distinction from Levels of Concern.

Toxic Contaminants in Shellfish

Polycyclic Aromatic Hydrocarbons in Dungeness Crab

Washington State Department of Fish and Wildlife scientists, from the PSAMP Fish Component and the Oil Spill Team, conducted a study in the spring of 2001 to evaluate background levels of PAHs in the hepatopancreas of Dungeness crab (*Cancer magister*). The goals of this pilot project were to determine whether crabs are sufficiently exposed to toxics (as measured by tissue burdens) to warrant their use as a monitoring species, especially for natural resource damage assessments in the event of an oil spill. This information is critical in helping the state Department of Fish and Wildlife determine if its trust resources have been injured following a spill. For this study, state Department of Fish and Wildlife scientists were interested in evaluating and refining the procedures for collecting crab tissue samples and to measure PAH exposure of crabs in Puget Sound to use as a baseline from which to compare conditions after an oil spill.

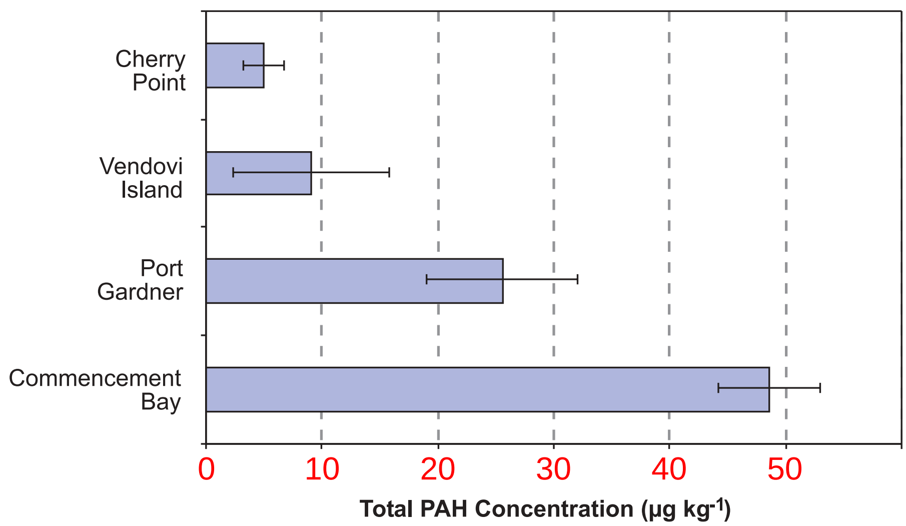
Dungeness crabs are both ecologically and economically important in Puget Sound. Their pelagic larvae are an important prey for out-migrating coho salmon and other fishes, and adult crab are eaten by a wide variety of Puget Sound's predators. In addition, Dungeness crab supports important tribal, commercial and recreational fisheries throughout much of Puget Sound. Because of their benthic feeding mode, abundance, and ubiquity in the food chain, they represent an important potential pathway for toxic contaminants in the ecosystem. In addition to exposure to toxics that predators experience from consuming contaminated benthic crabs, PAHs and other organic toxics such as PCBs may be passed to pelagic larvae from female crabs, resulting in transfer of toxics from sediments to the water column, where salmon, herring and other pelagic species feed.

In this study, PAHs were successfully measured in samples of crab hepatopancreas from four locations in Puget Sound and the observed pattern of contamination in crabs was correlated with degree of PAH sediment contamination. Preliminary analysis of these results shows that Dungeness crab from Commencement Bay (Thea Foss Waterway), one of Puget Sound's more PAH contaminated habitats, had significantly greater total PAH (TPAH) concentration than those from Port Gardner (situated near Everett), Vendovi Island, (outside of Bellingham Bay) and Cherry Point (Figure 4-6).

The crabs' primary detoxifying organ, the hepatopancreas, is less capable than vertebrate liver of metabolizing complex organic toxics like PAHs. For this reason their bodies accumulate PAHs, whereas fish metabolize and excrete them. Hence, crabs are better suited than fish as monitors of PAH accumulation in marine biota. In the future, state Department of Fish and Wildlife scientists will look at the patterns of distribution of individual PAH compounds to help understand better the origins of these toxics. If additional monitoring funds become available, they plan to analyze muscle tissue from these crabs as a first step in the process of assessing risk to humans from consuming this species. Scientists on the Oil Spill Team will also continue to investigate other potential indicator species such as the graceful crab (*Cancer gracilis*), a smaller, non-harvested crab, to characterize baseline or background conditions of oil-based toxic contaminants in Puget Sound biota.

Toxic Contaminants in Shellfish—King County Monitoring

In 1999 and 2000, King County scientists collected butter clams (*Saxidomus gigantea*) from six Puget Sound locations. Stations were located from Richmond Beach near the northern border of King County to Normandy Park in the south (Figure 4-7). Whole clam tissues were analyzed for metals, pesticides, PCBs, and semi-volatile organics.



Note corrected values in red 10-28-2010

Figure 4-6. Concentration of total PAHs in the hepatopancreas of Dungeness crab from four Puget Sound locations (mean of 3 to 4 replicate composites for each location, 5 crabs per composite, ± std. error). Mean concentration from Commencement Bay significantly greater than the other three stations, no significant difference between Port Gardner, Vendovi Island and Cherry Point, (one-way ANOVA, Tukey's post hoc multiple range comparison, $p<0.001$).

Source: Washington State Department of Fish and Wildlife

Figure 4-7. King County shellfish toxic contaminant monitoring stations.

Source: King County Department of Natural Resources and Parks

Table 4-1. Concentration of metals detected in butter clams in King County marine waters. Beryllium concentrations were measured but were below detection limits for all samples.

Source: King County Department of Natural Resources and Parks.

	Concentration (mg/kg dry weight)									
	Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Selenium	Silver	Zinc
FDA Level of Concern	55	3	11	---	0.80	---	80	---	---	---
1999										
Carkeek Park	12.5	0.257	2.22	8.00	0.951	0.040	4.30	1.46	2.81	69.7
West Point N	16.9	0.302	3.19	9.38	0.780	0.062	4.85	1.69	2.50	65.0
West Point S	15.3	0.291	3.16	9.09	0.575	0.042	5.35	1.77	1.65	66.1
Alki Point	21.7	0.315	2.44	9.42	0.519	0.050	5.74	2.03	2.77	76.7
Richmond Beach	17.5	0.379	2.43	21.4	0.964	0.060	4.51	2.18	3.90	71.9
Normandy Beach	23.4	0.369	2.63	7.70	0.589	0.073	5.11	2.62	5.39	81.0
2000										
Carkeek Park	13.4	0.344	1.88	8.27	0.804	0.041	5.34	2.04	4.34	70.9
West Point N	19.9	0.285	4.66	10.8	0.623	0.069	6.00	3.36	6.57	78.9
West Point S	15.1	0.314	4.64	10.5	0.621	0.035	7.40	2.29	1.00	79.7
Alki Point	18.2	0.296	3.52	9.3	0.507	0.033	5.43	2.02	3.13	77.5
Richmond Beach	15.3	0.466	1.65	7.05	0.801	0.045	5.80	2.24	3.35	78.4
Normandy Beach	18.7	0.306	3.11	8.2	0.625	0.037	4.50	2.19	5.85	76.5

Metals concentrations at all stations were well below the FDA Levels of Concern and mercury was below the Action Level. Beryllium was not detected in any sample either year. Cadmium, chromium, lead, mercury, nickel, selenium, and zinc concentrations varied only slightly between stations and were similar to values detected in previous years (Table 4-1). Normandy Park generally had the highest concentrations detected for most of the metals in 1999. In 2000, the highest metals concentrations were generally detected in sediments collected from West Point. Copper was unusually high at Richmond Beach in 1999, 21.4 mg/kg dry weight, which is nearly twice as high as the highest copper value in previous years.

Only one organic compound was detected in the shellfish samples: benzoic acid. Benzoic acid has always been detected in all shellfish samples. Benzoic acid is used as a food preservative and an anti-fungal agent and is also a degradation product of metabolic processes (see **Benzoic Acid** sidebar in earlier section of this chapter).

NOAA Mussel Watch Results for Puget Sound

Mussels filter large quantities of water and can accumulate contaminants that are present in that water. The National Mussel Watch Program, of NOAA's National Status and Trends Program, periodically samples mussels at 12 Puget Sound stations and four along the outer Washington coast. NOAA scientists found in data from 1997 through 1998 that a few organic chemicals—especially PAHs—accumulated to higher concentrations in Puget Sound mussels than in mussels (and oysters) elsewhere around the United States coastline. In contrast, many metals (including arsenic, copper, lead, mercury and silver) were present at lower concentrations in Puget Sound mussels than observed in more remote areas including the outer coast.

PCBs have been of special concern in Puget Sound. During the 1997-98 National Mussel Watch Program total PCB concentrations in Puget Sound mussels ranged from 24 ppb (parts per billion or µg/kg), dry weight (dw), at Cape Flattery to 533

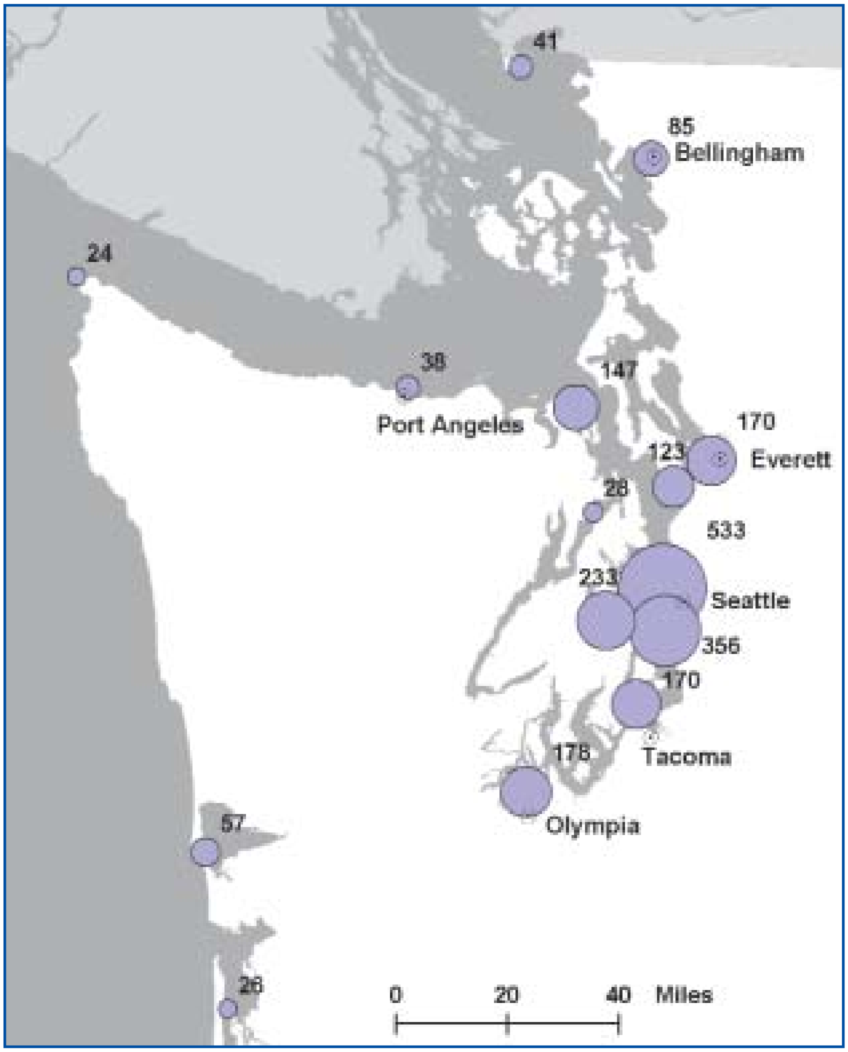
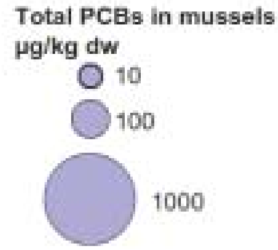


Figure 4-8. Total PCBs measured in Mussels, 1997-98.



Source: NOAA National Mussel Watch Program

ppb at Four Mile Rock beach near Magnolia (north Elliot Bay) with a median concentration of about 120 ppb dw and an average of 163 ppb dw (Figure 4-8). The Puget Sound median was slightly higher than the 1997-98 U.S. national median of 96 ppb dw but slightly lower than the national average of 255 ppb dw. Thus PCB concentrations in Puget Sound mussels were neither exceptionally high nor exceptionally low compared to the rest of the of the U.S.

NOAA scientists found that the outer Washington coast was not free of PCBs. In 1997 and 1998, PCB concentrations in mussels on the outer coast ranged from 24 ppb dw at Cape Flattery to 91 ppb dw at the Columbia River mouth. This information is important because it tells us that while concentrations in Puget Sound could be a lot lower, they won't be lower than what the coastal ocean is experiencing from other sources.

The NOAA National Mussel Watch data through 1998 provided evidence for multiple Puget Sound locations of long-term declining concentrations of the long-banned pesticides chlordane and DDT, and several metals such as lead and mercury. However, scientists also found that PCBs were no longer decreasing and were possibly increasing during the mid to late 1990s.

NOAA scientists now have PCB data from the 1999 and 2000 Mussel Watch surveys. The entire 16-year data record for selected stations in Puget Sound is shown in Figure

Figure 4-9. Time series of PCBs measured in mussels at selected sites in Puget Sound, 1985-2000.

□ Port Townsend

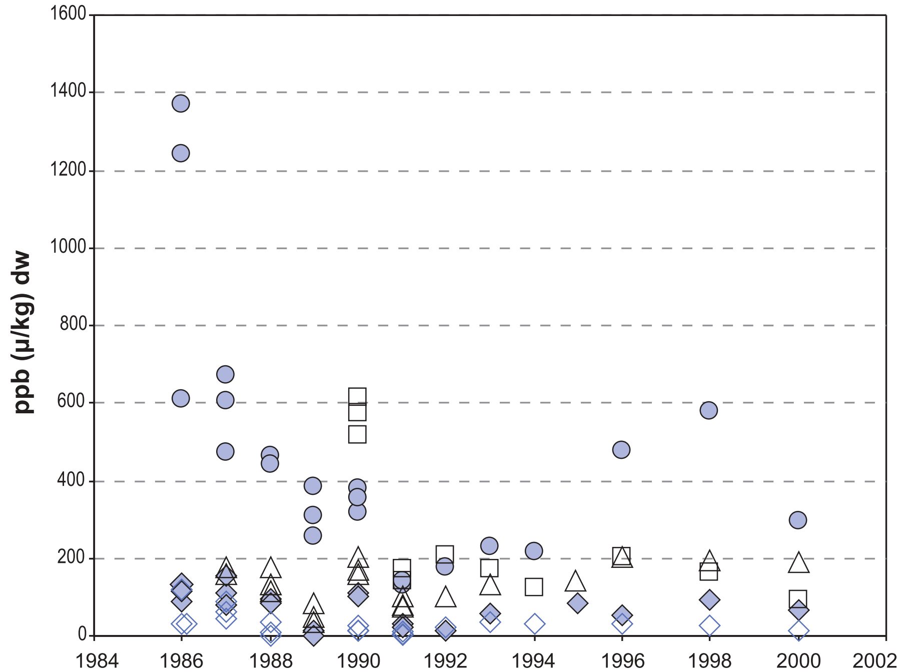
△ Budd Inlet

○ Magnolia (4 Mile Rock)

◆ Squalicum Marina (Bellingham)

◇ Cape Flattery

Source: NOAA National Mussel Watch Program



4-9. Three main features emerge from this time series. First, it is clear that concentrations of PCBs in mussels have generally declined during the past two decades. This decline is consistent with a Puget Sound decline that began in the 1960s and 1970s, as recorded in sediment layers in the bottom of Puget Sound. Second, regardless of the year, the highest concentrations were in mussels from central Puget Sound sites such as Four Mile Rock (Magnolia) and adjacent areas, consistent with this urban area as a long-term source. Third, the long-term downward trend was interrupted in the mid-1990s by increases at many locations. Fortunately, however, during 1999-2000, PCB concentrations in mussels began to decrease again.

We do not know the cause of this rise and fall during the past decade, but it occurred in remote areas (Washington coast, Alaska, etc.) as well as within Puget Sound. This suggests that mussels were experiencing PCB contamination caused or driven by some kind of large scale (ocean-wide) event or process. Possible causes include: increased atmospheric transport across the Pacific; increased input from land runoff; decreases in the food supply or growth rate of mussels (resulting in decreased tissue dilution) caused by prolonged periods of low plankton production associated with warm water conditions of the 1990s; or all of the above. Regardless of the cause, these data now indicate that we cannot be certain that PCBs will continue to decline at the dramatic rates seen during the 1970s to early 1990s.

Contaminants in Fish

Scientists at the state Department of Fish and Wildlife assess the status and spatial and temporal trends in contaminant accumulation in Puget Sound fishes and the effects of contamination on fish health. Currently they monitor English sole (*Pleuronectes vetulus*), demersal rockfish (*Sebastes* spp.), coho salmon (*Oncorhynchus kisutch*) and Pacific herring (*Clupea pallasi*). English sole have been monitored more than other species. This species has been sampled at 56 sites in Puget Sound and the Strait of Georgia, including eight core sites monitored annually. Since 1997, a substantial portion of this sampling effort has been redirected to better define small-scale spatial patterns (focus studies) in contaminant exposure and associated health effects for English sole and rockfish. Results from the focus studies on liver lesions in English sole from Elliott Bay (1997) and Sinclair Inlet (1998) were reported in the

2000 Update and the results of the Commencement Bay study (1999) are documented in this report (see Liver Disease in English sole). Currently, adult coho salmon returning to their natal streams are monitored biennially at five rivers in Puget Sound. In 1999, state Department of Fish and Wildlife scientists started monitoring contaminant exposure in adult herring stocks from northern, central and southern Puget Sound basins.

Pacific Herring

Following a successful pilot study of contaminant accumulation in individual herring from Fidalgo Bay in 1995 (described in the *2000 Update*), state Department of Fish and Wildlife scientists, in 1999, initiated an ongoing program to monitor contaminant levels in adult herring stocks from Puget Sound and the Georgia Basin. The objective was to measure contaminant exposure in adult herring from different spawning stocks from a broad geographic range to assess spatial variation in contaminant body burdens. Average contaminant exposure in adult spawning stocks should reflect environmental contamination from the geographic areas in which they reside. Furthermore, because herring are a short-lived species and only younger fish are sampled in this program, their contaminant loads reflect recent exposure to contaminants.

In 1999 state Department of Fish and Wildlife scientists sampled five spawning stocks (Figure 4-10): Denman/Hornby, Semiahmoo and Cherry Point, all in the Georgia Basin, Port Orchard in the central Puget Sound basin and Squaxin Pass in the southern Puget Sound basin. In 2000 they repeated their sampling on the Semiahmoo, Port Orchard and Squaxin Pass spawning stocks. Cherry Point fish spawn in April but all the other stocks complete their spawning by the end of February (Lemberg et al. 1997). Fish and Wildlife scientists estimated exposure to bio-accumulative organochlorines by measuring whole body concentrations of PCBs, chlorinated pesticides (DDT and its metabolites) and hexachlorobenzene (HCB). Recent exposure to PAHs, organic compounds that do not accumulate in fish, was estimated by concentrations of PAH metabolites, measured as Fluorescing Aromatic Compounds (FACs), in the fishes' bile.

Results from 1999 and 2000 indicate that Pacific herring from the central basin (Port Orchard), and to a lesser extent the southern Puget Sound basin (Squaxin Pass), had higher body burdens of PCBs than fish from more northern areas of Puget Sound and the Strait of Georgia (Table 4-2; O'Neill and West 2001). Lipid content of the samples also varied significantly among spawning stocks confounding the interpretation of these results. However, for the three stocks whose lipid values were similar to each other, (Denman/Hornby, Semiahmoo, and Port Orchard), PCB concentrations were highest in herring from the central Puget Sound (Figure 4-11). The elevated PCB concentration for Squaxin Pass fish, the most southern Puget Sound stock, was probably in part related to the significantly higher lipid levels observed for that spawning stock. However, the few Squaxin Pass samples with lipid levels that were similar to those from other locations had PCB concentrations that were more like those from Port Orchard than the Georgia Basin (Figure 4-11).

Significantly lower lipid levels were observed in the Cherry Point herring than all other stocks; however, for those individual samples where lipid levels were similar to those from fish in other Georgia Basin stocks, PCB concentrations were also similar. State Department of Fish and Wildlife scientists concluded that when differences in lipid content are taken into account (by expressing PCB concentration as per-lipid–weight basis), PCB concentrations in fish from central Puget Sound were significantly higher than at all other locations followed by fish sampled from Squaxin Pass and Cherry Point (Figure 4-12). PCB concentrations were lowest in fish sampled from the Strait of Georgia

Pacific Herring

Pacific herring are important prey to many other fish species, seabirds and marine mammals. Consequently, the health of these higher trophic levels is linked to the health of herring in the Puget Sound and Georgia Basin ecosystem. In the late winter and early spring, large spawning aggregations of adult herring provide rich sources of prey to piscivorous fishes and marine birds and mammals. Benthic fishes and seabirds consume the spawned eggs of Pacific herring. Larval and juvenile herring are also key components of the region's marine food web.

Because of their importance to the food web, there is concern that if herring accumulate toxic contaminants, much of the local food web could be affected.

Figure 4-10. Pacific herring sampling sites, 1995-2001.

Source: Washington State Department of Fish and Wildlife

Table 4-2. Mean (and standard deviations) organochlorine concentration (mg kg^{-1} wet weight) in Pacific herring stocks from the Georgia Basin and Puget Sound, 1999-2000.

Source: Washington State Department of Fish and Wildlife

	Mean Fish Age		% Lipids	Total PCBs		Total DDTs		HCB	
Stock	(years)	N	Mean	Mean	s.d.	Mean	s.d.	Mean	s.d.
Denman/Hornby	2.8	10	5.19	17.0	4.0	18.0	7.3	1.33	0.47
Cherry Point	2.8	10	3.59	54.9	13.0	12.7	3.0	0.35	0.19
Semiahmoo	2.8	20	5.62	52.3	24.7	17.8	7.0	1.54	0.27
Port Orchard	2.8	20	6.52	200.2	48.7	47.2	39.4	1.43	0.18
Squaxin Pass	2.9	19	9.15	165.8	48.8	20.9	5.0	1.43	0.27

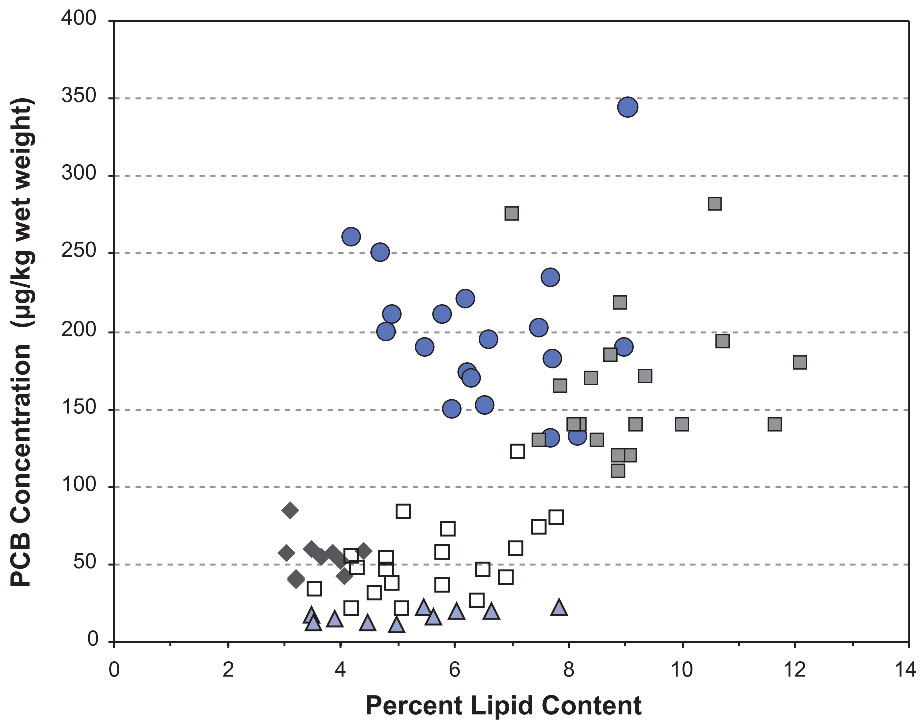


Figure 4-11. Relationship between lipid content and PCB concentration in whole bodies of Pacific herring from Georgia Basin and Puget Sound stocks, 1999-2000.

Source: Washington State Department of Fish and Wildlife

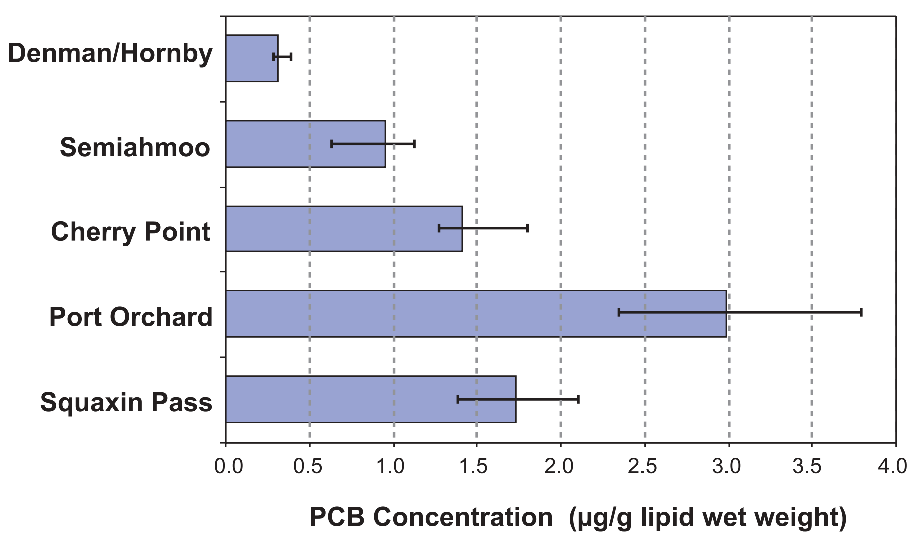


Figure 4-12 Median lipid-corrected PCB concentrations in whole bodies of Pacific herring from Georgia Basin and Puget Sound stocks, 1999-2000. Error bars indicate 25th and 75th percentile values.

Source: Washington State Department of Fish and Wildlife

State Department of Fish and Wildlife scientists also observed higher concentrations of DDTs (detected mostly as pp'-DDE, a metabolite of DDT) in fish from the Port Orchard stock (Table 4-2). The significance of these results is unclear as the concentration of pp'-DDE in Port Orchard fish was higher in 1999 than 2000. Low HCB concentrations were observed for all stocks but were lowest for the Cherry Point stock.

PAH Metabolites in Bile—Herring from the central Puget Sound also had higher PAH exposure than herring from other Puget Sound locations. Biliary FACs (PAH metabolites expressed as equivalents of benzo(a)pyrene and phenanthrene) were highest in herring from Port Orchard (Table 4-3). The Port Orchard bile samples also had significantly greater protein concentrations (a measure of bile diluteness that usually correlates positively with FAC concentrations) possibly explaining the elevated FAC levels. However, stock location was an important factor as well because for those

Table 4-3. Mean (and standard deviation) PAH metabolite concentrations measured in Pacific herring stocks from the Georgia Basin and Puget Sound, 2000. The metabolites include protein, benzo(a)pyrene (BaP) equivalents and phenanthrene (PHN) equivalents. The latter two are measured as fluorescing aromatic compounds (FAC).

Source: Washington State Department of Fish and Wildlife

		Protein (mg/ml)		FAC BaP (ng/g bile)		FAC PHN (ng/g bile)	
Stock	**N**	**Mean**	**s.d.**	**Mean**	**s.d.**	**Mean**	**s.d.**
Semiahmoo	10	6.62	2.63	224.6	68.5	22662	4074
Port Orchard	9	10.73	2.74	551.4	87.7	52237	4941
Squaxin Pass	10	5.77	2.86	305.0	91.4	26829	4955

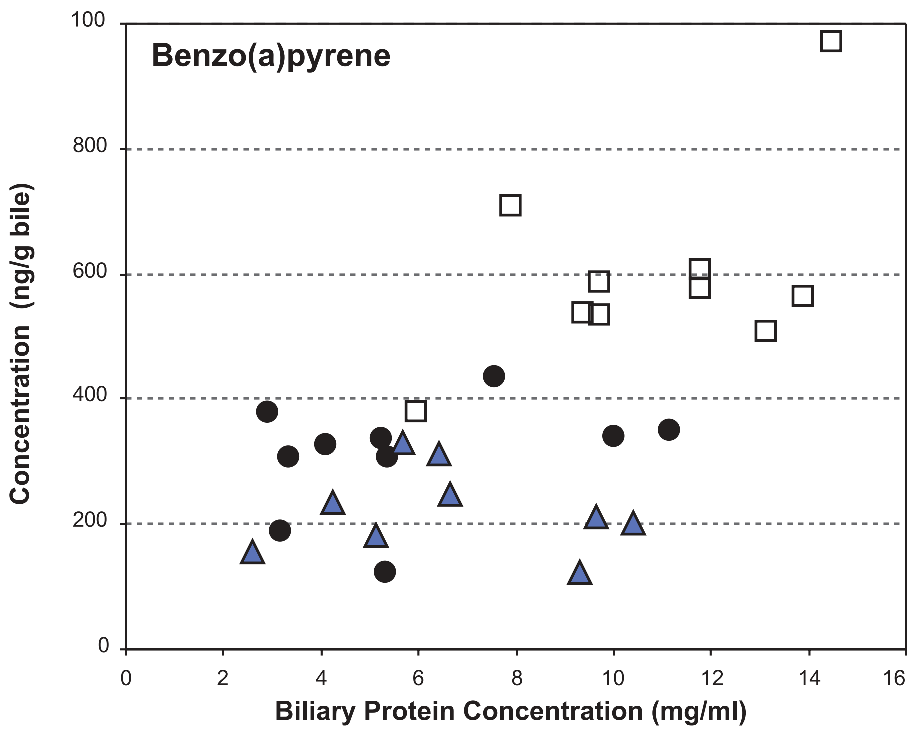
individual samples where protein values were similar among stocks, Port Orchard FAC levels were always higher than those observed in Semiahmoo and Squaxin Pass fish (Figure 4-13).

The higher toxics levels in herring from the central Puget Sound are likely associated with the greater sediment contamination, particularly in the industrialized bays and inlets, in this region of the Sound. Based on sediment sampling conducted by scientists from the Department of Ecology and NOAA (see previous **Sediment Contamination** section in this chapter), the central Puget Sound basin is known to have significantly higher concentrations of PCBs and PAHs, primarily from localized areas of contamination in urban bays, including Everett Harbor, Elliott Bay, Sinclair Inlet, Eagle Harbor, and Commencement Bay.

State Department of Fish and Wildlife scientists suggest that PCBs and PAHs are transferred from these contaminated sediments in the urban bays to the pelagic food web in the central basin and to a lesser extent the southern basin by variety of biological and physical processes. For example, macro-invertebrates and fishes associated with contaminated sediments may accumulate PCBs and PAHs that are then maternally transferred to their planktonic eggs and larvae, which in turn enter the herring's food web. Tidal action and storms may also re-suspend particulate matter containing PCBs and PAHs, that may then be transported to areas beyond the original contaminated sediment foot print. Re-suspension may also make PAHs and PCBs available to plankton and the pelagic food web of the central basin of Puget Sound and the relatively poorly flushed waters of south Puget Sound. In addition, new inputs continue from sources such as atmospheric deposition, surface water runoff and treated wastewater.

Through ongoing PSAMP studies, state Department of Fish and Wildlife scientists have documented that wild coho salmon from southern Puget Sound have higher lipid-specific PCB concentrations than fish from northern Puget Sound, possibly the result of their longer residence in central and southern Puget Sound during their out- and in-migrations (O'Neill et al. 1998). Similarly, scientists studying harbor seals have documented higher PCB concentrations in harbor seals in southern Puget Sound than in northern Georgia Strait (Calambokidis et al. 1988; Ross et al. 1998). Prey of these animals, such as Pacific herring, may be more contaminated in the more industrialized basins of central and southern Puget Sound than in the less developed basins of northern Puget Sound and Georgia Strait.

Based on a recent Adverse Effects Threshold for salmon developed by scientists with the National Marine Fisheries Service (Meador 2000), most herring from Puget Sound, with the exception of central Puget Sound fish, are not likely adversely affected by the levels of PCBs to which they are exposed. All of the Puget Sound herring PCB exposures measured to date from all sampling locations were well below the 50th-percentile threshold concentration (~12 µg/g lipid) that is associated with adverse effects in salmon. However, average PCB exposures in herring from the central Puget Sound basin were above the 10th-percentile concentration that is associated with adverse effects.



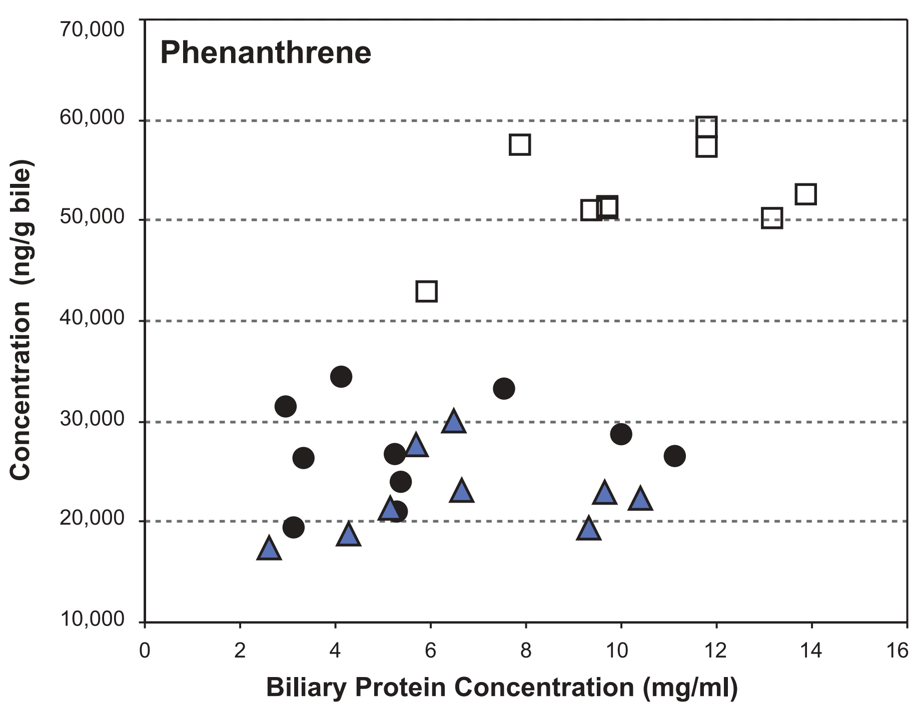


Figure 4-13. Relationship between concentration of biliary proteins and biliary FACs (estimated as equivalents of benzo(a)pyrene and phenanthrene) in Pacific herring stocks from the Georgia Basin and Puget Sound.

● **Squaxin Pass**

□ **Port Orchard**

▲ **Semiahmoo**

Source: Washington State Department of Fish and Wildlife

Future analyses should allow scientists to more accurately define spatial patterns in exposure of Pacific herring stocks in Puget Sound and the Georgia Basin to toxic contaminants. Ongoing monitoring should help to define the lipid:PCB, lipid:DDT, lipid:HCB and protein:bile FAC relationships, allowing better comparisons among sampling locations. State Department of Fish and Wildlife scientists have also initiated a study to assess whether organic contaminants are accumulated in spawned Pacific herring eggs.

Liver Disease in English Sole

Lesion prevalence in the livers of English sole is monitored as an indicator of contaminant-related fish health. Research by scientists with the National Marine Fisheries Service (NMFS) and the state Department of Fish and Wildlife has identified three primary risk factors associated with development of liver disease: (1) exposure to PAH contaminated sediments; (2) fish age; and (3) exposure to PCB contaminated sediments. Furthermore, reproductive impairment has also been observed in English sole at sampling sites with elevated occurrences of liver lesions (Johnson et al. 2001).

State and federal scientists continued their monitoring of the prevalence of liver disease at eight core sites in Puget Sound, including six sites that have been sampled regularly since 1989—non-urban sites in the Strait of Georgia and Hood Canal, a near-urban site in Port Gardner and three urban locations at Elliott Bay, Sinclair Inlet and Commencement Bay (Figure 4-14). Logistic regression analysis was used to calculate the risk of developing liver lesions in a population relative to a risk calculated for a reference population. The calculation of risk is based on the age distribution of the population as well as the liver lesion prevalence data. Scientists calculated risk at six core sites sampled annually between 1989 and 1999 against the baseline risk of developing liver lesions at 19 non-urban, relatively uncontaminated reference sites, sampled between 1989 and 1993. Relative risk of developing lesions at the reference site is 1.0 by definition. The calculation of relative risk from the prevalence data corrects for differences in fish age among sites.

Relative to baseline reference sites, the risk of developing liver disease at these core sites was highest at two urban bays (Elliott and Commencement), intermediate at Sinclair Inlet and Port Gardner, and lowest at non-urban sites in the Strait of Georgia and Hood Canal (Figure 4-15). This is one of the most powerful examples of impairment of fish health in Puget Sound that state and federal scientists have identified. Bottom dwelling English sole in two urban sites (Seattle waterfront in Elliott Bay and Thea Foss waterway in Commencement Bay), and one near-urban site (Port Gardner) had significantly higher risk of developing lesions than fish from reference areas in Puget Sound. PAH concentrations in sediments are also higher at these sites. At all other core sites, the risk of developing liver disease in English sole was not significantly different from reference areas in Puget Sound.

To further define the smaller spatial patterns in contaminant exposure and associated reductions in fish health, the state Department of Fish and Wildlife conducted focus studies in the three urban bays—Elliott Bay, Sinclair Inlet, and Commencement Bay. The team of scientists reported the results for liver disease in English sole for the Elliott Bay and Sinclair Inlet focus studies in the *2000 Puget Sound Update*. The results on liver disease in English sole sampled for the 1999 Commencement Bay focus study are presented in Figure 4-16.

Commencement Bay is a large urban embayment with many small waterways (or channels) at the head of the bay. Most of the industrial development is located in these waterways and the sediments there are significantly more contaminated than the

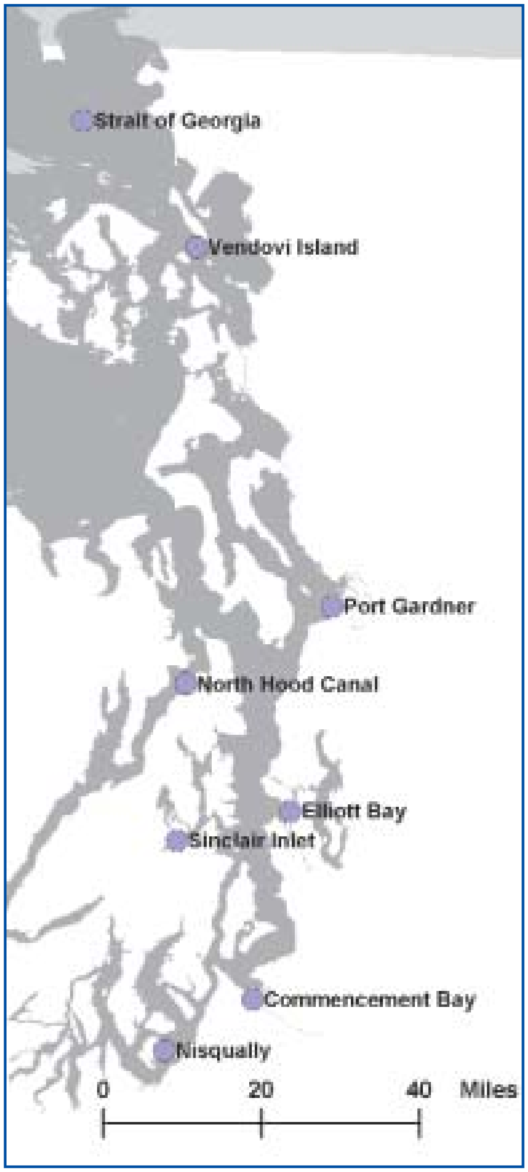


Figure 4-14. English sole sites sampled annually by PSAMP.

Source: Washington State Department of Fish and Wildlife

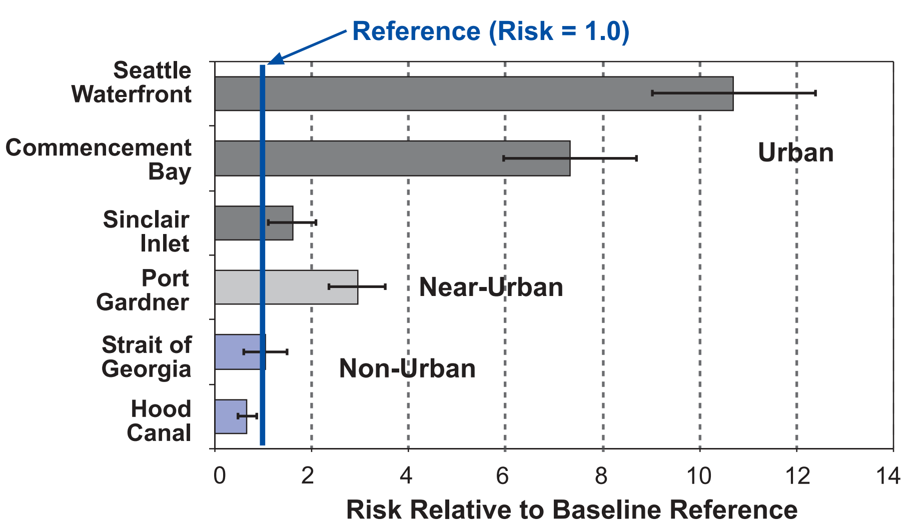


Figure 4-15. Average risk of developing liver disease in English sole at six core sites, sampled from 1989 through 2000, relative to risk at reference sites.

Source: Washington State Department of Fish and Wildlife

rest of the bay. Overall, the results from the 1999 focus study indicate that the risk of English sole developing liver disease in Commencement Bay is low and not significantly different than in baseline reference areas in Puget Sound (Figure 4-16). This focus study included the Thea Foss waterway that has been sampled by PSAMP since 1989.

Although the average risk of developing liver disease for English sole collected from the Thea Foss waterway in Commencement Bay between 1989 and 2000 was almost eight times higher than baseline reference sites in Puget Sound (Figure 4-15), risks in individual years were highly variable. In 1999, the risk was similar to baseline reference sites but in previous years it was as high as 16 times baseline reference (1993) and as low as 2.7 times baseline reference risk (1994). The high degree of variability observed in the risk of developing lesions in fish from the Thea Foss Waterway suggests that the sampled fish have not resided exclusively in the waterway during the several years over which liver lesions would have been developing.

Temporal Trends in Risk of Developing Liver Lesions in English Sole

Scientists with the state Department of Fish and Wildlife and NMFS have also monitored temporal trends in liver disease at these sites by estimating the risk of developing liver disease relative to baseline reference sites (non-urban sites sampled 1989 through 1993). The risk of liver disease increased in fish sampled along the Seattle Waterfront between 1989 and 1998 (see *2000 Puget Sound Update*), decreased in 1999 and was low again in 2000 (Figure 4-17). Scientists have not observed any trends in the risk of developing liver disease for English sole sampled from the other core sites.

State Department of Fish and Wildlife scientists reviewed the in-water activities that have taken place along the Seattle waterfront since 1989 that may have affected the risk of developing liver disease in English sole. Numerous sediment capping projects have been completed to the north, south and in the immediate vicinity of the Elliott Bay sampling site along the Seattle waterfront to sequester contaminated sediment. Capped sediment areas include: 2.8 acres in 1989 at the ferry terminal to the south; 3 acres in 1990 at the Denny Way Combined Sewer Overflow (CSO) to the north (Romberg et al. 1995); 4.5 acres in 1992 along Piers 53, 54 and 55, just inshore of the English sole sampling site, (Romberg et al. 1995); and 3.5 acres capped in 1994 at Bell Street Marina to the north.

Collectively, these projects should have lowered the PAH concentrations in surface sediments, reduced PAH exposure to English sole feeding in this area, and consistently lowered the risk of developing liver disease in these fish. There is evidence from other areas in Puget Sound that declines in liver disease in English sole associated with sediment capping projects are measurable with the type of sampling effort undertaken by PSAMP. Risk of developing liver lesions in English sole from Eagle Harbor declined significantly three to four years after the sediments in that area were capped with clean sediments and have remained consistently low (see next section).

The recent decline in risk of liver disease in Elliott Bay English sole suggests reduced exposure to PAHs; however, Elliott Bay sediment PAH concentrations actually increased during this period (Figure 4-18). The concentration of high molecular weight PAHs in the sediments at this site (monitored by King County) roughly doubled from 1993 to 2000. The King County monitoring station is located in 100 feet of water, and the end of Pier 63, between the Seattle Aquarium and the Bell Street Marina.

It is unknown if this observed increase in PAHs at the Seattle waterfront site is indicative of a broader increase of PAHs in Elliott Bay or whether this is a localized increase. Given the reductions in effluent associated with CSOs and the capping

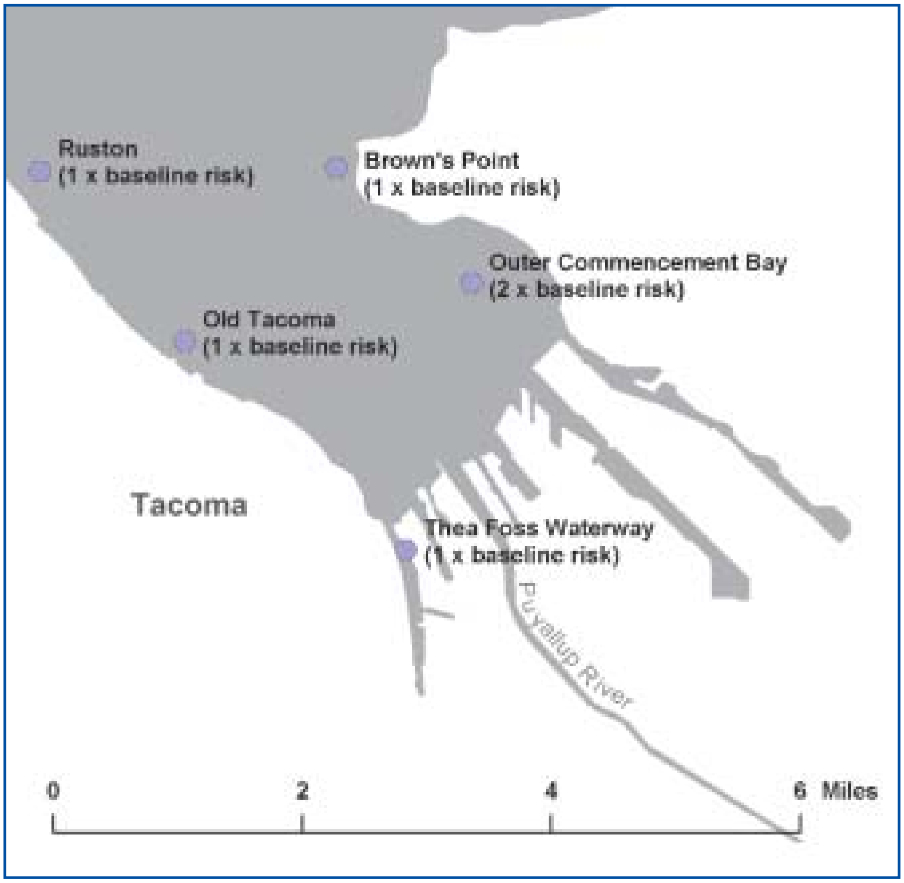


Figure 4-16 . Risk of developing liver lesions in English sole from various sites in Commencement Bay sampled in 1999, relative to baseline risk.

The risk at Thea Foss Waterway has been monitored since 1989 and is highly variable. While the figure reflects the relatively low risk seen at Thea Foss as part of the 1999 study, the average risk at this site from 1989 to 2000 was almost eight times higher than at the baseline reference sites.

Source: Washington State Department of Fish and Wildlife

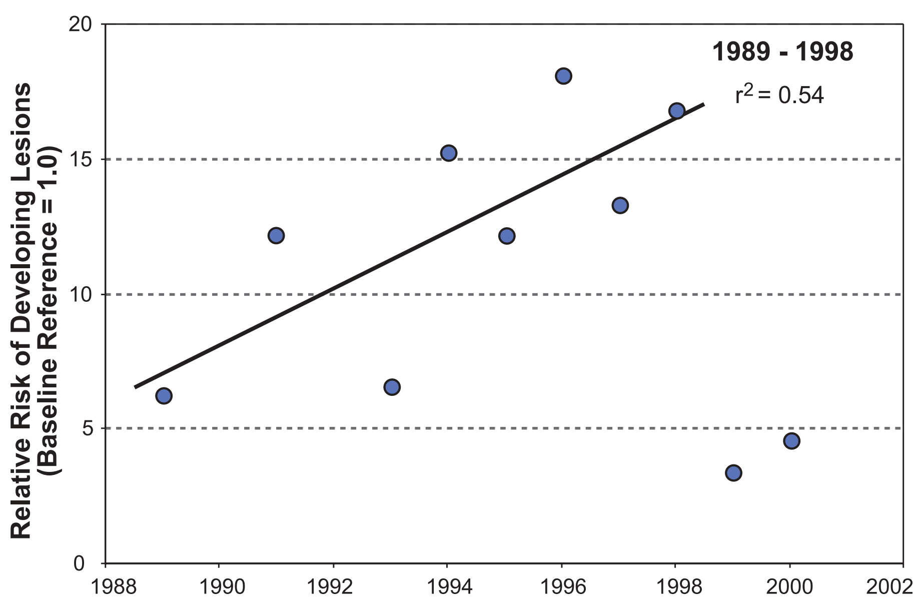
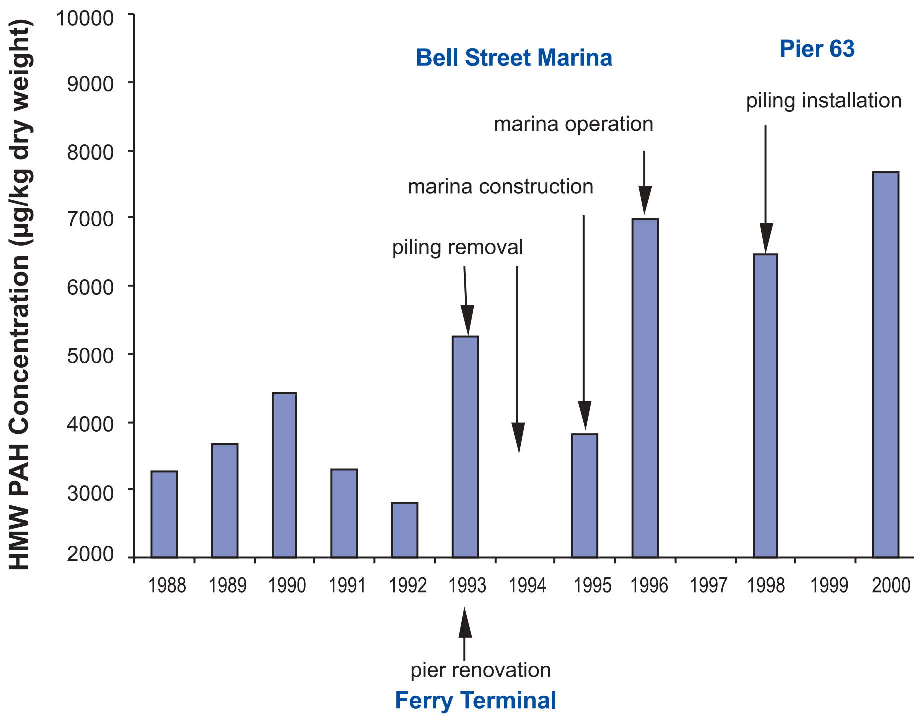


Figure 4-17. Risk of developing liver disease, relative to baseline reference, in English sole sampled along the Seattle Waterfront, 1989 – 2000.

Source: Washington State Department of Fish and Wildlife

Figure 4-18. High molecular weight PAH concentration in sediment along the Seattle Waterfront, 1989-2000, and the timing of major in-water activities.

Source: Washington State Department of Fish and Wildlife. Sediment data from King County Department of Natural Resources and Parks.



projects that have taken place along the Seattle waterfront, it is unlikely that there has been a bay-wide increase in the mass of PAHs in Elliott Bay. More likely, the concentration of PAHs at the Seattle waterfront site is a localized increase resulting from in-water activity associated with nearby pier modification (1993 to 1994 and 1998) and marina construction (1994 to 1995) (King County 1995). If this is the case, sediment PAH levels at the King County sediment site should decline in the future.

The increasing risk of English sole developing liver disease between 1989 and 1998 and the subsequent reduction 1999 and 2000 cannot be readily explained by the sediment chemistry at the King County monitoring station. From 1989 thru 1998, the risk of liver disease was well correlated with the average HPAH concentrations in sediments, but in 1999 and 2000, although the sediment PAHs remained high, the risk of developing liver disease declined (Figure 4-19).

To adequately interpret these results, state Department of Fish and Wildlife scientists would need additional information about the changes in PAH concentration along the whole of the Seattle waterfront and information on the home range of the English sole. Although the home range and feeding grounds of English sole is unknown, they likely extend over an area much greater than that represented by the sediments at the King County sampling site. Lacking such data, state Department of Fish and Wildlife scientists have several working hypotheses:

1. The 1999 and 2000 decline in the risk of developing liver disease may be due to an overall reduction to the mass of PAHs present in the surface sediments along the whole of the Seattle waterfront, independent of sediment changes observed at the specific site sampled over the years by King County.

2. The in-water activities described above may have displaced English sole, invalidating the assumption of a stable sampling population. Either direct physical disturbance during these activities, or less desirable habitat resulting from the placement of nonnative sediment may have led to this displacement.

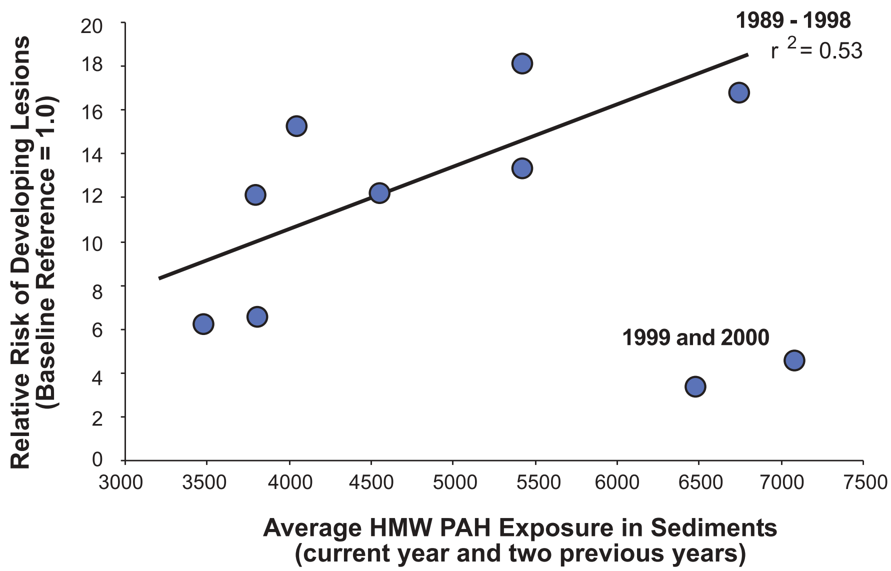


Figure 4-19. Relationship between the risk of developing liver disease in English sole, relative to baseline reference, and the average concentration of High Molecular Weight (HMW) PAHs in sediments.

Source: Washington State Department of Fish and Wildlife.

3. Finally, it is also possible that the observed increase in risk of liver disease was not a meaningful increase but rather a random variation in liver disease in English sole. State Department of Fish and Wildlife scientists plan to test this possibility with Monte Carlo simulations of risk of liver disease, to determine whether their sampling scheme is sufficient to overcome such variability.

Restoration of Fish Health Following Capping of Contaminated Sediment

In 1987, the U.S. Environmental Protection Agency identified Eagle Harbor, an embayment on Bainbridge Island in Puget Sound, as a Superfund site because of high sediment concentrations of PAHs released chronically from a nearby creosoting facility. Earlier studies at this site (1983-86) demonstrated high prevalences (up to approximately 75 percent) of toxicopathic (i.e. associated with exposure to chemical contaminants) liver lesions, including neoplasms (tumors), in resident English sole. NMFS scientists have demonstrated that neoplasia-related lesions can be induced experimentally by injections of a PAH-rich fraction extracted from Eagle Harbor sediment. Scientists have also studied the effects of PAH exposure in Eagle Harbor starry flounder and rock sole (1986-88) using several biochemical biomarkers, including hepatic CYP1A expression, biliary fluorescent aromatic compounds (FACs), and hydrophobic DNA adducts in liver. Prior to site remediation, hepatic lesion prevalences and biomarker values in these species from Eagle Harbor were among the highest found in Puget Sound.

The U.S. Environmental Protection Agency and Army Corps of Engineers placed a one-meter thick cap of relatively clean sediment (September 1993 to March 1994) over the most contaminated portions of Eagle Harbor in an attempt to sequester PAH-contaminated sediments. Scientists found that lesion prevalences and biomarker values just before capping began were generally reduced compared to historical data This is consistent with the creosoting facility closure and shore-based source controls.

Scientists found that toxicopathic liver lesion risk (a calculated parameter that considers lesion prevalence and fish age distribution), hepatic CYP1A, and biliary FACs from fish collected immediately after and at regular intervals up to two years after sediment capping, showed highly variable responses relative to values prior to cap placement. However, scientists found a significantly decreasing trend in risk for toxicopathic hepatic lesions in English sole (Figure 4-20) and rock sole, as well as for biliary FACs and hepatic DNA adducts in all three flatfish species, after approximately two years following the capping. Hepatic CYP1A levels showed no overall trend relative to time of sediment cap placement.

These results show that the sediment capping process has been relatively effective in reducing PAH exposure and associated biological effects in resident flatfish species, and that longer-term monitoring of pollutant responses in biological resources, such as resident fish, is critical to the demonstration of the efficacy of this type of sediment remediation.

Toxic Contaminants in Birds and Mammals

PCB Contamination in Orcas

Scientists from British Columbia (Ross et al. 2000) have reported "surprisingly high" concentrations of PCBs in the blubber of killer whales that reside in, or frequently visit, the coastal waters of British Columbia and Washington. The position of these whales atop a contaminated food web appears to be the primary reason for the observed levels of contamination.

The scientists analyzed blubber samples (biopsies), collected from orcas by dart between 1993 and 1996, for PCBs and chlorinated dioxins and furans. Samples were collected from the three major communities of orcas: transients, relatively elusive animals that occasionally visit the inland marine waters of British Columbia and Washington; southern residents, the orcas that spend much of the year in and around the southern Strait of Georgia and Puget Sound; and northern residents, a group of orcas that reside primarily in protected marine waters from the northern Strait of Georgia to southeast Alaska. The transient orcas, which feed primarily on seals, sea lions and other marine mammals, are among the most highly contaminated marine mammals in the world with total PCB concentrations of 250 milligrams per kilogram of lipid (mg/kg lipid) in males and 59 mg/kg lipid in females.

Resident orcas feed lower on the food web, primarily on fish and especially salmon, and their blubber contains lower PCB concentrations than observed in the transient whales. Males from the southern resident community showed the highest PCB contamination observed among residents, 150 mg/kg lipid. Based on extrapolations from their data, the scientists estimate that the southern resident orcas are four to six times more contaminated than the northern residents, presumably because their prey include more highly contaminated fish from the industrialized parts of Puget Sound and the southern Strait of Georgia.

Contaminants in Bald Eagles Nesting in Hood Canal

A recently completed study investigated levels of toxic contaminants in eggs, blood and prey of bald eagles (*Haliaeetus leucocephalus*) nesting in the Hood Canal area (Mahaffy et al. 2001). Another component of this study tracked the reproductive success of the Hood Canal bald eagle population (Chapter 6). The bald eagle is currently listed as a threatened species under the Endangered Species Act but is proposed for removal from the List of Endangered and Threatened Wildlife (USDI 1999). At the time the species was listed, environmental contaminants such as DDT were cited as the primary reason for its decline. Currently, bald eagle numbers are increasing in Washington State, but the U.S. Fish and Wildlife Service initiated this study because of the depressed bald eagle productivity in Hood Canal relative to Washington State as a whole.

U.S. Fish and Wildlife scientists collected 13 bald eagle eggs from Hood Canal territories in 1992 through 1993 and 1994 through 1997 and five additional eggs

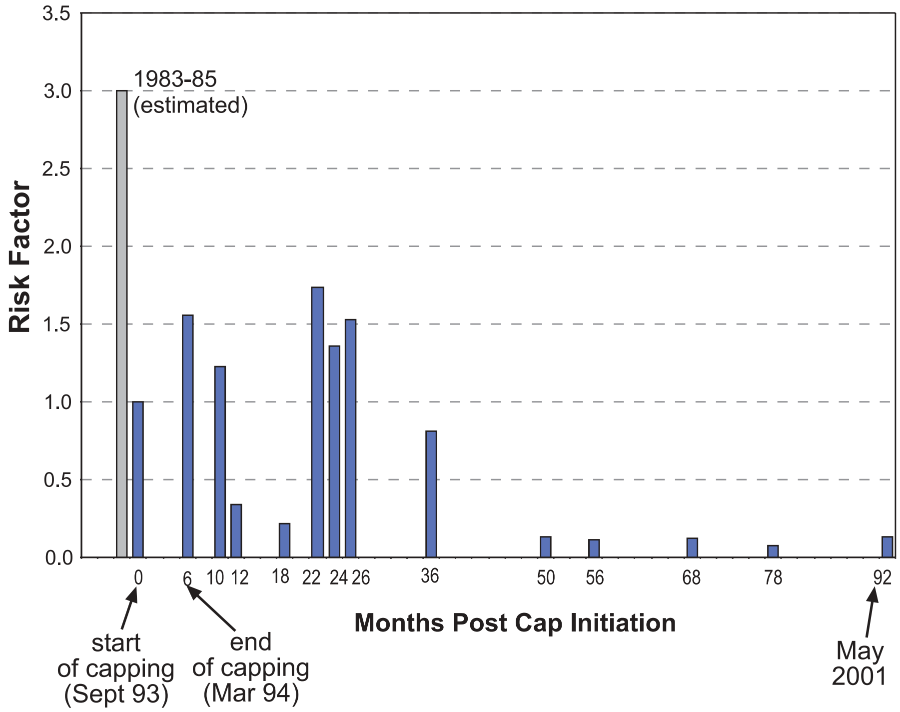


Figure 4-20. Risk of developing toxicopathic liver lesions in English sole from Eagle Harbor, prior to and following capping of contaminated sediment at this site, relative to risk at the time of capping.

Source: National Marine Fisheries Service

from territories outside Hood Canal. In addition, they sampled blood from the Hood Canal birds, and prey fish and sediments from Hood Canal for the measurement of contaminants.

If environmental contaminants were the cause of low productivity, then nests with the highest failure rates would be expected to have eggs with the highest contaminant concentrations. Twelve of the 13 Hood Canal eggs exceeded the 4.0 µg/g threshold total PCB level estimated for normal reproduction of bald eagles. Only one egg collected outside Hood Canal exceeded the 4.0 µg/g total PCB level. Based on these results, Mahaffy et al. (2001) conclude that PCBs likely reduced productivity in the Hood Canal bald eagle territories. In contrast, concentrations of DDE, a breakdown product of DDT, were less than concentrations considered to have an impact on bald eagle productivity.

Concentrations of mercury, selenium and arsenic were below levels of concern in the five eggs where they were analyzed. Detectable levels of PCBs and p,p'-DDE were present in blood samples. Contaminants measured in the fish and sediment samples from Hood Canal were not great enough to account for the elevated amounts found in bald eagles from this area. These results suggest that the contaminant pathway to bald eagles in Hood Canal is likely from food items other than fish, such as birds or marine mammals.

Acting on the Findings

The results presented in this chapter suggest that while we are still trying to understand the extent and effects of toxic contamination in ecosystems, we can successfully manage contamination in some specific cases. The reduction in risk of developing liver lesions in English sole following the capping of contaminated sediment at Eagle Harbor is an excellent example. Continued monitoring is necessary to evaluate such management actions. The need for continuing monitoring is particularly compelling when viewed in the light of new results that reveal toxic effects in organisms where they were previously unknown and studies that identify new compounds as toxic threats.

Some specific recommendations follow directly from the results of studies presented in this chapter:

- As much as possible, studies should be interdisciplinary in nature such that contaminant data can be integrated with population data and life history patterns. Understanding of the currently unexplained variability in some contaminant data will require such an approach.
- Further pilot studies are needed to assess toxic contaminant impacts in previously unstudied species to fully evaluate ecosystem effects of these contaminants.
- Continued monitoring is needed for biota affected by contaminants, even when contaminant levels and productivity are improving, as long as a contaminant impact is observed. This will ensure that recovery proceeds as expected, and important causal factors have not been overlooked.
- Further studies are needed to better understand sources of the recent increases in benzoic acid seen in sediments and shellfish as well as the ecological implications of these increases.
- For contaminants that are increasing in Puget Sound sediments, scientists needs to quantify sources and policy makers need to determine if current controls are inadequate to control these pollutants.
- The state Department of Fish and Wildlife needs to further investigate the source and pathways of contaminants in herring. Emphasis should be on assessing whether (1) dredged material management; (2) contaminated sediment cleanup; or (3) wastewater discharge control could reduce herring contaminant exposure.
- Scientists need to use developing food web models for Strait of Georgia and south Puget Sound and information on contaminant burdens in various organisms to see if they can accurately describe the major pathways of accumulation to rockfish, salmon, harbor seals, orcas and Hood Canal eagles. These studies can identify gaps and encourage additional study to fill these gaps. This work can also identify the leading opportunities to reduce accumulation of toxics in the food web.
- Scientists need to keep up efforts to relate fish contamination and disease to sediment contamination, especially at areas such as Seattle Waterfront and Thea Foss Waterway to try to learn more about how fish respond to cleanup efforts and sediment disturbances.
- More focused monitoring is needed to measure the effectiveness of alternative contaminant control measures.

5. Human Health

Bill Dewey, Taylor Shellfish Co., Inc.

Overview

This chapter discusses human health risks associated with toxic and pathogenic contaminants in Puget Sound. Human health threats from Puget Sound occur primarily through consumption of shellfish and fish, rather than through direct contact with water. Since shellfish are predominantly filter feeders, they accumulate pathogens and toxic contaminants present in the water, which can become concentrated in the organism tissues. This poses a risk to humans when these organisms are harvested for consumption. Some of the key results in this chapter include:

- The Washington State Department of Health reclassified four commercial shellfish growing areas in Puget Sound in 1999, five areas in 2000 and six in 2001. A total of 1580 acres were upgraded and 2069 acres were downgraded over these three years.
- The number of confirmed cases of human *Vibrio parahaemalyticus* infection continued the declining trend with each consecutive year since a major outbreak occurred in 1997. There were six cases in 2001 compared to 66 in 1997.
- The state Department of Health observed the greatest concentration of paralytic shellfish poisoning (PSP) toxin in shellfish along the

Strait of Juan de Fuca and scattered sites in the Main Basin and south Puget Sound. Areas free of PSP in 2000 included Hood Canal south of Lofall, south Puget Sound west of Anderson Island, Saratoga Passage, and Westcott Bay on San Juan Island.

Findings

Managing Risks from Shellfish Consumption Related to Pathogens

Washington State is among the top shellfish producing states in the nation. The state Department of Health, in collaboration with tribes and local health departments, maintains a classification system for shellfish growing areas and conducts sampling of shellfish meat to manage human health risks. These activities minimize direct exposure to pathogens (primarily bacteria) as well as exposure to biotoxins produced by non-pathogenic marine organisms.

Sanitation problems in areas that drain into shellfish-growing waters may contaminate shellfish with a number of pathogens. These potentially include bacteria that cause cholera, typhoid, dysentery and the virus that causes hepatitis A. The concentration of fecal coliform bacteria in marine water is used as an indicator of sanitation problems. The status and trend in fecal coliform observations are discussed in Chapter 3.

Commercial Growing Areas

The state Department of Health minimizes the risk of pathogen exposure associated with sanitation problems in commercial shellfish harvesting areas through classification of these areas. The classifications are based on evaluation of pollution sources and fecal coliform levels in marine water samples but may also reflect other factors such as presence of industrial contamination (e.g. metals, organic compounds). Commercial shellfish growing areas are classified as **Approved, Conditionally Approved, Restricted,** or **Prohibited.** These classes have specific standards derived from the National Shellfish Sanitation Program (NSSP) Model Ordinance. Areas that have not been surveyed and evaluated are included in the Prohibited class.

As of May 2001, the state Department of Health has classified nearly 200,000 acres in nearly 100 growing areas statewide as **Approved** or **Conditionally Approved** for shellfish harvest. In the 1980s, the state Department of Health downgraded almost 33,000 acres; only 1,000 acres were upgraded. However, in the 1990s, upgraded acreage nearly equaled downgraded acreage.

The NSSP guidelines ensure thorough assessment of fecal pollution conditions in shellfish harvest areas. Before an area is classified, the state Department of Health must collect at least 30 water samples from each sampling station in the growing area. While data are collected, a thorough sanitary survey must be done to locate and evaluate all potential pollution sources.

Two statistics are calculated from the 30 water samples. These are compared to the *NSSP Growing Area Criteria*: The criteria and their application are described below:

1. The *geometric mean* is not to exceed 14 MPN/100 ml water (applied in all cases).
2. The *90th percentile value* is not to exceed 43 MPN/100 ml water (applied to areas where only nonpoint sources are present:); or 10 percent of results are not to exceed 43 MPN/100 ml of water (applied when one or more point sources of pollution are present).

(Note: MPN means “most probable number” and represents a single fecal coliform bacterium.)

How shellfish growing areas are approved

To be **Approved** for harvest, a growing area must not only meet the NSSP water quality criteria, but a required shoreline survey must show no significant sources of fecal contamination. If the criteria are not met, but pollution events are shown to be episodic and predictable (e.g., rain-related runoff, etc.), an area may qualify as **Conditionally Approved**, i.e., harvest is allowed except during and immediately following the predictable pollution event. More data analysis is required to define the time limits of the conditional closure. To assure continued classification, sampling is continued and shoreline surveys are repeated periodically.

Growing Area	County	Year	Re-classification	Upgrade/ downgrade	Acres
Burley Lagoon	Pierce	1999	C → R	↓	210
		1999	P → R	↑	20
Port Gamble Bay	Kitsap	1999	P → A	↑	20
Portage Bay	Whatcom	1999	A → R	↓	90
Drayton Harbor	Whatcom	1999	A → P	↓	920
Sequim Bay	Clallam	2000	P → A	↑	750
Dungeness Bay	Clallam	2000	A → P	↓	300
Henderson Inlet	Thurston	2000	A → P	↓	8
Nisqually Reach	Thurston	2000	C → R	↓	74
		2000	C → A	↑	20
Similk Bay	Skagit	2000	A → P	↓	60
Duckabush	Jefferson	2001	R → A	↑	630
Dungeness Bay	Clallam	2001	A → P	↓	100
Henderson Inlet	Thurston	2001	A → C	↓	300
Burley Lagoon	Pierce	2001	R → A	↑	110
Filucy Bay	Pierce	2001	C → P	↓	7
Rocky Bay	Pierce	2001	P → A	↑	15

Table 5-1. Reclassifications of intertidal shellfish growing areas in 1999 and 2000.

A = Approved
C = Conditionally Approved
R = Restricted
P = Prohibited

Source: Washington State Department of Health

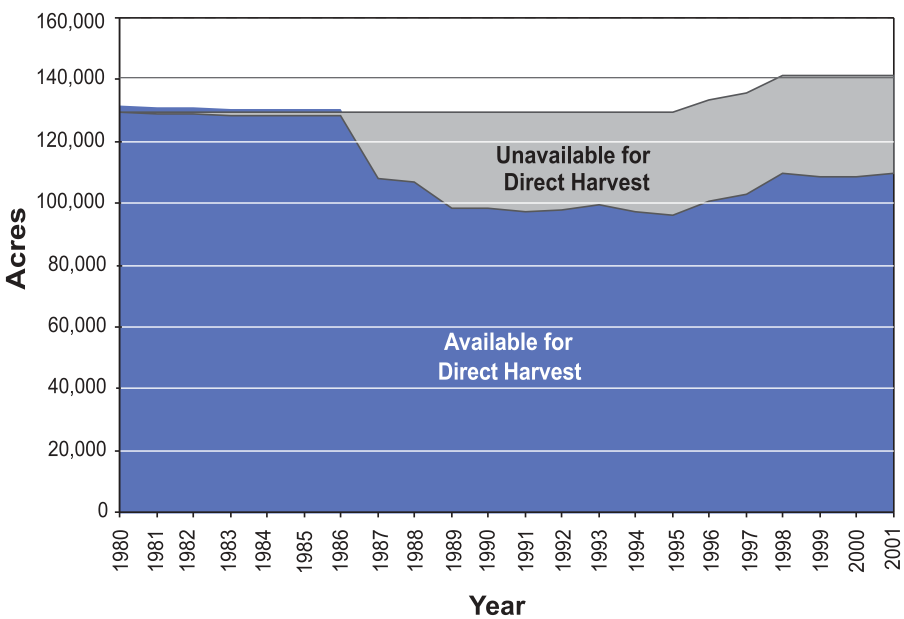


Figure 5-1. Trend in commercial shellfish growing areas in Puget Sound that are available (**Approved** and **Conditionally Approved**) and unavailable (**Restricted** and **Prohibited**) for harvest.

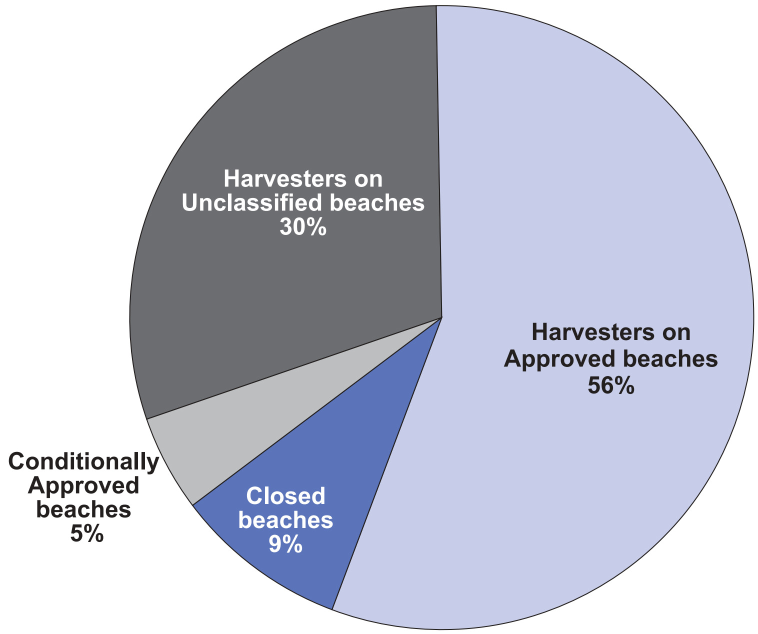
Source: Washington State Department of Health

The state Department of Health provides an annual Early Warning list of threatened growing areas to shellfish growers and local and state agencies. An area is deemed threatened if the 90th percentile calculated for a station within the growing area exceeds 30 MPN per 100 ml. The 90th percentile is used because experience has shown that this statistic responds more quickly to change than does the geometric mean.

The state Department of Health reclassified four commercial shellfish growing areas in Puget Sound in 1999, five areas in 2000 and six in 2001. This does not include subtidal geoduck tracts. These reclassifications are shown in Table 5-1. Relative to larger reclassifications of the past 20 years (Figure 5-1), the changes in 1999 through 2001 involved relatively small areas. A total of 1,580 acres were upgraded and 2,069 acres were downgraded.

Figure 5-2. Breakdown of recreational shellfish harvesters in 2001 by the state Department of Health beach classification.

Source: Washington State Department of Health



Recreational Shellfish Harvest at Public Beaches
Local health jurisdictions and the state Department of 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. Recreational shellfish beaches are classified as **Approved, Conditional, Closed** or **Unclassified**.

The Washington State Department of Fish and Wildlife monitors the numbers of recreational shellfish harvesters on public beaches. The agency estimates that there were 189,000 harvesters in 2001, a 23 percent decrease relative to 2000. Figure 5-2 shows that the majority (56 percent) of recreational harvesters in 2001 harvested on beaches classified as open by the state Department of Health. Despite the efforts of the state Department of Health, 9 percent of recreational harvesters were observed on closed beaches and 30 percent on unclassified beaches.

Vibrio parahaemolyticus
The *Vibrio parahaemolyticus* bacterium occurs naturally and is common in marine and estuarine environments worldwide. It is considered an emerging, or spreading, pathogen in North America (McCarter 1999). The organism causes gastroenteritis in humans. In the summer of 1997, the largest reported outbreak of *V. parahaemolyticus* infections in North America occurred in the Pacific Northwest, primarily associated with the consumption of raw oysters that had accumulated the bacterium. One person died (CDC 1998).

Following the 1997 outbreak, the state Department of Health began regular monitoring of shellfish meat for *V. parahaemolyticus* (Table 5-2). Sale of oysters is restricted when the bacterium reaches 10,000 cfu (colony forming units) per gram of oyster tissue, but this restriction did not prevent the 1997 outbreak (CDC 1998).

There are more than 30 species of aquatic *Vibrio* bacteria. The species of greatest concern in Puget Sound is *V. parahaemolyticus*, particularly during warm water conditions in the summer. Prior to 1997, confirmed cases of *Vibrio* infection ranged from two to 32 per year. The numbers of infections have been declining since 1997 (Table 5-3).

Year	Growing Area	Maximum Vibrio concentration (cfu/gram)
1998	Totten Inlet - Oyster Bay	24,000
	Hood Canal North -Seabeck	> 1,100
	Hood Canal North - Quilcene	24,000
	Hood Canal North - Dabob Bay	4,270
	Case Inlet - Rocky Bay	2,400
	Eld Inlet	1,410
	Hood Canal South - Twanoh	2,050
1999	Hood Canal North - Quilcene	1,100
2000	Little Skookum	2,400
	Samish Bay	4,600
	Hood Canal North - Seabeck	1,100
2001	Eld Inlet	4,620

Table 5-2. Observations of *Vibrio parahaemolyticus* greater than 1,000 colony forming units (cfu) / gram since sampling began in 1997.

Source: Washington State Department of Health

Year	Number of Cases
1997	66
1998	54
1999	17
2000	9
2001	6

Table 5-3. Number of confirmed cases of human *Vibrio parahaemolyticus* infection associated with the consumption of Washington shellfish, primarily oysters, or consumption of shellfish from multiple sources that include Washington State.

Source: Washington State Department of Health

There is a precedent for the successful control of a *Vibrio*—the virtual elimination of cholera, *V. cholerae*, from the U.S. The *Vibrio* group also includes *V. vulnificus* that can also infect humans from shellfish consumption but does not occur in Washington.

Biotoxins in Shellfish

Blooms of many phytoplankton species are a normal seasonal occurrence in Washington's inland marine waters. One dinoflagellate species, *Alexandrium catenella*, produces a toxin that causes paralytic shellfish poisoning (PSP). Shellfish filter the toxic algae out of the water while feeding and concentrate the toxin in their tissues. PSP toxin in shellfish is a serious threat to the health of shellfish consumers. Washington State has monitored PSP in shellfish since the 1930s. Monitoring was greatly expanded by the late 1950s, and now shellfish are monitored at hundreds of sites throughout Puget Sound and on the coast. In 1990, the state Department of Health set up a Sentinel Monitoring Program to provide systematic early warning of harmful levels of biotoxins. This year's *Update* reports on PSP from 34 Sentinel sites.

Another biotoxin, produced by diatoms in the genus *Pseudonitzschia*, causes amnesic shellfish poisoning (ASP) in humans, but these organisms are not found in Puget Sound and are not discussed here.

The state Department of Health scientists sorted all PSP results collected in 2000 into four categories based on PSP impact. The **PSP Impact Categories** are:

None: The PSP result was less than 80 µg per 100 grams of shellfish tissue (FDA action level).

Low: The PSP result ranged from 80-499 µg per 100 grams of shellfish tissue.

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.

Moderate: The PSP level ranged from 500-999 µg per 100 grams of shellfish tissue.

High: The PSP level was greater than 1,000 µg per 100 grams of shellfish tissue.

Figure 5-3 depicts the proportion of PSP results falling within each PSP impact category during 2000 as a pie chart for each sentinel site. The greatest impact occurred along the Strait of Juan de Fuca and at scattered sites in the Main Basin and south Puget Sound. Areas free of PSP in 2000 included Hood Canal south of Lofall, south Puget Sound west of Anderson Island, Saratoga Passage, and Westcott Bay on San Juan Island (although free of PSP in year 2000, blooms occurred in 1997 through 1998 and 2001).

Figure 5-3 suggests that 21 of 34 Sentinel sites experienced **Low** to **High** PSP impact during 2000. The remaining 13 sites showed no significant impact. These sites were ranked by calculating an annual PSP impact factor. To calculate the factor for each site, the number of PSP results in each category was weighted according to PSP (i.e., the number of **Low** PSP results x 1, the number of **Moderate** PSP results x 2, the number of **High** PSP results x 3). The weighted categories were added to produce the impact factor for each sentinel site (Figure 5-3).

There is little evidence that PSP impact is related to human activity. Some sites with the highest impact factors (Figure 5-4) are located in rural areas with minimal to moderate human activity (Burley Lagoon, Discovery Bay, Drayton Harbor, Sequim and Filucy bays). On the other hand, some urbanized areas (Squalicum Harbor near Bellingham, Liberty Bay, and Sinclair Inlet) showed relatively low impact.

The onset, intensity, and duration of PSP episodes cannot yet be predicted due to the interaction of many poorly understood environmental factors. As a consequence, the state Department of Health will continue routine comprehensive monitoring of shellfish throughout Puget Sound.

Toxic Contaminants in Fish and Shellfish

Health Risk Assessments and Consumption Advisories for Puget Sound Fish
Scientists from the state Department of Health have identified nine fish and shellfish consumption advisories related to toxic chemical contamination in various locations around Puget Sound. These advisories are summarized in Table 5-4.

The state Department of Health scientists are currently evaluating fish contaminant data from PSAMP to assess human health risks from the consumption of Puget Sound fish. Assessments incorporate information on the toxicity of contaminants and estimates of fish consumption by various segments of the population. They also consider duration of exposure to the contaminants. Assessment of PCB exposure should be available in 2002.

The state Department of Health used its estimate of a tolerable daily intake (TDI) for methylmercury (Washington State Department of Health 1999) to assess exposure from consuming fish in Puget Sound. These analyses indicate that recreational anglers consuming freshwater species have exposure levels below the TDI, as do almost all recreational anglers consuming saltwater fish (Mariën and Patrick 2001). However, exposure analyses indicate that many within Native American populations exceed the TDI even though they consume fish with mercury concentrations comparable to "background" concentrations found in fish from open waters. The state Department of Health will update its TDI value as further data become available.

Biotoxin Hotline

The Washington State Department of Health monitors biotoxin levels in shellfish throughout Washington's marine waters to protect shellfish consumers from biotoxin poisoning. When harmful levels of biotoxins are detected, the state Department of Health issues warnings to commercial shellfish growers, local health agencies, tribal resource agencies, and the public. Commercial harvest is stopped. Warnings are issued via newspapers, television, the Department of Health Biotoxin Hotline at (800) 562-5632, or by Internet (www.doh.wa.gov/ehp/sf/biotoxin.htm).

Effects of cooking shellfish

Cooking shellfish does not eliminate the toxin that causes paralytic shellfish poisoning (PSP). Cooking kills the organism, *Alexandrium catenell,* which produces the toxin, but the toxin remains.

Unlike PSP, vibriosis and the accompanying flu-like symptoms can be avoided by thoroughly cooking shellfish. This is especially important during summer months, when the bacteria that causes vibriosis, *Vibrio parahaemolyticus,* is more common.

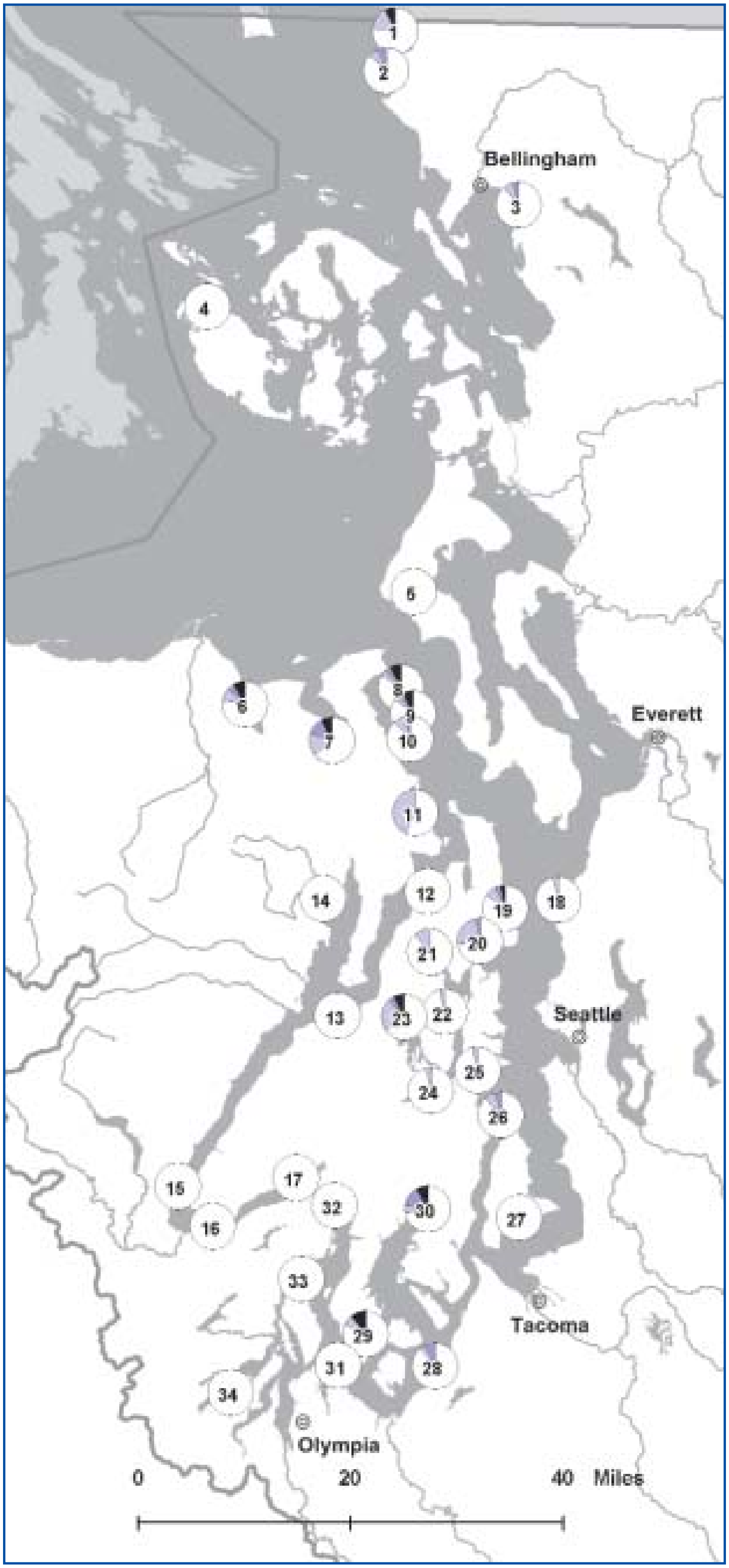
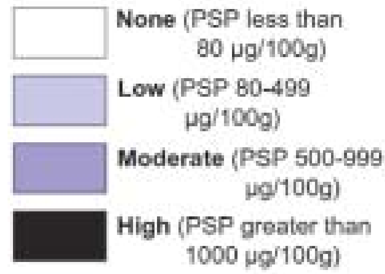


Figure 5-3. Spatial distribution of PSP impact in Puget Sound in 2000.

Source: Washington State Department of Health



Sampling Sites:

1. Drayton Harbor
2. Birch Bay
3. Squalicum Harbor
4. Westcott Bay
5. Penn Cove
6. Sequim Bay State Park
7. Discovery Bay
8. Fort Flagler
9. Mystery Bay
10. Scow Bay
11. Port Ludlow
12. Lofall
13. Seabeck
14. Quilcene Bay
15. Hoodsport
16. Union
17. Lynch Cove
18. Edmonds
19. Kingston
20. Miller Bay
21. Liberty Bay
22. Port Orchard Passage
23. Dyes Inlet
24. Sinclair Inlet
25. Manchester
26. Southworth
27. Quartermaster Harbor
28. Steilacoom
29. Filucy Bay
30. Burley Lagoon
31. Johnson Point
32. North Bay
33. Jarrell Cove
34. Totten Inlet

Figure 5-4. Ranking of PSP-impacted sites in Puget Sound and the straits of Georgia and Juan de Fuca in 2000.

Source: Washington State Department of Health

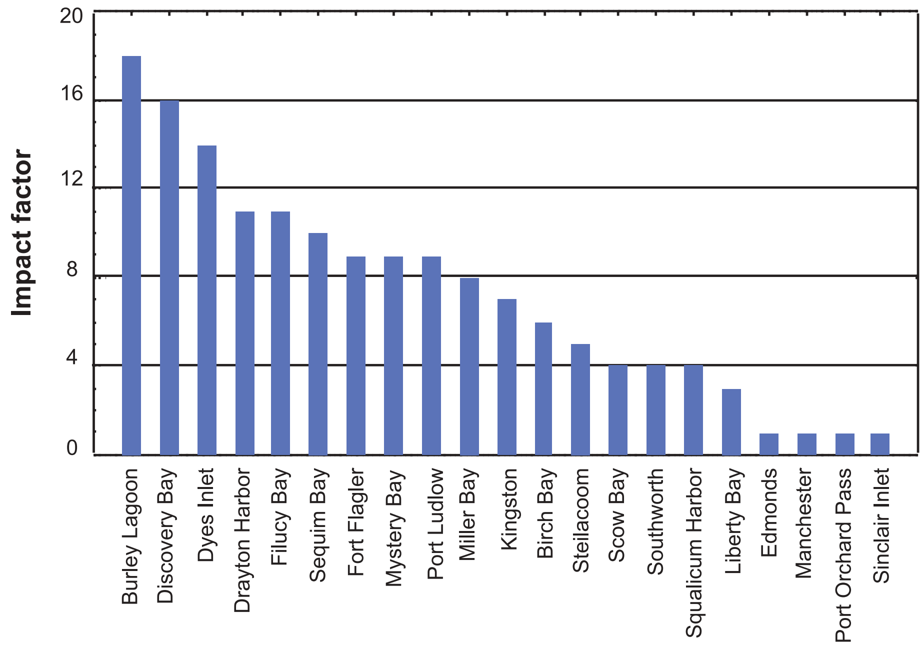


Table 5-4. 2001 Puget Sound fish and shellfish consumption advisories due to toxic chemical contamination.

Source: Washington State Department of Health

Location of advisory	Agency that issued advisory	Fish and shellfish affected	Contaminants identified
Budd Inlet, Olympia	Thurston County Health Dept.	Shellfish	Creosote, VOC, pentachlorophenol and dioxins
Commencement Bay, Tacoma	Tacoma-Pierce County Health Dept.	Bottom fish, shellfish and crab	PCBs and diethylphthalates, tetrachloroethylene, and metals
Dogfish Bay, Keyport	Bremerton-Kitsap County Health Dist.	Shellfish and bottom fish	metals and vinylchloride
Dyes Inlet, Bremerton	Bremerton-Kitsap County Health Dist.	Shellfish, bottom fish and crab	Naval ordnance
Eagle Harbor, Bainbridge Island	Bremerton-Kitsap County Health Dist.	Shellfish, bottom fish and crab	PAHs and mercury
Indian Island	US. Navy	Shellfish	Pesticides and metals
King County marine waters	Seattle-King County Dept. of Public Health	Shellfish, bottom fish, crab and seaweed	Contamination associated with historic industrial discharges
Manchester State Park, Port Orchard	Bremerton-Kitsap County Health Dist.	Shellfish	PCBs and dioxins
Sinclair Inlet, Bremerton	Bremerton-Kitsap County Health Dist.	Shellfish, crab, bottom fish	Mercury and PAHs

Acting on the Findings

The monitoring results discussed in this chapter suggest two recommendations for future studies and health management activities:

- Additional research is needed to understand the pattern and drivers that control the occurrence and spatial extent of PSP and *V. parahaemolyticus* shellfish contamination.
- The state Department of Health should provide information to help people manage human health risks associated with consuming Puget Sound fish. This should include state-issued fish consumption advice as the Department of Health has done for fish from Lake Whatcom, Lake Roosevelt and the Spokane River.

6. Biological Resources

Overview

Each of the plant and animal populations within the Puget Sound basin contribute to the biodiversity and ecosystem function in the region. Many species are also important economic and cultural resources. Plants and animals have always faced environmental stressors associated with predators, competition and pathogens. These species and the habitats upon which they rely have continually faced natural disturbances related to climatic or geologic events. However, the dramatic increase in human population and the introduction of industrial activities in the last century have brought intense pressure on many species through direct harvesting, alteration and contamination of food webs and loss of habitat. The introduction of invasive exotic species has also increased competitive pressures on many native species.

Most research has focused on relatively few economically or recreationally important species. Consequently, little is known about the majority of Puget Sound plant and animal species. Nevertheless, scientists have documented many cases of sharp declines in abundance in a diverse set of species that include fish, marine birds and a marine mammal (i.e., the southern resident orca population). Conversely there are examples of increasing abundance that confound a simple interpretation of a system in decline (e.g. harbor seal, merganser, bald eagle) and other species whose abundances reflect natural processes and events more so than human influences (e.g. kelp bed extent).

Efforts at a variety of organizational levels are directed at protecting biological resources. These include land-use planning efforts at the local level, management of fisheries and game species by tribes and the state, and direct protection by federal legislation such as the Marine Mammal Protection Act (MMPA) and the Endangered Species Act (ESA).

Photo credit clockwise from upper left: Wayne A. Palsson, Joseph Evenson, Randy Shuman and Brian Walsh.

A number of species in the Puget Sound area have received protection under ESA, most recently, several salmonid populations in 1999. Others have recently been studied for potential protection, for example the orca whale (*Orcinus orca*). Salmon species currently listed as threatened under ESA include Puget Sound chinook salmon (*Oncorhynchus tshawytscha*) and Hood Canal summer-run chum salmon (*O. keta*). coho salmon (*O. kisutch*) is currently a candidate species for listing. A number of marine fish species were also reviewed for ESA protection, but six were declined and Pacific whiting (hake) was retained as a candidate species. Protection of these species under ESA falls under the jurisdiction of the National Marine Fisheries Service (NMFS). The recovery of the bald eagle over large areas of the U.S., including Puget Sound, is considered a major success of the ESA—in this case under the jurisdiction of the U.S. Fish and Wildlife Service.

Marine reserves are another management tool available to protect biological resources from human activity. Marine reserves are currently attracting increasing interest and scientific inquiry to understand their effectiveness and design parameters (Palsson 2002; Eisenhardt 2002; Salomon 2002).

This chapter presents monitoring results from the Puget Sound Ambient Monitoring Program (PSAMP) and related efforts that cover a wide range of biological resources from primary producers at the bottom of food webs (phytoplankton and aquatic vegetation) through marine macro-invertebrates, fish, birds and marine mammals at intermediate trophic levels, to organisms at the top of their respective food webs, such as the orca whale and bald eagle. Some of the new findings and accomplishments highlighted in this chapter are summarized in the following list.

Vegetation, Phytoplankton and Macro-Invertebrates

- Scientists at the Washington State Department of Natural Resources completed a statewide inventory of the shoreline called the ShoreZone Inventory in 2000. The inventory characterizes shoreline geomorphology, vegetation, and anthropogenic development along the 3000 miles of saltwater shoreline in Washington State.
- In 2000, the Department of Natural Resources sampled eelgrass beds at 67 sites throughout Puget Sound as part of a new Submerged Vegetation Monitoring Program. This study provides the first estimate of the amount of eelgrass in Puget Sound, and other information on eelgrass bed characteristics. It also serves as a baseline for a long-term monitoring program.
- Kelp canopy area in the Strait of Juan de Fuca increased in both 1999 and 2000 following a strong decrease in 1997 associated with the most recent El Niño episode. In spite of high yearly variability, no long-term trend is apparent in kelp area between 1989 and 2000, suggesting that the population is stable over this time period.
- Phytoplankton blooms in central basin of Puget Sound in 1999 and 2000 were not as consistent as previous years in terms of spatial extent and timing.
- Diversity in intertidal macro-invertebrates is three times higher in northern Puget Sound relative to the southern Sound with a smooth gradient in between.

Fish

- The Washington State Department of Fish and Wildlife found in their 2000 trawl survey of groundfish in the eastern Strait of Juan de Fuca that most populations were less abundant than previously observed. Some numerically depressed species showed no population growth in response to the recent reduction of fisheries pressure.
- The trends in the status of groundfish populations for the larger Puget Sound area have improved slightly from that reported previously in the *Puget Sound Update*. However, many are still in poor condition, especially south of Port Townsend.
- NMFS determined in 2000 that the listing of seven marine fish species under ESA was not warranted, despite the sharp declines in many of these species in Puget Sound. NMFS determined the Puget Sound populations were part of larger Pacific population that, as a whole, are not declining. These seven species were the last to be considered in a 1999 petition for ESA listing that contained 18 species. A single species of that list, Pacific whiting (hake), has been retained as a candidate species pending further studies.
- The total amount of spawning herring increased modestly in Puget Sound in 2000 and 2001 although some stocks, particularly the Cherry Point stock, have shown tremendous declines and the reasons for this decline remain unknown.
- Isotopic and genetic studies of Puget Sound herring stocks, including the Cherry Point stock, were not conclusive but did not provide strong evidence in support of treating individual stocks as distinct units under ESA.
- The state Department of Fish and Wildlife observed an increase in marine survival of juvenile coho and other salmon in the Strait of Georgia in 2000. Other data suggest that this increase is associated with shifts in the food web and a decrease in predation on these species.
- Our knowledge of the status and population trends of many non-commercially valuable species remains very incomplete.
- Since the marine food web is complex, variations in populations of these undocumented species may affect the populations of those that are monitored.

Birds

- Baseline data on the pigeon guillemot population, collected in 1999-2000 as part of a new study, showed highest concentrations in the northern and southern areas with lower numbers in central Puget Sound.
- A new trend analysis of populations of wintering nearshore waterbirds in Puget Sound showed significant decrease in most species studied (grebes, cormorants, loons, pigeon guillemot, marbled murrelets, scoters, scaup, long-tailed duck and brant) between the late 1970s and the 1990s. In contrast, there was an increase in harlequin ducks and other species remained stable.

- Surveys of great blue herons conducted in 2001 showed good correspondence between data collected by aerial survey and more intensive ground surveys, suggesting the potential of expanded aerial surveys in the future. The largest numbers were seen in the northern Sound at Padilla Bay, Twassassen Ferry (B.C.) and Drayton Harbor.
- The bald eagle population in Hood Canal is increasing but still trails behind other Washington State populations in productivity.

Marine Mammals

- The sharp decline in the southern resident orca whale population continued in 2000 through 2001. This Puget Sound population declined from a recent maximum of 97 in 1996 to 78 in 2001. High contaminant levels, including PCBs, are a possible factor because they are greater than levels that have been shown to have a negative impact on other marine species. Declining food sources and artificial underwater sounds are other possible negative factors.
- In 2001, a consortium submitted a petition to NMFS to list the southern resident population of orcas, which reside for most of the year in Puget Sound/Georgia Basin, as threatened or endangered under ESA. NMFS completed a biological review and determined that protection under ESA is not warranted because the population does not meet specific criteria that are stipulated in the Act and in existing policy documents, not because NMFS contests the decline of the population.
- The state Department of Fish and Wildlife released a new trend analysis of the harbor seal population in Washington State (1978-1999) that shows an overall three-fold increase since enforcement began of the MMPA in 1978. The greatest growth has been in the San Juan Islands and the Strait of Juan de Fuca. Model analysis suggests the population is near the current carrying capacity of the inland marine ecosystem in Washington.

Exotic Species

- The Department of Natural Resources conducted a seven-day expedition in 2000 to survey exotic organisms in selected marine areas documented a total of 40 exotic species. Fewer exotic species were found in Elliott Bay and the Totten/Eld Inlet region (15 species each) compared to Willapa Bay on the outer coast (34 species).
- On this 2000 expedition, the greatest number and extent of invasions was found in the least physically altered system. This pattern appears to contradict the hypothesis that more disturbed habitats are more vulnerable to invasions.
- Coordinated efforts to control the spread of exotic *Spartina*, an invasive aquatic grass, have led to a reduction in the size of the Puget Sound infestation as a whole and the elimination in some areas.

Washington State ShoreZone Inventory

In 2000, scientists with the Nearshore Habitat Program at the Department of Natural Resources completed a statewide inventory of saltwater shorelines using the ShoreZone Mapping System.

The ShoreZone Inventory characterizes approximately 3,000 miles of saltwater shorelines statewide. Intertidal areas were surveyed between 1994 and 2000 using helicopter-based aerial videography. These recordings were then used to create geographic data that summarizes the physical and biological characteristics of the shoreline. The ShoreZone Inventory includes more than 50 parameters describing shoreline geomorphology, vegetation, and anthropogenic development. Inventory results show spatial patterns in features commonly considered to be indicators of habitat function and ecosystem condition. The data are useful for characterizing nearshore habitat at multiple scales, including the county scale for local management, and other geographic areas such as oceanographic basins.

The ShoreZone Inventory also includes data on shoreline modification (see Chapter 2).

County Name	Total Miles	Percent of Shoreline with Aquatic Vegetation			
		Eelgrass	Floating kelp	Non-floating kelp	Sargassum
Clallam	254	20%	40%	80%	1%
Grays Harbor	187	5%	< 1%	6%	< 1%
Island	214	63%	10%	18%	8%
Jefferson	254	58%	7%	33%	18%
King	123	62%	13%	27%	25%
Kitsap	254	48%	< 1%	21%	21%
Mason	232	28%	< 1%	24%	33%
Pacific	276	22%	< 1%	1%	< 1%
Pierce	239	26%	7%	44%	19%
San Juan	408	41%	31%	63%	47%
Skagit	229	51%	12%	26%	15%
Snohomish	133	22%	1%	1%	3%
Thurston	118	4%	< 1%	24%	4%
Whatcom	147	55%	7%	18%	34%
Puget Sound Coast	2469	43%	13%	38%	23%
Outer Coast	598	11%	9%	20%	<1%
Total	**3067**	**37%**	**11%**	**31%**	**18%**

Table 6-1. Percentage of vegetated coastal shorelines in Washington State.

Source: Washington State Department of Natural Resources

FINDINGS

Nearshore Submerged Aquatic Vegetation

Aquatic vegetation is recognized to be important fish and wildlife habitat by ecologists and policy makers. For this reason, information on the abundance and distribution of aquatic vegetation is needed to support research and planning activities.
Table 6-1 summarizes ShoreZone Inventory data to show the relative abundance of four types of shoreline vegetation that affect habitat condition.

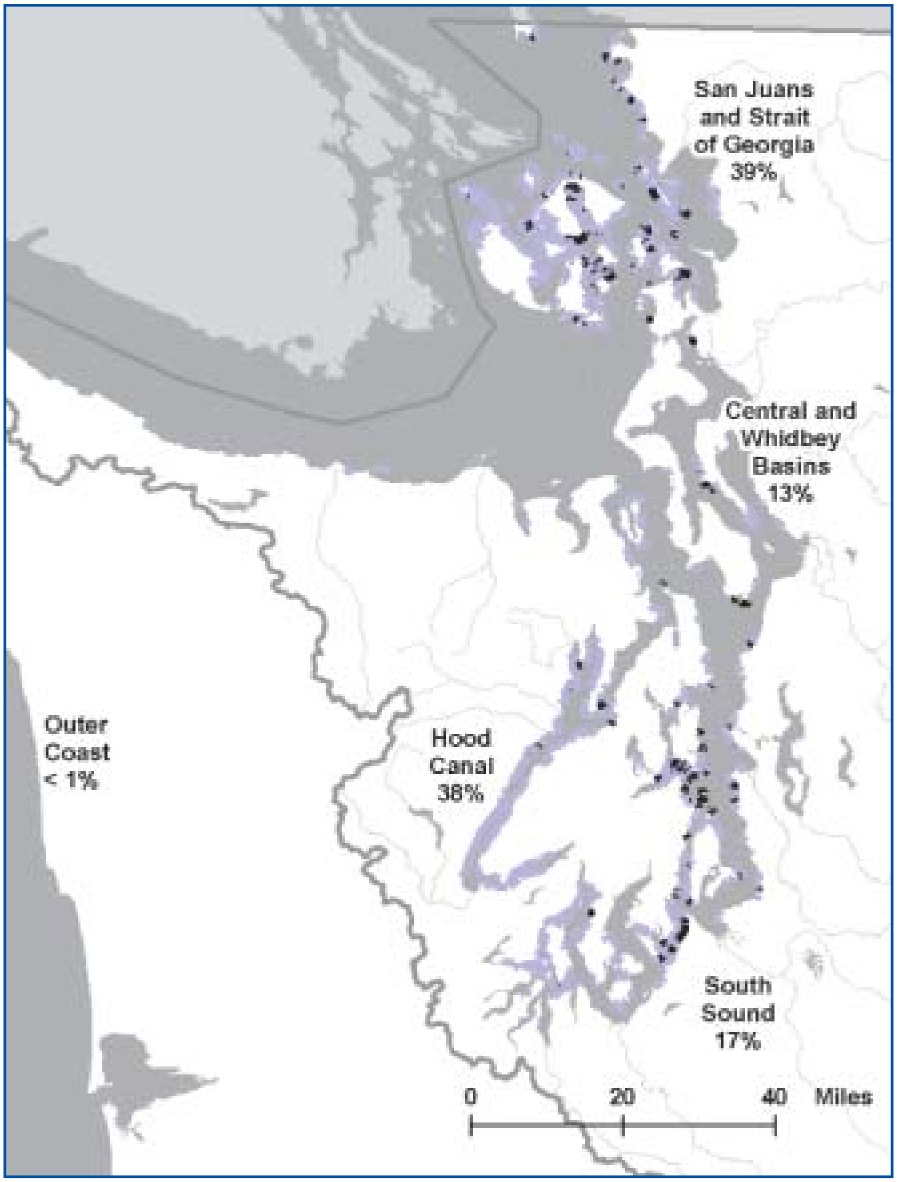
Eelgrass beds (*Zostera marina* and *Zostera japonica*) occur along 37 percent of shorelines. Island, King, Whatcom, Kitsap and Skagit counties have the highest percentage of eelgrass. Eelgrass is not common in South Puget Sound, and it does not occur in the extreme southern reaches, including Budd Inlet, Eld Inlet and Totten Inlet. While these data provide a useful snapshot of eelgrass distribution, they do not address temporal trends in eelgrass distribution and abundance (see Monitoring Eelgrass Abundance in Puget Sound later in this chapter).

Kelp beds are important nearshore habitats that support commercial and sport fish, invertebrates, marine mammals and marine birds. The ShoreZone Inventory shows very different patterns in the distribution of floating kelp (*Macrocystis integrifolia* and *Nereocystis leutkana*) and other non-floating kelp species (*Laminaria spp*., *Egregia menziesii* and other species). Statewide, shorelines with floating kelp are less common (11 percent) than non-floating kelp (31 percent). Floating kelp is most common in rocky, high energy environments, corresponding to high percentages of this habitat in Clallam and San Juan counties. In Jefferson County, floating kelp is common along the rocky outer coast headlands and around Port Townsend, but it is rare in Hood Canal. Floating kelp decreases gradually as energy decreases and rocky habitat becomes less common, leading to intermediate percentages in Whatcom, Skagit, Island and King counties. Floating kelp is rare in lower energy areas with predominantly sand and mud shallow subtidal substrates, including counties that border southern Puget Sound, Willapa Bay, and Grays Harbor. Like floating kelp, non-floating kelp is most common in counties with relatively high energy rocky

Figure 6-1. Percent of shoreline with *Sargassum* is shown by region.

Continuous
Patchy

Source: Washington State Department of Natural Resources



shorelines, such as San Juan and Clallam counties. However, non-floating kelp occurs in all counties. In protected, lower energy areas, the principal species is *Laminaria saccharina*. The lowest percentages are found in counties with extensive embayments, such as Grays Harbor, Pacific, and Snohomish counties.

Sargassum muticum is a non-indigenous brown alga from Asia. It has been known to be established in Washington for decades. However, little is known about its distribution or its interaction with local species. ShoreZone Inventory data shows that *Sargassum* is present along 18 percent of the state's shorelines, and its distribution is not even (Figure 6-1). *Sargassum* is found more often along shorelines in the Hood Canal, the San Juan Archipelago and the Strait of Georgia, leading to correspondingly high percentages in San Juan, Mason, and Whatcom counties. It is least common along the outer coast, in Clallam, Grays Harbor and Pacific counties.

Eelgrass

Eelgrass beds are important habitats because they provide substrate for many small organisms that are food for larger species, habitat for migrating salmon, and food for black brant and other waterfowl. Eelgrass also provides a source of carbon into nearshore habitats and stabilizes the sediments. Knowing how much of a resource exists and how it is changing is the first step to better protecting it for salmon and other wildlife.

Monitoring Eelgrass *(Zostera marina)* Abundance in Puget Sound

Eelgrass has been used as an estuarine health indicator in many parts of the world because it is sensitive to environmental degradation. In 2000, scientists with the Nearshore Habitat Program in the Department of Natural Resources initiated a project to assess spatial patterns and temporal trends in eelgrass habitat. Since no

	Flats (embayments)	Fringes (1,000 m segments of shoreline)	Total
n (number sampled)	14	53	67
N (number of potential sites)	72	2,420	
Basal Area Coverage (ha)	**5,436**	**5,516**	**10,951**
Percent	49.6%	50.4%	100%

Table 6-2. Estimate of basal area coverage of eelgrass in Puget Sound and the Strait of Juan de Fuca.

Source: Washington State Department of Natural Resources

single eelgrass parameter adequately describes eelgrass bed condition, several parameters are monitored: basal area coverage (number of square meters with eelgrass growing on it); maximum depth; depth range; shoot density; leaf characteristics; and patchiness of beds. Two types of eelgrass beds are defined to capture the different habitats where eelgrass occurs: fringing beds and flats. Fringing eelgrass beds occur along much of Puget Sound's shoreline, and provide a corridor for migrating salmon and other wildlife. Eelgrass also commonly grows on flats, in large shallow embayments and small pocket beaches.

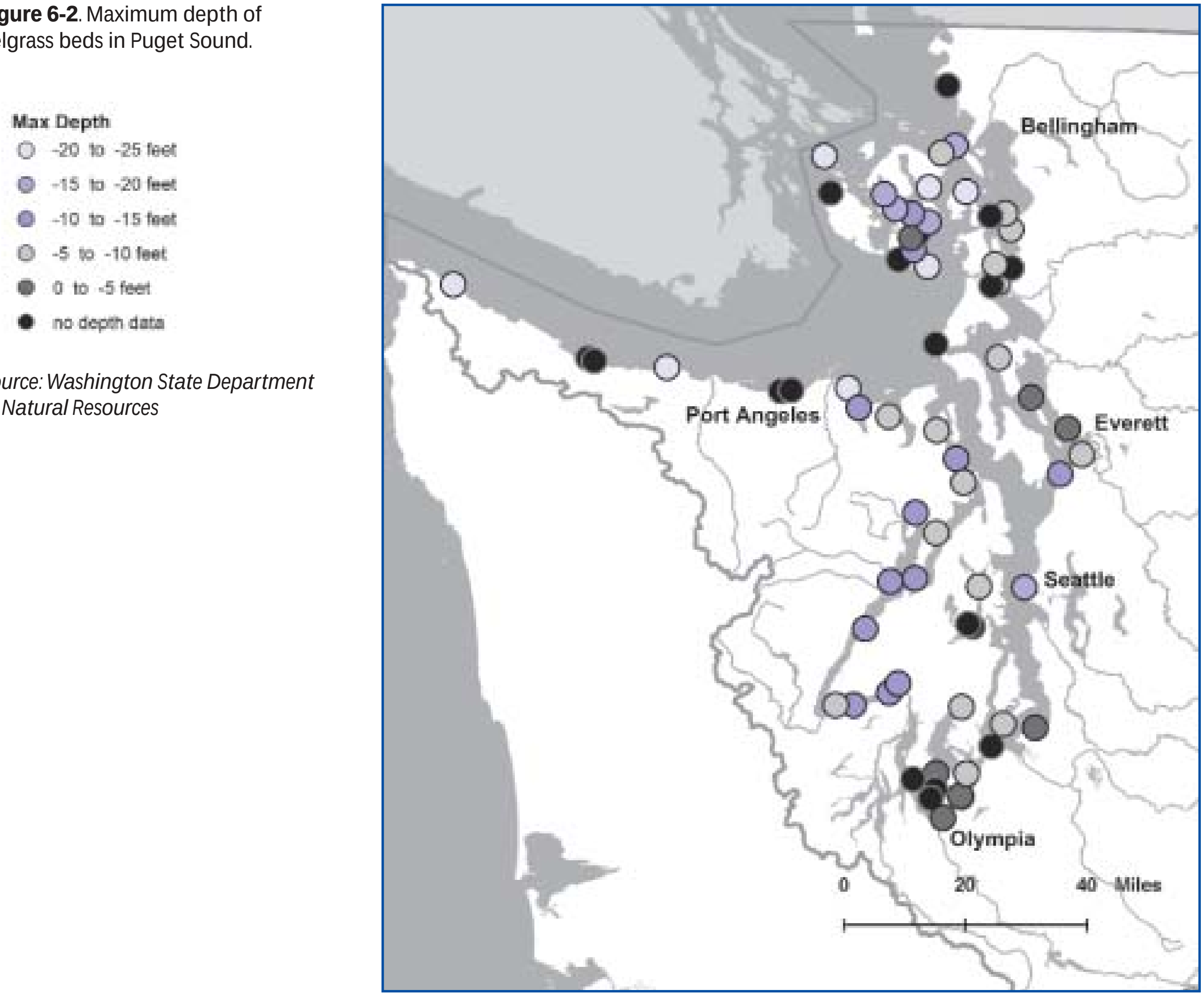
In 2000, 67 sites were surveyed throughout Puget Sound using underwater videography (Table 6-2). The results provide valuable baseline information on current eelgrass bed characteristics and on how to optimize sampling for long-term monitoring. Preliminary research results are reported here, while the final report is being completed.

There are approximately 11,000 hectares (27,180 acres) of native eelgrass *(Z. marina)* in Puget Sound. This estimate was derived from probabilistic sampling and consistent methods; therefore, it can be used for change detection. In order to maximize the monitoring program's ability to detect statistically significant changes in eelgrass, the Department of Natural Resources analyzed sources of variation and optimized future sampling efforts. After optimization, the scientists found that at the current level of effort, the monitoring program will be able to detect as little as a 20 percent change in eelgrass abundance over a 10-year monitoring period. With higher levels of funding, it would be possible to detect finer scale and regional differences.

The relative proportion of eelgrass in fringing beds and flats was previously unquantified. These data show an even distribution between flats and fringes, roughly half of the eelgrass occurs in each habitat type. However, eelgrass is not evenly distributed across the landscape; roughly one-fifth of the eelgrass grows in one large flat—Padilla Bay.

Another parameter measured by the monitoring program is maximum depth. The maximum depth of eelgrass beds is related to light availability in the water column. It can change in response to changes in water quality. Water quality is affected by many factors including natural events such as storms that re-suspend sediments, and human influences such as dredging and fertilization from urban run-off containing fertilizers. In Puget Sound, the Department of Natural Resources found that the mean maximum depth of eelgrass beds ranged from 2.5 feet (0.76 meters) below Mean Lowest Low Water (MLLW) to more than 24 feet (7.3 meters) in depth, with a median depth of -10 feet (–3.0 meters) (Figure 6-2). Overall, there was a general trend of deeper beds found nearer to oceanic waters and shallower beds in southern Puget Sound. Smaller scale gradients were associated with factors such as slope of the shore, substrate changes, and proximity to river mouths. Riverine influenced areas tend to have higher levels of suspended solids that affect light penetration in water column. Scientists at the Department of Natural Resources believe that higher levels of suspended solids in the southern Puget Sound, relative to the northern areas with greater oceanic influence, explain the shallower depths of eelgrass beds in southern

Figure 6-2. Maximum depth of eelgrass beds in Puget Sound.



Source: Washington State Department of Natural Resources

Sound. This hypothesis was supported by the finding that maximum depths of eelgrass beds were negatively correlated with water column light attenuation.

Unlike eelgrass in other parts of the world, eelgrass beds throughout the region are diverse and heterogeneous. For example, the density ranged from sparse to dense: 23 to more than 1,000 eelgrass shoots per square meter. Leaf lengths of this underwater plant were as small as 10 centimeters to as large as 2 meters. Some beds in Puget Sound were large continuous meadows, while others consisted of many discrete patches surrounded by bare sand and mud. Using several metrics to describe eelgrass beds will allow this monitoring program to capture how this resource is changing over time.

Temporal Trends in the Areal Extent of Canopy-forming Kelp Beds Along the Strait of Juan de Fuca

Kelp beds are important nearshore habitats that support commercial and sport fish, invertebrates, marine mammals and marine birds. Many factors, both natural and anthropogenic, affect the extent and composition of kelp beds. For example, elevated water temperature and intense sea urchin grazing can decimate 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 that decrease water quality by changing the

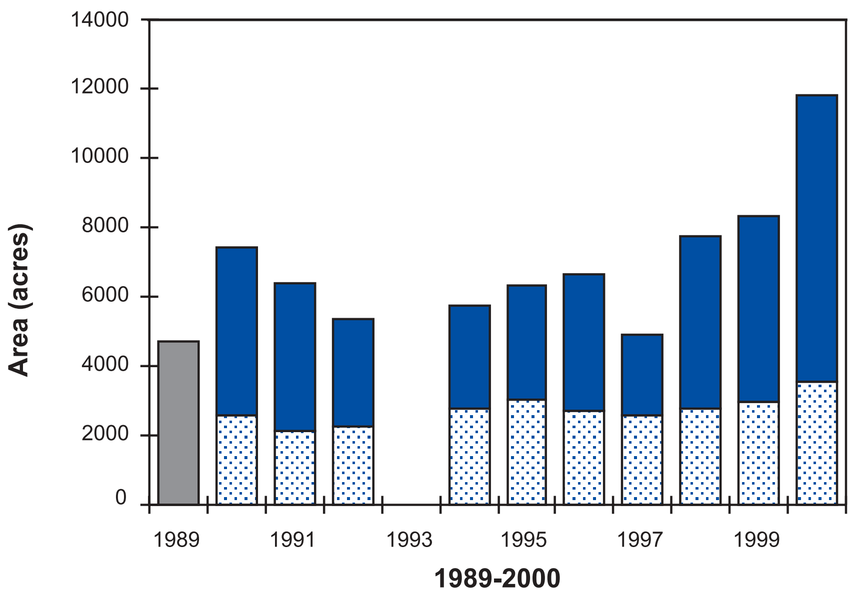


Figure 6-3. Kelp bed area in the Strait of Juan de Fuca, 1989-2000. No data were collected in 1993.

Source: Washington State Department of Natural Resources

nutrient levels and reducing light in the water column. Kelp plants also can be physically damaged by boat propellers and fishing gear. Commercial harvest of kelp is not a significant factor in Washington State due to a law prohibiting this practice.

Since 1989, scientists with the Department of Natural Resources have conducted annual inventories of canopy-forming kelp beds in the Strait of Juan de Fuca using aerial photography. This long-term dataset helps us to understand how the extent of kelp canopies changes over time. In addition to tracking overall changes in bed extent, the dataset differentiates patterns and trends in the extent of two species that make up canopy-forming kelp beds—giant kelp (*Macrocystis integrifolia*) and bull kelp (*Nereocystis luetkeana*). The scientific challenge is to differentiate the natural yearly fluctuation in this dynamic population from changes due to human impacts or due to local or regional environmental conditions.

Analysis of the 1989 through 2000 dataset for the Strait of Juan de Fuca shows that the areal extent of kelp varied highly from year to year (Figure 6-3). Changes in kelp extent were significantly different in seven out of the 10 yearly comparisons (95 percent confidence interval). The extent of kelp was lowest in 1989 (1,911 hectares, or 4,722 acres) and greatest in 2000 (4,788 hectares, or 11,832 acres). Because of high yearly variability, the increases over the last 4 years were not statistically significant and no long-term trend is apparent between 1989 and 2000. This suggests that the population is stable over this time period. When compared to beds on the outer coast, the Strait of Juan de Fuca kelp beds did not always exhibit similar changes in canopy extent over time, suggesting different responses to regional environmental conditions. For example, kelp bed extent throughout the study area was lowest in 1997, as compared to the lowest extent in 1989 for the Strait of Juan de Fuca alone.

While the population appears stable over the study area as a whole, some local losses of kelp are evident. One bed of concern is north of Protection Island near Port Townsend. It gradually dwindled from 181 acres in 1989 and disappeared in 1997. After two years of absence, 39 acres of kelp were observed at this location in 2000. This site is of special interest because local human impacts are presumed to be minimal; the island is a National Wildlife Refuge and access to the upland area is limited.

Species composition of the canopy-forming kelp beds varied greatly from year to year, reflecting the different responses of bull kelp and giant kelp to environmental conditions. Bull kelp canopies covered a larger area in nine out of 10 years monitored along the Strait of Juan de Fuca, as compared to seven out of 10 years in the study area as a whole. Bull kelp consistently had lower fractional cover ranging from 0.19 to 0.38, compared to giant kelp cover which ranged from 0.34 to 0.51. Bull kelp populations showed much higher year-to-year variation in total extent. The higher cover and relative year-to-year stability of the giant kelp population is attributed in part to life cycle differences. Giant kelp is a perennial that regrows yearly from its holdfast, and spores tend to disperse locally. Bull kelp is an annual, and its spores tend to disperse more widely, leading to greater year-to-year changes in its distribution and abundance.

In 1997, during an El Niño event, kelp canopy area throughout the study area decreased by 32 percent. Scientists are now trying to understand the relationship between the kelp population and this regional climate perturbation. In 1997, losses were highest in the bull kelp (*Nereocystis luetkeana*) populations along the outer coast, which experienced 75 percent loss. Over the same area, giant kelp (*Macrocystis integrifolia*) populations decreased by 8 percent. During the subsequent year, 1998, the overall floating kelp population increased by 87 percent, and the outer coast bull kelp populations increased by 423 percent. Kelp bed extent increased throughout the study area in both 1999 (11 percent) and 2000 (41 percent).

Phytoplankton

King County monitors chlorophyll-*a* concentrations as an indicator of phytoplankton abundance. Concentrations were measured from the surface down to a depth of 35 meters monthly at several offshore stations (from Admiralty Inlet to Colvos Passage) in the central Puget Sound basin in 1999 and 2000.

Although maximum concentrations vary from year to year, phytoplankton blooms usually occur in April or May and July in the central basin. Phytoplankton blooms in 1999 and 2000 were not as consistent as seen in previous years with blooms noted in some areas but not others and at different times of the year. For example, in 1999 phytoplankton blooms occurred in May, June and September at most stations in the central basin, with a large bloom in September (Figure 6-4). A bloom at Admiralty Inlet occurred in October—the latest month in which a bloom has been seen. In Possession Sound, a bloom was evident in April but not in June or July. In 2000, phytoplankton blooms were evident in May, June and August at all stations monitored. The northern area of the central basin (including Admiralty Inlet and southern Possession Sound) also exhibited a bloom in April that was not seen in other areas. Although the May and June blooms appear to be relatively consistent for both 1999 and 2000, the timing of the late summer/early fall bloom was variable. Additional sampling at stations in the northern part of the central basin for 1999 and 2000 indicates that phytoplankton blooms occur earlier there than other areas in the central basin.

The Washington State Department of Ecology also evaluates chlorophyll, but data more recent than 1997 were not yet available for this report. For information about the Department of Ecology's characterization of phytoplankton based on monitoring through 1997, please see the 1998 and 2000 *Puget Sound Updates* and the Department of Ecology's technical reports.

Intertidal Communities

Intertidal biological communities are made up of a diverse set of resident invertebrates and plants that respond to changes in a wide range of physical, chemical and biological conditions. It is important to monitor intertidal biological communities for their intrinsic biodiversity value and also because these communities have an impact on other organisms through the food web. Biological community monitoring is commonly used nationwide to study sites that have been disturbed by contamination. As interest mounts in monitoring nearshore habitat condition for salmonids and other species, the biological community is increasingly being used as a general measure of habitat health in local and regional projects.

Intertidal Biota

Spatial Patterns of Intertidal Biological Communities in Central and South Sound

Scientists with the Nearshore Habitat Program in the Department of Natural

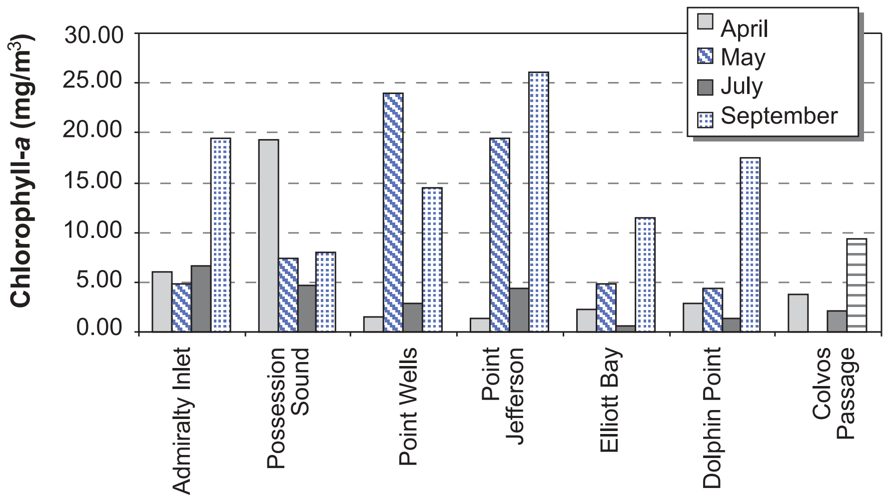


Figure 6-4. Occurrence of phytoplankton blooms at stations from north to south in 1999 for selected months.

Source: King County Department of Natural Resources and Parks

Resources have been studying intertidal biological communities in Puget Sound since 1997. The project goals are:

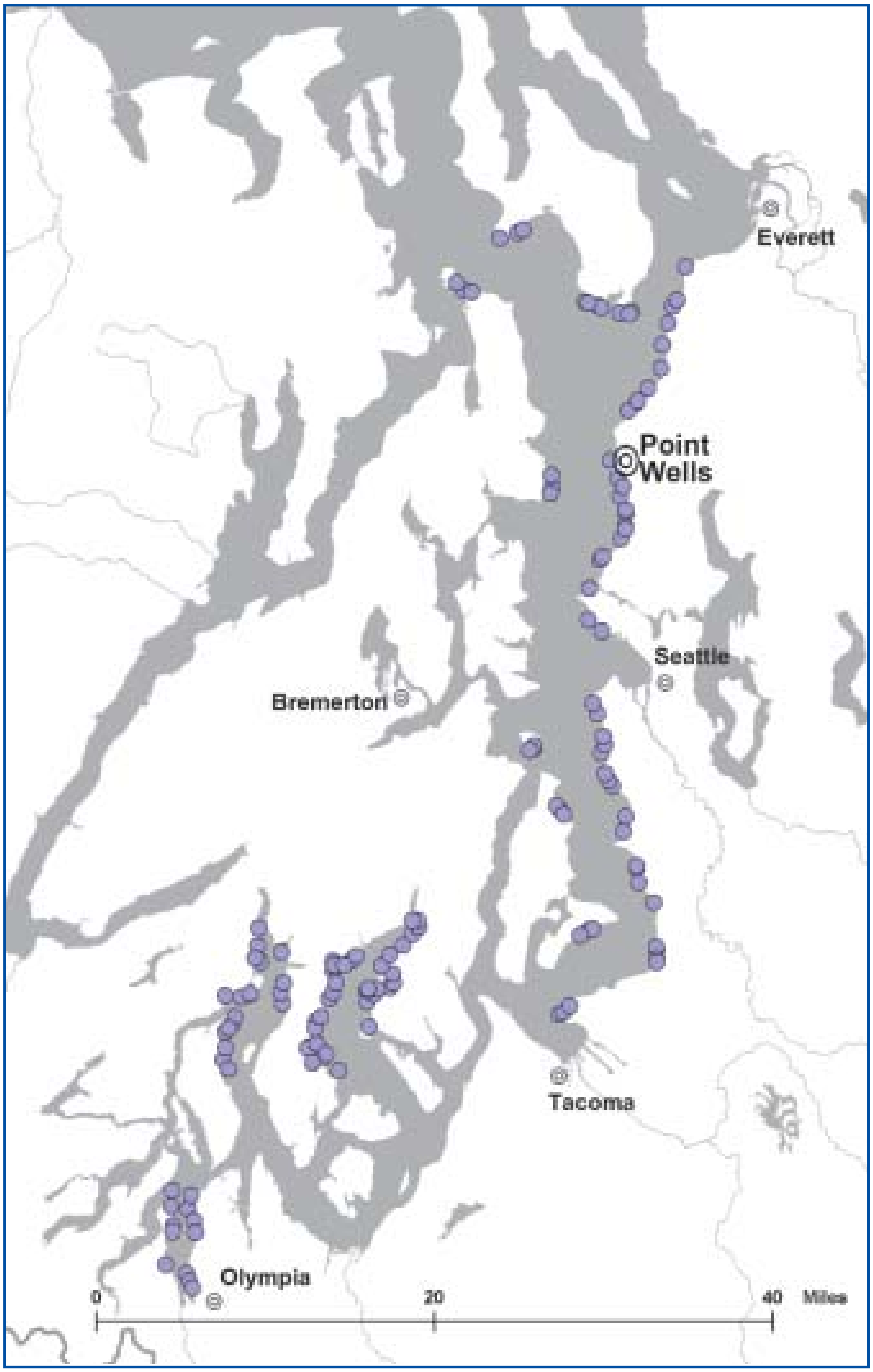
1. To collect baseline information on community patterns in Puget Sound.
2. To determine if the intertidal biological community is a suitable indicator of habitat condition for PSAMP.
3. To provide large-scale, contextual information for comparison to more detailed studies.

The biological community monitoring project samples organisms living on and in the substrate in the lower intertidal zone. In 1997, samples were collected in Carr Inlet. Since then, the geographic extent of the project has gradually expanded to include Case Inlet, Budd Inlet and central Puget Sound (Figure 6-5). Results from this work reveal spatial patterns and temporal trends in community structure. They also bring important considerations to light for groups who are considering monitoring biological communities:

- Species richness (the number of species present at a site) is a common measure of habitat condition. In Puget Sound, this study documented striking gradients in species richness over large spatial areas. Species richness was generally three times greater in the north, as shown by comparison of pebble beaches sampled between Olympia and southern Whidbey Island. Transitions in species abundance along this gradient were gradual as opposed to abrupt, suggesting that the basins of Puget Sound represent parts of a continuum. These patterns were shown in both the surface biota and the infauna.
- Interannual variation in biota is high. However, while temporal variation within the organisms on a beach is found from one year to the next, similar beaches within an area tend to change in the same ways and remain similar to each other. This finding has an important implication for other studies that compare multiple sites to gauge habitat condition: study designs should select sites that are nearby and compare data from the same year as much as possible.
- Comparison of recent surveys to historical surveys suggests change has occurred at some sites. Data from the central Sound were compared qualitatively to historical surveys from the 1970s and

Figure 6-5. Intertidal biological community sampling sites.

Source: Washington State Department of Natural Resources



1980s to assess whether there had been major shifts in the communities over time. In general, the historical surveys showed a high degree of overlap in flora and fauna. One exception was found in the beaches near Point Wells near Edmonds. Many taxa found in the historical surveys from Point Wells sampling sites were conspicuously missing from the recent surveys. Additionally, these beaches had lower richness and fewer juvenile clams compared to recent surveys of sites to the north and south. Possible causes of these absences include nearby pollution, other anthropogenic influences, or unusual substrate conditions occurring in the last 20 years.

- Samples of different habitat types reveal broad patterns in biotic communities that relate to physical conditions. For example, a total of 197 invertebrate and algal species were found in 1998. Mud beaches had the most species overall (91), followed by pebble (81), cobble (73) and sand (59). The average number of species per habitat type was highest for complex substrates including pebble (14.0) and cobble (8.5), and lowest for sand (3.5) and mud (6.2). These findings can be used to select the best habitat types to monitor, and to provide context for other studies. Generally, change detection is most likely to be successful in habitat types that have consistently high diversity.
- Because scientists lack the resources to sample biological communities everywhere, managers would like to be able to extrapolate data collected at sampled beaches to unsampled sites. In the event of a localized impact, such as an oil spill, the effects of that spill could then be assessed via detailed sampling of physically similar beaches that were not impacted. One goal of this study was to successfully extrapolate biological community results to unsampled beaches. The approach to meet this goal was to randomly select beaches and classify their physical characteristics in detail. To test whether these beaches were more widely representative, additional beaches were selected and compared to the original beaches. The comparisons showed that the organisms on the new beaches were very similar (statistically indistinguishable) from those beaches already sampled. This means that, in the case of an oil spill or other accident, the data would illustrate (with high statistical confidence) the biota that should have been on the beach before the spill.

Deep Puget Sound Benthos

A U.S. Geological Survey scientist recently analyzed a nearly 30-year record of sediment-dwelling organisms in central Puget Sound "to examine the concept of long-term stability in a deep-water (200m) community." (Nichols 2001). The analysis showed that the most abundant species were consistently present over the period studied, 1963 to 1992. However, the study also reveals a gradual change in the community indicated by changes in observed species composition and abundance of organisms, including:

1. Aperiodic, multi-year bursts in the abundance of the common species.
2. An overall increase in the total abundance of the benthic community beginning in the mid-1970s.
3. Periods of increased abundance, during the late 1970s and early 1980s, of two species that are tolerant of organic enrichment.
4. The surprisingly steady decline in abundance of the large burrowing echinoderm, *Brisaster latifrons*.

The researcher notes that these are conspicuous changes but that there are no obvious environmental factors to readily explain them. Circumstantial evidence suggests changes in climate, organic enrichment, and predator abundance as possible influences. The researcher concludes that the principal reasons for our inability to identify causes of long-term change in the sediment-dwelling organisms of Puget Sound are (1) presumed natural biological variability and (2) inconsistent long-term monitoring of environmental variables (i.e., related to changes in monitoring programs over time).

The results of this study underscore the need for consistent long-term data on biologically relevant environmental variables that scientists can use to analyze changes in key biological populations. This type of data and subsequent analysis will be needed to help us to understand the influences of human-caused environmental stressors and corrective actions.

Fish

In a recent review, the American Fisheries Society concluded that “the recovery of fish stocks at risk in Puget Sound appear to be the most complex in North America.” (Musick et al., 2000). This review identifies eight species of marine fish in Puget Sound to be “at risk,” meaning they face some risk of extinction or they risk falling into such a category in the near future.

Table 6-3 summarizes the Society’s findings about these eight species. The review also identifies a number of other species at risk over a larger geographic area including the marine waters of Washington State. The Society’s review relied heavily on data from marine fish monitoring similar to that described below.

Petition for Listing Puget Sound Marine Fish under the Endangered Species Act

In February 1999, NMFS received a petition for 18 species of marine fish that are found in Puget Sound to be considered as threatened or endangered under the provisions of ESA. A retired state Department of Fish and Wildlife employee developed the petition using stock assessments and other information developed by Fish and Wildlife staff as the basis of the petition. Besides Pacific herring, the other species were groundfish species that have been identified by Fish and Wildlife as in critical or depressed status in Puget Sound.

In June 1999, NMFS accepted the petition as meriting further consideration but limited the petition list to only seven species that were likely to have data available for a biological opinion. The seven species were Pacific herring, Pacific cod, walleye pollock, Pacific whiting (hake) and copper, brown and quillback rockfish. Since this initial determination, state Department of Fish and Wildlife staff consulted with NMFS numerous times to provide survey, stock structure and biological information that were important in the deliberations. During November 2000, NMFS announced its final decision regarding the ESA listings for codfishes and found that listings are not warranted for Pacific cod and walleye pollock populations from Puget Sound (Gustavson et al. 2000). NMFS did, however, retain Pacific whiting (hake) as a candidate species pending further genetic and other studies. Decisions were made for the remaining species in the spring of 2001. NMFS concluded that none of the other petitioned rockfishes and Pacific herring warranted listing (Table 6-4; Stout et al. 2001a, 2001b). In these cases, NMFS made this determination despite the sharp declines in many of these species in Puget Sound because the Puget Sound populations were found to be part of larger Pacific populations that as a whole are not declining.

Although none of the petitioned species warranted listing, the various panels of scientists and biologists reviewing the petition expressed concern about widespread, nearly synchronous decline of several fish species in Puget Sound. These declines include not just the petitioned marine fish, but some salmonid species as well. Joint consideration of the implications of these declines is beyond the scope of the ESA but may indicate ecosystem-level changes in Puget Sound. Such changes would be of deeper concern than the decline of any single species. The review teams pointed out the need to determine if these changes are anthropogenic (i.e., caused by fishing, habitat loss, etc.) or natural (caused by environmental variation and general ecosystem dynamics) and the overall significance of any ecosystem-level change.

Table 6-3. Marine fish at risk in Puget Sound as identified by the American Fisheries Society (Musick et al. 2000).

Species	Risk Category	Risk Factors / Comments
Copper rockfish	vulnerable	very low productivity; long-term decline since mid-1980s; spawner output decline >80% from 1979 to 1992
Brown rockfish	vulnerable	probable low to very low productivity; long-term decline since mid-1980s
Quillback rockfish	vulnerable	very low productivity; long-term decline
Black rockfish	vulnerable	low to very low productivity; long-term decline; has become rare
Pacific cod	vulnerable	Low productivity; may form localized spawning aggregations; vulnerable to overfishing; declined 80 to 90% since 1970s; no evidence of recovery despite fishing regulations; recovery may be hampered by warming water temperatures
Walleye pollock, South Puget Sound	endangered	low productivity; vulnerable to overharvesting; may be extirpated; fishery collapsed in 1988 and no specimens in recent trawl surveys; northern Puget Sound may be overharvested but not at risk
Pacific hake, South Puget Sound	vulnerable	low productivity; local concentrated South spawning aggregations vulnerable to heavy overharvesting; survey biomass declined from 45 million pounds in 1983 to 1 million pounds in 1998; high predation by pinnipeds may prevent recovery despite stringent fishing regulations
Pacific herring	vulnerable	medium productivity; evidence for metapopulation structure with stock aggregations spawning at specific sites; 4 of 8 stocks may have declined from overharvesting, annual natural mortality increased from 20 to 80% because of increased pinneped predation

Table 6-4. ESA listing status for marine fish species for Puget Sound.

Source: Washington State Department of Fish and Wildlife

Common Name	Scientific Name	Status
Pacific herring	*Clupea pallasi*	Not warranted
Pacific cod	*Gadus macrocephalus*	Not warranted
Pacific whiting (hake)	*Merluccius productus*	Candidate
Walleye pollock	*Theragra chalcogramma*	Not warranted
Copper rockfish	*Sebastes caurinus*	Not warranted
Quillback rockfish	*S. maliger*	Not warranted
Brown rockfish	*S. auriculatus*	Not warranted

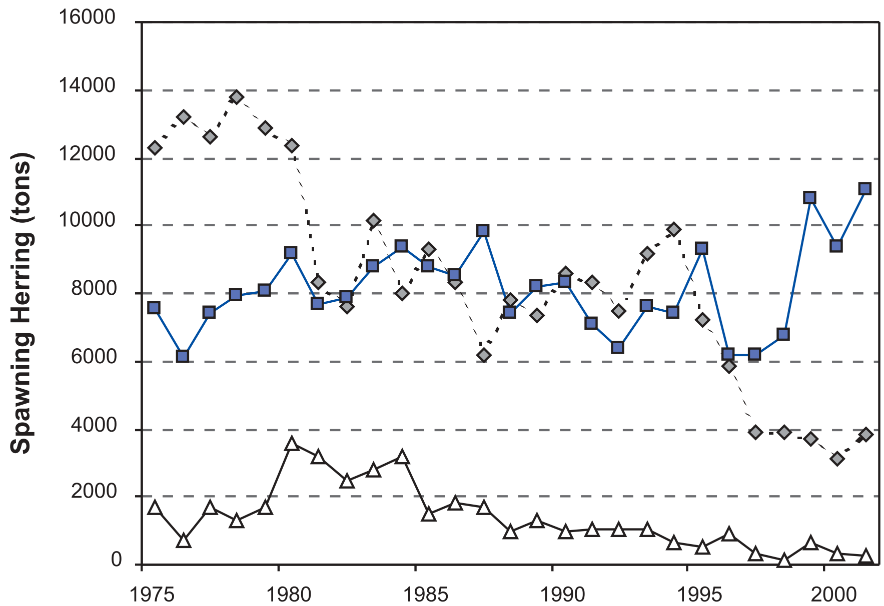
Figure 6-6. Annual Puget Sound herring run, 1975 to 2001.

North Sound

Central/South Sound

Straits

Source: Washington State Department of Fish and Wildlife



Pacific Herring in Puget Sound

The overall abundance of spawning Pacific herring (*Clupea pallasi)* in Puget Sound has increased from the low levels observed in the mid 1990s. Despite this overall increase, a few spawning stocks remain at low levels of abundance (Figure 6-6), especially the stocks spawning at Cherry Point (near Bellingham) and Discovery Bay.

The management of Pacific herring by the state Department of Fish and Wildlife is based on the stock concept. The department recognizes 19 herring stocks in the Puget Sound region, based largely on the location and timing of spawning aggregations. This is an increase of one stock since the publication of the *2000 Puget Sound Update*. An additional spawning ground was located in Hale Pass, south of the Tacoma Narrows Bridge. Herring spawning at this site have been reported to Fish and Wildlife in earlier years, but previous surveys had not detected any spawning activity. However, in 2000, a survey was conducted very early in the year, and spawning was detected. The amount of herring using this location in 2000 was small—140 tons of adults.

The total amount of spawning herring in Puget Sound was 12,800 tons in 2000 and 15,100 tons in 2001. These levels represent an increase from the 10,000 to 11,000 tons spawning annually in 1997 and 1998. This increase is largely due to increases in abundance at spawning grounds in Puget Sound south of Port Townsend.

Scientific studies coordinated by the state departments of Fish and Wildlife and Natural Resources are improving our understanding of Pacific herring in Puget Sound. Results of two Fish and Wildlife-funded studies provide evidence that the stock of herring that spawns in the spring near Cherry Point appears to be biologically distinct from other herring stocks in Puget Sound and the Georgia Basin. Results from a third study, funded by the Department of Natural Resources, indicate that herring larvae from the Cherry Point stock have lower survival potential than do larvae from other stocks in the region.

The Cherry Point stock, once the largest of these stocks, has seen substantial declines in recent years. For example, the spawning biomass of the Cherry Point stock declined from more than 4,000 tons in 1995 to 808 tons in 2000. This dramatic decline coupled with the potential effects of existing and proposed industrial development along the Cherry Point shoreline led to a number of investigations of the Cherry Point herring stock.

The state Department of Fish and Wildlife recently commissioned a pair of studies to investigate: (1) isotopic signatures in the bones of adult herring that can provide information on the environment in which the fish hatched and grew and (2) genetic variations in various Puget Sound stocks of Pacific herring. Significant results include:

1. Isotopic signatures in herring bones

The ratios of carbon and oxygen isotopes incorporated in the otoliths (ear bones) of adult herring soon after they hatched indicate that spawning herring collected at Cherry Point were hatched in a different environment than were adult herring collected from Port Orchard (central Puget Sound) and Squaxin Pass (south Puget Sound). The isotope ratios were similar in fish collected from Port Orchard and Squaxin Pass. This indicates that adult herring returning to spawn at Cherry Point experienced a different environment as newly hatched fish than did those adults spawning at Squaxin Pass and Port Orchard. This fidelity to spawning/hatching location implies that herring stocks may be threatened by environmental stresses occurring at the spawning/hatching location.

2. Pacific Herring—Genetic Analysis of Population Structure

In 2001, the state Department of Fish and Wildlife initiated a genetic study to obtain additional information about the number, geographic locations, and interrelationships of herring stocks. This study consisted of two parts, one was an investigation of micro-satellite DNA variation conducted by Fish and Wildlife staff and the other was a study of sequence variation in mitochondrial DNA conducted by Dr. Paul Bentzen at the University of Washington.

The micro-satellite DNA investigation analyzed seven collections: three collections of the Cherry Point stock (south of Birch Bay, Strait of Georgia spawners in April 1999; non-spawners in April 1999; spawners in May 2000); and individual collections of the Johnson Point stock (south Puget Sound, January 1999), the Fidalgo Bay stock (Padilla Bay, north Puget Sound, February 1999); the Semiahmoo stock (west of Birch Bay, Strait of Georgia, February 1999); and a collection from the Northumberland Channel in British Columbia (in the Strait of Georgia northwest of Nanaimo, February 1999). Twelve micro-satellite DNA loci were screened in a total of 692 fish. The investigation revealed significant differences between most pairs of collections suggesting there may be multiple genetically differentiated stocks of Pacific herring in the Puget Sound region while the similarity between the 1999 and 2000 Cherry Point stock collections (spawners) suggest that the genetic characteristics of at least this stock may be stable from year to year.

Sequence analysis of a 572 base pair portion of the mitochondrial DNA in 313 herring from six collections (1999 Cherry Point [2 collections], Johnson Point, Semiahmoo, Northumberland, and Port Gamble) revealed 82 different genetic types (haplotypes). Overall there was little evidence of heterogeneity among the six collections. While these data are consistent with the micro-satellite DNA data that indicate a genetic difference between the Cherry Point stock and the other stocks tested, they do not provide evidence for the existence of other genetically differentiated stocks of herring in the region. Staff at the Canada Department of Fisheries and Oceans (Pacific Biological Station, Nanaimo) have analyzed micro-satellite DNA variation in collections of Pacific herring from many Canadian localities. In general, the genetic differences observed among sites in the Strait of Georgia along the east side of Vancouver Island, are no larger than those observed within sites in different years. Thus, although there is evidence of genetic heterogeneity among collections, the heterogeneity does not seem to have a strong geographic basis, and does not appear to establish the existence of multiple, genetically differentiated stocks in this region.

Taken together, these studies of the genetics of Pacific herring in the Puget Sound region suggest the existence of multiple stocks but do not provide unambiguous proof that distinct stocks exist. Additional analysis employing more collections (annual repeats and additional localities) and possibly more loci may resolve the present uncertainty.

The findings of these state Department of Fish and Wildlife studies underscore the importance of studying the condition of Pacific herring spawning at Cherry Point. One study funded by the Department of Natural Resources (Hershberger and Kocan 2000) investigated the survival potential of herring larvae from Puget Sound, with special attention to the Cherry Point stock. The study found indications of decreased survival potential for Cherry Point herring as indicated by reduced larval hatch weights, greater percentage of larval skeletal abnormalities and insufficient larval yolk reserves at time of hatch. Causes remain undetermined, but Hershberger and Kocan have suggested that decreased age and size of adult spawners might partially explain the reduced fitness of Cherry Point herring larvae.

Recent Increase in Salmon Production in the Strait of Georgia

There was a major increase in early marine survival of juvenile coho and other Pacific salmon species in 2000 in the Strait of Georgia. This increase is most clearly seen in the July 2000 abundance of ocean age 0 coho although there are smaller increases for other species of juvenile salmon (Figure 6-7). We refer to this period in the salmon life cycle as the early marine period, thus the increased survival represents increased early marine survival.

The September 2000 data do not reflect the same relative increase in abundance seen in July 2000. In September 2000, there were 5.4 times the coded-wire tagged (CWT) coho captured per unit of effort outside of the Strait of Georgia than in any of the previous three years. This indicates that in 2000, juvenile coho were leaving the Strait of Georgia earlier than in the previous three years. Scientists with Fisheries and Oceans Canada (Beamish et al. 2001b) propose that the change in behavior is related to the improved growth, the greater abundance of coho, and possibly the greater densities of chum and pink salmon juveniles. The increased survival was associated with increased size and fitness.

There also was a major increase in euphausiid biomass and individual size, a common prey species for salmon and other predators. These changes suggest a more generalized increase in productivity in 2000 in the Strait of Georgia that could have important impacts throughout the food web. Beamish et al. (2001b) propose that the improved juvenile salmon survival was a result of reduced predation-based mortality. Previous work (Beamish et al. 2001a, 1992) showed that spiny dogfish (*Squalus acanthius*) are a major predator of salmon smolts when smolts first enter the Strait of Georgia. Spiny dogfish also feed on euphausiids, and Beamish et al (2001b) propose that the increased abundance of euphausiids may have provided alternate, and even preferred alternate prey, reducing predation on coho.

The dramatic improvement in production of coho and organisms at lower trophic levels, as well as the suggested shift in predation patterns that occurred in 2000 were associated with a dramatic change in climate. In 1998 there was a rapid change from El Niño conditions to a La Niña state (McPhaden 1999). These results suggest that the dynamics of salmon production can change abruptly in response to regional climate related processes and the direct impacts on the food web.

Puget Sound Groundfish

Groundfish are the marine fish species that live near or on the bottom for most of their adult lives. More than 150 species occur in Puget Sound, which once supported

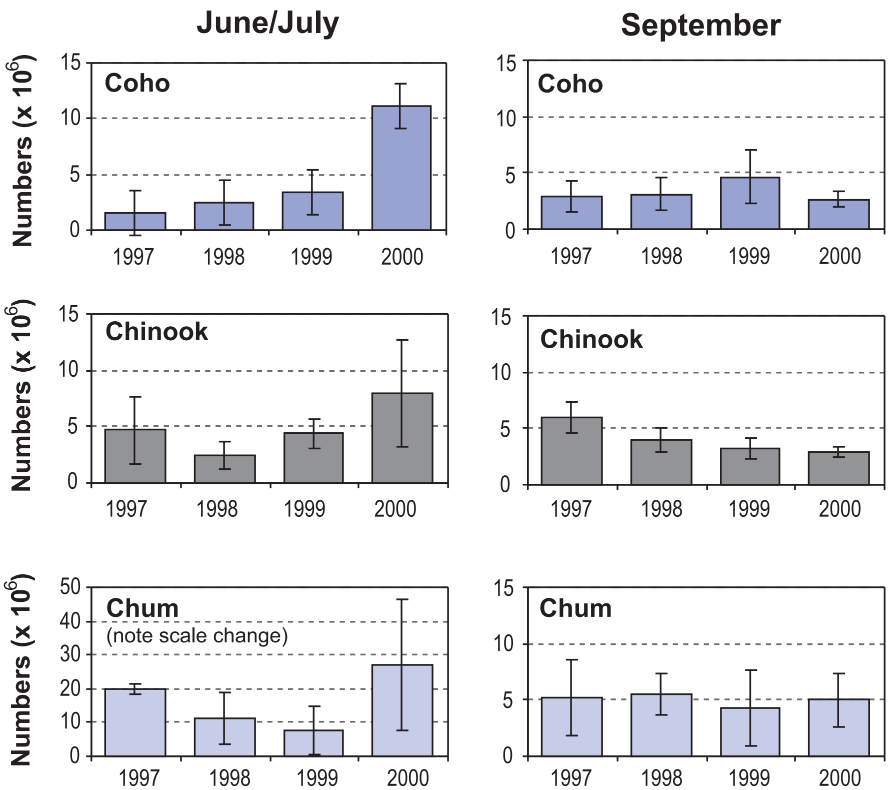


Figure 6-7. Abundance of ocean age 0 coho, chinook, and chum in eight surveys, 1997-2000. Error bars represent plus and minus two standard deviations of the mean.

Source: Fisheries and Oceans Canada

thriving commercial and recreational fisheries for groundfish. During recent times, many key groundfish populations have declined to alarming levels. The state Department of Fish and Wildlife is committed to conserving the local stocks of these fish and has enacted a number of stringent measures to promote stock rebuilding.

The methods to determine status and trend for Puget Sound groundfish stocks are in transition changing from information based upon fisheries to information based upon demographic and survey information. Many of the key species were assessed by methods developed primarily from information supplied by recreational or commercial fishers (Palsson et al. 1997). The time series of the fishing success can be used as an indicator of the relative population strength for groundfish species if the chance of catching a fish doesn't change over the assessment period. For some species such as rockfish, extreme changes in regulations prevent the use of fishing success as a relative population indicator. In other cases, fishery-dependent data may not accurately reflect population trends when fishing technology improves, or when market conditions change the nature of the fisheries. This edition of the *Update* includes much of the updated trend information from fishery data but also expands other data series including measures of reproduction over time and population abundance estimates from bottom trawl and acoustic surveys. For all of these time series, a comparison of the most recent two-year average indicators was made to historical or long-term averages of the indicators. Percent changes were categorized into five measures of stock status:

- Above average (change greater than 6 percent above average)
- Average (within 5 percent of average)
- Below average (6 percent to 35 percent less than average)
- Depressed (36 percent to 75 percent less than average)
- Critical (at least 76 percent less than average)

In the cases of sablefish, Pacific halibut and Pacific whiting in the Strait of Georgia, other stock assessments were used to infer population status in Puget Sound waters.

Most assessments were conducted separately for groundfish in north Puget Sound (north of Port Townsend to Sekiu and the Canadian border) and south Puget Sound (south of Port Townsend). Beginning with this *Update*, many stock evaluations are provided for basins within the inland marine waters of Washington. The assessments made for each basin should be considered tentative at this time pending a more full review of the data quality, statistical variability, and population dynamics.

In a preliminary 2002 assessment of the status of Puget Sound groundfish stocks (Table 6-5), state Department of Fish and Wildlife scientists find only a slight improvement in the status of these stocks compared to reports in recent years. In 2002, an equal number of stocks are listed in healthy condition as are listed in poor condition. As has been reported in previous Updates, south Sound has a greater proportion of stocks in poor condition (55 percent) than north Sound (44 percent). Among the basins, the Strait of Georgia-San Juan Archipelago has the greatest number of healthy stocks and south Sound the smallest. With the use of survey data and more specific fishery data, many of the previously unknown stock conditions are becoming resolved for Puget Sound.

Many species are thriving in the basins of Puget Sound including most of the flatfishes in the north Sound and lingcod in the San Juan archipelago and in the south Sound. English sole, starry flounder, rock sole, sand sole and skates are species targeted by bottom trawl fisheries in the north Sound and appear to be in above average condition in the Straits of Georgia and Juan de Fuca. Lingcod in the San Juan Archipelago are rebounding from very poor population conditions experienced in the mid-1990s. However, they are still in a depressed status in the Strait of Juan de Fuca, which is closer to coastal stocks that are in poor condition. Lingcod populations are in above average condition in central and southern Puget Sound basins as well as the Whidbey Basin. Species and species groups that are not sought as much by commercial and recreational fishers appear to be doing well. Spotted ratfish, greenlings, and sculpins are in average or above average condition in most basins. Other groundfish appear to be healthy in the north Sound and its basins.

Pacific halibut stocks are assessed on a larger scale than just for Puget Sound, and their populations continue to be in above average condition in the southern region (William Clark, International Pacific Halibut Commission, Personal Communication). Some important groundfish species continue to be in poor condition. Rockfishes in both the north and south Puget Sound are in depressed condition based on fishery-derived data, demonstrating a drastic decline in abundance or size during the past 25 years (Figure 6-8 and Figure 6-9). For copper rockfish, the primary indicator reflecting these changes has been the estimated spawning potential (Figure 6-10), which is a surrogate measure of the spawning biomass. The spawning potential is approximated by combining the relative change in populations (based upon catch rates) and the estimated fecundity of copper rockfish applied to observations of lengths in the recreational fishery. In both the north and south Sound, the recent spawning potential has declined approximately 75 percent since the historical peaks estimated during the 1970s. Many management authorities consider declines of more that 60 percent of the natural spawning potential as signs of population stress.

The sharp decline observed in fishing success and spawning potential in 2000 most likely reflects a new regulation instituted by the Fish and Wildlife Commission, which decreased the allowable daily take of rockfish from five in the north Sound and three in the south Sound to just one fish in almost all areas of Puget Sound.

Species	North Sound	Str. Georgia & SJ Is.	Str. Juan de Fuca	South Sound	Hood Canal	Central Sound	Whidbey Basin	Southern Sound
Spotted ratfish	below average	above average	below average	above average	above average	above average	unknown	above average
Spiny dogfish	depressed	depressed	depressed	depressed	critical	critical	unknown	critical
Skates	above average	above average	above average	depressed	depressed	below average	unknown	depressed
Pacific cod	below average	depressed	critical	critical	critical	critical	critical	critical
Walleye pollock	above average	above average	above average	critical	unknown	critical	critical	critical
Pacific whiting (hake)	unknown	average	unknown	critical	unknown	critical	critical	unknown
Rockfishes	depressed	unknown	unknown	depressed	unknown	unknown	unknown	unknown
Lingcod	below average	above average	depressed	above average	unknown	above average	above average	above average
Sablefish	below average	below average	below average	below average	below average	below average	below average	below average
Greenlings	above average	above average	above average	above average	unknown	above average	unknown	critical
Sculpins	above average	above average	above average	above average	above average	above average	unknown	above average
Wolf-eel	unknown	unknown	below average	average	average	average	unknown	average
Surfperches	below average	above average	depressed	depressed	above average	critical	unknown	critical
English sole	above average	above average	above average	below average	below average	average	unknown	below average
Rock sole	average	above average	above average	average	above average	average	unknown	average
Starry flounder	above average	above average	above average	average	above average	depressed	unknown	below average
Dover sole	depressed	critical	below average	depressed	above average	depressed	unknown	depressed
Sand sole	average	above average	above average	above average	above average	above average	depressed	depressed
Pacific halibut	above average	above average	above average	above average	above average	above average	above average	above average
Other groundfish	average	above average	above average	below average	above average	below average	unknown	below average
No. of Healthy Stocks	10	14	10	9	10	9	2	6
No. of Poor Stocks	8	4	8	11	5	9	4	12

Table 6-5. Preliminary status assessments of groundfish populations in Puget Sound.

North Sound includes the Strait of Georgia, the San Juan archipelago and the Strait of Juan de Fuca

South Sound includes Hood Canal, central Sound, Whidbey basin and southern Sound (south of Tacoma Narrows)

- **above average**
- **average**
- **below average**
- **depressed**
- **critical**
- **unknown**

Source: Washington State Department of Fish and Wildlife

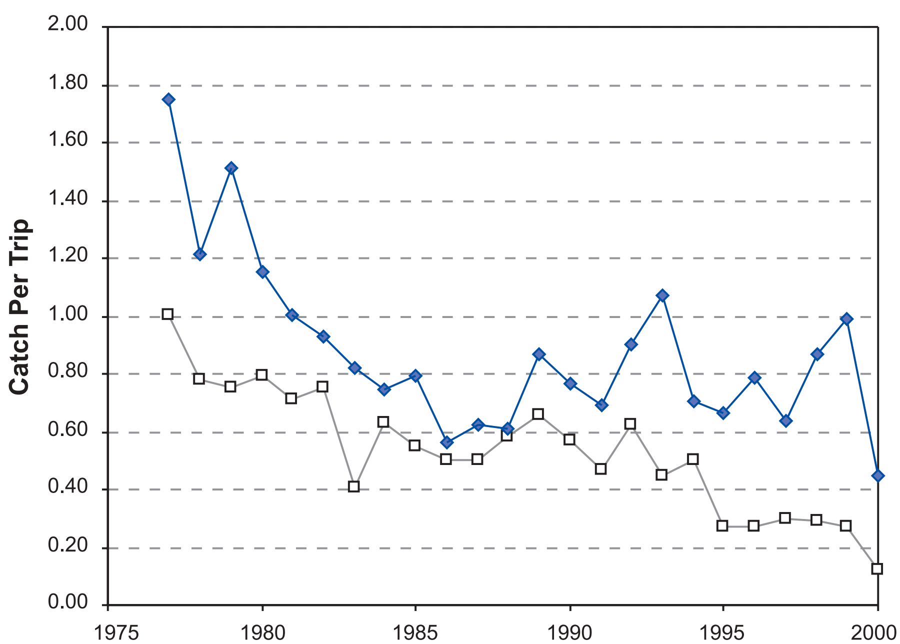


Figure 6-8. Recreational fishing success for rockfish in north and south Puget Sound.

Source: Washington State Department of Fish and Wildlife

Figure 6-9. Trends in the percentage of large copper rockfish in the recreational catch from north and south Puget Sound.

North

South

Source: Washington State Department of Fish and Wildlife

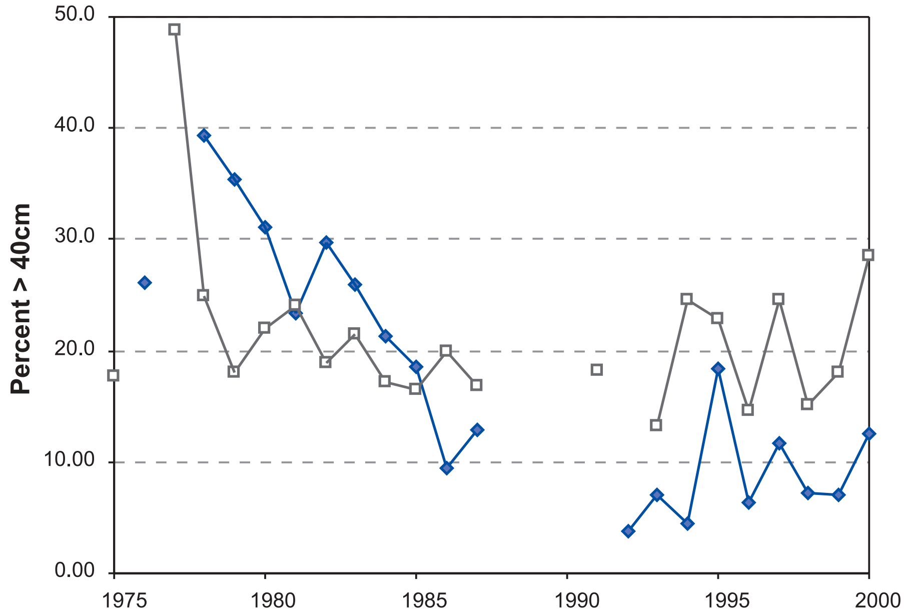
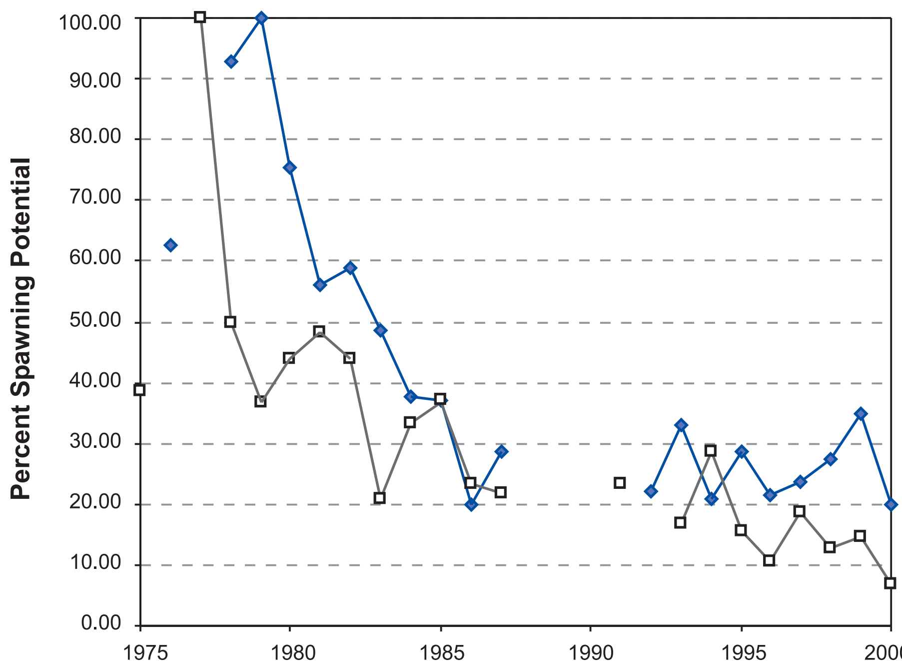


Figure 6-10. Trends in estimated egg production of copper rockfish in north and south Puget Sound.

North

South

Source: Washington State Department of Fish and Wildlife



While not reflected in these assessments, black rockfish appear to be making a local resurgence in the western Strait of Juan de Fuca and daily catch limits were increased based upon sustainable fishing modes in this area to take advantage of the increased abundance of this species.

Other groundfish species in poor condition include Pacific cod in the north and south Sound, Pacific whiting (hake) in the south Sound, and walleye pollock in the south Sound. Whiting in the Strait of Georgia are shared in common with Canada, and Canadian stock assessments find that whiting are in stable condition in the Strait of Georgia (Saunders and McFarlane 1999).

Spiny dogfish is a small shark sought by commercial fishers but is considered a nuisance by recreational fishers. Both fishery and trawl survey indicators show this species is depressed or in critical status in all areas of Puget Sound.

A number of species are in poor condition in south Sound including skates, surfperches, and Dover sole. Dover sole also appear to be in poor condition in the north Sound.

Sablefish mostly occur as juveniles in Puget Sound, and have become uncommon, as coastal stocks have declined. Coastal assessments of sablefish indicate they are below 40 percent of their unfished levels (Pacific Fishery Management Council) and are listed as below average for Puget Sound status.

A Trawl Survey of the Eastern Strait of Juan de Fuca and Discovery Bay. During May 2000, the state Department of Fish and Wildlife conducted a synoptic bottom trawl survey of the eastern Strait of Juan de Fuca and Discovery Bay in the transboundary waters of Washington and British Columbia. The stratified systematic survey was designed to estimate the numerical and biomass abundances of key benthic species, identify population trends, and quantify the impact of fisheries. The survey was also designed to describe the distribution of key commercial fishes that inhabit the Strait of Juan de Fuca and determine which are likely to move across the international boundary and are vulnerable to fisheries on either side of the border.

The survey included the collection of 40 trawl samples from 1,400 km^2 of the Washington Strait of Juan de Fuca and 25 samples collected in the 463 km^2 of the B.C. Strait of Juan de Fuca (Figure 6-11). A special survey of Discovery Bay included 12 trawl samples in the 31 km^2 study area.

Scientists collected 72 identifiable species of fish during trawling exclusive of the Discovery Bay survey. They collected 67 species of fish in Washington, and 48 fishes in B.C. An estimated 35,600 individual fish were caught during the trawl survey, and they weighed 7.9 metric tons (mt). Thirty-three species of fish were collected during the 12 trawls conducted in Discovery Bay. There was an estimated population of 132.2 million fish weighing 27,000 mt living in the eastern Strait of Juan de Fuca. Washington contained 112 million bottomfish while B.C. had 20 million individuals. The B.C. bottomfish resource constituted an estimated 8,000 mt while the Washington resource weighed an estimated 19,000 mt. As expected, Discovery Bay had far fewer fish than either of the two larger survey areas. There was a fish population of 2.9 million fish weighing and estimated 90 mt in Discovery Bay. Density, distribution, length, and population information was also collected on many large benthic invertebrates including Dungeness crab and shrimp.

Spotted ratfish made up more than 75 percent of the fish populations in Washington and B.C. Flatfish as a group was the second most dominant species group in Washington, while a complex of other species contributed to the diverse catches found in B.C.

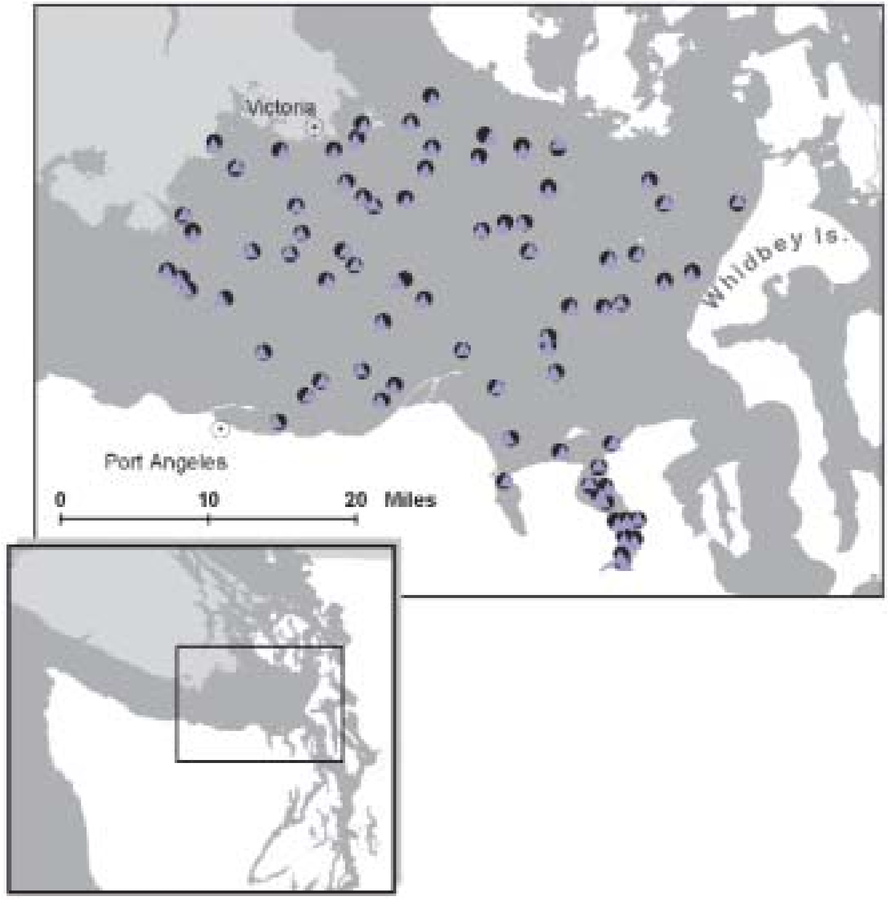
Overall, most populations were less abundant than estimated during previous surveys of the Washington Strait of Juan de Fuca (Figure 6-12). Depressed species such as Pacific cod and lingcod appear to show no response to the reduction of pressure from fisheries in recent years. However, both species almost uniformly were small, indicating strong survival has occurred in preceding years. Discovery Bay contains almost exclusively juvenile and small individuals of key species once harvested in commercial bottom trawl fisheries.

The geographic distribution and depth preferences of key species and invertebrates result in a complex pattern for transboundary management. The shallow banks and deep basins in the central Strait provide habitat for both deep and some shallow waters species resulting in a wide and continuous distribution spanning the international boundary (Figure 6-13). These continuous distributions indicate that

Figure 6-11. Planned and actual stations occupied during the 2000 Trawl Survey of the Eastern Strait of Juan de Fuca and Discovery Bay.

▲ Actual
● Planned

Source: Washington State Department of Fish and Wildlife



coordination between Washington and Canada will become important if substantial fisheries re-develop in the area.

A comprehensive assessment and management approach for groundfish is outlined in the Puget Sound Groundfish Management Plan adopted by the Fish and Wildlife Commission in June 1998 (Palsson et al. 1998) for non-tribal fisheries and resources. This plan implements the precautionary policy for managing Puget Sound groundfish adopted by the Commission several years earlier. The state Department of Fish and Wildlife has implemented many management actions to conserve and protect the declining populations identified by groundfish stock assessments. Such actions include reducing the number of allowable harvests of fish, closing areas to fishing, and eliminating directed fisheries. Further conservation and harvest plans will be developed as Fish and Wildlife forges co-management agreements for groundfish with the treaty tribes of Puget Sound.

Marine Birds and Waterfowl

Trends between 1978-1979 and 1992-2000 in wintering nearshore waterbirds

The marine bird component of PSAMP has used aerial surveys to monitor wintering nearshore marine birds in Puget Sound since 1992. State Department of Fish and Wildlife scientists compared density estimates from a subset of the PSAMP survey transects with those from the nearly identical winter aerial survey transects conducted during 1978 and 1979 in the northern portion of greater Puget Sound (Figure 6-14). The 1978-1979 study was part of the Marine Ecosystem Analyses (MESA) program administered by National Oceanic and Atmospheric Administration (NOAA) and funded by the U.S. Environmental Protection Agency

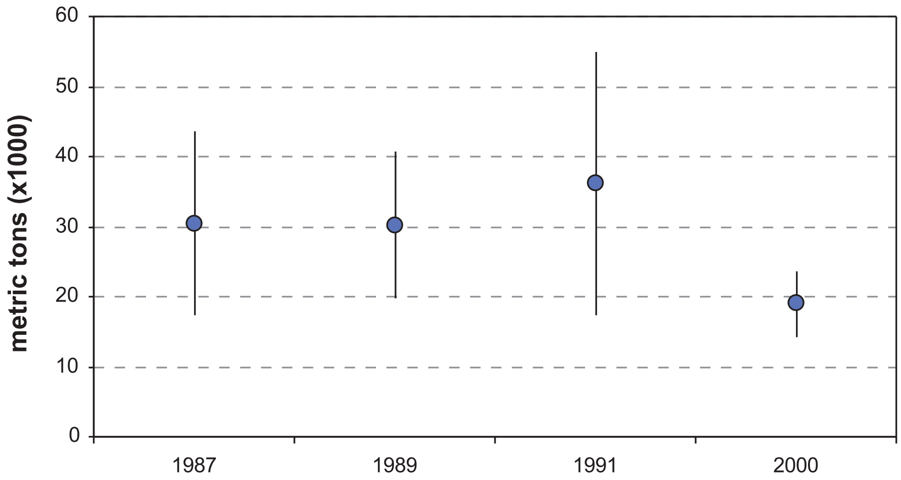


Figure 6-12. Estimated biomass (metric tons) and 95 percent confidence limits for all fish in the Washington Eastern Strait of Juan de Fuca.

Source: Washington State Department of Fish and Wildlife

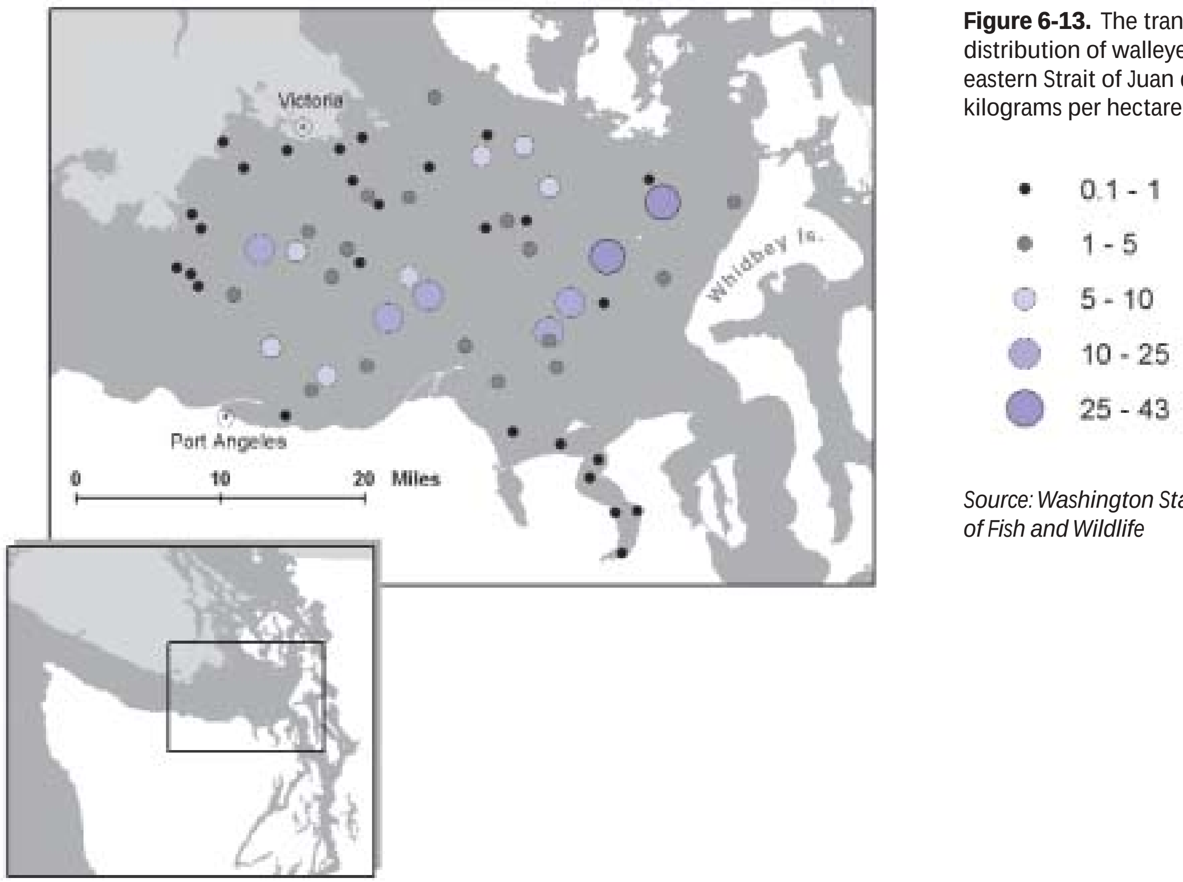


Figure 6-13. The transboundary distribution of walleye pollock in the eastern Strait of Juan de Fuca in kilograms per hectare.

Source: Washington State Department of Fish and Wildlife

(EPA). Trends in changing densities during the last 20 years were examined for 18 species or species groups (Figure 6-15, Figure 6-16, Figure 6-17): scoters, scaups, goldeneyes, bufflehead, long-tailed ducks, harlequin ducks, mergansers, all loons combined, common loon, western grebe, red-necked grebe, horned grebe, all cormorants combined, double-crested cormorant, brant, all gulls combined, pigeon guillemot and marbled murrelet. The results include a mixture of changes that range from significant decreases (grebes, cormorants, loons, pigeon guillemot, marbled murrelets, scoters, scaup, long-tailed ducks and brant) to stable or more slowly decreasing patterns (goldeneyes, buffleheads, and gulls) or increasing patterns (harlequin ducks and, probably, mergansers).

Waterfowl. The comparison of data from nearly identical MESA and PSAMP aerial transects indicates statistically significant decreases in densities for scoters (57 percent), scaup (72 percent), and long-tailed duck (91 percent), while showing significant increases for harlequins (189 percent increase). Changes for the other three species of diving ducks examined were not statistically significant (goldeneyes, bufflehead and mergansers). The MESA/PSAMP comparisons suggest a statistically significant decline in brant densities (66.3 percent).

Grebes and Loons. Western grebes appear to have declined even more so than diving duck species. In fact, all the loon and grebe species examined have experienced marked and statistically significant decreases in the MESA/PSAMP comparisons: red-necked grebe (89 percent decrease); horned grebe (82 percent decrease); common loon (64 percent decrease); or all loons combined (79 percent decrease).

Alcids. Comparisons are possible for both pigeon guillemots and marbled murrelets since they frequent the nearshore depth included in the comparable MESA and PSAMP transects. Even though aerial surveys miss some of these birds, especially marbled murrelets, the comparisons of densities seen on aerial surveys in both MESA and PSAMP efforts suggest statistically significant declines for these two species: pigeon guillemot (55 percent decline) and marbled murrelet (96 percent decrease).

Cormorants and Other Species. While wintering cormorant densities did not appear to change much during the PSAMP period, densities have decreased significantly between the MESA and PSAMP periods, either for identified double-crested cormorants (62 percent decrease) or for all cormorants including the unidentified category (53 percent decrease). It is unknown whether cormorants return to similar wintering areas each winter. The inner marine waters of Washington State are home to many other resident marine species as well as attracting many other wintering bird species, such as numerous gull species. The decrease in gull densities comes closest to significance.

Scientists have observed definite changes in bird populations during the last 20 years among the varied marine bird species that winter in greater Puget Sound, including many significant declines in numbers and densities. It is uncertain whether documented changes relate to cycles of change such as the North Pacific Decadal Oscillation or to more local changes in forage fish stocks. Bird species that either eat fish or depend upon certain spawning events of Puget Sound forage fish appear to have declined more than species that emphasize feeding on other parts of the food chain, such as crustaceans and invertebrates. The declines in scoters and scaup in Washington State have also been similarly documented in other marine areas throughout the Pacific Flyway. This suggests that they have not moved from Washington to some other part of their wintering range.

Monitoring of Breeding Pigeon Guillemots

To obtain an accurate estimate of pigeon guillemot population trends in Puget Sound, breeding colony censuses were conducted during 1999 and 2000 (the first years of a 5-year study). These boat surveys obtained partial coverage of all colonies within the inland marine waters of Washington State in 1999 because much of the effort was to identify colony locations. The 2000 surveys provided complete coverage of the colonies. Survey participants included the Olympia PSAMP staff from both the state Department of Fish and Wildlife and the U.S. Fish and Wildlife Service; staff from the U. S. National Wildlife Refuges; the Whale Museum; and regional staff and volunteers of the state Department of Fish and Wildlife.

The surveyors counted birds at colonies during May and June 1999 and May 2000. All counts were conducted by vessel from sunrise to 3.25 hours after sunrise, at sea

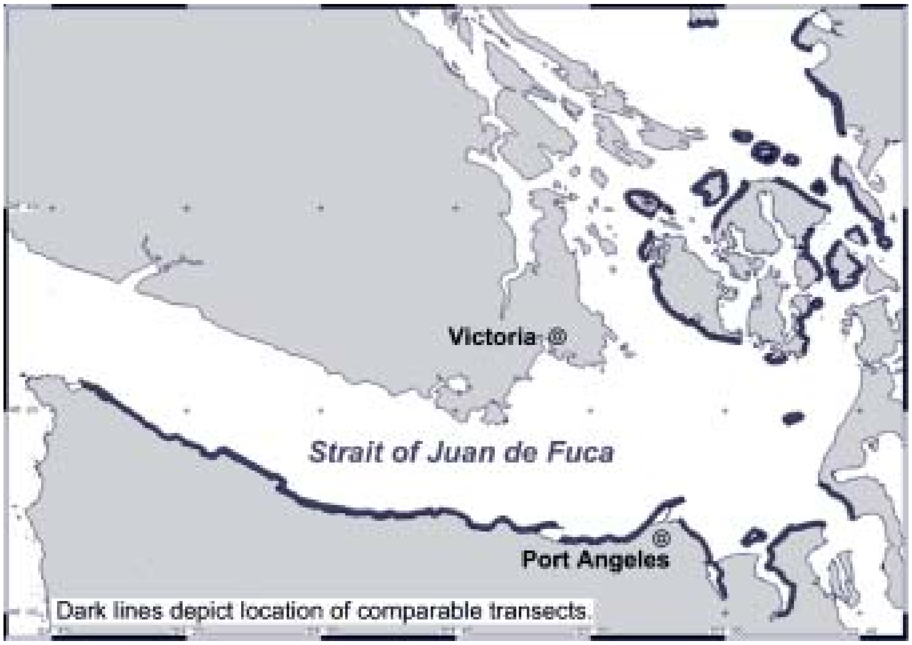


Figure 6-14 . Transect locations for comparisons of marine bird densities derived from aerial surveys conducted by MESA and PSAMP.

Source: Washington State Department of Fish and Wildlife

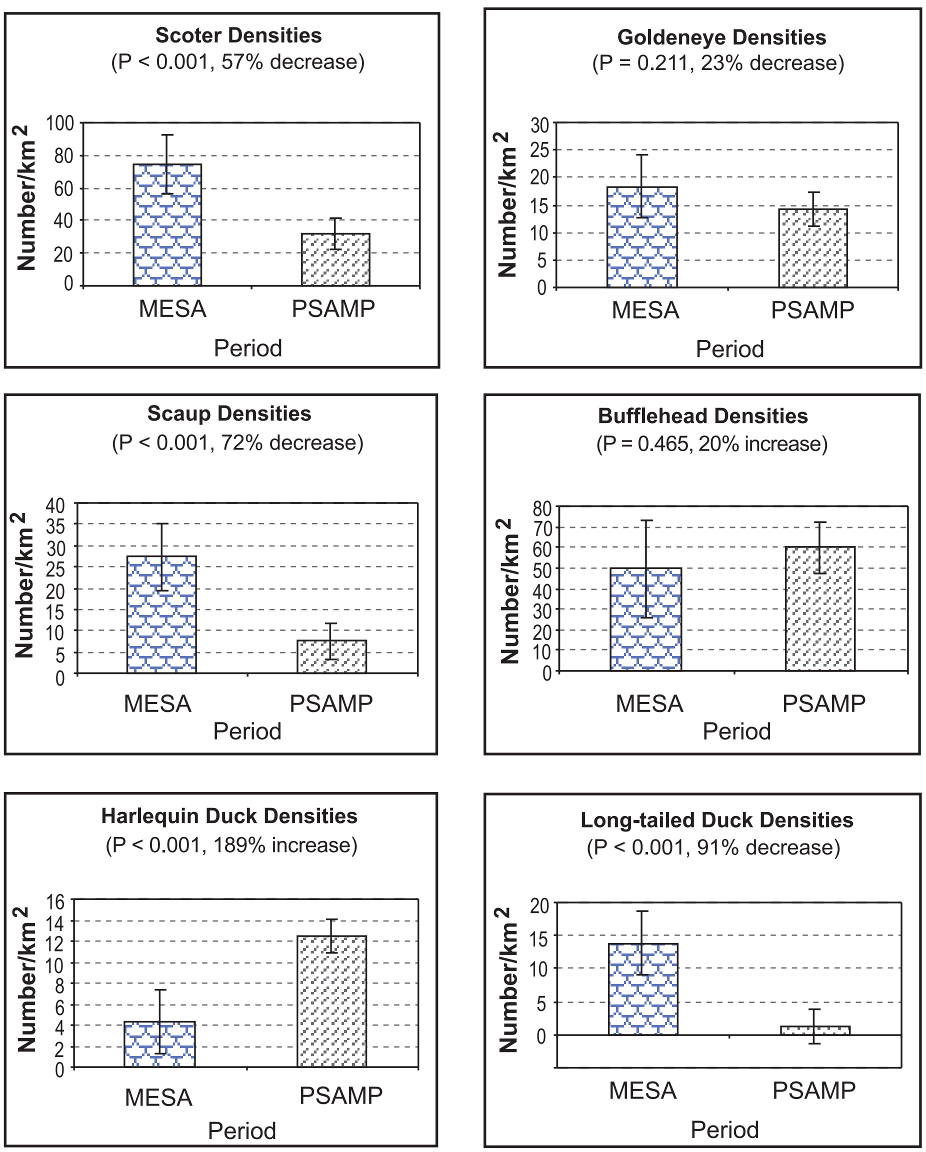


Figure 6-15. Changes in density (birds/km^2) of selected diving duck species observed on nearly identical transects between the 1978-1979 MESA and the 1992-1999 PSAMP aerial surveys.

Source: Washington State Department of Fish and Wildlife

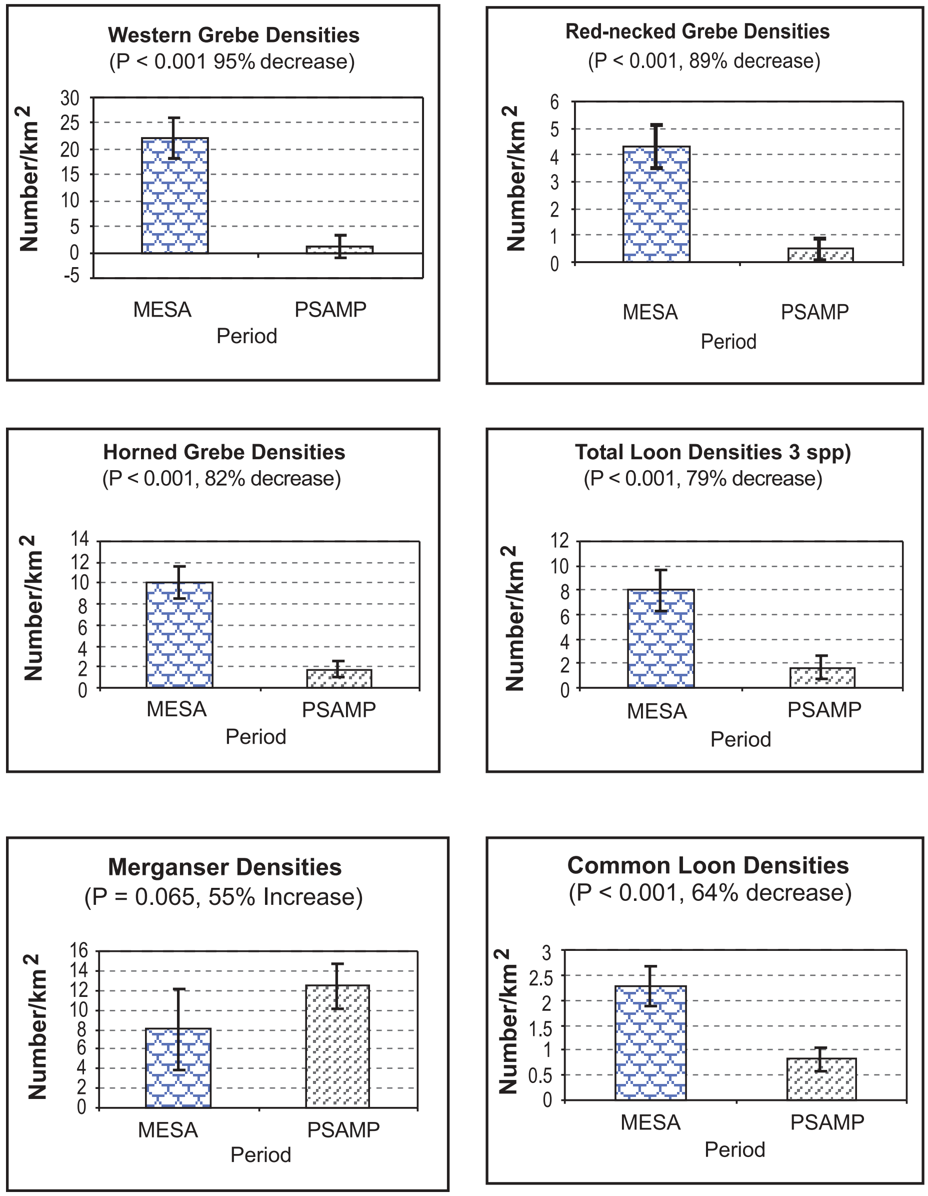


Figure 6-16. Changes in density (birds/km^2) of grebe, loon and merganser species observed on nearly identical transects between the 1978-1979 MESA and the 1992-1999 PSAMP aerial surveys.

Source: Washington State Department of Fish and Wildlife

states of less than or equal to Beaufort 3. All guillemot colonies listed in the *Washington Catalog of Seabird Colonies* (Speich and Wahl 1989) were counted. During 1999, counts occurred during May and June, with special emphasis to search for, and count, colonies not listed in the Colony Catalog; a minimum of one count was conducted in May at the colonies listed in the colony catalog. However, efforts were made to get three counts per colony. During 2000, areas not searched in 1999 for unlisted colonies were investigated in April, and all colony counts were conducted during May only, with an average of three counts at each colony.

The surveyors conducted counts at 273 colonies (maximum count of 9,172 guillemots) in May 1999 (Figure 6-18), with colonies previously listed (Speich and Wahl 1989) comprising 120 of these (6,740 guillemots counted). Figure 6-19 shows the 429 colonies counted during May 2000 (14,852 guillemots counted), with colonies previously listed comprising 121 colonies (7,840 guillemots counted) (Table 6-6). The maximum count of guillemots, at the 269 colonies counted during both years was 9,121 and 10,380, from 1999 and 2000 respectively. A total of 308 colonies, not previously recorded in the *Catalog of Washington Seabird Colonies*

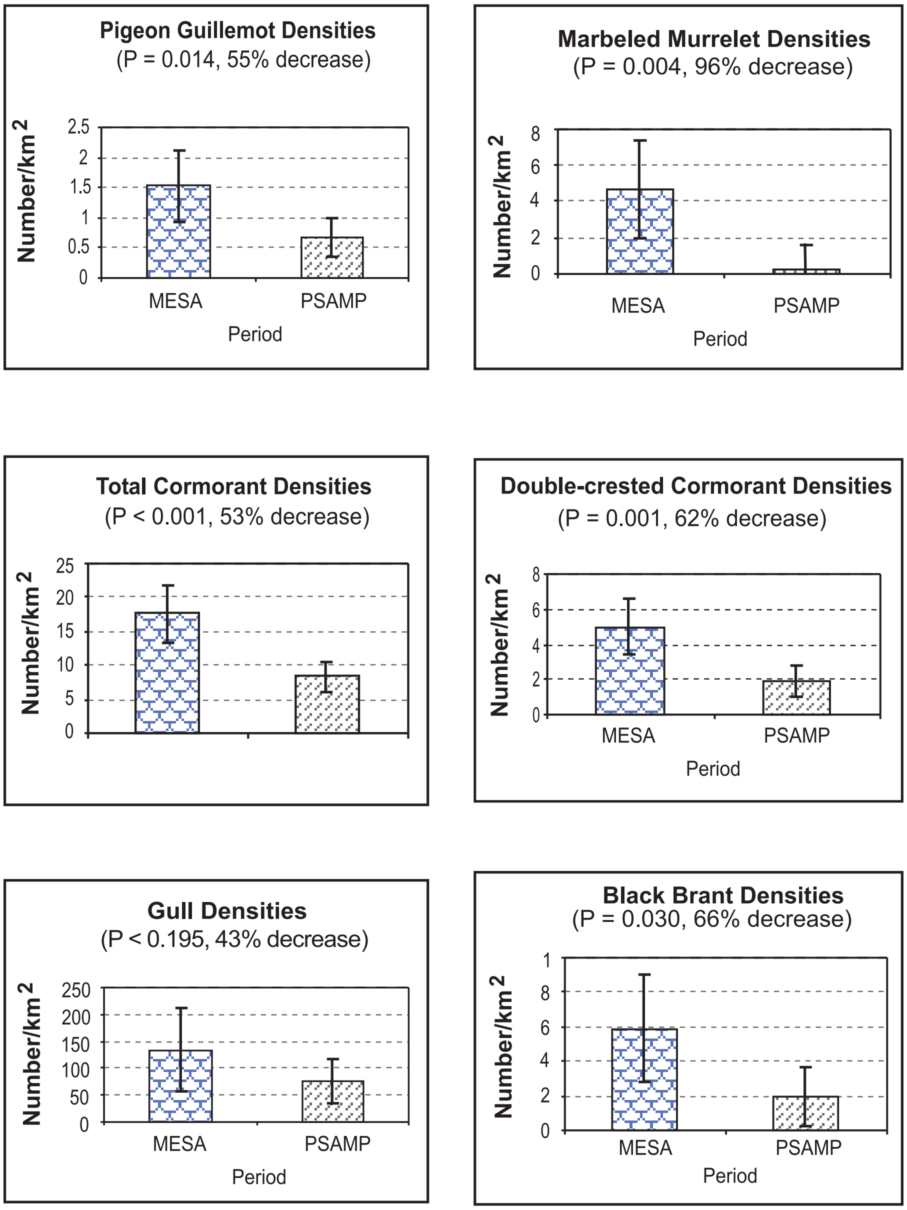


Figure 6-17. Changes in density (birds/km^2) of alcid, cormorant, gull and other species observed on nearly identical transects between the 1978-1979 MESA and the 1992-1999 PSAMP aerial surveys.

Source: Washington State Department of Fish and Wildlife

(Speich and Wahl, 1989), were documented, adding over 89 percent to the total number of breeding guillemots known. The importance of counting smaller colonies was apparent; 62 percent of the colonies in 2000 had 25 birds or fewer.

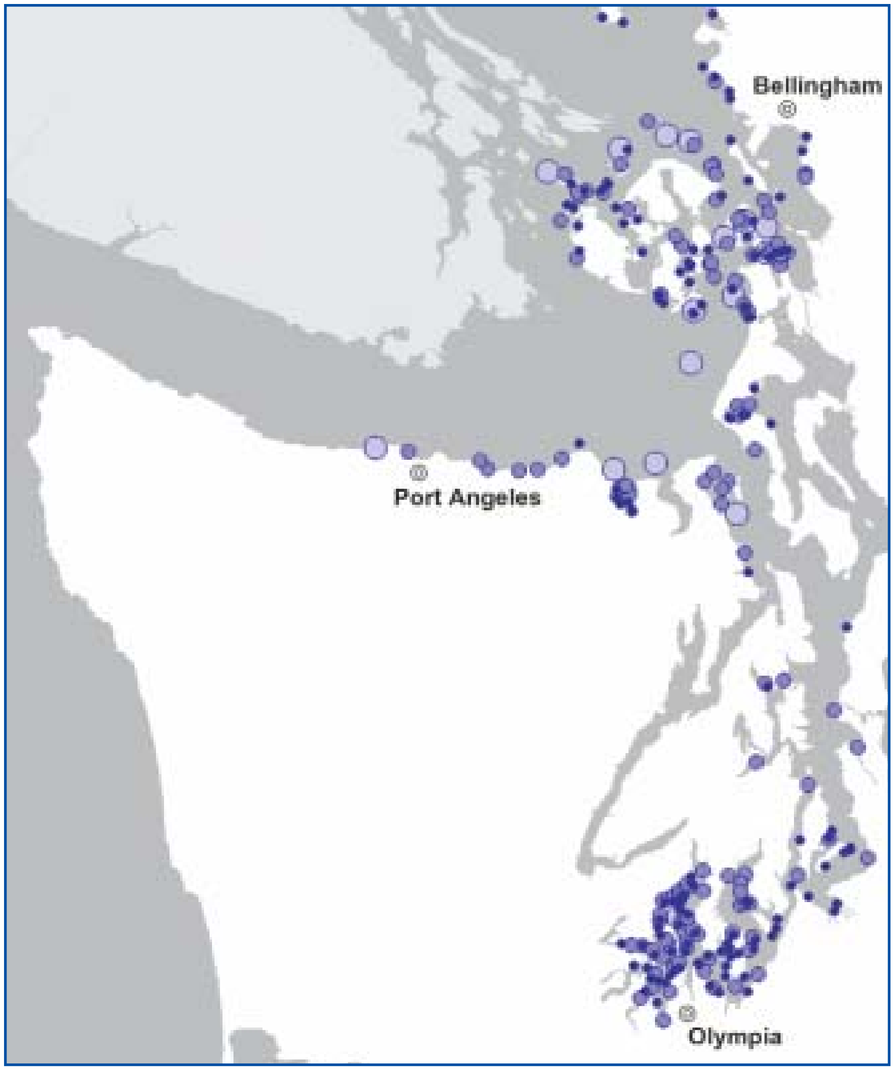
Even though the counts during 2000 were higher than observed in 1999, they should not be considered as an increase to 1999. In 1999 there were far fewer colonies counted, as the coverage was not complete, and there were fewer counts at each colony, leaving a smaller count sample at each colony. The 2000 census should be viewed as the first year of complete coverage of guillemot colonies to be used for future trend analysis.

By continuing this survey that combines standardized timing, methodology, replicates, and geographic coverage within each season, we can better understand pigeon guillemot population trends within the inland marine waters of Washington State.

Figure 6-18. Pigeon Guillemot colonies surveyed in May 1999.

- > 10 Guillemots
- 10 - 99 Guillemots
- >=100 Guillemots

Source: Washington State Department of Fish and Wildlife



Great Blue Heron Surveys—Comparing Aerial and Ground Surveys

A team of regional scientists, with participation of the state Department of Fish and Wildlife, investigated the use of summer foraging grounds by herons. The study focused on the eelgrass bed-associated colonies from Everett north to Boundary Bay. On June 3 and 9, 2001, flights were coordinated with volunteers on the ground counting herons during a minus tide. At this time in northern Puget Sound, herons have large chicks and both adults were expected to be foraging at minus tides. Attendance measures at two colonies confirmed that 95 percent of the nests with chicks were empty, indicating that both adults were out foraging.

The two flights show remarkable similarity and good agreement with the numbers of herons observed by ground observers throughout the low tide (Table 6-7). An additional benefit of this study was the new identification of a colony located on the Lummi peninsula and a potential colony at Portage Island, both on the Lummi Indian Reservation.

Goals for continuation of this work include:

1. Flights on days before and after maximum minus tides to reduce conflicts with shellfish surveys by the state Department of Fish and Wildlife and further focus upon the most efficient time.

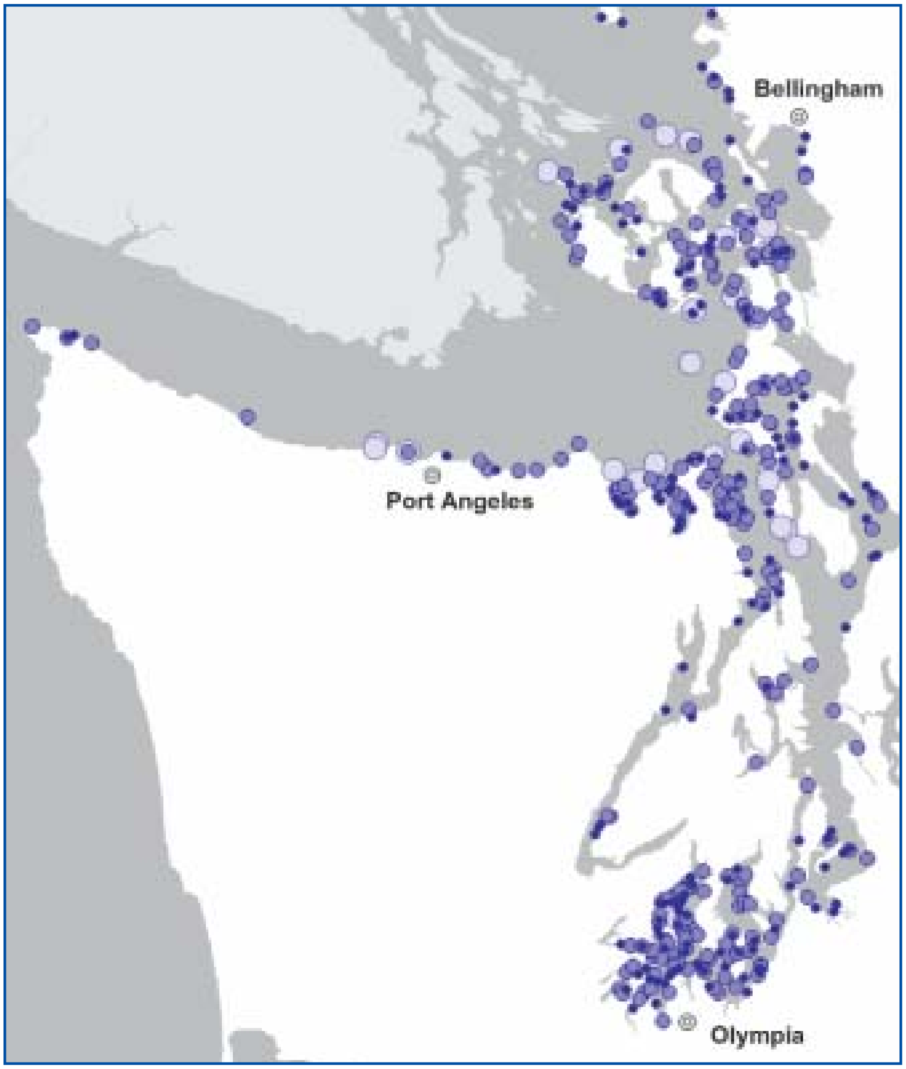


Figure 6-19. Pigeon guillemot colonies surveyed in May 2000.

● > 10 Guillemots

● 10 - 99 Guillemots

○ >=100 Guillemots

Source: Washington State Department of Fish and Wildlife

2. Surveys of other locations, especially the outer coast, earlier in the season, to help locate many of the smaller colonies by subsequent arrival and departure monitoring of herons at the foraging areas.
3. Surveys of lakes Washington and Sammamish in King County to locate potential foraging concentrations.
4. Surveys in August to obtain a summer total population count after fledging of chicks.
5. Capturing chicks or adults at some of the King County colonies and marking them to determine if birds from King County are foraging north in eelgrass beds.
6. Ground surveys for juvenile herons in south Port Susan from earlier nesting King County herons.

Hood Canal Bald Eagles

The bald eagle, *Haliaeetus leucocephalus*, ranges over much of North America but has a history of declining populations in the last century, which led to the Bald Eagle Protection Act in 1940 and ultimately to the bald eagle being listing as endangered (in most of the lower 48 states) and threatened (in some northern states including Washington) under the ESA in 1978. Populations have rebounded dramatically during the last 20 years, including in Washington State, leading to a proposal by the

Table 6-6. Summary of May 1999 and 2000 pigeon guillemot counts in the inland marine waters of Washington State. Counts are grouped by whether or not colonies were previously listed in the Catalog of Washington Seabird Colonies.

Source: Washington State Department of Fish and Wildlife

	Listed in Colony Catalog			Not Listed in Colony Catalog			All Colonies	
Year	# of Colonies	# of birds	% of total birds	# of birds	# of Colonies	% of total birds	# of Colonies	# of birds
1999	120	6,740	73%	153	2,432	27%	273	9,172
2000	121	7,840	53%	308	7,012	47%	429	14,852

Table 6-7. Comparison of Great Blue Heron counts from PSAMP aerial surveys and volunteer ground surveys, 2001.

(I) indicates incomplete sampling.

• ground-based count coincident with time of aerial survey

Source: Norman Wildlife Consulting

Region	PSAMP Aerial Survey June 3rd	PSAMP Aerial Survey June 9th	Ground Survey Count	Ground Survey Date
Snohomish River Delta	56	57	60	June 10
Port Susan	110	234	58*	June 3
			74*	June 9
Skagit Bay	124	104	(I)	-
Dugwalla Bay	no data	138	85*	June 3
			114*	June 9
Similk Bay Area	(I)	91	136	June 24
Fidalgo Bay	95	65	55	June 24
Padilla Bay	608	626	390*	June 3
			596*	June 9
Samish Bay	311	259	(I)	June 3
Bellingham Bay	18	1	4	June 9
Portage Bay	38	125	121*	June 9
Lummi Bay	168	75	177*	June 3
			67*	June 9
Birch Bay	38	29	62	June 3
			10	June 9
Drayton Harbor	165	327	236	June 3
			153*	June 9
Boundary Bay	152	137	(I)	June 3
Twassassen Ferry	342	343	315*	June 3
			610	June 24

U.S. Fish and Wildlife Service to remove the bald eagle from the List of Endangered and Threatened Wildlife (USDI 1999). Although the outlook for bald eagles in Washington State is good, the average productivity and success rate of eagles in the Hood Canal area have historically been below the average levels for the state. A new report reviews the population of bald eagles in Hood Canal focusing on toxic contaminant loadings in eagle eggs, blood, tissue and in fish that contribute to the bald eagle diet (Mahaffy et al. 2001).

In 1940, when the Bald Eagle Protection Act was passed, declining numbers were attributed to hunting, loss of nesting habitat and declining number of prey species. Soon after the act was passed, the use of DDT and other organochlorine pesticides became widespread. In the late 1960s and early 1970s, scientists determined that

DDE, the principal breakdown product of DDT, accumulated in the fatty tissues of adult female bald eagles. This impaired eggshell formation, resulting in thin shells and reproductive failure (USDI 1999). In 1972, DDT was banned in the U.S. and in 1986 a bald eagle recovery plan was adopted for the Pacific region, including Washington State. The Pacific recovery plan established goals of an average reproductive rate of 1.0 fledged young per occupied breeding area and an average success rate for occupied breeding areas of not less than 65 percent over a 5-year period (USDI 1999). The plan calls for these population goals to be met in at least 80 percent of management zones.

By 1999, the numeric population goals had been met over the Pacific region as a whole but only in 76 percent of the management zones. On a statewide basis, the Washington bald eagle population is near the recovery goals and fairly stable. The Hood Canal population has been less stable and not as productive as the statewide population (Figure 6-20, Figure 6-21). Nevertheless, the Hood Canal bald eagle population is increasing. This can be seen in the increasing number of occupied territories (Figure 6-22). It is believed that persistent environmental contaminants, especially PCB compounds, are responsible for reduced productivity in the Hood Canal area (see Chapter 4).

Marine Mammals

Petition for Listing of Southern Resident Orcas

In May 2001, the Center for Biological Diversity and 10 other entities petitioned NMFS to list the southern resident community of orcas (*Orcinus orca*), which reside for most of the year in Puget Sound and the Strait of Georgia, as threatened or endangered under the ESA. The population of whales in the three pods that make up the southern resident community declined from 97 to 78 individuals in recent years (Center for Biological Diversity 2001). The petition describes three factors related to this decline: reduced food availability; increased interaction with humans; and high levels of toxic contamination (see Chapter 4 for additional information about PCB contamination in orcas.)

NMFS accepted the petition, conducted a biological review, and announced in July 2002 that ESA listing was not warranted for the southern resident orca population. This decision was based on the fact that the population did not meet criteria contained in the ESA and in a 1996 joint policy document released by the U.S. Fish and Wildlife Service and NMFS. The particular criterion in question is related to the significance of the population to the entire species or subspecies. At this time the scientific community recognizes only one species of orca with no subspecies. This taxonomy is in question among marine mammal specialists, and the NMFS review panel stated that if orca taxonomy is modified, (e.g. if subspecies become recognized) then the question of listing under ESA could be revisited.

The decision was not a refutation of the decline of the population or the prognosis for long-term sustainability. In recognition of their decline, NMFS moved to have the southern resident population declared a “depleted” stock and thereby gain further protections under the Marine Mammal Protection Act (MMPA).

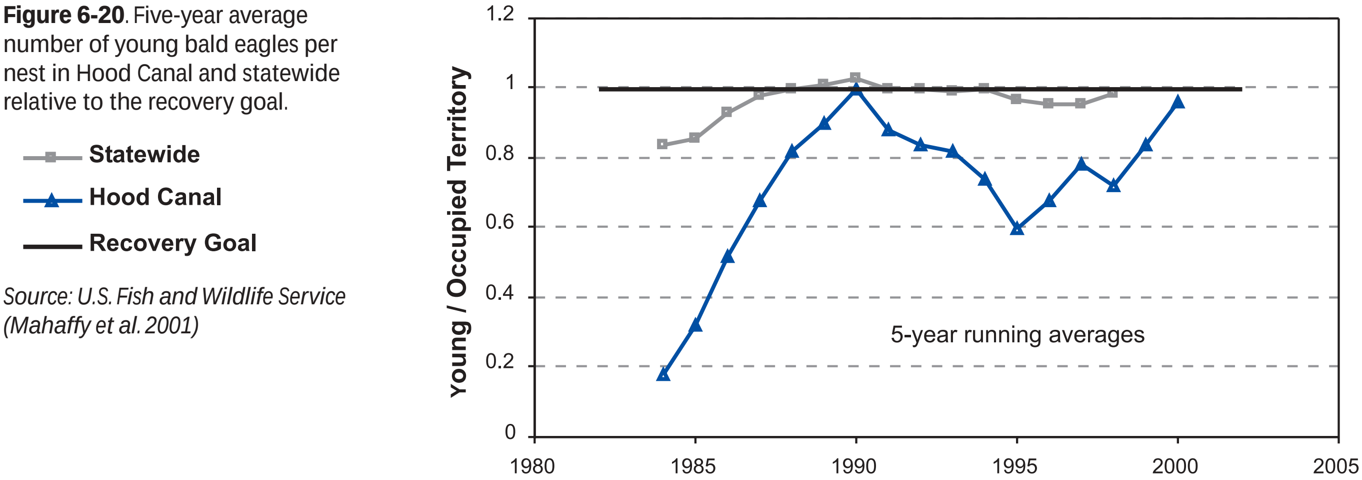
Harbor Seal Population, 1978-1999

In the first half of the 20th century, a state-financed population control program severely reduced the numbers of harbor seals (*Phoca vitulina richardsi*). Bounty hunters severely reduced harbor seal numbers in the early 1900s under a state-financed program that considered harbor seals to be predators in direct competition with commercial and sport fishermen. After the bounty program ceased in 1960 and

King County’s Herons: A Potential Connection to Eelgrass and Salmon

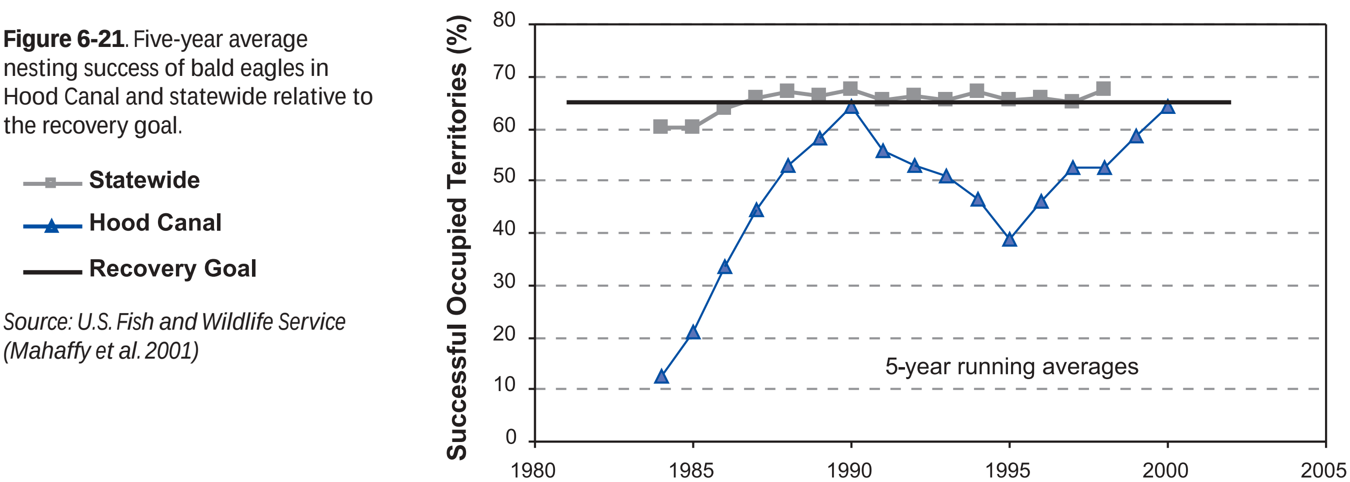
For her master’s thesis research in 2000, Amy Stabins confirmed some 250 successful heron nests at seven King County colonies associated with the Lake Sammamish and Lake Washington system. The colonies at Lake Sammamish State Park, Black River, Redmond Town Center, Kenmore, and Mercer Slough, began incubation almost a month earlier than marine colonies. These five colonies produced 83 percent of the 628 chicks, meaning 900 herons were looking for food in mid to late June. To nest so early requires a food source for the females in February, more than a month before daylight low tides and fish to catch. Groups of herons have been observed foraging at night at the mouth of the Cedar River in February when long-nosed smelt spawn in Lake Washington and possibly also on Lake Sammamish. Nesting at several colonies was earlier in 2001 (Kate Stenberg and Pam Cahn, personal communication). An overlay of the location of the King County colonies also shows an association of herons with locations where large numbers of hatchery sockeye salmon exit streams in April and May, when herons are foraging for their chicks. By June, the outmigrations are over, and food is in short supply—herons likely move to foraging at eelgrass beds. Scientists initiated a closer watch for juvenile birds at Port Susan in 2002.

Figure 6-20. Five-year average number of young bald eagles per nest in Hood Canal and statewide relative to the recovery goal.



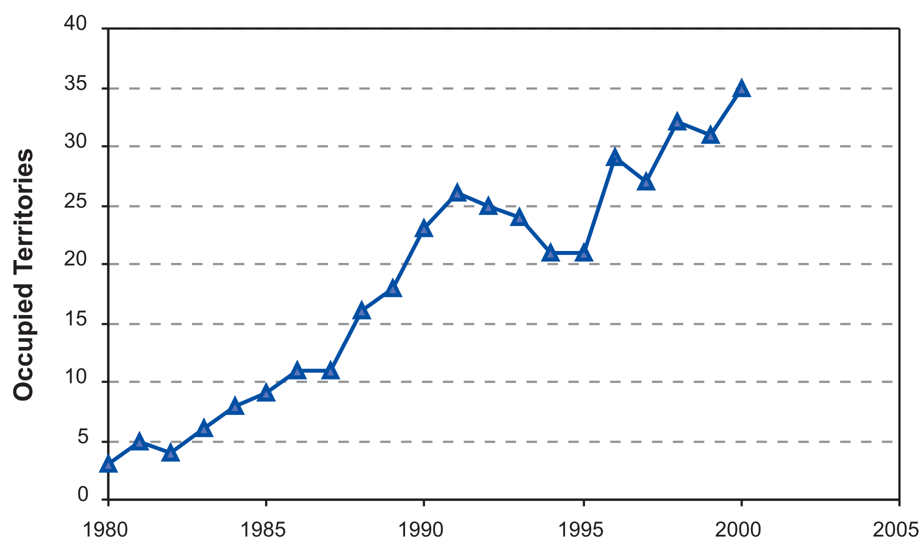
Source: U.S. Fish and Wildlife Service (Mahaffy et al. 2001)

Figure 6-21. Five-year average nesting success of bald eagles in Hood Canal and statewide relative to the recovery goal.



Source: U.S. Fish and Wildlife Service (Mahaffy et al. 2001)

Figure 6-22. Number of occupied bald eagle territories in the Hood Canal area.



Source: U.S. Fish and Wildlife Service (Mahaffy et al. 2001) the MMPA was passed in 1972, populations of harbor seals in Washington State began to recover. Newby (1973) estimated that 2,000 to 3,000 harbor seals resided in Washington State in the early 1970s.

State and federal scientists collaborated on systematic surveys of Washington's harbor seal population from 1978 to 1999. The aerial surveys of harbor seals reported below took place during the pupping season when maximum numbers were onshore. Since 1994, one of the objectives of the state Department of Fish and Wildlife's PSAMP monitoring efforts has been to continue efforts to monitor harbor seal population trends at haulout sites in Washington's inland waters.

The 22-year time series of systematic surveys of a recovering population provides a unique opportunity to describe population growth of an unharvested marine mammal population.

State Department of Fish and Wildlife scientists used the survey data to develop logistic models that were used to examine population trends and status relative to maximum net productivity level (MNPL), carrying capacity (K) and optimum sustainable population (OSP). The results of this model development are "best fit" parameters for the harbor seal population.

The 1999 count for Washington's inland harbor seal stock corrected for seals in the water during surveys was 14,612 (95 percent confidence interval: 11.154 to 19.140). This value is higher than the observations shown in Figure 6-23 because of the correction for seals in the water.

Survey counts and model results indicate that growth between 1978 and 1999 was not evenly distributed throughout all regions of the state. Between 1978 and 1999, the inland stock grew from 42 percent of the state population to 46 percent. Most growth in the inland stock occurred in the San Juan Islands and the Strait of Juan de Fuca and the least growth occurred in Hood Canal (Table 6-9).

Observed harbor seal abundance has increased three-fold since 1978 and estimated abundance has increased seven to 10 fold since 1970. The logistic growth model fit to the data for the total inland seal population is shown in Figure 6-23. The observed population size for Washington's inland harbor seal stock in 1999 is very close to the predicted carrying capacity (K) for this habitat. Model results also suggest that Washington's inland harbor seal stock is above MNPL. Because there are no records of the number of seals in Washington before exploitation, we don't know whether the present population is larger or smaller than historical levels or if Puget Sound's carrying capacity for harbor seals is different now then in earlier times.

Changes that might have lowered the carrying capacity include decreases in harbor seal prey such as Pacific Whiting (hake) (Gustafason et al. 2000) and herring (Stout et al. 2001a), reduced habitat and increased disturbance.

Harbor Seal Stocks

Harbor seals in Washington and Oregon are separated into coastal and inland stocks because of differences in cranial morphology, pupping phenology, and genetics (Temte 1986; Lamont et al. 1996). The Washington inland stock includes all harbor seals in U.S. waters east of a line extending north-south between Cape Flattery on the Olympic Peninsula and Bonilla Point on Vancouver Island. Interchange between Washington's inland and coastal stocks is unlikely, as no radio-tagged seals from the inland stock have been observed in coastal areas or vice versa.

Aquatic Nuisance Species

The Washington State Exotics Expedition:
A Comparison of Exotic Species in Three Regions

In the spring of 2000, Department of Natural Resources scientists coordinated a rapid survey of exotic organisms to provide baseline information about marine invasions. The cooperative study, called the 2000 Expedition, brought together 22 scientists from diverse institutions to survey exotic species in a broad range of shallow water habitat types. Three regions in Washington State were sampled to compare spatial patterns across a range of oceanographic conditions and patterns of human use:

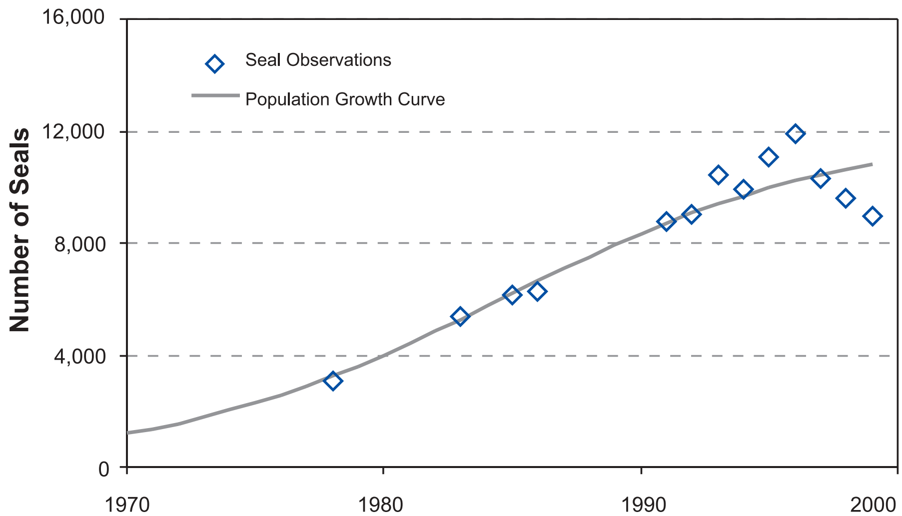
Table 6-9. Summary of harbor seal surveys for inland stock survey regions in Washington, 1978 to 1999.

Source: Washington State Department of Fish and Wildlife

Survey region	Range of surveys	No of years surveyed	Average no. of surveys/year	Mean counts (percent of population) 1978	1999
Strait of Juan de Fuca	1978-1999	18	1.9	417 (5.7)	1752 (9.0)
San Juan Islands	1978-1999	18	1.3	852 (11.7)	4189 (18.5)
Eastern Bays	1978-1999	17	1.8	755 (10.3)	1873 (9.6)
Puget Sound (south of Admiralty Inlet)	1978-1999	10	2.2	337 (4.6)	1025 (5.3)
Hood Canal	1978-1999	8	1.7	732 (10.0)	711 (3.7)

Figure 6-23. Generalized logistic growth curve for inland Washington stock of harbor seals.

Source: Washington State Department of Fish and Wildlife



- **Elliott Bay and the Duwamish River** estuary are located in the central basin of Puget Sound, near the City of Seattle. This is an area of intensive urban development and the site of a major international port, the Port of Seattle.
- **Totten and Eld inlets** are relatively protected bays in the southern basin of Puget Sound. Aquaculture and residential land uses predominate in these inlets. The Port of Olympia, a small international port, is in adjacent Budd Inlet.
- **Willapa Bay** is is a large outer coast estuary. It is the state's largest aquaculture center. Much of its shoreline is undeveloped. There is currently no commercial shipping in the bay.

The 2000 Expedition collected 40 exotic species during seven days of sampling and taxonomic analysis (Table 6-10). Most of the exotic species are native to the North Atlantic or the northwestern Pacific region, and most were introduced to the northeastern Pacific with oysters imported for aquaculture, as ship-fouling organisms or in ballast water. Four of the exotic species collected in Willapa Bay were not previously known from that bay. One of these, the spionid worm *Pseudopolydora bassarginensis*, is a new record for North America. A phyllodocid worm in the genus *Nereiphylla* may be either a new species or a previously unreported introduction. The collection of the native nudibranch, *Emarcusia morroensis*, in Elliott Bay substantially extended its documented range on the Pacific Coast. The terebellid worm *Neoamphitrite figulus*, collected in Willapa Bay during in March 2000, is a new record for the Pacific Coast of North America. (The record is not included among the results of the expedition since it was collected during an earlier reconnaissance survey.)

Among the three regions, 15 exotic species were collected in each of the Elliott Bay and Totten/Eld Inlet regions, and 34 were collected in Willapa Bay. The apparent ecological dominance by exotics was greater in Willapa Bay and slightly greater in Totten and Eld inlets than in Elliott Bay.

Among the three regions, Elliott Bay has experienced the most extensive physical alteration and Willapa Bay the least. Thus the greatest number and extent of invasions was found in the least physically altered system. This pattern appears to contradict the hypothesis that more disturbed habitats are more vulnerable to invasions (e.g. Elton 1958; Lozon and MacIssac 1997). However, it is important to note that while Willapa Bay is relatively undeveloped, it is far from pristine. Habitats and natural processes in the bay have been extensively altered by practices such as diking, agriculture, aquaculture, dredging and deforestation of the watershed. Dominant invaders (Atlantic cordgrass and Japanese oysters) have also altered the physical environment. These results also suggest the possibility that factors other than level of physical alteration play an important role in the level of invasions at these sites (e.g. proximity to other areas rich in exotic species).

Elliott Bay is an important international and coastal shipping center, which Totten/Eld Inlets and Willapa Bay are not. The latter two regions, however, are major historical and current sites for aquaculture. Since these regions appear to be as invaded as (or more invaded than) Elliott Bay, this suggests that aquaculture activities may historically have been as effective as (or more effective than) ship-associated mechanisms in moving organisms across and between oceans, and between bays. Scientists note that aquaculture activities have historically been efficient vectors for moving pests and parasites of shellfish. The shipment and planting of oysters for commercial aquaculture is considered to be a possible mechanism responsible for introducing onto the Pacific Coast 35 of the 40 exotic species collected by the expedition. In contrast, ballast water is considered a possible transport mechanism for 13 of the species, and all ship-associated mechanisms together (ship fouling, solid ballast and ballast water) for 28 of the species. All of these mechanisms would also be effective at moving organisms between bays on the Pacific Coast.

A study of the causes of species introductions throughout North America found the same vectors—aquaculture and shipping—to be the predominant vectors associated with species introductions into marine communities throughout North America (Ruiz et al. 2000). However, the order of importance of the vectors was reversed; shipping was found to be the most important vector for introductions into North America. Beyond the predominance of these two vectors, there remains a great deal of uncertainty about the relative contribution of each mechanism.

Control of Invasive Exotic Spartina

Spartina, commonly know as cordgrass, is a noxious weed that severely disrupts Washington State's 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.

In Puget Sound, known *Spartina* infestations occur or have occurred at a few locations along the Strait of Juan de Fuca and into Hood Canal, at three locations in San Juan County (one each on San Juan, Orcas and Lopez Islands), in numerous

Table 6-10. Origins, earliest records and mechanisms of introduction of exotic species collected in the 2000 Expedition. Native ranges, dates of earliest record (planting, collection or report) on the Pacific Coast of North America and in Washington State, and possible initial mechanisms of introduction to the Pacific Coast are given. Much of this information is expanded and revised from Carlton (1979), Cohen and Carlton (1995), Cohen et al. (1998) and Mills et al. (2000). Earliest 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:

- SF - in ships' hull fouling or boring
- SB - in solid ballast
- BW - in ships' ballast water or seawater systems
- PM - as packing material for shipped goods
- OA - with shipments of Atlantic oysters
- OJ - with shipments of Japanese oysters
- PL - with shipments of aquatic plants

Source: Washington State Department of Natural Resources

	Native Range	1st Pacific Coast Record	1st Wash. State Record	Mechanism of Introduction
Phaeophyceae				
Sargassum muticum	NW Pacific	1944	1948	OJ
Anthophyta				
Spartina alterniflora	NW Atlantic	ca. 1938	ca. 1938	OA,SB,PM
Zostera japonica	W Pacific	1957	1957	OJ
Porifera				
Clathria prolifera	NW Atlantic	1945-49	≤1967	OA,SF
Cnidaria				
Cordylophora caspia	Black/ Caspian Seas	ca. 1920	ca. 1920	BW,SF
Diadumene lineata	NW Pacific	1906	≤1939	OA,SF
Annelida: Polychaeta				
Hobsonia florida	NW Atlantic	1940	1940	OA,SF,PL
Neanthes succinea	N Atlantic	1896	≈1995	OA,SF
Polydora cornuta	N Atlantic	1932	1937	OA,SF,(BW)
Pseudopolydora bassarginensis	NW Pacific	2000	2000	OJ,SF,BW
Pseudopolydora kempi japonica	NW Pacific	1951	1968	OJ,SF,BW
Streblospio benedicti	N Atlantic	1932	≤1971	BW,OA,(SF)
Mollusca: Gastropoda				
Batillaria attramentaria	NW Pacific	1924	1924	OJ
Crepidula fornicata	NW Atlantic	1905	1905	OA
Ilyanassa obsoleta	NW Atlantic	1907	≤1945	OA
Ocinebrellus inornatus	NW Pacific	1924	1924	OJ
Urosalpinx cinerea	NW Atlantic	1890	≤1929	OA
Mollusca: Bivalvia				
Crassostrea gigas	NW Pacific	1875	1875	OJ
Mya arenaria	NW Atlantic	1874	1884	OA
Neotrapezium liratum	NW Pacific	1924	1924	OJ
Petricolaria pholadiformis	NW Atlantic	1927	≤1943	OA
Venerupis philippinarum	NW Pacific	1924	1924	OJ
Arthropoda: Crustacea: Ostracoda				
Eusarsiella zostericola	NW Atlantic	1953	1998	OA,SF,(BW)
Arthropoda: Crustacea: Cirripedia				
Balanus improvisus	N Atlantic	1853	1955	OA,SF
Arthropoda: Crustacea: Cumacea				
Nippoleucon hinumensis	NW Pacific	1979	1980	BW
Arthropoda: Crustacea: Isopoda				
Limnoria tripunctata	not known	1871 or 1875	1962	SF
Arthropoda: Crustacea: Tanaidacea				
Sinelobus stanfordi	not known	1943	≤1996	SF,BW
Arthropoda: Crustacea: Amphipoda				
Ampithoe valida	NW Atlantic	1941	1966	OA,SF,BW
Caprella mutica	NW Pacific	1973-77	1998	OJ,BW
Corophium acherusicum	N Atlantic	1905	1915	OA,SF
Corophium insidiosum	N Atlantic	1915	1915	OA,SF
Grandidierella japonica	NW Pacific	1966	1977	OJ,SF,BW
Jassa marmorata	NW Atlantic	1938	≤1995	SF,BW
Melita nitida	NW Atlantic	1938	1966	OA,SF,SB,BW
Bryozoa				
Bowerbankia gracilis	NW Atlantic?	≤1923	≤1953	OA,SF
Cryptosula pallasiana	N Atlantic	1943-44	1998	OA,SF
Schizoporella unicornis	NW Pacific	1927	1927	OJ,SF
Urochordata				
Botrylloides violaceus	NW Pacific	1973	1977	OJ,SF
Botryllus schlosseri	NE Atlantic	1944-47	late 1960s-1970s	OA,SF
Molgula manhattensis	NW Atlantic	1949	1998	OA,SF,BW

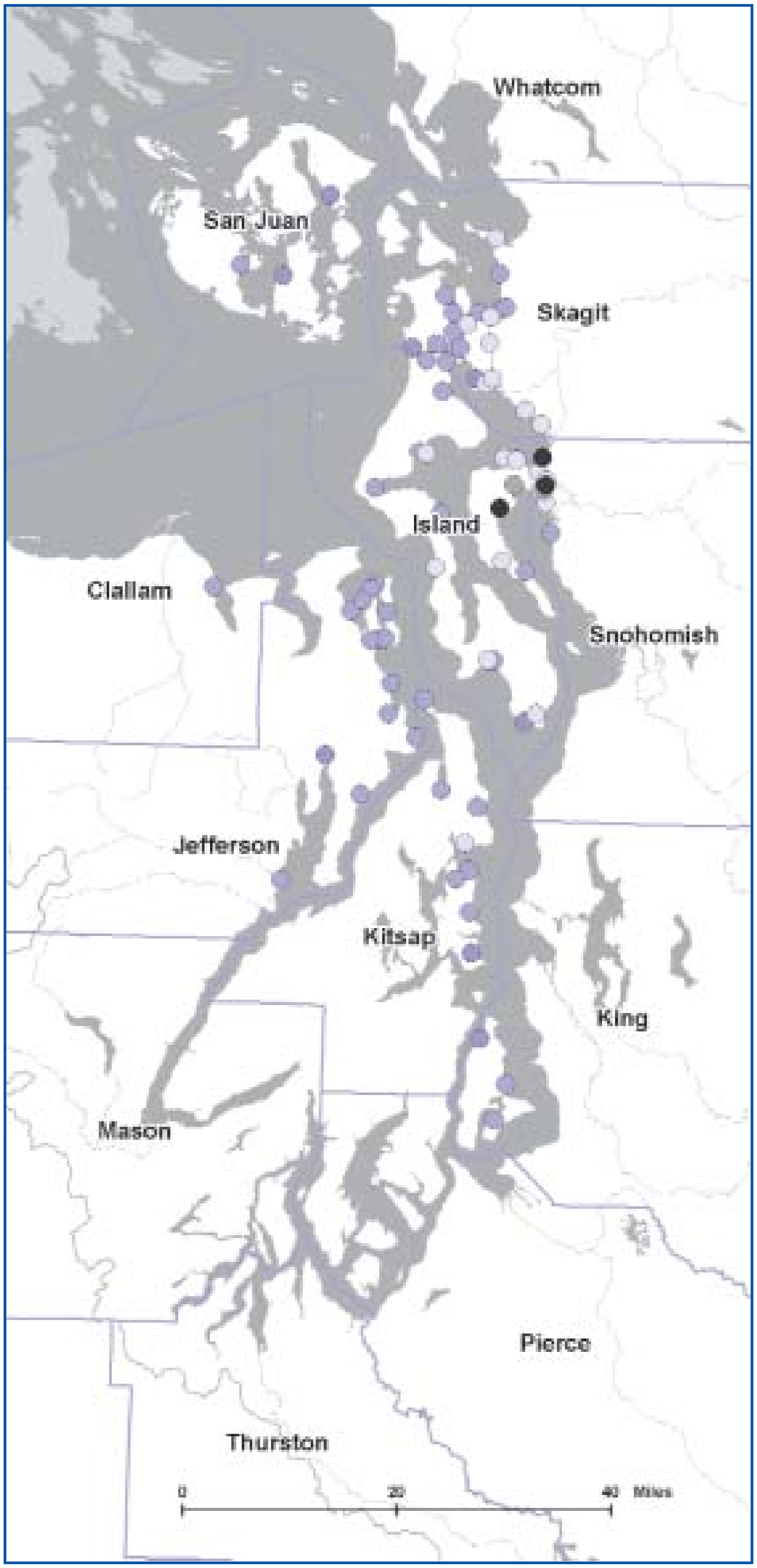


Figure 6-24. Area of *Spartina* infestations around Puget Sound, 2001.

Source: Washington State Department of Natural Resources

Green Crab

The European Green Crab *(Carcinus maenas)* is a small shore crab that is native to the Atlantic coasts of the Europe and northern Africa but has been seen in Grays Harbor and Willapa Bay since 1998. The green crab feeds on clams, other crabs, and other invertebrates. The state Department of Fish and Wildlife has an active control program on the outer coast and coordinates a monitoring network across Puget Sound to detect an invasion to the inland marine waters should it occur.

This invasive species presents a major risk to Dungeness crab, clam and oyster fisheries. The green crab may also compete with native fish and bird species for food.

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 6-24). *Spartina* has still not been found south of the Tacoma Narrows in Puget Sound.

The Washington State Department of Agriculture coordinates a *Spartina* eradication and control program. As part of this program, the department 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, private landowners and the Swinomish and Suquamish tribal communities. In addition, state 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 2001 control season, the control efforts of the Department of Agriculture and its partners have resulted in significant progress in reducing the size of the Puget Sound *Spartina* infestation (and in a few cases eradicating them). As the Department of Agriculture and collaborators such as the state Department of 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 infestations, such as south Skagit Bay, will become a bigger priority and the focus of additional funding.

The 2001 Washington State legislature appropriated more funds to the Department of Agriculture for the control of *Spartina* . With this enhanced level of funding Agriculture and its cooperators will be able to eradicate all known *Spartina* infestations in Puget Sound and Hood Canal in four years.

Acting on the Findings

The studies presented in this chapter affirm the importance of continued monitoring and the development of new monitoring studies when plant and animal populations change noticeably for unknown reasons.

Studies such as those presented here provided strong evidence supporting the strategy of basing resource management decisions on sound science. The best example lies in earlier studies that linked bald eagle decline with persistent toxic contaminants and ultimately led to the banning of these contaminants. Results of continued monitoring discussed in this chapter have affirmed this strategy by showing a decline of contaminant levels and recovery of the eagle.

The results from these monitoring studies have also led to direct management actions, especially in developing conservative harvest guidelines for groundfish and the consideration for a network of marine reserves for rockfishes and other species.

Some specific recommendations follow directly from the results of studies presented in this chapter:

- Monitoring designed to understand dynamics of stocks or populations should include organisms at a range of trophic levels in addition to the species of interest. Results have shown the importance of considering food web interactions in understanding a population in addition to direct relationships with the physical environment.
- Scientists and resource managers need to increase their focus on efforts to understand the causes underlying declining populations

where management actions have not brought expected improvements, such as with specific groundfish species.

- Scientists need to explore new techniques that may increase the scope of monitoring studies with limited funding resources. Examples include the use of remote sensing platforms (aircraft, satellite) to replace or augment ground surveys and automated instrumentation to replace manual data collection wherever possible.
- Wherever appropriate and feasible, multi-disciplinary monitoring should be employed such as coupling population surveys with collection of toxic contaminant or physical environmental data.
- Scientists need to focus on the detection of ecosystem-level changes, e.g. changes in the structure of food webs, that may not be obvious from a species or population perspective but may be fundamentally more significant.
- Since its release in 2000, The ShoreZone Inventory has been widely used by scientists and planners. More than 1,000 copies of the digital data have been distributed in response to data requests. Datasets like the ShoreZone Inventory can be used to improve resource management and land use planning. However, additional funding is needed for data distribution and support. Too often, funds are not provided because the importance of these tasks is not recognized. There is also a need for dedicated mechanisms to fund updating datasets and integrating feedback from users.
- Results presented in this chapter underscore the need for consistent long-term data on biologically relevant environmental variables that scientists can use to interpret changes in key biological populations. This type of data and subsequent analysis will be needed to help increase understanding of the influences of human-caused environmental stressors and corrective actions.

Resources

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Acronyms

CFU / cfu	Colony Forming Units. A measure of bacterium concentration.
CSL	Cleanup Screening Level. A sediment contaminant threshold.
DDT	dichlorodiphenyl-trichloroethane
ERM	Effects Range Median
ENSO	El Niño – Southern Oscillation
FAC	Fluorescing Aromatic Compounds
HCB	Hexachlorobenzene
HPAH	High [molecular weight] Polycyclic Aromatic Hydrocarbons
K	Carrying Capacity
LPAH	Low [molecular weight] Polycyclic Aromatic Hydrocarbons
MLLW	Mean Lowest Low Water
MMPA	Marine Mammal Protection Act (1972)
MNPL	Maximum Net Productivity Level
MPN	Mean Probable Number. Used to quantify fecal coliform levels.
MSMT	Marine Sediment Monitoring Team
mt	Metric Tons
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
OSP	Optimum Sustainable Population (in the context of population analysis) Oil Spill Team (in the context of toxic contaminants)
PAH	Polycyclic Aromatic Hydrocarbons
PCB	Polychlorinated biphenyls
ppDDE	para-para-dichlorophenyl-dichloroethylene; a breakdown product of DDT
PSAMP	Puget Sound Ambient Monitoring Program
PSWQAT	Puget Sound Water Quality Action Team
SQS	Sediment Quality Standards, Washington State
TPAH	Total PAH concentration
VOC	Volatile Organic Compounds
WDFW	Washington Department of Fish and Wildlife
WQI	Water Quality Index

COLOPHON

This document was written using Microsoft Word 2000 for Windows and designed in Quark 4.1 for Windows. Graphics were produced using a variety of means: Maps were generally created in ArcView 8.0 and exported as TIFs. These files were then fine tuned in Adobe PhotoShop versions 5 and 6. The cover was designed in PhotoShop as well. Graphs and charts were created in Excel and imported into Macromedia Freehand 7.0 for further formatting and saved as EPS files. Tables were originally created in Word and then placed in Quark for further formatting. The main text font is *A Garamond* and the headers and caption text are *Myriad Roman and Bold.* Colors used are Black and Pantone Matching System 2738 CVU (blue).