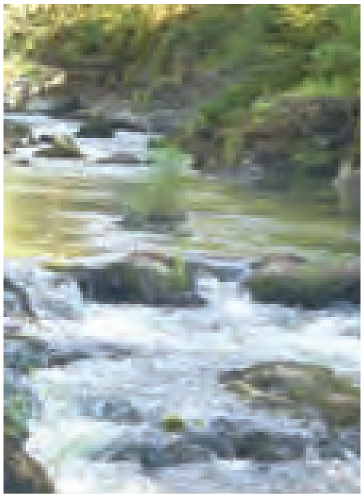
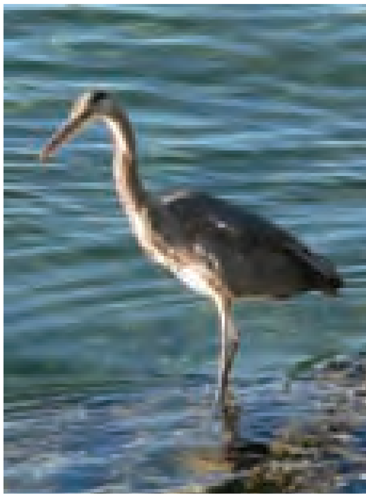
2007 Puget Sound UPDATE





Ninth report of the Puget Sound Assessment and Monitoring Program

Puget Sound Action Team
Office of the Governor | State of Washington

2007 Puget Sound
UPDATE

Ninth Report of the Puget Sound Assessment and Monitoring Program

February 2007

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Sarah Brace, WDFW scientists sampling English sole in Elliott Bay

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Back cover:

Rae Anne McNally, driftwood on beach

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Center for Whale Research, orca spyhopping

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Table of Contents

Glossary of Terms / List of Abbreviations

ANS .... Aquatic nuisance species
Aroclor .... Trade name for a particular PCB product
ASP .... Amnesic shellfish poisoning
BEACH .... Beach Environmental Assessment Communication and Health Program
Benthic .... Living on or near the ocean floor substrate
CBC .... Christmas Bird Count, National Audubon Society
CMP .... Citizen Monitoring Program
Congener .... Specific compound defined by the number and organization of chlorine (PCBs) or bromine (PBDEs) linked to a dual benzene ring core
CPS .... Central Puget Sound
CSL .... Cleanup Screening Level
CSO .... Combined sewer overflow
DDT .... dichloro-diphenyl-trichloroethane (pesticide)
Demersal .... Associated with the coast or sea floor
DIN .... Dissolved inorganic nitrogen
DO .... Dissolved oxygen
Domoic Acid .... Toxic substance released by *Pseudo-nitzschia* phytoplankton
DPS .... Distinct population segment
dw .... Dry weight
EDC .... Endocrine disrupting compound
ENSO .... El Niño Southern Oscillation
ESA .... Endangered Species Act
ESU .... Evolutionarily Significant Unit
FCB .... Fecal coliform bacteria
FOE .... Frequency of exceeding
FPI .... Fecal Pollution Index
HAB .... Harmful algal bloom
HCDOP .... Hood Canal Dissolved Oxygen Program
Infauna .... Marine organisms that live within the bottom substrate rather than on its surface
JEMS .... Joint Effort to Monitor the Straits
LOTT .... LOTT Alliance (Lacey, Olympia, Tumwater, and Thurston County)
MESA .... Marine Ecosystems Analysis
NH^4 .... Ammonium
NMFS .... National Marine Fisheries Service
NWSC .... Northwest Straits Commission
PAH .... Polycyclic aromatic hydrocarbons
PBDE .... Polybrominated biphenyl ethers, also called flame retardants
PBT .... Persistent bioaccumulative toxic
PCB .... Polychlorinated biphenyls

PDO	Pacific decadal oscillation
Pelagic	Associated with the open ocean or sea; water column
ppb	Parts per billion
ppm	Parts per million
PRISM	Puget Sound Regional Synthesis Model
PSAMP	Puget Sound Assessment and Monitoring Program
PSM	Prespawn mortality
PSP	Paralytic shellfish poisoning
SASSI	Salmon and Steelhead Stock Inventory
SPS-MEM	South Puget Sound Marine Environmental Modeling
SQS	Sediment Quality Standard
Substratum	Sea floor including sediments, rocky habitat or mud flats
SVMP	Submerged Vegetation Monitoring Program
TMDL	Total maximum daily load
TOC	Total organic carbon
WQI	Water quality index
WWU	Western Washington University
Xenoestrogens	Estrogen-mimicking compounds

Executive Summary

The *Puget Sound Update* is a technical report that summarizes the condition of Puget Sound as measured by ongoing monitoring and research activities of the Puget Sound Assessment and Monitoring Program (PSAMP). This report also includes research findings from a variety of additional monitoring and research efforts conducted by local governments, research institutions, Tribes, state and federal agencies, and citizen monitoring groups. The scope of the report is the marine and freshwater ecosystems of the Puget Sound Region focusing on water quality, toxic contamination, nearshore habitat and marine species.

The purpose of the *Puget Sound Update* is to:

- Share information among scientists engaged in Puget Sound.
- Provide a concise summary of scientific information that policy-makers can draw upon for actions to protect, conserve and restore Puget Sound's natural resources.
- Provide recommendations for action based on the science, and to serve as the basis of scientific information for the *State of the Sound* report (see box below).

The key audiences for the *Update* are resource managers, planners, scientists, educators, staff to elected officials and the interested public.

Puget Sound reports

Every two years, the Puget Sound Action Team produces a *State of the Sound* report highlighting indicators that reflect the condition of Puget Sound's water and submerged lands, habitats, and species, and threats to those resources. The document also reports the progress of the Puget Sound Action Team partner agencies to improve Puget Sound's health through management activities focused on improving water quality, habitat and species. The *State of the Sound*, published in January 2007, includes status and trend information drawn directly from the *Puget Sound Update* and other technical reports. The key audiences are state legislators and other elected officials, resource managers at all levels of government, the business and non-profit communities and the interested public.

The *Sound Science* document is a one-time, state-of-the-science document produced in 2007 by a broad group of scientists from Federal, state, local, and tribal governments and academia. The report summarizes what is known about the greater Puget Sound ecosystem including the terrestrial, freshwater and marine environments (e.g. species, food web structure, ecosystem processes, habitats, ecosystem services), explores the biological, chemical, and physical linkages between those elements, and provides analysis of how future changes in climate and human population growth might impact the functions provided by the Puget Sound ecosystem. The key audiences are scientists, resource managers at all levels of government, the business and non-profit communities, and the interested public.

The following are highlights from the *2007 Puget Sound Update*. They are grouped by topic. The information summarized represents key findings of PSAMP and other monitoring and research programs since the previous edition of the *Puget Sound Update* (2002).

Biological Resources

- Nearly 60 percent of groundfish stocks in Puget Sound are in good condition. Those in decline include middle-trophic-level predators such as **rockfishes**, **spiny dogfish**, **Pacific cod,** and **Pacific hake**.
- Spawning potential for **copper and quillback rockfish** dropped by nearly 75 percent between 1970 and 1999, and more recent information confirms a continued decline.
- Across Puget Sound, estimates of **herring** spawning biomass have varied from year to year but most stocks have declined in the last five years. In 2002, the combined biomass of Puget Sound herring stocks was estimated at 17,700 tons. In 2004, that figure dropped to about 11,000 tons—a decrease of about 40 percent. In 2006, biomass estimates are 12,000 tons.
- Southern resident **orcas** were listed on the federal endangered species list in 2005. The population currently consists of 86 whales, down from a peak of 98 in 1975.
- **Surf scoters, white-winged scoters,** and **black scoters** have collectively declined by approximately 57 percent between 1978 and 1999. This decline has continued from 1999 through 2005 in nearly all of the subregions of Puget Sound. The decrease in scoters represents the largest decline in biomass of marine birds over the last 25 years in Puget Sound.
- **Loons** and **grebes** that over-winter in Puget Sound have declined from 64 to 95 percent over the past 25 years. It is unknown whether this reflects declines in the overall populations or whether birds are over-wintering outside of Puget Sound.
- Native **eelgrass** has declined in Hood Canal for four consecutive years since 2001. The San Juan Archipelago has experienced declines in small embayments; in 11 embayments approximately 83 acres of eelgrass were lost between 1995 and 2004.
- **Sea lions** have become more abundant in Washington waters. The California sea lion populations have increased by about 5 percent annually, with a current population of 4,000 - 5,000 animals. Steller sea lions are also increasing in population by about 10 percent annually. Surveys conducted in 2005 of steller sea lions during peak abundances in fall and winter recorded 1,000 - 1,500 sea lions along Washington's outer coast. This species also regularly inhabits North Puget Sound.
- **Harbor seals** have been steadily increasing in population since the early 1970s, with current populations consisting of 16,000 seals along the outer Washington Coast and 14,000 in the inland waters of Puget Sound.
- The **pinto abalone**, a once fairly abundant native species in Hood Canal, north Puget Sound and the San Juan Islands, appears to be critically depressed and in such low abundance that

this species may be unable to naturally reproduce. In the San Juan Archipelago, between 1992 and 2005, abalone have declined from 351 animals to 103 animals at 10 long-term monitoring stations.

Physical Environment and Habitat

- The Pacific Ocean off the west coast of the U.S. experienced two unusual conditions in 2005 — a winter-like colder state that persisted through mid-July, followed by ocean warming that resembled a large El Niño event. The biological impacts of these alternating atypical ocean conditions in 2005 were significant. Zooplankton stocks were reduced by one half, salmon returns weakened, and sea bird deaths were extraordinarily high among common murre, cormorant, and Cassins' auklet populations. Several subtropical species, such as albacore tuna and Humboldt squid, became common in the offshore shelf waters.
- During the 20th century, the global average **air temperature** rose by approximately 1.1 degrees F (0.6 degrees C). In Puget Sound, the average temperature doubled the global average, increasing by 2.3 degrees F (1.3 degrees C) during the same period.
- Average global **sea surface temperature** has increased by 1.7 degrees F (0.9 degrees C) since 1921.
- Hood Canal, Budd Inlet, Penn Cove, Saratoga Passage, and Possession Sound are locations of highest concern, based on Ecology's **index of water quality** for Puget Sound. Eleven other areas are of high concern.
- Overall **dissolved oxygen** (DO) concentrations in Puget Sound appear to be continuing a downward trend. Very low DO was observed at 14 stations, seven of which had higher DO concentrations in the period from 1998 to 2000. Another seven stations with previously high DO concentrations experienced low DO during 2001-2005.
- **Hood Canal DO** levels measured during 2004 were at the historical low point for any recorded observations. Comparing oxygen data from 1930 through the 1960s with data from 1990 to 2006 shows that, in recent years, the area of low dissolved oxygen is getting larger and spreading northwards. Periods of hypoxia are persisting longer through the year.
- **Tidal wetland** losses were documented throughout Puget Sound and at present, approximately 82 percent of the historic extent of tidal wetlands in the region have been lost to development and other land uses.

Toxic Contamination

- Analysis of samples collected 1997-2003 indicate that approximately 1 percent of Puget Sound **sediments** are highly degraded, 31 percent are of intermediate quality, and 68 percent are of high quality. The 1 percent of highly degraded sediments are located primarily in urban bays.

- Chinook salmon sampled from Puget Sound in 2005 have three to five times the **PCB** levels of chinook from Alaska, British Columbia, and Oregon.
- Flame retardants, or **polybrominated diphenyl ethers** (PBDEs) occurred in 17 percent of sediment sites sampled in Hood Canal in 2004 and were detected in 16 percent of samples from 10 Puget Soundwide sediment sampling sites in 2005.
- **PBDEs** are now second to PCBs in order of importance in the Puget Sound food web. PBDEs in English sole from urban areas are almost 10 times higher than those levels measured in sole from the Georgia Basin. Herring from Puget Sound have nearly three times the levels of PBDEs in Georgia Basin herring. Harbor seals from Puget Sound have over twice the PBDEs found in seals near Vancouver, BC. Scientists estimate that PBDE levels are doubling every four years in marine mammals, including harbor seals and orcas, and will surpass PCB levels in these species by 2020.
- In Puget Sound sediments, **polycyclic aromatic hydrocarbons** (PAHs) have not changed significantly over the past decade, except in Bellingham Bay, Port Gardner, and Anderson Island, where levels have increased. Point Pully (in central Puget Sound) had a significant decrease in PAHs during this same period.
- In Dungeness crab sampled between 1998-2005, **PAH** exposure was six times higher in urban areas than in non-urban areas. English sole had three to four times the PAH exposure in urban areas, compared to non-urban areas.
- English sole from Elliott Bay and the Thea Foss Waterway currently have four to six times the risk of developing liver lesions, (typically associated with **PAH** exposure), compared to sole from Hood Canal or the Strait of Georgia.
- Six **endocrine-distrupting compounds** (bisphenol A, estradiol, ethynylestradiol, and three phthalates) were detected in 20 percent of samples from surface water locations in King County's lakes, rivers, streams, and stormwater discharges collected in a pilot study in 2003.
- Male English sole from several Puget Sound locations (including 30 percent of males sampled in Elliott Bay) are producing an egg-protein (vitellogenin) normally found only in female fish. This finding suggests that these fish have been exposed to **endocrine-disrupting compounds**.
- **Pre-spawn mortality** occurred in 25 to 90 percent of female coho salmon returning to urban streams in the Puget Sound region between 2002 and 2005, suggesting that contaminants from stormwater are posing a threat to the spawning success of salmon in urban streams.

Pathogens and Nutrients

Fresh Water

- In Ecology's 2004 Water Quality Assessment, 58 freshwater sites were identified with **DO** problems in Puget Sound because of excessive nutrients (phosphorus and nitrogen) in the streams. Nutrients sources include drainage from agricultural, forestry, and residential activities and other sources.
- Twenty-five of 38 freshwater stations were scored "Good" according to the **total nitrogen** Water Quality Index. Ten stations scored "Fair." Three stations (in Hood Canal and on the Deschutes River near Olympia) scored "Poor."
- In 2005, freshwater stations were nearly equally divided between "**Good"** and "**Fair"** for **phosphorus** and were stable in water years 2000 through 2005.
- The WQI for **fecal coliform** rated "Good" at 28 of 38 freshwater streams for fecal pollution. The remainders were "Fair." Fecal conditions appear to be stable since 2000.

Marine Water

- Hood Canal, Budd Inlet, Penn Cove, Saratoga Passage, and Possession Sound are locations of highest concern, based on Ecology's **index of water quality** for Puget Sound.
- Stations in Hood Canal, Penn Cove, Possession Sound, and Saratoga Passage had very high sensitivity to **eutrophication,** suggesting that these locations are at greatest risk for further declines in water quality, due to human additions of nutrients.
- The most recent Water Quality Assessment lists 76 water bodies in Puget Sound with **fecal coliform** problems. However, fecal coliform data collected at marine ambient stations suggest a general decline in fecal coliform contamination from 2001 through 2005. The highest levels of fecal contamination occurred in Budd Inlet, Commencement Bay, Elliott Bay, and near West Point (north of Elliott Bay), Possession Sound, and Port Angeles harbor.
- DOH determined that 31 of 98 shellfish growing areas in Puget Sound experienced significant **fecal pollution** in 2005. Those with the greatest impact were Drayton Harbor, Dungeness Bay, and Henderson Inlet. Samish Bay and Burley Lagoon show no evidence of change in fecal pollution since 2002.
- Between 1995 and 2005, over 12,500 acres of **shellfish growing areas** were upgraded and 5,000 acres were downgraded, for a net increase of 8,500 acres. As a result of Kitsap County's Pollution Identification and Correction Program, parts of four shellfish harvest areas have been cleaned up and reopened for harvest; Burley Lagoon, Cedar Cove (part of Port Gamble), Illahee State Park, and Dyes Inlet.
- Twenty percent of 428 recreational beaches in 12 Puget Sound counties are threatened by **fecal pollution**. Five percent of these beaches are closed because of **biotoxins**. Within King County, trends at 21 recreational beaches indicate that **fecal pollution** has declined since 1997. Ecology's Beach Environmental

Assessment, Communication and Health (BEACH) Program indicates that central Sound beaches typically have the highest measured bacterial pollution, most notably in Dyes and Sinclair Inlets.

- Eighteen of 29 **paralytic shellfish poisoning** (PSP) sampling sites (62 percent) had at least some PSP impact in 2005. Burley Lagoon ranked highest in PSP impact in 2005. The year 2003 appeared to be lowest in PSP activity throughout Puget Sound.
- In 2003, a short-lived ***Pseudo-nitzschia*** bloom occurred at Fort Flagler near Port Townsend. Mussels from the sentinel monitoring cage contained domoic acid slightly above the U.S. Food and Drug Administration's (FDA's) action level, and DOH closed the area to shellfish harvest. In October 2005, *Pseudo-nitzschia* blooms occurred at four places in north Puget Sound (Sequim Bay, Port Townsend, Holmes Harbor, and Penn Cove). Several shellfish species were affected. All four areas were closed to shellfish harvest.

1 Introduction

Northern Puget Sound near Anacortes and Mt. Baker. | *Shutterstock.com | Natalia Bratslavsky*

This is the ninth edition of the *Puget Sound Update*, a report first published by the Puget Sound Action Team in 1990. The *Puget Sound Update* summarizes the condition of Puget Sound as measured by ongoing monitoring and research activities of the Puget Sound Assessment and Monitoring Program (PSAMP). This report also includes research findings from a variety of additional monitoring and research efforts, conducted by local governments, research institutions, Tribes, state and federal agencies, and citizen monitoring groups. The purpose of the *Puget Sound Update* is to communicate the scientific understanding of the Puget Sound ecosystem, and the consequence of human and natural stressors on the Sound's physical and biological resources.

Since the previous edition of the *Puget Sound Update* was released in 2002, considerable attention has been focused on the condition of the nation's marine waters. The findings recently reported by the U.S. Commission on Ocean Policy (in 2004) and the Pew Oceans Commission (in 2003) suggest that many of the nations estuary, bays, and deep ocean waters are under severe stress from human activities, including over-harvest of marine species for consumption, development along sensitive coastal areas, and inputs of toxic contaminants from industry and urban runoff. In Puget Sound, Governor Chris Gregoire has placed Puget Sound high on her list of priorities by setting a goal of restoring Puget Sound's health by 2020. The roadmap for achieving this goal was presented to the Governor in the fall of 2006 by a group of high-level policy-makers, community leaders, and stakeholder representatives known as the Puget Sound Partnership.

Oceans and Human Health – A Context for this Report

Oceans are critical components of the earth's ecosystems and are explicitly linked with human health in a variety of ways. The oceans are the source of most of the world's biodiversity, as well as the largest producers of biomass. Oceans generate weather patterns, provide food for human populations, and play key roles in controlling greenhouse gases. However, these large bodies of water are also repositories for a wide range of compounds released into our waters and atmosphere, particularly near coastal urban centers. Releases of natural and man-made compounds as a result of human activities can seriously impact the oceans' ecosystems, which, in turn, can affect the health of the living marine resources on which humans rely. It is important to increase our understanding of these interactions in order to identify, predict, and lessen serious impacts to public health.

Humans are top-level consumers of marine fish and seafood and, as such, can be exposed to man-made toxics via consumption of contaminated marine organisms. These toxic compounds include industrial chemicals (e.g., PCBs, flame retardants), pesticides (e.g., DDTs), metals, and many other new contaminants of concern (e.g., pharmaceuticals, personal care products). Exposure to these toxic contaminants has been linked to immune suppression, reproductive failure, and other biological effects in mammals. Relatively high levels of these compounds occur in urban coastal environments. Humans can also be exposed to a variety of naturally occurring pathogens, capable of causing human disease, that exist in the marine environment in fish and shellfish. Human activities can also exacerbate the pathogens occurrences; many pathogens in estuaries and oceans are a result of human activities, including poor sanitation, inadequate water treatment practices, and agricultural runoff. Thus, the transmission of infectious disease and exposure to natural and man-made toxics are some of the current pathways by which ocean factors can negatively impact the health of humans.

Oceans may also provide information about current and potential impacts to public health, through examination of how toxins and pathogens affect marine organisms. Sentinel species, such as marine mammals, birds, and fish, can serve as important indicators of the status and trends in ocean health, and the observation and study of appropriate marine organisms can lead to a better understanding of potential public health risks.

The Puget Sound Assessment and Monitoring Program

When the first edition of the Puget Sound Update was published, PSAMP had been in existence only two years, and the report summarized only one or two years' worth of data. Now, 16 years later, PSAMP is one of the country's longest-running marine monitoring programs, with trend information from many components extending back to the first year of data collection. PSAMP has become a model program for monitoring the status and trends of many national and international estuaries and coastal areas.

The agencies and institutions that participate in PSAMP and their areas of focus include:

- Washington State Department of Ecology (Ecology)
  Marine sediment, marine water, and fresh water
- Washington State Department of Fish and Wildlife (WDFW)
  Contaminants burdens in marine fish, population abundance of fish, marine birds, and mammals
- Washington State Department of Natural Resources (DNR)
  Nearshore habitat, kelp and eelgrass
- Washington State Department of Health (DOH)
  Nearshore marine water quality, shellfish growing areas
- King County Department of Natural Resources and Parks (KC DNRP)
  Marine water, marine sediments, and shellfish
- U.S. Fish and Wildlife Service (USFWS)
  Bird abundance and contaminants

- Northwest Fisheries Science Center (NFSC), National Oceanic and Atmospheric Administration
  Contaminant burdens in marine fish, toxicology of contaminants
- University of Washington, Applied Physics Laboratory (UW APL)
  Marine water, modeling
- U.S. Environmental Protection Agency (EPA)
  Technical and programmatic support, sponsorship of targeted research studies
- Puget Sound Action Team (PSAT)
  Coordination of PSAMP activities and management

Scope and Structure of this Report

The *Puget Sound Update* is a technical report that integrates results of PSAMP and other scientific activities in Puget Sound focused on marine life and nearshore habitat, marine and freshwater quality, and toxic contamination. The report contains summary information on status and trends, as well as findings from focused studies, but does not include methodologies and analytical details found in agency reports or peer-reviewed publications. The target audience for this report is resource managers, scientists, decision-makers, and interested citizens.

The goal of the *Puget Sound Update* is to provide a clear summary of monitoring and research findings so that readers can evaluate the current condition of Puget Sound as well as understand how the water quality, sediments, and biological resources have changed over time. It is also expected that *Puget Sound Update* findings will be integrated into management activities aimed to protect, conserve, and restore Puget Sound's ecosystem.

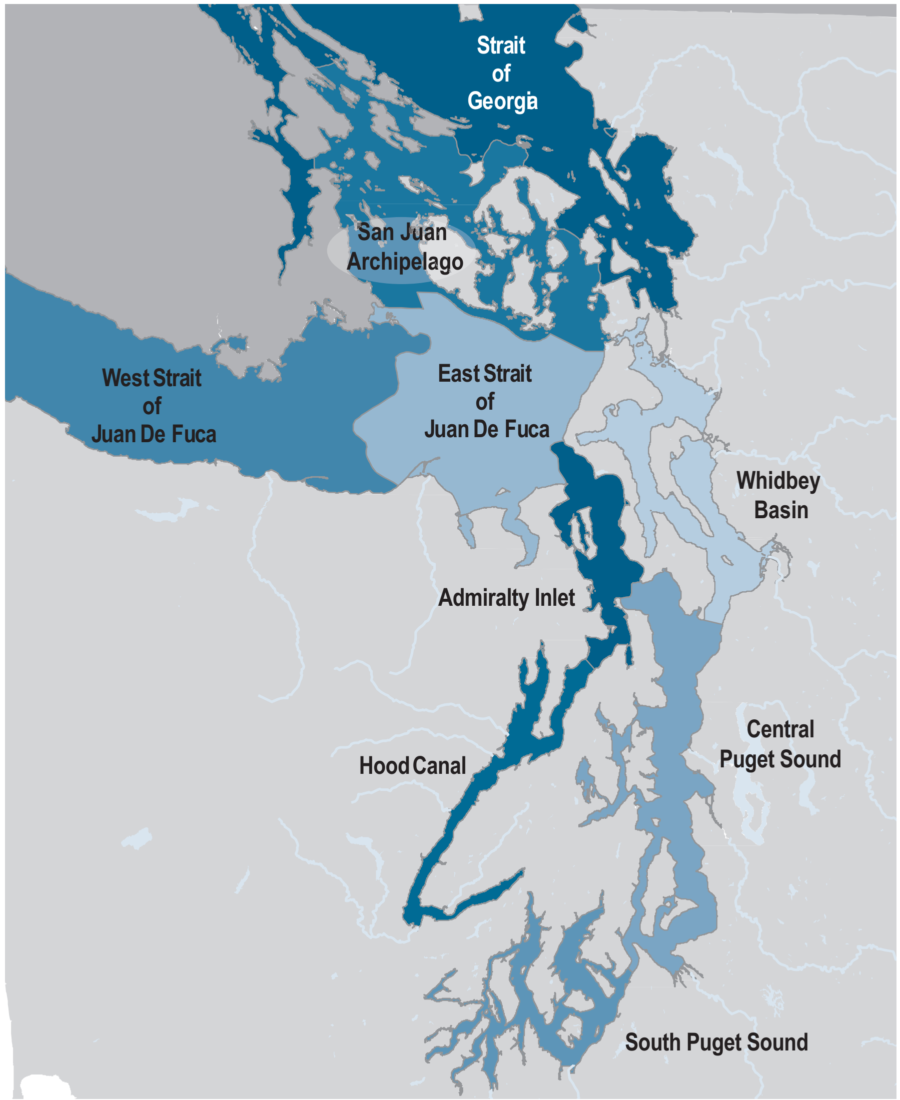
This edition of the *Puget Sound Update* is organized into four main topics:

- Biological Resources
- Physical Environment and Habitat
- Toxic Contaminants
- Nutrients and Pathogens

The breadth of spatial coverage in each chapter encompasses the greater Puget Sound Region, including Hood Canal and the San Juan Archipelago. To develop a common basis for monitoring and reporting, PSAMP has delineated six main basins in Puget Sound. From the north, the basis are: San Juan Archipelago, the Strait of Juan de Fuca, North Puget Sound (Whidbey Basin and Admiralty Inlet), Central Puget Sound, Hood Canal, and South Puget Sound (Figure 1-1). In some basins, the boundaries coincide with sills; for others, the demarcation is arbitrary. The report also includes data from studies where the range of sampling sites extend into the Strait of Juan de Fuca, the outer Washington Coast, or the Strait of Georgia.

Each chapter begins with an introduction to the topic and lists key findings from the information within the chapter. In some instances, topics are shared between chapters, in which case, cross-references are noted within the text. The status and trends of each topic are summarized and the ecological and human health implications of the findings are reported, when information was available. Each chapter concludes with recommendations that summarize data gaps and research needs, and provides recommended targets or goals for consideration by management when planning future research and monitoring activities.

Figure 1-1. Puget Sound and the six PSAMP basins referred to throughout this report.



2 Biological Resources

A cormorant dries its wings. | *Mike Yip*

1. Overview

Puget Sound's biological resources include all living organisms that inhabit the marine waters and shorelines. These resources are plankton, invertebrates, fish, birds, mammals, and aquatic vegetation, including species that are either residential or migratory.

Significant changes in the biological communities of Puget Sound have occurred in the past 30 years, including declines in forage fish, salmonids, bottomfish, marine birds, and orcas. These changes have not gone unnoticed, resulting in restricted and closed fisheries, petitions to list species under state programs and the federal Endangered Species Act (ESA), and development of recovery and management plans for several species. Coordinated efforts by PSAMP and other monitoring and research programs have been underway to evaluate the declines, identify the stressors affecting the populations, and develop actions and solutions to stem the declines and begin rebuilding populations of species at risk.

Many stressors are affecting or have affected biota in Puget Sound in ways that we are only beginning to understand. These include climate change, toxic contamination, eutrophication (low oxygen due to excess nutrients), and nearshore habitat alteration.

This chapter characterizes what is known about the many biological components of the Puget Sound ecosystem and, when possible, provides information about the status and trends of each resource. Where appropriate, the factors that limit or enhance the biological component will be identified, discussed, and linked with other sections of the *Puget Sound Update*.

Our knowledge of the Puget Sound ecosystem is still developing. While this section presents species-specific information on status and trends, sophisticated models of trophic, demographic, and population stressors that link the different components of the ecosystem are only beginning to be developed. In time, scientists will be able to predict the impact of stressors, understand natural variation, and link peaks and valleys of one species with those of others. The information presented in this section, however, does represent the most comprehensive look ever taken at Puget Sound biological resources.

Key findings from this chapter include:

- Nearly 60 percent of groundfish stocks in Puget Sound are in good condition. Those in decline include middle-trophic level predators such as **rockfishes**, **spiny dogfish**, **Pacific cod,** and **hake**.
- Spawning potential for **copper and quillback rockfish** dropped by nearly 75 percent between 1970 and 1999, and more recent information confirms a continued decline. Although the overall number of groundfish has not changed significantly in the last few decades, many popular harvest species have sharply declined while others have increased.
- The total Pacific herring spawning biomass from Puget Sound's 19 stocks decreased between 2002 and 2005, and increased in 2006. The Cherry Point stock in North Puget Sound has experienced a dramatic decrease since a high of 12,000 tons in 1976, a low of only 800 tons in 2000, followed by a gradual increase to 2200 tons in 2006.
- Southern resident **orcas** were listed on the federal endangered species list in 2005. The population currently consists of86 whales, down from a peak of 98 in 1975.
- **Surf scoters, white-winged scoters,** and **black scoters** have collectively declined by approximately 57 percent between 1978 and 1999. This decline has continued from 1999 through 2005 in nearly all of the subregions of Puget Sound. The decrease in scoters represents the largest decline in biomass of marine birds over the last 25 years in Puget Sound.
- **Loons** and **grebes** that over-winter in Puget Sound have declined by nearly 75 percent over the past 10 years. It is unknown whether this reflects declines in the overall populations or whether birds are over-wintering outside of Puget Sound.
- Native **eelgrass** has declined in Hood Canal for four consecutive years since 2001. The San Juan Archipelago has experienced declines in small embayments. In eleven embayments approximately 83 acres of eelgrass were lost between 1995 and 2004.
- **Sea lions** have become more abundant in Washington waters. The California sea lion populations have increased by about 5 percent annually, with a current population of 4,000 - 5,000 animals. Steller sea lions are also increasing in population, by about 10 percent annually. Surveys conducted in 2005 of steller sea lions during peak abundances in fall and winter recorded 1,000 - 1,500 sea lions along Washington's outer coast. This species also regularly inhabits North Puget Sound.

- **Harbor seals** have been steadily increasing in population since the early 1970s, with current populations consisting of 16,000 seals along the outer Washington Coast and 14,000 in the inland waters of Puget Sound.
- The **pinto abalone**, a once fairly abundant native species in Hood Canal, north Puget Sound and the San Juan Islands, appears to be critically depressed and in such low abundance that this species may be unable to naturally reproduce. In the San Juan Archipelago, between 1992 and 2005, abalone have declined from 351 animals per site to 103 animals per site at 10 long-term monitoring stations.
- Restoration of the **Olympia oyster**, a native shellfish species, has been successful in expanding the oyster's historic range in Puget Sound.
- Results from monitoring **marine reserves** in Puget Sound have shown that, within a decade, lingcod have become abundant and, as top predators, are keystone species that help characterize the trophic and ecological structures of rocky habitats.

2. Species of Concern

Species of concern are native species that warrant special attention to ensure their conservation. Within the Puget Sound region, the state of Washington and the federal government assess which species require special initiatives to ensure protection and survival of their populations. A recent study (Gaydos 2004) identified 47 marine species of concern in the Puget Sound—three invertebrates, 23 fishes, one reptile, 11 birds, and nine mammals (Table 2-1). (A full list of federal and state listed species is contained in Appendix A). In status reviews conducted for the 14 species listed as threatened or endangered by Washington state or the federal government, contaminants, habitat loss, and over-harvest were the most frequent causes cited for species declines.

	Washington State	U.S.A.	TOTAL
Invertebrates	3	2	3
Fishes	23	6	27
Reptiles	1	1	1
Birds	11	7	23
Mammals	9	4	9
Total	47	20	63

Table 2-1. Total number of species of concern in Washington, listed by state and federal government.

3. Plankton

Plankton are single-celled and multicellular organisms that float in the water and are the basis of the marine food web. While some are mobile, most plankton species are dispersed by the action of tides and currents. There are two major types of plankton: phytoplankton and zooplankton.

Phytoplankton are microscopic plants that contain chlorophyll-*a*, the main pigment involved in photosynthesis, and draw energy from sunlight and nutrients in the water column. They are comprised mainly of diatoms and dinoflagellates, with diatoms accounting for most of the phytoplankton biomass in Puget Sound.

Glowing plankton

Named for its ability to bioluminesce, or glow, at night, *Noctiluca scintillans* is a large dinoflagellate species. *Noctiluca sp*. is not photosynthetic, because it has no pigments of its own, but obtains the pigment from the phytoplankton it feeds on. This organisms belongs to the group of red tide-forming organisms, but unlike some red tides, it does not produce toxins and is not harmful to humans or marine organisms. However, when large blooms start to decay, they can deplete oxygen in the water column to levels where fish and other organisms become stressed or die. In daylight, large accumulations of *Noctiluca* appear to be orange-red to rust brown, resembling tomato soup. For several weeks during late spring or early summer, this organism is often found in Central Puget Sound.

Under certain conditions, phytoplankton can form large accumulations, referred to as blooms. Daily plankton productivity rates in Puget Sound are among the highest of West Coast estuaries (Emmett et al. 2000). Diatoms dominate phytoplankton populations in fall and winter and during spring blooms, while dinoflagellates become more abundant in spring and summer.

Zooplankton are the animal components of the plankton and include invertebrates such as crustaceans and jellies, as well as fish larvae. Zooplankton are not photosynthetic and generally consume other plankton species. Phytoplankton and zooplankton are critical components of Puget Sound's food web, but their distributions, abundances, and life histories are not well understood.

a. Phytoplankton

Phytoplankton levels in Puget Sound vary, depending on the time of year, and are driven mainly by light and nutrient availability. When the ideal combination of conditions exists, plankton blooms can occur. Such blooms can last from days to weeks. The geographic distribution and abundance of phytoplankton is linked to nutrient upwelling, river runoff, stratification, mixing of surface waters, and wind—all important factors in providing nutrients for plankton growth. These conditions also influence the duration (or residence time) of plankton blooms within a basin. For example, at the Tacoma Narrows, the upwelling of nutrients to surface waters caused by tidal mixing helps support the high productivity of the Central Puget Sound Basin. Remixing of the upper water layer into deeper waters in Admiralty Inlet causes an increase in chlorophyll and a decrease in nutrients at depth in this area (Boss et al. 1998).

Factors such as turbidity, surface water mixing, and zooplankton abundance also influence the occurrence of phytoplankton blooms. The annual productivity of Elliott Bay, for example, has been estimated to be about two-thirds less than the rest of the Central Basin (Strickland 1983) because of turbidity and short residence times when there are high freshwater flows from the Duwamish River. When the freshwater flow from the Duwamish River is low, large blooms can occur because residence time of water in Elliott Bay is longer, allowing an opportunity for phytoplankton to accumulate (Strickland 1983). This pattern is typical of other Puget Sound embayments that have significant seasonal freshwater inputs.

Status and Trends

King County and Ecology conduct monthly water column measurements throughout Puget Sound to estimate chlorophyll-*a* concentrations. Although phytoplankton growth and abundance varies in geographic location and timing from year to year, most large phytoplankton blooms[1] typically occur from April through July, although large blooms can occur in late winter and late summer/early fall[2] (Figure 2-1). For example, in 2005, an April bloom at the King County monitoring stations appears to have been due to early stratification of the water column caused by warm air temperatures and lack of cloud cover. In contrast, the absence of a fall bloom in September 2004 may be attributed to lower-than-normal water and air temperatures compared to the past 30-year average.

[1]Bloom is defined as chlorophyll-*a* > 10 mg/l

[2]For this analysis, a large bloom is defined by waters having chlorophyll-*a* concentrations ≥10 µg/L

The timing of phytoplankton blooms at stations sampled repeatedly by PSAMP over the past five years (Figure 2-1) show that, in most years, the greatest numbers of blooms occurred in May and June; however, there was considerable inter-annual variability with maximum numbers of blooms also occurring in April, July, and August. Prolonged phytoplankton blooms can have important ecological consequences, because the increased production can drive reductions in the dissolved oxygen available to organisms living at depth. For example, the high number of months in which blooms have occurred in south Hood Canal in recent years may be responsible for lengthening the seasonal period of low dissolved oxygen. Similarly, locations such as Budd Inlet, Penn Cove, Possession Sound, Saratoga Passage, Bellingham Bay, and South Admiralty Inlet, which also are prone to low dissolved oxygen, had blooms in seven or more months of the year.

Harmful algal blooms

Harmful algal blooms (HABs) in Puget Sound are those that can cause Paralytic Shellfish Poisoning (PSP) and Amnesic Shellfish Poisoning (ASP). The region's first recorded PSP incident occurred in June 1793, when four crewmen with Captain Vancouver's expedition became sick and one died shortly after eating shellfish along the central coast of British Columbia. In Puget Sound, the poison that causes PSP is saxitoxin, produced by the dinoflagellate *Alexandrium catenella*. (See Chapter 5, section 4, for additional information on HABs.)

b. Zooplankton

Zooplankton can be divided into microzooplankton and macrozooplankton, based on size. Copepods and crustacean larvae dominate the mircozooplankton of the Central Puget Sound Basin (Hebard 1956); jellyfish, salps, and ctenophores dominate the macroplankton. The latter prey upon copepods and ichthyoplankton (fish larvae) and can be important in controlling the populations of their prey species.

Planktonic food web structure is important to the support of culturally and commercially important fish. The diets of salmon species have been well defined for Puget Sound. Pink and chum salmon move offshore and shift to pelagic prey once they reach a length of 1.9 inches (50 mm) to 2.5 inches (60 mm). Pinks and chums, in turn, fall prey to juvenile coho salmon, steelhead, and sculpins. Juvenile chinook and coho salmon have a larger and more diverse prey spectrum, including terrestrial insects, invertebrate plankton, and epibenthos (organisms that live on or in the sea-floor sediments), and progressing to include juvenile fishes. In turn, these fish fall prey to larger fishes, including sockeye salmon, steelhead, and cutthroat trout (Dexter et al. 1981). Forage fishes, such as herring, sand lance, and smelt, also depend upon zooplankton for food, often forming dense schools at tidal fronts (rip-tides) where plankton becomes concentrated. Larger salmon, dogfish, seabirds, and other predators take advantage of these zones and concentrate the forage fish into tight schools—or bait balls—and feeding frenzies ensue.

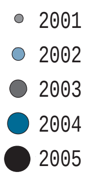
4. Aquatic Vegetation

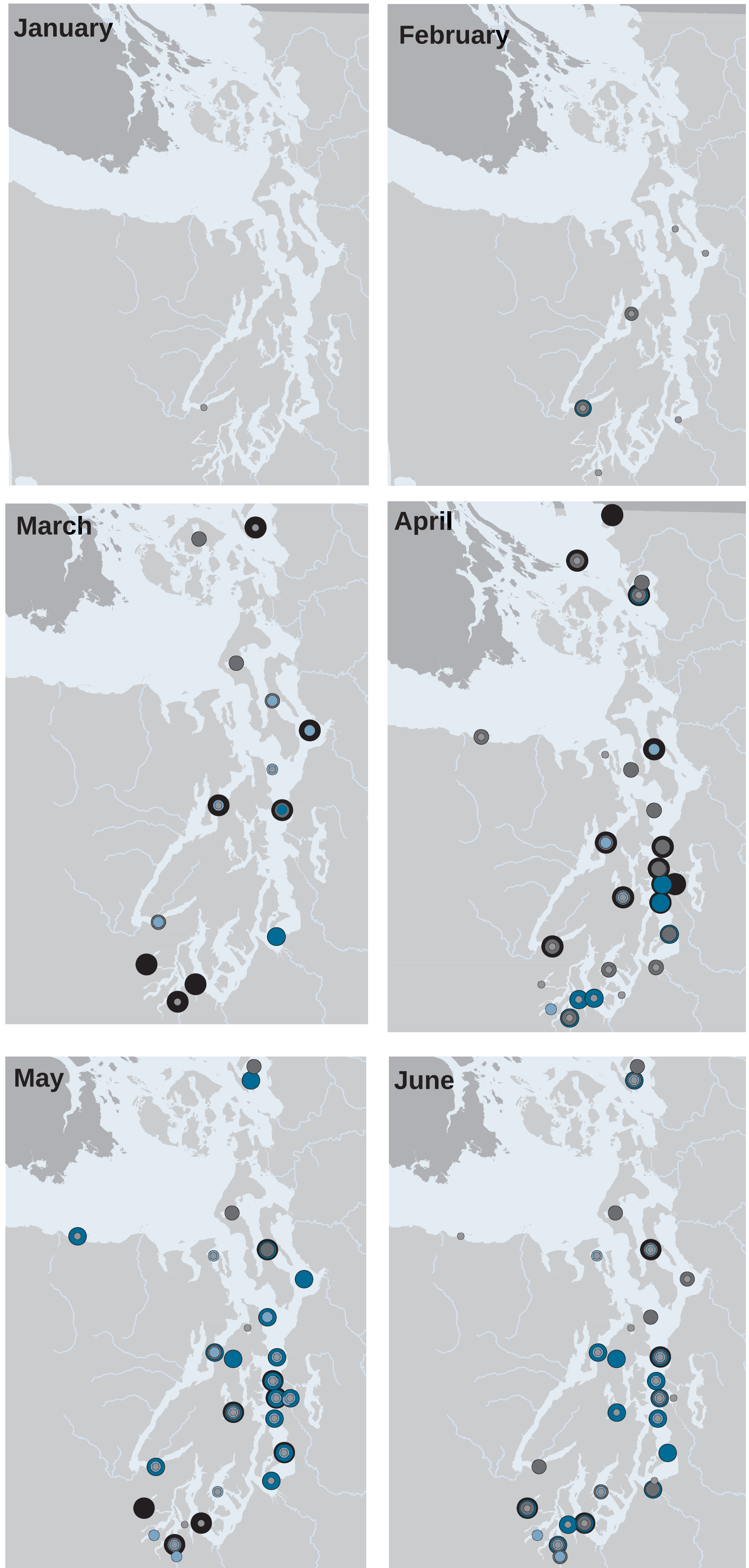
Aquatic vegetation is a key component of the nearshore environment that supports the ecosystem through primary production and by providing habitat to numerous species of fish, invertebrates, birds, and mammals. Puget Sound is home to a diverse assemblage of aquatic plants and algae, each with unique habitat requirements. Major threats to submerged aquatic vegetation include physical disturbance, loss of water clarity, and excessive nutrients. Known to be important ecosystem components that are sensitive to anthropogenic stressors, eelgrass and kelp species are commonly recognized indicators of aquatic vegetation health.

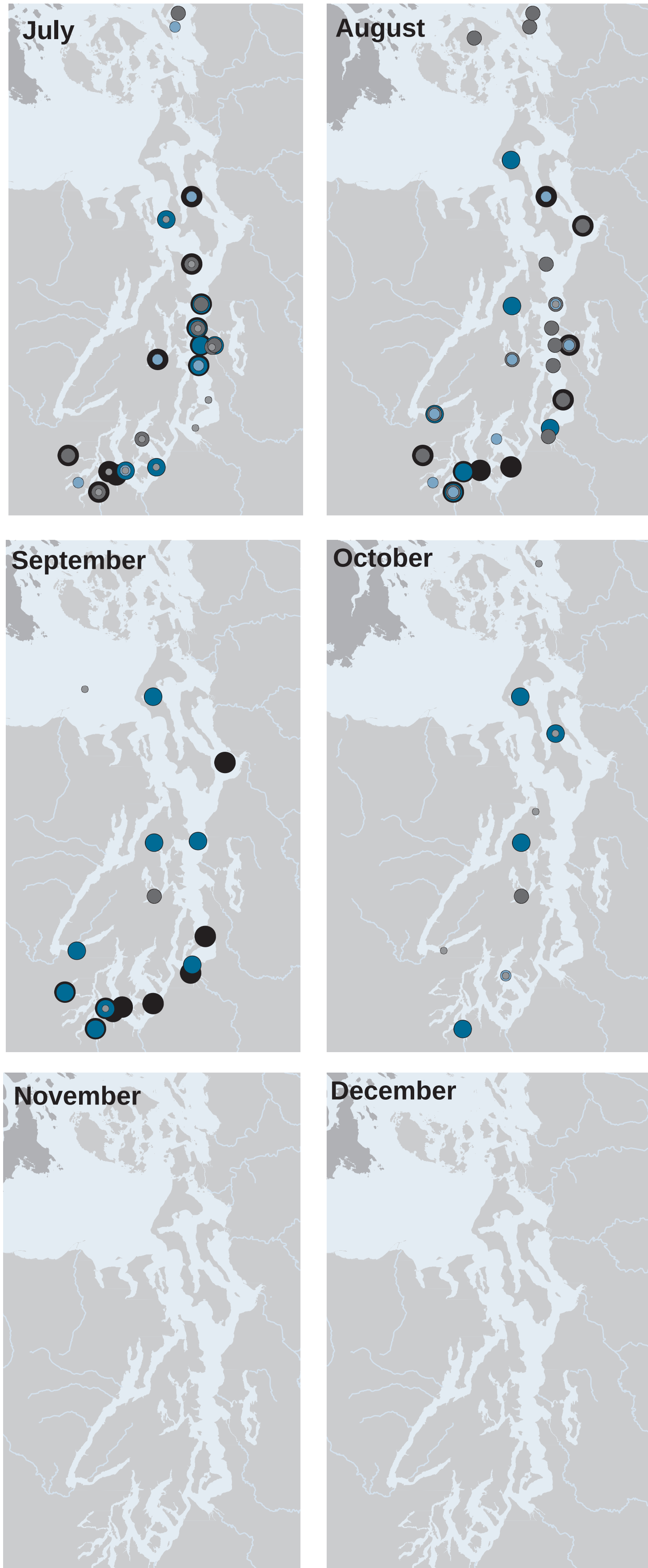
a. Kelp

Kelps are large seaweeds in the Order Laminariales. Twenty-six species of kelp grow along Washington's shorelines, making the state one of the richest sites of kelp diversity in the world (Gabrielson et al. 2000). Kelp beds support commercially and recreationally important fish and invertebrates, as well as marine mammals and birds (Dayton 1985, Duggins et al. 1989). Many factors, both natural and human-caused, affect the extent and composition of these important nearshore habitats (Duggins 1980, Dayton and Tegner 1984, Foster and Schiel

Figure 2-1. Distribution of phytoplankton blooms for Puget Sound stations sampled from 2001-2005. Note that stations are sampled monthly, which is not an adequate interval to capture short-term changes in phytoplankton abundance. The earliest phytoplankton blooms occurred in January (2001), February (2003, 2004), and March (2002, 2005); the latest blooms were observed in November (2004), October (2001, 2002, 2003), and September (2005). All stations with early (January, February) and late (October, November) blooms had low to moderate dissolved organic nitrogen levels, indicating possible nutrient limitation and suggesting that, under appropriate conditions, small inputs of nutrients could induce blooms.
(Source: Ecology)






July
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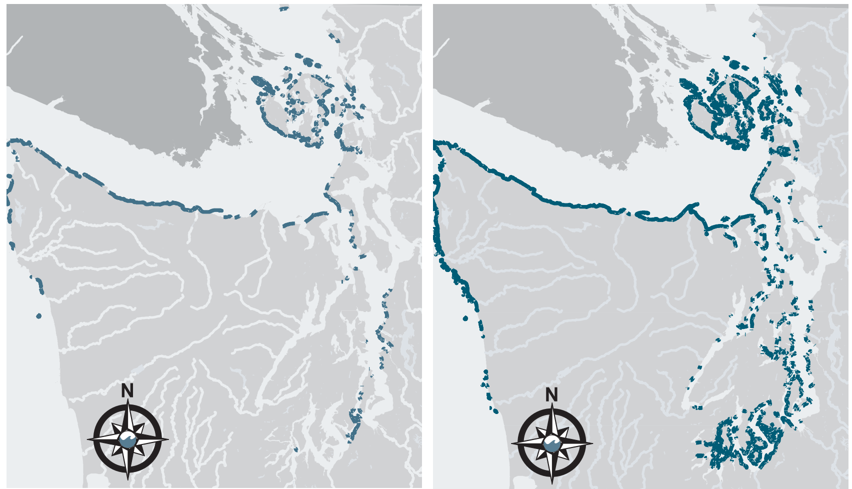


Figure 2-2. The distribution of floating kelp and understory kelp in Washington state. There is a gradient in the occurrence of kelp in Puget Sound due to natural environmental conditions. Floating kelp is most common in rocky, high-energy environments, with greatest abundance in the San Juan Archipelago and the Strait of Juan de Fuca. Kelp beds gradually decrease in size and frequency in central and southern Puget Sound. Kelp is uncommon in Hood Canal. Understory kelp is more common than floating kelp throughout Washington, with the most notable difference occurring in southern Puget Sound, where understory kelp is found along higher current shorelines with suitable substrate. (Source: DNR)

1985). Kelp species can be grouped by their growth forms: floating kelp produces buoyant bulbs and blades that spread out on the water surface, while understory kelp canopies extend horizontally near the bottom.

PSAMP scientists with the Nearshore Habitat Program of DNR have inventoried floating kelp beds annually (with the exception of 1993) since 1989 along the Strait of Juan de Fuca and the outer coast. Color-infrared photography is used to measure two parameters: canopy area (the area of the water surface covered by stipes, bulbs, and blades) and bed area (including both canopy area and gaps between plants that are less than 82 ft (25m) wide).

Status and Trends

Floating kelp occurs along approximately 11 percent of Washington's saltwater shorelines (Nearshore Habitat Program 2001). There is a gradient in the occurrence of floating kelp in Puget Sound due to natural environmental conditions (Figure 2-2). Floating kelp is most common in rocky, high-energy environments, with greatest abundance in the San Juan Archipelago and the Strait of Juan de Fuca. Floating kelp beds gradually decrease in size and frequency in central and southern Puget Sound. Floating kelp is uncommon in Hood Canal.

Bull kelp (*Nereocystis luethkeana)* is the primary floating kelp species found throughout Puget Sound. The southernmost persistent bull kelp bed is located off Squaxin Island, near Olympia. Along the western Strait of Juan de Fuca and outer coast, giant kelp (*Macrocystis integrifolia*) also occurs. Giant kelp forms extensive surface canopies that are either intermixed with bull kelp or grow closer to shore than bull kelp. Bull kelp is generally more abundant than giant kelp in the Strait of Juan de Fuca, in terms of total bed area. However, giant kelp forms denser beds. While both species are fairly variable from year-to-year, bull kelp exhibits higher inter-annual variation.

High year-to-year variability is common in kelp beds (Dayton 1985, Dayton and Tegner 1984, Grove et al. 2002). Along the Strait of Juan de Fuca, bed area extent was lowest in 1989 (1,911 hectares, or 4,722 acres) and greatest in 2000 (4,788 hectares, or 11,832 acres). Despite high year-to-year variability, significant trends in floating kelp are apparent along the Strait of Juan de Fuca and the outer coast (Berry et al. 2005). In order to identify areas of change at a high resolution, data were analyzed for trends at the scale of shoreline sections ranging from 3-9 miles

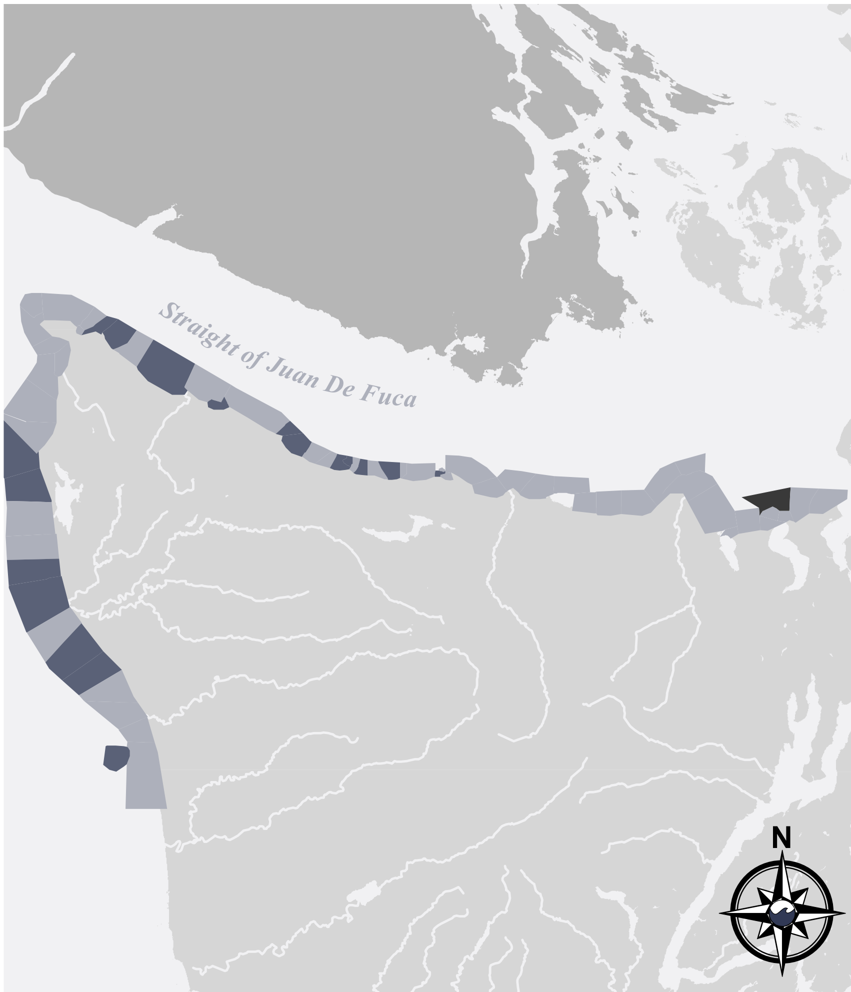
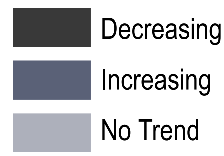


Figure 2-3. Trends in kelp canopy in Washington waters. Significant trends in kelp canopy area within shoreline sections, based on annual surveys between 1989 and 2004. Increasing trends are confined to the western Strait of Juan de Fuca and the outer coast. The only declining trend was found near Protection Island in the eastern Strait.
(Source: DNR)



(5-15 km), with boundaries defined by geomorphological features. Canopy area increased significantly in 18 sections, decreased significantly in one section, and did not change significantly in 47 sections (Figure 2-3)[3]. In some areas, significant increases occurred in two adjacent sections, suggesting that patterns of change might be occurring over larger areas than sections. Of two parameters studied—canopy and bed area—the pattern of trends were similar, but with more significant trends observed in canopy area. This finding suggests that canopy area is the more sensitive of the two parameters.

Multiple factors could be contributing to observed trends in floating kelp beds. Sea otter population growth and range expansion could have indirectly increased kelp communities by depleting the sea urchin populations that feed on kelp (Estes et al. 1978, Duggins 1980). Sea otters were re-introduced to Washington state in 1969 and 1970, after being extirpated in the early 1900s by hunting, and populations have grown an average of eight percent annually since reintroduction (Lance et al. 2004). Sea otters were initially limited to the outer coast around Destruction Island, then gradually expanded into the western Strait of Juan de Fuca in 1995, with populations reported as far east as Pillar Point.

Other factors influencing kelp abundance and distribution include high water temperatures and low nutrient concentrations associated with El Niño conditions, which are known to cause short-term losses (Foster and Schiel 1985). Pacific

[3] For this analysis, $p<.01$

Oscillations (PDOs) could be driving changes over longer time periods. Increased fine sediment from rivers or substrate movement influences the amount of available habitat for attachment. Increased sediment in the water causes reduction of light available to fuel growth. Competitive interactions among algal species can lead to a community shift from high disturbance species, such as bull kelp, to lower disturbance species, including giant kelp and stalked kelp (*Pterygophora californica*) (Dayton 1985).

Human harvest of sea urchins could have indirectly affected kelp canopy area by decreasing populations of these herbivores. Sea urchins are harvested along the Strait of Juan de Fuca portion of the floating kelp study area but not the outer coast (M. Ullrich, WDFW, pers. comm.) Peak landings occurred between 1988 and 1992, and harvest levels have decreased since then, with closures due to depleted stocks in portions of the Strait of Juan de Fuca. (For more information on sea urchins, see Section 5c of this chapter.)

Impacts to the Ecosystem

Because of their large biomass and rapid growth rates, kelp beds form one of the world's most productive habitats (Mann 1982). Kelp supports the food web through direct consumption by grazers, consumption of drift material by benthic herbivores, consumption of particulate detritus by suspension feeders, and utilization of organic carbon by a wide range of organisms (Duggins 1987).

Changes in kelp abundance and distribution affect habitat availability for valued species. Kelp beds form structurally complex, three-dimensional habitats that are used by invertebrates, fish, birds, and mammals. Juvenile rockfishes associate with floating kelps, and this habitat may be an important stepping-stone in the life history of splitnose and tiger rockfishes (Buckley 1997). Also, massive mats of drift kelp can be found at all depths of Puget Sound (W. Palsson, WDFW, pers. comm.). This material provides substrate for benthic and epibenthic organisms, which is believed to lead to increases in the abundance, biomass, and diversity of other nearshore organisms (Duggins 1987). As a result of the important role kelp plays, widespread losses of kelp beds would have repercussions for the broader Puget Sound marine system.

b. Eelgrass

Eelgrass (*Zostera marina*) is the dominant seagrass in Washington. It provides habitat, supports complex food webs, promotes biodiversity, and improves water quality throughout Puget Sound (Phillips 1984, Thom et al. 1998, Hemminga and Duarte 2000, Green and Short 2003). It has been documented as habitat for salmon, spawning grounds for herring, and a food resource for black brant and other waterfowl (Thayer and Phillips 1977, Phillips 1984, Simenstad 1994, Wilson and Atkinson 1995). In addition, eelgrass provides a source of carbon in nearshore habitats (Simenstad and Wissmar 1985, Kentula and McIntire 1986), stabilizes sediments (Fonseca 1996), and, because of its sensitivity to environmental degradation, has been used as an estuarine health indicator in many parts of the world (Dennison et al. 1993, Hemminga and Duarte 2000, Lee et al. 2004, Krause-Jensen et al. 2005). Eelgrass grows in fringing beds along much of Puget Sound's shoreline and also grows commonly on flats, in large shallow embayments, and along small pocket beaches.

In 2000, as part of PSAMP, scientists with the Nearshore Habitat Program of DNR initiated the Submerged Vegetation Monitoring Project (SVMP) to assess spatial patterns and temporal trends in eelgrass habitat (Berry et al. 2003). Because no single parameter adequately describes eelgrass bed condition, several parameters

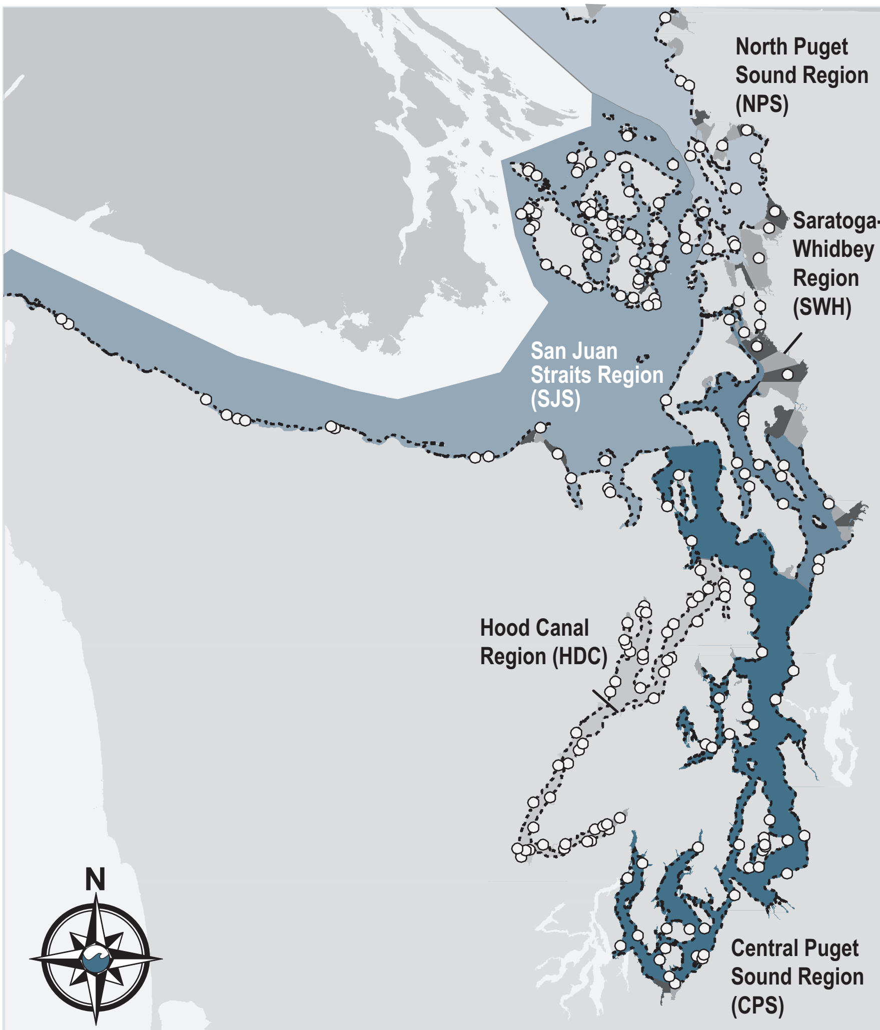
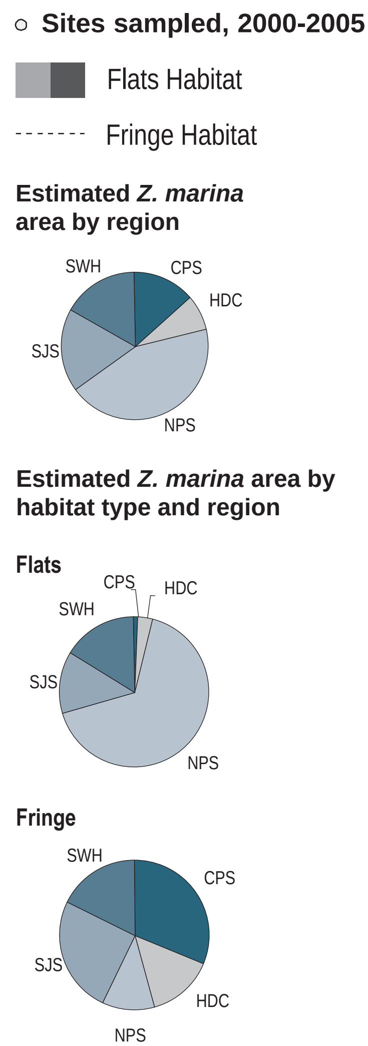


Figure 2-4. Estimated eelgrass *Z. Marina* in Puget Sound. All sites sampled by the SVMP, 2000-2005, and the five regions that make up the greater Puget Sound study area. Each 3,000-ft (approx. 1,000 m) linear segment represents a site. The pie charts show the 2005 estimated distribution of eelgrass area by region, both overall and within the flats and fringe habitats. (Two colors of shading are used to distinguish adjacent discrete sites.) Eelgrass is not evenly distributed across Puget Sound. The greatest portion is in the NPS region, which is dominated by eelgrass in flats sites. In this region, approximately 27 percent of the total eelgrass in Puget Sound is found within Padilla Bay and Samish Bay. In contrast, CPS is dominated by eelgrass in fringe sites; in the other regions, the eelgrass is more evenly mixed among flats and fringe sites. (Source: DNR)



were monitored: eelgrass area (number of square meters with seagrass growing on it), maximum and minimum depth, and patchiness of beds (both fringe and flats). At the current level of effort, the monitoring program will be able to detect as little as a 20 percent change in Soundwide eelgrass abundance over a 10-year monitoring period. The SVMP also monitors changes at five subregions within greater Puget Sound and at individual sites (Figure 2-4).

Status and Trends

In 2005, there were approximately 50,400 acres of eelgrass in Puget Sound, evenly distributed between flats and fringe habitat types (Gaeckle et al. in prep). However, eelgrass is not evenly distributed across the Sound; results in 2005 confirm earlier reports that 27 percent of the eelgrass in Puget Sound grows in Padilla Bay and Samish Bay (Dowty et al. 2005). This indicates that the extensive eelgrass meadows in these two bays provide unique habitat on a scale that is not replicated elsewhere within greater Puget Sound.

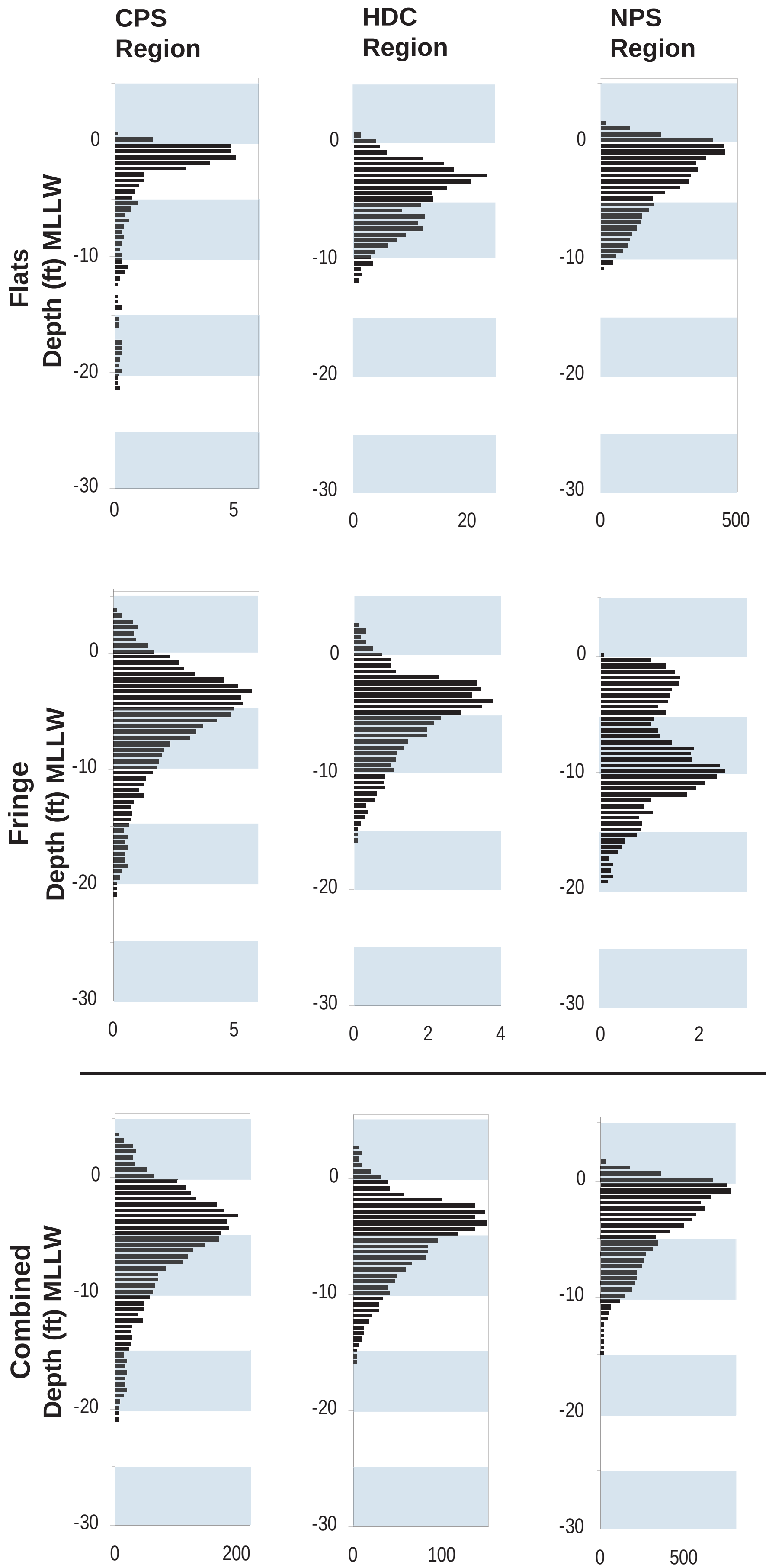
In 2005, the SVMP completed a study of the spatial differences in eelgrass depth distribution throughout Puget Sound and created depth profiles for the habitat types (flats and fringes) on a regional and Soundwide basis[4] (Figure 2-5) (Selleck et al. 2005). The profiles clearly show that eelgrass in Puget Sound is predominantly subtidal and that there are strong regional differences. The

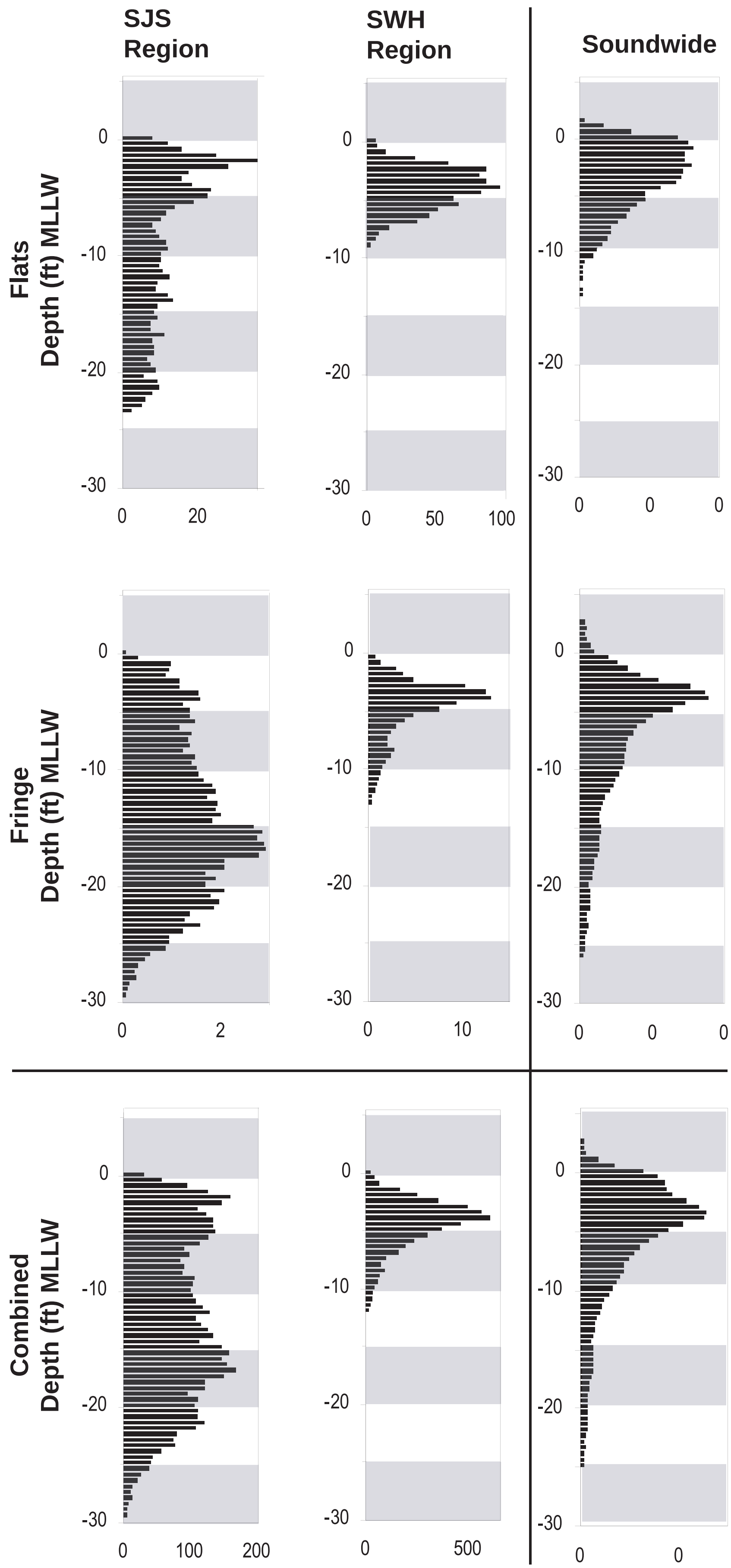
[4]Sample sites are randomly selected from potential flats and fringe habitat.

Figure 2-5. Eelgrass depth in Puget Sound. Depth profiles of eelgrass aggregated by the SVMP regions—flats, fringe habitat and combined flats and fringe habitat—based on data from 2002–2004, relative to Mean Lower Low Water. These profiles varied greatly among regions, flats, and fringe habitat types, as well as between individual sites. Overall, eelgrass in Puget Sound is predominantly subtidal and tends to grow shallower at flats sites and deeper at fringe sites concurring with differences in depth profiles of the available habitat in these areas. The sensitivity of eelgrass to water clarity is clearly seen in the deeper eelgrass in the SJS region, where clarity tends to be greater. Note: eelgrass was observed at depths greater than 30 ft (9 m) in the SJS region; however, such data do not appear in the depth profiles because of the small quantity of these observations and, therefore, are not included in the figure.
(Source: DNR)

Eelgrass Study Regions

CPS	Central Puget Sound
HDC	Hood Canal
NPS	North Puget Sound
SJS	San Juan Straits
SWH	Saratoga Whidbey




SJS
Region
SWH
Region
Soundwide
Flats
Depth (ft) MLLW
Fringe
Depth (ft) MLLW
Combined
Depth (ft) MLLW
0
-10
-20
-30
0
20
50
100
2
10
100
200
500

greatest depths with eelgrass were observed in the San Juan Straits (SJS) region, an indication of improved water quality in this area because of extensive ocean flushing and high water clarity. Overall, the maximum depth of eelgrass at sampled sites ranged from 5.9 feet (1.8 m) above Mean Lower Low Water (the long-term average depth of the lowest tide per day) to -39 feet (-11.9 m) (Dowty et al. 2005, Selleck et al. 2005). The maximum depth of eelgrass is dependent not only on water clarity (indication of available light) but also on nutrient and dissolved oxygen concentrations (Greve and Krause-Jensen 2005).

On a Soundwide scale, there has been no evidence of a trend in eelgrass area (Dowty et al. 2005). At a smaller scale, yearly estimates of eelgrass area change within the Hood Canal region (HDC) indicate four consecutive years of decline. This estimated loss is of particular concern, given the current scientific and political focus on the conditions of low dissolved oxygen in Hood Canal (Newton and Hannafious 2006). Three other regions—North Puget Sound (NPS), Saratoga Whidbey Region (SWH), and San Juan Straits (SJS)—were variable and did not present evidence of change. In Central Puget Sound (CPS), eelgrass area declined over the last two years, but these declines were not statistically significant (Figure 2-6).

Focus Areas

In 2004, DNR scientists initiated a focus-area effort that involves more intensive sampling within one of the five SVMP regions each year. The study rotates through different focus areas on a five-year schedule in an effort to improve status estimates on regional scales and to better identify patterns of decline within regions (Berry et al. 2003). In 2004, focus-area sampling started in the San Juan Archipelago area of the SJS region. In 2005, the focus-area sampling was directed to the HDC region, to help address the relationship between the observed low dissolved oxygen and eelgrass health and status (Newton and Hannafious 2006). Change analysis within each focus area will be completed after a region is sampled again in five years.

Non-native Seagrass

The presence and widespread distribution of the introduced species *Zostera japonica* demonstrates its opportunistic behavior and generates questions as to its ecological function and how it competes for resources with other eelgrass (Figure 2-7) (Harrison 1976). Dwarf eelgrass, native to the western Pacific and first observed on the Pacific coast of North America in 1957, occupies higher intertidal areas compared to eelgrass, but there are areas where the range of these two species overlaps. Presently, there is a dwarf eelgrass eradication program in Humboldt Bay, California, and, although the presence of this species has provoked numerous debates in Washington, there are currently no efforts to remove it from Puget Sound.

Impacts to the Ecosystem

There are numerous anthropogenic and environmental factors that cause widespread seagrass loss (Short et al. 1991, Short and Wyllie-Echeverria 1996, Short and Neckles 1999, Duarte 2002). The loss of seagrass in Puget Sound could lead to a significant decline of marine and estuarine biodiversity, including a vast amount of associated flora (epiphytic algae) and fauna that coexist with seagrass. In addition, many organisms utilize seagrass for shelter or protection, as foraging grounds, or as habitat for migration purposes (Thayer and Phillips 1977, Phillips 1984, Simenstad 1994, Wilson and Atkinson 1995, Green and Short 2003). Seagrass dampens wave and current energies and its loss would lead to increased shoreline erosion (Fonseca 1996). Its ability to support a productive nearshore ecosystem through nutrient regeneration and filtration (Hemminga et al. 1999)

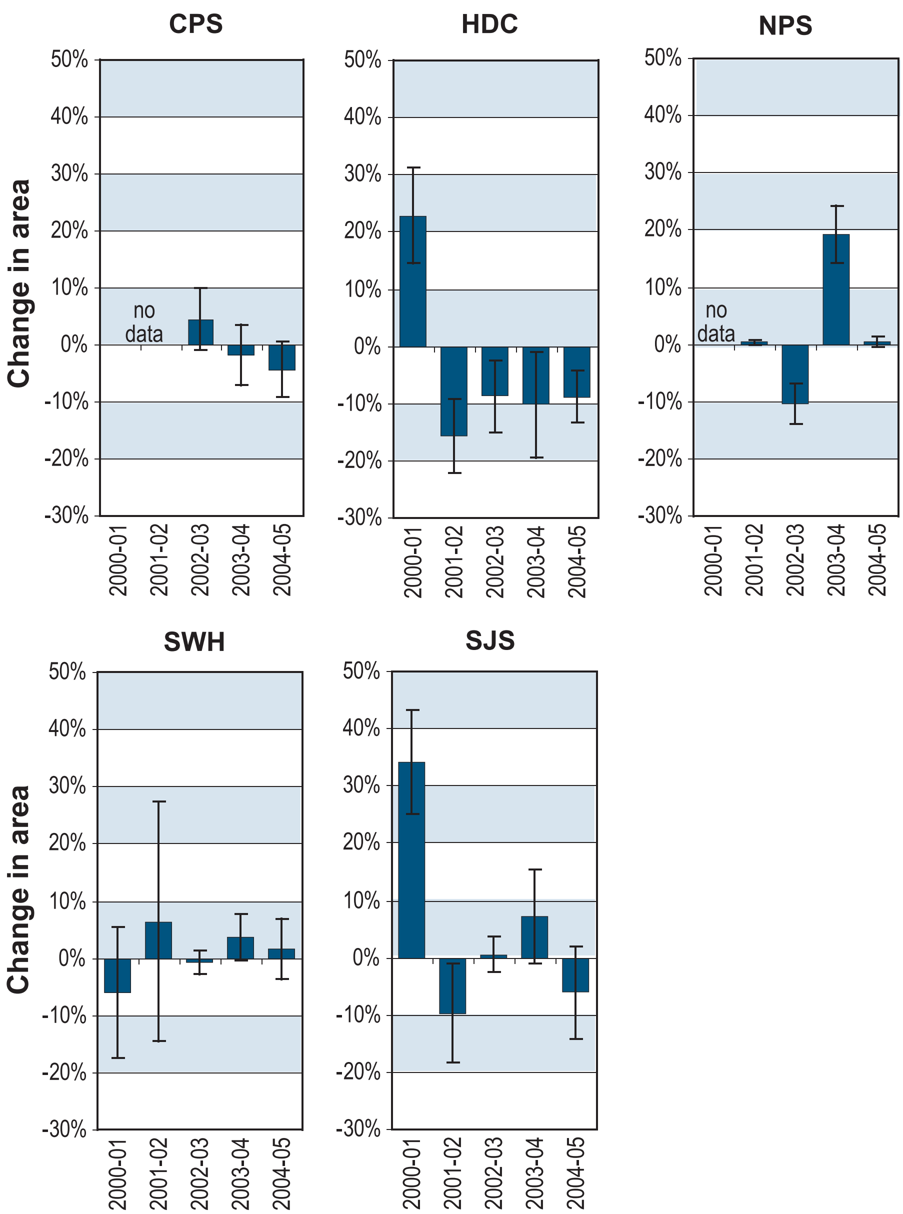


Figure 2-6. Estimated annual change in eelgrass in Puget Sound, 2000 to 2005. Throughout Puget Sound, there has been no evidence of seagrass decline. At a smaller scale, yearly eelgrass estimates in three of the five regions—NPS, SWH, and SJS—were variable and did not present evidence of persistent change. In CPS, seagrass area declined over the last two years, but these declines were not statistically significant. The pattern of eelgrass area change within HDC, a region with significant seagrass decline, has continued for a fourth consecutive year. (Source: DNR)

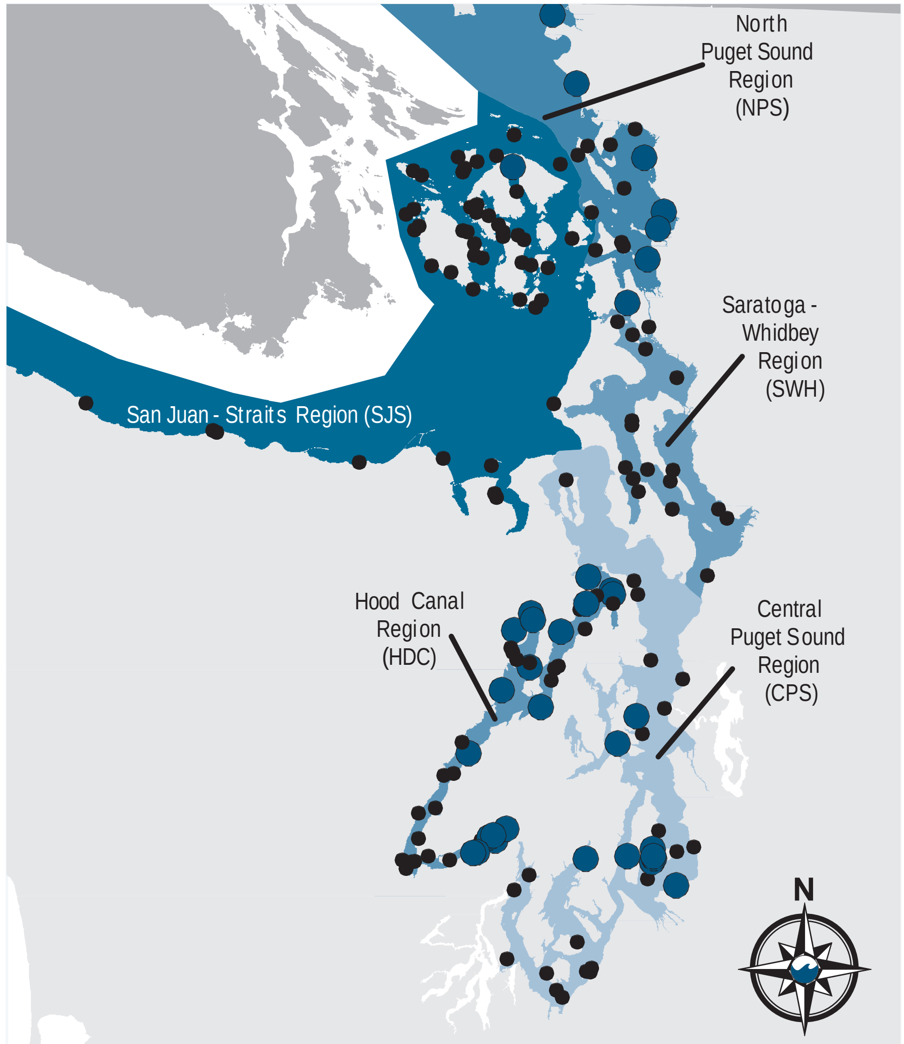
and oxygen production (Vermaat and Verhagen 1996) would also be lost. The implications of seagrass loss could have significant consequences to biodiversity, productivity, and ecological stability throughout Puget Sound.

d. Eelgrass and Climate Variation in Puget Sound

Long-term monitoring indicates that the abundance and distribution of eelgrass can vary significantly from year to year. Emerging evidence shows a potential linkage between climate and variations in eelgrass abundance. In particular, massive (700 percent) changes in eelgrass abundance in Willapa Bay corresponded with the El Niño - La Niña event at the end of the 1990s (Thom et al. 2003). The production of flowering shoots also increased substantially during the El Niño - La Niña transition. Puget Sound experienced two extreme climate events in the latter half of the 20th century (1982-1983, 1997-1998) that were likely to have affected eelgrass (Thom and Albright 1990, Thom et al. 2003). Data from these events can help scientists understand the magnitude and perhaps the mechanisms responsible for variations in eelgrass abundance and distribution.

Figure 2-7. The distribution of non-native dwarf eelgrass *(z. japonica)* at the 2004 and 2005 SVMP sampling sites. (Source: DNR)

- *Z. japonica* present
- *Z. japonica* not present



Suspected climate-related factors driving seagrass variation are extremes in temperature and changes in mean sea level. Temperature affects rates of eelgrass photosynthesis and respiration. The optimal temperature for eelgrass growth is within a very narrow range of 41-46 degrees F (5-8 degrees C) (Thom 1995). This range of temperatures is typical of winter, but light tends to be lower and, therefore, growth is reduced. Conversely, improved light conditions in spring and summer can coincide with warmer temperatures, which impede growth. The optimal mix of temperature and light conditions occurs within a narrow period, suggesting that eelgrass can be significantly affected by variations in climate.

Mean sea level is dramatically affected by climate, with higher sea levels (up to about 11.8 inches, or 30 cm) during strong El Niño conditions, and lower levels (- 7.9 inches, or -20 cm) during strong La Niña conditions. Scientists predict that sea-level rise may benefit shallower, flat-dwelling eelgrass by reducing impacts of desiccation and heat stress, because the plants are covered by water for longer periods. However, deeper-dwelling eelgrass showed reduced abundances during El Niño conditions (Thom et al. 2003), attributed to turbidity and shallower light penetration in the water column.

Focus Study

Eelgrass declines in the San Juan Archipelago

An estimated total of 82 acres (33 hectares) of eelgrass disappeared from small embayments in the San Juan Archipelago between 1995 and 2004 (Figure 2-8; Table 2-2). Westcott Bay is one of several shallow embayments within the San Juan Archipelago and, because population loss was both rapid and complete at this site, the first phase of the ensuing research plan was to determine if losses might be occurring within other shallow embayments in the archipelago. An interdisciplinary team of scientists from the University of Washington, DNR, Ecology, Coastal and Marine Geology Branch of USGS, the University of South Alabama, and Friends of the San Juans (FOSJ) set out to determine the causes of this decline.

Beginning in 2004, researchers examined historical aerial photos for the presence of eelgrass. For this analysis, 11 shallow embayments were selected for further evaluation. Selection was based on the size of the embayment, the availability of quality aerial photo data for the period when loss was observed in Westcott Bay, and geographic distribution within the archipelago. Scientists discovered that aggregate losses totaling 50 acres (20.2 hectares) occurred between 1995 and 2001. Eight of the 11 locations experienced declines of eelgrass. These historical data were compared with data collected in 2003; the comparison showed that, while recovery took place at three sites, the trend of decline detected in 2001 continued in six locations, with two additional sites—Garrison Bay and Nelson Bay—also experiencing local extinctions. Eelgrass acreage at a fourth site, the eastern reach of Mitchell Bay, increased between 1995 and 2001 but was completely gone in 2004.

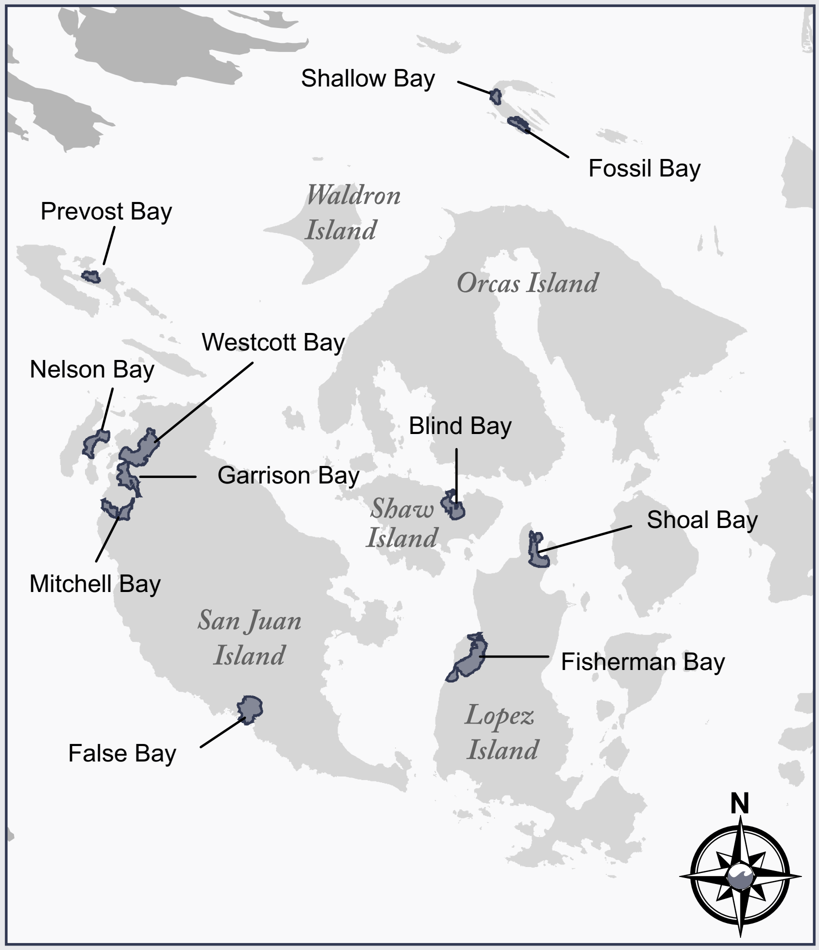


Figure 2-8. Location of eelgrass loss in the San Juan Archipelago. The location of sites selected for retrospective analysis following the sudden loss of eelgrass within Westcott Bay in the San Juan Archipelago between 1995-2003. (Source: UW)

Location	1995	2001	2003	2004	2003/04*
Blind Bay	14.8	5.2	n.d.	4.9	4.9
False Bay	9.4	4.7	n.d.	10.1	10.1
Fisherman Bay	34.1	29.1	23.7	n.d.	23.7
Fossil Bay	12.8	11.4	n.d.	4.4	4.4
Garrison Bay	5.2	5.2	0	.n.d.	0
Mitchell Bay	2.5	3.5	n.d.	0	0
Nelson Bay	17.8	5.6	n.d	0	0
Prevost Harbor	8.9	9.4	4.9	n.d.	4.9
Shallow Bay	7.7	6.4	12.8	n.d.	12.8
Shoal Bay	6.4	4.4	n.d.	7.9	7.9
Westcott Bay	31.4	16.3	0	n.d	0
Total (acres)	**151**	**101**	**41.4**	**27.3**	**68.7**

Table 2-2 Comparison of eelgrass acreage estimates at 11 sites within San Juan County between 1995 and 2004. There has been a steady decline in total acreage during this period, with Westcott Bay and Nelson Bay experiencing the largest losses. (n.d.= no data available) (Source: UW, FOSJ and DNR)
* Data in this column was determined using DNR sampling techniques and protocol. (Berry et al. 2003)

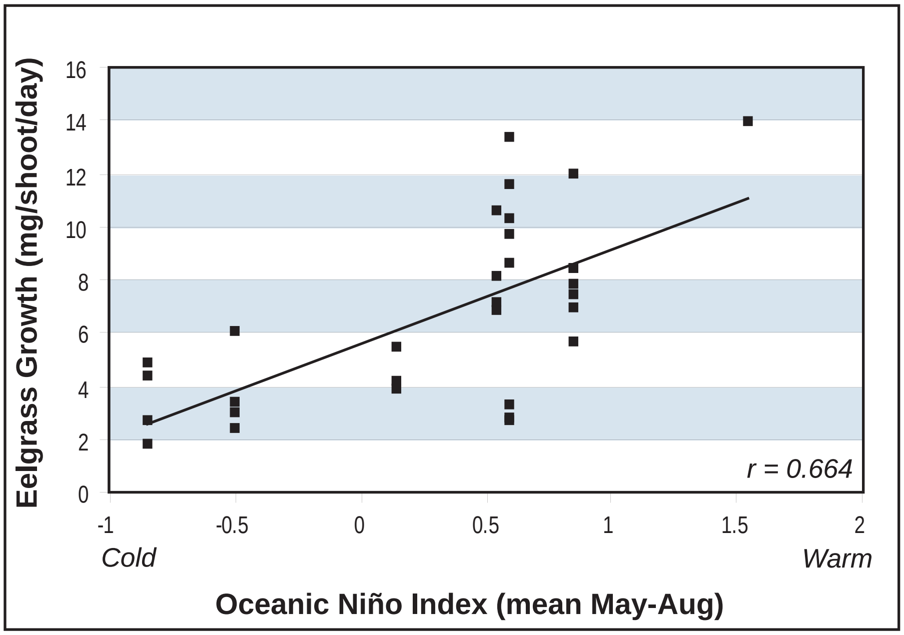


Figure 2-9. Eelgrass growth and climate. The growth rate of eelgrass in 10 summers between 1991 and 2005 at Sequim Bay was strongly correlated with the Oceanic Niño Index, suggesting there may be a climate-related cause for differing growth patterns. During colder years the plants grew slower, and during warmer years the plants grew faster. The fastest growth rates were measured in the summer of 1997, at the start of the strongest El Niño event in the 20th century. The values are means of growth for at least 30 replicate plants. Three to four growth rate experiments were conducted in each of the 10 years. (Source: PNNL)

Status and Trends

During 10 summers between 1991 and 2005, eelgrass growth rates near the mouth of Sequim Bay varied substantially. The fastest growth rate ever recorded was in 1997 at the start of the El Niño period. Growth rates of eelgrass correlate with the PDO Index and the Oceanic Niño Index (Figure 2-9). The PDO is a measure of conditions in the Northeast Pacific Ocean and can be used to explain variations in plankton and salmonid survival in the eastern North Pacific Ocean.

Annual studies of subtidal eelgrass density near the Clinton ferry terminal on Whidbey Island show a strong correlation with El Niño conditions, with greatest densities occurring during neutral (average) conditions. There is some evidence that links climate to eelgrass abundance, but further study is needed to verify mechanisms and the multiple factors that contribute to eelgrass variation. Climate change combined with sea-level rise may result in eelgrass losses at lower depths and expansions at the upper limits of eelgrass' present distribution.

Impacts to the Ecosystem

Eelgrass meadows perform several important functions to the ecosystem. In particular, eelgrass provides a source of habitat and organic matter to the food web. Anecdotal observations from researchers in Alaska indicate that during the 1997-1998 El Niño event, brant populations along the coast suffered because of reductions in the amount of eelgrass.

5. Intertidal Biota

Intertidal biotic communities are comprised of the invertebrates, seaweeds, and plants living on shorelines that are exposed during low tides and underwater during high tides. These communities are important for their biodiversity values and for their roles in ecosystem processes. Common intertidal biota on Puget Sound's beaches include well-known species, such as oysters, clams, crabs, sea stars, and snails, along with lesser known species, such as polychaetes, amphipods, and algae. Shorebirds, marine bird, fish, and mammals depend upon many of these organisms for food, and humans utilize shellfish beds for ceremonial, recreational, and aquacultural opportunities.

Intertidal organisms are sensitive to environmental changes and may serve as indicators of environmental health (Warwick and Clarke 1993). Because the intertidal zone lies between the marine and terrestrial environments, organisms living in this zone are affected by a complex array of stressors from both land (when exposed) and sea (when immersed). In Puget Sound and other estuaries, intertidal organisms contend on daily and seasonal bases with highly fluctuating environmental gradients, especially in salinity and temperature. In addition, organisms in these ecosystems must survive, or may succumb to changes in water quality and sediment quality or alterations to habitats caused by development.

a. Intertidal Biotic Communities

DNR's Nearshore Habitat Program and the University of Washington's Department of Biology have monitored intertidal communities in the South and Central Basins of Puget Sound since 1997. Scientists sample epibiota (organisms on the surface of the sediment) and infauna (organisms that burrow within the sediment) in the lower intertidal zone of pebble/sand beaches that share similar geomorphological characteristics. The extensive data set demonstrates a strong coupling between the nearshore waters of the Sound, the physical environment on the beach, and the resident intertidal biotic communities (Schoch and Dethier 1997, 1999, 2001, Dethier and Schoch 2000, Dethier 2005). It also describes large-scale gradients throughout Puget Sound in the biota of pebble beaches (the most common beach type in the Sound). The data are now sufficiently extensive to reveal ecologically significant differences among beaches.

Status and Trends

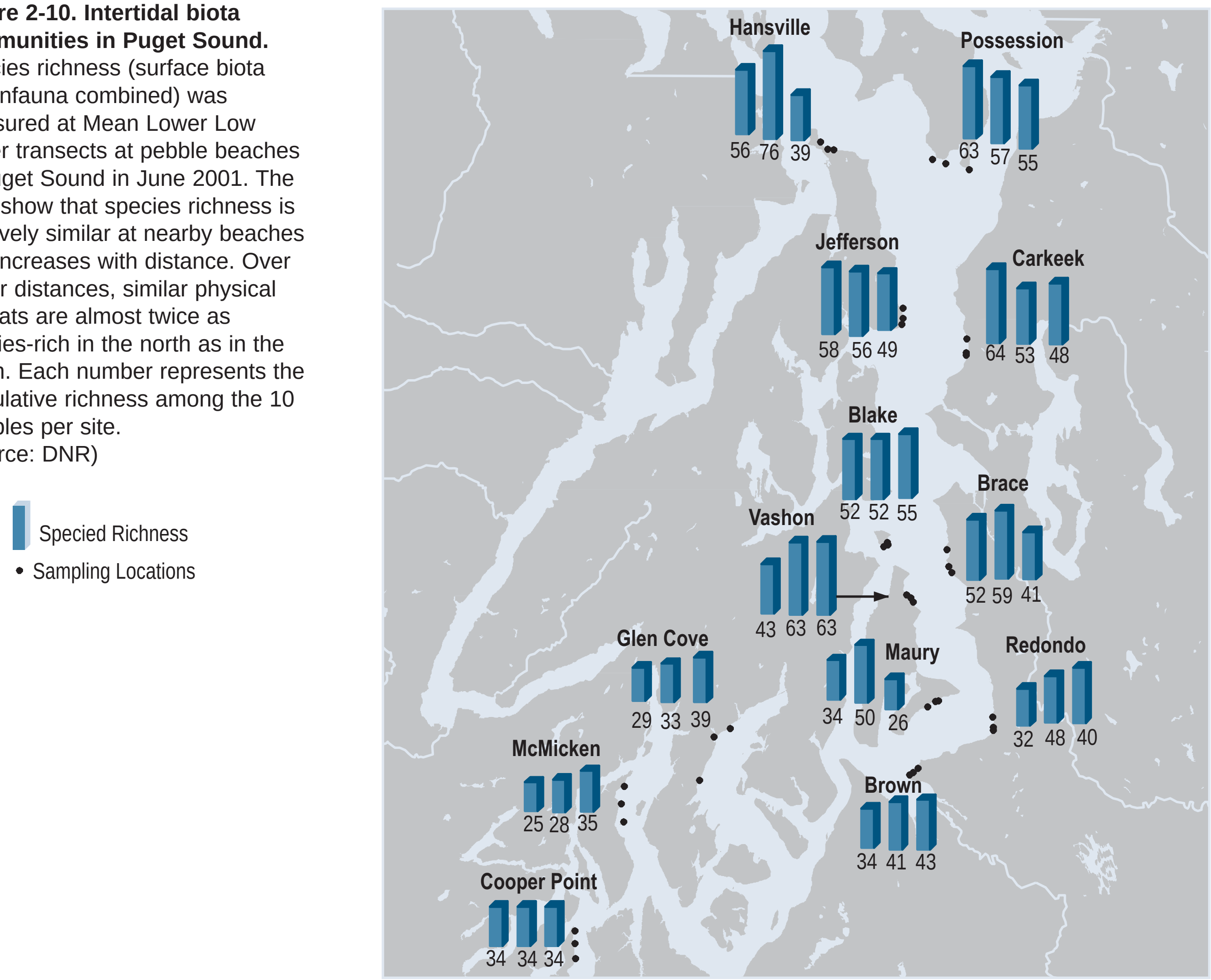
Intertidal benthic communities in pebble/sand beaches of south and central Puget Sound show a striking, temporally consistent pattern in species richness in both surface- and sediment-dwelling organisms (Dethier and Schoch 2005). Biological communities in Puget Sound are consistent among beaches that share similar physical characteristics and are within several kilometers of each other, but show gradual differentiation at increasing distances, especially from south to north (along latitudinal gradients). Over larger distances, similar physical habitats are almost twice as species-rich in the north as in the south (Figure 2-10). Similar patterns can be seen in data collected from 1999 through 2005; however, in those years, fewer sites were sampled. Higher richness in the northern samples parallels other estuarine studies that find the greatest benthic diversity in areas near the mouths of estuaries, where salinities and temperatures tend to be the least variable (and most marine), wave action is highest, turbidity and sedimentation are lowest, and water residence time is the lowest. Any or all of these factors may affect observed trends in the abundance of biota in Puget Sound, although the Central Basin is oceanographically well-mixed, compared with many estuaries.

Intertidal bivalve populations monitored by WDFW in Puget Sound on public tidelands are generally healthy and stable. Native littleneck clam stocks along Port Susan and Saratoga Pass beaches are an exception. These clams experienced a large mortality event in 2001 that appeared to affect only this species. Interestingly, during this same time period, butter clams in Port Susan and Saratoga Pass have increased. Manila clam populations on several public beaches in Hood Canal are still recovering from a severe winter kill in 2002, in which cold temperatures killed up to 33 percent of the population. Low dissolved oxygen problems in Hood Canal, however, have apparently had little or no impact on intertidal bivalves to date. Annual surveys on public tidelands in the Potlatch area have shown little change in clam biomass, for example.

Eelgrass as carbon sink in Puget Sound?

Studies are being conducted to determine the role seagrass could play in carbon dioxide sequestering (uptake and storage). Laboratory experiments showed that carbon dioxide can stimulate eelgrass growth on the order of 250 percent (Thom 1996). To date, however, there is no way of predicting the effect on Puget Sound eelgrass of rising CO2 levels in the atmosphere.

Figure 2-10. Intertidal biota communities in Puget Sound. Species richness (surface biota and infauna combined) was measured at Mean Lower Low Water transects at pebble beaches in Puget Sound in June 2001. The data show that species richness is relatively similar at nearby beaches and increases with distance. Over larger distances, similar physical habitats are almost twice as species-rich in the north as in the south. Each number represents the cumulative richness among the 10 samples per site. (Source: DNR)



Impacts to the Ecosystem

Beaches form the interface between terrestrial and marine ecosystems and are vulnerable to human impacts on both ecosystems. Degradation of intertidal areas can result from a wide variety of human-induced causes, including changes in water quality, losses or unnatural increases in sediment supply, overharvesting of native shoreline organisms, introduction of invasive species, and shoreline development. Such changes can kill intertidal organisms directly (e.g., Olympia oysters poisoned by pulp mill waste) or indirectly (e.g., shoreline armoring causing the removal of fine sediments from beaches, leading to the loss of habitat for clams). Although intertidal biota monitoring does not assess water quality or other direct impacts, it serves as an indicator of the effects of environmental degradation, by detecting substantial changes to the communities living in and on a beach.

6. Subtidal Biota

The subtidal zone refers to shallow waters below the low tide mark. Common subtidal species include worms, crabs, clams, sea urchins, and sea cucumbers. The once-familiar pinto abalone (*Haliotis kamtschatkana*) has undergone dramatic declines during the past two decades. Many species form habitat or are preyed upon by other invertebrates and fish, thus becoming important components of the food web. A wide range of subtidal species is monitored through PSAMP as part of the characterization of marine sediments for determining the health of Puget Sound.

a. Hood Canal Invertebrates

Episodes of low dissolved oxygen in Hood Canal have impacted populations of invertebrates living in Hood Canal, both recently and historically. Invertebrate kills and movement of organisms from deep to shallow waters have been observed and recorded by citizens and scientists. Less is known about the effects of these low dissolved oxygen events on the communities of microscopic invertebrates that live within the sediments of Hood Canal. These organisms are important parts of the food web, supporting populations of bottom-feeding fish and macroinvertebrates.

As part of PSAMP, sediment and near-bottom water samples were collected from 30 stations along the length of Hood Canal in June 2004. Sediment samples were analyzed for grain size, total organic carbon (TOC), toxicity, chemical contaminants, and benthic infaunal community composition. Dissolved oxygen (DO) levels were measured in the water samples. Values were mapped to determine patterns of each variable throughout the canal, and analyses were conducted to determine the relationships between the measures.

Status and Trends

Measures of toxicity and chemical contamination were very low in the Hood Canal sediment samples and not correlated with benthic infaunal indices (described in detail in Long et al. in prep.). Measures of sediment grain size (percent fines) and TOC, near-bottom water DO concentrations, and benthic community indices of total abundance and taxa richness (number of species or other taxanomic groups identified in a sample) at each of 30 stations are geographically displayed in Figure 2-11. Total abundance and taxa richness appear to be positively related to each other and to DO levels at these stations and to be inversely related to percent fines and TOC levels in the sediments.

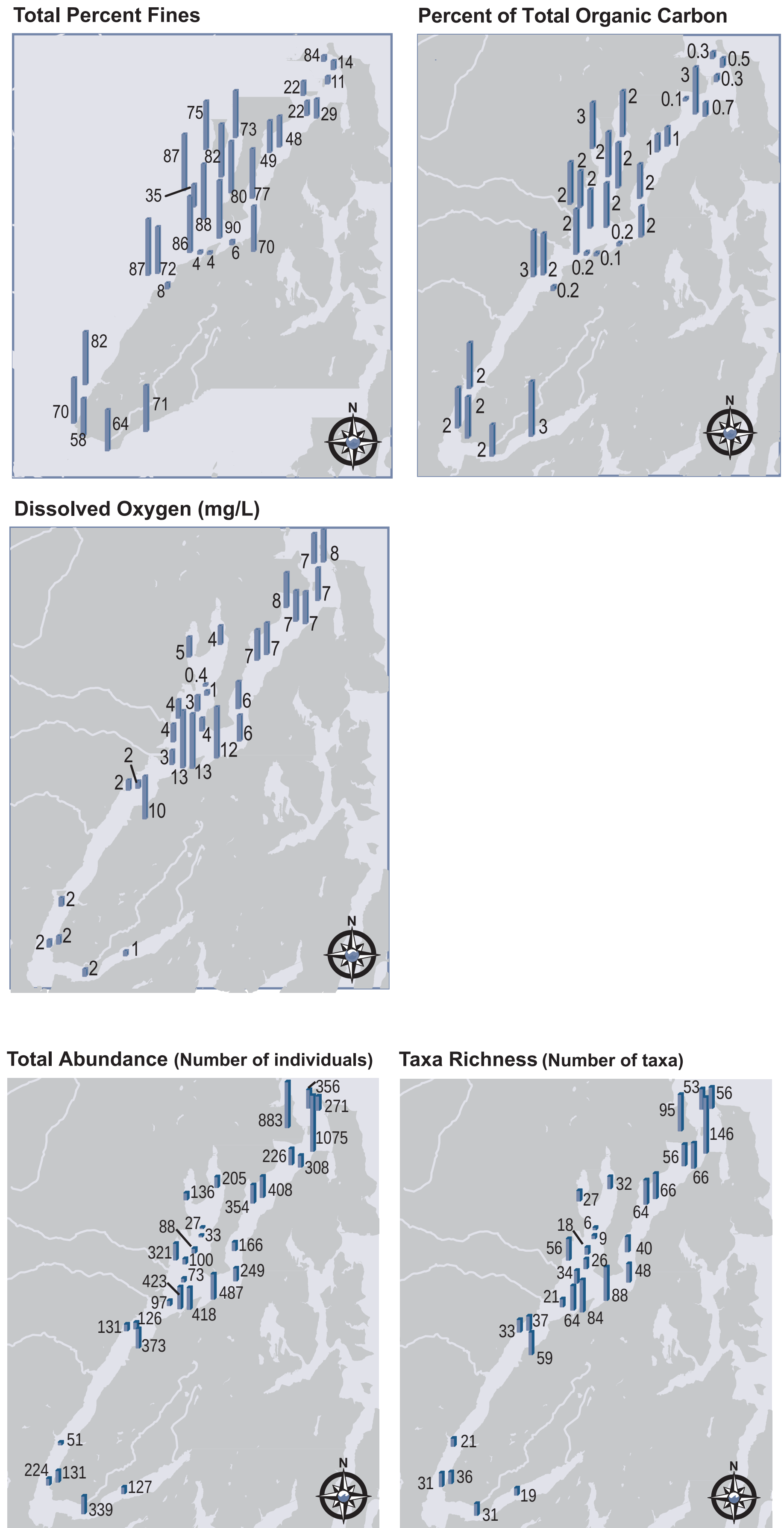
Examination of the geographic distribution of the abundance of the major taxa groups and the dominant taxa at each station suggests different suites of animals in five different regions of Hood Canal (Figure 2-12). Benthic assemblages in stations in northern Hood Canal are composed primarily of a mixture of annelids, arthropods, and molluscs. Dominant species include *Macoma carlottensis* and *Axinopsida serricata* (both widespread bivalves throughout Hood Canal) and a stress-sensitive ostracod (*Euphilomedes* spp.). In the central region of the canal, the shallow-nearshore station assemblages are primarily a mix of annelids and molluscs, but have fewer arthropods. Assemblages in the deepwater central channel of the central region of the canal are composed primarily of chaetopterid annelids. Assemblages in Dabob Bay and the southern part of the canal are composed mainly of differing suites of stress-tolerant annelids and molluscs, while stress-sensitive arthropods are absent. Dominant stress-tolerant annelids in Dabob Bay included a number of species of capitellids, *Cossura bansei, Lumbrineris cruzensis,* and *Leitoscoloplos pugettensis*. The bivalve *M. carlottensis* was again dominant. In southern Hood Canal, the bivalve *A. serricata* was dominant, along with a number of stress-tolerant cirratulid, capitellid, and pectinarid annelids.

Benthic infaunal indices were pooled within five ranges of near-bottom water DO concentrations for analysis (Figure 2-13). In general, indices decreased as DO levels decreased. Abundance patterns were also examined for 17 species thought to have differing sensitivities to DO levels. Some species increase in number with slightly lower DO, but most responded negatively to DO levels lower than 3 mg/l. (Figure 2-14, page 36).

Re-establishing Olympia Oysters in Puget Sound

Washington's only native oyster, the Olympia oyster (*Ostreola conchaphila*), has been the focus of cooperative research and restoration efforts in recent years. Olympia oysters commonly occur throughout Hood Canal and southern Puget Sound, wherever suitable intertidal habitat is available. Loss or lack of shell substrate appears to be a limiting factor in several areas where native oysters were historically present in large numbers. Restoration efforts in Liberty Bay provide this missing substrate by adding Pacific oyster shell to soft, muddy areas. A similar restoration project using Pacific oyster shell is underway in Discovery Bay, where European explorers to the Northwest first encountered Olympia oysters.

Figure 2-11. Taxa richness in Hood Canal. Sediment grain size, total organic carbon, near-bottom dissolved oxygen, benthic infauna and taxa richness measured at 30 Hood Canal stations in June 2004. Abundance and taxa richness appear to be positively correlated to DO levels and negatively to grain size and TOC.
(Source: Ecology)



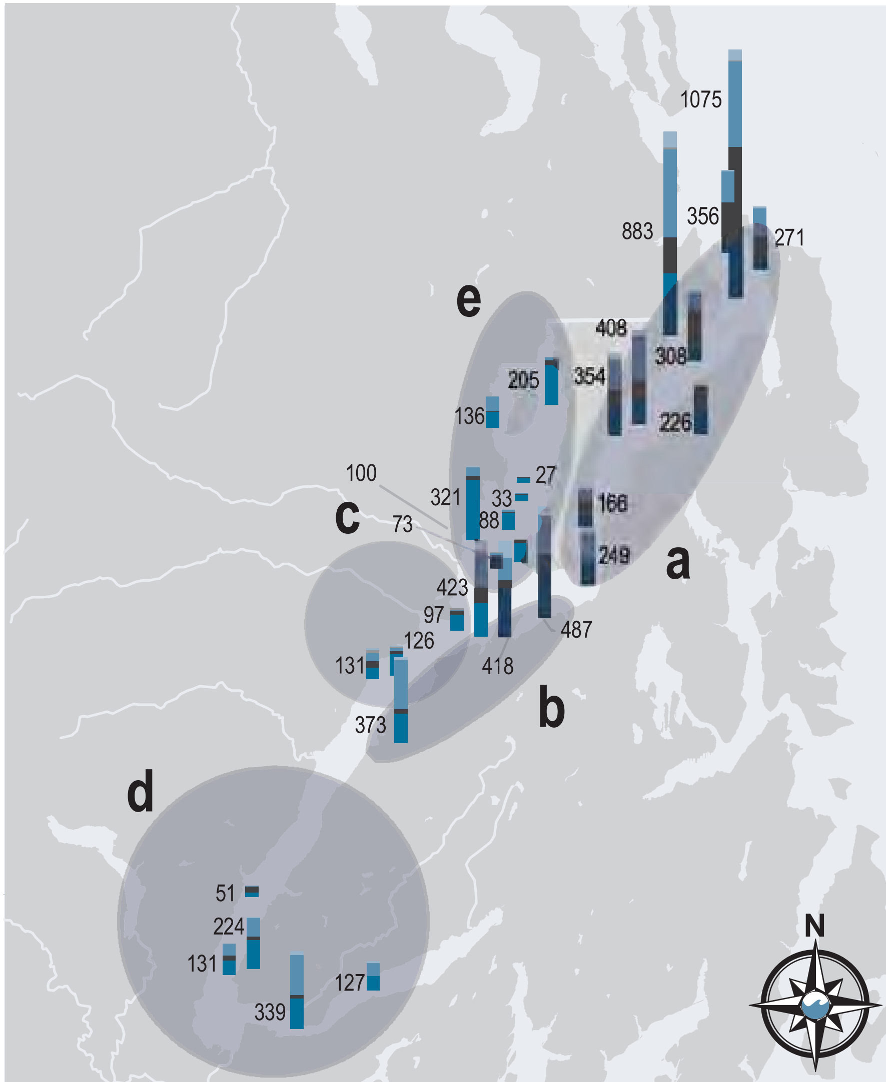


Figure 2-12. Major taxa abundance in Hood Canal. Abundance of major infaunal invertebrate groups measured at 30 Hood Canal stations in June 2004. Five groups of stations with similar assemblages were identified: northern (a), central near-shore (b), central deep (c), and southern (d) Hood Canal and Dabob Bay (e) (Source: Ecology)

Number of individuals within major taxa groups

- Other
- Echinoderm
- Mollusca
- Arthropod
- Annelid

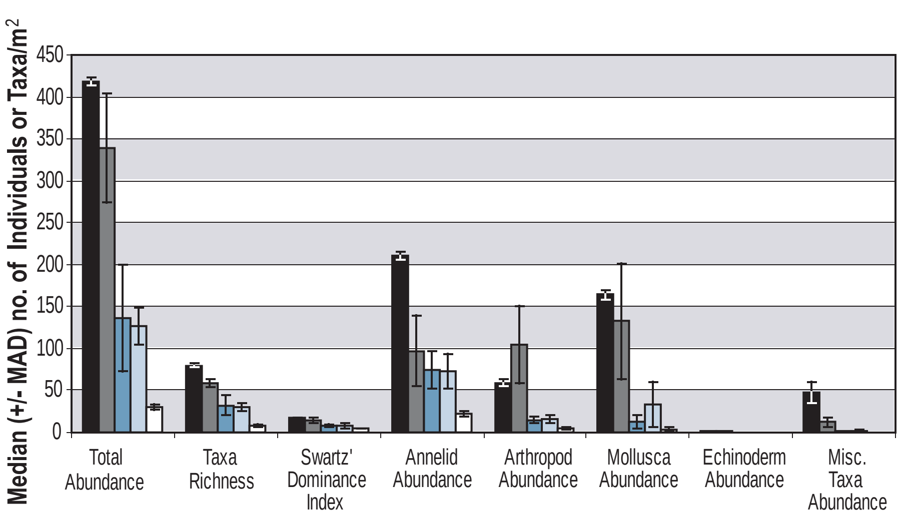
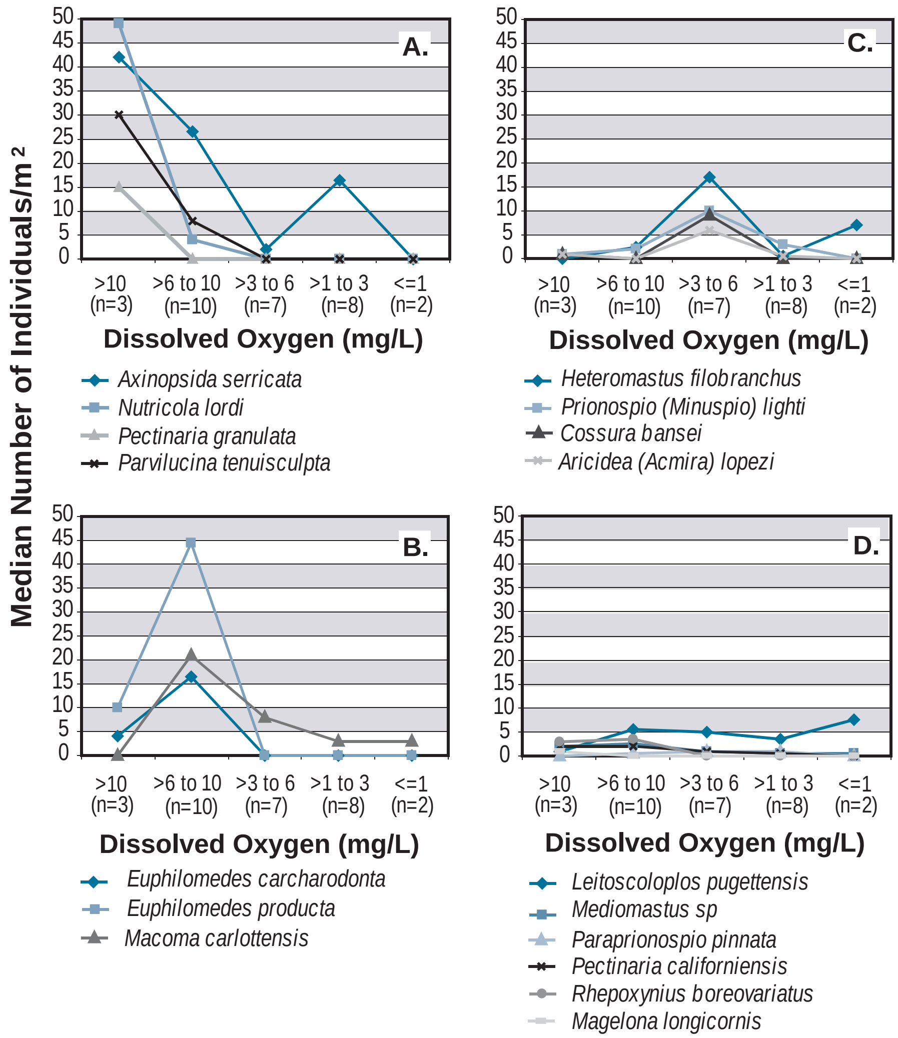


Figure 2-13. Hood canal and benthic invertebrate taxa abundance. Median number of individuals or taxa of benthic invertebrates per unit area for selected near-bottom DO categories. Samples were collected from Hood Canal in June 2004. Patterns varied between measures, but most decreased at lower DO concentrations. (Source: Ecology)

Dissolved Oxygen (mg/l

- >10 (n=3)
- >6 to 10 (n=10)
- >3 to 6 (n=7)
- >1 to 3 (n=8)
- <=1 (n=2)

Figure 2-14. Impact of low dissolved oxygen (DO) on Hood Canal's invertebrates. The relationship between species abundance and near-bottom DO levels at 30 Hood Canal stations sampled in June 2004. The abundance of most species drops dramatically at low DO concentrations. (Source: Ecology)



Impacts to the Ecosystem

The pattern in losses of valued benthic organisms measured in Hood Canal in 2004 resembles that described previously for other fjords (Pearson and Rosenberg 1976). The most sensitive species found were among those previously identified elsewhere as most at-risk from the effects of hypoxia (Diaz and Rosenberg 1995). However, because many other natural factors can influence the structure of infaunal invertebrate communities, the actual causes of benthic impairment in Hood Canal are not certain. It is probable that the DO concentrations are limiting and contributory, but they may not be the sole cause of impairment. Results of this study will serve to better quantify the relationships between sediment and water column variables that impact benthic invertebrate communities in Hood Canal and will improve our ability to predict the impact of continued decreasing DO levels on these communities and the populations of bottom-feeding fish and macroinvertebrates that rely on benthic invertebrates as food sources.

Human Health Consequences

Low dissolved oxygen in marine waters does not directly affect humans, but several major fish kills that may be associated with hypoxia have occurred in Hood Canal during the past several years. The results of the 2004 sediment quality survey also suggest that Hood Canal's infauna is adversely affected by hypoxia. Many of these species are important prey for fish, such as sole and flounder, and invertebrates, such as shrimp and crabs, that support valuable commercial and recreational fisheries.

b. Geoduck Clam

The large burrowing Pacific clam (*Panopea abrupta*), also known as the geoduck, is abundant and an important suspension-feeder in the inland waters of Puget Sound. The geoduck is long-lived (162+ years), and represents a large portion of the animal biomass embedded in the benthos. Geoducks have historic cultural significance to tribal communities and have been harvested in the intertidal zone by Washington residents since the late 1800s. The subtidal geoduck population has been commercially exploited since 1969, with harvest occurring in south and central Puget Sound, Admiralty Inlet, northern Hood Canal, and the eastern Strait of Juan de Fuca. Geoduck beds are found outside of these regions but may encompass smaller areas and have lower average densities than commercial beds.

Status and Trends

The statewide geoduck biomass estimate from commercial beds was 181 million pounds in 2005. The stock assessment information for geoduck populations is gathered through scuba surveys between the water depths of -18 to -70 feet (-5 to 121m)[5]. An additional 47 million pounds are estimated but were unavailable for commercial harvest, because of pollution status. The geoduck fishery continues to be the largest and most economically important clam fishery on the west coast of North America. In 2005, the combined state and tribal commercial geoduck harvest was 4.6 million pounds (Figure 2-15).

Estimates of geoduck biomass have increased over time (Figure 2-16), because of increased survey and harvest area and refinement and reduction of closed and prohibited area classifications by the Washington Department of Health. In 1996, the statewide commercial geoduck biomass estimate was about 134 million pounds and, in 2005, this estimate had increased to 181 million pounds.

Despite the recent increase in harvestable biomass, geoduck recruitment (establishment of new individuals) appeared to be in decline from the 1920s to the 1980s, in both British Columbia and Washington state. A focused effort to obtain large samples of geoduck (500 to 1,000 animals per sample site) from many locations was undertaken from 1999 to 2005, to age the individuals and examine trends in spatial and temporal patterns of geoduck recruitment. Although analysis is continuing, the work has helped to confirm a relative decline in geoduck recruitment from the mid-1950s through the mid-1970s and more recently an improvement in recruitment. It is believed that recruitment has returned to historic levels; however, the environmental factors that may have contributed to the observed trends are under further study. Preliminary results indicate that the geoduck population is healthy and the commercial fishery is being managed on a sustainable basis.

Impacts to the Ecosystem

Along with oysters, mussels, and other clam species, geoducks are important grazers of phytoplankton in Puget Sound. Examination of geoduck gut contents suggests that geoducks feed exclusively on phytoplankton. Removal of geoducks might affect phytoplankton levels on a localized basis, although geoducks in the upper photic zone are not harvested in the commercial clam fishery.

[5] Corrected to the 0.0-foot tide level.

Figure 2-15. Landings and values of commercial geoduck clams fisheries in Washington. Landings are the same as harvests in commercial fisheries whereas biomass is calculated from surveys. (Source: WDFW)

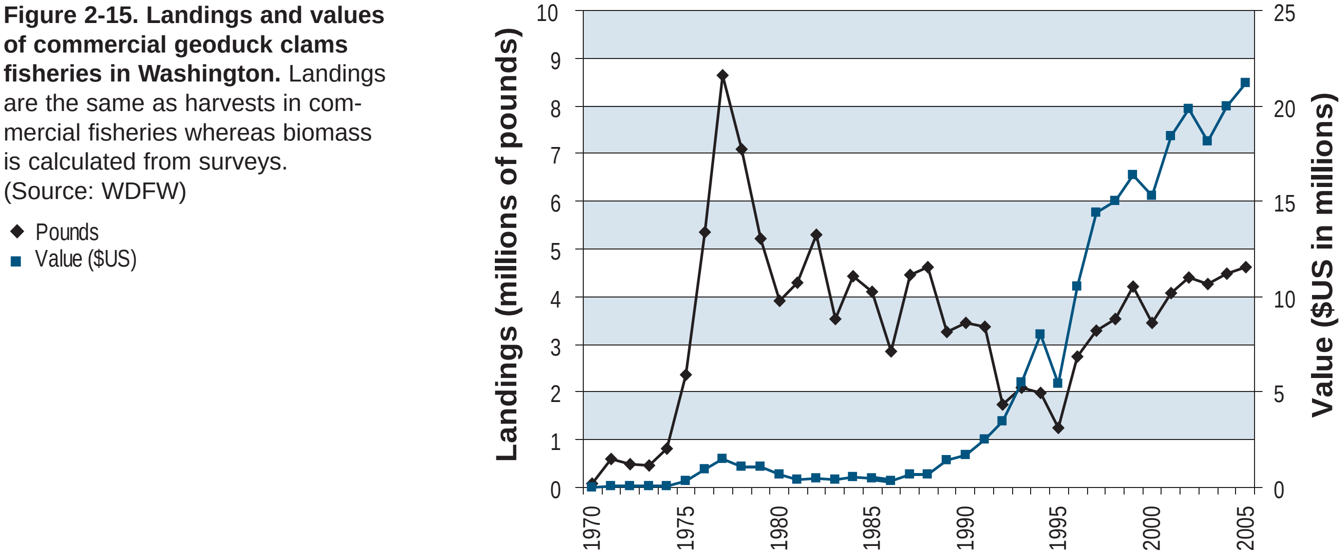
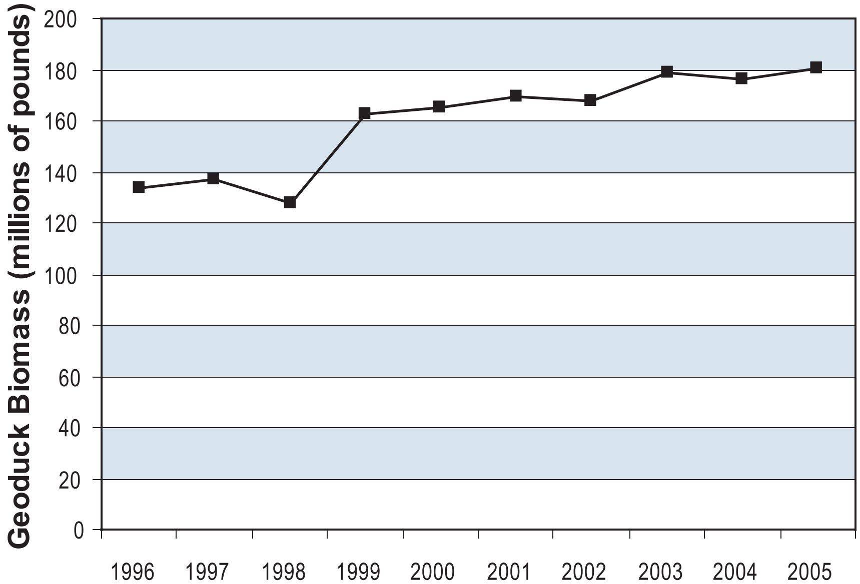


Figure 2-16. Geoduck biomass estimates for Puget Sound. Changes in commercial geoduck biomass estimates over the last 10 years, based on scuba surveys. Surveyed biomass estimates have increased during this period. (Source: WDFW)



Focus Study

Geoduck Studies in Hood Canal

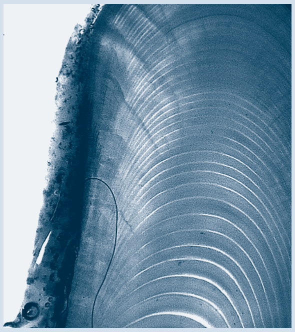


Figure 2-17. Cross-section of geoduck shell, showing annual growth rings. Photo courtesy of Juan Valero, University of Washington

Stock assessment surveys of subtidal geoduck populations in Hood Canal have been ongoing since 1969. Most of these surveys have been conducted using scuba transects between the -18 ft and -70 ft (-5 to 21m) water depths. In 2005, the Washington State Legislature required DNR to conduct a two-year study to determine if geoduck populations in Hood Canal have changed over time and, specifically, if they have been affected by recent low DO events. Geoduck shell chemistry may be used to reconstruct environmental conditions that may have been experienced by geoducks over the past several decades.

The initial phase of the Hood Canal study examined geoduck density changes on unharvested "tracts" in southern, central, and northern Hood Canal. Density estimates were then compared with prior surveys dating back to 1974. The second phase of this study includes studying geoduck shells from large samples (600+ animals from each subregion) to obtain age/frequency distributions and to analyze spatial and temporal geoduck recruitment patterns.

Human Health Consequences

Filter feeders remove substances from the water column and may help in removal of pathogens and toxics from the environment. The potential of geoduck clams to consume and bioaccumulate hazardous substances in the marine environment is not well studied; however, Ecology does have an ongoing evaluation program to assess levels of PSP toxins in geoduck tissue from commercial tracts. The high value of the geoduck clam resource has made the geoduck a prime target for illegal harvest, which could include harvests from polluted areas. If polluted clams, taken illegally, should make it into the marketplace, then there is a risk of human injury or death, as well as possible damage to the commercial clam fishery and the livelihoods of those involved in the fishery.

c. Sea Urchin

Three species of sea urchin—red, green, and purple—occur commonly within the inland marine waters of Washington state. Of these, red (*Stronglyocentrotus franciscanus)* and green (*Stronglyocentrotus droebachiensis*) sea urchins support important tribal and state commercial fisheries. Based on observed trends in fishery-dependent data (primarily on catch per unit effort) and direct stock assessment (abundance and size frequency), the Puget Sound sea urchin population is generally considered stable. However, population declines in specific geographic areas have necessitated harvest reductions or complete area closures because of stock conservation concerns.

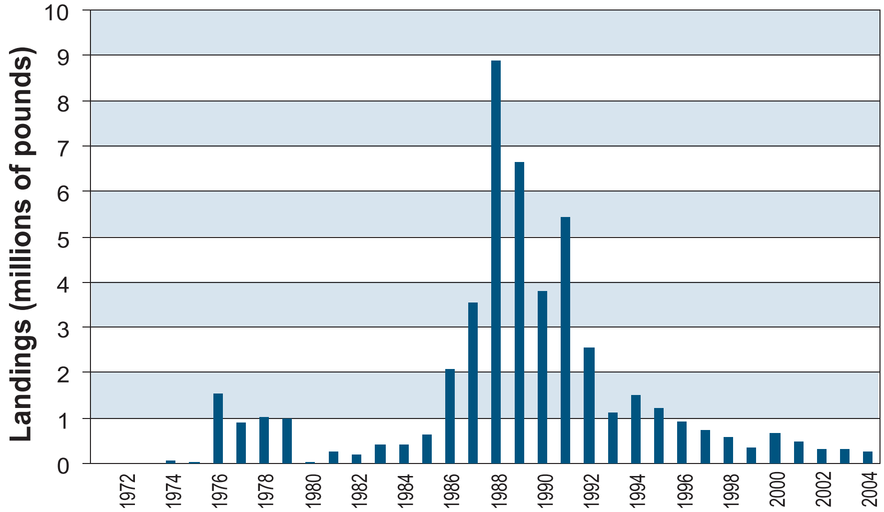
Status and Trends

The Washington state commercial fishery for red sea urchin began in 1971. The average annual landing total for the period between 1976 and 1986 was 279 metric tons (Figure 2-18). During the late 1980s, an increase in price caused a rapid expansion of harvest activities, and the red sea urchin catch rates rose sharply during this period, peaking during the 1988-1989 season. Since the early 1990s, and in response to documented declines in red sea urchin populations, annual harvest quotas have incrementally limited red sea urchin catches. Current red urchin harvest levels are 83 percent less than those from the early 1990s and 97 percent less than the peak season of 1988-1989. For the 2004-2005 harvest season, 114 metric tons of red sea urchin were landed.

The age of geoducks can be determined by analyzing the growth patterns in annuli (annual growth increments), which are analogous to growth rings in trees (Figure 2-17). This information can also be used to construct catch curves and estimates of instantaneous natural mortality for each subregion in Hood Canal. Another part of the second phase is to establish index stations for geoducks, to determine relative changes in abundance from recruitment, growth, and natural mortality.

A third phase of the Hood Canal study is to sample annuli in shells from geoducks dug in the second phase, to determine patterns of change in shell chemistry over time. This study will look for links between geoduck growth patterns with climatic conditions, including seawater temperatures and influx of fresh water from river discharges. Ratios of stable isotopes in geoduck shells and the relative oxidation states of elemental iron and magnesium in the shell matrices may also provide a pattern of oxygen-rich and oxygen-poor conditions experienced by geoducks. The geoduck is a good candidate for this type of analysis, because it is long-lived, and sufficient samples can be obtained to cross-validate growth patterns.

Figure 2-18. Landings of red sea urchins in Washington from 1971-2004. During the late 1980s, an increase in price caused a rapid expansion of the harvest, and red sea urchin catch rates rose sharply, peaking during the 1988 - 1989 period. Co-management of sea urchins between Washington State and tribes began in 1994 and resulted in annual harvest quotas to address the documented declines in red sea urchin populations. (Source: WDFW)



In 2004, a stock assessment survey of red urchins in the eastern Strait of Juan de Fuca determined that the harvestable (legal-sized) biomass was approximately 60 percent lower than that established by a survey completed in 2001 and approximately 84 percent lower than an estimate of biomass in 1991. Based on this significant and continued declining trend, sea urchin co-managers decided that a commercial harvest closure was necessary to avoid a collapse of the fishery stocks and to evaluate population dynamics in the absence of harvest.

Green sea urchin commercial fisheries in Puget Sound began in 1986. Green sea urchin landings peaked in 1988, when 461 metric tons were landed (Figure 2-19). Since 1995, landings have remained relatively stable, averaging about 100 metric tons per year. For the 2004-2005 harvest season, 87 metric tons of green sea urchin were landed statewide.

Predation from an expanding Washington state sea otter population has also resulted in significant reduction of sea urchin abundance in some localized populations in the western Strait of Juan de Fuca. A 1995 survey of red sea urchins in the Neah Bay harvest management area indicated a 71 percent reduction in population levels from a survey completed the previous year. This reduction was directly attributed to sea otter foraging during a documented range expansion of approximately 120 sea otters wintering in the Neah Bay area. Since this initial sea otter incursion, two additional documented sea otter range extensions have occurred (in 1998 and 2000) within the Strait of Juan de Fuca. A 2003 urchin survey within the Sekiu harvest management area indicated significantly reduced red sea urchin populations in localized areas. These areas corresponded to areas of documented sea otter occupation during range expansions.

Impacts to the Ecosystem

Sea urchins have been identified as the primary herbivores of Puget Sound's marine macroalgae. The ecological relationships between sea urchins and marine algal communities have been well documented. Sea urchins can be highly effective grazers of brown algae, specifically those species, such as *Nereocystis* sp. and *Macrocystis* sp., that make up kelp forests. In high enough densities and in the absence of predators, sea urchin populations can create barrens (areas denuded of macroalgae). Puget Sound ecosystem linkages to this urchin/kelp relationship may include species highly dependent on kelp assemblages (such as marine fish) or species found in association with urchin barrens (such as pinto abalone). While the dynamics of sea urchin grazing on macroalgae are quite evident, these secondary species relationships are not well understood.

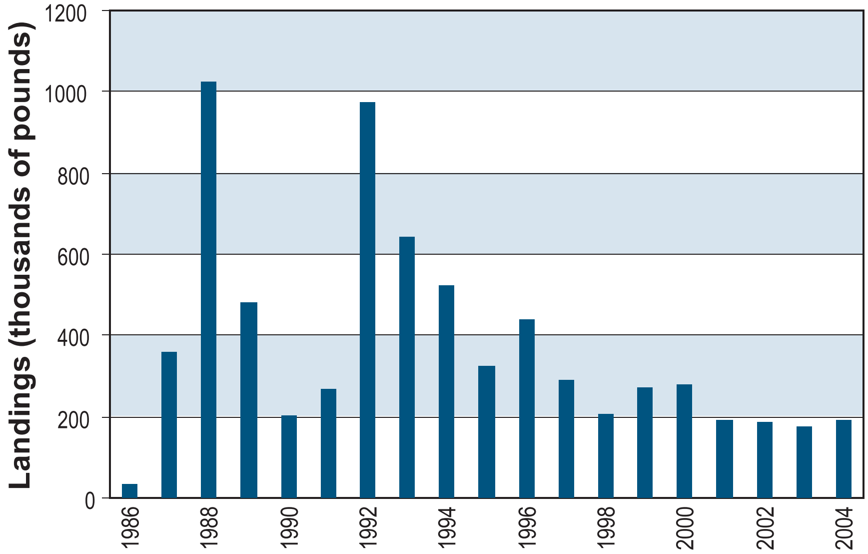


Figure 2-19. Landings of green urchin in Washington from 1986 - 2004. As with the red urchin, an expansion of green urchin harvest occurred during the mid-1980s. Green urchin landings have been relatively stable, following the onset of more controlled harvest practices in the early 1990s. (Source: WDFW)

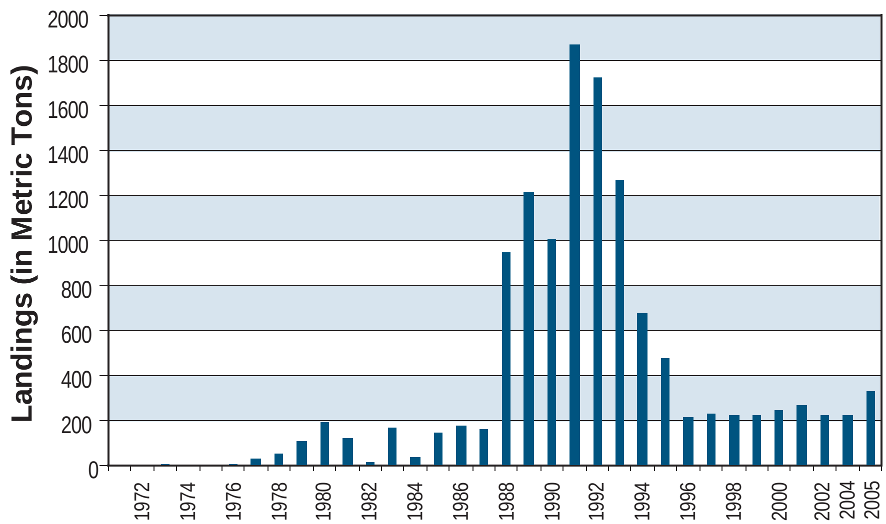


Figure 2-20. Sea cucumber landings in Washington, 1971 - 2005. Commercial harvest began in the early 1970s and, in 1994, sea cucumber harvest quotas were established for all management areas. Annual harvest quota amounts have remained fairly stable since that time. (Source: WDFW)

d. Sea Cucumber

The red sea cucumber (*Parastichopus californicus*) is ubiquitous throughout Puget Sound. It occupies a wide range of habitats, from soft mud bottoms of quiet embayments to current-swept rocky substrates and can be found from the shallow intertidal to at least 650 ft (223 m). Little is known about the basic biology and trends in abundance of the red sea cucumber in Puget Sound even though populations support a significant tribal and non-Indian commercial fishery.

Status and Trends

Commercial sea cucumber harvest began in 1971 and, since then, fishery-dependent data and limited survey information have been used to monitor and regulate sea cucumber harvests. Initially, sea cucumber harvest was permitted as an experimental fishery. Landings were relatively low and variable, averaging 188.7 metric tons between 1978 and 1987 (Figure 2-20). Harvest effort in the fishery increased dramatically, beginning in 1988 and peaking in 1991 at an annual harvest of 1,865.4 mt. The rapid increase in harvest activity led to more intensive management efforts. The current harvest management scheme is considered conservative, relative to historic high rates; however, the real harvest impact remains uncertain due to a lack of biological information.

Impacts to the Ecosystem

Throughout the world, sea cucumbers have been identified as serving an important marine ecological niche in the processing of benthic detrital materials. They may also serve as integral components in marine biogeochemical cycling. Algal blooms in Puget Sound may inhibit eutrophication because nutrients are removed from the water column. However, as the algae dies and settles to the bottom, it may cause anaerobic conditions immediately above and on the sediment layer. The role of the red sea cucumber in Puget Sound is not well understood; however, other deposit-feeding holothurians have been linked to inhibiting this anaerobic process. In laboratory experiments, algal biomass and organic matter concentrations on the substrate are reduced when deposit-feeders are present. Declining sea cucumber populations worldwide have been an issue of recent debate. Sea cucumbers are extremely vulnerable to over-exploitation due to their late maturity, density-dependent reproduction, low survival of larvae, and ease of collection by humans. Many sea cucumber fisheries around the world are over-exploited. These declining populations not only result in a reduction of harvestable product but may have a prolonged impact on sediment cycling.

e. Pinto Abalone

Pinto abalone (*Haliotis kamtschatkana*) are most commonly found in nearshore rocky habitats at depths ranging from shallow subtidal to 35 ft (10.7 m). Individuals are occasionally found at deeper depths, over 100 ft (30.5 m). Adults feed on drift macroalgae, with the major component of the diet being giant kelp. Abalone have a relatively short planktonic larval phase, which lasts between four to seven days. A specific type of algae called crustose coralline algae may play an important role in the settlement of larval abalone onto suitable rocky habitat. Abalone may also be associated with red and green sea urchins. These three animals are important herbivores in the nearshore rocky environment and keep rocky substrate clear, allowing settlement of other invertebrate species.

Status and Trends

Data from 10 index sites in the San Juan Archipelago from 1992 to 2005 and anecdotal information from historic abalone observations suggest the pinto abalone is undergoing significant declines. Commercial harvest of abalone has never been permitted, and statewide recreational harvest of abalone was closed in 1994. WDFW listed the pinto abalone as a candidate species for protection in 1996, and NOAA Fisheries listed it as a species of concern in 2004.

Focus Study

Sea Cucumber Recruitment Study

In 2005, WDFW initiated a fishery independent pilot study to test the feasibility of using juvenile sea cucumber collecting devices as an index to determine sea cucumber recruitment. At each of three locations throughout Puget Sound, 12 juvenile sea cucumber collectors were installed and monitored. Juvenile sea cucumbers were found in collectors at two of the three study sites. Initial settlement was by juvenile sea cucumbers ranging in size from 0.12 inches (3 mm) to 0.67 inches (17 mm). Future implementation of monitoring systems to study long-term annual recruitment could provide managers with an important population assessment tool for detecting trends in the health of exploited sea cucumber populations. Given the wide range of habitat types and depths that sea cucumbers inhabit, monitoring juvenile red sea cucumber recruitment in Puget Sound could serve as a useful indicator of overall ecosystem health.

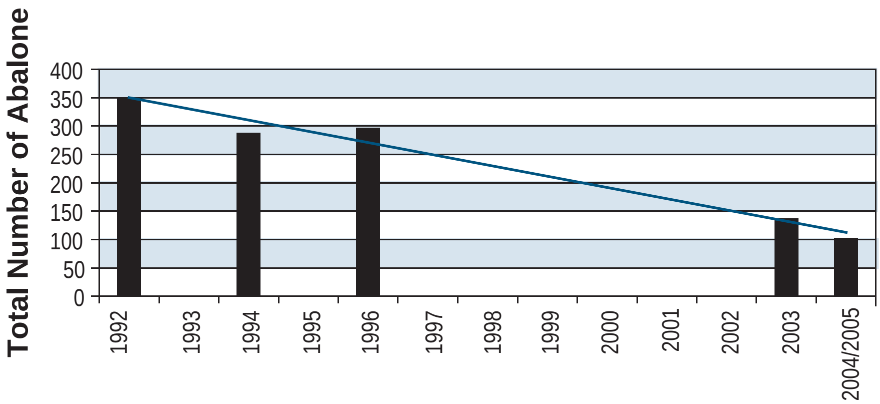


Figure 2-21. Abalone abundance in San Juan Archipelago. Abalone abundance at 10 index stations from 1992-2005 in the San Juan Archipelago indicates a steady decline in number of animals per site. Even with the elimination of fishing in 1994, pinto abalone continue to decline dramatically throughout Washington. (Source: WDFW)

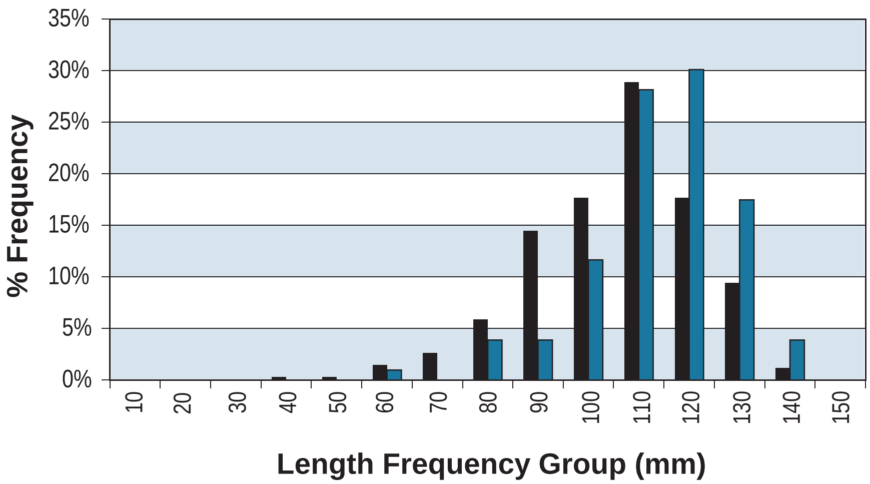


Figure 2-22. Abalone shell size in San Juan Archipelago. Abalone shell measurements from index sites in the San Juan Archipelago indicate fewer smaller animals in 2004-2005 compared with 1992. The mean size of abalone in 1992 was 4.2 inches (105.3mm), and, in 2004-2005, the size was 4.5 inches (113.7 mm). This suggests a shift in population from smaller (younger) to larger (older) animals, which may reflect a decline in recruitment at these sites. (Source: WDFW)

Between 1979 and 1980, WDFW conducted dive surveys at 30 locations in the San Juan Archipelago. Twenty-three of these stations were re-visited between 1990 and 1991. Comparisons showed that abalone numbers had declined by roughly 50 percent from 1979 to 1991. Counts at one site had increased, counts at four of the sites were the same, nine sites had fewer abalone, and no live abalone could be found at the remaining nine sites.

Because of problems with duplicating the original survey method, WDFW established 10 permanently delineated abalone index sites in 1992. These sites were distributed around the perimeter of the San Juan Archipelago. The sites range in size from 1,453 ft^2 (135 m^2) to 4,090.3 ft^2 (380 m^2), and individual animals are counted during each survey. The site surveys have been repeated in 1994, 1996, 2003, and 2004-2005. Data from these surveys show a trend of continued decline in abalone abundance of roughly 70 percent from 1992 to 2004-2005 (Figure 2-21). Limited data exist for the Strait of Juan de Fuca populations, but anecdotal information suggests similar trends to those observed in the San Juan Archipelago.

WDFW also conducted shell length surveys to measure abalone age demographics from the index sites. Shell length data show a significant decrease in smaller abalone (less than 35.4 inches or 90 mm in shell length) since 1992. The mean length of abalone at index sites in 1992 was 4.2 inches (105.3 mm). By 2004-2005, the mean had increased 0.3 inches (8.4 mm) to 4.5 inches (113.7 mm) in length (Figure 2-22), representing a shift in the population from smaller (younger) to larger (older) animals.

It appears from the San Juan data that abalone in Washington state are experiencing recruitment failure. This failure is not completely understood. It may represent an Allee effect, in which reproductive potential of the population is reduced through shift in age distribution of individuals and decline in the density of organisms. Abalone and other broadcast-spawning sedentary invertebrates need minimum densities of >1.1 to 0.5 individuals per ft^2 (>0.33 to 0.15 individuals per m^2) for successful reproduction (Babcock and Keasing 1999). In 1996, five of 10 stations fell within this density threshold. By 2003, only one of 10 stations was within this range. Other research has shown that juvenile abalone recruitment drops significantly, or is eliminated entirely, if the adult population drops below 50 percent of its initial density (Richards and Davis 1993). WDFW data suggest that similar magnitudes of decline have occurred at least twice over the past 25 years.

Impacts to the Ecosystem

Abalone are important herbivores in nearshore rocky habitats. In conjunction with other herbivores, such as red, green, and purple sea urchins, they have the ability to bio-engineer—that is, change—their local ecosystems. These important herbivores keep areas of rocky habitat open for settlement by other marine invertebrates. While the primary consequence of large populations of herbivores grazing on macroalgae is quite evident in the form of urchin barrens (areas where urchins have extensively grazed algae down to bare rock), the secondary consequence of species diversity and composition is not well understood.

f. Puget Sound Crabs

Several species of crab are found in Washington's marine waters and along its shores. Dungeness crab (*Cancer magister*) is the primary target for commercial and recreational fishers with some non-commercial effort focused on red rock and graceful crab. Puget Sound's Dungeness crab fisheries target males only, with a minimum shell carapace width of 6.25 inches (158.8 mm). The seasons of the fisheries occur only when 80 percent or more of the legal-sized males are in hard shell condition, in order to reduce fishing-induced mortality on the grounds. The design of Puget Sound's Dungeness crab fisheries begins with the conservation criteria and includes allocation objectives required to meet state and federal mandates.

Status and Trends

Currently, there is no monitoring of crab populations and harvest numbers are used to reflect abundance and, thus, estimate the population size. Three criteria—sex, size, and season—are factored into the population estimates. Dungeness crab harvest trends since the 1995-1996 season show a stable and steady increase from six million pounds per season to eight million pounds per season taken from Puget Sound by all groups (Figure 2-23).

7. Fish

a. Groundfish

Groundfish are those marine fish species that live near or on the bottom for most of their adult lives. Over 150 groundfish species inhabit Puget Sound, and several of these once supported thriving commercial and recreational fisheries. Groundfish species also comprise a major component of the biomass of the Puget Sound ecosystem and contain many links in the food web, connecting nearshore and midwater components to the benthos. During the past two decades, species including Pacific cod (*Gadus macrocephalus*) and Pacific hake (*Merluccius productus*),

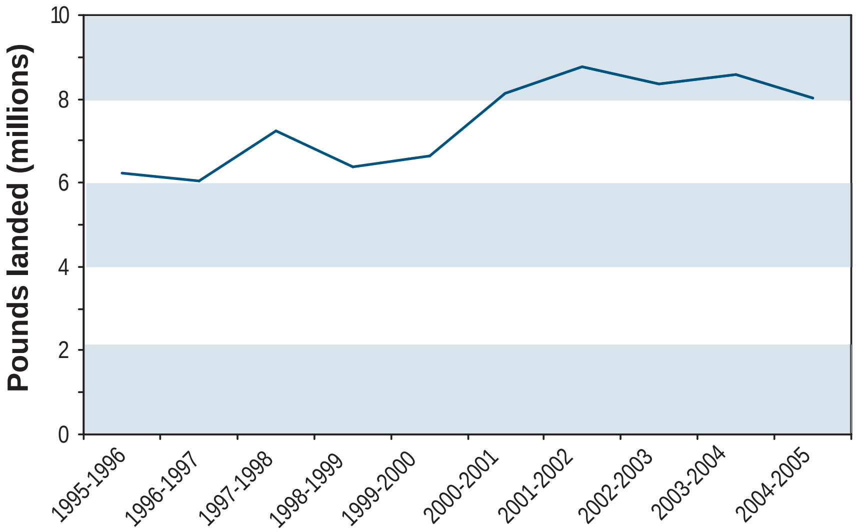


Figure 2-23. Puget Sound Dungeness crab harvest. Current estimates of crab abundance are based on pounds harvested. The sex, size, and season of the catch help determine the remaining crab abundance. Between 1995 and 2005, the biomass of crab harvested annually has increased from six million pounds (2.7 million kilograms) to approximately eight million pounds (3.6 million kilograms).
(Source: WDFW)

walleye Pollock (*Theragra chalcogramma*), spiny dogfish (*Squalus acanthias*), and several species of rockfish have declined to alarmingly low levels. Among the species in decline are many major predators of fish and shrimp that linked lower trophic levels with upper ones. In 1999, petitions for most of these species were filed to NOAA Fisheries for consideration under the ESA. The subsequent review did not find sufficient evidence of genetic uniqueness or of decline that threatened extinction; however, Pacific hake remained a federal candidate species. In addition, cod, pollock, hake, and 13 species of rockfish were added as candidate species to the Washington State Endangered Species List. In mid-2006, a new ESA petition was filed to consider copper (*Sebastes caurinus*) and quillback (*Sebastes maliger*) rockfish in waters south of Port Townsend as threatened or endangered.

WDFW co-manages groundfish with the treaty tribes of Washington. WDFW has reviewed the status of many groundfish species (Palsson et al. 1997, PSAT 2000, PSAT 2002) and found that the majority of stocks have been in poor condition in north and south Puget Sound. WDFW's management approach is defined under the Puget Sound Groundfish Management Plan (Palsson et al. 1998), which outlines a precautionary approach to management through the creation of conservation and harvest plans. The management of most groundfishes is separated into two regions: North Sound (the Strait of Juan de Fuca, San Juan Archipelago, and the Strait of Georgia and adjacent bays) and South Sound (Puget Sound proper, Hood Canal, the Whidbey Basin, and Southern Puget Sound).

Status and Trends

Previous reviews of groundfish populations in Puget Sound have primarily depended upon the relative measures of how well fisheries have performed over time. With the decline of important groundfish populations and the corresponding restrictions of their fisheries, most of these fishery-dependent measures are no longer as useful. WDFW has been conducting surveys that do not depend upon the performance of commercial and recreational fisheries and that also mirror the relative change in fish populations without having to control for changes in fisheries management actions. The primary survey has been the bottom trawl survey, conducted at irregular intervals since 1987 (Schmitt and Quinnell 1989, Palsson et al. 2002, 2003), and the trend results of this and scuba and video surveys generally correspond to the trends in fishing performance (Palsson 2002).

Table 2-3. 2006 Groundfish stocks status in Puget Sound. North Sound is defined as the Straits of Juan de Fuca and Georgia and the San Juans; South Sound is defined as those waters south of Port Townsend. While the trend categories of above average, average, below average, depressed, and critically depressed do not necessarily represent biological reference points, they roughly correspond to limits established by fishery managers for maintaining healthy spawning biomasses or the criteria for marine fish stocks at risk. (Source: WDFW)

Species	North Sound	South Sound
Spiny Dogfish	Below average	Depressed
Skates	Below average	Above Average
Spotted Ratfish	Average	Above Average
Pacific Cod	Critical	Critical
Walleye Pollock	Below Average	Critical
Pacific Whiting	Above Average	Critical
Rockfishes	Critical	Critical
Lingcod	Above Average	Above Average
Sablefish	Critical	Average
Greenlings	Unknown	Average
Wolf-eel	Unknown	Unknown
Surfperches	Unknown	Below Average
Sculpins	Above Average	Above Average
English Sole	Above Average	Above Average
Rock Sole	Above Average	Below Average
Starry Flounder	Above Average	Average
Dover Sole	Average	Depressed
Sand Sole	Average	Above Average
Pacific Halibut	Above Average	Above Average
Other Groundfish	Unknown	Unknown
Good Condition	12	9
Poor Condition	6	9
Unknown	2	2

For the purposes of this report, survey or fishery trends will be reviewed and compared to the criteria established by Palsson et al. (1997). While the trend categories of above average, average, below average, depressed, and critically depressed do not necessarily represent biological reference points, they roughly correspond to limits established by fishery managers for maintaining healthy spawning biomasses or to the criteria for marine fish stocks at risk (Musick 1999). When applying trawl survey trends in north Puget Sound to stock assessment, only the results from the southern Strait of Georgia and eastern Strait of Juan de Fuca will be used to characterize the entire area.

As of 2005, almost 60 percent of the groundfish stocks in Puget Sound were in good (average or above-average) condition (Table 2-3)—a change over the previously evaluated stock conditions that were either equivocal or mostly in poor condition. In the North Sound, 10 stocks were in good condition, six were in poor condition, and the status of four stocks was unknown. In the South Sound, 10 stocks were in good condition, eight were in poor condition, and two were in unknown condition. In general, populations of codfishes continue to be in poor or critical condition, except Pacific hake in the North Sound. Most flatfish, sculpin, and lingcod populations are in above-average condition, dogfish populations are in poor condition, and rockfish populations are in critical condition.

Among the assessed sharks and skates, trawl survey of spiny dogfish biomass indicate that these populations have declined by 30 percent in North Sound and by 69 percent in South Sound resulting in status classifications of below average and depressed respectively. Skates were below average condition in North Sound, having declined by 32 percent among trawl surveys but were in above average condition in South Sound. Spotted ratfish, the most dominant species of groundfish, was in average condition in North Sound but has increased in biomass by 57 percent in recent times in South Sound, compared to the long-term average.

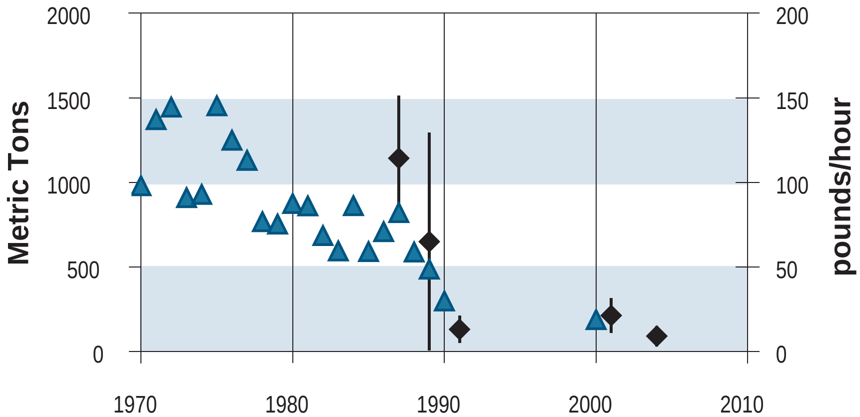


Figure 2-24. Pacific cod biomass in north Sound. Fishery and survey trends of Pacific cod abundance in the north Sound indicating a steady decline in this species since the mid-1970s. (Source: WDFW)

◆ Survey
▲ Trawl pounds/hour

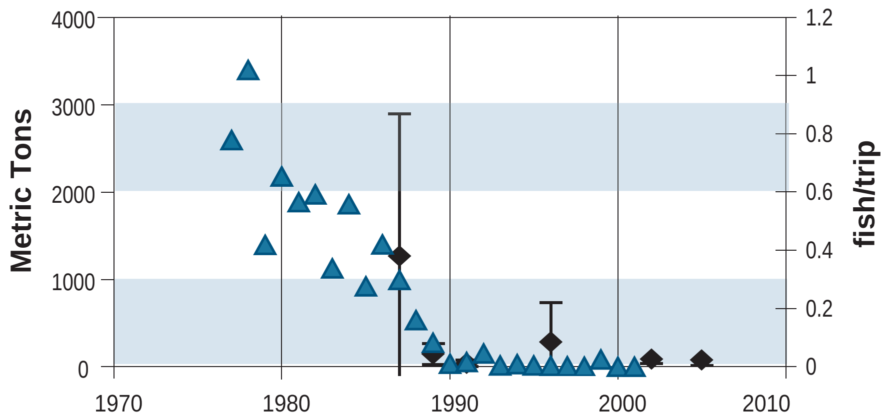


Figure 2-25. Pacific hake biomass in south Sound. Fishery and survey trends of Pacific cod abundance in the south Sound reveal a nearly depleted stock in the past 15 years. (Source: WDFW**)**

◆ Trawl
▲ Catch per unit effort

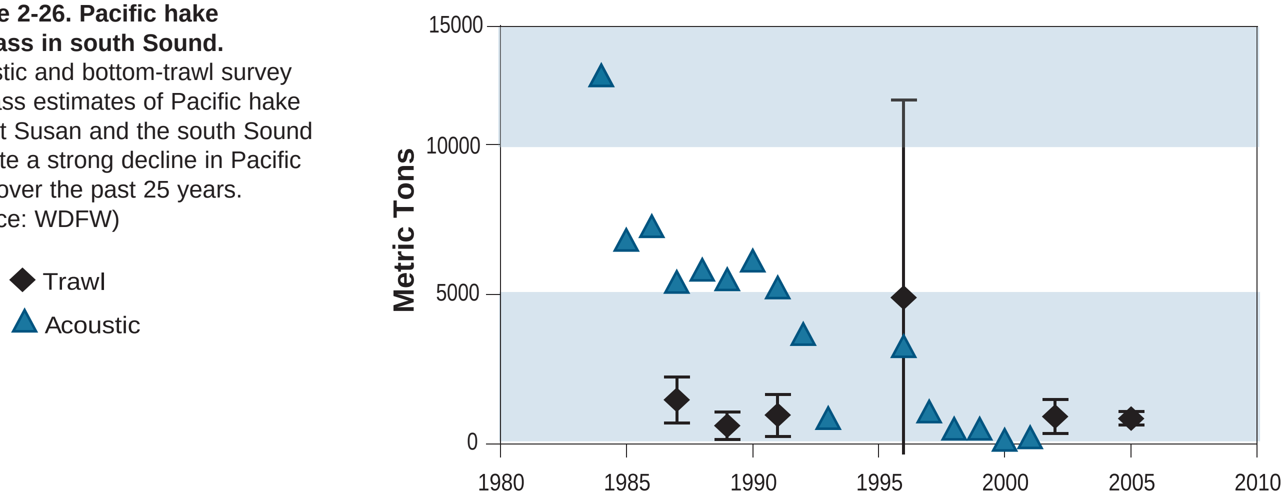
Most populations of codfishes, especially Pacific cod, have undergone dramatic declines in previous decades and have shown little signs of recovery despite prohibitions or restrictions on their fisheries. Pacific cod were once targeted by commercial and recreational fishers and were easily caught during the 1970s and early 1980s. However, indices of fishing success have declined by 60 percent before the commercial fishery in the Strait of Georgia and north Sound was restricted to quota management for cod in 1997 (Figure 2-24) and by 76 percent in the south Sound before the recreational fishery was closed in 1991 (Figure 2-25). The trawl surveys confirm that these trends are continuing. In North Puget Sound, recent biomass estimates have declined by 80 percent, and, in the south Sound, biomass estimates have declined by 75 percent compared to the 20-year mean status assessments of critical for both stocks.

Along with cod and pollock, Pacific hake (also known as Pacific whiting) was considered for ESA listing. In the north Sound, hake populations appear to be doing well, with recent trawl survey biomass 89 percent above the long-term mean (1980-2005). In the south Sound, hake in the Everett area were once assessed by an acoustic-trawl survey. Over time, the abundance of the adult population decreased by 78 percent, with some suggestion of a rebound in 2002, when the acoustic survey ended (Figure 2-26). The bottom trawl survey is not the best means to assess stocks of these pelagic fishes, but it does indicate a 47 percent decline over the long-term mean. As a result, the south Sound hake population status is characterized as critical.

What is a fish ‘stock?’

A stock is an interbreeding group of fish that is reproductively isolated (spawning at a different location or time) from other such groups.

Figure 2-26. Pacific hake biomass in south Sound. Acoustic and bottom-trawl survey biomass estimates of Pacific hake in Port Susan and the south Sound indicate a strong decline in Pacific hake over the past 25 years. (Source: WDFW)



Recent biomass estimates of walleye pollock in north Sound were 32 percent below the long-term mean, resulting in a below-average status. In the south Sound, the recreational fishing success for pollock declined to zero by the late 1980s, but recent trawl survey biomasses are only slightly below the long-term average. The apparent recovery may be due to relatively abundant concentrations in the Port Townsend area. Regardless, the collapse of the pollock fishery and low abundance in more southern extremes results in a critical condition status for pollock in the south Sound.

Over 27 species of rockfishes have been recorded in the inland marine waters of Washington. Only 10 of these have been commonly captured in recreational fisheries and two, copper and quillback rockfishes, are the most dominant species. Fishery and survey data are most available for these two species. The fishery-dependent information is used to estimate the spawning potential index of these common species. This index combines the changes in size composition of the populations and the corresponding fecundity with and the index of relative abundance based upon the fishing success of the recreational anglers fishing success. From the mid-1970s to 1999 (the last year of relatively unrestricted fishing), the spawning potential curves declined to less than 26 percent of either copper or quillback rockfishes in the north or south Puget Sound (Figures 2-27 and 2-28). Trawl, scuba, and video surveys of rockfish corroborate these continued declining trends in most regions as exemplified by the declining abundance of quillback rockfishes in south Sound observed from trawl surveys (Figure 2-29) and result in critical classifications for rockfishes in both the north Sound and south Sound.

Many other populations of groundfish are thriving. In particular, English sole (*Parophrys vetulus*), most other flatfishes, and lingcod (*Ophiodon elongatus*) are in above-average condition in the north and the south Puget Sound. Lingcod in the north Sound were abundant during the late 1970s and early 1980s, but declined to extremely low abundance in the early 1990s (Figure 2-30). Changes to fishing regulations and the fish's good survival resulted in increased harvest success in recent years. In the south Sound, increasing success in lingcod fishing has occurred since the early 1980s when fishing was resumed after a five-year moratorium.

All monitored flatfish species are in average or above-average abundance in the north Sound, with recent English sole biomass 42 percent greater than the long-term average. After several years of decline during the 1990s, English sole biomass

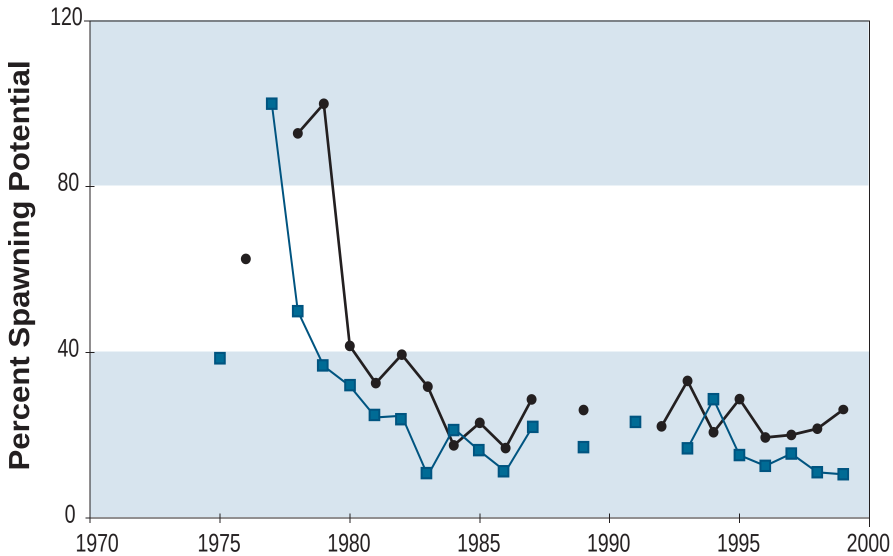


Figure 2-27. Copper rockfish spawning potential in Puget Sound. Spawning potential of copper rockfish in Puget Sound has dropped significantly since the late 1970s and continues to remain low. (Source: WDFW)

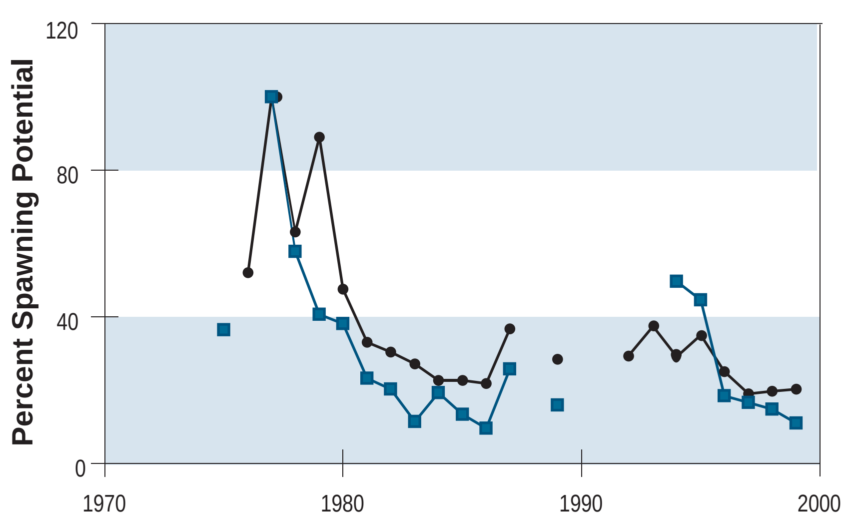


Figure 2-28. Quillback rockfish spawning potential in Puget Sound. Spawning potential of quillback rockfish in Puget Sound has dropped dramatically since the late 1970s and has continued to decline in recent years. (Source: WDFW)

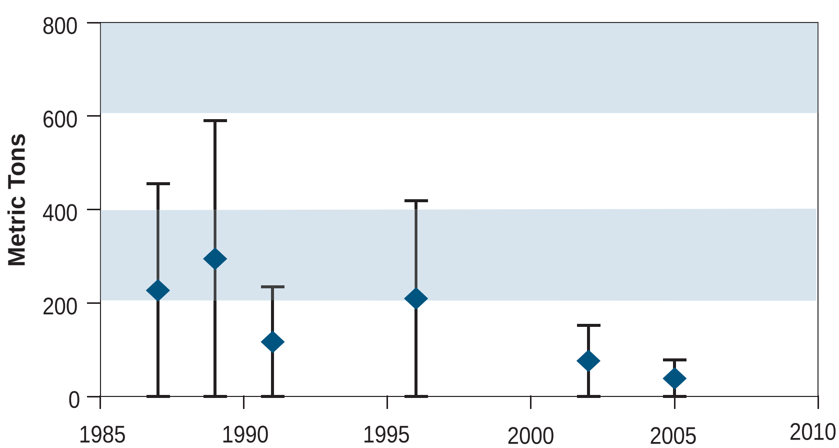
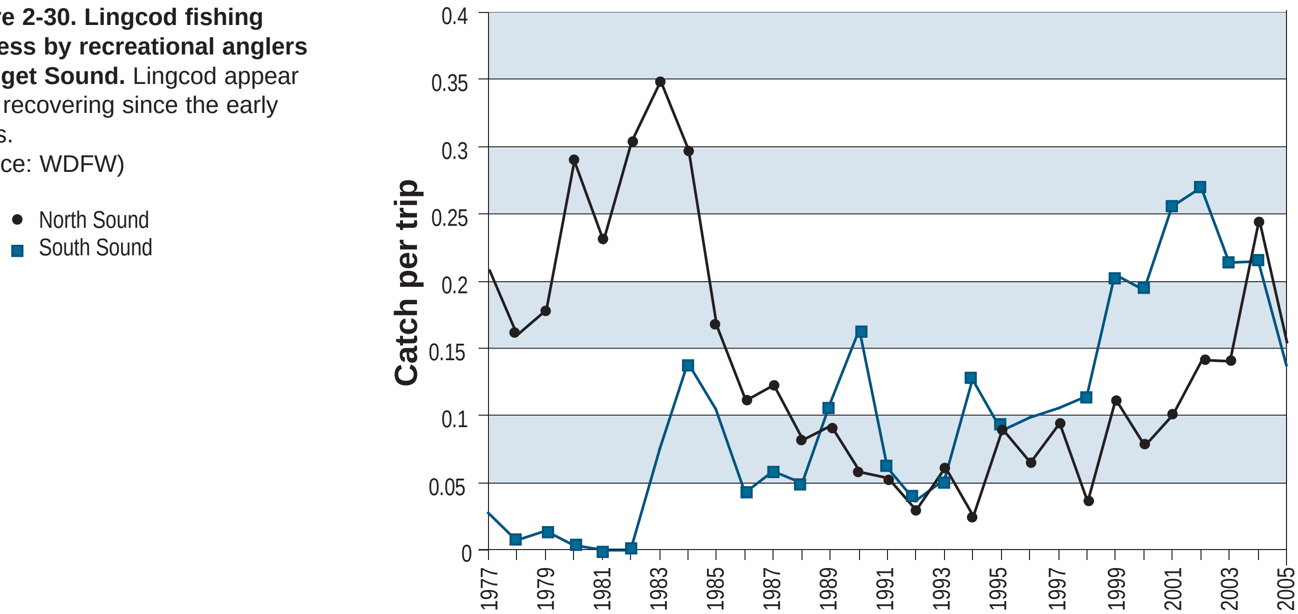


Figure 2-29. Quillback rockfish biomass in south Sound. The biomass of quillback rockfish, as determined by bottom-trawl surveys, indicates the continued decline in this species in South Puget Sound. (Source: WDFW)

Figure 2-30. Lingcod fishing success by recreational anglers in Puget Sound. Lingcod appear to be recovering since the early 1990s.
(Source: WDFW)



in the south Sound has recovered to levels observed in the late 1980s. Recent survey biomass is now 17 percent above the long-term average. Starry flounder and sand sole are in average and above-average abundances, but long-term declines of rock sole and Dover sole have resulted in below-average and depressed stock status for these species.

Impacts to the Ecosystem

The reasons for the declines of groundfish species are complicated because the cause-and-effect relationships are difficult to establish and many suspected stressors have been simultaneously at play. Pacific cod and walleye pollock populations are the most southerly distributed groundfish that occur along the West Coast, and warmer Puget Sound temperatures may be suppressing their spawning success. Spiny dogfish and rockfishes share life history characteristics, including delayed maturity, slow growth rates, and longevity that make them vulnerable to fishing pressure. The dramatic differences in abundance and size of rockfishes from marine reserves and fished areas in Puget Sound strongly support the conclusion that fishing controls the abundance, size and structure of populations and may be responsible for the declines of once-commonly caught species. Other stressors to fish populations may be acting in concert with more direct stressors. Toxic compounds have been shown to be prevalent in English sole and rockfish and may alter these fishes' success at reproduction and growth. How all these stressors interact is not known; however, there appear to be long-term changes in the community and trophic structure of groundfishes in Puget Sound. In the north Sound, the overall abundance of groundfish has not changed since 1987, but codfishes, other groundfish, and dogfish have become less abundant, while flatfishes have increased in biomass (Figure 2-31). In the south Sound, biomass was lower in 1989 and 1991 but, more recently, has been comparable to the 1987 level. However, over time, codfishes and dogfish have become extremely low in abundance, with a concomitant increase in ratfish. Whether or how the trophic structure is changing is not yet understood, but it has been suggested that declines in cod and dogfish, which feed on juvenile crabs and fishes, may have released ratfish, flatfishes, and Dungeness crab from predation pressure or limited food resources, enabling these fishes to increase in abundance.

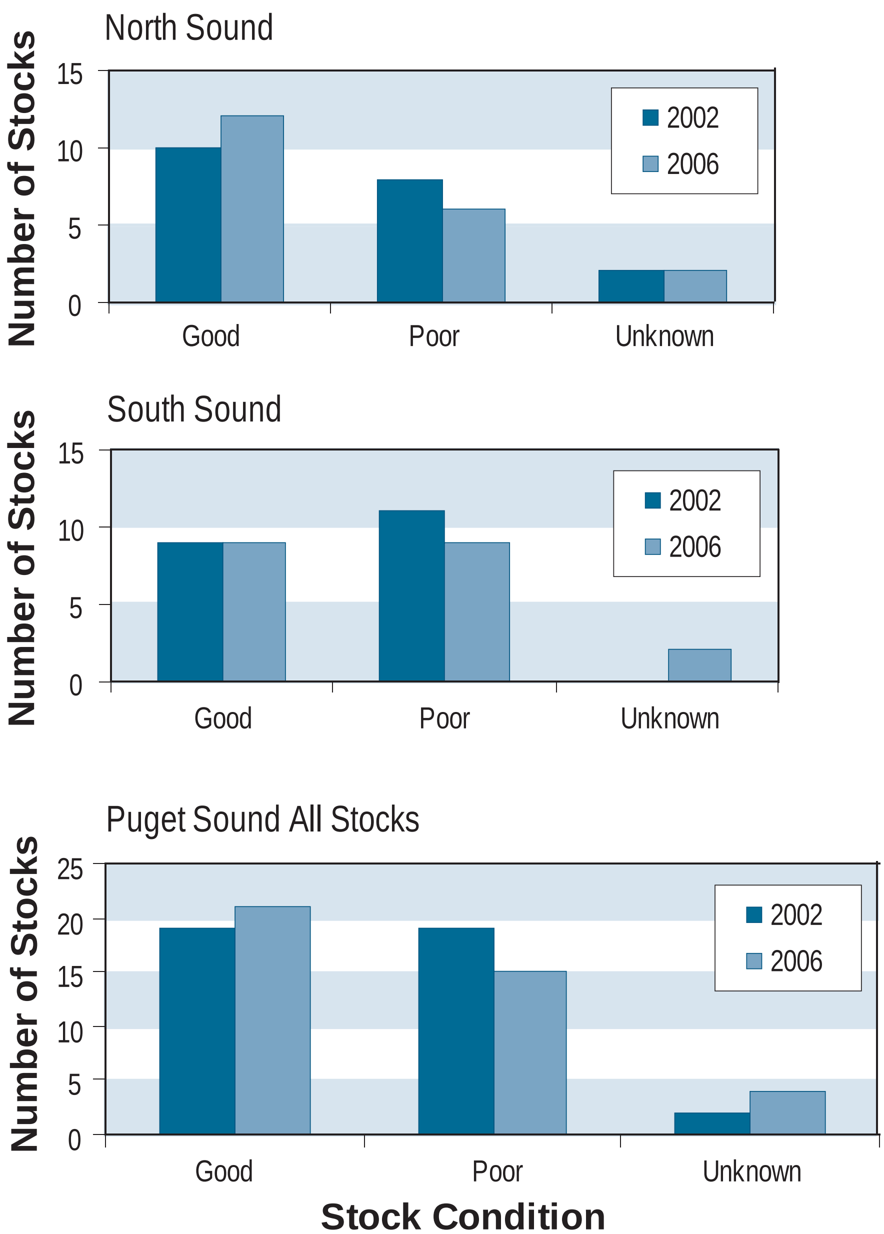


Figure 2-31. Groundfish stock conditions 2002-2006 north Sound and south Sound. Ratfish have increased in South Sound, although dog fish and cod have declined throughout Puget Sound. Flatfish remain fairly steady in south Sound and have increased in abundance in north Sound. (Source: WDFW)

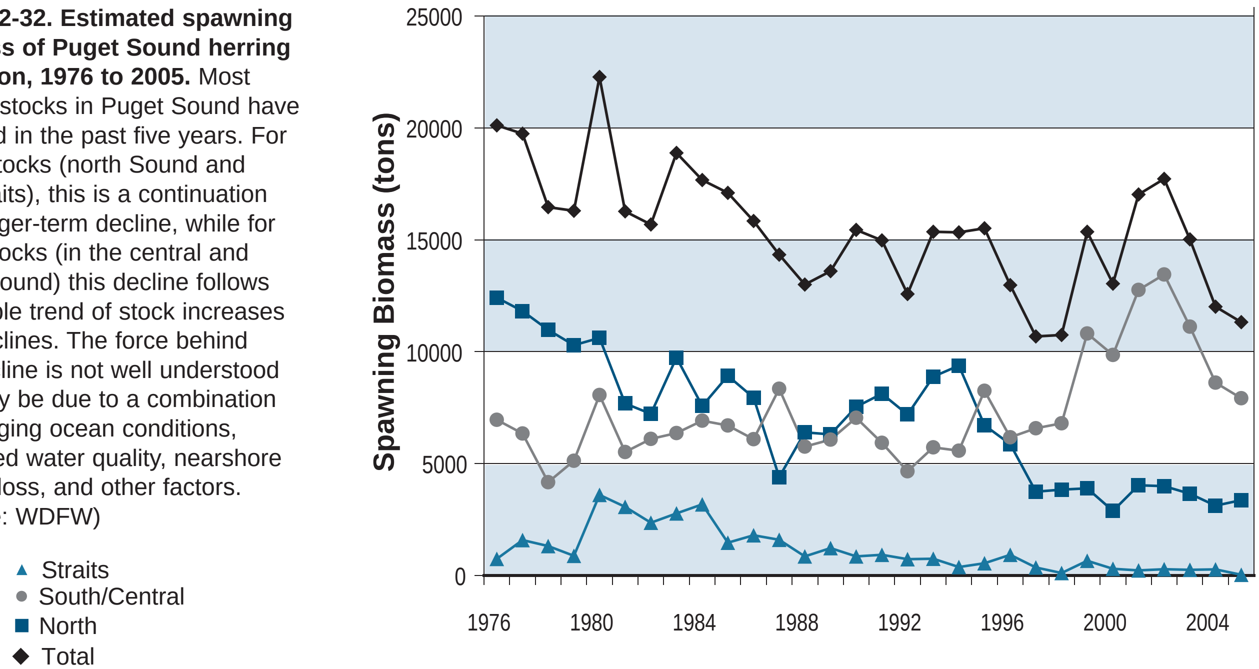
b. Forage Fish in Puget Sound

Forage fish are small schooling species that are important food organisms for a wide variety of animals, including seabirds, marine mammals, and predatory fish. They feed mainly on zooplankton and phytoplankton and reside in the upper levels of the water column and in nearshore areas.

i. Pacific Herring

WDFW recognizes 19 different stocks of Pacific herring (*Clupea pallasi*) in Puget Sound, based primarily on the timing and location of spawning activity. Annual herring spawning biomass is estimated for each stock using spawn deposition surveys and acoustic-trawl surveys. Spawn deposition surveys provide a direct estimate of herring spawning biomass. Marine vegetation on spawning grounds is

Figure 2-32. Estimated spawning biomass of Puget Sound herring by region, 1976 to 2005. Most herring stocks in Puget Sound have declined in the past five years. For some stocks (north Sound and the Straits), this is a continuation of a longer-term decline, while for other stocks (in the central and south Sound) this decline follows a variable trend of stock increases and declines. The force behind this decline is not well understood and may be due to a combination of changing ocean conditions, degraded water quality, nearshore habitat loss, and other factors. (Source: WDFW)



sampled for the location of spawn deposition and spawn density, and those data are converted to an estimate of spawning escapement. Acoustic-trawl surveys are conducted in the areas where spawners aggregate early in the spawning season, when pre-spawner abundance is peaking.

Status and Trends

The cumulative abundance of spawning herring in Puget Sound has decreased since 2002, when the total reached 17,700 tons (Figure 2-32). This total reflects the trend exhibited by the combined biomass of south and central Puget Sound herring stocks, which increased from 1997 to 2002, then decreased through 2005.

In northern Puget Sound, herring stocks have remained suppressed, primarily because of the continued critical status of the Cherry Point herring stock. Recent research has indicated that the Cherry Point herring population is genetically distinct from other Puget Sound and British Columbia herring stocks. However, a review by NOAA in 2005 concluded that this stock did not meet the ESA criteria

Focus Study

Sixgill shark study in Puget Sound

WDFW, in partnership with the National Marine Fisheries Service (NMFS), has been conducting basic biological research on sixgill sharks (*Hexanchus griseus*) in Puget Sound since 2003. This research is oriented towards obtaining basic biological knowledge on the abundance, age, geographical distribution, and movements of these sharks within Puget Sound. Sixgill sharks have been captured with longline fishing gear and tagged with visual external tags or internal acoustic tags. The Seattle Aquarium is also conducting a companion study in Elliott Bay.

Between 2003 and 2005, 291 sixgill sharks have been captured. Of these, 262 have been tagged with visual tags and 22 tagged with both visual and acoustic tags. All of the fish encountered to date have been juveniles, averaging nearly seven feet in length. (Adults can exceed 15 feet (4.6 m) in length.) Despite extensive searches in the central and south Sound, Admiralty Inlet, and the San Juan Islands, no sexually mature adult has been detected. Preliminary results of the acoustical tagging indicate that the juveniles are resident in Puget Sound, making few long-distance movements out of the Sound.

Little is known about the behavior and ecological function these large, predatory fish have in Puget Sound's food web. They may be an important apex predator that plays a role the population dynamics of other species.

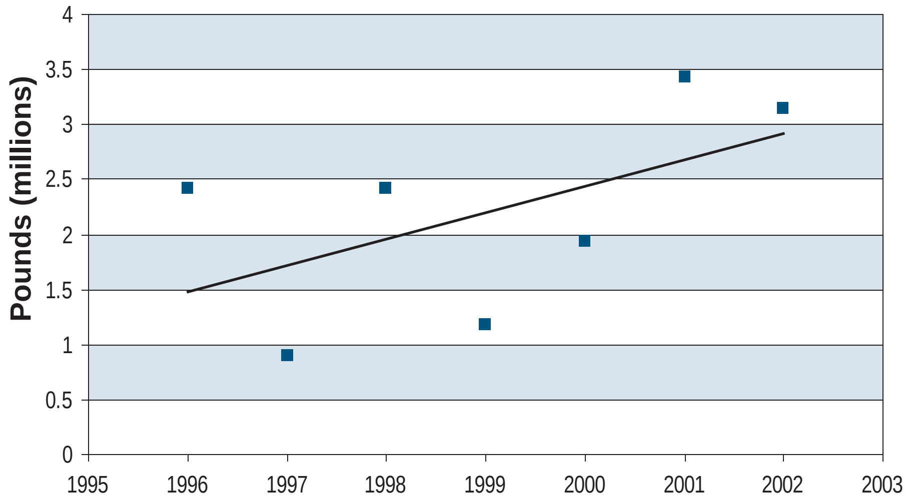


Figure 2-33. Estimated annual catches of surf smelt by recreational fishing, 1995 to 2002. While catch loads have been steadily increasing, little is known about the overall abundance of this species or its ecological functions. (Source: WDFW)

as a distinct population segment. The estimated spawning biomass for this stock decreased from 3,095 tons in 1996 to a low of 808 tons in 2000, followed by an encouraging, if modest, rise to 2,010 tons in 2005. This particular stock has been variable in size, ranging from 3,100 tons to nearly 15,000 tons between 1973 and 1995. While the recent increases in abundance are encouraging, the stock remains a focus of concern.

Herring spawning biomass levels in the Strait of Juan de Fuca region are also low. Following a peak spawning biomass of 3,200 tons in 1980, the Discovery Bay herring stock has decreased dramatically and steadily. Recent spawning biomass levels have been between 200 tons and 250 tons per year. Currently, the Dungeness/Sequim Bay stock is also at a very low level of abundance.

Impacts to the Ecosystem

Because of the ecological and economical importance of herring in Puget Sound, several studies have attempted to determine causes of declining abundance, especially in northern Puget Sound. These studies have found several potential causes of decline, including increased incidence of disease, chemical contamination, and larval deformities.

ii. Surf Smelt

Surf smelt (*Hypomesus pretiosus*) is a species of forage fish that utilizes intertidal habitat for spawning. Surf smelt deposit their eggs onto beaches at high tide where they incubate for several weeks prior to hatching. Because of the vulnerability of the spawning habitat to human destruction, management efforts have focused on identification and protection of surf smelt spawning areas.

Status and Trends

Little is known of the abundance of surf smelt in Puget Sound. However, surf smelt is harvested by both commercial and recreational fishing and catch sizes may give some indications of the fish's abundance. Between 1993 and 2002, annual catches of surf smelt averaged 295,000 pounds; 40 percent of this amount has been taken in commercial fisheries. Recreational catches in recent years have been variable but generally increasing (Figure 2-33). Recreational fishing for surf smelt receives considerable interest; surf smelt is the most common marine fish species caught by Puget Sound's recreational fishers.

iii. Northern Anchovy

Northern anchovies (*Engraulis mordax*) have appeared in south Puget Sound over the past decade and their geographic distribution and abundance seems to be expanding. Recent reports from many parts of the central and south Sound indicate prevalence of post-larval anchovies, approximately 1.2 inches (30 mm) in size, in the nearshore in late summer and early fall, with juvenile and adult fish in the 4-10 inch (100 mm to 150 mm) size range visible in offshore waters throughout much of the year. Anchovies are known to be pelagic multiple spawners, with newly hatched larvae living among the plankton for about three months before reaching a post-larval life stage.

Sizable schools of juvenile anchovies attract overwintering birds, especially double-crested cormorants, grebes, and mergansers, as well as harbor seals and, presumably, salmon, cutthroat trout, and dogfish and other mid-water and surface-feeding fish. Further research is needed to understand the importance of this species as a major component of the food web in the south and central Sound and southern Hood Canal, where this species has also been sighted in recent years. Recently, a multi-agency research effort has begun to design a comprehensive forage fish study to address bio-energetics, seasonal migration and distribution, disease prevalence, and relative abundance of major forage fish species, including herring, surf smelt, Pacific sand lance, and anchovies.

a. Pelagic Fish

i. Market Squid

Market squid (*Loligo opalescens*) are cephalopods, about 6 to 10 inches (152.4-254 mm) long, with eight sucker-laden arms and two tentacles. They are nocturnally active predators in Puget Sound that travel in large schools and forage in mid-water. Market squid are generally believed to live for only one or two years. There is some indication that dense spawning congregations occur in Puget Sound, but it is not clear how frequently. It is unknown if the squid remain in the Sound for their entire lives or move out into the open ocean during certain months. At present, there is no active monitoring of squid in Puget Sound; thus, their population size is unknown and may fluctuate greatly from year to year.

Status and Trends

Only harvest records provide an indication of market squid abundance. The commercial squid fishery is presently at a low level, with peak harvest taken only when abundance is high. About 3,000 pounds (1,361 kg) per year of commercial harvest have been documented since the 1950s, with some years showing no harvest at all (Figure 2-34). In the 1990s, harvests rose above the average, with over 16,000 pounds (7,256 kg) taken in 1994, 25,000 pounds (11,339 kg) taken in 1995, and about 10,000 (4,536 kg) pounds taken in 1996. Since 1996, no landings have been recorded, except for 1,000 (454 kg) pounds taken in 2004.

ii. Salmonids

Puget Sound salmonids include salmon, steelhead, and rainbow trout (coastal cutthroat trout, bull trout). WDFW, Washington tribes, and federal agencies (NMFS and USFWS) have examined the status of Puget Sound salmonids in 1992 and again in 2002. The results of state, tribal, and federal status assessments of Puget Sound salmonids are presented in this section.

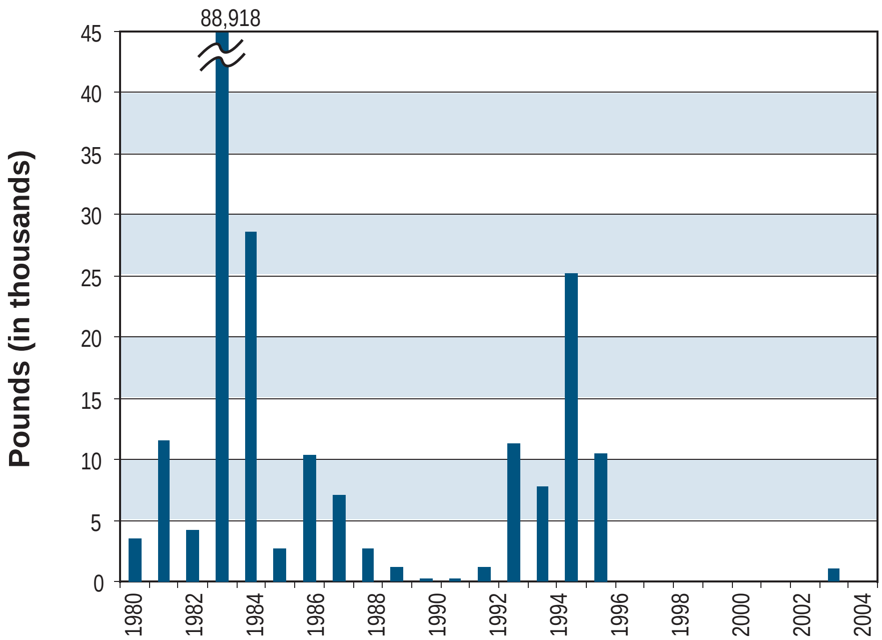


Figure 2-34. Annual commercial landings of market squid from Puget Sound, 1980 to 2004. No abundance data have been collected for squid, so harvest loads and casual observations are the only estimates of abundance. (Source: WDFW)

Status and Trends

A state/tribal assessment of salmon and steelhead status was first conducted in 1992. Results were published in the Salmon and Steelhead Stock Inventory (SASSI), which identified independent stocks (WDFW et al. 1993). The status of each stock was rated as healthy, depressed, critical, unknown, or extinct. Healthy status means that stock abundance shows no pronounced negative trends in recent years, is consistent with available habitat, and is within the range of natural variation in survival for the stock. Depressed means that abundance is declining or is lower than expected, based on available habitat and natural variation in survival, but not so low that permanent genetic damage (loss of genetic diversity) is thought to have occurred. Critical also reflects declining or chronically low abundance, but to a degree that permanent genetic damage is thought to have occurred or is imminent. Stock status is unknown when there are inadequate abundance data to rate status with confidence. Extinct stocks are those that are no longer present in their historical range, and whose disappearance has been documented by state, tribal, federal, or other professional fish biologists. The number of extinct stocks is probably greater than documented.

Table 2-4 presents the numbers of Puget Sound salmonid stocks by region and status in both 1992 and 2002. The north Sound region includes streams west of the Cascade Crest from the Canadian border south through the Snohomish River system. The south Sound includes streams from the Lake Washington system south and on the east side of the Kitsap Peninsula. Hood Canal includes streams south of the Hood Canal Floating Bridge on both the east shore of the Olympic Peninsula and the west shore of the Kitsap Peninsula. The Strait of Juan de Fuca includes streams north of the Hood Canal Floating Bridge and west along the strait to Cape Flattery.

The number of Puget Sound chinook (*Oncorhynchus tshawytscha*) stocks was reduced from 29 in 1992 to 27 in 2002, because of changes in the Snohomish River basin and Hood Canal stock lists. The number of healthy stocks declined from 10 to four, while the number of depressed and critical stocks increased from

Table 2-4. Status of Puget Sound salmonid stocks in 1992 and in 2002.

[1] The status of one South Sound chinook stock was not rated in 2002, which accounts for the difference in the number of stocks and the numbers of stocks with SaSI ratings in 2002 (27 vs. 26).

[2] The status of one South Sound steelhead stock was not rated in 2002, which accounts for the difference in the number of stocks and the numbers of stocks with SaSI ratings in 2002 (60 vs. 59)

Region	Total Stocks		Healthy		Depressed		Critical		Unknown		Extinct	
	1992	2002	1992	2002	1992	2002	1992	2002	1992	2002	1992	2002
Chinook												
North Sound	15	13	3	1	7	9	2	2	3	1	0	0
South Sound[1]	10	9	5	3	0	2	1	1	4	2	0	0
Hood Canal	1	2	1	0	0	1	0	1	0	0	0	0
Strait	3	3	1	0	1	2	1	1	0	0	0	0
Total	29	27	10	4	8	14	4	5	7	3	0	0
Chum												
North Sound	12	12	8	8	0	0	0	0	4	4	0	0
South Sound	23	23	18	17	0	1	0	0	4	4	1	1
Hood Canal	12	22	10	10	0	4	1	1	1	1	0	6
Strait	8	10	2	1	1	2	1	1	4	5	0	1
Total	55	67	38	36	1	7	2	2	13	14	1	8
Coho												
North Sound	14	14	4	8	3	0	0	0	7	6	0	0
South Sound	11	10	8	6	3	3	0	1	0	0	0	0
Hood Canal	9	9	4	6	5	1	0	0	0	2	0	0
Strait	12	12	4	6	5	2	1	1	2	3	0	0
Total	46	45	20	26	16	6	1	2	9	11	0	0
Pink												
North Sound	7	5	5	5	0	0	0	0	2	0	0	0
South Sound	2	2	2	0	0	1	0	0	0	1	0	0
Hood Canal	3	3	2	1	1	2	0	0	0	0	0	0
Strait	3	3	0	0	1	1	2	2	0	0	0	0
Total	15	13	9	6	2	4	2	2	2	1	0	0
Sockeye												
North Sound	1	1	0	1	0	0	1	0	0	0	0	0
South Sound	3	3	0	1	3	2	0	0	0	0	0	0
Hood Canal	0	0	-	-	-	-	-	-	-	-	-	-
Strait	0	-	-	-	-	-	-	-	-	-	-	-
Total	4	4	0	2	3	2	1	0	0	0	0	0
Steelhead												
North Sound	22	22	7	3	3	6	1	0	12	12	0	0
South Sound[2]	13	13	7	1	1	5	0	1	5	5	0	0
Hood Canal	11	11	0	0	5	6	0	0	6	5	0	0
Strait	14	14	2	4	6	3	0	0	6	8	0	0
Total	60	60	16	8	14	20	1	1	29	30	0	0

Region	Total Stocks	Healthy	Depressed	Critical	Unknown	Extinct
1998 Status Assessment						
Bull Trout / Dolly Varden						
North Sound	9	2	0	0	7	0
South Sound	6	0	0	0	6	0
Hood Canal	3	1	0	0	2	0
Strait	4	1	0	0	3	0
Total	22	4	0	0	18	0
2000 Status Assessment						
Coastal cutthroat trout						
North Sound	8	1	0	0	7	0
South Sound	4	0	0	0	4	0
Hood Canal	2	0	0	0	2	0
Strait	3	0	0	0	3	0
Total	17	1	0	0	16	0

eight to 14 and from four to five, respectively. Increased abundance data resulted in the number of unknown stocks declining from seven to three.

The number of Puget Sound chum (*Oncorhynchus keta*) stocks increased from 55 to 67 between 1992 and 2002, following state/tribal re-examination of summer chum stocks in Hood Canal and the Strait of Juan de Fuca that resulted in the addition of 12 stocks, including eight known to have become extinct (WDFW and PNPTC 2000). The number of healthy stocks decreased slightly, from 38 to 36, while the number of depressed stocks increased from one to seven, due mainly to the addition of summer chum stocks in Hood Canal and the Strait. There was no change in the number of critical stocks. The number of stocks of unknown status increased from 13 to 14, because of the addition of a new summer chum stock (Dungeness summer chum) in the Strait, for which abundance data are lacking.

Puget Sound coho (*Oncorhynchus kitsutch*) stocks decreased from 46 to 45 between 1992 and 2002 because the Newaukum Creek stock (Green River tributary) was combined with the Green River/Soos Creek stock. The number of healthy stocks increased from 20 to 24 while the number of depressed stocks decreased from 16 to six. The number of critical stocks increased slightly from one to two. The number of stocks of unknown status increased from nine to 11.

The number of Puget Sound pink salmon (*Oncorhynchus gorbuscha*) stocks decreased from 15 to 13 between 1992 and 2002. Genetic analysis indicated that North Fork/Middle Fork Nooksack pinks were not genetically distinct from South Fork Nooksack pinks, so those two stocks were combined into a single Nooksack stock. Similarly, genetic analysis showed no difference between the North Fork and South Fork Stillaguamish pink stocks, and they were also combined into a single Stillaguamish stock. The number of healthy stocks declined from nine to six, and the number of depressed stocks increased from two to four. There was no change in the number of critical stocks. The number of stocks of unknown status decreased from two to one.

Sockeye (*Oncorhynchus nerka*) stocks in Puget Sound did not change between 1992 and 2002. The number of healthy stocks increased from none to two, and there were corresponding decreases in the number of depressed and critical stocks.

There was no change in the number of Puget Sound steelhead (*Oncorhynchus mykiss*) stocks between 1992 and 2002. The number of healthy stocks decreased from 16 to eight. The number of depressed stocks increased from 14 to 20. The number of critical stocks was unchanged. The number of unknown stocks increased from 29 to 30.

Bull trout (*Ssalvelinus confluentus*) and Dolly Varden (*Salvelinus malma malma*) have been combined because they are difficult to distinguish from one another. Rather esoteric morphological differences have been identified, but WDFW biologists have found that these differences are not reliable statewide. Abundance data on additional stocks have been collected since 1998; however, the inventory has not been revised.

As with bull trout/Dolly Varden information, abundance data are largely lacking for Puget Sound coastal cutthroat. As such, the status of most cutthroat stocks is unknown.

In addition to state/tribal status assessments, NMFS undertook extensive status reviews of West Coast salmon (Myers et al. 1998, Weitkamp et al. 1995, Hard et al. 1996, Johnson et al. 1997, Gustafson et al. 1997), steelhead (Busby et al. 1996),

Table 2-5. ESA status of Puget Sound salmonid species as of 2005.
(Source: WDFW)

Distinct Population Segment (DPS) or Evolutionarily Significant Unit (ESU)	ESA Status	Date of Listing
Puget Sound Chinook ESU	Threatened	March 1999
Puget Sound/Strait of Georgia Chum ESU	Not Listed	
Hood Canal Summer-Run Chum ESU	Threatened	March 1999
Puget Sound/Strait of Georgia Coho ESU	Not Listed	
Odd-Year Pink ESU	Not Listed	
Even-Year Pink ESU	Not Listed	
Baker River Sockeye ESU	Not Listed	
Puget Sound Steelhead DPS	Proposed Threatened	March 2006
Coastal-Puget Sound Bull Trout DPS	Threatened	November 1999
Puget Sound Coastal Cutthroat Trout DPS	Not Listed	

and cutthroat trout (Johnson et al. 1999) in the mid to late 1990s, in response to a number of petitions to list these species as threatened or endangered under the federal ESA. The status for chinook, chum, coho, pink, sockeye, steelhead, and coastal bull and cutthroat trout are listed in Table 2-5. ESU stands for Evolutionarily Significant Unit and DPS is Distinct Population Segment. They are both terms that identify ESA listable units that are smaller than an entire species.

8. Marine Birds

Over 100 species of marine birds rely on Puget Sound's marine food web during some or all of their life histories. Since the early 1970s, approximately 30 percent of these species have been researched for PSAMP by scientists at WDFW, Washington University, and other agencies and organizations. Studies have focused on population surveys, foraging habits, contamination levels, and dispersal patterns. Research has also been conducted to assess overall population densities for major species of marine birds utilizing Puget Sound's marine food web.

The following section reports on overall marine bird density status and trends according to several monitoring and research programs. It is followed by an overview of the status and trends of individual bird species that are currently monitored or have been recently surveyed in Puget Sound.

What is a marine bird?

Marine bird is an umbrella term for seabirds, seaducks, and shorebirds.

Seabirds (excluding waterfowl) frequent coastal waters and the open ocean. Examples are gulls, murres, pelicans, cormorants, and albatrosses.

Seaducks are diving ducks that frequent the sea, such as scoters, harlequins, long-tailed ducks, and mergansers.

Shorebirds are any birds that frequent the seashore, such as western sandpipers and black oystercatchers.

a. Overall Marine Birds

The first comprehensive effort to assess overall marine bird populations in Puget Sound was the Marine Ecosystems Analysis (MESA) in 1978 and 1979. MESA was administered by NOAA with funding from EPA. MESA researchers used a variety of techniques to assess overall bird densities, including population counts from over 100 shore-based sites, transect counts from ferries and small boats, breeding island counts, and aerial surveys.

The next comprehensive marine bird survey to assess trends began in winter 1992-93 and has continued annually since, with trend data through 2006. These aerial surveys are conducted annually by PSAMP scientists from WDFW to monitor wintering nearshore marine birds They then compared density estimates from a subset of their survey transects with the nearly identical MESA aerial survey transects. Results from this comparison showed a mixture of changes that ranged 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) and some increasing trends (harlequin ducks and, probably, mergansers) (PSAT 2002).

Birds that have declined by 20 percent or more since 1970s:	Species that have increased by 20 percent or more since the 1970s:
Pacific and Red-throated Loons	Common Loon
Western Grebe	Double-crested and Pelagic Cormorant
Red-necked and Horned Grebes	Great Blue Heron
Brandt's Cormorant	Bald Eagle
Common Murre	Pigeon Guillemot
Marbled Murrelet	Rhinoceros Auklet
Bonaparte's and Heermann's Gull	White-winged Scoter
Black Brant	Harlequin Duck
Surf Scoter	Common Merganser
Scaup species combined composed largely of Greater Scaup	Northern Pintail
Ruddy Duck	American Widgeon
Long-tailed Duck	
Common and Barrow's Goldeneye	
Mallard	

Table 2-6. Changes in marine birds and ducks in northern Puget Sound between the 1970s and 2003–2005. These estimates are derived by comparing MESA land-based and ferry-based surveys with WWU surveys (Bower et al. unpubl.). (Source: WDFW)

Between 2003 and 2005, scientists from Western Washington University (WWU), with funding from Washington Sea Grant and other sources, conducted a marine bird census that closely replicated the 1970s MESA research. WWU scientists, with help from students and volunteers, conducted monthly land and water surveys between September and May in the inner marine waters of north Puget Sound and south Georgia Straits. The observed species trends from the WWU census were similar to those previously reported by PSAMP, with the exception of double-crested cormorant, pigeon guillemot, common loons and harlequin ducks (Figure 2-35). Some of the differences in monitoring trends between PSAMP and WWU might be an artifact of combining migration and wintering populations. Combined with the 1992-2000 PSAMP surveys (Nysewander et al. 2001), these new data from WWU provide additional trend information on the overall marine bird abundance in Puget Sound for a 25-year period.

Based on the WWU survey, the total number of marine birds in Puget Sound has declined by 27 to 47 percent overall[6] since the MESA surveys in the 1970s. Of the 30 most common species in the 1970s, 19 declined by 20 percent or more (Table 2-6).

It is not entirely clear what is driving the decline in marine birds, although researchers point to a variety of known and/or likely factors, including pollution, climate change, non-native species, collisions with man-made structures, derelict fishing gear, some fishing practices, prey unavailability, and loss of habitat.

Impacts to the Ecosystem

Increases and decreases in marine bird densities in Puget Sound are difficult to connect quantitatively to specific ecosystem impacts. However, some work has been done linking declines in forage fish populations, particularly the Cherry Point herring stock, to fattening rates in surf scoters. In other species, it is assumed that declining forage fish populations would force avian predators to switch to other marine organisms or habitats and would put greater predator pressure on those resources. Fewer avian predators would possibly reduce mortality aspects related to some depressed stocks of forage fish or some standing stocks of shellfish. Presently, it is unknown how these decreases play out in the marine ecosystem (i.e., whether they are causes or effects).

[6] Observations during the September - May period are combined. This is somewhat problematic, because migration and wintering groups are lumped together.

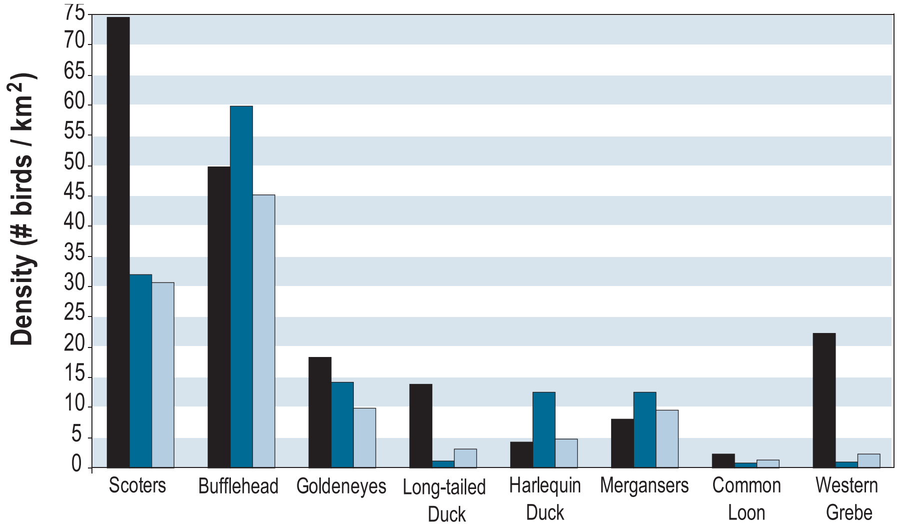


Figure 2-35. Marine bird populations in Puget Sound based on three surveys between 1970 and 2004. Surveys indicated major declines in scoters, goldeneyes, long tailed ducks and western grebes. The causes of these declines are not known, as most marine ducks spend only a portion of the year in the Puget Sound region.
(Source: WDFW)

- MESA (1978-79)
- PSAMP (1992-1999)
- PSAMP (2000-2006)*

* More sites sampled than in previous surveys.

b. Scoters

Puget Sound attracts some of the largest wintering scoter populations on the west coast of North America (Wahl et al. 1979). Puget Sound is also one of the three most important staging areas and one of the two major molting areas for other West Coast populations, including scoters that winter in California, Mexico, and British Columbia.

Puget Sound's scoter populations, including the wintering, staging, and molting populations, consist primarily of surf scoters (*Melanitta perspicillata*) and white-winged scoters (*Melanitta fusca*). Black scoters (*Melanitta perspicillata*) are also present, but in much smaller numbers. Scoters spend eight to 10 months in marine waters, then migrate to the Canadian interior to breed on freshwater lakes. Washington's wintering scoters spend from eight to 10 months in marine waters, with males spending approximately a month longer than females. Scoter populations have dropped precipitously in the past 25 years. Studies are underway to determine the causes of the declines and to assess out how different West Coast subpopulations are faring.

Scoters use a broad range of foraging habitats. They have been observed feeding on newly settled mussel beds, foraging in soft substrates inhabited by clams and other shellfish, and feeding on shorelines on which forage-fish roe has been deposited. Additional observations suggest they may be feeding on organisms such as shrimp, euphausids, and sand lance, that are highly clumped.

Since 2003, WDFW researchers have tracked wintering populations of scoters from British Columbia and Washington using both satellite and VHF radio transmitters. These technologies helped gather information on migration routes as well as local breeding and molting grounds for scoters from Washington and British Columbia. Understanding the scoters' local and large-scale movements and their use of habitat throughout the year will help direct management activities to restore populations.

Status and Trends

Based on historic surveys (Wahl et al. 1981) and WDFW's annual monitoring program initiated in 1992, densities for all three scoter species in Puget Sound nearshore waters have declined as follows: surf scoters, 64 percent; white-winged scoters, 33 percent; and black scoters, three percent. Collectively, these populations

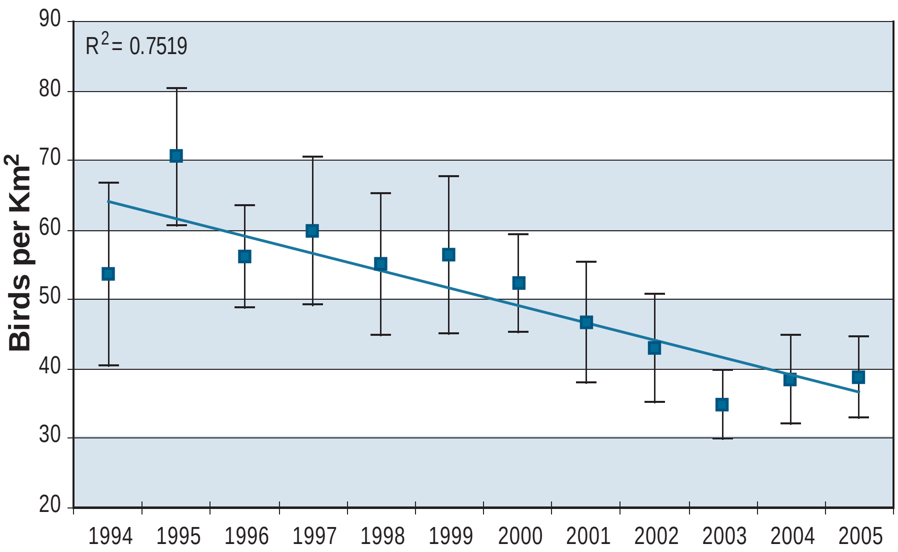


Figure 2-36. Trends in annual scoter densities. Annual winter scoter (surf scoter, white-winged scoter, and black scoter) densities from PSAMP aerial surveys in the inland marine waters of Washington, winter 1993-1994 through 2004-2005. Data show a significant decline over the 12-year period.
(Source: WDFW)

declined by approximately 57 percent between 1978 and 1999. This decline has continued between 1999 and 2005 (Figure 2-36) in most all of the subregions of Puget Sound (Evenson et al. 2002, Nysewander at al. 2003, 2004-05 WDFW aerial survey results). This decrease represents the largest decline in biomass of marine birds in Puget Sound over the past 25 years, although some other species, such as the western grebe, lost a larger percentage of their original populations. Studies are underway to determine the causes of the decline and to assess how Washington subpopulations are faring.

In 2003, WDFW began tracking white-winged scoters to better understand their dispersal patterns. The program was expanded in 2004 to include surf scoters. By March 2006, WDFW had deployed 94 VHF radio transmitters[7] on 91 surf scoters and three white-winged scoters and 73 satellite transmitters[8] on 47 surf scoters and 26 white-winged scoters. In addition, approximately 200 scoters were captured, examined, and banded each year of the four-year study.

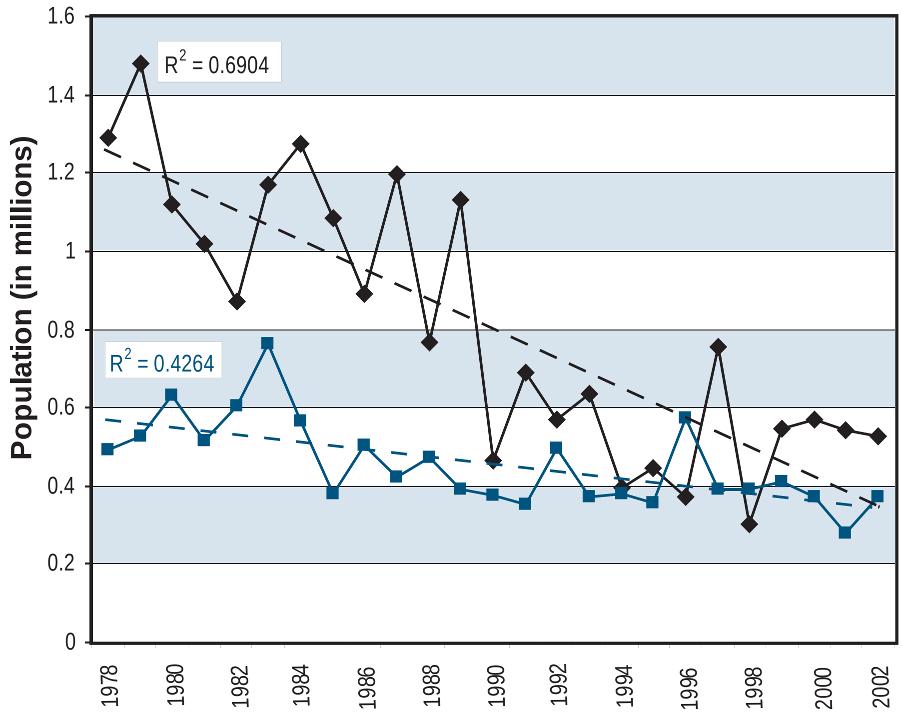
Researchers tracked scoters to their spring breeding and molting areas and back to their wintering areas in Puget Sound, with the following results: 13 percent of the birds died on the breeding grounds or on return migration, and 87 percent returned to the Puget Sound region to winter again. Of those returning, 89 percent returned to the exact same wintering site frequented the previous winter, and 11 percent returned to within 30 to 50 miles of their previous wintering sites. The scoters fitted with the more location-precise VHF transmitters also exhibited high degrees of fidelity to winter sites.

Almost exclusively, Washington's scoter populations migrate to breed in Canada's boreal forest region. This is an area that stretches from the Great Bear Lake to Great Slave Lake and Lake Athabaska in the Northwest Territories. Satellite and radio-tracking data indicate that the greatest declines of breeding scoters are occurring in this region. Figure 2-37 shows how this region's breeding scoters have declined more than in other scoter breeding areas, such as in Alaska.

[7] VHF transmitters are able to measure locations much more precisely than satellite transmitters. However, if a bird disappears (i.e., the signal is lost), researchers cannot determine the cause (mortality, lost transmitter, etc.).

[8] Satellite transmitters have mortality signals and temperature gauges and thus enable researchers to understand exactly what happens to each bird. However, these transmitters are less precise in determining location.

Figure 2-37. Trends in yearly breeding scoter populations from USFWS aerial surveys in the Canadian Interior and Alaska, 1978-2002. Trend lines are derived from different breeding strata used by scoters, defined by geographic area. The “not Washington strata” include California birds, Oregon birds, and British Columbia birds. Scoters are not declining uniformly across their whole range but are declining more in the center of their range (Puget Sound), which historically had the highest densities. The declines in breeding populations mirror the wintering scoter declines observed by the MESA (1978-1979) and PSAMP (1993-1999) aerial surveys (57 percent) . (Source: WDFW).



Recent tracking results suggest that Puget Sound surf scoters follow different migratory paths than do other surf scoters in the Pacific Flyway. (Nysewander and Evenson unpubl. data). The majority (65 percent) of Puget Sound’s wintering scoter populations stage in Washington in the spring before heading to their breeding grounds. The remaining 35 percent do their spring staging in northern British Columbia or southeast Alaska, following the herring spawning events that occur at these locales later in the spring. In contrast, the majority of California’s scoter population (80 to 85 percent) uses Southeast Alaska for their main spring staging areas. Most of the remaining populations use Puget Sound for their spring staging. This is also true for scoters from Baja, Mexico, and British Columbia, 14 to 17 percent of which use the spring staging areas in Washington. The spring staging areas in Puget Sound are located primarily between Padilla and Samish Bays in Skagit County and Boundary Bay at the mouth of the Fraser River.

Impacts to the Ecosystem

Scoters commonly feed on herring spawn, and recent declines in Puget Sound herring stocks (particularly the Cherry Point stock in north Puget Sound) may be affecting their foraging success.

c. Loons and Grebes

The six species of loons and grebes most common to the inner marine waters of Washington include the common loon (*Gavia immer*), Pacific loon (*Gavia pacifica*), red-throated loon (*Gavia stellata*), horned grebe (*Podiceps auritus*), red-necked grebe (*Podiceps auritus*), and western grebe (*Aechmophorus occidentalis*). All six of these species breed in freshwater habitats, though only four of the six (the western grebe, red-necked grebe, common loon, and, occasionally, the horned grebe) breed in Washington. A large number of coast loon and grebe populations spend a significant portion of the winter in Puget Sound, each species displaying a somewhat different distribution and habitat-use pattern. (Table 2-7)

Species	Distribution/habitat use
Horned grebes	Widely dispersed, closest to the shoreline.
Red-necked grebes	Dispersed in slightly deeper waters and tidal rips or eddies.
Western grebes	Seen in larger concentrations, most often in the highly concentrated resting flocks during the daytime. Feed over large areas in crepuscular or nocturnal periods.
Common loon	Disperses throughout the inner waters, usually in 1 or 2 pairs at any one place or time.
Pacific loon	Seen in larer flocks long tide rips,eddies, offshore banks, and other features that concentrate or direct the movement of forage fish schools.
Red-throated loon	Seen in larger flocks, typically in shallower nearshore waters.

Table 2-7. Distribution and habitat use of grebes and loons in Puget Sound.
(Source: WDFW)

Status and Trends

Monitoring results indicate that most Puget Sound loon and grebe species have declined significantly in recent years, with declines ranging from 64 to 95 percent (Nysewander et al. 2002) to 50 to 82 percent (Bowers et al. unpubl. data).

Historic and current breeding population levels for loons are not well known in Washington, with most of the available information dating from the past 15 years (Richardson et al. 2000). Surveys and mixed reports from 1979 to 1999 counted a total of 20 confirmed and 12 unconfirmed common loon nest sites in Washington. The densities of common loons are the lowest of all loon species (Figure 2-38) observed on Washington's marine waters during winter (Nysewander et al. 2002; recent unpubl. data). Although there has been some loon recovery on the marine waters in recent years, it is not evident from the most recent nesting surveys, which found that only 12 territorial pairs remain breeding in widely separated locations across the state. Of the approximately 32 breeding lakes in Washington, only eight were used for nesting in 2005 (Poleschook and Grumm , unpubl. data). The winter aerial surveys conducted by PSAMP from 1995 to 2005 indicated wintering common loons with the lowest density of all the loons but remaining fairly stable (Figure 2-38).

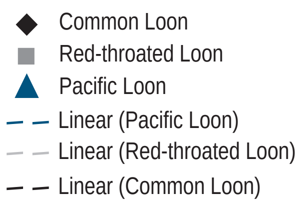
Focus Study

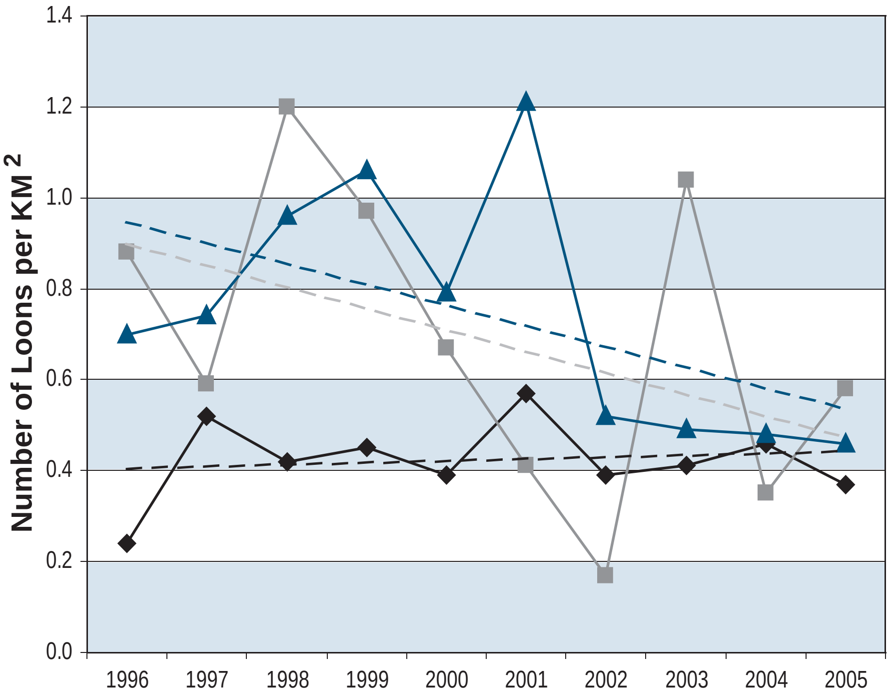
Seasonal Scoter Use of Herring Spawn and Eelgrass Habitat

Scoters congregate in dramatic numbers to consume herring spawn along much of the Pacific Ocean coast of North America, including Puget Sound. However, spawning activity in Puget Sound has declined substantially over recent decades. Surveys conducted in 2004 and 2005 by researchers from the University of Wyoming, involving captures and diet preferences, indicate that, when spawn is locally available, scoters consume little else. This same research indicates that spawn availability and scoter fattening rates are correlated. These studies also show that consumption of herring spawn for even a few days significantly increases scoters' fat reserves. The relative importance of spawn to scoters that are preparing for spring migrations and reproduction may depend on habitat characteristics of their winter foraging sites. Thus, availability of herring spawn in late winter and spring may be a limiting factor for scoters.

Research at 12 herring spawning areas in Puget Sound shows that surf scoters aggregate in greater numbers and are likely to travel greater distances to spawning events than are white-winged scoters. Eelgrass beds and their associated epifaunal prey are also important for scoters. At Padilla Bay, which contains 25 percent of Puget Sound's eelgrass beds and represents one of the 12 spawning areas surveyed, the number of scoters increased greatly and their fat reserves were more stable between early and late winter. At another surveyed area, Penn Cove bay, with mixed/hard substrates and little vegetation, both the numbers of scoters and the fat reserves on the birds declined substantially between early and late winter. Population surveys, telemetry data, and habitat characterizations are being used to evaluate whether eelgrass habitat and herring spawn play similar roles for scoters in bays throughout Puget Sound.

Figure 2-38. Annual trends in winter loon densities. Winter loon (common loon, Pacific loon, and red-throated loon) densities from PSAMP aerial surveys in the inland marine waters of Washington, winter 1995-1996 through 2004-2005. Declines are evident in both the Pacific Loons and red-throated loons, although the common loon seems to be stable during this period.
(Source: WDFW)





Wintering populations of Western grebes have declined in all wintering sites in Puget Sound covered by Christmas bird counts (Figure 2-39). The winter aerial surveys in western Washington 1994-2005 (Nysewander et al. unpubl.) also confirm the same type of decline in wintering numbers for Western grebes in the inner marine waters. This species exhibits the greatest percentage of decline (81 to 95 percent) over the last 30 years for any one marine species. Despite these declines, Washington continues to support globally significant numbers of western grebes between late autumn and early spring. Up to 20 to 25 percent of the world population of western grebes (Kushlan et al. 2002) over-winter in the state. This suggests that Washington will play an important role in any conservation effort expended towards this species.

Relatively little is known about the breeding of western grebes or other grebe species in Washington. There is a relatively small number of western grebe breeding sites in Washington, centered in the Columbia Basin, especially Grant County (Wahl et al. 2005). The total breeding population is probably fewer than 1,500 adults, based on rough estimates for Grant County (J. Tabor pers. comm.).

The Western Washington University surveys also indicate a decline in red-throated and Pacific loons (Bowers et al. unpubl. data). Red-throated loons have declined by 73 percent and Pacific loons by 52 percent over the past 30 years.

Impacts to the Ecosystem

All loon and grebe species feed on young forage fish or other marine fish and invertebrates in greater Puget Sound. Since the distribution patterns during winter are different for each of these bird species, impacts on any particular prey population will depend on the timing and distribution of foraging birds. Although this has yet to be documented, declines in marine bird numbers are likely to have some impact on the forage fish or invertebrates they consume, on a local scale.

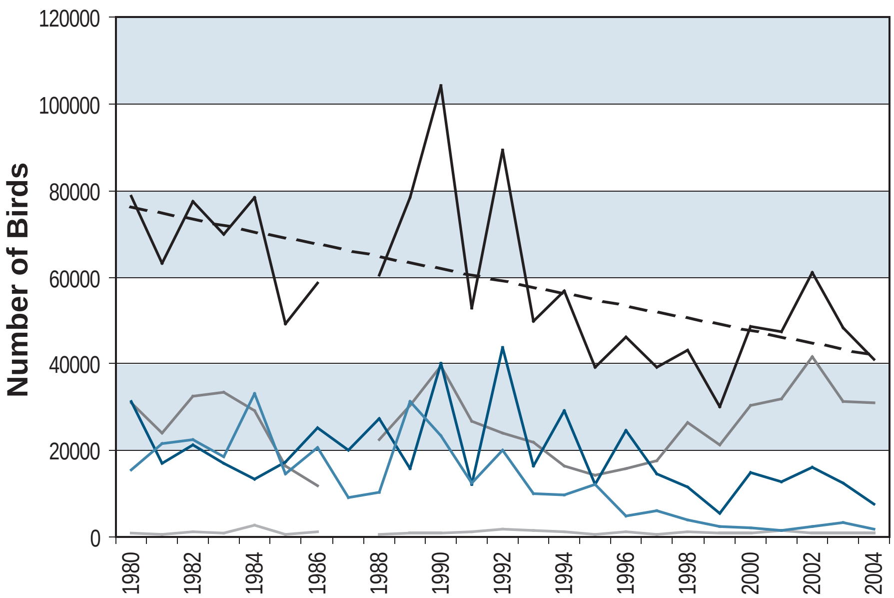


Figure 2-39. Annual Audubon Society Christmas Bird Counts of western grebes, 1980-2004. Trends from Oregon, Washington, and British Columbia show a notable decline, especially from the late 1980s and early 1990s to the mid-2000s. During these same periods, California experienced a similar decrease through the mid-1990s, then an increase through the mid-2000s. The increases in California, however, are not great enough to compensate for declines in the northern regions. (Source: WDFW)

d. Alcids

Pigeon guillemot (*Cepphus columba*), rhinoceros auklet (*Cerorhinca monocerata*), and marbled murrelet (*Brachyramphus marmoratus*) are the major species of alcids in Puget Sound. The Pacific coast population of marbled murrelets south of the Canadian border is listed as threatened by both USFWS and WDFW. The federal listing decision was based on the determination that the marbled murrelet was threatened from loss and modification of nesting habitat, primarily due to commercial timber harvesting of older forests, mortality associated with gillnet fisheries off the Washington coast, and mortality resulting from oil pollution.

Status and trends

The rhinoceros auklet is the most abundant breeding alcid in the inner marine waters of Washington; however, populations are concentrated at only two sites—Protection and Smith Islands. Recent publications (Wilson et al., 2005) confirm that breeding pairs of Rhinoceros auklets on these islands have declined from 17,000 pairs in 1975 to 12,000 pairs in 2000—a 30 percent decline.

Pigeon guillemot surveys completed in 2003 indicate that there are at least 471 colonies of pigeon guillemots in Puget Sound, with a total of approximately 16,000 breeding birds (Evenson et al. 2003). This makes this species the second most abundant alcid in Puget Sound during the breeding season. However, an absence of historical data on guillemot abundance makes it impossible to determine trends in population size. There are some conflicting reports from surveys of specific wintering areas (Nysewander et al. 2001, Bower et al. in prep.) that show both decreasing and increasing numbers for this species. The movement of pigeon guillemots in winter is not clear, and some evidence suggests that pigeon guillemots along the California and Oregon coasts move north to winter in Washington and British Columbia.

Marbled murrelets are non-colonial seabirds whose breeding distribution extends from the Aleutian Islands of Alaska to Santa Cruz, California. Estimated population size is about 859,000 in Alaska, 55,000 to 78,000 in British Columbia, and 17,000 to 27,000 in Washington, Oregon, and California (McShane et al. 2004). Six years of at-sea population monitoring now indicates that the

Has the marbled murrelet recovery plan made a difference?

Marbled murrelet populations have significantly declined in Washington over the past 25 years. Population modeling included in the marbled murrelet recovery plan (1997) suggested that populations were likely to be declining by four to seven percent per year. To monitor murrelet population trends more accurately, the Marbled Murrelet Effectiveness Monitoring Group (an entity made up of representatives from the U.S. Forest Service, USFWS, and state wildlife agencies) designed a coordinated at-sea monitoring program for the entire Pacific Ocean coast, south of the Canadian border. Results from the first six years of monitoring indicate that the population has been fairly stable during this period; however, variability in the results will require additional years of surveys to more accurately determine population trends (Miller et al. 2006, Raphael 2006).

Washington population is between 3,600 and 19,000 birds. From 2000 to 2005, annual population size estimates for three areas in Puget Sound ranged from 2,100 to 6,000 for the Strait, 1,300 to 2,200 for the San Juan Archipelago and northern Hood Canal, and 417 to 3,000 for southern Puget Sound. The highest densities of marbled murrelets in Washington are in the San Juan Islands, the Strait of Juan de Fuca, and along the northern outer coast (Cape Flattery to Point Grenville) (M.G. Raphael and S.F. Pearson unpubl. data).

Impacts to the Ecosystem

Alcids feed on forage fish and invertebrates, and declines in avian numbers may have an impact on abundance of species these birds normally consume. However, no studies have examined the effect of marine bird consumption on forage fish stocks.

e. Cormorants

The three cormorant species that frequent Puget Sound are the double-crested (*Phalacrocorax auritus*), pelagic (*Phalacrocorax pelagicus*), and Brandt's (*Phalacrocorax penicillatus*) cormorants. All three species breed on the Washington coast and are found throughout Puget Sound during winter. The double-crested and pelagic cormorants also breed and nest in portions of Puget Sound. Double-crested cormorants use both fresh and marine waters and, in some locations, travel between the two each day. In recent years, double-crested cormorants have been observed feeding on the increasing stocks of anchovy and other forage fish in southern Puget Sound.

The breeding success and breeding strategies of cormorants has been impacted by the recovery of Puget Sound bald eagle and peregrine falcon populations. Cormorant colonies are vulnerable to attacks and predation by both eagles and falcons, due to their nesting preference of open ground and cliffs. Both adult and immature eagles have been observed attacking cormorant nest sites and have likely disrupted or reduced nesting success for that year. Cormorants have developed several strategies in response to this predation, by selecting different nesting sites and varying the timing of egg-laying activities (Nysewander pers. comm.).

Status and Trends

The number of Pelagic cormorant nests in Puget Sound grew from 1,067 in the early 1980s (Speich and Wahl 1989) to 1,112 in 2003, a 4 percent increase. In addition to their customary Protection and Smith Islands sites, there were three large nesting colony sites observed in 2003: on Henry Island in the San Juan Archipelago, on Guemes Island in Skagit County, and at an urban site on the Warren Avenue bridge in Bremerton.

The number of Double-crested cormorant nests in Puget Sound grew from 550 during the early 1980s to 874 in 2003—a 59 percent increase. Populations are also increasing in the Great Lakes, the Mississippi River, and areas of the eastern U.S. The traditional colony sites in the San Juan Islands, including Protection and Smith islands, were used by lower numbers of breeders in 2003 than in previous years. However, a larger concentration of nests were found on the numerous, older pilings at the mouth of the Snohomish River near Everett in 2003. This represents 40 percent of the total number of cormorant nests in Puget Sound (Nysewander and Cyra, WDFW unpubl. data).

There has been both public and scientific interest expressed in determining whether cormorants that are currently roosting in Henderson and Totten Inlets in south Puget Sound might start using those locations to breed. To date, no nesting attempts have been reported in these areas.

Brandt's cormorants visit Puget Sound during winter but do not breed here. Their wintering populations in Puget Sound are unkown. However, USFWS has conducted a survey of Brandt's cormorants on the outer coast.

Impacts to the Ecosystem

Little is known of the impacts of cormorants on fish populations, although in recent years, double-crested cormorants have been observed feeding on the increasing stocks of anchovy and other forage fish in southern Puget Sound. Research is currently underway on the Columbia River to determine potential impacts of double-crested cormorants to salmon runs. Preliminary findings suggest that, while double-crested cormorants may consume portions of salmon runs, they also consume sizable numbers of salmonid predators, including the northern pike-minnow (Thompson pers. comm.). Future research will help determine how fish predation by cormorants positively or negatively affects salmon runs.

f. Caspian Terns

Caspian terns (*Sterna caspia*) are uncommon in Puget Sound, although nesting colonies have been documented in recent decades. A sizable colony resided near Everett until the U.S. Navy base was built there in the early 1990s. Until it was displaced in 2002, another colony nested near the ASARCO plant on the shoreline of Tacoma's Commencement Bay. Smaller groups of Caspian terns have been seen each summer in various locations around Puget Sound but they are not monitored. Caspian terns forage fairly high over salt water or fresh water, often plunge-diving for small fish.

Status and Trends

USFWS conducted a study in 2004 and 2005 to monitor nesting Caspian terns on the Dungeness Spit within the Dungeness National Wildlife Refuge. This nesting colony was first observed on the refuge in 2003. In 2004, the colony consisted of 233 to 293 nesting pairs and in 2005, the colony more than doubled to 680 nesting pairs. There is speculation that most of the birds now nesting at this new colony site are from the displaced colony that nested in Commencement Bay from 1999 through 2002.

Impacts to the Ecosystem

Implant tags from young salmonids found at the colony sites reveal that Caspian terns prey on young salmon (smolts). While debate continues on the relative importance of Caspian tern predation on salmonid smolts, an attempt was made to move tern colony sites along the Columbia River away from concentration areas where young salmonids are most vulnerable. This relocation of the colony site was successful, but there is another effort underway to move the colony even further away.

g. Gulls

Approximately 10 species of gulls are found in Puget Sound. Only two of these species, the glaucous-winged gull (*Larus glaucescens*) and the western gull (*Larus occidentalis*), breed in Washington's marine waters. Both species breed (and interbreed) on Washington's outer coast. The glaucous-winged gull also breeds in the inland marine waters of Puget Sound. Of these two gull species, the glaucous-winged gull is the most common.

The most common of the gull species that use Puget Sound habitats after breeding elsewhere include the Heermann's gull (*Heermanni philadelphia*), which breeds in Mexico, the Bonaparte's (*Larus philadelphia*), Mew (*Larus canus*), Thayer's (*Larus thayeri*), and Herring gulls (*Larus argentatus*), which breed in the north, and the Ring-billed (*Larus delawarensis*) and California gulls (*Larus californicus*), which breed inland. Some, including Heermann's gull, come to Washington's marine waters during the summer and fall, in between breeding seasons. Others tend to visit Washington during winter months.

Status and Trends

Gull populations grew during the early 1900s because of increased human-generated food opportunities (such as landfills) and declines in egg and feather harvesting. However, the recovery of bald eagle and peregrine falcon populations during the past 25 years coupled with the removal and/or covering of landfills and other human-generated food sources has resulted in a decrease in gull populations at traditional marine colony sites. Declining forage fish stocks near colony sites may have also played roles in these declines.

In the 1980s, there were an estimated 8,851 glaucous-winged gulls breeding on 36 sites in the vicinity of the San Juan Islands (Speich and Wahl 1989). PSAMP re-visited the same 36 sites in 2001 and documented 3,568 breeding birds, a 60 percent decrease (Nysewander unpubl. data). Most of the individual nesting sites appear to have declined, with the exception of two islands in the Cattle Pass area, where the population either remained the same (Hall Island) or increased (Goose Island). This decline may be accounted for through redistribution to larger colonies, such as Smith or Protection Islands; however, surveys of gull nesting efforts on Protection Island in 2005 revealed large declines associated with factors such as the increase in numbers of eagles frequenting the colony (Joe Galusha pers. comm.). Nevertheless, it is possible that gulls may be redistributing to urban and industrial habitats along the Columbia River (J. Galusha pers. comm., R. Woodruff pers. comm.). However, these urban and industrial areas have not yet been surveyed. USFWS's Migratory Bird Program in Portland, Oregon is planning some coordinated surveys in the next few years to look at all of these habitats, including urban, industrial, and military locations.

WWU scientists who replicated the 1978-1979 MESA surveys from ferry or land-based observations during September to May each year in 2003-2005 also reported declining trends for Heermann's (89 percent), Bonaparte's (68 percent), and glaucous-winged gulls (14 percent) (Bowers et al. unpubl. data).

Impacts to the Ecosystem

It was once thought that the increasing gull populations might have considerable negative impacts through predation on other marine bird species nesting nearby. However, since gull populations are decreasing, they don't appear to be having the same impact on other birds.

i. High Arctic Black Brant

Wintering flocks of the Western high arctic black brant (*Branta bernicla*) can be seen from late November through May in Padilla, Samish, and Fidalgo bays of Skagit County in Puget Sound. This unique stock of brant breeds in the Parry Islands of the Northwest Territories of Canada. Other wintering flocks of brant that visit Puget Sound breed in other arctic areas of Canada and Alaska. Areas used by brant in Puget Sound include Dungeness Spit (approximately 1,000 birds), and Hood Canal (approximately 500 birds), although smaller flocks occur in isolated areas in southern Puget Sound.

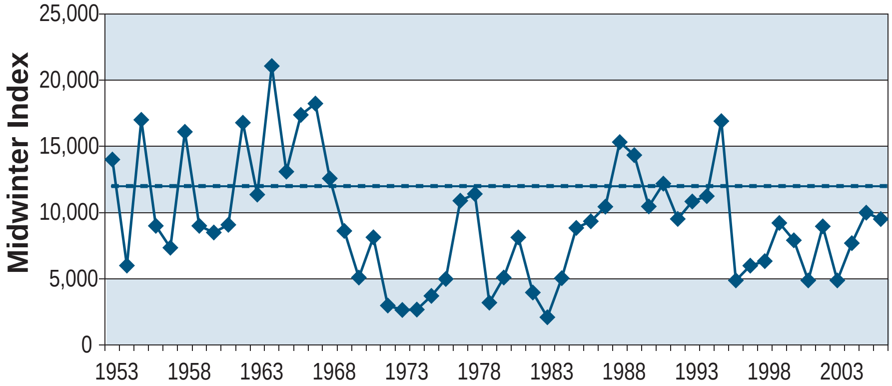


Figure 2-40. Western high arctic black brant populations in Puget Sound. The midwinter index is calculated from January aerial surveys of Skagit County. The target for brant populations in Puget Sound is 12,000 (dotted line). (Source: WDFW)

Status and Trends

Numbers of brant have declined since the 1960s, when the entire brant population was approximately 13,330 birds. Since 1970, the population has varied from a low of 2,105 in 1983 to a peak of 16,900 in 1995, with an average of 7,283 between 2001 and 2005. The midwinter index shown (Figure 2-40) is derived from January aerial surveys of Skagit County.

Impacts to the Ecosystem

Brant are an integral part of the north Puget Sound ecosystem. They are dependent on eelgrass beds and have been documented to use herring spawn for feeding during spring migration. In addition, they provide food for primary predators including bald eagles.

j. Great Blue Heron

The great blue heron (*Ardea herodias*) is found across most of North America. In Washington, two subspecies occur (Payne 1979, Butler 1997). The coastal subspecies, commonly referred to as the Pacific great blue heron, is distributed along the Pacific Ocean coast from Washington to Alaska. This heron is non-migratory and marine-oriented, nesting close to tidal shorelines and foraging within estuaries and marine waters of Puget Sound. Primary threats to the heron population include bald eagle depredation, habitat loss, and human disturbance (Norman et al. 1989, Butler 1997, Butler and Vennesland 2000).

The majority of herons is concentrated in north Puget Sound and is associated with extensive eelgrass beds near breeding colonies. Areas of high heron numbers include, Drayton Harbor, Port Susan, and Lummi, Portage, Samish, Padilla, and Skagit Bays.

Status and Trends

Population trends for Pacific great blue heron are unclear, because historic data on colony size were collected using non-standardized methods. Today, an estimated 6,000 to 12,000 Pacific great blue herons occur in south coastal British Columbia and western Washington. This rough estimate is based on populations in colonies, which can be difficult to locate. In addition, herons move frequently and often abandon colonies, particularly smaller ones. Conducting systematic counts of herons on their feeding grounds may prove valuable to monitor changes in population numbers; the assumption is that locations of colonies may shift in the uplands, but the major foraging areas remain constant.

In 2003 and 2004, biologists with WDFW began a pilot study at nine heron colonies, distributed from south to north Puget Sound and Hood Canal to evaluate the use of foraging ground counts of herons as an index for change in adult breeding heron populations in these areas. For this study, researchers examined the timing of breeding, surveyed forage areas by air and ground, and documented changes in heron numbers on tidal foraging areas.

Breeding timing was highly synchronous among heron colonies in Puget Sound and Hood Canal in 2004. In general, herons returned to colonies by mid-March, with egg-laying beginning by late March and peaking by early April. Eggs began hatching in mid- to late April, with a peak in late April and early May, and most chicks fledged by late June or early July. On days of maximum annual spring tides in early June, numbers of herons increased on tidal foraging areas as the tide ebbed. Numbers of herons typically peaked around the time of peak minus tides and showed variable rates of decline in numbers on flooding tides. During minus tides in mid-May 2004, a total of 3,069 great blue herons was counted along mainland shorelines from the Fraser River estuary through Puget Sound and Hood Canal. During the maximum spring tides of early June 2003, 3,846 herons were counted, compared to 4,262 during this same period in 2004. In mid-June 2004, 4,546 herons were counted during minus tides.

A small number of great blue heron colonies are known along the outer coast. In 2005, WDFW biologists conducted an aerial survey of great blue herons from the entrance of the Columbia River north along the outer coast, including Willapa Bay and Grays Harbor, north to Cape Flattery and east to Port Townsend. A total of 1,227 great blue herons were counted, with the majority of herons occurring in Willapa Bay and Grays Harbor.

k. Bald Eagle

Bald eagles (*Haliaeetus leucocephalus*) are currently listed as threatened under the ESA. U.S. Fish and Wildlife Service proposed to change this status in 1999; however, the change was not completed. In June 2004, the process of delisting the bald eagle was proposed again, and, in 2005, state and federal agencies conducted a pilot study to guide development of a national monitoring plan. In Washington, the northern subspecies is the common bald eagle.

The average home range of a bald eagle in Puget Sound is 2.6 square miles (673 hectares) (Watson and Pierce 1998). In Clallam and San Juan counties, each active nest encompasses approximately four to 5.6 miles (1,450 hectares) of shoreline (Stinson et al. 2001). The winter ranges are larger and more varied than breeding home ranges (Watson and Pierce 2001); however, the post-breeding dispersal of the bald eagle is partially known. Many of Washington's breeding eagles move northward to coastal British Columbia and Alaska after nesting to feed during the late summer and fall salmon runs (Stinson et al. 2001), although some birds remain in Washington after breeding. Regular winter concentrations on the major rivers (such as those seen annually over 24 winters on the Skagit River), are primarily composed of northern birds, migrating south from Alaska and Canada to feed on salmon runs (Watson and Pierce, 2001).

Foraging areas for this species are considered the most essential component of the habitat used by bald eagles (Stalmaster 1987), followed by the presence of large nesting trees (Watson and Pierce 1998). The nesting pairs continually work to maintain their nests which may be functional for 5 and 20 years (Stinson et al. 2001). Eagle pairs will also usually build alternative nests within the nesting territory. Because of the need for alternate nests and protection of nest trees from wind throw, mature forest stands with several large trees are needed to provide support over a long period. Foraging habitats must include consistent supplies of food and minimal human disturbance (Stinson et al. 2001) and be optimally located in open areas with nearby nesting, roosting, and perching trees (Stalmaster 1987). During the summer on Washington's outer coast, bald eagles feed opportunistically on intertidal invertebrates and wildlife carcasses. However, reductions in the bald eagle's principal prey—dying salmon in Puget Sound's rivers—are a primary concern for year-round resident eagles. Habitat degradation, non-native species introductions, and loss of prey resources may also affect the annual survival and reproductive success of the bald eagle (Spencer et al. 1991, in White 1994). Currently, low salmon escapement in the Skagit River watershed is a limiting factor for wintering eagle populations (Dunwiddie and Kuntz 2001, in Stinson et al. 2001).

Protecting Bald Eagles

Bald eagle habitat is protected under the Bald Eagle Protection Law of 1984, which requires the establishment and enforcement of buffer zones around bald eagle nests and roost sites. A subsequent Bald Eagle Protection Rule, the primary focus of which is to protect habitat via site management plans, was established by a group of stakeholders and adopted by the Washington State Wildlife Commission in 1986.

Status and Trends

WDFW has been monitoring bald eagle abundance in Washington for over 25 years. Surveys and individual site visits are limited primarily to areas of high eagle density in Puget Sound, including the Strait of Juan de Fuca and San Juan Islands, as well as sites along the outer coast (D. Stinson pers. comm.). The historical population of this species was estimated at 6,500 birds (based on carrying capacity), but is currently estimated at 4,400 birds statewide (Stinson et al. 2001). This reduction in population is likely to be a result of human encroachment into critical nesting, roosting, and foraging habitats, exposure to biocides and other contaminants, and the reduction of food resources. Many bald eagles have become urbanized, utilizing alternative, human-built structures and environments to maintain local populations.

In 2005, a total of 503 territories, or 1,014 nests, were surveyed within the Puget Sound Bald Eagle Recovery Zone (Figure 2-41 and Figure 2-42) representing an increase over the past 10 years. Of the territories visited, 354 were confirmed occupied, with breeding pairs present at 94 percent of the occupied sites. Breeding activity is confirmed by the presence of eggs or shells in or around the nest or observations of adults incubating eggs or brooding chicks.

Bald eagle surveys in Puget Sound involve checking for new and previously utilized nests and documenting whether the nests are occupied. This is due in part to increased survey effort, but also indicates an increase in breeding population. The population increase is best reflected by comparing years with similar survey efforts. Specifically, WDFW conducted comprehensive statewide surveys in 2001 and 2005 and found an increase in nesting pairs—that is, more new and occupied nests were located in 2005 than in 2001.

Impacts to Ecosystem

Bald eagles are both predators and scavengers and play important roles in nutrient cycling in Puget Sound's shorelines and watersheds.

Figure 2-41. Locations of known bald eagle nests in Puget Sound in the Bald Eagle Recovery Zone (highlighted area) as of May 2006. The number of new and existing territories has increased within the past 10 years. (Source: WDFW)

Nest Location

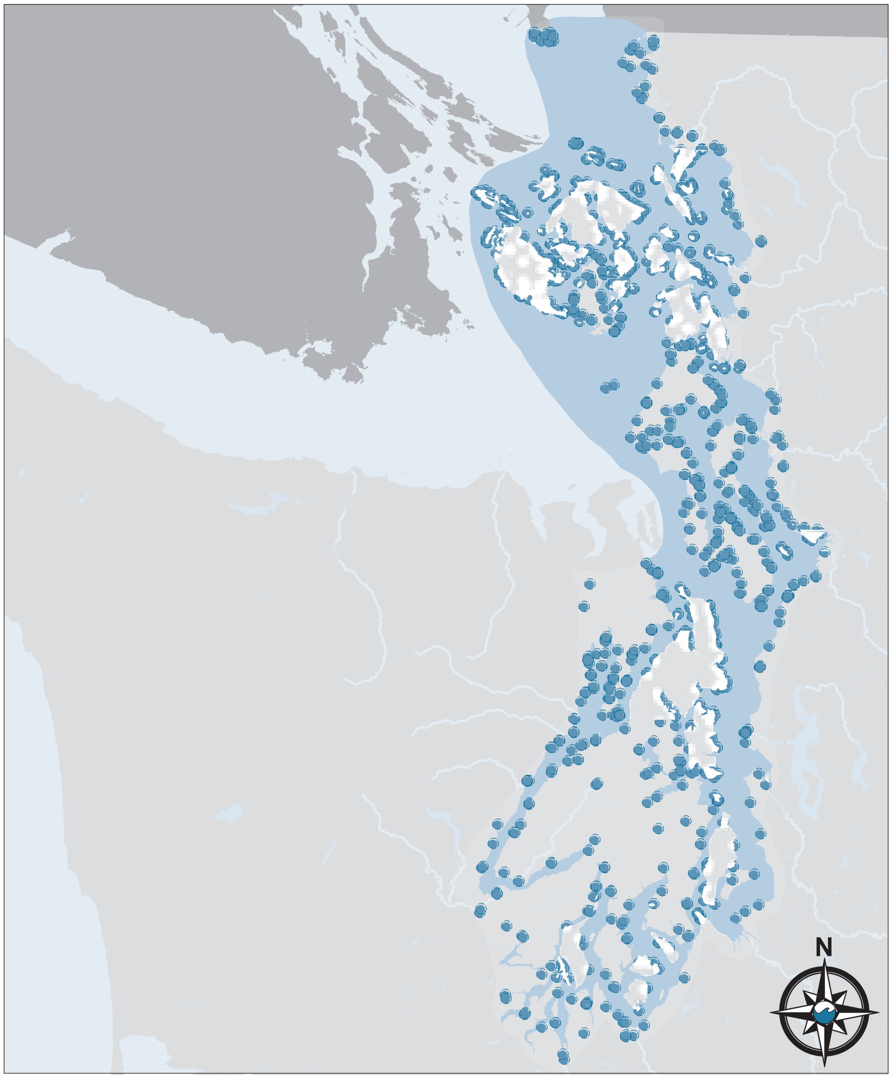
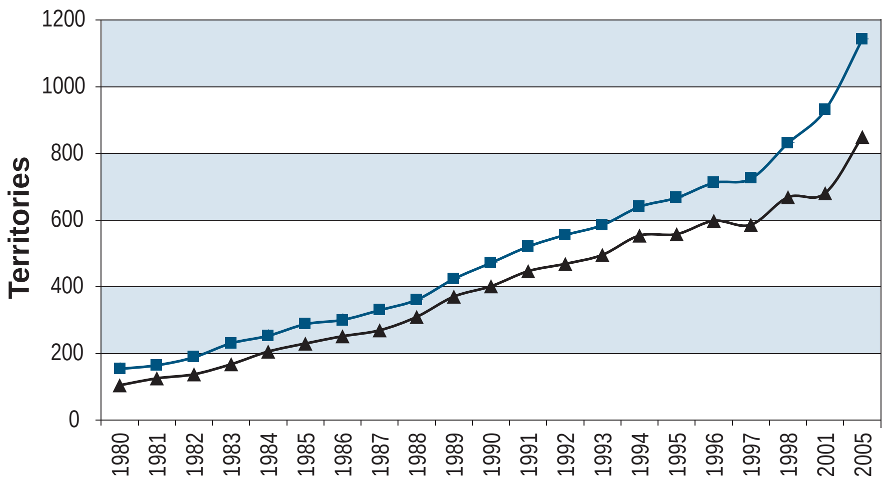


Figure 2-42. Eagle surveys in the Puget Sound Recovery Zone 1980-2005. The number of new and existing bald eagle territories in the Puget Sound Bald Eagle Recovery Zone. The number of discovered and checked sites has increased within the past 10 years, in part because of increased survey efforts and an increase in the breeding population. There were more nesting pairs in 2005 (new and occupied nests) compared to 2001. (Source: WDFW)



■ Territories checked

▲ Territories occupied

9. Marine Mammals

a. Sea Otters

Sea otters (*Enhydra lutris kenyoni*) were common along Washington's Pacific Ocean coast until they were extirpated during the fur trade early in the 20th century. The current population off the Washington coast was reestablished by translocation from Alaska's Amchitka Island in 1969 and 1970, when a total of 59 otters was released.

The Washington sea otter population is subject to protection under the federal Marine Mammal Protection Act, as well as listed as endangered by the state of Washington. In recent years, anomalous strandings of sea otters on the ocean coast have led to concern that sea otters may be ingesting contaminated prey and suffering increased mortality rates as a result of immunosuppression from contaminants or *Morbillivirus*, which has recently been detected in this population. USFWS, along with its partners, embarked on a study to address the questions surrounding the contaminant and mortality issues facing the Washington sea otter population.

Status and Trends

In the latest census, conducted in July 2005, 814 sea otters were counted—a 10 percent increase from 2004. Overall, there has been an average rate of increase of 8.2 percent since 1989, and it would appear that the sea otter population, which currently ranges from Kalaloch to the western Strait of Juan de Fuca, is still in a positive growth phase.

In 2001 and 2002, a survey for pathogen exposure in sea otters was conducted by WDFW. Thirty animals were captured and tested for a variety of parameters. Whole blood was collected to determine exposure to a variety of pathogens, including *Morbillivirus*, *brucella*, *leptospirosis*, and *toxoplasmosis*. Samples from live otters never yielded positive tests for brucella or calicivirus, but testing for *neospora* (50 percent), *sarcocystis* (29 percent), and *leptospirosis* (3 percent) was positive in some animals. The most interesting findings were the toxoplasmosis and *Morbillivirus* titers. Sixty percent of the live animals tested positive for toxoplasmosis, while 80 percent tested positive to *Morbillivirus*. Generally, the *Morbillivirus* results were higher for the canine distemper strain of the virus; however in a few instances, the phocine distemper virus results were equivalent or higher for individual animals. This was the first positive finding of *Morbillivirus* in sea otters.

Impacts to the Ecosystem

Analyses of samples from live captured sea otters off the Washington coast indicate relatively low exposure to contaminants but suggest evidence of pathogen exposure. Infectious disease presents a potential risk to Washington sea otters, particularly because of their relatively small population size and limited distribution. Despite these significant findings in live otters, cause of death of stranded sea otters has not generally been attributable to either *Morbillivirus* or *Toxoplasma*, and many of the sea otters that tested positive for these pathogens were tracked following this investigation and found to be alive and presumably well. The high prevalence of antibodies to *Morbilliviruses* in the sampled animals suggests that the Washington sea otter population is fairly well protected against a widespread *Morbillivirus* outbreak. Individual deaths may occur, but a population-threatening die-off from this disease is unlikely while population immunity remains high.

Washington's sea otter population continues to grow, with an estimated 800 animals currently inhabiting Washington waters. However, the population remains well under historic levels, and the population has not yet reached its carrying capacity. As such, is still considered at high risk to catastrophic events such as oil spills.

b. Harbor Seals

The harbor seal (*Phoca vitulina*) is a small, stocky, eared seal found throughout the temperate and Arctic waters of the northern hemisphere and has the widest distribution of any pinniped. In the Pacific Ocean, harbor seals inhabit coastal and estuarine waters from Baja California to Japan. Harbor seals are generally considered non-migratory, breeding and feeding in the same general area throughout the year. Within their residing areas, their activity may be driven by daily and seasonal variation in tides, weather, prey availability, and reproduction.

Harbor seals are the most common, widely distributed pinniped in nearshore waters of Washington. They use hundreds of sites to rest or haul out, including intertidal sand bars and mudflats in estuaries, intertidal rocks and reefs, islands, logbooms, docks, floats, and sandy, cobble, and rocky beaches. Group sizes typically range from a dozen or fewer animals on small intertidal rocks or reefs to several thousand animals hauled out seasonally in coastal estuaries. Males and females are similar in size (to 250 lbs) and coloration. Pelage patterns are typically a light base with dark spots, although the pelage of some individuals is reversed in coloration, with dark base and light spots.

Harbor seals have an annual reproductive cycle with the birth season typically lasting up to two months. Females produce one pup per year, beginning at age four or five. Pups are precocious at birth, capable of swimming and following their mothers into the water immediately after birth. Pups typically remain with their mothers until weaning at four to six weeks of age. Harbor seal pupping seasons vary by geographic area in Washington, with pups born along the ocean coast from mid-April through June and in the inland waters from June through August. Hood Canal is somewhat of an anomaly, with births and nursing pups recorded from July to January.

Status and Trends

During the first half of the 20th century, numbers of harbor seals (as well as sea lions) were severely reduced in Washington by a state-financed bounty and control programs that considered seals and sea lions to be salmon predators in direct competition with commercial and sport fishermen. After bounties and control programs ended, and federal protection was established with passage of the Marine Mammal Protection Act in 1972, harbor seal populations in Northwest waters recovered and are now at or near historic levels. Today, Washington's harbor seal population numbers are in excess of 30,000 animals, with 16,000 on the outer coast waters and 14,000 in inland waters.

Impact to the Ecosystem

As a long-lived, non-migratory, high-trophic-level predator in Puget Sound, harbor seals are excellent indicators of contaminants in the marine environment. With a diet consisting of a variety of prey, including Puget Sound herring, anchovy, Pacific hake, salmonids, cod, flatfish, pricklebacks, greenlings, sculpins, lamprey, and smelts, harbor seals bioaccummulate persistant toxins (PBTs) from these prey via dietary intake. Spatial studies of various persistant bioaccumulative toxins in harbor seal blubber have shown that Puget Sound animals are seven times more contaminated with PBTs than those inhabiting the Strait of Georgia (see Chapter 4, Section 3c). Recent studies have also profiled the rapid emergence of flame retardants, or polybrominated diphenylethers (PBDEs) in marine food webs by looking at concentrations in harbor seals as well (See Section 3c in Chapter 4). Harbor seals continue to provide a valuable tool for looking at contaminants in the marine food web and an overall indicator of the health of Northwest waters.

c. California Sea Lions

California sea lions (*Zalophus californianus*) are the most frequently sighted otariid, or eared seal, found in nearshore coastal waters of Washington. Animals present in Washington waters typically include all age classes of males ranging in size from 100 to 1,000 lbs. Females with pups and juveniles typically remain to feed in waters near their breeding rookeries off the California coast. (Note: In recent years, a few females have been reported in Northwest waters but are still considered rare outside of California waters.) Coloration of males is usually a dark or chocolate brown. A high forehead, or sagittal crest of the male is distinctive. In older males, the hair on top of the head becomes blond in color. Vocalizations can be described as barking. Male California sea lions migrate northward in search of food during late summer and early fall as a result of dispersal from their breeding rookeries in the Channel Islands off California. This dispersal results in animals moving into nearshore waters off Oregon, Washington, and British Columbia. These animals remain in Northwest waters until late spring, when the majority head south to their breeding rookeries off California.

California sea lions use a variety of haul-out sites, such as offshore rocks and islands, jetties, logbooms, navigation buoys, and marina docks. In Washington, this species uses haul-out sites along the Olympic Peninsula coast (Carroll Island, Cape Alava, and Tatoosh Island), in the Strait of Juan de Fuca (Race Rocks) and in Puget Sound (logbooms near Everett and most navigation buoys). This species is also frequently seen throughout Puget Sound, resting alone or rafted together in groups with flippers in the air.

Status and Trends

Population estimates for California sea lions in U.S. waters are based on multiplying pup production by the fraction of newborn pups in the population. Using this method, it is estimated that 237,000 to 244,000 animals inhabited U.S. waters in 2003. Based on an analysis of pup counts from 1983 to 2003, the California sea lion population has been increasing by five to six percent annually. The largest California sea lion aggregations in Washington have occurred near Everett in Puget Sound, where numbers increased from 108 in 1979 to a maximum of 1,234 in the spring of 1995. Since 1995, a shift in distribution from inland waters to the outer coast has been observed, with 4,000 to 5,000 animals observed near Cape Alava on the Olympic Peninsula coast in the fall. An additional 1,000 to 1,500 California sea lions are present seasonally in British Columbia.

Impacts to the Ecosystem

California sea lions are opportunistic feeders that prey on a wide variety of fish and invertebrates. Their diet is diverse and varies seasonally by location. Some of the common prey in Northwest waters includes herring, Pacific hake, salmon, steelhead, anchovy, sardines, smelts, lamprey, dogfish, squid, and octopus. California sea lions tend to congregate at the mouths of rivers or estuaries, where prey is abundant, and are known to feed on seasonal concentrations of smelt, salmon, and steelhead entering these rivers and estuaries. Movement and re-distribution of California sea lion concentrations in Northwest waters have been correlated with spawning aggregations of various prey, including Pacific whiting, herring, and salmonids, and indicate the ability of California sea lions to find locally abundant concentrations of these species. Predation on salmonids by this species has been identified as an area of concern at the Hiram M. Chittenden Locks in Ballard, Willamette Falls, Bonneville

Dam, and other locations. Salmon is a seasonally important prey of California sea lions, which are considered to compete with orcas for salmon.

d. Steller Sea Lions

Steller (or northern) sea lions (*Eumetopias jubatus*) are the largest otariid in Northwest waters and are present year-round. This species ranges along the North Pacific Ocean coastline, from California to Japan. For management purposes, the Steller sea lion population is divided into two distinct segments or stocks, designated as the Eastern U.S. Stock (distributed from California to Cape Suckling, Alaska) and Western U.S. Stock (distributed from Cape Suckling, Alaska, to Hokkaido, Japan). Steller sea lions in Washington are considered part of the Eastern U.S. Stock. Both sexes occur in Washington waters, with adult males (to 2,200 lbs or 1,000 kg) being considerably larger than females (to 700 lbs or 317 kg). Coloration varies from tawny through yellowish brown to dark brown. Vocalizations from adults can be described as deep growling sounds.

Status and Trends

Breeding rookeries are located along the California, Oregon, British Columbia, and Alaska coasts. With the exception of rookeries in California, the Western U.S. population has increased at over three percent annually since the 1970s and is currently estimated at over 31,000 animals. Four main haul-out areas are located along the outer Washington coast near Split Rock, Carroll Island, Cape Alava, and Tatoosh Island. Peak abundances occur during fall and winter months, with 1,000 to 1,500 animals along the outer Washington coast. These animals are assumed to be immature animals and nonbreeding adults associated with rookeries from other areas. At these same seasons and into the spring, 800 to 1,000 animals move through the Strait of Juan de Fuca and into the Strait of Georgia to feed on herring (that spawn north of Nanaimo) and Pacific hake. Relatively small numbers use haul-out areas in the San Juan Islands at Whale Rock, Bird Rocks, Peapod Rocks, Speiden Island, and Sucia Island. Aerial surveys conducted by the WDFW since the early 1990s show the Washington Steller sea lion population increasing at a rate of 9.6 percent annually.

Impacts to the Ecosystem

Steller sea lions are an opportunistic predator that feeds primarily on fish, octopus and squid, with prey varying by season, area, and water depth. Their diet consists of herring, hake, salmon, cod, lamprey, rockfish, flatfish, skates, squid, and octopus. Salmon are seasonally important and range from six to 33 percent of the animals' diet. Steller sea lions compete with other pinnipeds and with orcas for salmon returning to Washington rivers and streams.

e. Porpoises

Harbor porpoise (*Phocoena phocoena*) and Dall's (*Phocoenoides dalli*) porpoise are members of the Phocoenidae family, sometimes called true porpoises. They are the most common small cetacean in the greater Puget Sound area (Osborne et al 1988, Calambokidis and Baird 1994). Both are fairly small and generally less than 2 meters (6-feet long). Dall's porpoise often approach boats to bow-ride and are capable of high speeds that allow them to streak through the water, creating characteristic rooster tails. Their dramatic black-and-white coloration confuses many people into thinking they are baby orcas. Harbor porpoise tend to avoid boats and are much less distinct in coloration and behavior. Their small, nondescript size makes them easy to overlook in all but the calmest of conditions.

Dall's porpoise occur broadly in the northern North Pacific in inshore, coastal, and pelagic waters. Harbor porpoise utilize primarily coastal and inland waters (generally less than 328 feet or 100 m deep) and occur in Northern Hemisphere temperate and Arctic waters. Both species can occur in almost all Puget Sound waters, although Dall's porpoise are currently more common than harbor porpoise in Puget Sound proper. Information from contaminant ratios and genetics suggest harbor porpoise form fairly distinct, localized populations (Calambokidis and Barlow 1991, Chivers et al. 2002), raising concern about the impact of localized causes of mortality.

Status and Trends

Harbor porpoise were considered the most common small cetacean in Puget Sound in early accounts from the 1940s. Sightings within Puget Sound have been rare in the last 30 years. The reason for their virtual disappearance from Puget Sound is not known but is consistent with declines in other areas and is likely the result of some combination of factors, including high vessel traffic, entanglement, and contaminants. There have been some indications of increased sightings of harbor porpoise within Puget Sound in recent years.

Concern over harbor porpoise status and, specifically, the impact of mortality from entanglement in fishing nets has prompted the National Marine Mammal Laboratory, in collaboration with Cascadia Research, to conduct periodic aerial surveys to estimate harbor porpoise abundance. Surveys were most recently conducted off Oregon, Washington, and southern British Columbia, including the inside waters, in 2002 and 2003. These provided an estimate of 10,682 harbor porpoise in Washington's inside waters and an estimate of 37,745 for waters along the Pacific Ocean coast of Oregon (north of Cape Blanco) and Washington (J. Laake et al. Unpubl. data). Estimates in outer coastal waters were similar to the previous survey in 1996 and 1997, while those in inside waters were higher than had been previously documented (Laake et al. 1998, Calambokidis et al. 1997).

Impacts to the Ecosystem

Harbor porpoise and Dall's porpoise are both caught in nets incidental to commercial fishing activities. They generally consume small fish and are not competitors for commercially valuable fish. Both are occasional prey of transient, mammal-eating orcas. They are also known to occasionally interbreed and hybrids between the two species have been documented frequently in the San Juan Islands (Willis et al. 2004).

f. Orcas

Orcas (*Orcinus orca*), also known as killer whales, are distributed throughout the marine waters of Washington. Three main populations are referred to as southern residents, transients, and the offshore population (Wiles 2004). These populations rarely interact and do not interbreed, despite having largely similar year-round geographic ranges extending into British Columbia and other areas along the west coast of North America. Southern resident and transient orcas are the only populations that regularly enter the state's coastal waters, whereas offshore orcas mainly inhabit the open ocean off the outer coast. The southern residents are thought to feed almost exclusively on salmon, especially chinook and chum. They occur in small, highly stable social units known as matrilines, in which all individuals are maternally related. Pods are larger social groups comprised of several matrilines and typically hold about 10 to 60 animals. In contrast, transient orcas feed primarily on harbor seals and other marine mammals. They also travel in small matrilineal groups, which typically contain one to six animals, but these

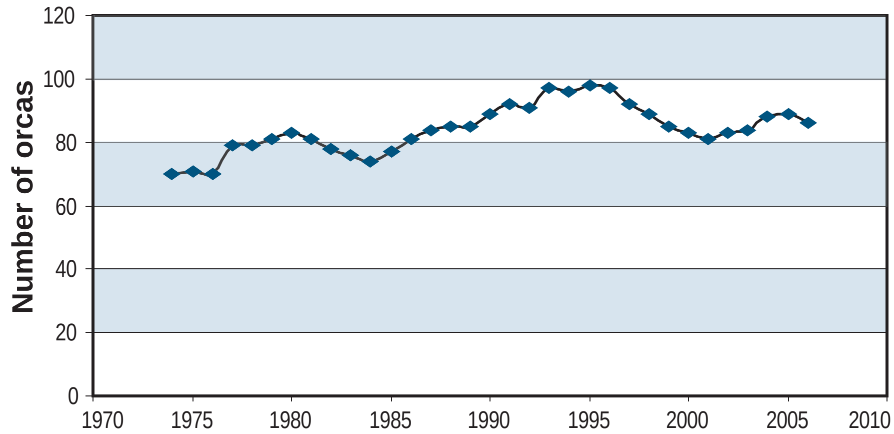


Figure 2-43. Population size and trend of southern resident orcas, 1974-2006. Currently the population consists of 86 individuals. Between 1974 and 1995, the population increased from 70 to 98 whales, but this gain was followed by a rapid net loss of 17 animals, or 17 percent of the population, between 1996 and 2001.
(Source: Center for Whale Research)

associations are generally looser than among resident groups. Few details are known about the biology of offshore orcas, but these are typically larger groups and the members are believed to be mainly fish-eaters.

Status and Trends

The southern resident population consists of three pods (identified as J, K, and L pods), which contain the majority of orcas found in Washington. The three pods are usually present in the Georgia Basin and Puget Sound waters from late spring to fall. The population travels more extensively during other times of the year to sites as far north as northern British Columbia and as far south as central California. Data on earliest southern resident population trends are from 1960, when roughly 80 whales were present; these numbers may not reflect true historic population sizes as whales may have been depleted by indiscriminant shooting by fishermen. The population's recovery was impaired during the early- and mid-1960s and 1970s, when live captures for aquaria removed or killed at least 47 individuals.

The southern resident population has been closely monitored since 1974, with exact numbers of animals and other demographic details learned through annual photo-identification surveys. Between 1974 and 1995, the population increased from 70 to 98 whales but this gain was followed by a rapid net loss of 17 animals, or 17 percent of the population, from 1996 to 2001 (Figure 2-43). J and K pods generally maintained their numbers during the decline, but L pod, which comprises about half of the southern resident population, sharply declined. L pod's decline involved both increased mortality of members and lowered birth rates. Southern resident numbers have again been growing since 2001 and are currently at 90 individuals, although reports at press time indicated three orcas may have died of starvation in the fall of 2006. Population trends of transient and offshore orcas are not known, because of their greater mobility and more sporadic occurrences, which makes it difficult for researchers to maintain detailed photographic records of both groups.

Orcas in Washington face several main potential threats. These include: large historic declines in salmon for the southern residents; declining health and reproductive capacity due to high levels of pollutants—PCBs, DDTs, PBDEs, and, perhaps, other chemicals; increased noise and disturbance from whale-watching boats and other vessels; and major oil spills.

Impacts to the Ecosystem

Orcas are top-level predators. Their impacts on salmon populations are unknown but are probably fairly minimal under most circumstances. Effects on pinniped populations are also likely to be minor, except where whales remain for long periods within localized areas. For example, groups of transients are thought to have substantially reduced the harbor seal population in Hood Canal during multi-month stays in 2003 and 2005.

Human Health Consequences

Transient and southern resident orcas are among the most highly contaminated marine mammals in the world—a condition that results from their position as apex predators. This reflects a continuing presence of worrisome levels of certain pollutants in the greater Puget Sound area and the region's other marine ecosystems. Washington's orcas and humans share certain foods, especially salmon; thus, there is concern that humans may be consuming unhealthy levels of the same pollutants. These problems signal a greater need for stronger anti-pollution regulations and enforcement, plus additional cleanup activities.

g. Minke Whales

The first minke whale (*Balaenoptera acutoraostrata*) described in Puget Sound was a 27-foot (8m) female stranded in Admiralty Inlet in 1874 (Scammon 1874). Live minke whales have more recently been observed in various parts of Puget Sound and the Straight of Juan de Fuca. The International Whaling Commission identified three North Pacific minke whale stocks: two in the western Pacific and a third, the remainder stock, consisting of whales in the eastern Pacific (Donovan 1991). NMFS further divided the remainder stock into Alaskan, Hawaiian, and the California-Oregon-Washington (CA-OR-WA) stocks, which was partially based on research showing that the coastal minke whale stock consisted of small, regional populations. Individual minke whales have sited multiple times within and between years in the 1980s, with no movement observed between Washington, British Columbia, and California populations. Sightings occurred year-round (Scammon 1874, Everitt et al. 1979), although the greatest research effort was made during summer months (Dorsey et al. 1990).

The Makah Indians of Cape Flattery occasionally hunted the minke whale (Scammon 1874; Scheffer and Slipp, 1948). Currently, the whales are the subjects of whale-watchers in the Straight of Juan de Fuca.

Status and Trends

The current size estimate for the CA-OR-WA minke whale population is 1,015 individuals, with a minimum population size estimate of 585 individuals. Net fisheries and ship-strike interactions are a concern. The stock has never been hunted commercially, so the reason for the small population size is unknown. Three primary feeding areas have been discovered for minke whales. These are Waldron Island, the San Juan Channel, and the Strait of Juan de Fuca. Individuals in these areas often use distinctive feeding behaviors associated with the kinds of available prey (Dorsey 1983, Dorsey et al. 1990, Hoelzel et al. 1989). Hoelzel et al. (1989) identified prey as herring and sand lance. In the 1980s, the Waldron Island area was consistently occupied by at least five individuals during the summer months. Although monitoring efforts have been reduced since the 1980s in this area, only a few scattered sightings have been reported. More sightings were reported in the Strait of Juan de Fuca. In 2003, minke whales were again seen north of San Juan Island.

Impacts to the Ecosystem

The impact of minke whales on the Puget Sound ecosystem is unclear, but under investigation. About 17 individuals were identified per year in the early 1980s (Dorsey et al. 1990). They feed in the area and consume an unknown quantity of herring and sand lance (Hoelzel et al. 1989). They are most frequently seen over submarine banks and in areas of vigorous tidal activity—areas with high concentrations of prey.

h. Humpback Whales

Humpback whales (*Megaptera novaeangliae*) occur in all oceans of the world. They are listed as endangered, due to the decimation of their populations from commercial whaling, which continued up to 1966. Whaling stations operated near Puget Sound in the 1900s, including Bay City (Grays Harbor) and several locations on Vancouver Island. Humpback whales were historically fairly common in the inside waters of Washington and British Columbia. An intensive but short period of whaling, targeting these whales in inside waters, appeared to eliminate this population.

Humpback whales make extensive migrations from feeding areas in colder, productive waters in summer months to warm water breeding areas in winter. Recent research has indicated that humpback whales off northern Washington are a somewhat distinct feeding aggregation with fairly little interchange with feeding areas to the north and south. Humpback whales that feed off Washington migrate to winter breeding areas off Mexico and Hawaii.

Status and Trends

Humpback whales have been recovering in a number of areas, although populations in most regions remain well below those that existed prior to whaling. Although most humpback whales occur in waters off the Washington coast, sightings in Puget Sound have become increasingly more common in recent years. This has included several animals that spent periods of two to three months in areas of Puget Sound and the Strait of Juan de Fuca.

Since 2004, an international collaboration of researchers has been conducting an intensive study of humpback whales throughout the entire North Pacific. The study, called SPLASH, will be the first complete census of humpback whales in the entire North Pacific and will determine abundance, trends, population structure, movements, and human impacts.

Impacts to the Ecosystem

Humpback whales feed on both krill and small fish. Most of the whales feeding on krill tend to do so in waters near the continental shelf edge in offshore waters. Humpback whales in inside and more coastal waters typically feed on fish, and this was likely the case for humpback whales in Puget Sound and Strait of Juan de Fuca. The declines in a number of species of small fish, such as herring in Puget Sound, could limit the recovery of humpback whales in these waters.

i. Gray Whales

Gray whales (*Eschrichtius robustus*) make one of the longest migrations of any mammal. The eastern Pacific gray whale travels from winter breeding areas off Baja California to summer feeding areas primarily in the northern Bering Sea and into Arctic waters. While it was once thought all gray whales make this migration, recent research has revealed the existence of a component of the population that can spend the entire spring, summer, and fall feeding in the waters of the Pacific

Northwest, from California to Southeast Alaska. This group has been referred to as seasonal residents, or the Pacific coast feeding aggregation of gray whales.

Gray whales are still hunted in Russia under a provision for aboriginal hunting allowed by the International Whaling Commission. In 1995, the Makah Tribe of Washington asserted their treaty right to whale and resume their historical hunts for gray whales. Their proposed hunt of up to five gray whales a year was the source of legal battles that continue today. To date, only a single whale has been killed (in 1999) by the Makah Tribe. Gray whales also are killed by entanglement in nets and crab lines as well as ship strikes. While there had been concern in the 1980s and 1990s about the role of contaminants in the mortality of gray whales in Puget Sound, tests of gray whale tissues have revealed contaminant levels that are much lower than in many other marine mammals species and that the mortality is the result of other factors.

The eastern Pacific gray whale population had been considered one of the success stories for recovery from commercial whaling. The population had been reduced to a few thousand animals during several different periods of whaling that targeted this species in the 19th and 20th centuries. The population increased steadily to approximately 23,000 to 26,000 whales by the late 1990s. The recovery of the eastern Pacific gray whale led to its removal from the federal list of endangered species in 1995.

Status and Trends

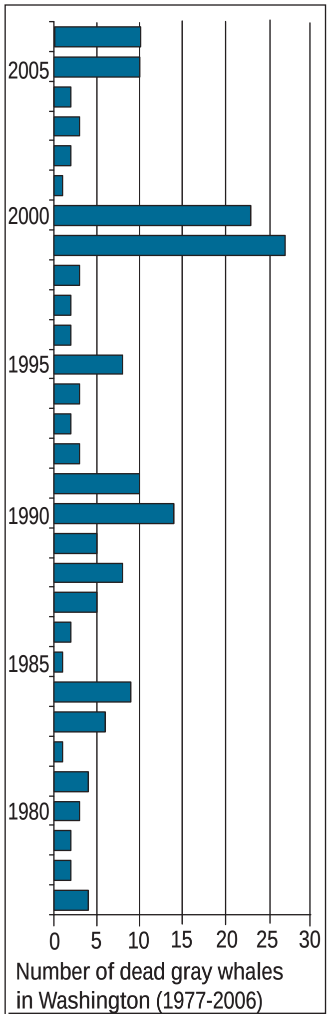
In 1999 and 2000, an unusually large number of dead gray whales were found from Mexico to Alaska. In Washington state, 27 dead gray whales washed ashore in 1999—considerably more than the average of about four a year prior to that. Another 23 whales washed ashore in 2000 (Figure 2-44). Additionally, low numbers of calves were born, and many live animals appeared emaciated. Examination of dead animals revealed most were in very poor nutritional condition and appeared to have starved to death. The overall gray whale population was reduced to about 17,000. This mortality is thought to have been a result of combination of events: a recovery in gray whale numbers to pre-whaling population size and a decline in prey species populations.

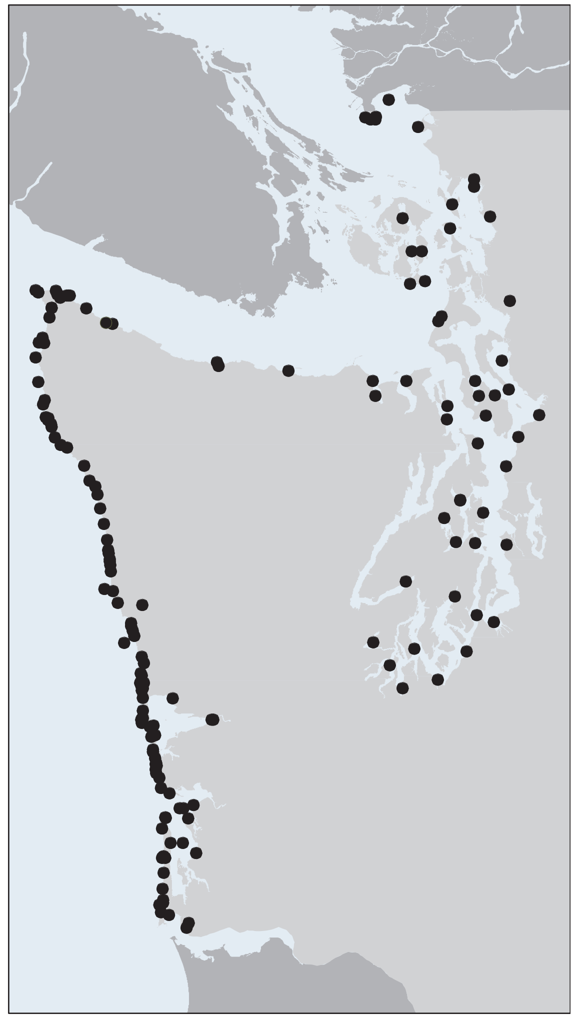
Recent research in Puget Sound has revealed three primary patterns in gray whale activities. The main part of the population migrates past Washington in winter and spring en route between winter breeding areas and summer feeding areas. A small number of whales wander into unusual areas of Puget Sound in spring and appear to be stragglers from this migration; they often appear emaciated and often die. A group of about 250 seasonal residents spend springs, summers, and falls feeding in the Pacific Northwest, farther south of the majority of the population. In northern Puget Sound, a small group of regular animals spend two to three months feeding primarily on ghost shrimp in the waters around Whidbey and Camano islands.

Impacts to the Ecosystem

Gray whales generally utilize a fairly unique feeding method. They primarily feed on organisms along the bottom and in the upper layer of sediment that they suck into their mouths and, then, filter through baleen plates. Recent research has revealed gray whales can also be surprisingly versatile feeders, occasionally capturing a wide variety of prey, including fish, krill, and the larvae of fish and crabs.

Figure 2-44. Number of gray whale carcasses found in Washington state, 1977 to 2005. There was high mortality in 1999 and 2000. Map shows location of caracasses found since 1977. (Source: WDFW)





10. Aquatic Nuisance Species

Aquatic nuisance species (ANS) are non-native aquatic plants or animals which can out compete native species for habitat and food, altering the natural ecosystem. They also threaten the biodiversity of Puget Sound.

Purple loosestrife (*Lythrum salicaria*), *hydrilla* spp. and *Spartina* spp. are a few examples of plants that currently threaten estuaries, wetlands, rivers, and lakes in the Puget Sound Basin. Non-native tunicates commonly called sea squirts, are animals that multiply rapidly and are a recent arrival to several locations in Puget Sound. The European green crab, Chinese mitten crab, and zebra mussel are ANS that could arrive at anytime and threaten the Sound.

One means of ANS introduction to Puget Sound and its tributaries is ballast water discharged by ships. A large percentage of 52 documented non-native species found in Puget Sound was probably introduced in ballast water discharges. ANS also arrive on fouled hulls of ships, as hitchhikers on imported aquaculture species, in shipments of live seafood and bait and their packaging, and on recreational boats transported into and around the state.

a. Tunicates

Tunicates are primitive invertebrates in the phylum Chordata. They occur in colonies and also as solitary individuals and are aggressive spawners, reproducing as frequently as once every 24 hours. They colonize on many types of marine structures and habitats, overgrowing and smothering other organisms on the seabed, sometimes covering the siphons of infaunal bivalves. Tunicate species have the potential to spread rapidly throughout Puget Sound by traveling on the hulls of recreational and commercial boats.

Status and Trends

In late 2004 and early 2005, researchers found three non-native invasive tunicates in Puget Sound. An Asian colonial tunicate, *Didemnum,* was found in waters off Edmonds, and promptly eradicated at that site. Subsequently, researchers found the species at the Des Moines marina and on mussel lines in Totten Inlet and Dabob Bay. There are also huge infestations off Vancouver Island and in Okeover Inlet on Desolation Sound in British Columbia.

In the summer of 2006, WDFW surveyed for and found the solitary club tunicate *Styela clava* in high densities at Pleasant Harbor marina in Hood Canal and at the Blaine and Semiahmoo marinas. Divers from WDFW attempted to prevent the club tunicate from spreading to other areas by removing all animals that fouled boat hulls at the infested marinas.

Another solitary non-native tunicate, *Ciona savignyi* was found in high densities on geoduck tracts at the south end of Hood Canal near the mouth of the Tahuya River. There were no *C. savignyi* at this site in the 1990s but these invertebrates are now abundant and are the dominant species in this area of Hood Canal. Researchers also reported large populations at the Des Moines marina, Eagle Harbor, Edmonds, and the Tacoma Yacht Club.

b. European Green Crab

The non-native European green crab is not currently found in Puget Sound, but because it is present on Washington's ocean coast, monitoring is underway to patrol for its presence in Puget Sound. Volunteers continue to monitor over 100 sites in the Puget Sound region for the presence of green crab.

c. Atlantic Salmon

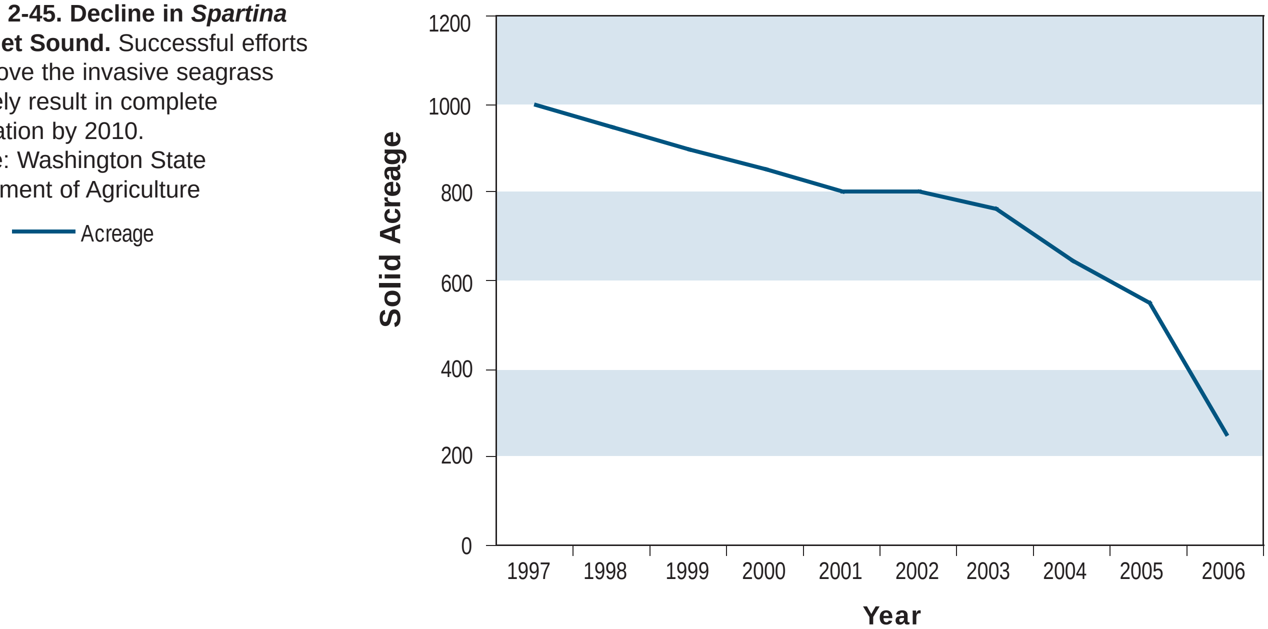
Four locations in Puget Sound have net pens for raising Atlantic salmon (*Salmo salar*). These locations include the Port Angeles Harbor in Clallam County, Rich Passage in Kitsap County, and Cypress and Hope Islands in Skagit County. In addition, private operators raise Atlantic salmon at two hatcheries in Washington—one on Scatter Creek and another at Cinnabar Creek on Mayfield Lake. Scatter Creek, in Thurston County, is a tributary to the Chehalis River, and Cinnabar Creek is in Lewis County; both are outside of Puget Sound.

Between 1996 and 1999, 613,000 Atlantic salmon escaped from net pens in Washington. Less than four percent of these fish were recovered, raising concern that the remaining escapees may reproduce in Washington waterways.

d. Aquatic and Riparian Plants

WSDA lists 29 species of wetland and aquatic plants as being prohibited for sale in the state. Most are not found in this region and some have limited populations.

Figure 2-45. Decline in *Spartina* in Puget Sound. Successful efforts to remove the invasive seagrass will likely result in complete eradication by 2010. Source: Washington State Department of Agriculture



Others, such as invasive *Spartina*, knotweed, and purple loosestrife are found in the Puget Sound region and resource managers are actively controlling their populations.

i. Spartina

Spartina, commonly known as cordgrass, is an aggressive noxious weed that severely disrupts the ecosystems of native saltwater estuaries in the state. It outcompetes native vegetation and converts mudflats into monotypic *Spartina* meadows, destroying important migratory shorebird and waterfowl habitat, increasing the threat of flooding, and severely impacting the state's shellfish industry. *Spartina* spreads by seed production and below-ground root growth.

Spartina was introduced in Puget Sound by various landowners, who planted it to stabilize shorelines. It was also planted at a farm located in Port Susan in the early 1960s as bank stabilizer and for cattle feed.

Four species of non-native *Spartina* are found in Puget Sound estuaries. *Spartina alterniflora* is found in Skagit, Clallam, and in Jefferson Counties. *Spartina patens* occurs at only one location in Jefferson County. *Spartina anglica* is present in Skagit, Snohomish, Island, San Juan, Whatcom, King, Kitsap, and Jefferson counties. *Spartina densiflora,* from South America, is found within Race Lagoon in Island County.

Status and Trends

WSDA partners with local noxious weed control boards, tribal governments and WDFW to eradicate *Spartina*. WSDA has estimated that 520 acres of *Spartina* were treated in Puget Sound and Hood Canal in 2005—approximately 95 percent of the overall infestation. The Puget Sound infestation, estimated at 1,000 acres in 1997, has been reduced by about 46 percent (Figure 2-45). From the spring of 2004 to the spring of 2005, an estimated 16 percent reduction occurred. At the current removal rate, agencies are on track to effectively eradicate spartina from Puget Sound by 2010.

ii. Knotweed

Five species of non-native knotweed plants grow in the Puget Sound basin: Japanese knotweed, giant knotweed, bohemian knotweed, and Himalayan

County	River	Miles surveyed	Acres treated
Whatcom	N and S fork of Nooksack	15	7.5
Skagit	Skagit and Sauk rivers	500	4.5
Snohomish	Stillaguamish River	43	139
Island	County wide		3
Clallam	Dungeness, Hoko, Hoh and Queets rivers	55	94
King	Green/Duwamish	18	9
TOTAL in 2005		631 miles	257 acres

Table 2-7. River miles surveyed and area of knotweed species treated in Puget Sound in 2005. (Source: WSDA)

knotweed. Knotweed species will grow in most habitats but are most commonly found along stream corridors. It outcompetes native vegetation, including alder and cottonwood trees, forms dense, impenetrable walls along waterways, and potentially reduces precious salmon habitat.

Status and Trends

In 2005, approximately 631 river miles were surveyed for knotweed and approximately 257 acres were treated in the Puget Sound area by tribal governments, local, state, federal agencies, and non-governmental organizations (Table 2-7).

e. Bivalves

The eastern softshell clam is believed to have arrived from the Atlantic in the late 1800s. The varnish clam is a more recent arrival from Asia. First encountered in the San Juan Islands in the 1980s, varnish clams have been increasing in biomass, abundance and distribution. They are now found in the Strait of Juan de Fuca, the San Juan Islands, and as far south as Potlatch in southern Hood Canal. A 2005 WDFW survey on Spencer Spit on Lopez Island found varnish clam densities of up to 80 clams per square foot.

f. Nutria

Nutria (*Myocastor coypus*) are large rodents originally from South America. Nutria consume approximately 25 percent of their body weight in plant matter per day. High reproduction rates coupled with their feeding habits can result in losses to native vegetation and important habitat for wildlife. As semi-aquatic creatures, they prefer aquatic and emergent plants; however, nutria are opportunistic feeders and will consume tree bark, crops, and lawn grasses. They destroy vast swaths of marshes and wetlands and threaten infrastructure such as dike and levee systems.

Status and Trends

Researchers and resource managers have not determined the size of nutria populations in the Puget Sound Basin, nor have they developed a comprehensive management plan for these non-native animals. However, nutria populations in the Puget Sound Basin appear to be on the rise and are currently found in Whatcom, Skagit, Snohomish, King, Pierce, and Thurston counties.

11. Marine Conservation Tools

a. Marine Reserves Monitoring

WDFW has developed a network of 18 marine reserves in Puget Sound (Figure 2-46). These consist of Conservation Areas, which are fully-protected, and Marine Preserves which are partially-protected. A core series of the marine reserves will be monitored on a frequent basis, and additional subtidal reserves will be monitored on a periodic basis. The monitoring plan builds upon field research at many of these sites that was begun as early as 1986. The fieldwork primarily consists of visual censuses conducted by scuba divers along strip transects. Along with estimating fish densities, divers measure individual fish and identify and quantify lingcod nesting activity.

Specific monitoring activities in 2004 included surveying many of the Puget Sound reserves and comparable fished sites. Several reserves in central Puget Sound were visited six times during 2004 as an extension of a study initiated in 1999 to take advantage of the previous information collected at Orchard Rocks. This site was declared as a fully protected reserve in 1998 but was a fished site monitored in 1986 and 1987 and from 1995 to 1997. With the addition of a new fished site treatment at Point Glover, the newly created refuge in a formerly monitored fished area is an excellent opportunity to evaluate the before-and-after impacts of refuge creation with a comparable fished site treatment. WDFW also created several new reserves in 2002. These included subtidal reserves at Admiralty Head and Keystone Jetty in Admiralty Inlet and Zee's Reef in southern Puget Sound. Monitoring was initiated at Zee's Reef in 2002 with six surveys conducted again in 2004. The reserve at Colvos Passage was also monitored during the same survey series.

The marine reserve monitoring studies conducted in the San Juan Islands, Hood Canal, and central Puget Sound confirmed that most marine reserves had higher densities of copper rockfish and lingcod than comparable and nearby fished areas. These fishes were also larger in the long-term reserve at Edmonds (Brackett's Landing) than at the fished areas. In Hood Canal, where the existing reserves amount to almost 20 percent of the available nearshore rocky habitat, increasing sizes of copper rockfish have been observed since 1996 at a site set aside as a reserve in 1994. The densities of copper rockfish are significantly greater in the Hood Canal reserves than the fished area. In the San Juan Islands, rockfish and lingcod densities in the reserves are also greater than at nearby fished areas, but there have not been any discernible trends in size or density for copper rockfish over a span of 10 years of monitoring and 12 years after reserve creation. For lingcod at these sites, the winter-time densities are substantially greater than in fished areas, but densities in both reserve and fished area treatments have been increasing. At Orchard Rocks, the central Sound reserve created in 1998, there has not been an increase in copper rockfish abundance, but lingcod abundance has increased.

The analysis also found a major change at the long-term reserve at Edmonds. The study site once harbored a sizeable school of large copper rockfish that conferred a high estimated reproductive advantage on the long-term reserve compared to fished areas. Since 1999, this school has disappeared with a resulting decrease in the density of copper rockfish at the site. During the same period, lingcod abundance has dramatically increased simultaneously with the decline in copper rockfish. While a number of competing hypotheses to explain these patterns cannot be ruled out, the shift to a site dominated by large piscivores may reflect a shift in the trophic dynamics of the reserve.

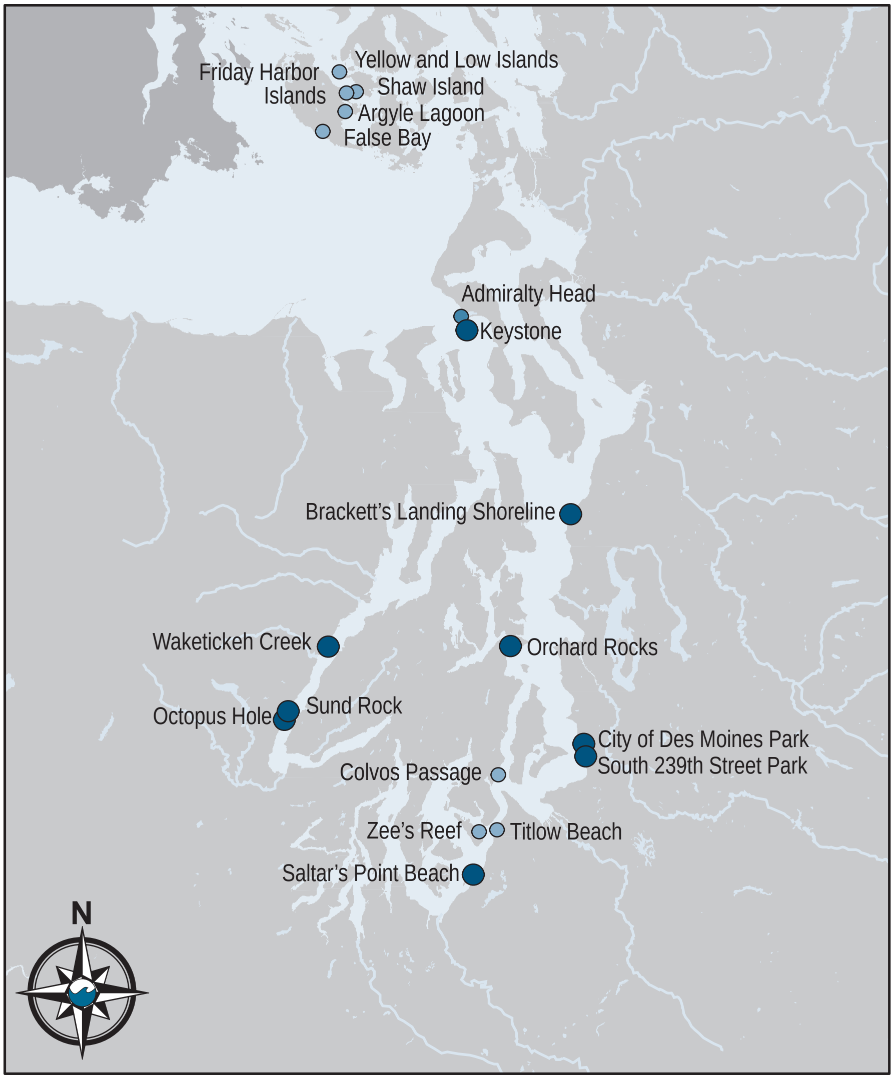


Figure 2-46. WDFW non-tribal marine reserves in Puget Sound. Conservation Areas are fully-protected, and Marine Preserves are partially protected. (Source: WDFW)

- Fully Protected Conservation Areas
- Partially Protected Marine Preserves

12. Recommendations

In the *2002 Puget Sound Update*, recommendations were provided based on the results of the studies reported in the document. The recommendations related to biological resources and progress made through 2006 on those recommendations are summarized below:

Recommendation from the ***2002 Update Report*** for Biological Resources	Progress made through 2006 on recommendations in the ***2002 Update Report***
Monitoring designed to understand dynamics of stocks for populations should include organisms at a range of tropic 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.	• Food web dynamics are beginning to be understood through the passage of toxic contaminants through trophic layers (via herring, salmon, and marine mammals). • Trophic studies are also being initiated in Hood Canal and Puget Sound. • Synoptic surveys for fishes also collect information on macroinvertebrates.
Scientists and resource managers need to increase their focus on efforts to understand the causes underlying declining population where management actions have not brought expected improvements, such as with specific groundfish species.	• WDNR initiated the Eelgrass-Stressor Response Project to investigate factors responsible for eelgrass decline. • Studies on Marine Protected Areas and comparable fished areas have shown that fishing is the major factor affecting rockfish and lingcod size and density. These and other studies indicate lingcod recovery may affect the abundance and recovery of rockfish. • Studies in Hood Canal have shown that hypoxia can kill substantial portions of fish populations and limit and affect the distribution of benthic infauna.
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.	• Sea floor mapping tools have been utilized to map the bathymetry of portions of the San Juan Archipelago. • Remote-operated vehicles are providing a platform to study marine resources in both shallow and deep waters.
Wherever appropriate and feasible, multi-disciplinary monitoring should be employed (such as coupling population surveys with collection of toxic contaminant or physical environmental data).	• Combined monitoring of sediment and water quality parameters as part of the PSAMP program have provided insight into the effects of low DO on infaunal communities in Hood Canal.
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.)	• Analysis of infaunal invertebrate communities in Hood Canal are providing insight into ecosystem-level effects of low DO. • Changes in communities and declines in seagrasses in the Strait of Georgia that my be linked to climate-driven changes in precipitation (see Habitat chapter) have been revealed by PSAMP monitoring. • Studies in marine reserves and from surveys provide key information on the changing structure of the food web.
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.	• While the publishing of studies, reports, and databases in bound media are still important, researchers in Puget Sound have made great progress in placing databases, inventories, and reports on the web. This has resulted in thousands of web hits and downloads of scientific information and has substantially alleviated the need to print and distribute reports and data disks. As an example, the ShoreZone Inventory has been queried by thousands and data CDs are no longer requested.

Recommendation from the ***2002 Update Report*** for Biological Resources	Progress made through 2006 on recommendations in the ***2002 Update Report***
Results represented 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.	• *The 2007 Puget Sound Update* report summarizes the latest results in long-term biological monitoring that are critical for improving our understanding of Puget Sound ecosystems. Efforts should be continued to collate and analyze species status reports. • Fishery-independent surveys are providing the means to evaluate groundfish populations. This has become especially important since fishery data has been greatly affected by new management strategies.

Moving forward on Puget Sound Science

In looking ahead to what recommendations to report on in future editions of the *Puget Sound Update,* it makes sense to focus on the goals and strategies that have been recommended in the *2006 The Puget Sound Partnership Final Report*, the PSAT *2007-2009 Conservation and Recovery Plan for Puget Sound,* and the 2006 PSAMP Review. Collectively, these three sources provide targets and goals developed and supported by a large scientific community and reflect both short-term (two year) and long-term considerations for protecting and restoring Puget Sound's health.

The following bullets summarize the goals and strategies put forth in by the Puget Sound Partnership, PSAT, and PSAMP that are related to biological resources (Chapter 2 of this report). Progress towards these goals and strategies will be reviewed in the next edition of the *Puget Sound Update*.

Puget Sound Partnership Final Report (from Appendix A):

Goal: Puget Sound Species and the web of life thrive.

- Terrestrial, aquatic and marine species exist at variable levels into the future and biodiversity of the overall ecosystem is naturally maintained.
- Invasive species do not significantly reduce the viability of native species and the functioning of the food web.
- The harvest of fish, wildlife, shellfish and plants is balanced, viable and ecosystem based.

2007-2009 Conservation and Recovery Plan for Puget Sound

Priority 6. Protect species diversity; manage Puget Sound to protect the full range of its biological diversity.

Strategies:

- Achieve significant progress on overall ecosystem and food web protection and recovery to support recovery of the at-risk species.
- Implement the *Puget Sound Salmon Recovery Plan,* the *Hood Canal Summer Chum Recovery Plan,* the *Recovery Plan for the Coastal-Puget Sound Bull Trout* and the *Proposed Conservation Plan for Southern Resident Killer Whales (Orcinus orca)*. Use monitoring, coordination, and adaptive management to evaluate and modify the implementation.

- In anticipation of completion of a rockfish conservation plan, support regulatory and voluntary tools for rockfish recovery.
- Launch a multi-agency effort to assess the relative abundance and geographic distribution of major forage fish species in Puget Sound as the basis for management and recovery strategies.
- Identify research needs and develop management strategies for marine bird populations considered at risk.
- Increase efforts to reestablish and protect Puget Sound Olympia oyster populations.

Detailed recommendations for further research and monitoring

Many of the following recommendations are an outcome of the 2005-2006 PSAMP review and have been included as recommended actions in the 2007-2009 Puget Sound Conservation and Recovery Plan. Progress towards these and previous recommendations will be reported in the next of the Puget Sound Update.

Marine Species Assessments

- A shared agreement is required that establishes and funds a long-term strategy and system for monitoring the status of species at risk, sustainable populations of species and food web elements.
- A complete forage fish assessment, monitoring and research plan tailored to important species in Puget Sound and compatible with the Fish and Wildlife Commission's Forage Fish Management Plan is designed and implemented. This plan should include:
    - An assessment of forage fish populations and productivity.
    - Identification and mapping of forage fish spawning areas and tracking the number of forage fish spawning grounds in healthy condition.
    - Studies to measure forage fish predation by marine birds, fish, and marine mammals.
- Develop strategies to assess and conserve dogfish, Pacific cod, walleye Pollock, Pacific hake, and other depressed or keystone species in the Puget Sound ecosystem. These strategies should include modeling demographic structure of key groundfish species and develop models that link transfer among lower and higher trophic levels.
- Initiate monitoring of plankton (both zooplankton and phytoplankton) communities in Puget Sound. Develop linkages to phytoplankton and understand the dependencies by juvenile fishes. Protect Puget Sound from invasive phyto and zooplankton species through ballast water management.
- Continue ongoing monitoring of marine bird populations and investigate causes of ongoing declines; initiate long-term monitoring of abalone, sea urchin, cucumber, Dungeness crab and geoduck populations.
- Track biodiversity in intertidal biotic communities throughout Puget Sound.
- Develop studies and information that identify the effects of climate, harvest,

The Role of Science

Strategies:

- Continue ongoing monitoring of the status and trends of key components of the Puget Sound ecosystem.
- Provide scientific information to stakeholders, decision-makers and the public.
- Direct new monitoring activities to focus on the effectiveness of management activities and policy initiatives.
- Develop a roadmap to prioritize, finance, and conduct focused research on emerging topics or research questions that are brought forth through PSAMP and science programs.

pollution, habitat loss, and other stressors on key species and ecosystem elements and that distinguish these from natural variation.

Habitat and Fisheries Management

- Use marine reserves to understand baseline conditions, especially trophic structure and the impacts of fisheries. Continue monitoring marine reserves and determining their potential role as a fisheries management tool and their effectiveness in recovering declining species such as rockfishes.
- Rationalize fisheries of invertebrates, salmon, and groundfish with the need for ecosystem function. This would include tracking the number of fisheries, not limiting the productivity of marine species. Compare fishery-dependent and independent stock assessment methods to each other for status and trends of indicators.
- Assure invasive species do not limit the persistence of naturally occurring species by developing a systematic screening process, limit the sources of invasion, and controlling their spread through early eradication and knowledge of limiting life history requirements.

Modeling

- Link processes, structure, habitats, and stressors to species through a conceptual model. Use this model to organize and communicate scientific information. Develop cause and effect models that predict the impacts of harvesting, invasive species, bulkheading, climate change, and other disturbance.
- Assess the key predator-prey linkages between major guilds and habitat complexes and the effectiveness of modeling with ECOPATH and ECOSIM.

Processes and Connections

- Assess the relationship between biodiversity, ecosystem health and productivity. This would include assessing whether density dependent effects are suppressing the recovery of species at risk (Allee Effect).
- Continue on SVMP for eelgrass; develop additional focus studies where eelgrass has declined in herring spawning areas. Test for causal linkages between success of spawning and decline of eelgrass. Develop methods to survey the status of subtidal kelps and other algae and develop understandings of how climate change, eutrophication, and habitat change can affect their abundance.

3 Physical Environment and Habitat

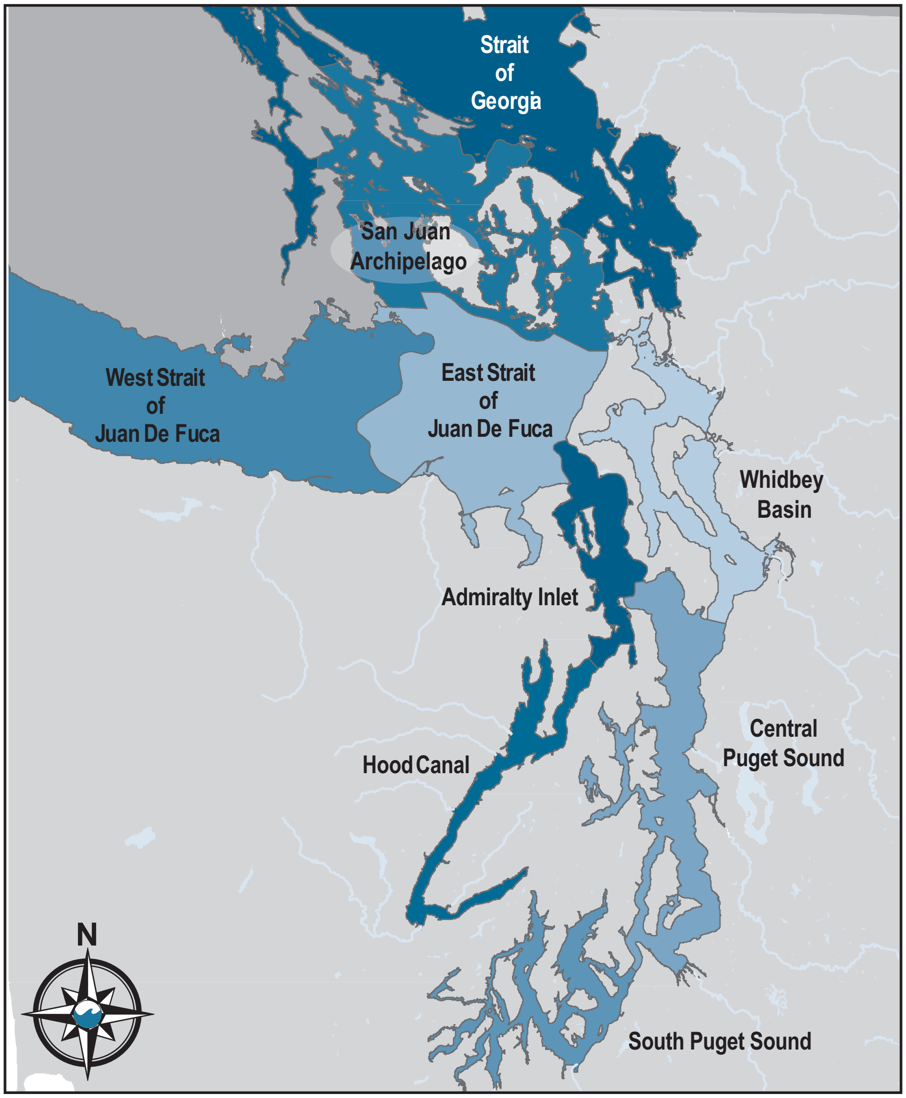
Starfish on rocky intertidal habitat, Oak Bay Park, Jefferson County. | *Toni Weyman Droscher*

1. Overview

Puget Sound is a large inland fjord carved by glaciers, fed by over 10,000 rivers and streams that flow into the Sound from the encircling Cascade and Olympic mountain ranges. The Sound is deep, with average depth of 450 feet (137 meters), and the maximum depth of 930 feet (283 meters) occurring immediately north of Seattle. Ten large rivers—the Nooksack, Skagit, Snohomish, Stillaguamish, Cedar/Lake Washington Canal, Green/Duwamish, Puyallup, Nisqually, Skokomish, and Elwha—flow into Puget Sound and contribute nearly 85 percent of the fresh water that enters the Sound. The unique geology and large dynamic river systems help shape the shoreline, which consists of 2,500 miles (4,023 km) of beaches, bluffs, bays, estuaries, mudflats, salt marshes, and wetlands.

The Strait of Juan de Fuca connects Puget Sound with the Strait of Georgia to the north and Pacific Ocean to the west. Within this region are numerous basins, sub-basins, passages, and bays. To develop a common basis for monitoring and reporting, PSAMP has delineated six main basins in Puget Sound. From the north, the basins are: San Juan Archipelago, the Strait of Juan de Fuca, North Puget Sound (Whidbey Basin and Admiralty Inlet), Central Puget Sound, Hood Canal, and South Puget Sound (Figure 3-1). The boundaries of many basins coincide with sills; for others the demarcation is arbitrary.

Figure 3-1. Puget Sound and the six PSAMP basins referred to throughout this report.



This chapter summarizes climate patterns, stream flows, fresh and marine water quality, modeling efforts and selected restoration activities. It also summarizes several newly established monitoring activities.

Key findings in this chapter include:

- The Pacific Ocean off the west coast of the U.S. experienced two unusual conditions in 2005—a winter-like colder state that persisted through mid-July, followed by ocean warming that resembled a large **El Niño** event. The biological impacts of these alternating atypical ocean conditions in 2005 were significant. Zooplankton stocks were reduced by one half, salmon returns weakened, and sea bird deaths were extraordinarily high among common murre, cormorant, and Cassins' auklet populations. Several subtropical species, such as albacore tuna and Humboldt squid, became common in the offshore shelf waters.

- During the 20th century, the global average **air temperature** rose by approximately 1.1 degrees F (0.6 degrees C). In Puget Sound, the average temperature doubled the global average, increasing by 2.3 degrees F (1.3 degrees C) during the same period.

- Average global **sea surface temperature** has increased by 1.7 degrees F (0.9 degrees C) since 1921.
- Hood Canal, Budd Inlet, Penn Cove, Saratoga Passage, and Possession Sound are locations of highest concern, based on Ecology's **index of water quality** for Puget Sound. Eleven other areas are of high concern.
- Overall **dissolved oxygen** (DO) concentrations in Puget Sound appear to be continuing a downward trend. Very low DO was observed at 14 stations, seven of which had higher DO concentrations in the period from 1998 to 2000. Another seven stations with previously high DO concentrations experienced low DO during 2001-2005.
- **Hood Canal DO** levels measured during 2004 were at the historical low point for any recorded observations. Comparing oxygen data from 1930 through the 1960s with data from 1990 to 2006 shows that in recent years, the area of low dissolved oxygen is getting larger and spreading northwards. Periods of hypoxia are persisting longer through the year.
- **Tidal wetland** losses were documented throughout Puget Sound and at present, approximately 82 percent of the historic extent of tidal wetlands in the region have been lost to development and other land uses.

2. Population Growth and Urban Impacts

One of the major threats to the Puget Sound landscape is the change from native forest cover to urban development, mostly driven by population growth. It is estimated that, in the next 20 years, the population in the Puget Sound Basin will reach over 5 million people (Figure 3-2), which will likely result in significant land conversion and development, increasing the amount of nonporous surfaces in the region. Stormwater runoff from urban development is on of the major nonpoint pollution sources in Puget Sound. Much of the growth as a result of this population increase is likely to occur in the 12 counties that border Puget Sound (Figure 3-3), following a nationwide trend of disproportionate growth in coastal areas.

3. Puget Sound Climate

Much attention is currently focused on the potential impacts of climate change on the Puget Sound region. The answers are not straightforward as the region is subject to complex meteorological and climate regimes that interact with the Olympic and Cascade mountain ranges in the region. This section briefly summarizes the climate trends in air temperature, precipitation, and sea-level rise as reported.

a. Changes in Temperature and Precipitation

During the 20th century, the global average air temperature rose by approximately 1.1 degrees F (0.6 degrees C). In Puget Sound, the average temperature doubled the global average, increasing by 2.3 degrees F (1.3 degrees C) during the same period (Figure 3-4). Much of this change occurred in the latter half of the 1900s. Minimum (colder) temperatures increased more than maximum (warmer)

Figure 3-2. Projected human population growth in Puget Sound. Population growth in the Puget Sound region is projected to exceed twice the 1970 population size by 2025. Much of this growth is taking place in coastal areas. (Source: Washington State Office of Financial Management)

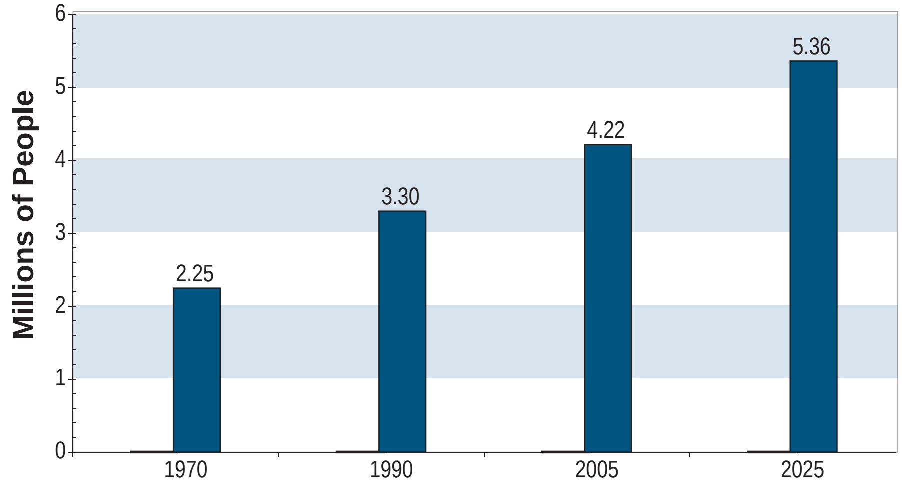
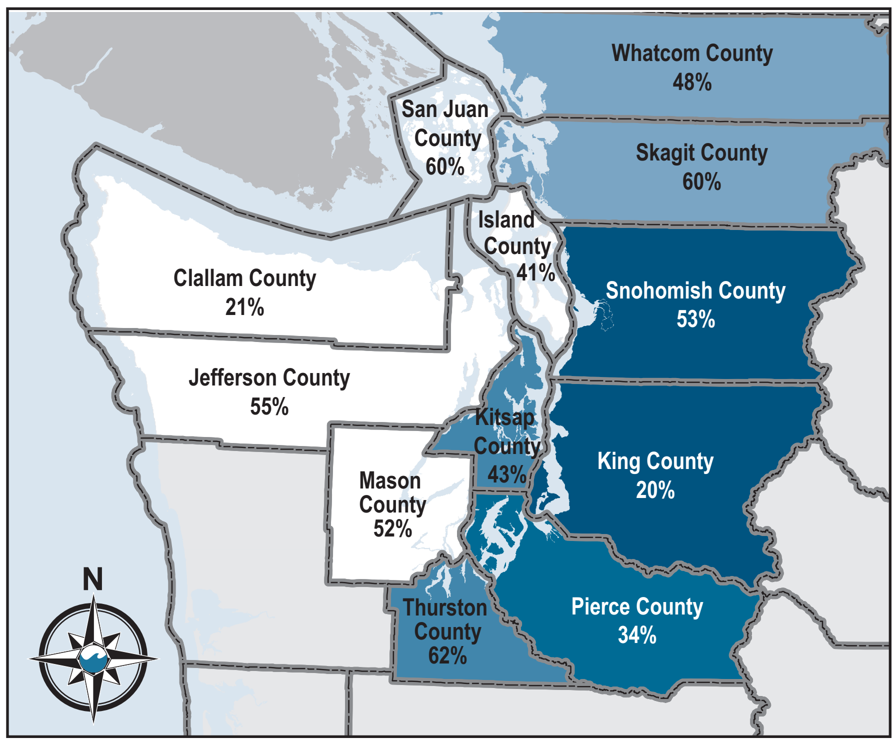


Figure 3-3. Projected human population in Puget Sound counties between 2000 and 2025. San Juan, Thurston, and Skagit Counties are expected to grow the most, by 60 percent or more, during this period. (Source: Office of Financial Management)

Projected increases in the number of people by county (in thousands)

- < 50
- 50-100
- 100-200
- 200-300
- 300-400

Percentages represent the predicted percent increases in county populations



temperatures, and, across the Pacific Northwest, winter months incurred the greatest warming. Fall months experienced a smaller temperature increase.

Precipitation patterns do not track temperature changes in the region for the 20th century, and models predict variable increases (between 0 and 10 percent) in precipitation by 2050. Although these projected changes are relatively uncertain, they do fall within the range of variability experienced in the 20th century. However, the timing and possible shift in stream flows that may result from warming temperatures is significant. More precipitation in the Pacific Northwest may fall as rain and any snowpack that does accumulate may thaw earlier in the spring. As river systems and functions alter, the shifted hydrologic pattern may have significant consequences to fish, wildlife, and humans.

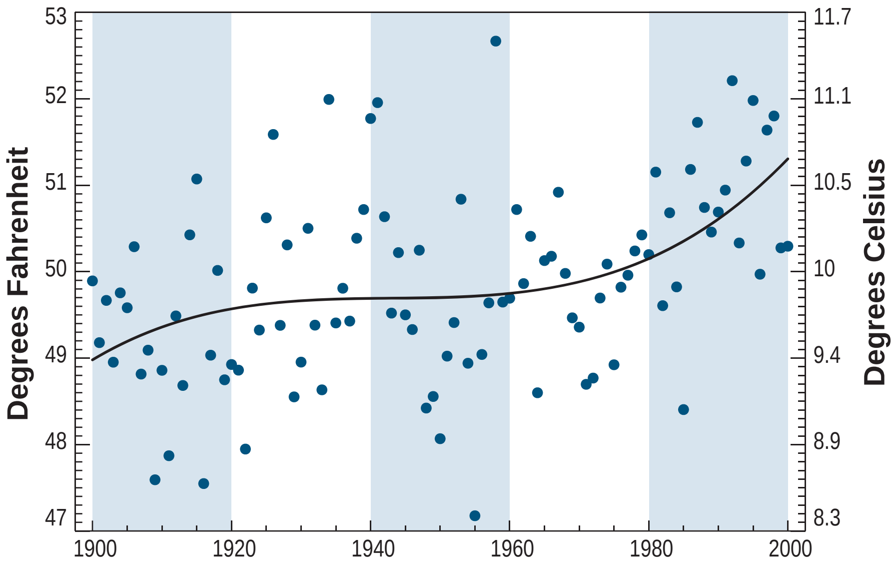


Figure 3-4. Air temperature trends in the Pacific Northwest. Data show an increase of 2.2 degrees F during the 20th century. (Source: PSAT)

b. Potential Sea-level Rise

Sea levels fluctuate over the course of hours, months, and years, with the largest fluctuations occurring during twice-daily tides. Atmospheric pressure and wind patterns, as well as local land movements (caused by subsidence or earthquakes), can drive sea level changes up or down. During the 20th century, the global sea level rose by approximately four to eight inches (10.2 to 20.4 cm) as a result of both the warming of ocean waters (which causes water to expand) and the melting of glaciers, small ice fields, and polar ice sheets (PSAT 2006).

In the Puget Sound region, there are many complex geological factors influencing the rates of sea-level rise. In southern Puget Sound, land is sinking at a rate of more than eight inches (20.3 cm) per century, while in the northern portion of the Olympic Peninsula and Strait of Juan de Fuca, land is uplifting (PSAT 2005). As a result of subsidence and uplift actions, the net local sea-level rise in northern Puget Sound is close to the global average and in southern Puget Sound, it is nearly double the global average.

Models predict that global sea-level rise is likely to accelerate as the planet continues to warm, with changes predicted in the range of four to 35 inches (10.1 to 88.9 cm) during the 21st century (PSAT 2006). Additional sea-level rise in coastal waters, which would affect Puget Sound, associated with changes in winds patterns, may result in an additional eight inches of sea-level rise (Figure 3-5). These coastal changes, coupled with geologically influenced changes in sea level in the south Sound, may mean that portions of Puget Sound may experience sea-level rise as rapidly, if not faster, than the global average rate of sea-level rise.

4. Fresh Water

Freshwater quality characteristics are important controlling factors on the Puget Sound marine environment. Ecology regularly monitors water quality at a number of rivers and streams in the Puget Sound Basin as part of PSAMP. It initiated a freshwater sampling program in 1970 and currently samples 12 water quality parameters on a monthly basis.

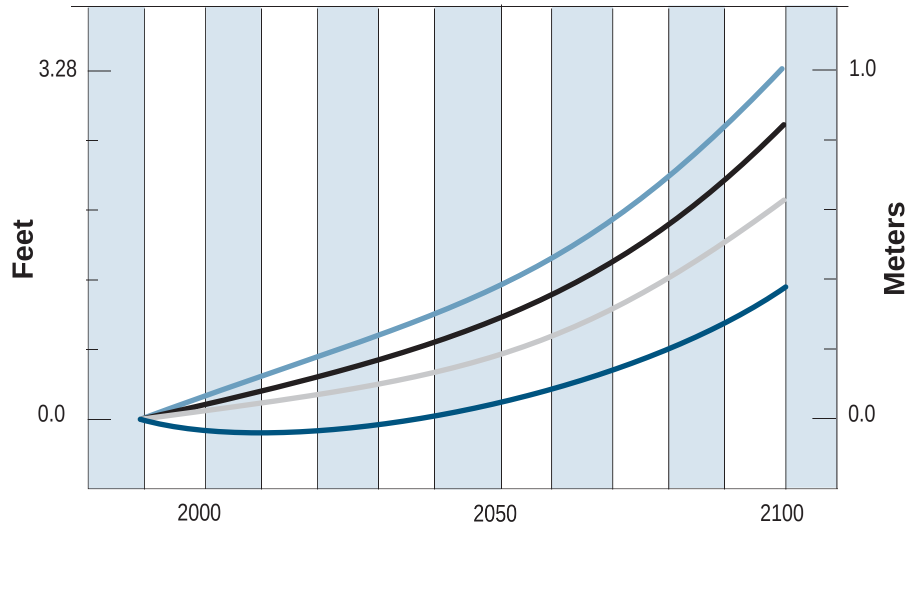


Figure 3-5. Future sea-level rise scenarios for various locations in Puget Sound. The different scenarios reflect the fact that the land masses of southern Puget Sound (including Tacoma) is sinking, while the northern Olympic Peninsula (including Neah Bay) is rising. Depending on the variability in climate factors, sea-level scenarios could be 20 to 200 percent of the mid-range scenario shown here.
(Source: PSAT)

Ecology has been reporting freshwater conditions over the past few years, using a Water Quality Index (WQI) for eight of the 12 regularly monitored parameters (not included are conductivity, nitrate, nitrite, ammonia, and orthophosphorous). In addition, Ecology aggregates results from these individual WQI parameters into a single overall WQI for each sampling station (Hallock 2002). This overall WQI value consists of results from one year of sampling of nutrients (total nitrogen, total phosphorus), pathogens (fecal coliform bacteria), and other physical parameters (water temperature, DO, pH, total suspended solids, turbidity) (Hallock et al. 2004). Information on the physical parameters is presented in this chapter; information on pathogens and nutrients in fresh water is contained in Chapter 5.

a. Freshwater Water Quality Trends

Water quality characteristics of freshwater inputs are important controlling factors on the Puget Sound marine environment. As part of PSAMP, Ecology monitors water quality parameters monthly at 38 river and stream sampling stations in the Puget Sound Basin. Ecology initiated a freshwater sampling program in 1970 and currently samples eight water quality parameters on a monthly basis. These include measures of physical parameters (water temperature, DO, pH, total suspended solids, and turbidity) (Hallock et al. 2004).

Status and Trends

Figure 3-6 displays the overall WQI analysis for the freshwater monitoring stations in the Puget Sound Basin for 2005 (October 2004 through September 2005). The results indicate that fair to good water quality conditions exist in the basin. Fair conditions dominate from the Puyallup River basin northward to the Nooksack Basin. A single station in King County (Fauntleroy Creek, near the mouth) had poor conditions.

The temperature WQI is shown in Figure 3-7. Temperature is an important parameter that influences life-stage development and survival for a number of aquatic organisms. Results show that water temperature conditions were fair in the lower mainstem rivers of King County during 2005. These locations included the Green, Cedar, Snoqualmie, Snohomish, and Stillaguamish rivers.

In general, water temperature has not been a problem in rivers and streams of the Puget Sound Basin. However, this can gradually change with an increasing human

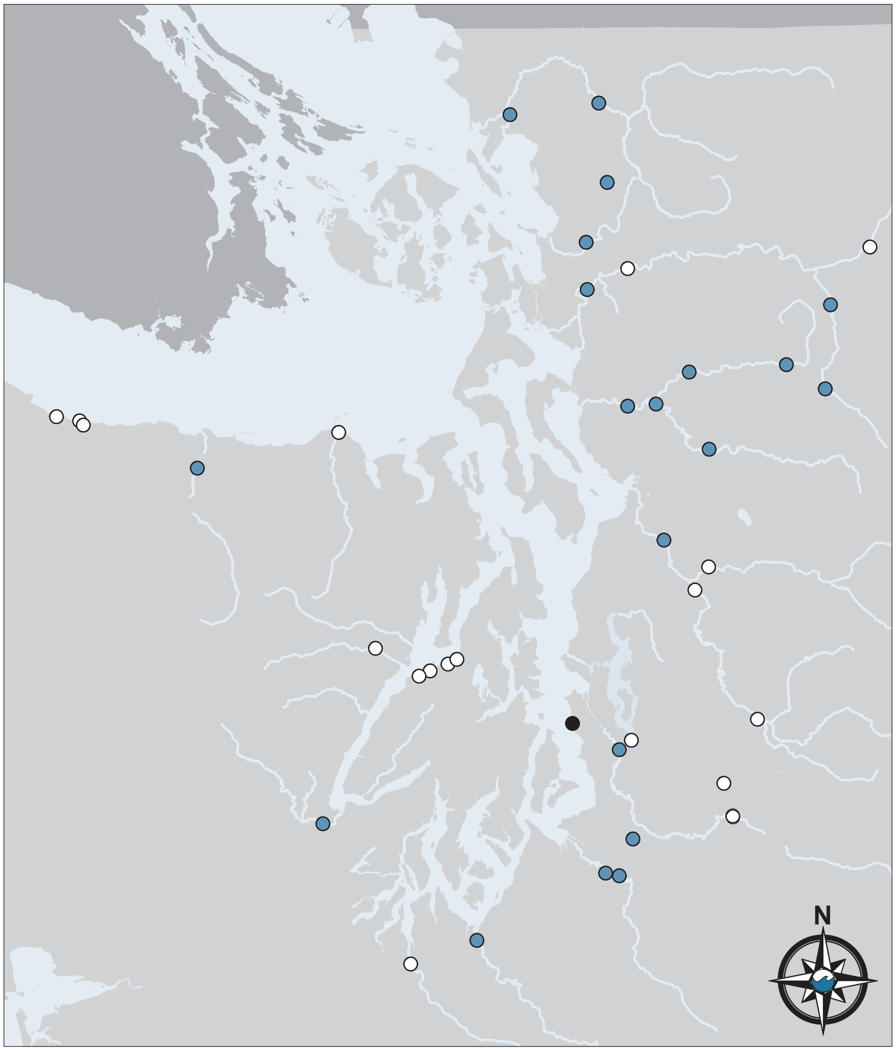


Figure 3-6. Freshwater long-term and rotating monitoring stations and overall Water Quality Index (WQI) scores. Fair to good water quality exists throughout the Sound, with one poor site at Fauntleroy Creek, near Seattle. (Source: Ecology)

● Poor
● Fair
○ Good

presence. The ambient air temperature increases in and around cities and will affect streams that run through these areas. Any alterations in seasonal temperature patterns will also affect the smaller streams to an extent that cumulative effects appear in the larger lower mainstems of rivers emptying into Puget Sound or Hood Canal.

Trend analysis based on data collected from 1996 through 2005 showed improvements in overall WQI scores at seven of 24 long-term stations (Figure 3-8). This data do not include Ecology's six rotating stations. There were no significant declining trends in overall water quality for any of the 24 monitoring stations during this 10-year period (Hallock et al. 2006).

5. Stream Flow

a. Historical Changes in Stream Flow

Stream flow is fed by rainfall runoff, stormwater, snowmelt, and groundwater intrusion (where groundwater flows to the surface). Climate patterns in the Pacific Northwest typically result in: higher stream flows from October through January, during peak rainfall; a drop in flows from January through March, as precipitation declines but moisture remains contained in the snowpack; a second peak in early spring, associated with accelerated snowmelt; and low flows through the summer as the snowpack shrinks.

Figure 3-7. Freshwater long-term and rotating ambient monitoring stations and Water Quality Index scores for temperature. Water temperature has not been a problem for Puget Sound rivers and streams in the past decade. (Source: Ecology)

- Poor
- Fair
- Good

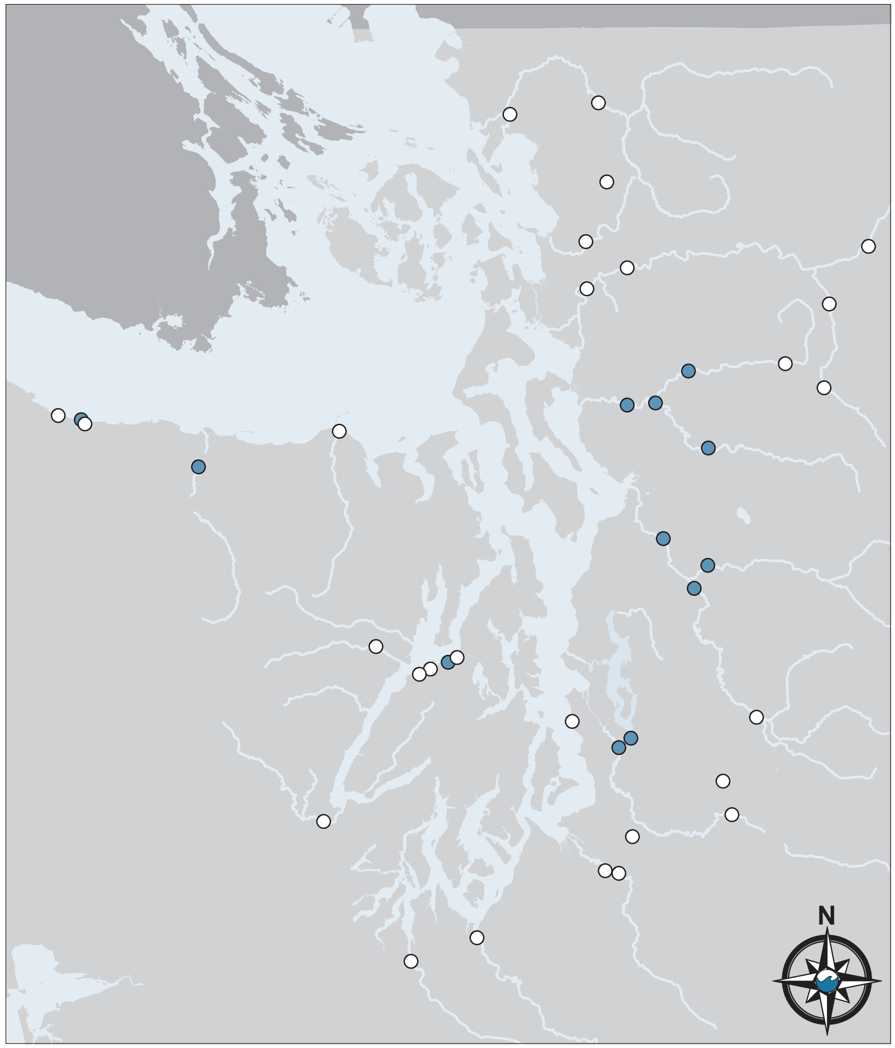
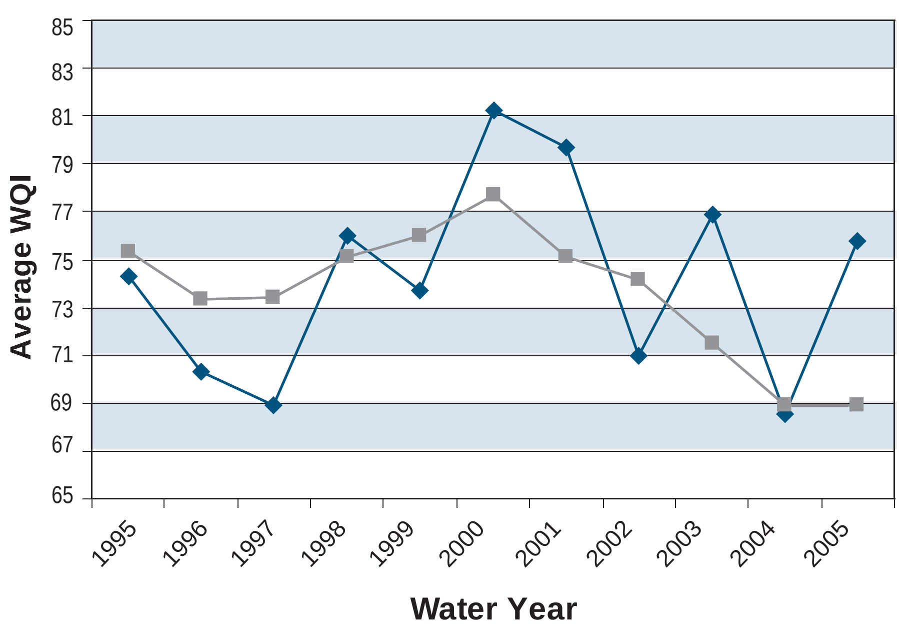


Figure 3-8. Trends in average and flow-adjusted overall WQI scores for 24 long-term stations in Puget Sound. The average WQI adjusted for flow shows an overall improvement (lower WQI score) in the past six years. (Source: Ecology)

- Average WQI
- Average WQI Adjusted for Flow



Mean annual flow rates for five major rivers in Puget Sound (the Nooksack, Duckabush, Skokomish, Puyallup, and Snohomish) from 1989 through 2005 are presented in Figure 3-9, along with average stream flow for Race Rocks near Victoria, B.C. Stream flow levels vary by river size and extent of watershed, but most track the pattern of precipitation. Additional factors that contribute to stream flow include groundwater discharge, surface water runoff, and hydrologic changes due to land cover conversion.

6. Marine Water

a. Sea-surface Temperature

Water properties in Puget Sound are affected by air temperature, winds, sunlight, river flows, and the properties of oceanic water entering the Sound. Sea-surface (the top layer of marine water) temperature varies seasonally, due to differences in air temperature, cloud cover, wind speed, and solar radiation. Maximum water temperatures are reached during July and August, as air temperatures rise and the amount of solar radiation increases. Conversely, minimum water temperatures typically occur in February. However, in addition to cool weather, water temperatures can be lowered by an influx of deep cold water from upwelling along the outer coast. In the late spring and summer, northerly winds along the Pacific Ocean coast drive upwelling, which brings cold, high-salinity, nutrient-rich water with low DO concentrations closer to the surface. This water enters the Strait of Juan de Fuca and moves through Admiralty Inlet and constitutes the deeper waters in much of Puget Sound.

Since the 1950s, average sea-surface temperature has increased by 1.8 degrees F (1 degree C) at Race Rocks, B.C. (Figure 3-10). If marine water temperatures continue to increase, there may be marked changes in the diversity, distribution, and abundance of plankton that thrive in the upper layers of the marine waters, and this, in turn, may drive other changes in species composition and abundance in the marine food web.

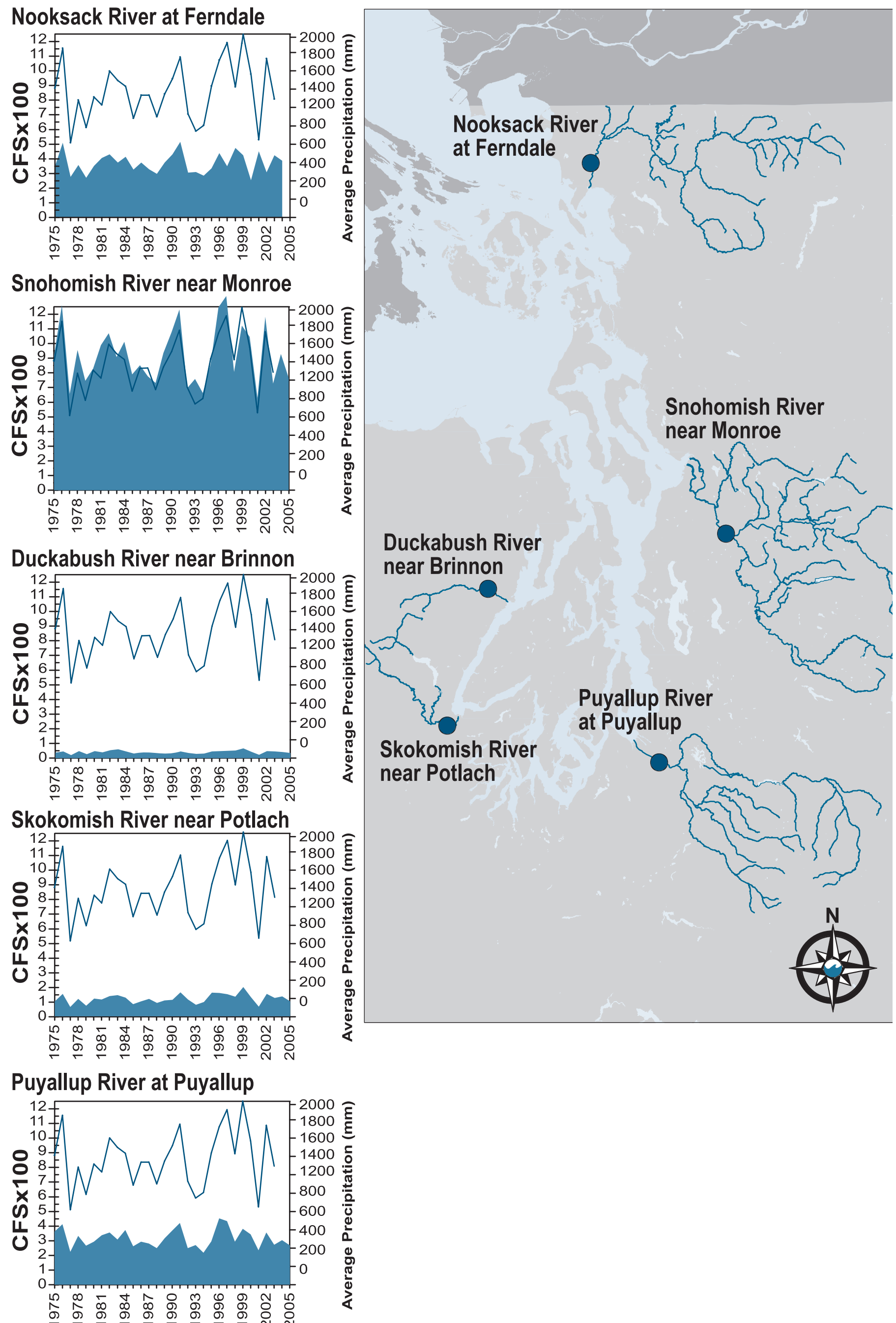
The Pacific Ocean off the west coast of the U.S. experienced two unusual conditions in 2005—a winter-like colder state that persisted through mid-July, followed by ocean temperature warming resembling a large El Niño event. The biological impacts of these alternating atypical ocean conditions in 2005 were significant. Zooplankton stocks were reduced by one-half, salmon returns weakened, and sea bird deaths were extraordinarily high among common murre, cormorant, and Cassins' auklet populations. Several subtropical species, such as albacore tuna and Humboldt squid, became common in shelf waters.

b. Salinity

As with temperature, Puget Sound experiences seasonal variation in salinity. Salinity is usually lowest during the spring and early summer, when the flow of fresh water from snowmelt is at its peak. The highest salinities typically occur in late summer and fall, associated with upwelling (Barnes and Collias 1958) and decreased freshwater flows. From 2002 through 2004, salinities at King County stations ranged from 24.08 to 30.85. As in previous years, the lowest salinity occurred in the surface waters of inner Elliott Bay during the winter and spring, when freshwater inputs from the Duwamish River are at its lowest. The highest salinities occurred from August through December, presumably because of reduced freshwater flows and, possibly, the influx of higher salinity water from upwelling.

Figure 3-9 Stream flow from five major rivers in Puget Sound from 1989 through 2005. Stream flow is shown with average precipitation from Race Rocks, B.C., to illustrate how stream flow generally tracks precipitation. This figure also illustrates the large range of flow in these rivers. There are other contributions to stream flow, such as groundwater discharge, surface water runoff, and alterations in flow associated with changes in landcover.
(Source: PSAT)

- Mean Annual Streamflow
- Mean Annual Precipitation



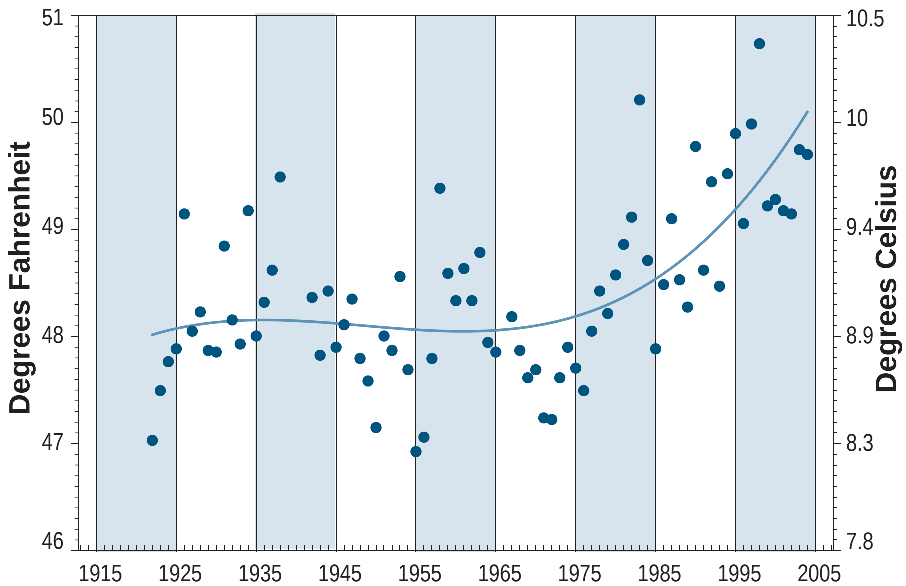


Figure 3-10. Sea-surface temperature measured at Race Rocks, B.C. 1915 to 2005. Average marine water temperature has increased by 1.8 degrees F (1 degree C) since the middle of the previous century, with a steady increasing trend over the last 50 years.
(Source: PSAT)

c. Density

Another important water property, density is affected by both temperature and salinity. Because of the seasonal cycles of temperature and salinity, surface waters have a light density phase during the spring and summer, followed by a dense phase in the fall and winter. Months in which salinities are relatively uniform throughout the water column occur when rainfall is low and input from rivers and runoff is reduced. Changes in density affect the circulation of Puget Sound, including processes such as the flushing of bays and inlets, and have important impacts on a variety of other physical and biological processes, discussed more fully in the next section.

d. Stratification

Important properties with widespread effects on water quality are the intensity and persistence of stratification—the layering of waters with different densities (Mann and Lazier 1991). If there are large differences in the density of water from surface to bottom (e.g., when lighter fresh water overlies heavier, cooler, and more saline water), the water column is stratified. In contrast to stratified waters, well-mixed waters show much smaller density differences. The intensity and persistence of stratification is influenced by a variety of factors, some of which include air temperatures, solar radiation, winds, tides, and the amount of fresh water the Sound receives from rain and river flows. In Puget Sound, stratification is most strongly influenced by inputs of fresh riverine water and the amount of solar radiation.

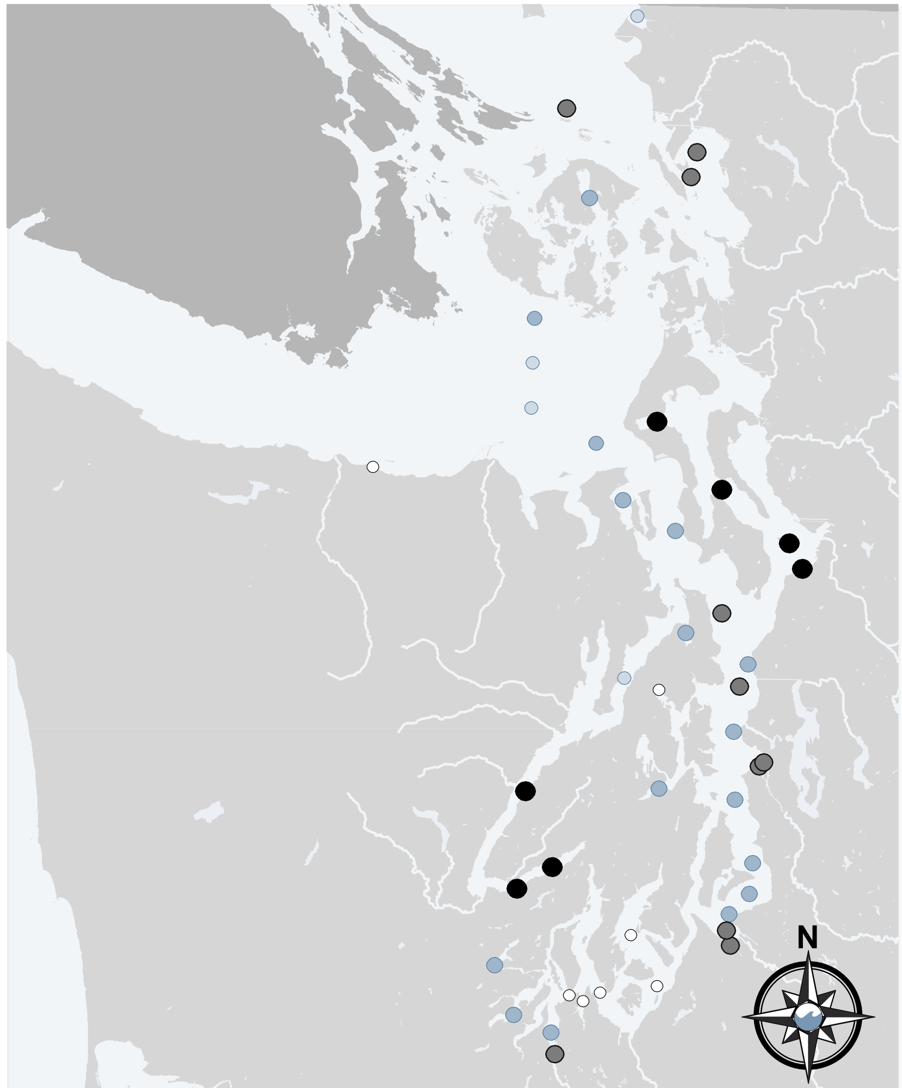
The intensity and persistence of stratification influences physical processes such as mixing and circulation, which, in turn, affect biological and chemical processes that determine water quality. These processes include the development of phytoplankton blooms, the creation and maintenance of oxygen and nutrient gradients, and the prevalence of human-introduced pollutants, including fecal coliform bacteria and ammonium (Newton et al. 2002).

Because stratification is influenced by a variety of atmospheric and oceanographic factors, estimates of its strength and persistence vary from year to year. Nonetheless, overall trends and the relative amounts of stratification at given locations provide important insight into potential changes in Puget Sound.

Figure 3-11. Intensity of water column stratification at marine monitoring stations in Puget Sound, based on 2001-2005 data. Strong and persistent stratification can impact water quality properties, such as dissolved oxygen and nutrient concentrations, by reducing mixing within the water column. More stratified sites are generally located in areas with high freshwater inputs or limited mixing. Sites with moderate or weak stratification occur in areas with high mixing or low inputs of fresh water.
(Source: Ecology and KC DNRP)

Stratification

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



Status and Trends

Figure 3-11 shows the intensity and persistence of stratification observed at King County and Ecology marine monitoring stations throughout Puget Sound. Five categories were used to characterize stratification at these stations: strong and persistent, strong and intermittent, moderate and intermittent, moderate and infrequent, and weak and infrequent. These categories reflect the strength of stratification (i.e., the difference in densities between surface and bottom waters) and the amount of time that the water column is stratified at each station. Together, these factors determine the impact that stratification has on physical, chemical, and biological processes at each station.

The stratification properties observed from 2001 through 2005 were very similar to those previously reported for the period from 1998 through 2000. For example, seven of nine stations with strong persistent stratification in 1998 through 2000 retained that classification. The remaining two stations continued to have strong stratification, but the stratification was less persistent than in the previous period. This type of variation is expected because of small year-to-year differences in atmospheric and oceanographic influences on stratification. In general, the most strongly stratified sites were located in areas with high freshwater inputs, and sites with moderate and weak stratification were located in areas with strong mixing or low inputs of fresh water.

A significant drought during 2000 and 2001 resulted in substantially reduced river flows that, in turn, markedly affected water properties. Scientists found a densification (reduction in water density between the surface and bottom of the water column) that appeared throughout the Sound. There were also widespread reductions in stratification, due to higher-salinity surface waters. This observation is notable because stratification regulates numerous biological and physical processes, including the timing of spring phytoplankton blooms, mixing, and flushing. Furthermore, scientists observed that changes in the density gradient in the Strait of Juan de Fuca led to a marked reduction in flushing during the drought year, compared with the higher-flow period of 2001 and 2002. This difference has implications for larval and plankton dispersal and retention, as well as for water quality.

e. Dissolved Oxygen

Oxygen occurs in much lower concentrations in fresh or marine water (in a dissolved state) than in air, and it is just as critical for the survival of marine organisms. In Washington state, the impacts of low DO on marine life in Hood Canal have become the focus of the news media during the past several years, with numerous accounts of fish and invertebrate die-offs associated with episodes of low DO.

Dissolved oxygen concentrations are determined by a series of complex interactions between the biological processes of photosynthesis and respiration and physical factors, such as inputs of fresh and oceanic waters, stratification, circulation, mixing, and the exchange of oxygen across the air/water interface. In the simplest terms, low DO concentrations occur when organic material, primarily dead phytoplankton, sinks and undergoes oxygen-consuming decomposition in waters that are not well-mixed with the atmosphere or more oxygenated waters.

The greatest potential for severe oxygen depletion occurs when high phytoplankton growth rates are fueled by abundant nutrients and strong, persistent water column stratification inhibits mixing. Human contributions of nutrients from excessive fertilizer use, leaking septic tanks, and other sources can dramatically increase phytoplankton growth and subsequent decay, driving dissolved oxygen concentrations at depths low enough to impair or kill marine organisms. Susceptibility to such severe dissolved oxygen depletion varies substantially throughout the Sound. For example, enclosed bays with high nutrient inputs and slow flushing of bottom waters are more susceptible than are open, well-mixed locations.

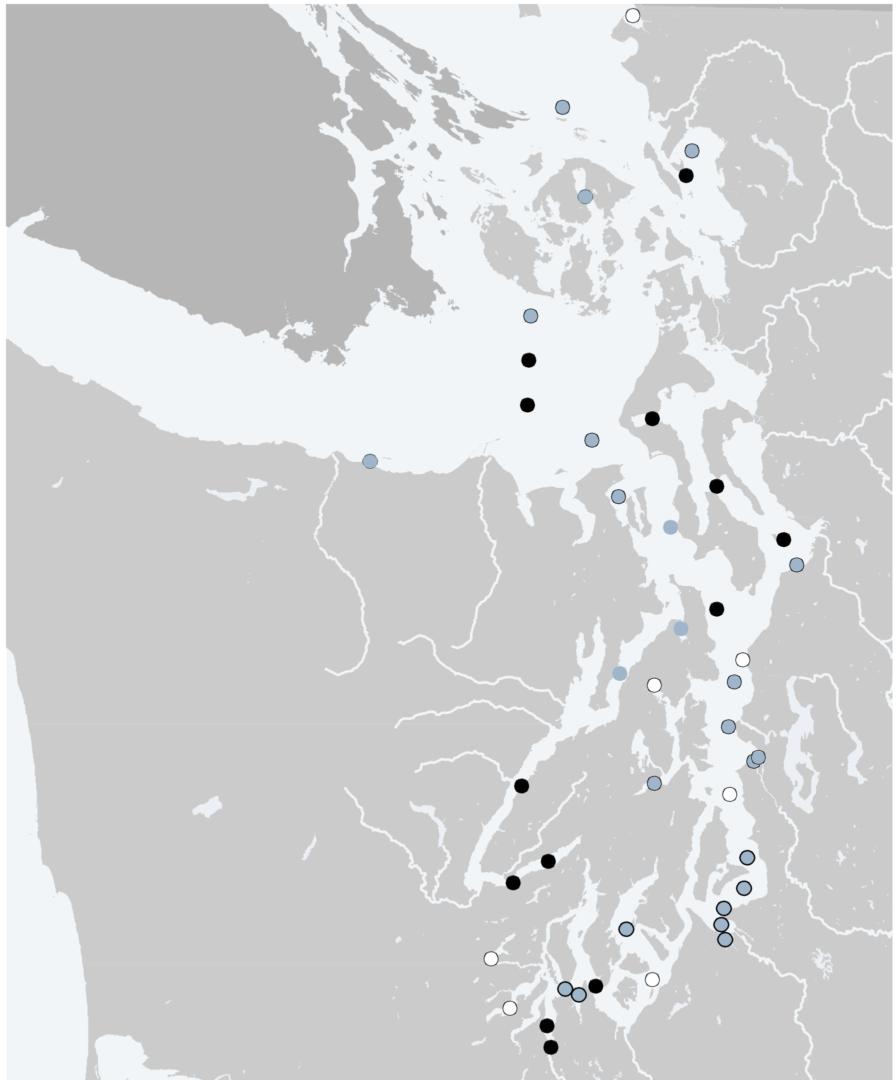
Low dissolved oxygen concentrations can also occur naturally. For example, upwelling along the Pacific Ocean coast during spring and summer typically brings up water with low levels of dissolved oxygen from the depths. When these upwelled waters enter Puget Sound through the Strait of Juan de Fuca and Admiralty Inlet, low bottom water DO concentrations result. However, once in Puget Sound, the levels of DO in these waters may further decline by the human-driven influences described above.

Dissolved oxygen concentrations vary throughout the year, because of seasonal changes in nutrient availability, solar radiation, and water column stratification (layers of water of different density, temperature, and salinity). For example, observations from King County stations in the central Puget Sound Basin have shown maximum near-surface DO concentrations in the upper 35 meters at all stations during the spring and summer. These DO maximums corresponded with

Figure 3-12. Minimum water column DO concentrations at marine monitoring stations in Puget Sound, based on 2001-2005 data. Low DO can potentially cause problems for fish and other marine organisms. Low DO concentrations are affected by strong stratification, slow circulation, increased algal blooms driven by high nutrient inputs, and other location-specific influences, including the influx of Pacific ocean water with naturally low DO. (Source: Ecology)

Dissolved Oxygen

- ● Very Low (<= 3 mg/l)
- ● Low (> 3 mg/l & <= 5 mg/l)
- ○ High (> 5 mg/l)



maximums in chlorophyll-*a* concentration, temporally and spatially, and, therefore, may be attributed to primary productivity. In contrast, minimum dissolved oxygen concentrations were observed below 35 meters in late summer and fall, presumably because of the seasonal influx of dense, low-oxygen Pacific Ocean water and the decay of organic matter from spring, summer, and early fall phytoplankton blooms. Increased water column density stratification in the spring and summer also contributed to low DO levels at depth, by impeding vertical mixing. In fall and winter, as the density gradient breaks down, the water column becomes well mixed, with little variation in DO levels from top to bottom.

Status and Trends

Figure 3-12 shows minimum DO concentrations observed at Puget Sound stations monitored between 2001 and 2005. The data are divided into categories chosen to reflect biologically important concentrations. Five mg/l is often used as the reference concentration at which biological effects can first begin to occur, although effects on growth have been observed at DO concentrations as high as six mg/l in some species. Similarly, a wide range of species experience serious biological effects at DO levels below three mg/l, so this concentration is often used as an indicator of hypoxia. It is important to note that these data represent the single lowest value observed at each station between during 2001 through 2005, so they can inordinately reflect a single good or bad year, rather than showing a continuing upward or downward trend. In addition, most samples were collected monthly during the day, so short-term variability, including nighttime measures, when DO is lowest, is not captured.

Overall DO concentrations in Puget Sound seem to be continuing a downward trend (Figure 3-12), with the proportion of stations experiencing low (>3 mg/l and <= 5 mg/l) or very low (<=3 mg/l) DO rising from 62 percent between 1998 through 2000 to 84 percent from 2001 through 2005. Very low DO was observed at 14 stations, seven of which had higher DO between 1998 through 2000. Another seven stations with previously high DO experienced low DO from 2001 through 2005. Dissolved oxygen increased at only one station, Bangor in Hood Canal, but movement of the sampling location in response to U.S. Navy security concerns may be the cause, rather than real improvement. Stations located in southern Hood Canal continue to experience very low dissolved oxygen concentrations. Other places with very low DO include Budd Inlet, Penn Cove, Saratoga Passage, Possession Sound, Bellingham Bay, and Nisqually Reach.

Locations with naturally low DO are found in the Strait of Juan de Fuca, the Strait of Georgia, and Admiralty Inlet. The low DO concentrations in these areas reflect the seasonal influx of coastally upwelled water with low dissolved oxygen concentrations into Puget Sound. Other areas with low DO that may be driven more by human activities are Carr, Case, and Budd inlets in southern Puget Sound.

f. Hypoxia in Hood Canal

Hood Canal is a 60-mile-long (100 km) fjord-like basin. It is 300 to 600 feet (90-180 meters) deep and a little over a mile (1.2 km) wide. The canal is a highly productive estuary with strong seawater density stratification and slow circulation (months to a year), compared to the rest of Puget Sound. These conditions are conducive to seasonally low oxygen concentrations (below 2-3 mg/l), known as hypoxia, which have been observed in records dating back to the 1930s. While this phenomenon, or even anoxia (areas of complete oxygen depletion) is not a new phenomenon in Hood Canal, research suggests that this problem has increased in severity, persistence, and spatial extent (Curl and Paulson 1991; Newton, et al. 1995; 2002).

The most severe low DO conditions occur in the southern end of the canal, at the point furthest from water exchange with the rest of Puget Sound. A comparison of oxygen data from 1930 through the 1960s with data from 1990 through 2000s shows that, in recent years, the area of low DO is growing and spreading northwards. Periods of hypoxia are persisting longer through the year (Collias et al. 1974; Newton et al. 2002). Inventories of deepwater oxygen in the southern main stem of Hood Canal (Dabob Bay to Great Bend) for these time periods show that, while variation is evident, the recent data are generally lower; levels measured during 2004 were at the historical low point for any recorded observations. (See Figure 3-13, Appendix C: Color Figures.)

Although records of fish kills in Hood Canal date as far back as the 1920s, repetitive fish kills during 2002, 2003, and 2004 indicate that the increasing hypoxia may be having biological consequences. Two fish kill events in Hood Canal during 2003 galvanized public awareness of the water quality challenges faced by this system. In addition, DNR found that Hood Canal is the only region in Puget Sound to have consecutive years of eelgrass losses since annual PSAMP monitoring began in 2000. Initial findings from 2005 suggest eelgrass declines are more severe in Hood Canal than previously observed, particularly in the southern end of the canal.

Citizen monitoring in Hood Canal

As part of the Hood Canal Dissolved Oxygen Program (HCDOP), the Hood Canal Salmon Enhancement Group, developed the Citizen's Monitoring Program (CMP), which has captured weekly marine water data at established sampling transects along Hood Canal since August 2003. The resultant trend data obtained from the CMP sampling effort have provided a tremendous increase in the understanding of the marine water dynamics. The weekly transect data obtained through the CMP is being used by the HCDOP study to help verify marine biogeochemical models. The near-sea-bed oxygen data from Lynch Cove show the persistence of the hypoxia for multiple years (Figure 3-14).

g. Water Quality Concern

Marine monitoring data are used to assess current conditions and long-term trends in Puget Sound water quality. The water quality variables measured include temperature, conductivity, salinity, density, pH, nutrients, chlorophyll, and light transmission. Various combinations of these variables can be used to rank locations based on water quality concern factors and assess risk of eutrophication, the influx of sewage waste into marine waters, the amount of food available to other organisms in the food web, and pelagic habitat quality. The variables can also be used to determine compliance with federal and state water quality standards.

Ecology uses five indicators to calculate an index of water quality concern: fecal coliform bacteria levels, concentrations of dissolved inorganic nitrogen (DIN), ammonium, DO, and the strength and persistence of stratification. High fecal coliform bacteria levels indicate the presence of a nearby contaminant source. Low DIN levels indicate that phytoplankton growth may be nutrient-limited and, therefore, the water body may be at risk for eutrophication, due to additions of nutrients from human sources. High ammonium concentrations indicate the presence of a nutrient source, and strong and persistent stratification indicates that mixing of surface and bottom waters is reduced. Low DO is a symptom of a combination of stratification strength and high productivity, driven by high nutrient availability. Detailed information on nutrients and fecal coliform bacteria is presented in Chapter 5 of this update.

Status and Trends

Figure 3-15 shows the distribution of waters of concern throughout Puget Sound, based on Ecology and King County monitoring data from 2001 through 2005. To calculate the index, numerical scores were assigned to two threshold values for each indicator, and the total score for all five indicators was calculated. Categorical values for the five indicators at each station are shown in Table 3-1. As in 1998 - 2000, Hood Canal, Budd Inlet, and Penn Cove continue to be locations of highest concern. Hood Canal—southern Hood Canal in particular—has strong, persistent stratification, very low DO, and low DIN concentrations. These indicate that Hood Canal is highly susceptible to increases in phytoplankton productivity, due to changes in nutrient inputs. The 2002 Puget Sound Update reported that it appeared that Budd Inlet could be improving, but this region continues to be a concern, because of strong stratification, very low dissolved oxygen, high fecal coliform levels, and moderate levels of DIN and ammonium. Penn Cove also has had strong, persistent stratification, low DO, and moderate DIN and ammonium concentrations, placing it high on the index of concern.

Saratoga Passage and Possession Sound were also added to highest concern category for 2001-2005. Both locations have experienced strong persistent stratification and very low DO, but Possession Sound also has high fecal coliform

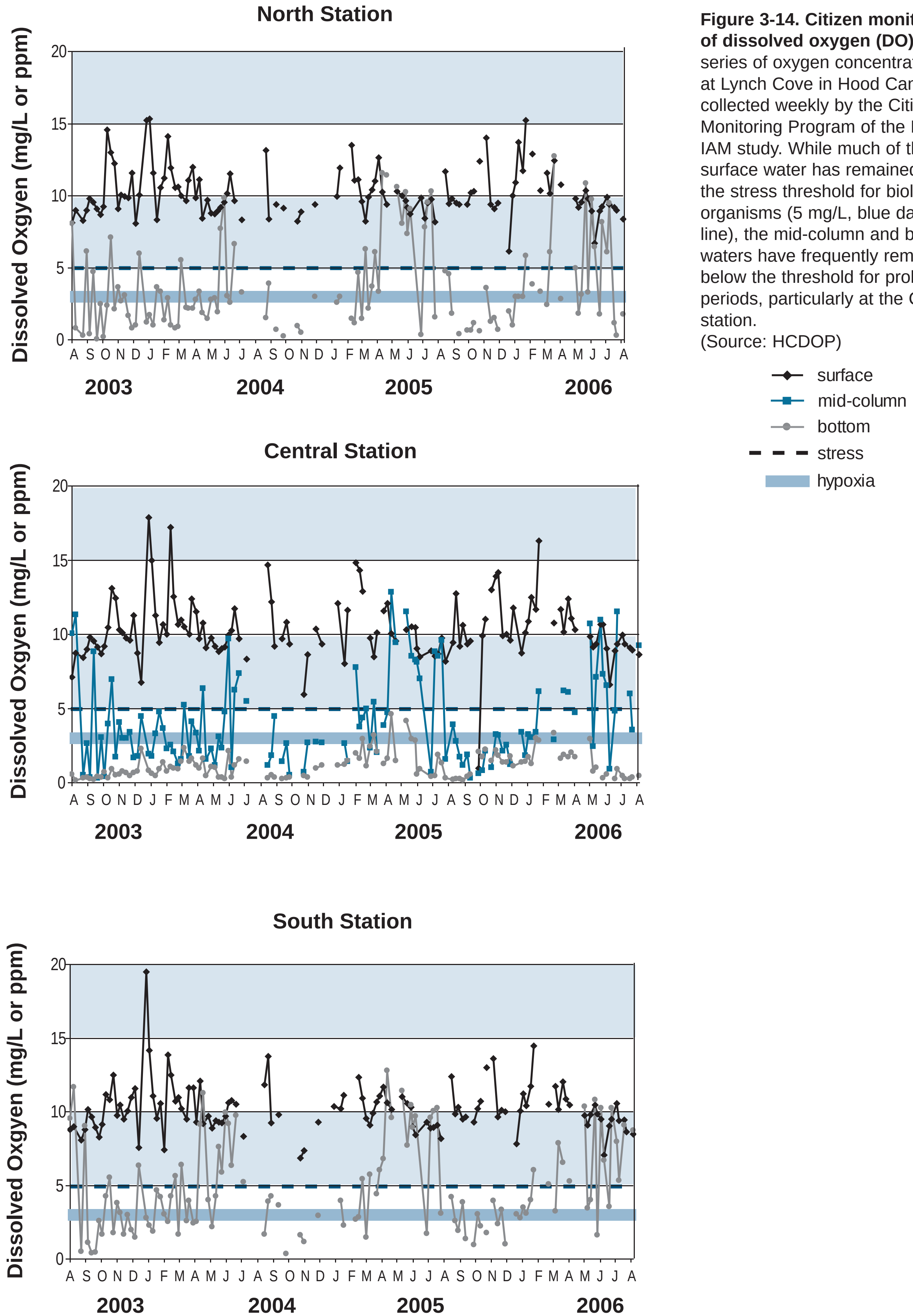
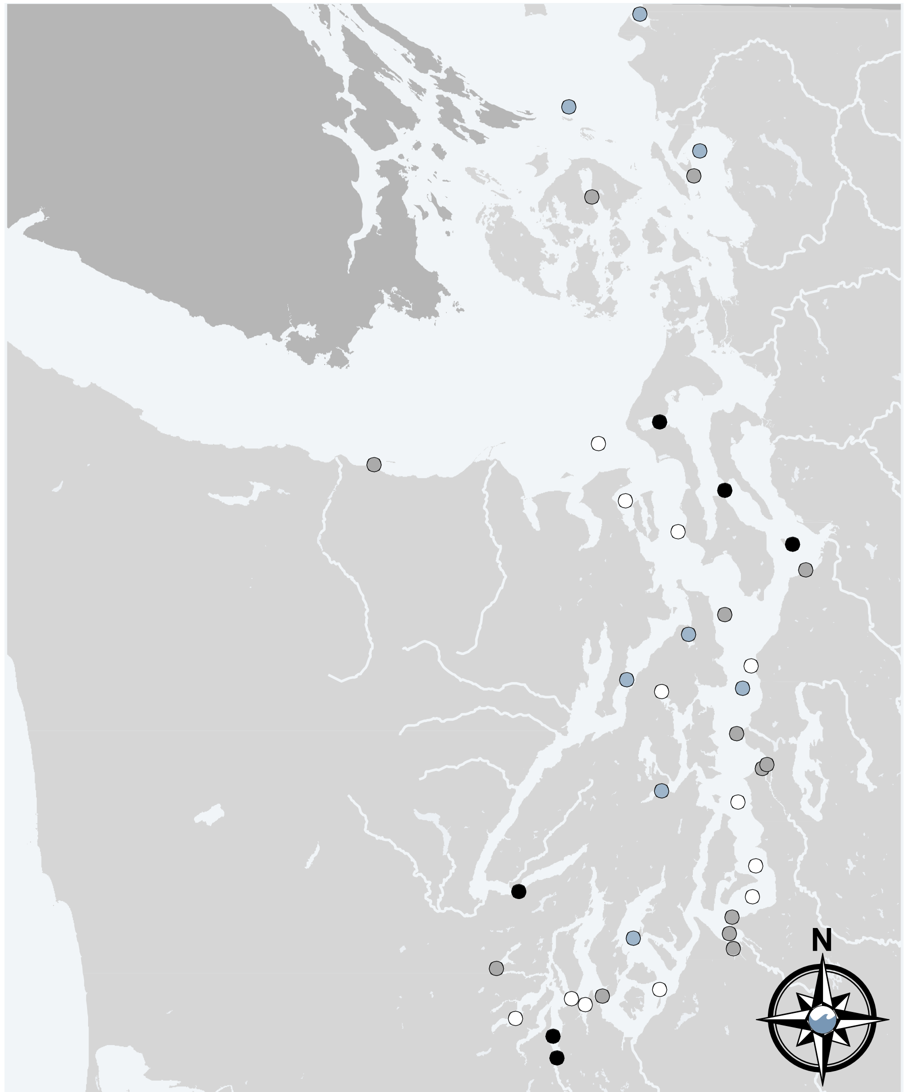


Figure 3-14. Citizen monitoring of dissolved oxygen (DO). Time series of oxygen concentrations at Lynch Cove in Hood Canal, collected weekly by the Citizen's Monitoring Program of the HCDOP-IAM study. While much of the surface water has remained above the stress threshold for biological organisms (5 mg/L, blue dashed line), the mid-column and bottom waters have frequently remained below the threshold for prolonged periods, particularly at the Center station.
(Source: HCDOP)

Figure 3-15. Water quality concern index for marine monitoring stations in Puget Sound, based on 2001-2005 data. Stations are scored by assigning points to each of five indicators. Highest values are given to very low DO, strong stratification, low DIN, high ammonium (NH4), and high fecal coliform levels (FCB). Scores are summed to determine a relative level of diminished water quality, with stations of the highest concern scoring in two or more of these indicators. See Table 3-1 for individual station rankings. (Source: Ecology)

- Highest Concern
- High Concern
- Moderate Concern
- Lowest Concern



and low levels of DIN. Along with Penn Cove, these stations are located in an area that has strong urban influences and somewhat reduced interchanges of water with the rest of the northern Sound, making them more susceptible to eutrophication and its effects on DO concentrations.

In areas of high concern, which include Commencement, Elliott, and Bellingham bays and other urban locales, as well as less urbanized locations such as Oakland Bay, Nisqually Reach, and East Sound, the causes of concern are more varied, although most of these sites have low DO. However, many of the more urbanized locations have high fecal coliform counts and elevated ammonium levels, features typical of waters adjacent to areas with large populations.

Although not located in Puget Sound, Ecology water quality stations in Grays Harbor and Willapa Bay provide an interesting contrast and are included in Table 3-1. These stations vary considerably in their locations within each estuary, ranging from locations near sources of freshwater input to those experiencing relatively direct influences of incoming waters from the outer Pacific Ocean coast. As a result, they also span the range of concerns for marine waters. For example, stations located near the Chehalis River in Grays Harbor and the Willapa River in Willapa Bay are in high or extremely high concern categories because of strong,

Location	DO	FCB	DIN	NH4	Stratification*	WQ Concern
Possession Sound	Very Low	High	Low	Low	SP	Very High
Penn Cove	Very Low	Low	Low	Mod	SP	Very High
Budd Inlet - South Port	Very Low	High	High	High	SI	Very High
Saratoga Passage	Very Low	Low	Low	Low	SP	Very High
Hood Canal - Sisters Pt.	Very Low	Low	Low	Low	SP	Very High
Budd Inlet - Olympia Shoal	Very Low	High	Mod	Mod	MI	Very High
Grays Harbor - Chehalis River	High	High	High	Mod	SP	Very High
Bellingham Bay - Pt. Frances	Very Low	Mod	Mod	Mod	SI	High
Commencement Bay	Low	High	High	Mod	SI	High
Willapa River - Raymond	High	High	High	Mod	SI	High
Willapa River - John. Slough	High	High	High	Mod	SI	High
Quartermaster Harbor	Low	Low	Mod	High	MI	High
Oakland Bay	High	High	Mod	Mod	MI	High
Elliott Bay	Low	High	High	Low	SI	High
Commencement Bay - Browns Pt.	Low	High	High	Low	SI	High
Admiralty Inlet South	Very Low	Mod	High	Low	SI	High
Willapa Bay - S. Jenson Pt.	High	Low	Low	Mod	WI	High
Willapa Bay - Nahcotta Channel	High	Low	Low	Mod	MI	High
West Point	Low	High	High	Low	MI	High
Port Gardner West	Low	Low	High	Low	SP	High
Port Angeles Harbor	Low	High	High	Low	WI	High
Nisqually Reach	Very Low	Low	High	Mod	WI	High
Grays Harbor - South Channel	High	High	High	Mod	MI	High
East Sound	Low	Low	High	High	MI	High
Sinclair Inlet	Low	Mod	Mod	Mod	MI	Moderate
Willapa Bay - Naselle River	High	Mod	Mod	Mod	MI	Moderate
Point Jefferson	Low	Mod	High	Low	SI	Moderate
Carr Inlet	Low	Low	Mod	Mod	WI	Moderate
Bellingham Bay - Nooksack	Low	Low	High	Mod	SI	Moderate
Willapa Bay - Toke Point	High	Mod	Mod	Low	MI	Moderate
Strait of Georgia	Low	Low	High	Low	SI	Moderate
Port Gamble	Low	Low	Mod	Low	MI	Moderate
Hood Canal - Bangor	Low	Low	High	Mod	M Int	Moderate
Drayton Harbor	High	Low	Mod	Mod	M Int	Moderate
Totten Inlet	High	Low	High	Mod	MI	Low
Port Townsend	Low	Low	High	Low	MI	Low
Port Orchard	High	Low	Mod	Low	WI	Low
Point Wells	High	Low	High	Mod	MI	Low
Henderson Inlet	Low	Low	High	Low	WI	Low
Grays Harbor - Damon Pt.	Low	Low	High	Low	MI	Low
East Passage	Low	Low	High	Low	MI	Low
Dana Passage	Low	Low	High	Low	WI	Low
Admiralty Inlet - Quimper Pn.	Low	Low	High	Low	MI	Low
Admiralty Inlet - Bush Pt.	Low	Low	High	Low	MI	Low
Gordon Point	High	Low	High	Low	WI	Low
Dolphin Point	High	Low	High	Low	MI	Low

Table 3-1. Indicator results and water quality concern index for Puget Sound marine monitoring stations, based on 2001-2005 data. (Index calculations are described in Figure 3-14 and text.) (Source: Ecology)

*Stratification is characterized as:
- SP = Strong and persistent
- SI = Strong and intermittent
- MI = Moderate and infrequent
- M Int = Moderate and intermittent
- WI = Weak and infrequent

persistent stratification—a result of density differences resulting from incoming fresh water—as well as high fecal coliform concentrations and moderate levels of ammonium. In contrast to Puget Sound, the reasons that stations in these estuaries warrant moderate to high concern levels are highly variable. However, the stations share one attribute: none have very low dissolved oxygen concentrations. This variability in the factors most affecting water quality reflects the fundamental differences between Puget Sound and these coastal estuaries, which are shallow, generally well mixed, and have strong tidal exchange with oceanic waters.

7. Circulation

a. General circulation patterns

Central Puget Sound has shallow sills at its northern and southern ends. Sills are shallow submerged piles of debris or rocky ridges formed by retreating glaciers. Major sills beneath northern and central Puget Sound (Admiralty Inlet and the Tacoma Narrows, respectively), and at the mouth of Hood Canal separate Puget Sound from the Strait of Juan de Fuca. Sills are locations where strong mixing and short residence times occur and where water is rapidly transported by tidal currents. The sills alter the normal pattern of estuarine circulation by causing mixing and by restricting the exchange of water with adjacent basins. These alterations contribute to the singular patchiness and productivity of the main basin.

A conceptual flow model of Puget Sound suggests that considerable seaward-flowing surface water from the main basin is mixed downward into the bottom water entering at the southern end of the Admiralty Inlet sill. This process returns the downward mixing surface water to Puget Sound, but as part of the deep water below the sill. This process, known as refluxing, means that some fraction of the water, along with any dissolved and suspended constituents it contains, will not leave the basin immediately, but will make additional trips through Puget Sound. In fact, about two-thirds of the deep water entering the main basin is thought to be main basin surface water caught in the deep inflow during mixing at Admiralty Inlet, rather than water from the Strait.

b. Upwelling

The climate of the northeast Pacific Ocean oscillates between warm and cold states every 20 to 30 years. These changes in state have come to be known as climate regimes. A warm phase dominated most years between 1927 and 1946, with a cool phase dominating from 1947 to 1976 and a warm phase, again, from 1977 to 1998. In the northern California current off Oregon and Washington, these regimes appear to be characterized by low productivity during warm phases (where there is weaker upwelling) and high productivity during cool phases (associated with strong upwelling). The impact of these alternating regimes on salmon, for example, is that both coho and chinook salmon do well under cool regimes and poorly during warm regimes.

Recently, a dramatic reversal of regimes was observed in September 1998, when large-scale cooling was initiated in the North Pacific (Peterson and Schwing 2003). This climate shift led to increased biomass of zooplankton and baitfish, significant increases in survival and return rates of both coho and chinook salmon, changes in recruitment rates of other fishes and increased reproductive success of marine birds. Returns of chinook from 2000 to 2002 were among the highest in recent history. Many scientists postulated that the shift, initiated in late 1998, represented the start of a new cold, productive climate regime. They hoped this event signaled a new 20-year-long cycle of productive ocean conditions, resulting in improved salmon returns. However, this productive regime proved to be short-lived, lasting only four years. Beginning in late 2002, the ocean began to warm and continued to do so through 2005, such that during spring and early summer of 2005, ocean conditions closely resembled conditions observed during the large El Niño event of 1997 and 1998. Warm ocean conditions observed during the summer of 2005 were the result of a lack of significant upwelling until late-July—about two to three months later than average.

8. Current Modeling Efforts in Puget Sound

Models that emulate the circulation, water quality, and other parameters of waters in Puget Sound are important scientific tools for understanding how the Puget Sound ecosystem functions and for predicting future scenarios. A wide variety of local, state, and federal agencies, as well as educational institutions and private entities are involved in the development of circulation models that are used to help us understand basic physical, chemical, biological, and ecological processes, or to guide managers by providing the means for evaluating the effects of different management approaches. Figure 3-16 indicates the general vicinity and target component of the major modeling efforts in Puget Sound.

The following sections provide an overview of several of the modeling projects underway in Puget Sound.

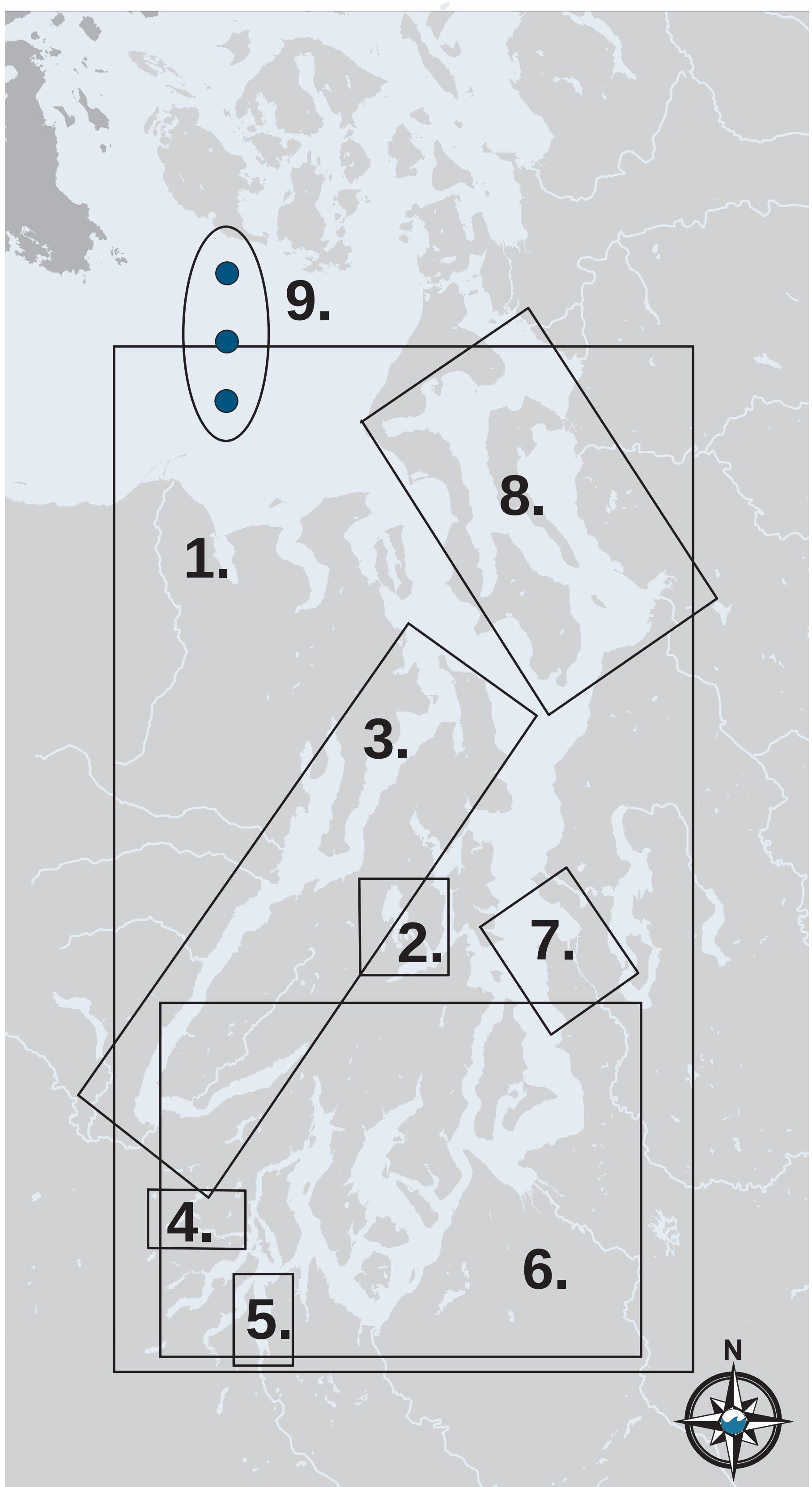
a. Puget Sound Marine Environmental Modeling

The Puget Sound Marine Environmental Modeling (PSMEM) is a partnership of Ecology, UW, King County DNR, EPA, USGS, U.S. Navy, Battelle Pacific Northwest National Labs, NOAA, and the private non-profit Ocean Inquiry Project that seeks to develop predictive circulation and ecosystem models for Puget Sound. The goals of PSMEM are to maintain and operate simulation models, develop a system for managing oceanographic data and model results, facilitate the sharing of resources, and conduct research to develop our understanding of the Sound's working and address questions and issues related to management of the Sound. Current modeling activities by PSMEM members include the development and use of circulation models to:

- Support nearshore habitat restoration efforts, improve fish passage and understand effluent fate and transport in the Whidbey basin area. (Battelle PNNL).
- Evaluate the impacts of increased nutrient loading on south Puget Sound. (Ecology)
- Support TMDL activities and pollutant source control for locations such as Budd Inlet/Capitol Lake and Oakland Bay. (Ecology).
- Support wastewater and sewage management planning in Puget Sound and specific locations such as the Duwamish River estuary and Elliott Bay. (KC DNRP)
- Understand the causes of low dissolved oxygen in Hood Canal and inform possible management actions. (HCDOP-UW, USGS)
- Evaluate fecal coliform loading, transport, and fate to support source management and the evaluation of CSOs in Sinclair and Dyes Inlets. (U.S. Navy)

Figure 3-16. Modeling efforts underway in Puget Sound and the Strait of Juan de Fuca. Included are joint and collaborative modeling.

1. **PRISM:** (UW, King County, DNR, Ecology) and **Brightwater** (King County, DNR). Hydrodynamics, temperature, and salinity. Future additions are nutrients, phytoplankton, zooplankton, and DO for POM-ABC model. Brightwater analysis included hydrodynamics, temperature, salinity, and tracer.
2. **Dyes/Sinclair Inlet:** (PSNS, Ecology). Hydrodynamics, temperature, salinity, and fecal coliform.
3. **Hood Canal:** (HCDOP, UW, USGS, Ecology). Hydrodynamics, temperature, salinity, nutrients, phytoplankton, and DO.
4. **Oakland Bay** (Ecology) Hydrodynamics, temperature, salinity, and fecal coliform.
5. **Budd Inlet** (Ecology, LOTT). Hydrodynamics, temperature, salinity, nutrients, phytoplankton, and DO.
6. **South Sound** (Ecology, SPS-MEM). Hydrodynamics, temperature, salinity, nutrients, phytoplankton, and DO.
7. **Duwamish Estuary/ Elliott Bay** (KC, DNR). Hydrodynamics, temperature, salinity, metals, organics, and fecal coliform.
8. **Whidbey Basin** (PNNL). Hydrodynamics, temperature, and salinity.
9. **JEMS** (Ecology, UW-PRISM & UW Friday Harbor). DO, temperature, density and salinity.



- Integrate research and education through the development of a Soundwide Puget Sound Regional Synthesis Model (PRISM). (UW)

b. Modeling Puget Sound Currents

Researchers at the University of Washington are studying Puget Sound currents and developing models to provide a clearer picture of how and where water moves in the Sound. Maps from models can show the movement and spread of water, starting from a given location, as well as preferred paths of movement of water. For example, surface particles released April 1, 2000 in the North Puget Sound and Central Puget Sound basins (Figure 3-17a) and in the Whidbey Basin (Figure 3-17b) are efficiently carried out of the Sound in the outgoing surface layer of the exchange circulation within one to two weeks. The surface waters of the Whidbey Basin are renewed rapidly, because of the large volume of river discharge that this basin receives.

In contrast, particles released in the South Puget Sound Basin (Figure 3-17c) become trapped and are recirculated around Vashon Island and are retained in the region for three weeks or longer, before they head out to Admiralty Inlet or get mixed down to deeper layers by the strong tidal currents in the Tacoma Narrows. There is a distinct front lying between West and Alki Points, which slows recirculation, and only a small portion of the particles cross this barrier after three weeks of drift. (See Figure 3-17, Appendix C: Color Figures.)

Particles can be tracked vertically in the water column, as well as horizontally. Tracking vertical movement of particles reveals regions of large vertical velocities and mixing. Admiralty Inlet is one such region (See Figure 3-18, Appendix C: Color Figures).

Detailed knowledge of patterns of water movement will help in both scientific understanding and practical applications. Flow patterns will control migrations of water-borne organisms, such as plankton, and influence the spread of paralytic shellfish poisoning and certain invasive species. Understanding current patterns and being able to predict them are essential in search-and-rescue operations, oil and contaminant spill response, and other applications.

c. South Puget Sound Water Quality Study

Residential development in south Puget Sound has risen sharply in the past two decades, and the trend is expected to continue. There is growing concern that marine water quality in the south Sound may be adversely affected by eutrophication from the increases in nutrient loading that typically accompany urbanization. Hood Canal's chronically low DO concentrations and frequent fish kills have received extensive coverage within the state and throughout the nation. Other areas in the Sound—most notably the South Puget Sound and Whidbey basins—are also at significant risk for similar problems.

The South Puget Sound Basin has numerous blind inlets and is separated from the mouth of Puget Sound by over 60 miles. These factors contribute to long water residence times and slow flushing rates, which limit the dilution and exchange of nutrients and pollutants with the Pacific Ocean. As a result, the South Puget Sound Basin is particularly susceptible to water quality problems, including low DO, reduced water clarity, and algal blooms.

During the first phase of the South Puget Sound Water Quality Study, cruises were conducted in the south Sound to assess the potential for future water quality problems. During the cruises, samples were collected to measure seasonal variability in water quality, analyze point and nonpoint source pollutant loads, and to begin initial development of a hydrodynamic water quality model for the South Puget Sound Basin. Such models allow scientists to track the movement and persistence of pollutants.

Cruise results showed that parts of the South Puget Sound Basin are sensitive to the addition of nutrients and that low DO levels occur in a number of inlets (See Figure 3-19, Appendix C: Color Figures) confirming the potential for serious water quality degradation from increased nutrient loading. Case, Carr, and Budd inlets appear to be most susceptible to eutrophication. Smaller, shallower inlets also showed nutrient sensitivity at times, but strong tidal mixing inhibits the development of low DO. High inputs of other contaminants, such as fecal coliform bacteria, are also a concern in these inlets.

The analysis of pollutant loads found that point sources represented two percent of inflows to South Sound but contributed 30 to 50 percent of the nutrient load. In contrast, only 0.2 percent of the fecal coliform load came from point sources. These results suggest that the combined impact of many small pollutant sources can lead to significant water quality degradation.

For the second phase of the South Sound Study, Ecology proposes to further refine, calibrate, and verify the model for use as an important management tool.

d. Joint Effort to Monitor the Strait of Juan de Fuca

The Strait of Juan de Fuca is where deep in-flowing oceanic waters mix with out-flowing Puget Sound and Georgia Basin surface waters. The Joint Effort to Monitor the Straits (JEMS) is a program that collects water quality data (temperature, salinity, density and DO) from the Strait, enabling valuable comparison of incoming and departing water masses over time.

The incoming ocean water can fluctuate between high-density waters with low oxygen and high nutrient content, versus low-density waters with high oxygen and low nutrient content. These conditions are in response to upwelling and downwelling patterns generated by coastal winds and changes in coastal circulation. High-nutrient/low-oxygen water can mimic conditions that exist during human-caused eutrophication. Therefore, estimates of water quality impairment may be misrepresented if ocean conditions, instead of human-caused nutrient inputs and oxygen drawdown, are responsible.

Moreover, the Strait represents a choke-point on which to monitor in-flowing oceanic waters (deep layer), as well as the integration of out-flowing Puget Sound and Georgia Basin waters (upper layer), enabling valuable comparison of both water masses over time (See Figure 3-20, Appendix C: Color Figures.)

The JEMS oxygen data were recently used by PSAMP scientists to evaluate whether several stations in Puget Sound should be included on the 303(d) list (the State's list of impaired water bodies in Puget Sound). The data are also used to evaluate the extent that ocean-derived oxygen concentration may be influencing hypoxia conditions in Hood Canal.

8. Habitat Modification

Throughout Puget Sound, the threat of habitat loss increases as growth and associated urbanization, agriculture, and resource extraction convert the landscape from native species cover to human-altered landscape. As a result, many land cover types have been dramatically reduced; this may have significant consequences on habitat quality for marine and aquatic species.

a. Changes in Puget Sound Wetlands and Tidal Marshes

Coastal wetland ecosystems are among the most disturbed natural environments. While most coastal wetlands have been lost due to draining and filling, other major impacts include increased nutrient loading (which can lead to eutrophication), changes in hydrology, introductions of toxic materials, and changes in species composition, due to over-harvest and introductions of non-native species (Day et al. 1989; Mitsch and Gosselink 1993; Neumann et al. 2000).

Previous statewide studies suggest than an estimated 69 percent (938,000 acres) of historic wetlands remain in the state (Dahl 2000). However, research focused on estuarine wetlands suggest that a larger proportion of tidal wetlands have been lost (Thom and Hallum 1990). Urban and rural development are the primary causes of estuarine wetland loss, accounting for 43 percent of the losses in Washington (Dahl 2000).

Beginning in 2004, scientists from DNR contracted with University of Washington researchers to characterize the distribution, type, and amount of historic tidal wetlands throughout Puget Sound. The project resulted in spatial GIS maps of wetlands, based on historic and current datasets. Researchers used historic maps to better understand the distribution, character, and amount of tidal wetland habitat loss in Puget Sound. Wetland losses were assessed, both in terms of the loss of wetland area and loss of discrete wetland units (discussed in this document's wetland complexes section).

Status and Trends

Wetlands are found throughout Puget Sound. They are not uniform in their distribution and abundance, with some basins having much higher historical abundances of wetland habitat than others. Some types of wetlands appear to have suffered disproportionately high levels of loss over time. In particular, one type of estuarine wetland (scrub-shrub) and riverine wetlands have declined more than 90 percent from historic levels, and a different type of estuarine wetland (emergent) have declined 67 percent (Table 3-2). Loss of riverine and scrub-shrub wetlands may be attributed to the relative ease (compared to emergent wetlands) with which these wetland types can be converted to developed lands.

From a geographic perspective, all basins have experienced measurable losses of tidal, estuarine, and riverine wetlands. Basins that historically supported the largest amount of tidal wetland habitat include the Whidbey, San Juan Archipelago, Fraser Lowlands, and central Puget Sound (Figure 3-21). The losses of wetland habitat have also been asymmetrical, with the Strait of Juan de Fuca and Hood Canal retaining more than 50 percent of their historical wetland areas, and the San Juan Islands/South Georgia Strait and Central Puget Sound Basins have lost more than 90 percent of their wetland areas (Figure 3-22). One oceanographic basin—the Whidbey Basin—contains more than half of the historic and current wetland areas in Puget Sound, and more than half of the Puget Sound wetland losses have occurred in this basin.

Table 3-2: Amount and type of tidal marsh mapped in Puget Sound for historic and current conditions. Large declines in the total area of tidal wetlands have reduced habitat for many species, including birds and salmon, while changes to the relative abundance of wetland types has increased the importance of remaining scrub-shrub and riverine tidal wetland habitat. (Source: DNR)

Type	Historic Area (acres)	Current Area (acres)	Percent Loss
Estuarine	50,162 (65%)	11,589 (84%)	77
Emergent	34,348 (44%)	11,218 (81%)	67
Scrub-shrub	15,814 (21%)	370 (3%)	98
Riverine-tidal	27,428 (35%)	2,273 (16%)	92
Tidal Wetlands (Total)	77,590 (100%)	13,862 (100%)	82

Note: Percentages in parentheses represent the proportions of total wetlands within each time period.

Figure 3-21. Historic and current wetland area losses. Earliest surveys of wetlands were conducted from the 1850s through the 1890s. The Whidbey Basin includes the Skagit River delta, which underwent significant loss of wetlands through diking, river channel alteration, and land-use conversion, primarily to agriculture. (Source: DNR)

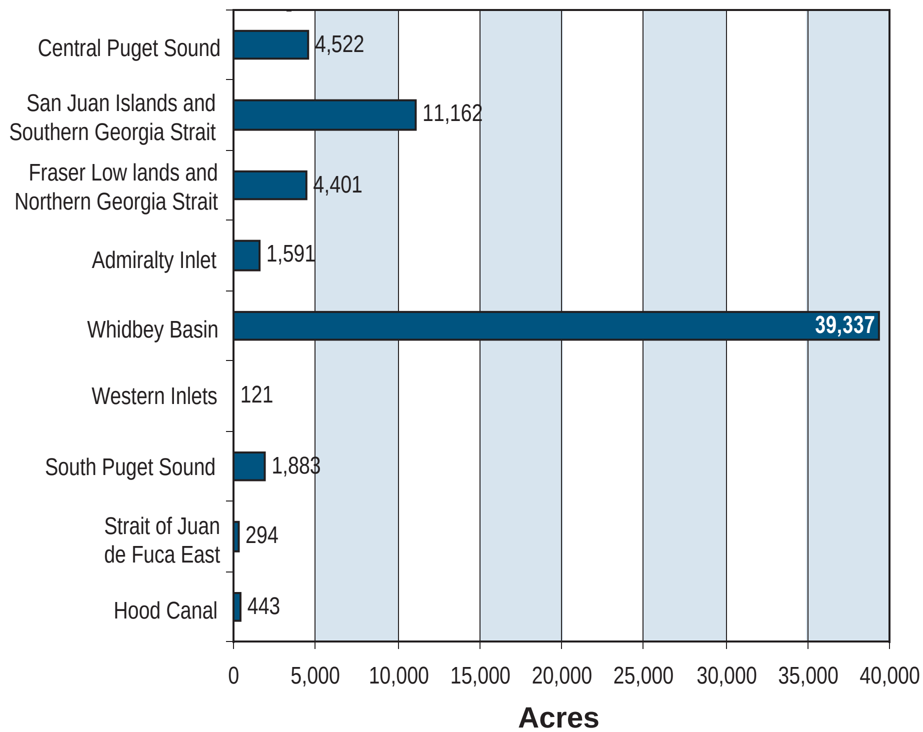
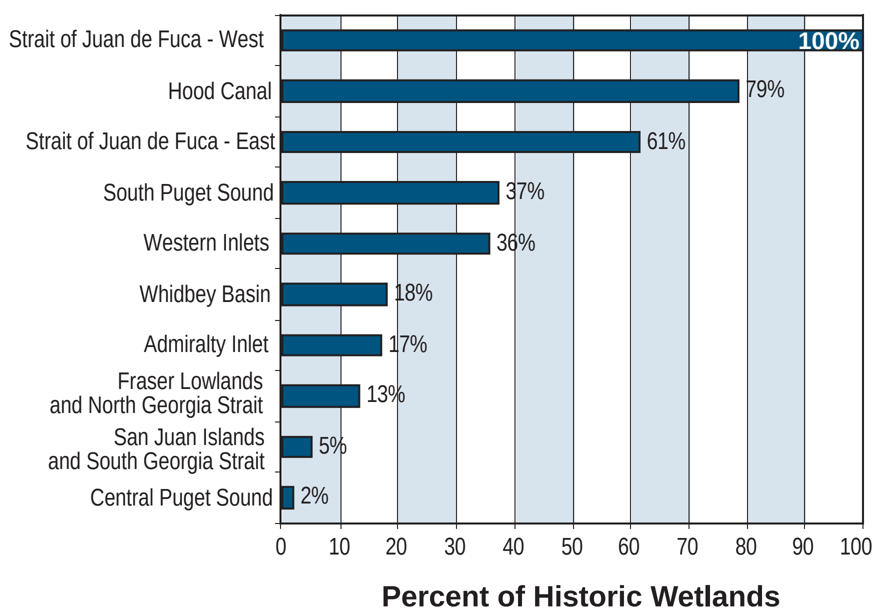


Figure 3-22. Current wetland area as a percentage of historical area. While three basins have more than 50 percent of their historical wetland areas (western and eastern Strait of Juan de Fuca and Hood Canal), wetlands have been nearly eliminated from several basins, with the most impacted basin, Central Puget Sound, retaining only two percent of its historical wetland area.
(Source: DNR)

Note: Due to incomplete historical mapping and/or wetland expansion over the past 150 years, there are more acres of tidal wetlands in the western portion of Strait of Juan de Fuca than mapped historically.



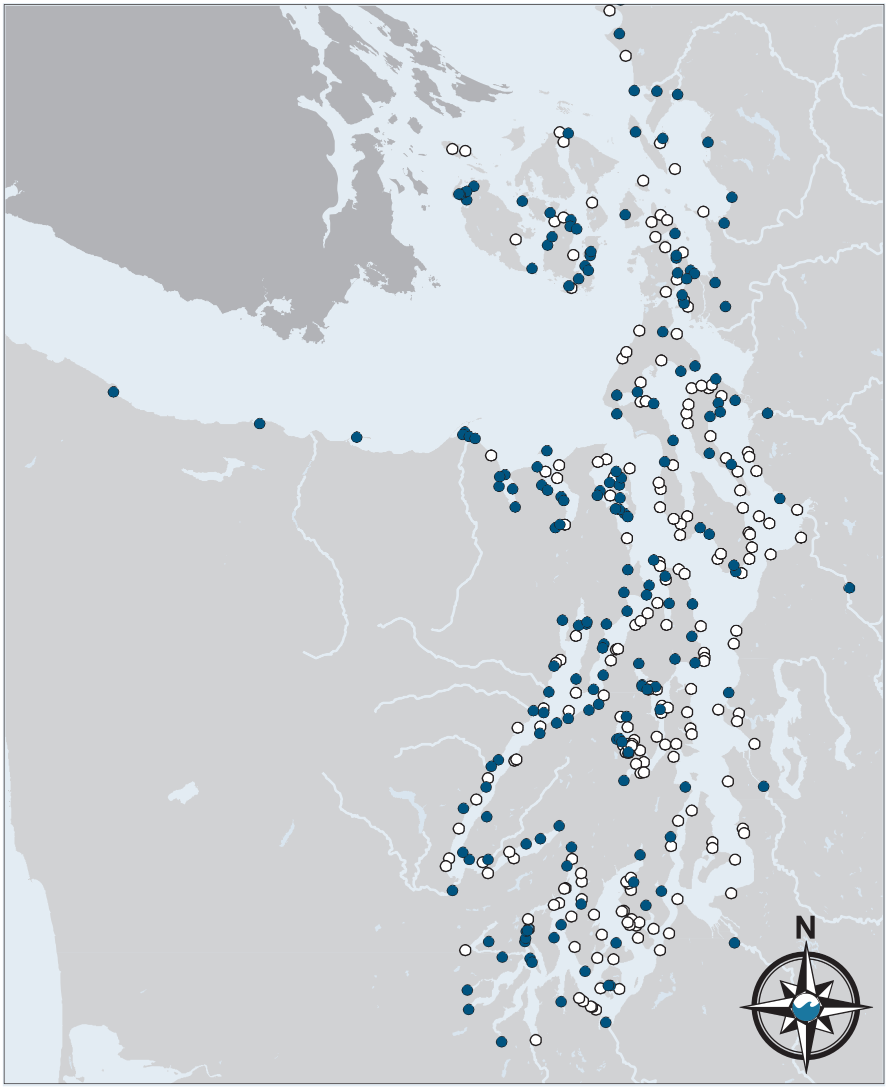


Figure 3-23. Disappearance of wetland complexes in Puget Sound. This includes tidal wetland complexes that have been eliminated since historic maps were created, as indicated by the lighter-colored marks on the map. (Source: DNR)

Tidal Wetland Complexes

- ● Historic wetlands complexes on both historic and current maps
- ○ Wetlands on historical map, not on current map

Losses of wetland complexes appear to be concentrated in areas along the urbanized eastern shores of Puget Sound, between Tacoma and Anacortes. Locales that appear to have experienced the most loss of wetland complexes include central Puget Sound, Whidbey Basin, and the San Juan Archipelago (Figure 3-23).

Calculating the change in wetland area in the western portion of the Strait of Juan de Fuca is not possible, due to challenges comparing current and historic wetland records in this area.

Impacts to the Ecosystem

Tidal marshes are among the most productive ecosystems in the world, providing essential breeding habitat for roughly one-quarter of North American bird species and supporting about 50 percent of the animal species listed as endangered. An estimated 95 percent of commercially important fish and 85 percent of sport fish spend portions of their life cycles in coastal wetland and estuarine habitats (Mitsch and Gosselink 2000).

The loss of tidal wetlands has reduced the productivity of the local ecosystem, thereby restricting the carrying capacity for many species that depend on wetlands for feeding, rearing young, and nesting. Asymmetrical losses in wetland habitats have resulted in a current condition in which scrub-shrub and riverine tidal wetlands have become much less common and remaining fragments are carrying the burden on maintaining populations that rely on these wetland types. Furthermore, species that rely on these wetlands for feeding or refuge now must travel greater distances between wetlands in many areas.

Human Health Consequences

Wetlands offer critical buffers before water reaches, lakes, rivers, and Puget Sound. Pollutants and fertilizers flowing off the landscape are often intercepted and retained by wetland systems. Services provided by wetlands include habitat for species, protection against floods, water purification, and recreational opportunities. Efforts to quantify the economic value of wetlands suggest that bird watching and commercial fish services are the highest-valued wetland services (Woodward and Wui 2001).

b. Fraser River Sediment Plume

The PSAMP long-term monitoring program provides a vital record of sediment conditions in Puget Sound and offers insights into the effects of both natural and human-driven stressors on the Sound. Data from the fixed sentinel stations monitored in this program can raise red flags, highlighting important environmental changes affecting Puget Sound. These results are critical for guiding the policy and regulatory decisions needed to effectively manage and maintain the environmental health of Puget Sound.

Ecology's PSAMP sediment program sampled sediments at 10 fixed stations throughout Puget Sound each spring from 1989 through 2000 (Figure 3-24). Stations were chosen from a variety of habitats and geographic locations in Puget Sound. Sediments from each station were analyzed for particle size, organic carbon content, and the presence of more than 120 chemical contaminants, as well as the types and abundances of sediment-dwelling organisms.

Large-scale changes in grain size and the numbers and types of sediment-dwelling organisms were observed at the Strait of Georgia station and appeared to be linked to natural, rather than human-caused stressors.

Status and Trends

From 1989 through 1995, the amount of fine-grained sediment (percent silt) at the Strait of Georgia station varied between 25 and 50 percent. Between 1995 and 1997, it rose to approximately 90 percent, then declined to about 50 percent between 1998 and 2000. During the study, the community of sediment-dwelling organisms changed from one characterized by the annelid worm species *Prionospio*, *Pholoe*, and *Cossura*, to one consisting primarily of *Cossura*—a mobile, burrowing worm that tolerates living in a wide range of sediment grain sizes. The community finally changed to one dominated by the bivalve mollusks *Macoma* and *Yoldia*, also active burrowers (Figure 3-25).

Examination of the flow and discharge plume of British Columbia's Fraser River, which can carry heavy sediment loads into the Strait of Georgia (See Figure 3-26, Appendix C: Color Figures), suggested a possible cause for the observed changes. Annual rainfall, Fraser River flow volumes, and the percent silt at the Strait of Georgia station all exhibit similar temporal patterns (Figure 3-25).

It is hypothesized that the changes in the sediment community observed in the Strait of Georgia were driven by above-average precipitation in 1996 and

Figure 3-24. Location of 10 long-term sediment monitoring sites in Puget Sound.
(Source: Ecology)

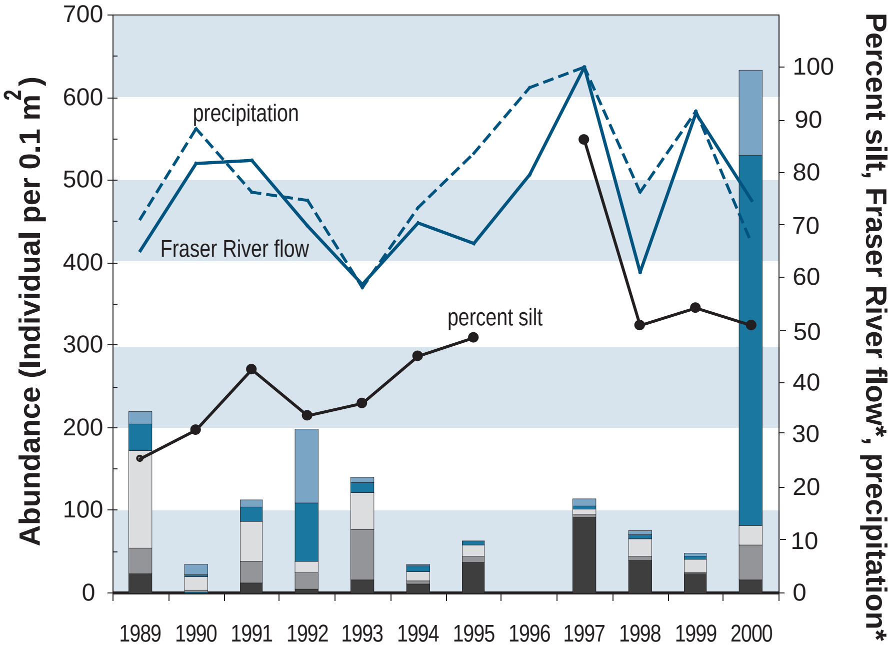
1997, which increased water flows in the Fraser River and resulted in increased deposition of fine sediments in northern Puget Sound. Changes in grain size are known to influence community structure. The increase in fine sediments at this station may be associated with increasing numbers of active burrowing organisms.

Impacts to the Ecosystem

Changes in the sediment community in the Strait of Georgia, in response to naturally occurring variation in rainfall and river flow, clearly show the value of long-term monitoring for furthering our understanding of the effects of stressors on the Puget Sound ecosystem.

Understanding these processes on a local scale can help explain similar changes in other regions. For example, the sediment and community changes observed in the Strait of Georgia may hold the key to understanding recent declines in San Juan Island eelgrass populations. Acting on the results of this study, investigators from the University of Washington and the USGS conducted sediment surveys in June 2006 to determine if the decline in eelgrass abundance can also be linked to the deposition of fine-grained sediments from the Fraser River (S. Wyllie-Echeverria, pers. comm.).

Figure 3-25. Fraser River sediment flow into the Strait of Georgia. Changes in percent silt and abundance of dominant annelids and mollusks at the Strait of Georgia station, along with patterns in Fraser River flow and precipitation at the Vancouver International Airport. High-flow years delivered increased sediment loads to the Georgia Strait, changing biodiversity of invertebrates. Most recent sampling shows a dramatic increase in mollusks over previous years.
(Source: Environment Canada)



Mollusca
- Yoldia
- Macoma

Annelida
- Prionospio
- Pholoe
- Cossura

* Flow and precipitation values for each year are represented as their percentage of the corresponding 1997 values.

10. Efforts to Improve Water and Habitat Quality

There are many restoration activities underway in Puget Sound, carried out by federal, state and local agencies, and citizen groups. Progress on many of these restoration projects is reported elsewhere. The following descriptions of restoration projects and conservation tools are a small subset of the projects underway in Puget Sound.

a. Elwha Dam Removal

Between 1911 and 1913, two dams were built on the Elwha River, one of 10 major rivers on the Olympic Peninsula. The dams effectively blocked 10 runs of anadromous fish from returning to over 70 miles of spawning habitat in the upper Elwha River. Prior to dam construction, the Elwha was one of the most productive salmon rivers in the Puget Sound region, with runs numbering in the hundreds of thousands (Wunderlich et al. 1994). Without fish passages at either dams, salmon spawning is limited to the lower 4.9 miles of the river. Currently approximately 4,000 wild salmon now spawn in a stretch of river between the lower dam and the Strait of Juan de Fuca.

The dams have also prevented downstream transport of sediments and nutrients, greatly altering structure and composition of the river's riparian areas, delta, and beaches at its mouth. About 13.8 million cubic yards of sediment are trapped in Lake Mills, and up to four million cubic yards are trapped in Lake Aldwell. This sediment will be permitted to naturally move downstream as the dams are deconstructed.

Impacts to the Ecosystem

Dam removal will begin in 2007, and the resulting restoration of the Elwha River will open up over 70 miles of largely pristine salmon habitat. There are estimates that the removal of the two dams would produce approximately 390,000 salmon and steelhead in about 30 years, compared with less than 50,000 fish if the dams were fitted with upstream and downstream fish passage facilities.

b. Derelict Fishing Gear Removal

Derelict fishing gear is lost or abandoned nets, pots, and fishing line that are found in the marine environment. As of March 2006, the Northwest Straits Commission (NWSC) completed 41 days of survey operations, covering 25 square nautical miles of seabed. In this area, which represents less than five percent of Puget Sound fishing grounds, over 3,500 derelict crab pots and 32 nets were encountered. Although it is not known how much derelict gear is in Puget Sound, it is estimated that only three percent has been located and less than one percent removed. NWSC has set goals of 2,500 tons of derelict pilings and 800 tons of beach debris to be removed throughout Puget Sound. Most of the beach projects will continue to be sited in the Northwest Straits, and the piling efforts will be spread out through the Sound.

Status and Trends

In 2002, NWSC initiated a pilot project to develop and test protocols for locating, removing, and disposing of derelict fishing gear. It partnered with the WDFW to set up a reporting system that includes a telephone hotline and Web site. From underwater surveys and public reporting of gear, over 3,400 pieces of derelict have been entered into a database, and 1,041 of these pieces have been removed. Removals include: 361 gillnets, 3 purse seine nets, 1 aquaculture net, and 945 crab pots. By removing derelict nets, over 73 acres (30 hectares) of underwater marine habitat have been cleaned up. The nets contained a total of 1,469 marine invertebrates, 102 marine birds, 372 fish, and eight marine mammals. Crab pots contained over 1,560 live and dead marine invertebrates and other animals. These numbers represent only the marine life that was on the gear at the fixed point in time when removal occurs. There are no data available to identify how many animals are caught, killed, and subsequently, decompose while such gear is in the water.

Impacts to the Ecosystem

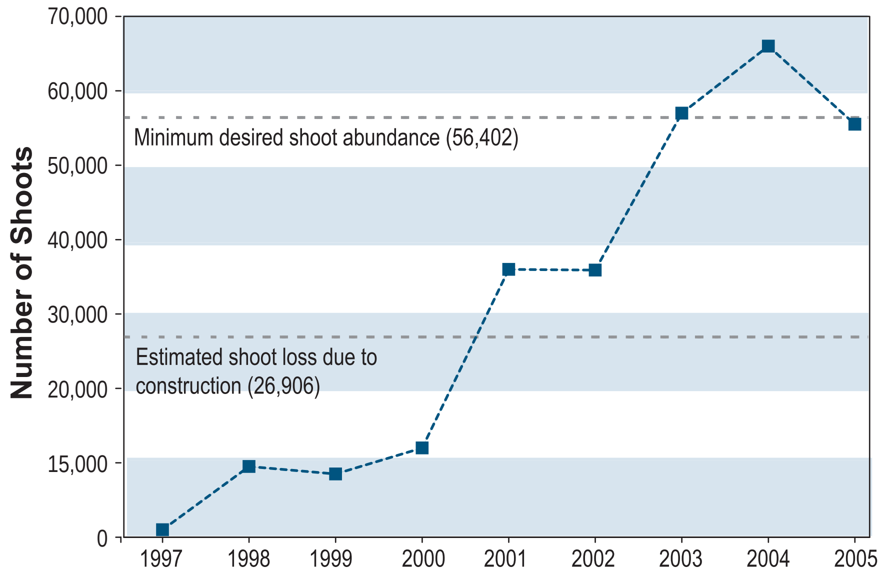
The impact of derelict nets on marine habitat is significant. Rocky reef habitat is particularly susceptible to net entanglement, making the habitat unusable by species that typically inhabit these areas. Derelict nets, sometimes four to six layers deep, inhibit access to critical habitat and trap fine sediments that can suffocate the sedentary life of valuable rocky reef habitat, substantially degrading the habitat's natural function.

Lost and abandoned fishing gear is also a hazard to humans. It can entangle divers and swimmers, with the threat to divers being especially great. Derelict fishing gear also damages propellers and rudders of recreational, commercial, and military vessels, as well as cruise ships, putting crews and passengers in danger. Derelict fishing gear has been known to entangle and overturn small boats and is a navigational hazard for all vessels.

c. Eelgrass Restoration in Puget Sound

The restoration of eelgrass in Puget Sound has received growing attention since the late 1980s. Researchers from Battelle's Marine Research Laboratory in Sequim have been working on eelgrass restoration for several years. It is difficult to predict the precise outcome of eelgrass restoration projects. However, based on field studies at the Clinton ferry terminal, Holmes Harbor, Grays Harbor, and several other locations in the Pacific Northwest, researchers in Sequim have developed an adaptive management framework (Thom et al. 2005) that provides an improved understanding of light, substrata, nutrients, temperature, wave energies, currents, grazing, and other factors that control the development of eelgrass. By understanding these factors, sites for future restoration can be evaluated.

Figure 3-27. Eelgrass density following transplant, 1997-2005. The total number of eelgrass shoots that developed from the transplanting project has resulted in a net gain in eelgrass near the Clinton ferry terminal. To offset the unavoidable loss of approximately 26,000 shoots by construction of the new terminal, restoration efforts reinstated approximately 60,000 replacement shoots. After completion of construction in 2001, eelgrass shoot abundance exceeded pre-construction numbers.
(Source: PNNL)



Status and Trends

Five years of monitoring eelgrass restoration following initial planting at the Clinton ferry terminal revealed several interesting factors about eelgrass restoration. For example, the shoot density one year after planting is a good indicator of the possible density five years after planting (Figure 3-27).

d. Marine Reserves and Conservation Tools

Brackett's Landing Shoreline Sanctuary is a 22-acre underwater park located near the ferry terminal in Edmonds. Established in 1970, it is part of the network of reserves being developed by WDFW to manage rockfish and other rocky habitat species. The reserve is one of the most popular dive sites in Puget Sound and contains human-made trails consisting of concrete blocks, ropes, and other artificial objects to attract fish and other marine organisms. Large anemones cover much of the artificial structures. Many marine mammals, such as harbor seals, sea lions, seabirds, and diving ducks may be found at the site.

Several times each year, WDFW scientists in scuba gear conduct visual surveys to assess fish populations within the reserve. Fish species are identified, counted, and measured along permanent transect corridors within the reserve. These observations provide parameters such as fish density, size distributions, and population sizes that can be compared with similar surveys conducted at nearby areas open to fishing.

The Edmonds site has become an important reference area at which to study the effects of harvest closures on fish populations. Research conducted at the site has indicated that a 30-year absence of harvesting has resulted in dramatically increased fish density, individual sizes, and reproductive outputs, compared with these features at other fished sites. The largest lingcod to be caught in Puget Sound was landed at this site. Healthy beds of eelgrass separate the intertidal and subtidal areas, and bladed kelps and sea lettuce are found on site. Species of fish that are found in the reserve are listed in Table 3-3.

Common Name	Scientific Name
Copper rockfish	Sebastes caurinus
Quillback rockfish	Sebastes maliger
Lingcod	Ophiodon elongatus
Cabezon	Scorpaenichthys marmoratus
Kelp greenling	Hexagrammos decagrammus
Painted greenling	Oxylebius pictus
Black rockfish	Sebastes melanops
Pipefish	Sygnathus leptorhynchus
Juvenile codfish	Gadus macrocephalus
Surf perch	Embiotocidae spp.
Shiner perch	Cymatogaster aggregata

Table 3-3. Fish species in Edmonds underwater park. Includes several rock fish and nearshore species. (Source: WDFW)

11. Recommendations

In the *2002 Puget Sound Update*, recommendations were provided, based on the results from the studies reported. Progress made on the recommendations for physical environment and habitat are briefly summarized in the following table:

Recommendation from the 2002 Update Report for Toxic Contaminants	Progress made through 2006 on recommendations in the 2002 Update Report
Resource managers and planners should investigate opportunities to integrate the developing understanding of climate cycles into ecosystem-based management of the region's habitats and species.	The Climate Impacts Group (under contract to PSAT) summarized research and monitoring findings on impacts of climate change to Puget Sound ecosystems and species. This document can help serve as a launching point for incorporating climate information into management and planning.
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 singe-family residences, to ensure patterns of modification are balanced with the protection of Puget Sound.	Recent updates to the guidance for Shoreline Master programs by Department of Ecology call for a precautionary approach to shoreline armoring including the use of buffers and setbacks where feasible and a preference for softer alternatives to bulkheads and other armoring. The Puget Sound Action Team released a report in September 2006 on evaluating the effectiveness of several of these alternative shoreline treatment technologies.
Scientists need to better understand the role of groundwater in Puget Sound's freshwater budget.	No progress to report.

Moving forward on Puget Sound Science

In looking ahead to what recommendations to report on in future editions of the *Puget Sound Update,* it makes sense to focus on the goals and strategies that have been recommended in *2006 The Puget Sound Partnership Final Report*, the PSAT *2007-2009 Conservation and Recovery Plan for Puget Sound* and the 2006 PSAMP Review. Collectively, these three sources provide targets and goals developed and supported by a large scientific community and reflect both short-term (two year) and long-term considerations for protecting and restoring Puget Sound's health.

The following bullets summarize the goals and strategies put forth in by the Puget Sound Partnership, PSAT and PSAMP that are related to physical environment and habitat (Chapter 3 of this report). Progress towards these goals and strategies will be reviewed in the next edition of the *Puget Sound Update*.

Puget Sound Partnership Final Report (from Appendix A):

Goal: Puget Sound Habitat is protected and restored.

- The amount, quality, and location of marine, nearshore, freshwater, and upland habitats sustain the diverse species and food webs of Puget Sound lands and waters.
- The amount, quality, and location of marine, nearshore, freshwater, and upland habitats are formed and maintained by natural processes and human stewardship so that ecosystem functions are sustained.

2007-2009 Conservation and Recovery Plan for Puget Sound

Priority 5: Protect functioning marine and freshwater habitats.

Strategies:

- Preserve functioning habitats through a variety of conservation tools.
- Help effectively update and implement regulations that protect functioning marine and freshwater habitats.
- Integrate and implement local watershed, salmon recovery, and other plans through regulatory and voluntary approaches.
- Prevent the introduction of new aquatic nuisance species in Puget Sound through regulatory and volunteer approaches.
- Develop a network of sustainable resources to support Soundwide landowner education and stewardship.
- Identify and fill information needs to monitor and improve the effectiveness of protection strategies.

Priority 6: Restore degraded marine and freshwater habitats.

Strategies:

- Restore degraded habitats by restoring habitat-forming processes.
- Plan and undertake large-scale nearshore restoration initiatives through Puget Sound Nearshore Partnership.
- Improve restoration projects by applying the best scientific principles and a process-based approach.
- Improve and streamline permitting for restoration projects.
- Control and stop aquatic nuisance species from spreading and rapidly and effectively respond when **any new species are detected.**

The Role of Science

Strategies:

- Continue ongoing monitoring of the status and trends of key components of the Puget Sound ecosystem.
- Provide scientific information to stakeholders, decision-makers and the public.

- Direct new monitoring to focus on the effectiveness of management activities and policy initiatives.
- Develop a roadmap to prioritize, finance and conduct focused research on emerging topics or research questions that are brought forth through PSAMP and science programs.

Detailed recommendations for further research and monitoring

The following recommendations are an outcome of the 2005-2006 PSAMP review and have been included as recommended actions in the *2007-2009 Puget Sound Conservation and Recovery Plan*. Progress towards these and previous recommendations will be reported in the next edition of the *Puget Sound Update*.

Habitat Characterization

- Map nearshore and subtidal marine habitats so that the amount, distribution, and linkages of habitats can be completely identified. Create a coordinated habitat research team that systematically researches and evaluates scientific habitat studies.
- Inventory and map all Puget Sound marine and nearshore habitats with multibeam sonar and LIDAR.
- Integrate WDFW Hydraulic Project Approval actions with nearshore inventories to monitor changes to the nearshore and to watersheds.
- Improve the science of habitat restoration by developing a systematic framework to map restored habitat and monitor how well restoration mimics natural habitat function.
- Determine the effects of derelict fishing gear on habitats, species, and productivity and monitor amount of derelict fishing gear recovered.
- Track sea-level changes.
- Inventory and measure input of nutrients and other contaminants.

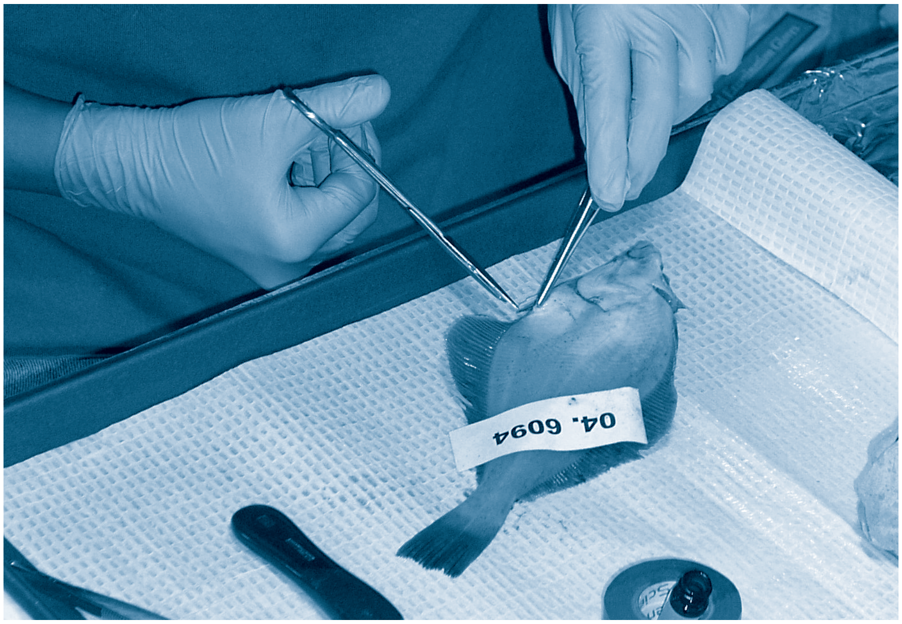
Management of resources

- Use a science-based approach to set goals for habitat abundance and distribution needed to support target species assemblages and productivity.
- Track the amount of areas open to various types of fishing activities.
- Monitor effectiveness of individual restoration projects with restoration efforts that plan for and fund validation and effectiveness monitoring.
- Monitor sediment quality at appropriate spatial scales for informing management actions and tracking the success of cleanup efforts.
- Monitor and assess water quality changes at restoration sites in addition to structural habitat parameters.
- Monitor the amount of nearshore and deepwater habitat disrupted by human activities including filling, dredging, dumping, armoring, and the effects on habitat processes.
- Better integrate mapping and scientific studies with agency management processes.

Processes and function

- Improve the understanding of nearshore ecosystem processes and linkages to watershed and marine ecosystem functions, human health, and species at risk.
- Improve the understanding of and ability to predict the incremental and cumulative effects of restoration and preservations actions on nearshore ecosystems.
- Improve the understanding of the relationships of nearshore processes to important ecosystem functions, such as support of human health and at-risk species.
- Further develop circulation modeling capabilities.

4 Toxic Contamination



A scientist studies an English sole from Elliott Bay. | *Sarah Brace*

1. Overview

In the past 150 years, people have released a wide variety of chemicals into Puget Sound and watersheds, many of which are toxic to humans, animals, and plants. While contamination by a number of toxics, such as lead, polychlorinated biphenyls (PCBs), and dioxins, has been reduced by use restrictions, other chemicals continue to be used and many enter into Puget Sound through stormwater runoff, wastewater discharges, and nonpoint sources, adding to a legacy of contamination.

Puget Sound is unique among North American estuaries, because of its geologically young, deep, narrow, fjord-like structure. Several shallow sills restrict the entry of deep oceanic water into Puget Sound, which reduces flushing of these inland marine and estuarine waters compared to the other urbanized estuaries of North America. Thus, toxic chemicals that enter Puget Sound remain longer within the system, and the trapping of toxics means that biota are subject to increased exposure. This hydrologic isolation also puts Puget Sound at higher risk from nutrients and pathogens that may enter the system.

The combination of hydrologic isolation with the persistent (resisting degradation) and bioaccumulative (increasing within in organisms over time) nature of many chemical contaminants creates additional risk for the Puget Sound ecosystem. For example, chinook salmon that remain as residents in Puget Sound (both as a result of natural tendencies and hatchery practices), rather than migrate to the ocean, are several times more contaminated than other chinook populations along the West Coast. Another disturbing indication of this is found in Pacific herring, one of Puget Sound's keystone forage fish species. These fish live almost all of their lives in pelagic waters, so one might suspect they would be among the least contaminated of fish species. However, PSAMP scientists have shown high body burdens of PCBs in this species from the central and Southern basins of Puget Sound—comparable to herring from northern Europe's severely contaminated Baltic Sea.

Table 4-1. Chemicals of concern in Puget Sound.
(Source: PSAT)

Metals (and organometals)	Organic compounds
Arsenic	Polychlorinated biphenyls (PCBs)
Cadmium	Polycyclic aromatic hydrocarbons (PAHs)
Copper	Pesticides
Lead	Dioxins and furans
Mercury	Phthalate esters
Tributyl tin	Polybrominated diphenyl ethers (PBDEs)
	Hormone-disrupting chemicals – including bisphenol A, nonylphenol, 17b-estradiol, and ethynylestradiol

The toxic contaminants that harm or threaten the health of the Puget Sound ecosystem include chemicals designed and synthesized to meet industrial needs, agricultural products such as pesticides, byproducts of manufacturing or the combustion of fuel, fossil fuels, and naturally occurring toxic elements that may become unusually highly concentrated in the environment because of human uses or other activities. Table 4-1 lists chemicals currently of highest concern in Puget Sound. Release of these chemicals to the environment can occur through designed and controlled human actions (e.g., application of pesticides or the discharge of wastes through outfall pipes, smokestacks, and exhaust pipes) or as unintended consequences of human activities (e.g., oil and chemical spills, leaching from landfills, and runoff of chemicals from the deterioration or wear of roofs, pavement, and tires).

Key findings reported in this chapter include:

- Approximately one percent of Puget Sound sediments are highly degraded, 31 percent are of intermediate quality, and 68 percent are of high quality. The **degraded sediments** (as measured by toxicity, chemistry, and benthic infauna) are mainly associated with urban embayments that are often located near river deltas and other highly productive nearshore habitat of importance to Puget Sound species.
- Chinook salmon from Puget Sound have nearly three to five times the **PCB** levels of chinook from Alaska, British Columbia, and Oregon.
- Flame retardants, or **polybrominated diphenyl ethers** (PBDEs) occurred in 17 percent of sediment sites sampled in Hood Canal in 2004 and were detected in 16 percent of samples from 10 Puget Soundwide sediment sampling sites in 2005.
- **PBDEs** are now second to PCBs in order of importance in the Puget Sound food web. PBDEs in English sole from urban areas are almost 10 times higher than those levels measured in sole from the Georgia Basin. Herring from Puget Sound have nearly three times the levels of PBDEs in Georgia Basin herring. Harbor seals from Puget Sound have over twice the PBDEs found in seals near Vancouver, BC. Scientists estimate that PBDE levels are doubling every four years in marine mammals, including harbor seals and orcas, and will surpass PCB levels in these species by 2020.
- In Puget Sound sediments, polycyclic aromatic hydrocarbons (**PAHs)** have not changed significantly over the past decade, except in Bellingham Bay, Port Gardner, and Anderson Island, where levels have increased. Point Pully (in central Puget Sound) had a significant decrease in PAHs during this same period.

- In Dungeness crab, **PAH** exposure was six times higher in urban areas than in non-urban areas. English sole had three to four times the PAH exposure in urban areas, compared to non-urban areas.
- English sole from Elliott Bay and the Thea Foss Waterway had four to six times the risk of developing liver lesions, (typically associated with **PAH** exposure), compared to sole from Hood Canal or the Strait of Georgia.
- Six **endocrine-distrupting compounds** (bisphenol A, estradiol, ethynylestradiol, and three phthalates) were detected in more than 20 percent of surface-water samples collected in King County's lakes, rivers, streams, and stormwater discharges.
- Male English sole from several Puget Sound locations (including 30 percent of males from Elliott Bay) are producing an egg-protein (vitellogenin) normally found only in female fish. This finding suggests that these fish have been exposed to **endocrine-disrupting compounds**.
- **Pre-spawn mortality** occurred in 25 to 90 percent of female coho salmon returning to urban streams in the Puget Sound region between 2002 and 2005, suggesting that contaminants from stormwater are posing a threat to the spawning success of salmon in urban streams.

Pathways of Toxics into Puget Sound

Toxic chemicals can be introduced into Puget Sound through:

- Discharges of wastewater and stormwater through outfalls.
- Nonpoint runoff and groundwater discharges to surface waters.
- Spills.
- Atmospheric deposition.
- Release of by-products from other contaminants that break down or change in the environment over time.
- Import of contaminants through biological migrations.
- Re-suspension, re-circulation, and bioaccumulation of contaminants into other organisms or other parts of the ecosystem.

2. Sediment Quality in Puget Sound

Chemical contaminants from industrial and municipal point sources, stormwater runoff, and atmospheric deposition in the Puget Sound watershed are generally discharged, flow, or fall into the nearest water body. Ultimately, most make their way to Puget Sound. Those that are not water-soluble typically bind to silt and clay particles in the water and settle to the bottom. Bottom sediments in Puget Sound are final repositories for many chemical contaminants and serve as records of what is being (or has been) released into the environment.

a. Sediment Monitoring

Some contaminants have physical and chemical properties that bind them tightly to the sediments, and they become biologically unavailable to organisms that contact them. Many remain bioavailable and, whenever organisms live in or ingest contaminated sediments, they can be directly harmed or, indirectly, can accumulate these chemicals in their tissues and transfer them to other animals in the food web.

Collection and analysis of Puget Sound sediments have been conducted over many years to reveal the identities and quantities of contaminants that have been released into the environment and have accumulated in various locations. Sediment analyses also measure the harm chemical contaminants may cause to the estuarine organisms that live in or on them.

Assessing the condition of Puget Sound's sediments

The Sediment Quality Triad Index was developed as a weight-of-evidence approach that combines the results of the sediment chemistry, toxicity, and benthic invertebrate analyses generated in this study to classify the overall quality of the sediment samples. Four categories of sediment quality were generated to define each station and, ultimately, each sediment monitoring region and strata of the study. They are:

High Quality: No degradation detected in any of three test parameters.

Intermediate/High Quality: Degradation detected in one of three test parameters.

Intermediate/Degraded Quality: Degradation detected in two of three test parameters.

Degraded Quality: Degradation detected in all three test parameters.

Status and Trends

Ecology developed estimates of degraded sediments in Puget Sound from 1997 to 1999[1] (Long, et al. 2003, 2005). These estimates indicated that approximately one percent of Puget Sound sediments are degraded, 31 percent are of intermediate quality, and 68 percent are of high quality. Recent sediment quality data was collected in 2002 and 2003 from 81 new stations in three additional Puget Sound regions, including the San Juan Archipelago, the eastern Strait of Juan de Fuca, and Admiralty Inlet (Long, et al. in prep.). Data on chemistry, toxicity, and benthic infaunal community structure from all 381 stations were used in a Sediment Quality Triad Index to identify spatial (geographic) patterns and spatial extent of degraded sediment quality in eight monitoring regions, five strata (such as harbors and bays) and for the entire Puget Sound study area. These data complete the sediment quality baseline for Puget Sound, spanning from 1997 through 2003.

Sediment monitoring regions were defined by their hydrologic, bathymetric, and geological features, as well as by the distribution of biota and differences in the degree of sediment quality in these regions (Figure 4-1). The majority of stations and the highest percent of the area from the Strait of Georgia, Whidbey Basin, Admiralty Inlet, Hood Canal, and South Sound regions were of high quality. Samples classified as degraded were collected in the Whidbey Basin, central Sound, Hood Canal, and south Sound regions, representing 0.2 percent, 2.3 percent, 0.9 percent, and 0.1 percent, respectively, of the area within each region. Degraded sediments in these four regions were identified primarily from Everett Harbor, Elliott and Commencement bays, Port Gamble, Port Ludlow, and Budd Inlet. The largest percentages of stations and areas with intermediate sediment quality were found in the San Juan Archipelago, Strait of Juan de Fuca, central Puget Sound, and south Puget Sound regions.

Sediment monitoring strata—harbor, urban, basin, passage, and rural—are defined by their major geographic features and degree of anthropogenic activity (Long et al. 2003). The strata also differed dramatically in their degrees of sediment quality (Figures 4-2: Basins, Harbors, Passages, Rural and Urban). The largest percentages of stations (47 percent) and areas (14 percent) with degraded sediment quality were found in the harbor stratum, while five percent of the stations and four percent of the area were degraded in the urban strata. Intermediate sediment quality was also most pervasive in harbors, followed by urban strata. Highest sediment quality was measured in passage, basin, and rural strata.

When calculated for the whole 1997-2003 Puget Sound baseline study area, the Sediment Quality Triad Index indicated that sediments from approximately 7 $miles^2$ (19 km^2), or 0.8 percent of the study area, were degraded (Table 4-2, page 138). Sediments with intermediate quality were distributed over 318 $miles^2$ (826 km^2), or about 35 percent of the area. High-quality sediments were found in 596 $miles^2$ (1543 km^2) representing 65 percent of the study area.

Impacts to the Ecosystem

The health of Puget Sound may be negatively affected by even a small proportion (0.8 percent) of degraded sediments. The areas classified as degraded are located in and around the urban/industrial embayments of the Sound, primarily in river deltas known to be critical nearshore habitat for many species. Most of the Puget Sound species identified as endangered or threatened rely on the nearshore habitat and their declines may be, in part, related to degraded sediments.

[1] For PSAMP and NOAA's National Status and Trends Program.

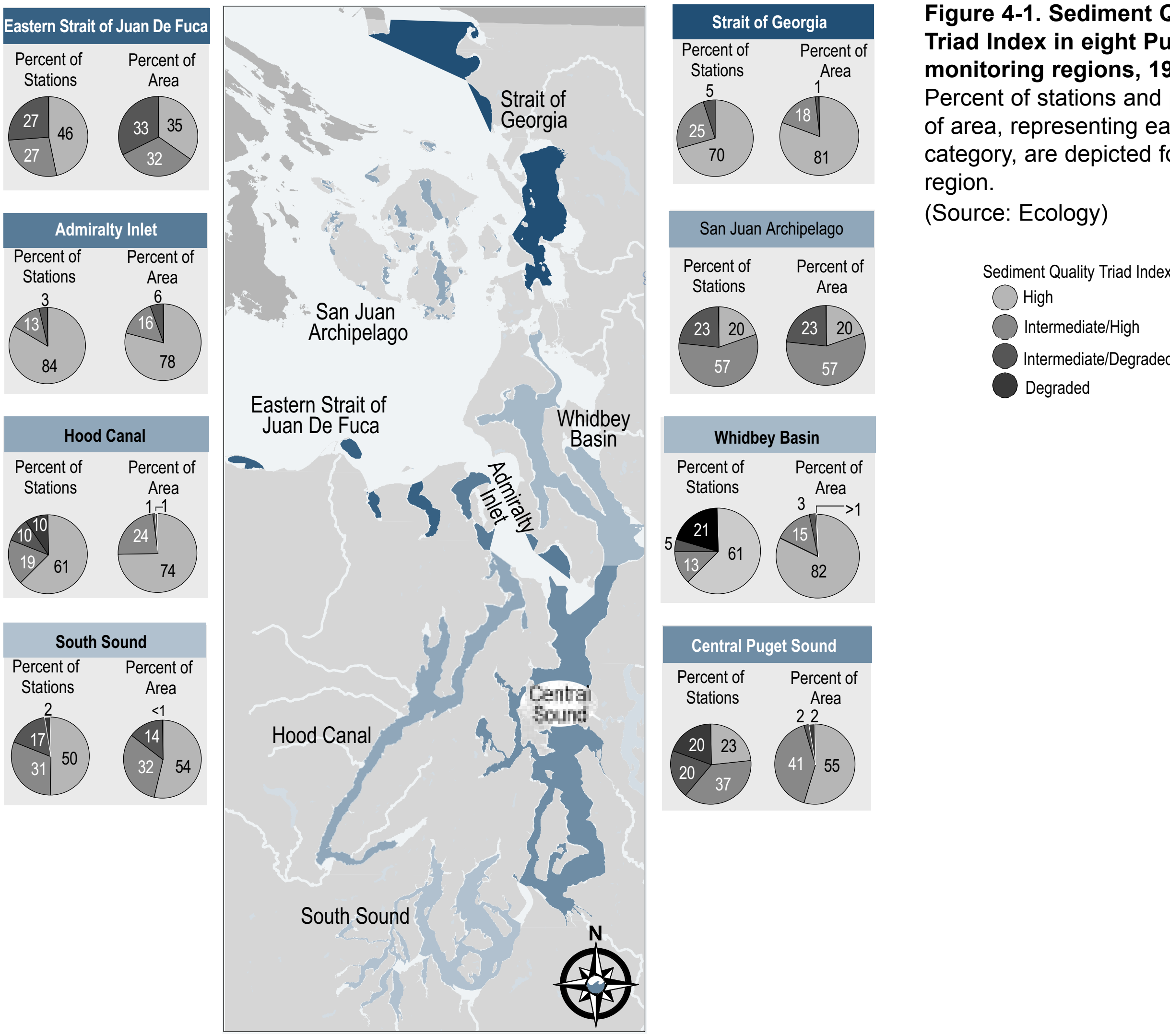
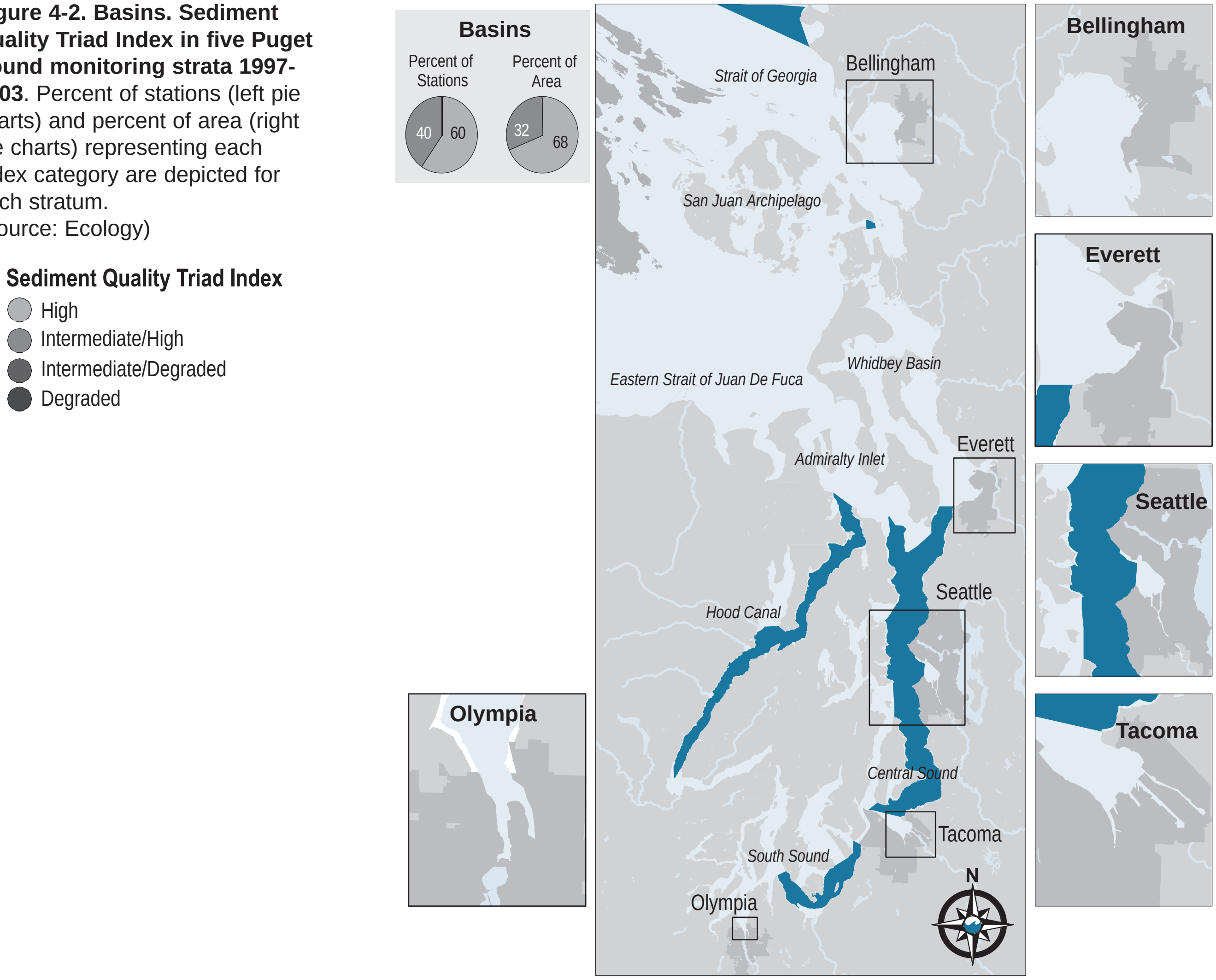


Figure 4-1. Sediment Quality Triad Index in eight Puget Sound monitoring regions, 1997-2003. Percent of stations and percent of area, representing each index category, are depicted for each region. (Source: Ecology)

High levels of toxic chemicals are present or are linked to health impairment in organisms that reside in, or whose food resources are tied to, the more urban and industrialized embayments of central and southern Puget Sound (PSAT 2002, 2004). Examples include high levels of PAHs and/or PCBs measured in the bodies of shellfish (Dungeness crab), fish (English sole, demersal rockfish, coho salmon, and Pacific herring), birds (bald eagle eggs collected from Hood Canal), and marine mammals (southern Puget Sound harbor seals and southern resident orca whales), all associated with the more highly contaminated Central and Southern Puget Sound basins. Different populations of many of these species residing in northern Puget Sound and the Strait of Georgia or feeding on prey from these cleaner locales had lower contaminant levels in their tissues.

In addition to focused attention on the 0.8 percent of the study area with degraded sediments, there is a sizeable area (34.6 percent) classified with intermediate quality sediments. Intermediate quality sediments may work together with other environmental stressors such as low dissolved oxygen levels and climate change to further negatively impact Puget Sound. Future attention and monitoring must occur in these areas to determine whether sediment conditions improve, remain stable, or deteriorate further.

Figure 4-2. Basins. Sediment Quality Triad Index in five Puget Sound monitoring strata 1997-2003. Percent of stations (left pie charts) and percent of area (right pie charts) representing each index category are depicted for each stratum.
(Source: Ecology)



Human Health Consequences

As a natural resource, Puget Sound depends on high-quality sediments to maintain a viable ecosystem and economy. Toxic chemicals in sediments are a major concern, because the trophic web of Puget Sound is detritus-based (Kennish 1997). Animals that live in or on contaminated sediments may absorb the toxic chemicals and distribute them throughout the food web.

Human health risks occur primarily through consumption of fish and shellfish that have bioaccumulated contaminants. DOH and local health districts around the Sound have issued fish and shellfish consumptions advisories that warn people not to eat contaminated seafood (PSAT 2004). These advisories have been made primarily in the Whidbey Basin and Central Puget Sound, two regions identified by PSAMP with some of the largest percentages of degraded sediments. Possible health concerns from exposure to contaminants may include effects on neurological, reproductive, and immune systems, as well as cancer.

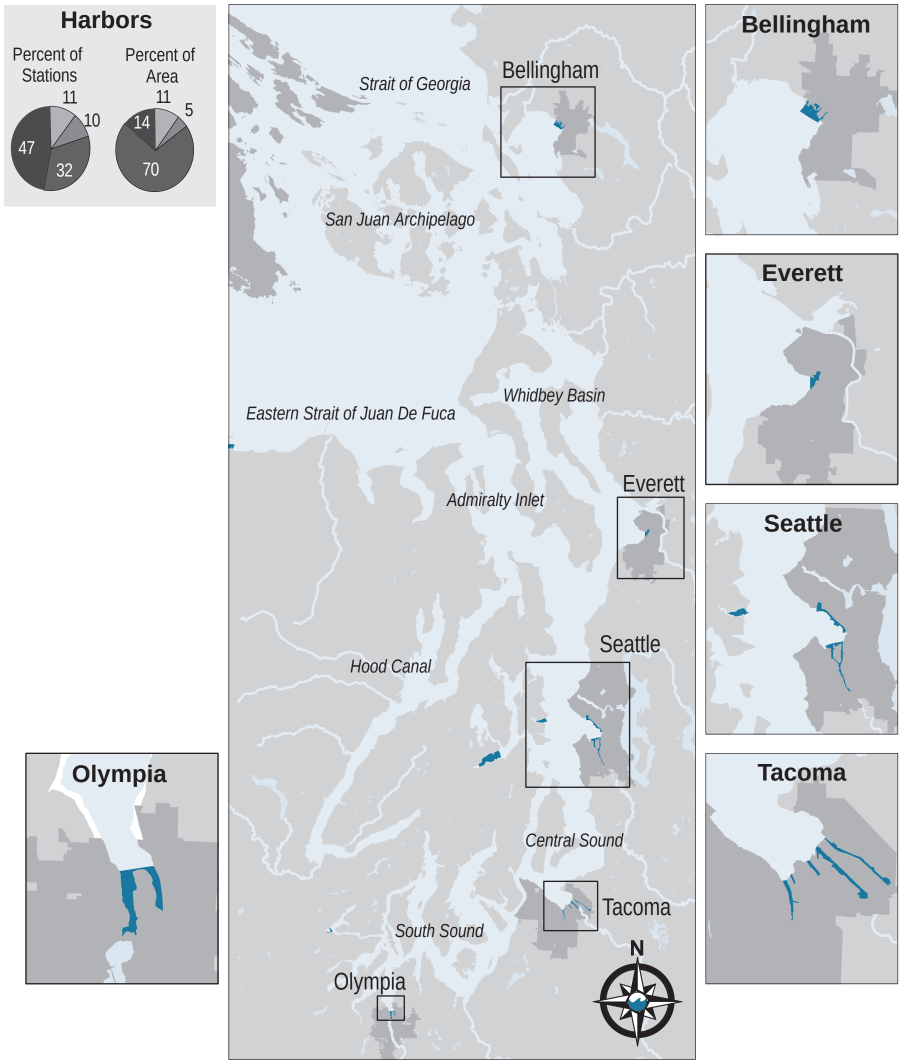
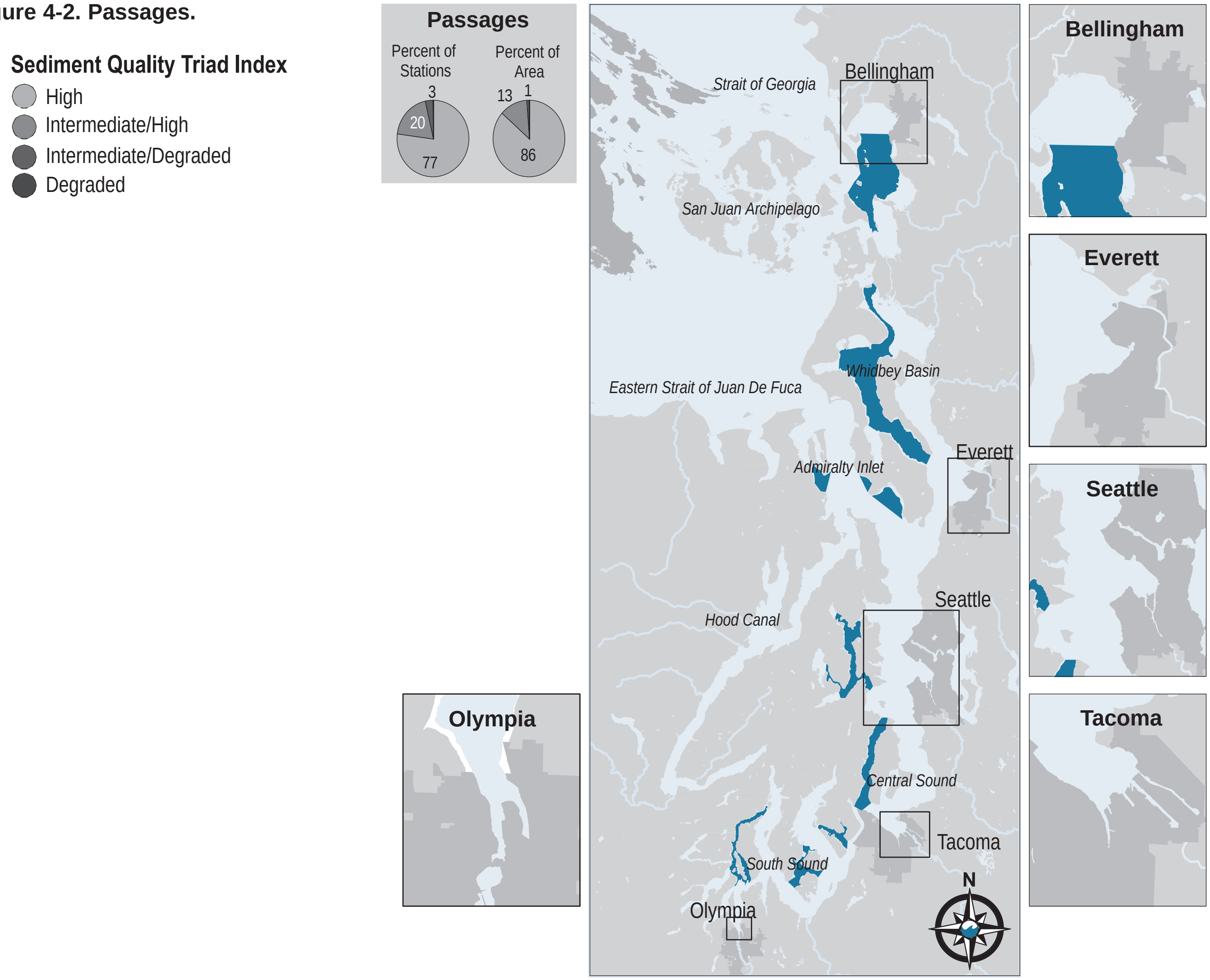


Figure 4-2. Harbors.

Sediment Quality Triad Index

- High
- Intermediate/High
- Intermediate/Degraded
- Degraded

Figure 4-2. Passages.



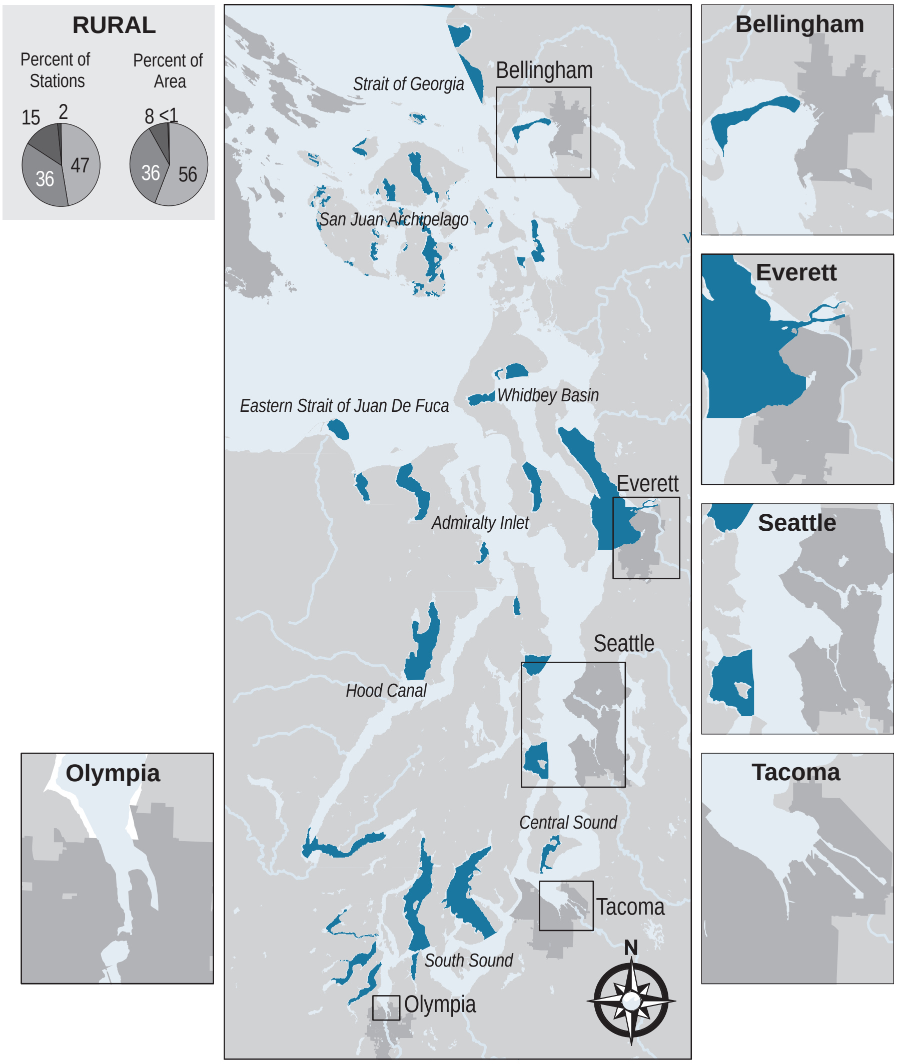


Figure 4-2. Rural.

Sediment Quality Triad Index

- High
- Intermediate/High
- Intermediate/Degraded
- Degraded

Figure 4-2. Urban.

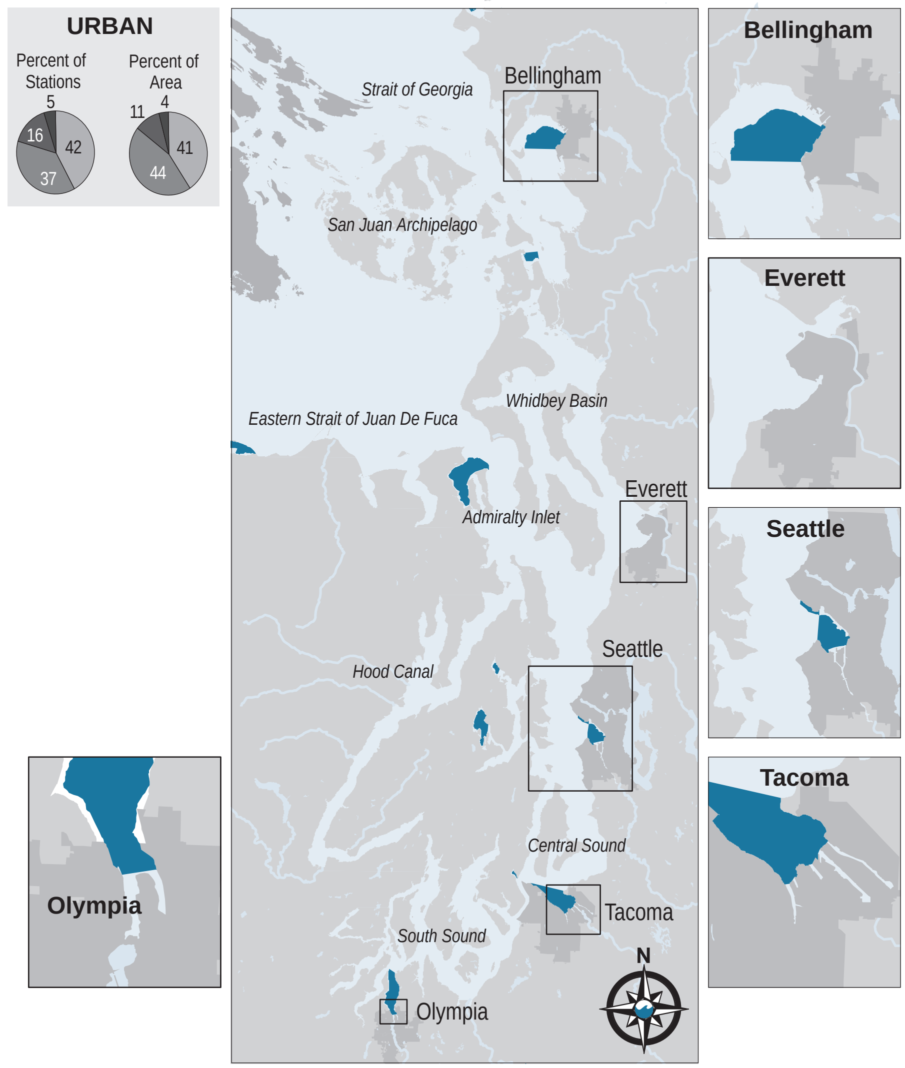


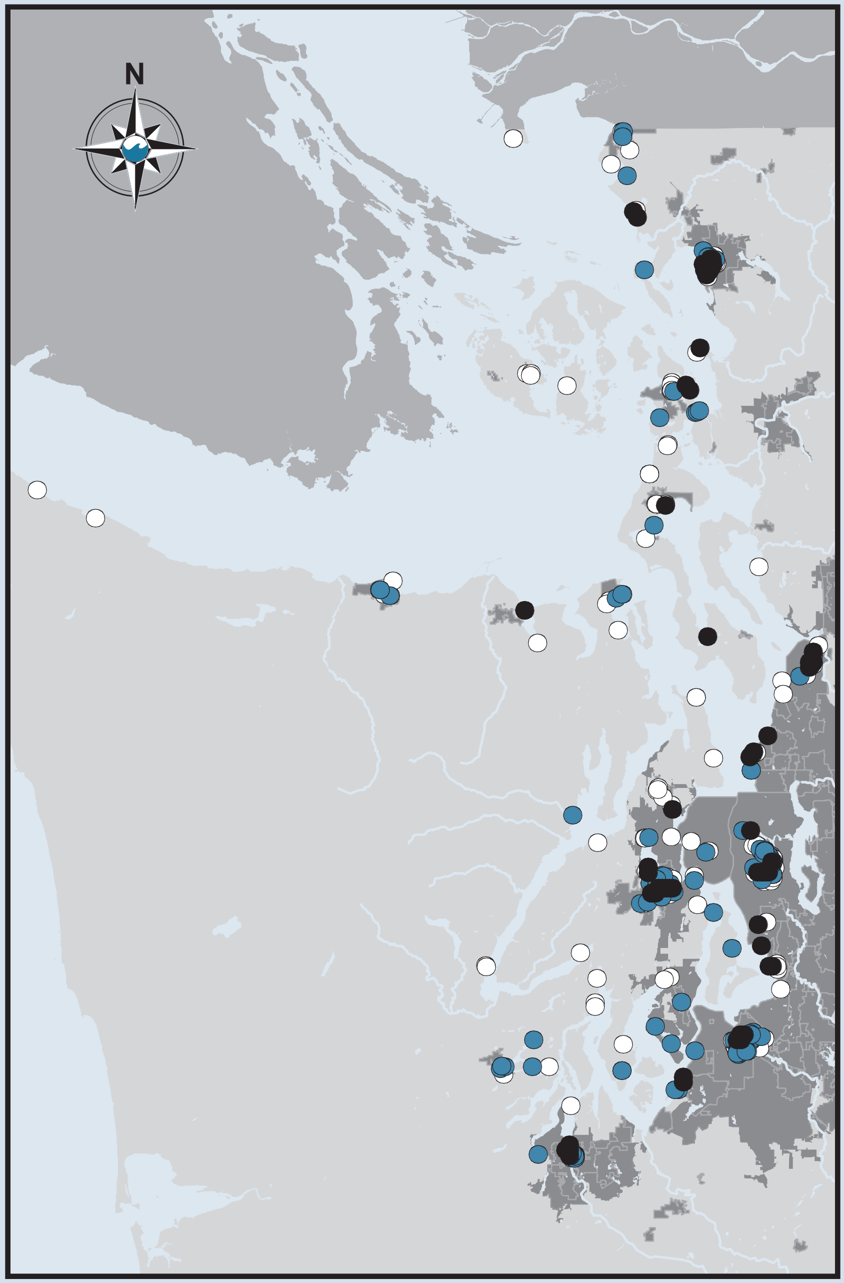
Table 4-2. Sediment Quality Triad Index in the entire Puget Sound study area, 1997-2003. The index rates sites based on chemistry, toxicity, and benthic infauna community structure. (Source: Ecology)

Sediment Quality Index Category	Stations		Area	
	No.	percent	mile²/km²	percent
Total Study area	381	100.0	1481/2389	100.0
High	176	46.2	959/1543	64.6
Intermediate/High	114	29.9	429/692	29.0
Intermediate/Degraded	55	14.4	84/134	5.6
Degraded	36	9.4	12/19	0.8

Superfund and Other Contaminated Sediment Site Cleanup Efforts in Puget Sound

EPA's Superfund program has been investigating and cleaning up contaminated Puget Sound sediments since 1980. A total of 3.85 million cubic yards of contaminated sediments have been dredged and 206 acres capped at six Puget Sound Superfund sites, with more sites under investigation (Figure 4-3). Contaminants addressed in these cleanups include PCBs, PAHs, other organic contaminants, and metals.

Additionally, Ecology's Toxic Cleanup Program is currently commencing work to clean up sediment contamination at smaller sites outside major urban areas. Target sites will be chosen, based on each site's relative ecological sensitivity and importance (for instance, whether the site provides habitat for juvenile fish and invertebrates). The first site chosen for cleanup is an area of wood-waste contamination in Port Gamble (C. Asher, Ecology's Toxic Cleanup Program, pers. comm.). Cleanup and monitoring are scheduled to occur through 2007.



● Impaired marine sediment sites

Impaired marine sediment sites are based on Ecology's 303(d) impaired sediment listings (categories 4a and 4b)

Puget Sound state and federal upland cleanup sites

- State cleanup sites waiting remedial action. (115 sites)
- State and federal sites withremedial action in progress. (553 state and federal sites)

Ecology defines a Puget Sound contaminated upland sediment site as any site within 1/2 mile of the Puget Sound shoreline.

Puget Sound Urban Areas

Figure 4-3. Current contaminated sites in Puget Sound region (through mid-2006). Impaired marine sediment sites are locations where in-water sediments have been tested and found to have toxic pollutants that exceed state standards. Locations marked in blue are awaiting clean up. Those marked in white have clean up in progress.
(Source: Ecology)

Benthic, demersal, pelagic —what's the difference?

Benthic organisms, such as tube worms, sculpins, and sole, spend most of their lives living on or in the sediments of the seafloor.

Demersal organisms, such as rockfish and Pacific cod, are associated with the seafloor.

Pelagic organisms, such as herring and salmon, dwell in open waters, rarely making contact with the seafloor.

3. Persistent Bioaccumulative Toxics in the Food Web

Persistent bioaccumulative toxics (PBTs) are chemicals that persist in the environment because they resist degradation from environmental or metabolic processes. They also accumulate in tissues or fat of animals and humans and are only slowly metabolized, so that, over time, their concentrations increase in individuals. Many of these contaminants also increase (bio-magnify) as they move throughout the food web.

Most of Washington's urban and industrial centers, and the majority of its population, are located along Puget Sound's shoreline. These centers represent ongoing and historical sources of toxic contaminants, including PBTs, that are deposited into the Puget Sound estuary by natural transport and sedimentation processes. Most of the contaminants that enter the Sound are thought to attach to particles and settle out of the water column, to accumulate in bottom sediments. PSAMP has documented that the bottom sediments in urban bays of Puget Sound (and the bottomfish species associated with them) are contaminated with PBTs, and significant efforts are underway to remediate contamination in these bays. However, recent PSAMP studies have shown that Puget Sound's important pelagic species (Pacific herring and salmon) are more contaminated than herring or salmon from the Georgia Basin and other coastal estuaries of the west coast of North America. These new studies have shown that PBTs permeate the Puget Sound food web, not only in its bottom-dwelling species, but in the pelagic component of the food web as well.

Ecology recently adopted a rule (WAC Chapter 333) that identifies PBTs of greatest concern for Washington, establishes criteria for their selection, and outlines preparations for PBT chemical action plans. PCBs and PBDEs are prominent PBT groups in Ecology's rule, and they are also toxics of high prominence in PSAMP's monitoring, along with others such as aldrin/dieldrin, benzo(a)pyrene, chlordane, DDT, dioxins and furans, hexachlorobenzene, mercury, and toxaphene.

Toxic contaminants enter the Puget Sound ecosystem via water (e.g., river or stream inputs, point sources like industrial or wastewater discharges or nonpoint sources like stormwater and other runoff) the atmosphere (transport from both local and distant sources) and in the bodies of migrating organisms (biotransport). Puget Sound's semi-enclosed nature, combined with the depth and current patterns of its basins, entrain water, nutrients, toxic contaminants, and organisms, resulting in a physically and biologically isolated ecosystem that tends to retain introduced chemical contaminants. Fat-bonding, or lipophilic contaminants, such as PCBs and PBDEs, can be taken up and retained by plankton, or attach to particles and settle into the bottom sediments. PBTs retained by plankton are rapidly assimilated into the food web and accumulated by pelagic consumers such as zooplankton, and forage fish and then amplified and recycled throughout the food web to high-level predators like salmon, orcas, birds, and humans.

a. Benthic Food Web

The benthic food web comprises the complex, interrelated predator-prey relationships that exist among the plants, animals, and microbes inhabiting the seafloor. In the soft sediments of Puget Sound, benthic organisms include bacteria, foraminifera, micro- and macroalgae, sedentary species including small, tube-dwelling and burrowing invertebrates, bivalve mollusks (such as clams) that live within the sediments, and larger, mobile surface-dwelling or burrowing invertebrates (e.g., crabs and shrimps), and fishes. Chemicals absorbed by these sediment-dwelling species can accumulate in their bodies and become magnified in the predators that consume them.

Although PBTs may be concentrated in soft sediments, the area, or zone of biological impact of those concentrated PBTs may be much larger, because of the movement patterns and feeding relationships of its occupants. Fish and invertebrate species that live on harder or more consolidated substrates such as cobble or rocky reefs (substrates where PBTs are unlikely to accumulate) often forage, or search for prey, in surrounding soft sediments, where PBTs may accumulate. Conversely, organisms that are exposed to PBTs in the soft sediments can move around and be consumed by organisms in less contaminated areas. This biotransport of PBTs can occur from a very small scale to a hemispheric scales, when migratory fish and bird species pick up PBTs in one part of the world and transport them to another.

i. PBTs in the Sediments

Sediment monitoring by Ecology and NOAA indicates that PCB-contaminated sediments are mainly concentrated in urban and industrialized bays, and the remainder of Puget Sound sediments are relatively uncontaminated (Long et al. 2005). Recent data also indicate that PBDEs are detectable in our urban bays and estuaries, although at lower levels than in other urban estuaries on the West Coast.

Status and Trends

In 2004, Ecology scientists added PBDEs to the list of chemicals measured in sediments collected annually for PSAMP. PBDE levels were measured for five congeners in June 2004 from Hood Canal and 12 congeners in April 2005 from 10 long-term sediment monitoring stations located throughout Puget Sound. Data from these samples will establish a baseline for PBDE concentrations in sediments throughout Puget Sound, from which changes over time can later be determined, and allow comparisons with levels measured nationally and worldwide. Also, comparisons of levels in marine waters and biota can be made to assess the role of these contaminants in both benthic and pelagic food webs.

For the 2004 PSAMP sediment quality survey in Hood Canal, five PBDE congeners (BDE-47, -99, -100, -153, and -154) were measured in sediments from 30 randomly selected stations. These congeners are predominant in commercially available PBDE mixtures, and their levels in the environment have been measured worldwide. Of 180 measured values, 17 percent had detectable levels of PBDE congeners, while 83 percent were below the level of detection. Congener BDE-47 was detected in 17 of 30 samples, congener BDE-99 was detected in 10 of 30 samples, and congeners BDE-100 and -153 were detected in one of 30 samples. Congener BDE-154 was not detected (Figure 4-4). All detected values were qualified as estimates, indicating they were detected in the samples at levels below the laboratory's reporting limits.

Concentrations of a broader suite of PBDEs were measured in sediments collected in April 2005 at 10 PSAMP temporal sediment monitoring stations located throughout Puget Sound. Congeners measured included the five penta-BDE congeners measured in 2004, plus BDE-209 (the primary congener in the commercial deca-BDE mixtures), and BDE-49, -66, -71, -138, -183, and -184. Of 422 measured values, 16 percent of the samples had detectable levels of PBDE congeners, while 83 percent were below the level of detection. As in Hood Canal, congeners BDE-47 and -99 were detected most frequently. Congener BDE-47

PCBs

Polychlorinated biphenyls (PCBs) are synthetic organic molecules characterized by a double phenyl ring surrounded by one to 10 chlorine atoms. There are 209 different individual PCB chemical compounds, called congeners, that differ only in the number and placement of chlorine atoms. PCBs were invented for use in many industries; as electrical and thermal insulators for hydraulic equipment, plasticizers in paints, plastics, and rubber products; in pigments, dyes, and carbonless copy paper; and many other applications. These compounds were designed to resist degradation, which makes them long-lasting for their intended use. Unfortunately, this characteristic makes them persistent in the environment, and the chemical structure of these molecules can be highly toxic. The unintended consequence of releasing PCBs is persistent toxic contamination of aquatic food webs. Prior to cessation of their production in the U.S. and Canada in the 1970s, more than 1.5 billion pounds of PCBs were manufactured in the U.S. alone.

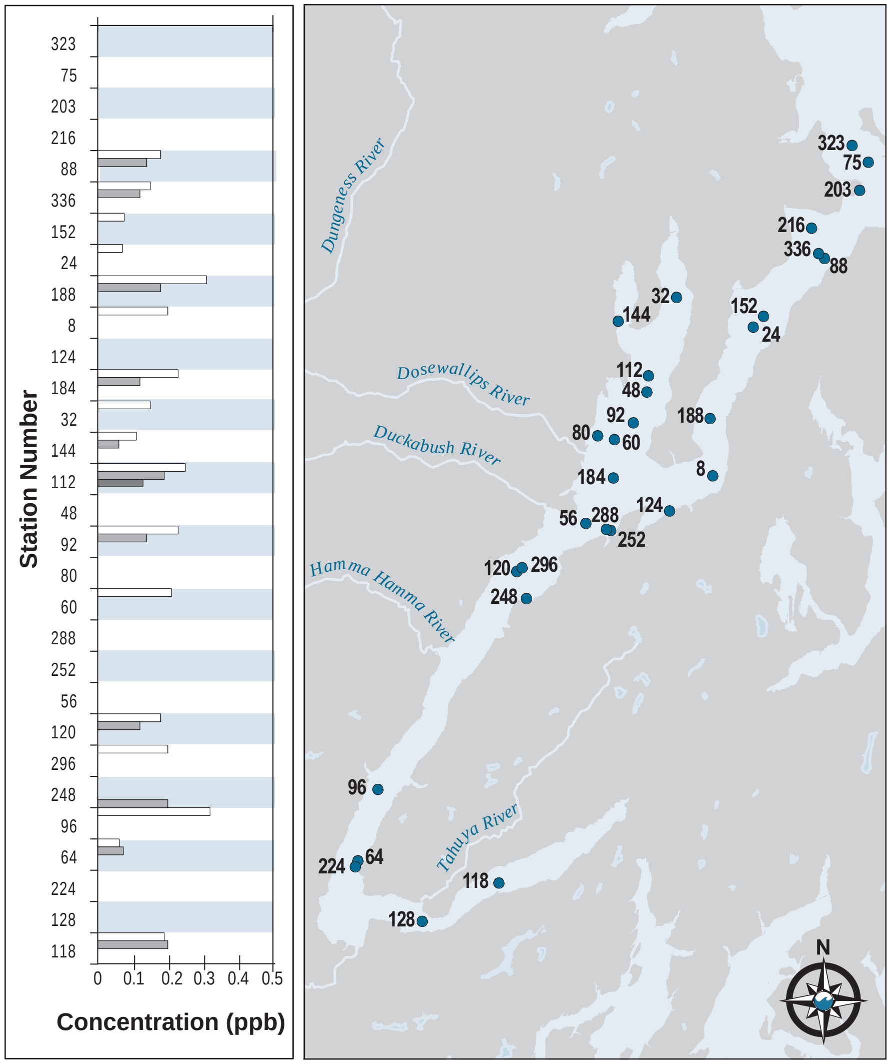
Figure 4-4. Flame retardants (PBDEs) in Hood Canal. In June 2004, sediments from 30 randomly selected stations throughout Hood Canal were sampled for five congeners of PBDEs (BDE-47, -99, -100, -153, and –154). These congeners are predominant in commercially available penta-BDE mixtures, and their levels in the environment have been measured worldwide. Congeners BDE-47 and -99 were detected in 17 and 10 of 30 samples, respectively, and BDE-100 and -153 were each detected in one of 30 samples. Congener BDE-154 was not detected in any of the samples. (Source: Ecology)

PBDE Congener Monitoring

- Monitoring Station

BDE Congeners

- BDE-47
- BDE-99
- BDE-100
- BDE-153



PBDEs

Polybrominated diphenyl ethers (PBDEs) are chemicals that were designed as flame-retardants for common household items, including textiles and electronics. Like PCBs, they are persistent, bioaccumulative, and toxic. PBDEs are similar in structure to PCBs except that they contain bromine instead of chlorine atoms. There are also 209 congeners of PBDEs. In January 2006, Ecology and DOH published a chemical action plan for PBDEs; their recommendations for reducing PBDEs in the environment include educating the public on minimizing exposure to PBDEs, prohibiting the manufacture, distribution, or sale of new products containing penta- and octa-PBDEs, encouraging the legislature to ban deca-PBDEs, working with stakeholders to encourage manufacturers to develop safer, effective alternatives, and ensuring that workers in certain industries are not exposed to unacceptable levels of PBDEs.

at all 10 stations, while BDE-99 was detected at five of the stations, including the deep, depositional Shilshole and Point Pully stations, as well as at the stations near urban and industrial areas, such as Port Gardner, Sinclair Inlet, and the Thea Foss Waterway. Congener BDE-209 was also detected at these five stations and at the station in Budd Inlet. Congener BDE-49 was detected at three of the stations, congener BDE-71 was detected at two of the stations, and BDE-66 and -100 were detected at only one station. Congeners BDE-138, -153, -154, -183, and -184 were not detected in any samples (Figure 4-5).

Comparisons of the Puget Sound sediment PBDE data with data from the San Francisco estuary and various European and Asian marine surveys indicated that congeners BDE-47, -99, and -209 were found in the highest concentrations worldwide. Levels of BDE-209 in Puget Sound were the lowest of all measured, while BDE-47 and -49 were lower only in three of the six other surveys (Figure 4-6).

ii. PBTs in English Sole

English sole are bottom-dwelling flatfish, widely distributed throughout Puget Sound and coastal regions of the northeastern Pacific Ocean. They are closely associated with the bottom sediments, have relatively high site fidelity, and consume benthic invertebrates. English sole is an ideal indicator species because it

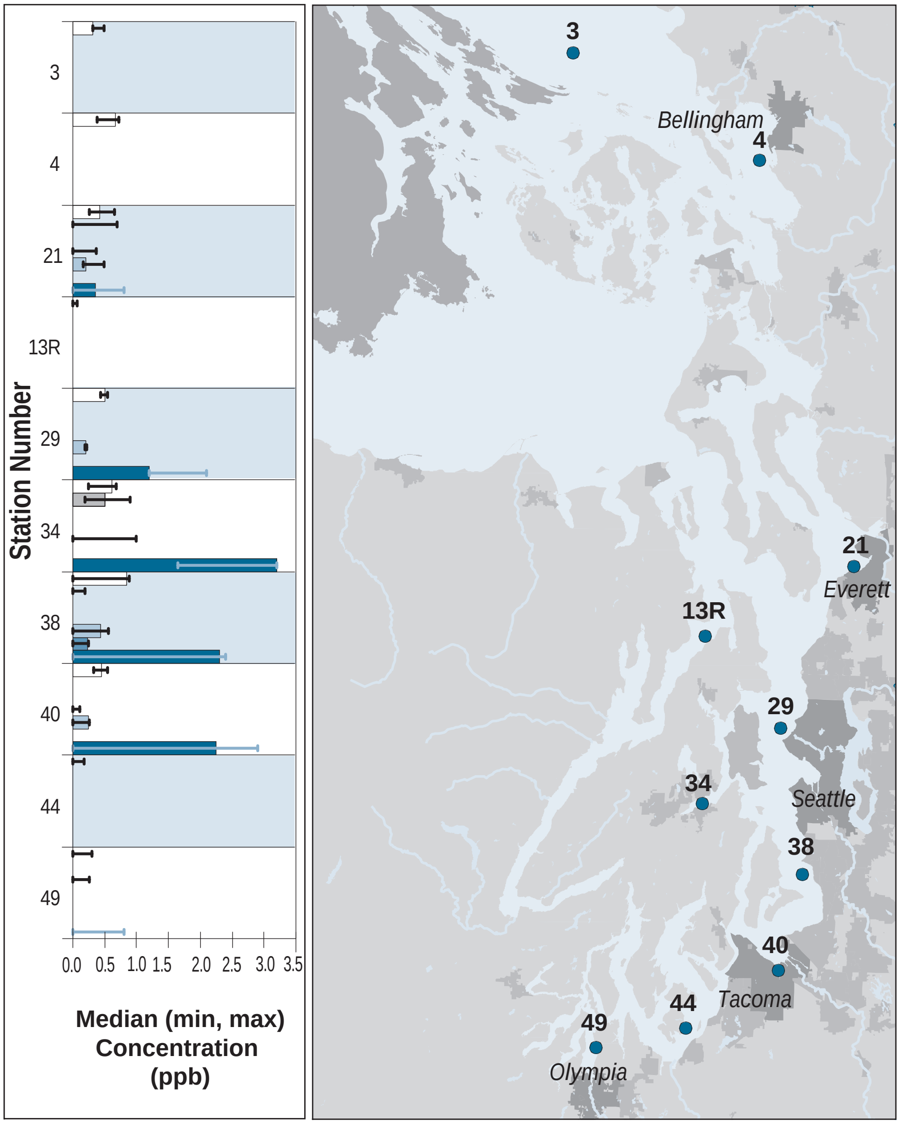
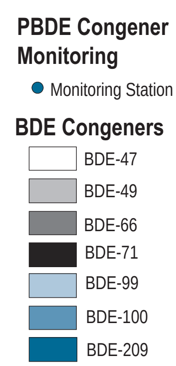


Figure 4-5. Flame retardants (PBDEs) in Puget Sound. Concentrations of a broader suite of PBDEs were measured in sediments collected in April 2005 at 10 PSAMP temporal sediment monitoring stations located throughout Puget Sound. Congeners measured included the five penta-BDE congeners measured in 2004, plus BDE-209 (the primary congener in commercial deca-BDE mixtures), and BDE-49, -66, -71, -138, -183, and -184. As in Hood Canal, BDE-47 and -99 were detected most frequently. Congener BDE-47 was detected at all 10 stations and BDE-99 was detected at five of the stations, including the deep, depositional Shilshole and Point Pully stations, and the stations near urban and industrial areas, including Port Gardner, Sinclair Inlet, and the Thea Foss Waterway. Congener BDE-209 was also detected at these five stations, and at the station in Budd Inlet. Congeners BDE-49, -66, -71, and -100, were detected at three, one, two, and one station(s), respectively. Congeners BDE-138, -153, -154, -183, and -184 were not detected in any samples. (Source: Ecology)



is abundant, found in many habitats, and the levels of certain contaminants (such as PCBs) in its tissues reflect the levels of contaminants in the sediments at sites where it lives.

Status and Trends

WDFW scientists have sampled English sole consistently from the early 1990s to present at eight index sites for describing temporal trends in PBTs, and periodically at over 40 other randomly selected sites in north, central, and southern Puget Sound to describe the spatial distribution of PBTs in this species. In addition, they conducted more intensive focus studies in the three most contaminated urban bays of Puget Sound (Elliott Bay in 1997, Sinclair Inlet in 1998, and Commencement Bay in 1999) to gain a better understanding of contaminant patterns near to their sources.

PBT accumulation in fish is mostly closely related to the magnitude of PBTs in their environment. However, other factors, such as a fish's fat content, its position in the food web (trophic status), age, and gender can also determine the extent to which PBTs in the environment are accumulated. WDFW scientists have already documented elevated levels of PCB in the muscle tissue of English sole from

Figure 4-6. Concentration of 12 BDE congeners measured in marine sediments worldwide. Congeners BDE-47, -99 and -209 are detected in Puget Sound sediments but at relatively low levels compared to the UK or San Francisco measurements. (Source: Ecology)

Global Sampling Sites

- 2004 Hood Canal (n=30)
- 2005 Puget Sound temporal stations (n=30)
- 2002 San Francisco Bay (n=33)
- 2000 Denmark marine (n=10)
- 2000 UK marine (n=23)
- 1987 Baltic Sea core (n=1)
- 1999 Norway core (n=1)
- 2000 Korea marine (n=80)

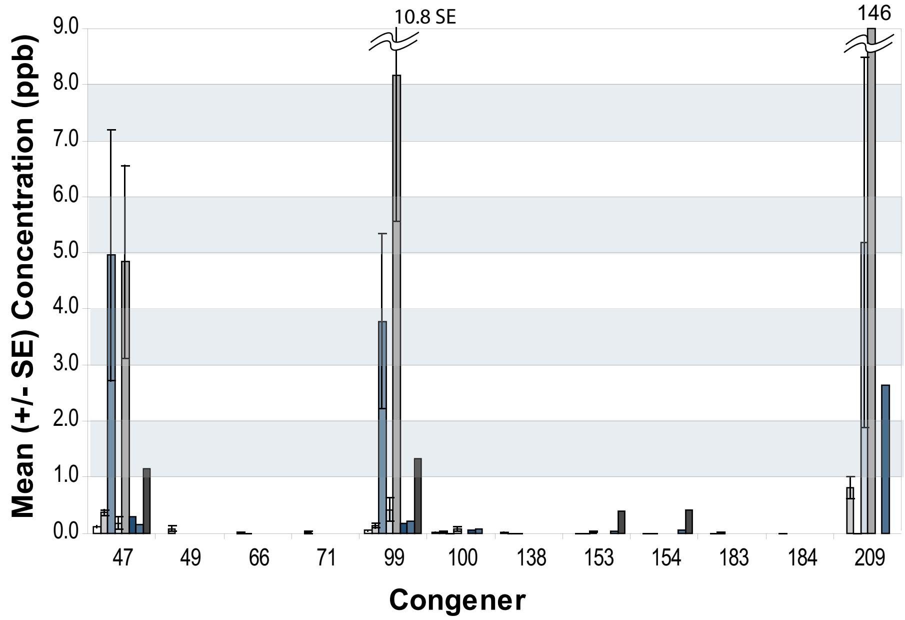
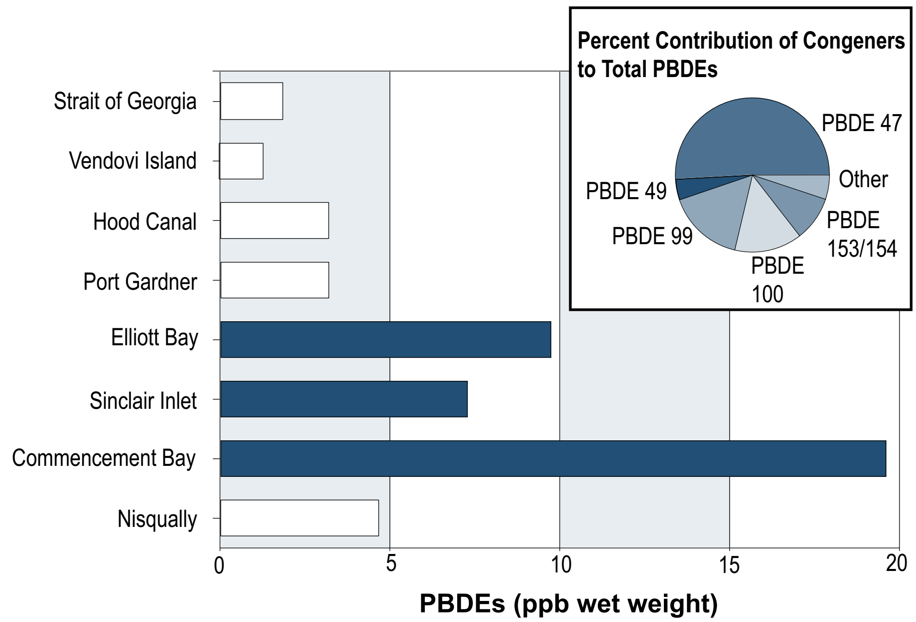


Figure 4-7. PBDE concentrations in English sole. Fish were sampled from three urban (shaded bar) and five non- or near-urban (open bar) Puget Sound locations in 2003. Each bar represents a composite value from 20 skinless muscle fillets. Highest concentrations of PBDEs were measured in fish from urban bays in central and southern Puget Sound. (Source: WDFW)



urban harbors and bays of Puget Sound, and have shown that PCB accumulation in English sole can be predicted primarily by the concentration of PCBs in sediments where the fish live, with additional accumulation as fish age (O'Neill and West, draft 2002 manuscript). Sediment PCB concentration was the stronger predictor, accounting for 70 percent of variation in English sole PCBs, while age contributed only four percent of the variation observed. In general, the more contaminated the sediments, the more contaminated the fish, and older fish from contaminated areas had slightly higher PCB exposures than did younger fish. In contrast, mercury accumulation in English sole can be predicted mostly by fish age (63 percent of the observed variation) and only slightly by sampling location (four percent of the observed variation).

Recent WDFW data indicate that PBDEs behave in a fashion similar to PCBs – PBDE levels are elevated in English sole from the urbanized bays of Puget Sound (Figure 4-7), at concentrations considerably higher than those reported by Ikonomou et al. (2006) in English sole in the Georgia Basin. The pattern, or relative proportion of congeners that make up the total PBDE concentration was similar among all English sole samples, regardless of where the samples were collected, yet it was different from the PBDE congener pattern observed in sediments. This suggests that individual PBDE congeners move through the food web at different rates.

iii. PBTs in Rockfish

Quillback, copper, and brown rockfish are long-lived demersal predators, usually associated with rocky substrate. Because of their longevity and high position in the food web, their probability of exposure to PBTs is great. These species have small home ranges, suggesting that they will reflect local patterns of contamination. Because they are popular targets of recreational fisheries in Puget Sound, rockfish also represent a food-web pathway through which contaminants can move from the environment to humans.

Populations of some rockfish species are in decline, making their utility as indicators problematic. Rockfish have become rare in many areas of Puget Sound, including the South Puget Sound and Whidbey basins, so they are unsuitable as broad-scale indicators. WDFW scientists began sampling rockfish in 1989 but ended targeted sampling in 1997, after which specimens were taken only as by-catch from other efforts. Although sample sizes are small in some cases, adequate numbers have been collected to characterize three of the four highly urbanized embayments of central Puget Sound, non-urban areas of central Puget Sound, Admiralty Inlet, and the San Juan Islands.

Status and Trends

WDFW scientists have sampled rockfish from six of WDFW's nine Sport Fisheries Management Areas (Figure 4-8). They observed the greatest PCB exposure in fish from Elliott Bay (Management Area 10) and Sinclair Inlet (Management Area 13)—two of the most contaminated embayments in central Puget Sound (Figure 4-9). PCBs were also present at lower levels in rockfish from Commencement Bay (Management Area 11) and Port Gardner (Management Area 8-1), and in non-urban locations in Management Area 11. PCBs were rarely detected in rockfish from all other management areas, which reflects either a lack of exposure to PCBs (i.e., their habitats were uncontaminated), or that samplers failed to represent the full range of individuals in a population. For example, Commencement Bay habitats are contaminated with PCBs; however, rockfish are rare in the areas sampled by WDFW, and only very young fish (from two to eight years of age) were obtained from Commencement Bay.

WDFW scientists have observed that male rockfish can accumulate measurably greater concentrations of PCBs than females can. This probably results when females lose PCBs during reproduction, as they transfer PCB-laden fats to their eggs and larvae. This may happen in other species as well; however, rockfish present a particularly good opportunity to observe the phenomena, because they live long enough to accumulate high PCB levels (males) and lose PCBs through many reproductive cycles (females) (Figure 4-10). Although PCBs were highly variable in both sexes, the greatest concentrations (exceeding 200 ng/g wet wt.) were measured in the oldest males (15 to 30 years of age) from Elliott Bay and Sinclair Inlet. PCBs were almost always relatively low in females; their greatest concentration was 156 ng/g in a 9-year-old female from Sinclair Inlet (not shown) and 90 ng/g in a 10-year-old female from Elliott Bay. PCBs in females from both locations declined after this age, probably related to the start of their reproductive life.

What are congeners and Aroclors?

PCB and PBDEs are categories, or families, of chemical compounds. At their core, PCBs and PBDEs are both dual-benzene-ring structures, linked by a single carbon-to-carbon bond. With PCBs, the number of chlorine atoms and their position on the dual-ring core defines the resulting chemical, called a **congener**. PBDEs have identical dual-ring structures at their cores; however, chlorine atoms are replaced with bromine. For both PCBs and PBDEs, there are 209 congeners.

PCBs can be directly measured by quantifying and combining the 209 congeners (or a subset) that exist in a medium such as sediments or tissue, or they can be estimated by comparing the signal observed in a medium with well-known, commercial mixtures of congeners. In the Pacific Northwest, the most commonly used of these mixtures was **Aroclors**. Aroclor is a trade name applied to a number of specific PCB products, each of which contains varying degrees of chlorination, depending on the intended use of the product. For example, Aroclor 1260 contains 60 percent of its weight as chlorine, whereby Aroclor 1254 contains 54 percent, based on the specific mixture of congeners included in the product.

Figure 4-8. **WDFW's Recreational Fisheries Management Units.** Samples were collected from all nine Management Areas, but PCBs were rarely detected in Management Areas 6 and 7. Highest PCB levels measured in rockfish were from Management Areas 10 and 11. (Source: WDFW)

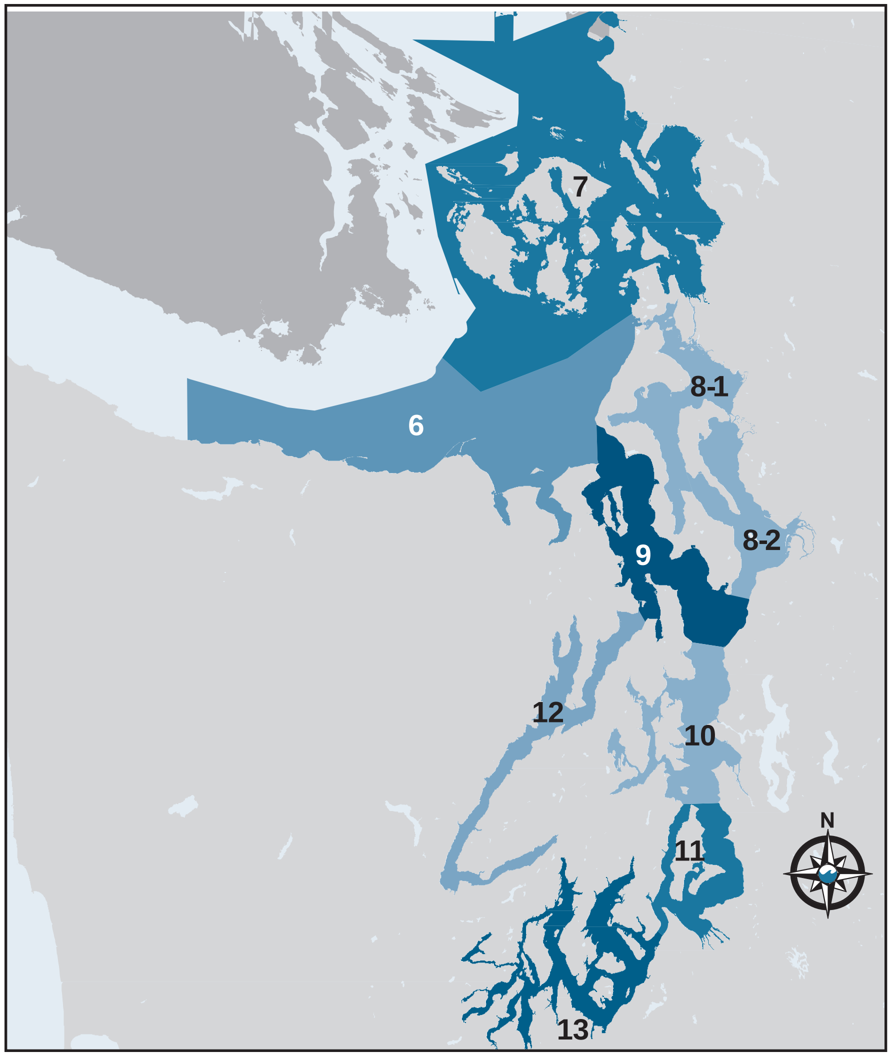
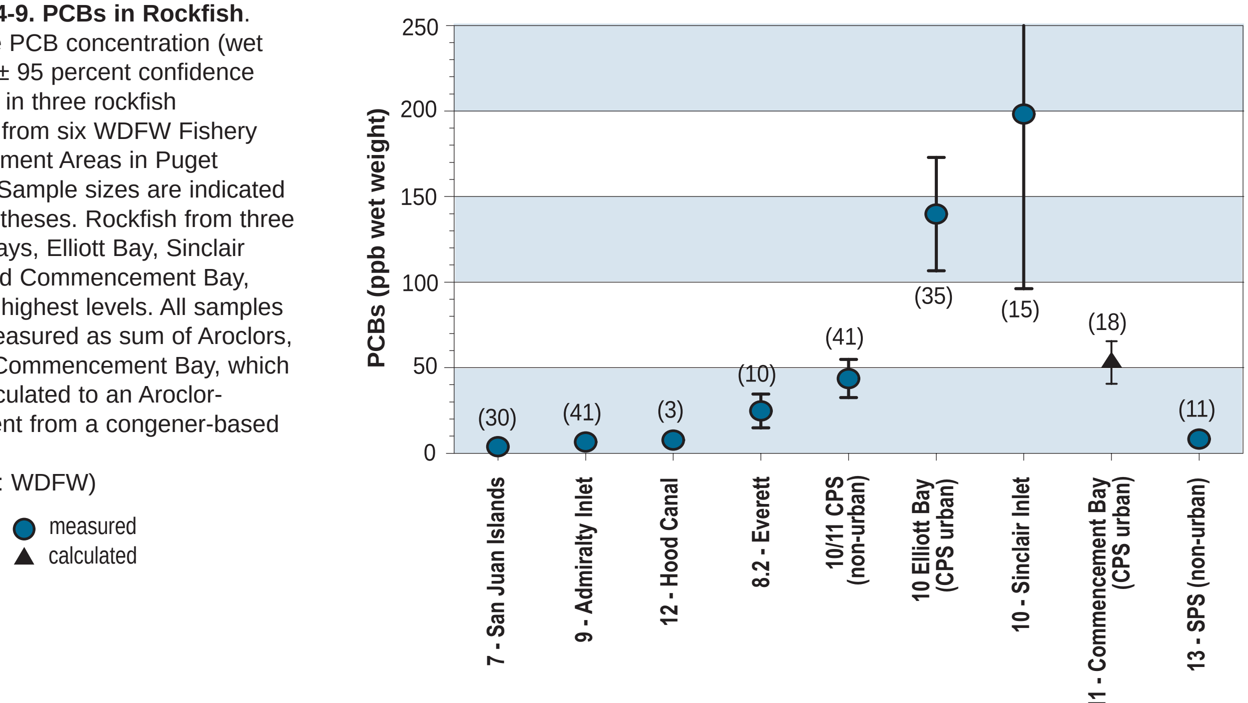


Figure 4-9. PCBs in Rockfish. Average PCB concentration (wet weight, ± 95 percent confidence interval) in three rockfish species from six WDFW Fishery Management Areas in Puget Sound. Sample sizes are indicated in parentheses. Rockfish from three urban bays, Elliott Bay, Sinclair Inlet, and Commencement Bay, had the highest levels. All samples were measured as sum of Aroclors, except Commencement Bay, which was calculated to an Aroclor-equivalent from a congener-based method. (Source: WDFW)



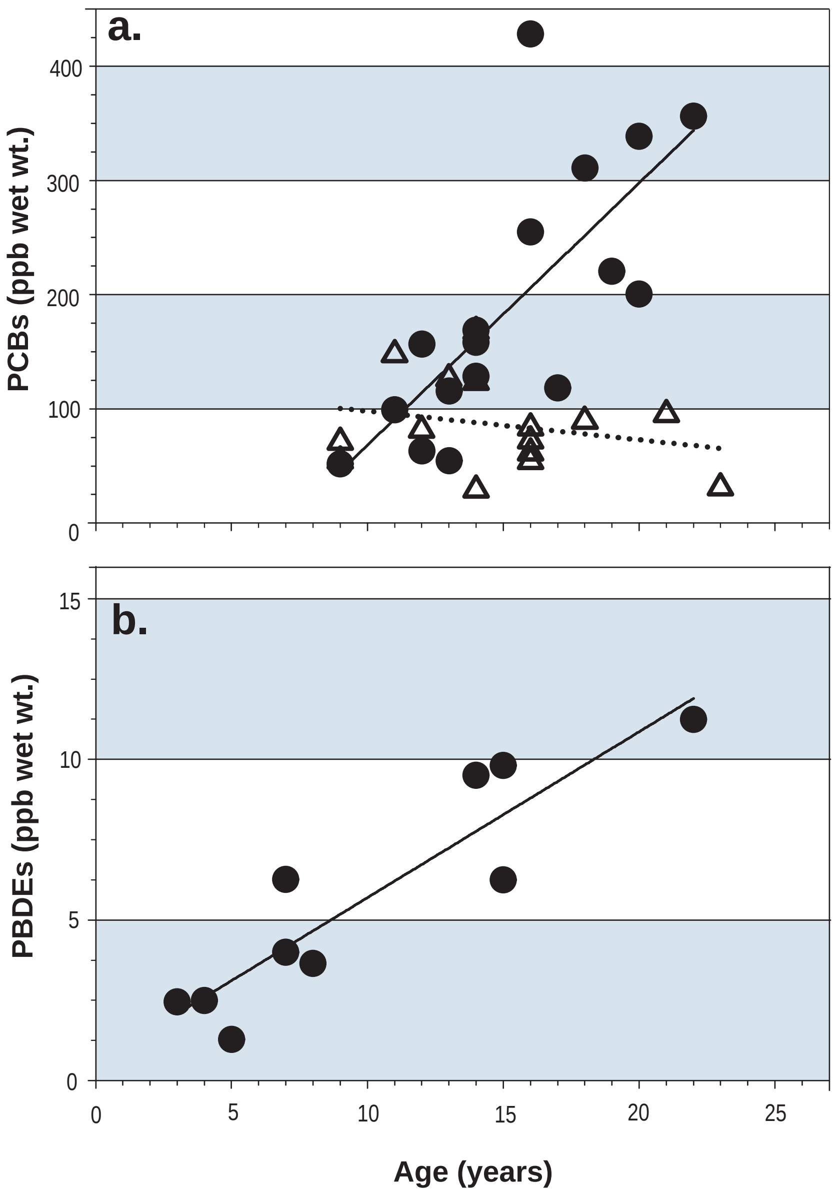


Figure 4-10. Accumulation of (a) PCBs and (b) PBDEs with age in male rockfish sampled from the Seattle waterfront. Unlike male rockfish, females do not accumulate PCBs with age, probably because they maternally transfer their body burdens of PCBs to their young. Female rockfish were not sampled for PBDEs, but it is expected that, like with PCBs, PBDE accumulation will remain low as fish age.
(Source: WDFW)

(a) PCB accumulation

Males ●	**Females** △
$r^2=0.54$	$r^2=0.06$

(b) PBDE accumulation

Males ●	**Females** △
$r^2=0.83$	Not sampled

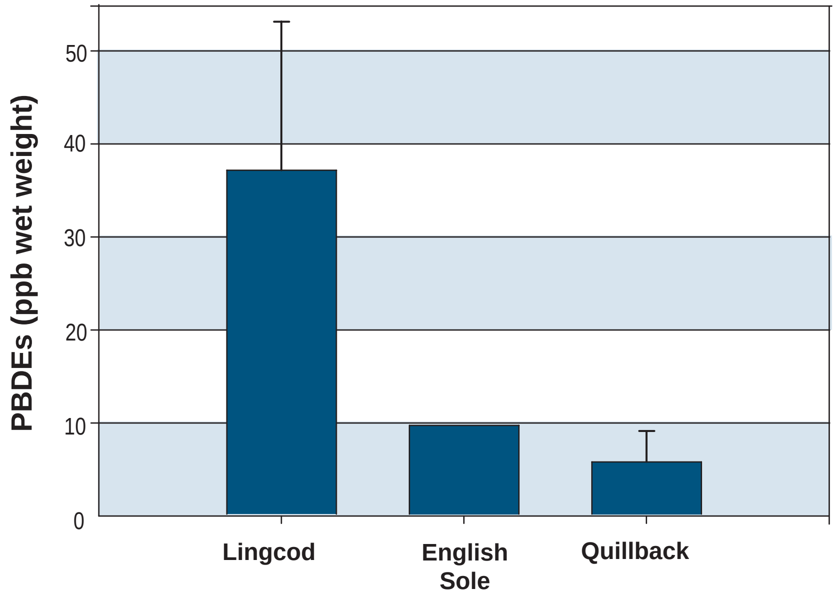
As in English sole, PBDEs appear to behave similarly to PCBs in rockfish. Based on a subset of male quillback rockfish sampled along the highly urbanized Seattle waterfront[2], male rockfish also appeared to accumulate PBDEs as they aged (Figure 4-10); however, PBDE concentrations were lower than the PCB levels observed for these same fish, possibly indicating that environmental levels of PBDEs have not yet reached those of PCBs, a conclusion that is supported by PBDE results reported in the Sediments chapter of this update.

iv. PBTs in Lingcod

Lingcod are voracious benthic carnivores that are typically associated with rocky or vegetated habitats, and they consume a wide range of fish and invertebrate prey. They are sedentary, exhibiting a relatively small home range. Because of their large size and piscivorous (fish-consuming) natures, they are one of the few predators of adult rockfish. These characteristics indicate that the lingcod's risk of exposure to PBTs is relatively high.

[2] PCBs were measured as the sum of Aroclors.

Figure 4-11. Average total PBDE concentrations detected in muscle tissue of benthic and demersal fish species sampled along the Seattle waterfront in 2003. Lingcod values are based on an average of five females (95 percent confidence interval). English sole sample is a composite sample of 20 fish, and quillback rockfish represents the average of 10 males.
(Source: WDFW)



Status and Trends

In 2003, WDFW collected lingcod, quillback rockfish, and English sole along the Seattle waterfront for PBDE analysis. PBDE concentrations were highest in lingcod, followed by English sole and quillback rockfish (Figure 4-11). Additional data (not shown) indicate that PBDEs did not accumulate with age in lingcod, although only females were sampled; as with rockfish, it is expected that PBDEs would accumulate to higher concentrations in male lingcod.

b. Pelagic Food Web

The pelagic food web comprises the complex, interrelated predator-prey relationships that exist among the plants, animals, and microbes that inhabit the water column of Puget Sound. The foundation of the pelagic food web consists of phytoplankton (single-celled algae) that fix sun energy via photosynthesis. Accordingly, they grow only in the sunlit surface layer (photic zone) of Puget Sound, which is typically less than 60 feet in depth on average. Phytoplankton is consumed by protozoa and zooplankton, which, in turn are prey of higher levels of marine food web species, including fish and whales.

Even though pelagic and benthic food webs are presented separately in this update, these two webs are also strongly linked. Pelagic species often consume benthic species, and vice versa. In addition, many marine organisms, including most benthic fishes and invertebrates produce planktonic eggs or larvae which mix with zooplankton species that spend their entire lives in the water column.

PBTs that enter the Puget Sound must pass through the water column before they reach the sediments, and it is this phase where pelagic organisms can intercept PBTs. PBTs can be absorbed by or attached to phytoplankton, microbes, and others, thereby directly introducing PBTs in the pelagic food web. In addition, sediment-PBTs may become re-suspended into the water column by storms, dredging, or animals' activities (e.g., digging and burrows), making them available to the pelagic food web. Once in the biota, PBTs can accumulate and biomagnify.

PSAMP scientists and their collaborators evaluate water-column contamination by measuring PBTs directly in the water, as well as in various species selected as indicators. Recent results from King County's water-column sampling efforts in Elliott Bay and the Duwamish River, planktivorous blue mussel sampling from NOAA's Mussel Watch program, and WDFW's Pacific herring and Pacific salmon monitoring efforts are presented in the following sections of this update.

i. King County Water PCB Levels

King County completed a Water Quality Assessment of the Duwamish River and Elliott Bay in 1999, to evaluate the effects of combined sewer overflows (CSOs) in these water bodies. The Environmental Fluids Dynamic Computer Code (EFDC) model—a hydrodynamic and fate and transport numerical model—was used as part of this assessment, to estimate chemical concentrations under conditions with and without CSO discharges. King County is currently updating the EFDC model, in part to refine the predictions of total PCB concentrations in the water column of the Lower Duwamish Waterway.

Status and Trends

King County collected a limited number of water samples in the Duwamish River, Green River, and Elliott Bay. Data from the latter two locations will provide information on boundary conditions and for measuring PCBs in the water column, as inputs from freshwater flows and marine tidal flows to the Duwamish River. Water samples were collected in August, September, November, and December 2005 from four locations, identified in Figure 4-12, and date are listed in Table 4-3.

The August and September samples represent dry-weather, low-flow conditions and the November and December samples represent wet-weather, higher-flow conditions. All samples were analyzed for 209 PCB congeners. These data constitute a relatively small sample set, and King County is currently in discussion with other parties involved in the Lower Duwamish Waterway cleanup efforts, to evaluate the possibility of further study of PCBs in the Duwamish River.

ii. PCBs in Mussels

Since 1986, NOAA's National Status and Trends (NS&T) Program has been monitoring contaminants in mussels (*Mytilus edulis* and *M. californicus*) from Puget Sound, the Strait of Juan de Fuca, and the Pacific Ocean coast of Washington as part of their Mussel Watch program. The NS&T Program analyzes nearly 150 separate chemicals in whole soft tissue from composites (consisting of tissue from multiple individuals mixed into one sample) of mussels collected at each of each of 17 sites in Washington and one at the Columbia River south Jetty. Samples were collected annually to 1994 and every other year since then.

Mussel tissue is considered an indicator of the water-column contamination, because this species consumes (by filtering) primarily phytoplankton. The Mussel Watch data can help track changes in contaminants, including PBTs, PAHs, and metals that accumulate in mussel tissue, providing a gauge of local water quality near monitoring sites.

Status and Trends

Data from five Washington sites in 2003 indicate that total PCB concentrations in mussels have averaged slightly higher than the 2003/2004 national median of 50 ppb dry weight (Figure 4-13). Fourmile Rock, located near Elliott Bay in Seattle, had especially high PCB levels in the early 1980s, (more than 1,500 ppb) followed by general decline to 262 ppb dry weight in 2002. This level though lower, is still more than five times the national median for PCBs in mussels.

Figure 4-12. King County's 2005 water column PCB congener sampling locations in Puget Sound.
(Source: KC DNRP)

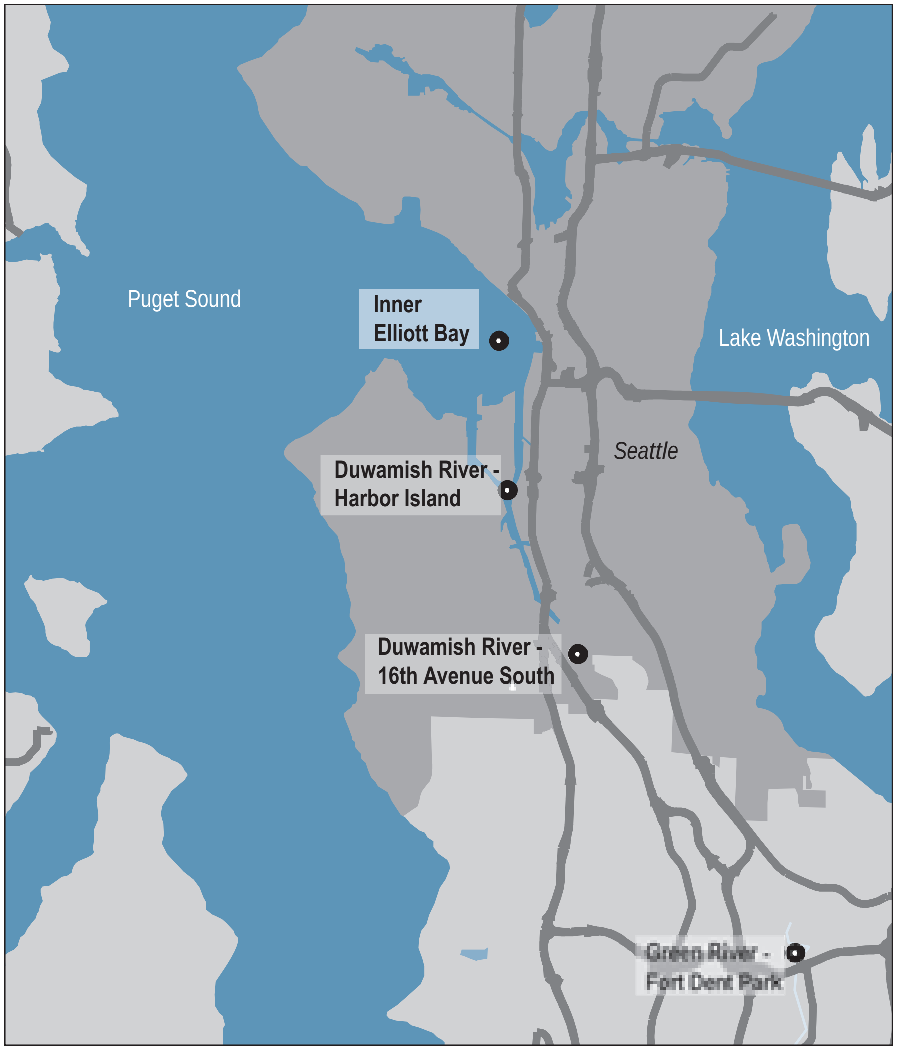
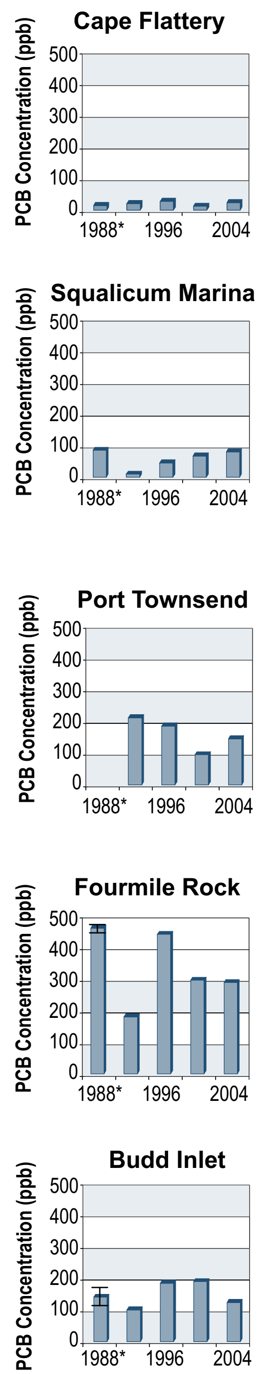


Table 4-3. The total PCB concentrations detected during the four sampling periods in the Duwamish River, Elliott Bay, and Green River, 2005. The Duwamish River and Green River sites generally had higher PCB levels in the late summer (August and September), whereas the Elliott Bay site had lower levels during this period.
(Source: KC DNRP)

		Total PCBs	(pg/L)	
Station/Depth	Aug-05	Sep-05	Nov-05	Dec-05
Inner Elliott Bay (15 meters)	65.6	152	151	131
DR – Harbor Island (1 meter)	1,800	1,100	616	2,050
DR – Harbor Island (salt wedge)	1,810	No Data	261	679/524*
DR – 16th Ave. S. (1 meter)	1,430/1,620*	1,160	474	1,130
DR – 16th Ave. S. (salt wedge)	3,120	1,720	185	1,340
Green River (surface)	248	814	933/113*	82.9

*Field replicate samples

Figure 4-13. PCBs in Puget Sound mussels. Average PCB levels in Puget Sound mussel tissue—approximately 80 ppb dw—are 60 percent higher than the national median of 50 ppb dry weight. Fourmile Rock, located near Seattle, had five times the national median PCB levels in 2002, 262 ppb dry weight. However, this level is considerably lower than concentrations in the mid-1980s.
(Source: NOAA)



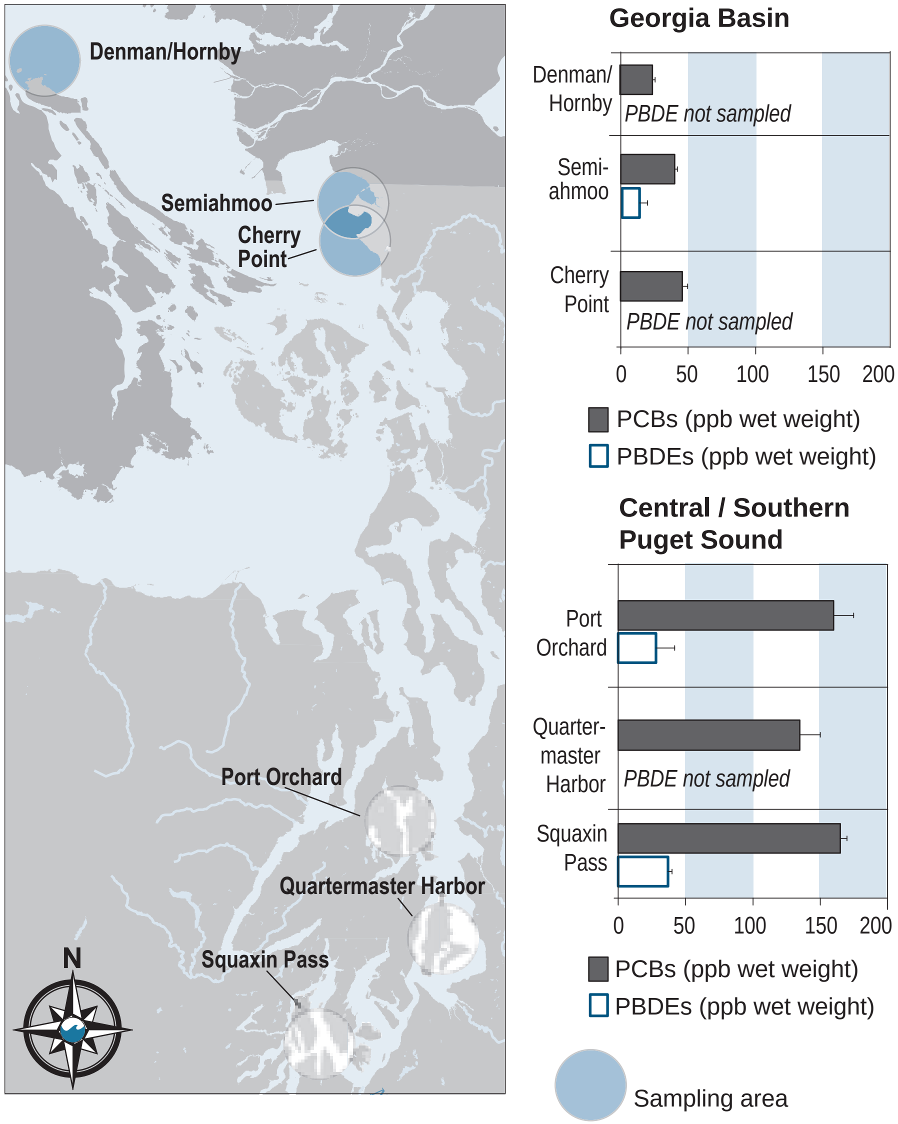
Elsewhere throughout Puget Sound and the Straits of Juan de Fuca, PCB concentrations were about 100 to 200 ppb in the mid-1980s and have since declined to below 100 ppb by 2002, with the exception of a slight increased in the mid-1990s. This peak was highest at the Fourmile Rock and Duwamish Head (near Seattle) sites but also occurred elsewhere in Puget Sound, such as at Sinclair Inlet. Following this peak, PCB concentrations have been declining again.

Generally, over the past two decades, sites with the lowest PCB concentrations were along Washington's outer coast, in northern Puget Sound and the Straits of Juan de Fuca.

iii. PCBs in Herring

Pacific herring are important prey to many fish species, as well as seabirds and marine mammals. Consequently, the health of these higher trophic level organisms is linked to the health of herring in Puget Sound and the Georgia Basin ecosystem. PCBs and other lipophilic compounds that may be present in the environment are accumulated in fatty fish such as herring. Also, because of their pelagic schooling behavior, average contaminant exposures in adult spawning stocks of herring will likely reflect environmental contamination from the geographic areas in which they reside. WDFW collects whole body samples for PSAMP, as general indicators of contamination of forage fishes in the pelagic food web.

Figure 4-14. Concentrations of PCBs and PBDEs in whole-body samples of Pacific herring. Fish were sampled from six spawning populations in the Georgia Basin and Puget Sound. Concentrations of PBDEs in central and southern Puget Sound herring samples are almost three times higher than concentrations in herring from the southern Georgia Basin. (Source: WDFW)



Status and Trends

The levels of PCBs in Pacific herring sampled from central and southern Puget Sound from 1999 to 2004 are four to nine times higher than those from the Georgia Basin sites (Figure 4-14), and showed no trend from 1999 through 2004 (Figure 4-15). The levels in Puget Sound herring are similar to those measured recently in herring from the heavily industrialized Baltic Sea—long considered one of Europe's most contaminated inland seas (Figure 4-16).

Pacific herring sampled in central and southern Puget Sound in 2004 also exhibited PBDE levels almost three times greater than those in herring from the southern Georgia Basin (Figure 4-14). Although trend data are not yet available for PBDEs in Pacific herring, data from other studies show that, unlike PCBs, PBDEs are rapidly increasing in the marine food web (Ikonomou et al. 2006).

Elevated PBT levels in Pacific herring from Puget Sound are another indication that the Puget Sound water column is contaminated with PBTs. Pacific herring consume zooplankton, which have no obvious, direct trophic connections to benthic biota. Phytoplankton may directly intercept PBTs as they enter marine waters from outside sources (e.g., atmospheric transport, point sources, and

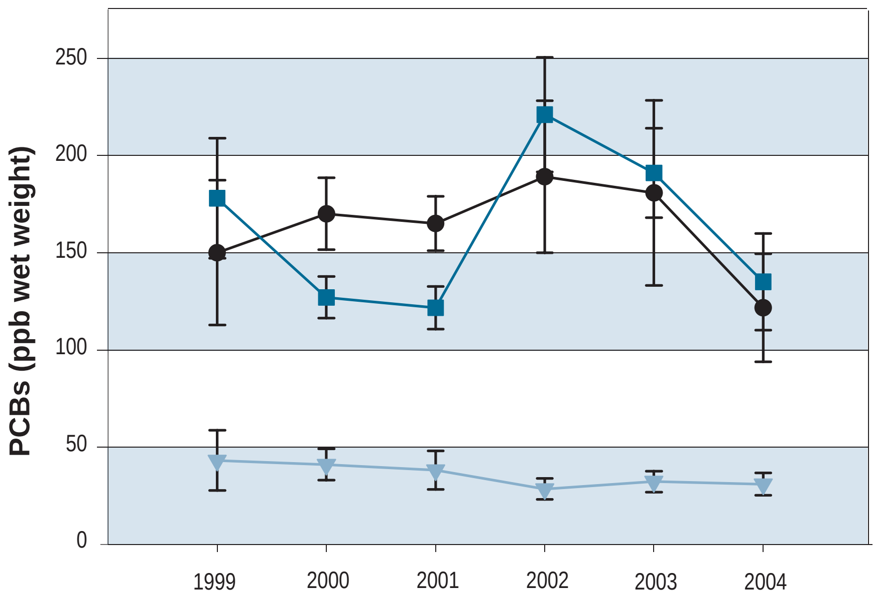


Figure 4-15. Trends of PCBs in Pacific herring. Samples were from two Puget Sound (Squaxin and Port Orchard) and one Georgia Basin (Semiahmoo) population from 1999 through 2004. PCB levels in Puget Sound herring were four to nine times higher than the Georgia Basin population. (Source: WDFW)

● Port Orchard
▼ Semiahmoo
■ Squaxin

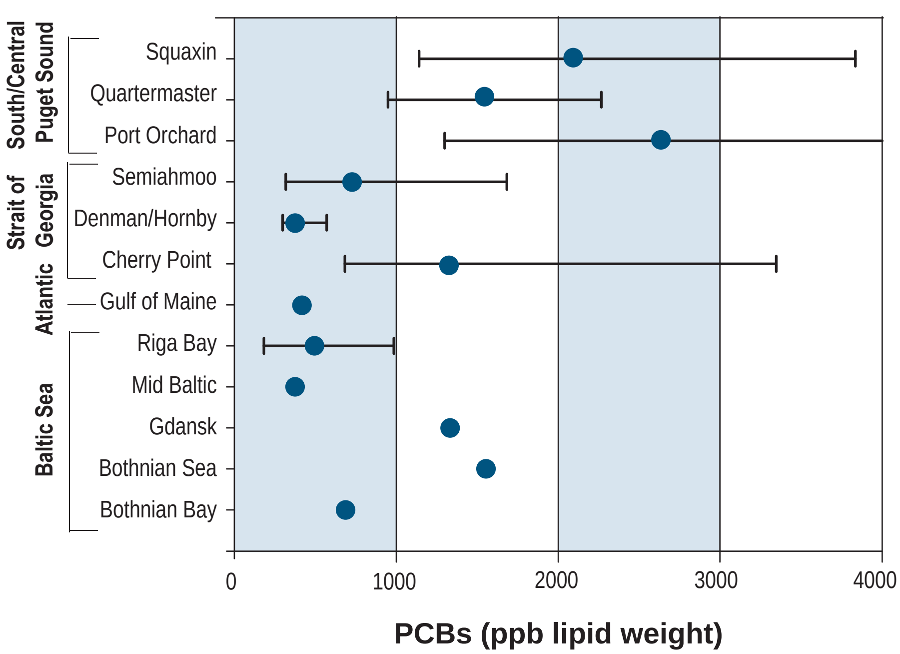


Figure 4-16. A comparison of current PCB levels in herring from the Puget Sound and Georgia Basin with other locations worldwide. Data points (circles) show reported measures of central tendency (mean or median) of lipid-weight concentrations, and short vertical lines indicate minimum and maximum reported values, when available. PCB levels in herring from three Puget Sound populations exceeded levels measured from one Atlantic Ocean and five Baltic Sea locations. (Source: WDFW)

nonpoint source fresh waters) before they settle to sediments or, perhaps, from internal processes, such as when PBTs are re-suspended from sediments via storms, waves, and other physical processes. Contaminants in phytoplankton can be transferred to zooplankton, which are then transferred to herring. This is because many zooplankton are larvae of benthic fish and invertebrates, which may be contaminated by maternal transfer of PBTs from female benthic fishes and invertebrates that feed in contaminated urban harbors and bays.

iv. PBTs in Pacific Salmon

The level of exposure to PBTs in Pacific salmon and other fishes depends for the most part on where the salmon live and what they eat. Highly migratory species such as Pacific salmon can encounter a wide range of contaminant conditions in their lives, from highly polluted estuaries like the lower Duwamish River to the comparatively cleaner waters of the Pacific Ocean. However, the great majority of PBT accumulation by salmon occurs not in their freshwater or estuarine phase, but in the marine phase of their lives (O'Neill et al. 1998). Habitats used by salmon in their marine phase include the inland marine waters of Puget Sound and the Georgia Basin, as well as the Pacific Ocean, and it is in this phase where most of the salmon's growth occurs.

In their first year at sea, pink, chum, and sockeye salmon rapidly migrate northward and westward through marine waters of the West Coast to the open waters of the North Pacific Ocean, Gulf of Alaska, and Bering Sea (Quinn 2005). Hence, the majority of their growth occurs at a great distance from coastal pollution sources. In contrast, chinook and coho salmon have a more coastal marine distribution along the continental shelf (Quinn 2005) and so may be more exposed to PBTs from coastal pollution sources.

The PSAMP herring contaminant studies (described in Section 3b.iii of this chapter) have indicated that the pelagic food web of the central and southern Puget Sound is more contaminated with PBTs than is the Strait of Georgia. Hence, salmon populations that originate from the central or southern Puget Sound are more likely to be exposed to PBTs because they feed on contaminated Puget Sound prey during their migration to and from the ocean. Moreover, salmon that remain as residents in central or southern Puget Sound (rather than migrating to the ocean) have a greater likelihood of PBT exposure because they feed on Puget Sound prey for a greater proportion of their lives.

In addition to proximity of salmon to contaminant sources, the position of each species in the food web (i.e., what they eat) can strongly affect its exposure to PBTs. The five species of salmon that occur in Puget Sound and Georgia Basin utilizes a wide range of feeding strategies. Chinook salmon occupy the highest position in the food web and, therefore, have the greatest likelihood of exposure to and biomagnification of PBTs such as PCBs. Chinook salmon consume fish and invertebrates, but more of their food comes from herring and other forage fish. In contrast, pink and chum salmon eat mostly invertebrates that accumulate lower levels of contaminants.

Status and Trends

The following sections present recent PSAMP analyses that support the hypothesis that residency (or time spent) in Puget Sound increases exposure of coho and chinook salmon to persistent bioaccumulative toxics like PCBs and PBDEs. Some wild chinook salmon, and, to a lesser extent, coho salmon, may naturally reside in Puget Sound—particularly populations from southern Puget Sound. In addition, some artificial rearing practices are designed to encourage residency in Puget Sound (such as delaying the release of yearling chinook salmon from hatcheries and extending rearing of coho salmon in marine net pens) which may inadvertently increase the fish's exposure to PCBs. Results include both artificially reared salmon and wild salmon.

Coho Salmon

PCB accumulation in adult coho salmon returning to spawn appears to be primarily related to the fish's migration distance through, or their residency in, Puget Sound (Figure 4-17). Agate Pass net-pen-reared coho, whose release had been delayed to encourage Puget Sound residency, exhibited the greatest PCB concentrations of any coho group sampled by PSAMP in the period from 1998 through 2002. All other coho, which consisted of a mixture of wild fish and

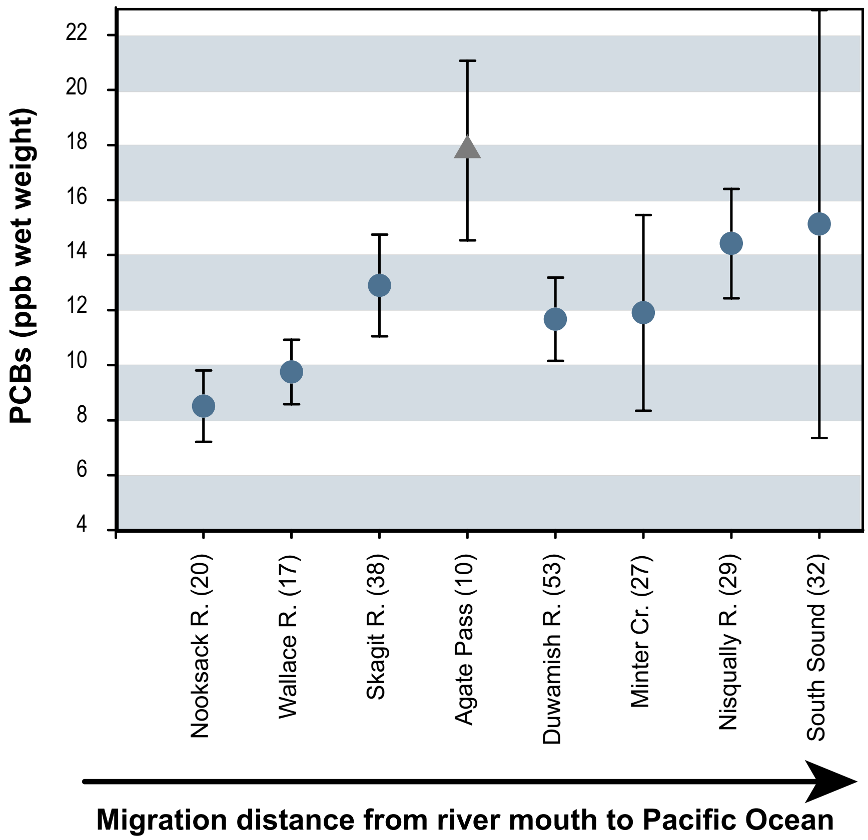


Figure 4-17. Average PCB concentration in fillets from adult coho salmon sampled from 1998 through 2002. The highest PCB levels (congeners) were measured in net-pen-reared fish whose release was delayed to prolong their residence time in Puget Sound. In all other groups, a strong trend of increasing PCBs is evident in coho salmon populations as their migration distance through Central and Southern Puget Sound increased.
(Source: WDFW)

● Hatchery (normal release) and Wild

▲ Net Pen - delayed release

hatchery-reared fish that had been released with normal timing, exhibited an increase in PCB concentrations, with increasing migration distance through central and southern Puget Sound. This corroborates previous PSAMP work by O'Neill et al. (1998), who documented higher PCB concentrations in wild coho salmon returning to spawn in central and southern Puget Sound, relative to coho returning to the Nooksack and Skagit rivers in the North Puget Sound and southern Georgia Basin. These results support the migration-distance hypothesis, or, alternatively, suggest that coho salmon populations from southern areas of Puget Sound may have a greater proportion of naturally-occurring Puget Sound-resident individuals. PSAMP scientists are continuing these studies, and have collected coho salmon from a number of locations throughout Puget Sound in 2006.

Chinook Salmon

A comparison of PCBs in chinook salmon from Puget Sound and other West Coast populations indicated that overall, Puget Sound chinook salmon fillets are nearly three times more contaminated than fillets of chinook salmon from other West Coast populations (Figure 4-18). Data shown are from Puget Sound samples that were collected 1992-1996 and data from other areas were adapted from other reports (Krahn et al. 2003; Hites et al. 2004; Missildine et al. 2005; EPA 2002). As mentioned previously, chinook salmon accumulate most of their PCBs in the marine environment, so the elevated PCB levels in Puget Sound chinook salmon suggest that these fish distribute themselves differently in marine waters from other populations along the West Coast. Moreover, the PCB concentrations in Puget Sound chinook salmon varied greatly among individuals, further suggesting that not all Puget Sound chinook salmon have the same marine distribution.

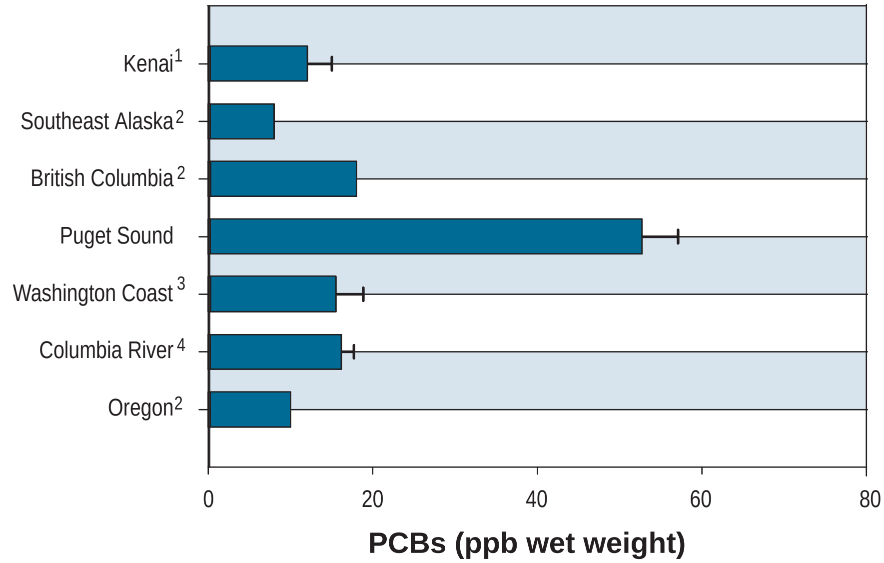


Figure 4-18. PCBs in chinook fillets. Average PCB concentration in chinook salmon fillets (wet weight, with 95 percent confidence interval) sampled from Alaska, British Columbia, Puget Sound, the Columbia River, and the coast of Washington and Oregon. Data for Puget Sound were based on fillet samples collected by PSAMP from 1992–1996 and the results for the other six locations were adapted for use here from other reports. Chinook salmon fillets from Puget Sound had nearly three times the concentrations of PCBs than chinook salmon from other areas. This may be due to longer residency times in Puget Sound. (Source: WDFW)

Adult Puget Sound chinook salmon typically migrate to coastal waters rather than offshore (Myers et al. 1998), however the total time a chinook salmon spends feeding in coastal waters as opposed to residing within Puget Sound waters is unknown, and probably highly variable. Based on the range of contaminants observed in PSAMP studies, a significant proportion of Puget Sound chinook salmon are probably at least partially resident in Puget Sound, and some Puget Sound chinook may reside in these waters year-round. Feeding within Puget Sound on herring and other forage fish exposes the chinook salmon to higher contaminant levels than along the Pacific Ocean coast or in the open ocean.

A recent independent PSAMP/NOAA Fisheries study of PBT accumulation in whole body samples of individual chinook salmon along the West Coast confirmed that summer/fall chinook from Puget Sound were considerably more contaminated than other West Coast populations (Figure 4-19). Furthermore, Puget Sound resident chinook salmon (i.e., chinook salmon captured in central Puget Sound outside the normal migration time for adult fall chinook salmon) had the highest concentrations of PBTs.

PBDEs were measured above the limit of detection (1 ppb) in five of these seven chinook salmon groups, and concentrations ranged from roughly one-fifth to one half that of PCBs. In addition, the pattern of PBDEs matched that of PCBs, suggesting that PBDEs and PCBs behave similarly in the ecosystem.

c. Extended Food Web

i. PBTs in Osprey

Ospreys are long-lived, fish-eating birds of prey with high nest fidelity and that, typically, catch fish within short distances of their nest sites. Nesting osprey in the Pacific Northwest are migratory, spending winters in southern Mexico and northern Latin America, where industrial contamination is low (Henny et al. 2002). The osprey is a good avian indicator species of toxic, persistent, and bioaccumulative contaminants, such as PCBs, as well as selected emerging toxics (such as PBDEs and herbicides). Because osprey fish close to their nesting sites, contaminants in osprey eggs reflect local exposures to chemicals in breeding areas. Figure 4-20 shows an osprey with a flatfish (known to contain high concentrations of PCBs and other contaminants).

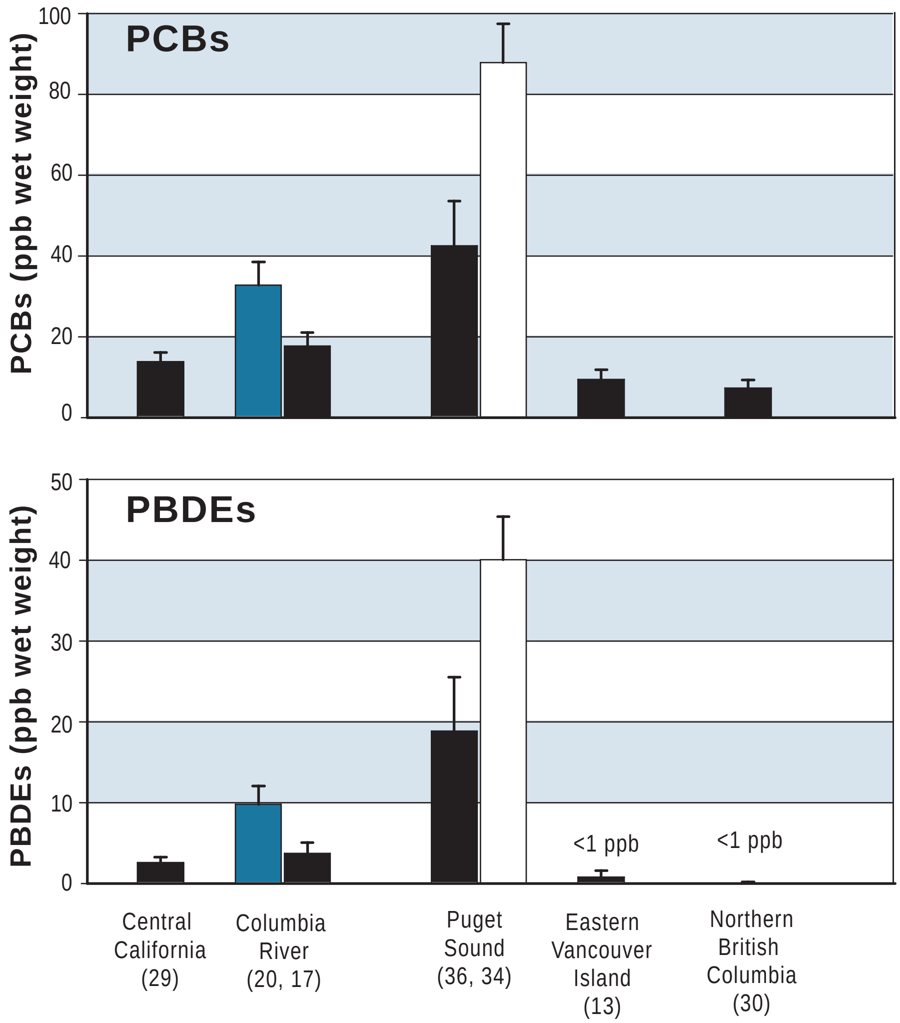


Figure 4-19. PCBs and PBDEs in whole body chinook. Average concentrations of PCBs and PBDEs (with 95 percent confidence interval) in whole body samples of individual chinook salmon caught in terminal fishing areas. River populations represented include fish returning to the Sacramento/San Joaquin (central California); Columbia (spring and fall run); Nooksack, Duwamish, and Nisqually Rivers (Puget Sound); the Fraser and Nimpkish Rivers (eastern coast of Vancouver Island, Georgia Basin); and the Skeena River (northern B.C.). Additional data are shown for sub-adult chinook salmon that were resident in Puget Sound in the winter months.
(Source: WDFW)

Spring Run
Fall Run
Sub-adult Winter Resident

Figure 4-20. Osprey along the Duwamish River. Left: Osprey delivers a starry flounder to its young in a nest on a piling near Everett Harbor. Right: Osprey nest on Duwamish River with two eggs. **(**Photos: Chuck Henny, USGS)

Status and Trends

Since 1993, scientists with the Contaminant Biology Program of the USGS Forest and Rangeland Ecosystem Science Center in Corvallis, Oregon, have conducted studies of nesting osprey populations in Washington and Oregon to assess contaminant exposure and impacts. Initial findings, based on studies conducted along the Columbia River (Henny et al. 2004) and Willamette River in Oregon (Henny et al. 2003), show that some contaminants biomagnify from fish to an osprey egg by a factor of up to 174-fold.

USGS scientists studied ospreys nesting on the Snohomish River delta near Everett Harbor in 2002 and the Duwamish River and Lake Washington area in 2003. The researchers evaluated contaminant concentrations, reproductive performance, foraging locations, and prey species preferences. During the 2002 investigation, scientists collected four osprey eggs from nests near Everett Harbor and in 2003 collected 11 eggs from the Duwamish Waterway/Duwamish River and vicinity (see Figure 4-20 for photograph of osprey eggs). These eggs were analyzed for legacy contaminants (e.g., PCBs. DDT, dioxins, and furans) as well as PBDEs and herbicides. The herbicide analysis resulted in the first reported detection of herbicides in osprey eggs (Chu et al. 2006). Additional analysis of 2002 osprey and cormorant egg samples from near Everett Harbor is planned in order to compare residue concentrations of PBDEs and herbicides from this site with that of osprey eggs from Everett Harbor and the Duwamish River.

ii. Harbor Seals

Harbor seals provide an integrated signal of food web contamination in Puget Sound. Feeding on a wide variety of fish and invertebrate species, they are particularly vulnerable to contamination by PBTs. While many PBTs were banned in North America following widespread environmental contamination and associated impacts on wildlife in the 1970s (e.g., PCBs and DDT), PBDEs represent an emerging PBT concern. One of the three commercial PBDE products, deca (a name that refers to its molecular structure) remains on the market, ensuring continued inputs into Puget Sound by way of wastewater, landfill leachate, incinerator ash, and nonpoint source pollution.

Studies of contaminants in harbor seal pups in the Puget Sound and Georgia Basin region were carried out by Department of Fisheries and Oceans and WDFW.

Status and Trends

Although regulation led to a dramatic reduction in PCBs in harbor seals from Puget Sound's Gertrude Island between the early 1970s and the present (Calambokidis et al. 2001), recent research has found an exponential increase in concentrations of PBDEs in harbor seals during the period from 1984 to 2003 (Figure 4-21) (Ross et al. 2005). While PBDE concentrations in 2003 were present at relatively low levels, (1/15th the concentration of PCBs in seals), the trend observed suggests that PBDE concentrations are doubling every four years and, by 2020, will surpass PCBs as the number-one PBT concern in Puget Sound seals.

Impacts to the Ecosystem

Harbor seal food-basket studies indicate that PBDEs are now second, after PCBs, in order of importance in Puget Sound food webs, having surpassed DDT (Cullon et al. 2005). As local sentinels of food-web contamination, harbor seals offer strong evidence that the Puget Sound ecosystem is rapidly becoming contaminated with a chemical that can be harmful to other animals, including seabirds and orcas (Ross 2006).

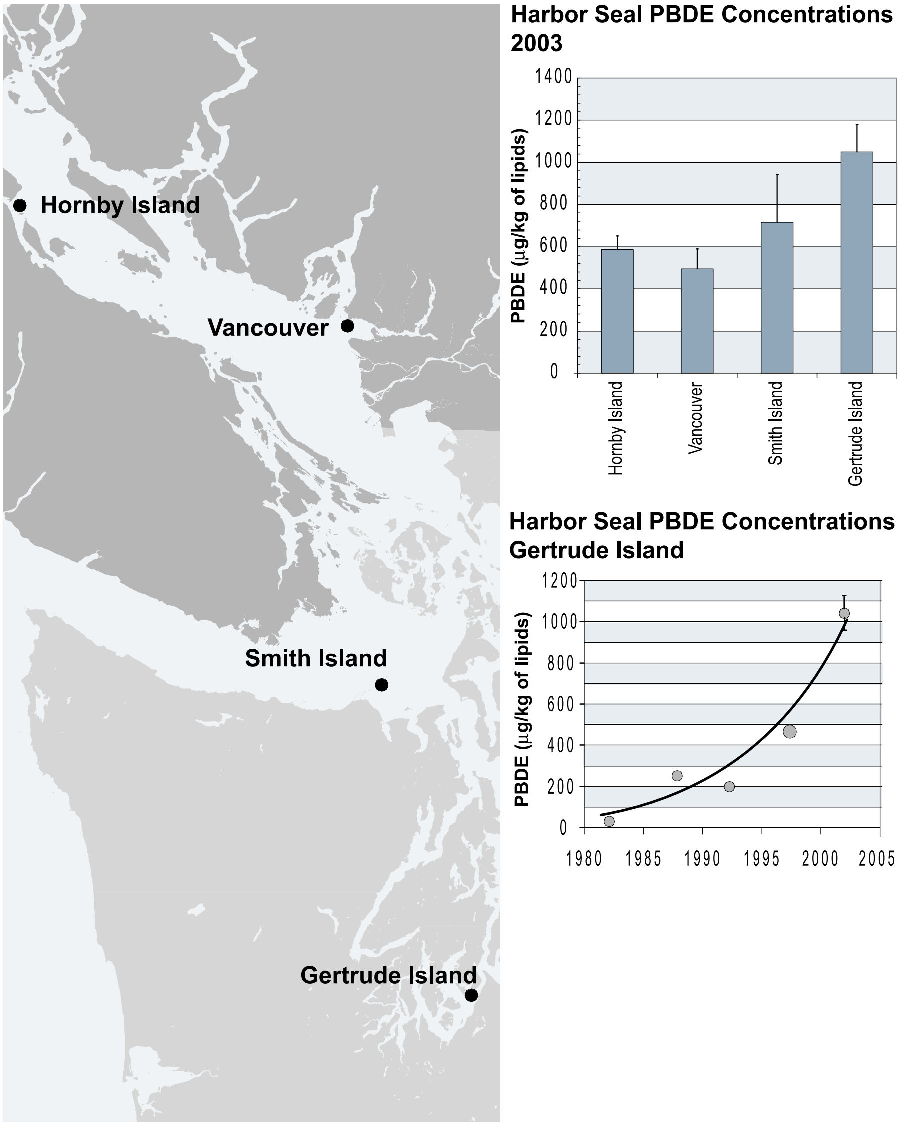


Figure 4-21. PBDEs in harbor seals from the Georgia Basin and Puget Sound. The map illustrates the locations of collection sites in 2003 near Hornby Island, Vancouver, B.C., Smith Island and Gertrude Island, and Puget Sound. Seals pups near Gertrude Island in Southern Puget Sound had nearly twice the PBDE levels of Vancouver seals (upper graph). Analysis of archived tissue (lower graph) shows the exponential increase in PBDEs since the early 1980s.
(Source: WDFW and Fisheries and Oceans Canada)

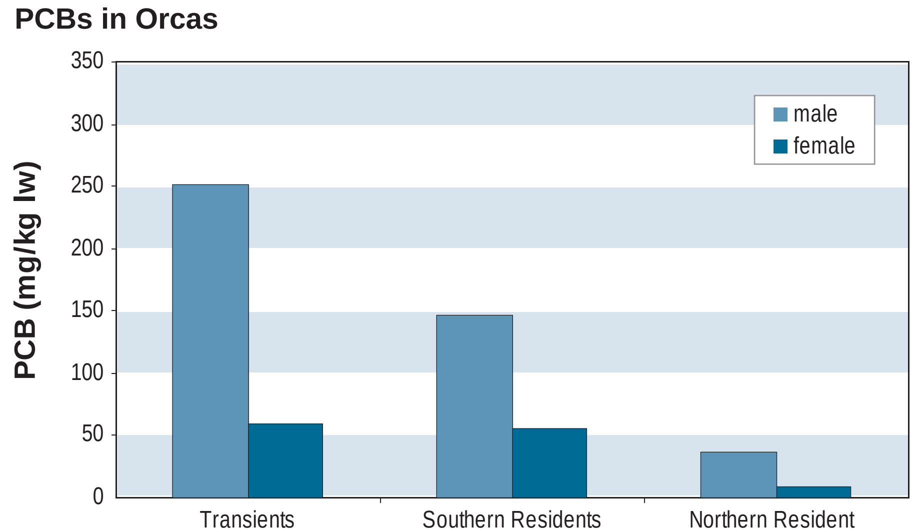
iii. PBTs in Orcas

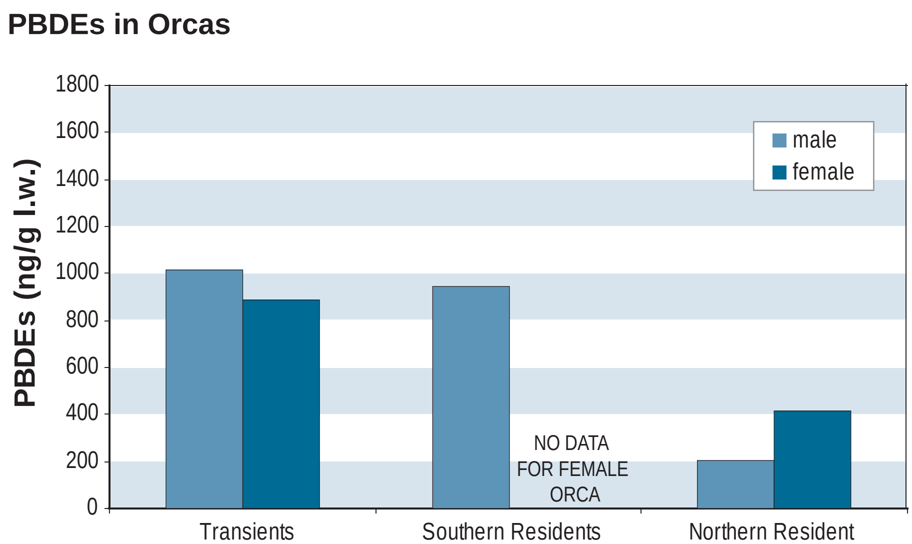
The southern resident orcas spend a portion of the year in Puget Sound, from March to September. Their exact whereabouts the remainder of the year is not known although members of the southern residents have been sighted in Monterey, California. Throughout their range, the southern resident orcas consume primarily fish, and preferably salmon. Their position at the top of the food chain is reflected in the high level of contaminants in their tissue. Females tend to have lower PBT levels as they typically pass a considerable amount of contaminants to their offspring through fetal development and nursing.

Status and Trends

Southern resident orcas feed on salmon returning to Puget Sound and the Georgia Basin in the summer and fall and have three times the levels of PCBs than northern resident orcas that feed on salmon returning further north of the Georgia Basin region (Ross et al. 2000, Rayne et al. 2004, Ross 2006). Transient whales which occasionally visit Puget Sound have the highest PBT levels of the three populations sampled (Figure 4-22). This is consistent with the transient's

Figure 4-22. PBDEs and PCBs in transient, southern resident, and northern resident orcas from samples collected between 1993-1996. Transients occasionally visit Puget Sound and prey primarily on marine mammals, and the levels of PCBs and PBDEs are highest in the transient population. Southern residents have 3-4 times the levels of these compounds compared to the northern residents, which feed further north of the Puget Sound Georgia Basin region. Both southern and northern resident orcas feed mainly on salmon. (Source: Department of Fisheries and Oceans Canada)





preference for marine mammals which are higher trophic species. Even still, both northern and southern resident orcas are more contaminated with PBTs than other north Pacific resident orca populations (Ylitalo et al. 2001; Herman et al. 2005). PBDE levels are increasing exponentially in these animals and are expected to surpass PCB levels by 2020.

iv. PBTs and Humans; analysis of breast milk from several countries

The highest levels of PBDEs in human tissues have been found in the U.S. and Canada, nations which produce and purchase the greatest amount of products with PBDE flame retardants. Levels of PBDEs in human tissues (fat, blood, and breast milk) in the U.S. are 10 to 40 times higher than reported for Europe and Japan and appear to be increasing (Figure 4-23). Studies conducted on animals show that prenatal exposure to PBDEs can impact the brain, affecting behavior and learning after birth and into adulthood. Animal studies have also shown that PBDEs can affect the thyroid and liver. Currently, the levels of PBDEs that cause these effects in animals are higher than the levels of PBDEs that most people encounter. However, if trends continue, similar effects could be seen in humans.

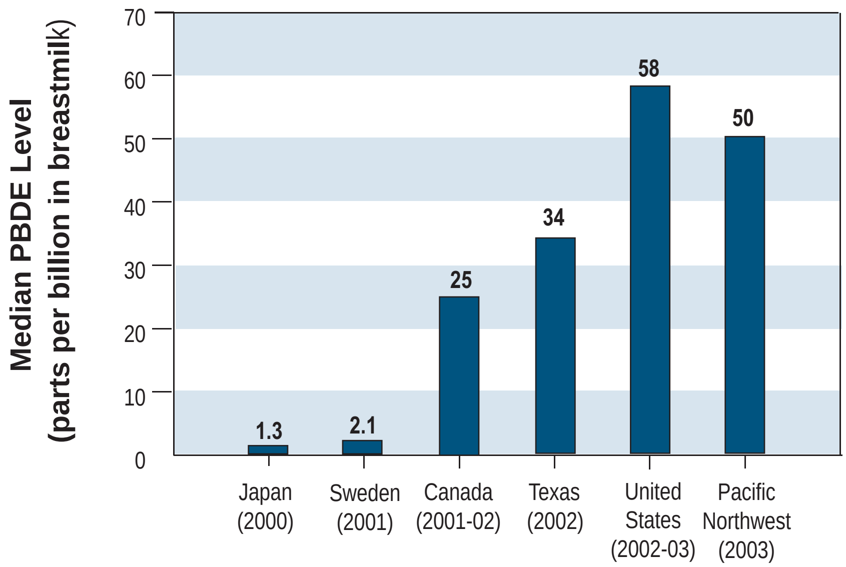


Figure 4-23. PBDEs in breast milk from Japan, Sweden, Canada and the U.S. in 2003. Numbers in the figure are the median ppb measurements from regions sampled. Overall, the highest levels of PBDEs were found in the U.S. The Pacific Northwest had the highest median levels in the country at 50 ppb. Sweden, with a median level of 2.1, banned PBDEs in the early 1990s out of health concerns. (Source: Sightline Institute)

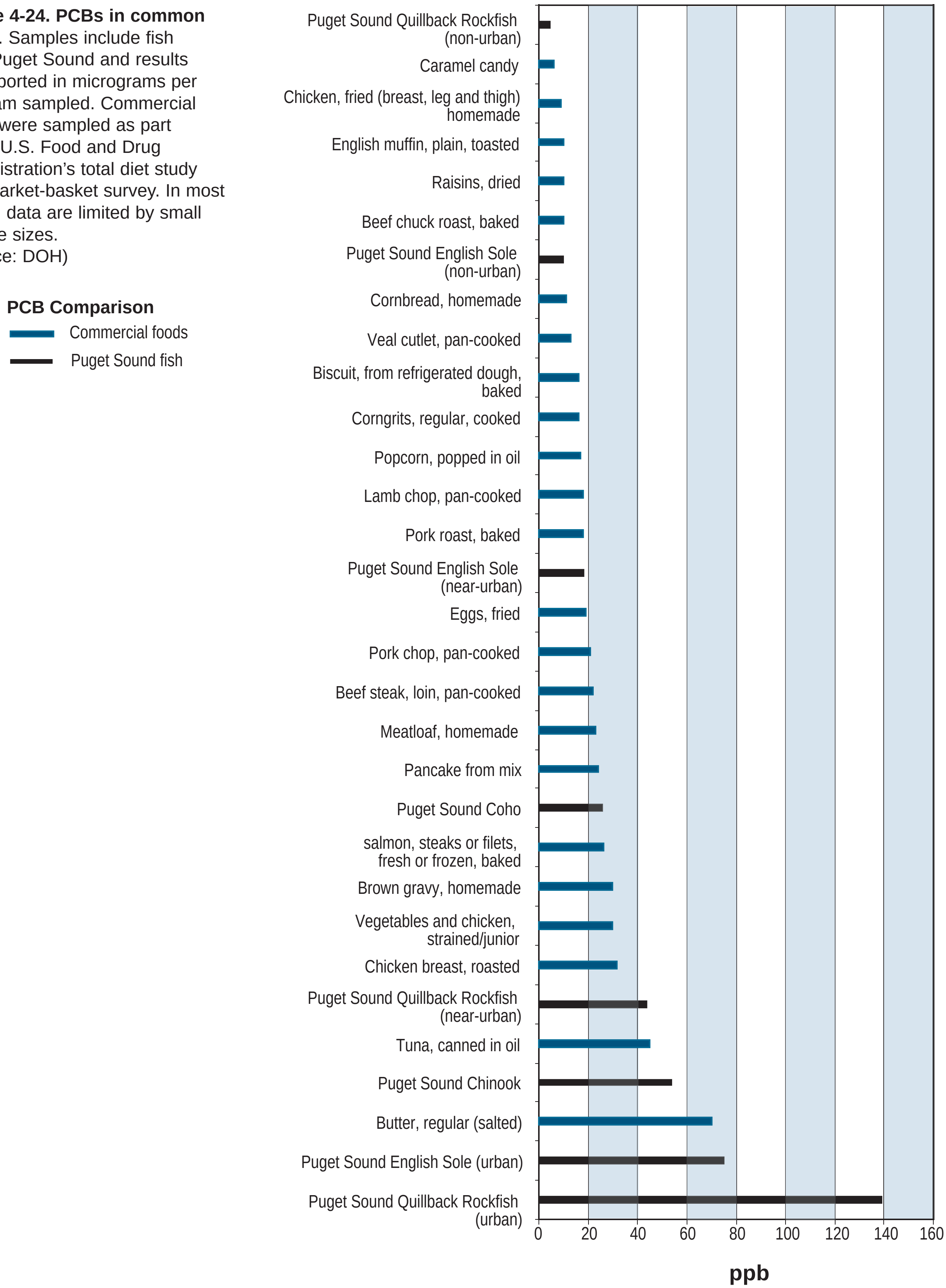
Human Health Consequences

Recent studies have attempted to quantify and compare the risks of eating contaminated fish with the benefits associated with their ingestion. Further work is expected on this subject, as more reports on fish contaminant levels and human health become available. Limited data show a link between fish consumption and a decrease in development of some cancers. Eating fish has also been associated with impacts on brain function, including protection against cognitive decline.

Studies have analyzed items from a wide range of food groups for PCB content, to determine the relative risk from consuming shellfish and fish from Puget Sound (Figure 4-24). These results are limited because, for many foods listed, only one or a few samples were analyzed.

DOH provides information to the public on fish and shellfish consumption advisories issued for specific water bodies in Washington, warning of chemical contamination. Most Puget Sound advisories address consumption of fish from urban areas (Dyes Inlet, Eagle Harbor, Sinclair Inlet, the Duwamish River, Commencement Bay, and Budd Inlet). WDFW found that PCBs and mercury in bottom fish are higher in urban bays, lower near urban sites, and approach background levels in most non-urban areas.

Figure 4-24. PCBs in common foods. Samples include fish from Puget Sound and results are reported in micrograms per kilogram sampled. Commercial foods were sampled as part of the U.S. Food and Drug Administration's total diet study and market-basket survey. In most cases, data are limited by small sample sizes. (Source: DOH)



4. PAHs in Puget Sound

PAHs are toxic and carcinogenic chemicals formed by the incomplete burning of organic matter, including petroleum, oil, coal, and wood (Newman and Unger 2003). Vehicles release PAHs into the atmosphere in exhaust emissions and deposit them on the ground through oil and gasoline leaks. Such leaks can be transported to streams, rivers, and estuaries in stormwater runoff. Long-term aquatic sediment core studies in Puget Sound and nationwide found that PAH levels peaked in the mid-1940s through 1960s. Decreases were seen in the 1970s and 1980s, followed by more recent increases. It is believed that the early declines in PAH concentrations can be attributed to the switch from coal to oil and natural gas for home heating, improvements in industrial emissions controls, and increases in the efficiency of power plants. More recent increases have been linked to increasing urban sprawl and vehicle traffic in urban and suburban areas (Lefkovitz et al. 1997; Van Metre et al. 2000, in press). Recent studies by USGS have also measured high PAH concentrations in stormwater runoff from parking lots sealed with coal-tar-based asphalt sealants (Mahler et al. 2005).

a. PAHs in sediments

Ecology sampled sediments at 10 fixed stations each spring from 1989 through 2000 (Figure 4-25). Stations were chosen from a variety of habitats and geographic locations in Puget Sound. Sediments from each station were analyzed for particle size, organic carbon content, and the presence of more than 120 chemical contaminants, as well as the types and abundances of sediment-dwelling organisms.

Chemical contaminants in the sediments were measured yearly from 1989 through 1996 and again in 2000. The contaminants examined included priority pollutant and ancillary metals, as well as organic compounds, such as PAHs, chlorinated pesticides, and PCBs. Changes in sediment condition over this time included increases in levels of PAHs at some stations.

Status and Trends

Concentrations of most PAH compounds did not change significantly over the study period; however, most of those that *did* change increased in concentration. There was a significant overall increase in benzofluoranthenes and increases in PAHs at stations in Bellingham Bay, Port Gardner, and Anderson Island. In contrast, there was a significant decrease in PAHs at the Point Pully station (Table 4-4).

Impacts to the Ecosystem

The PSAMP sediment monitoring program provides a vital record of sediment conditions in Puget Sound and gives insight into the effects of both natural and human-driven stressors on the estuary. The fixed sentinel stations monitored in this program can raise red flags, highlighting important environmental changes affecting Puget Sound.

b. Biota Exposure to PAHs

Exposure studies allow researchers to determine if an organism has been exposed to a compound or contaminant in the environment. The concentration of a known compound is typically measured from muscle tissue, lipids, or the whole organism. Exposure studies do not indicate whether the organism's health has been affected.

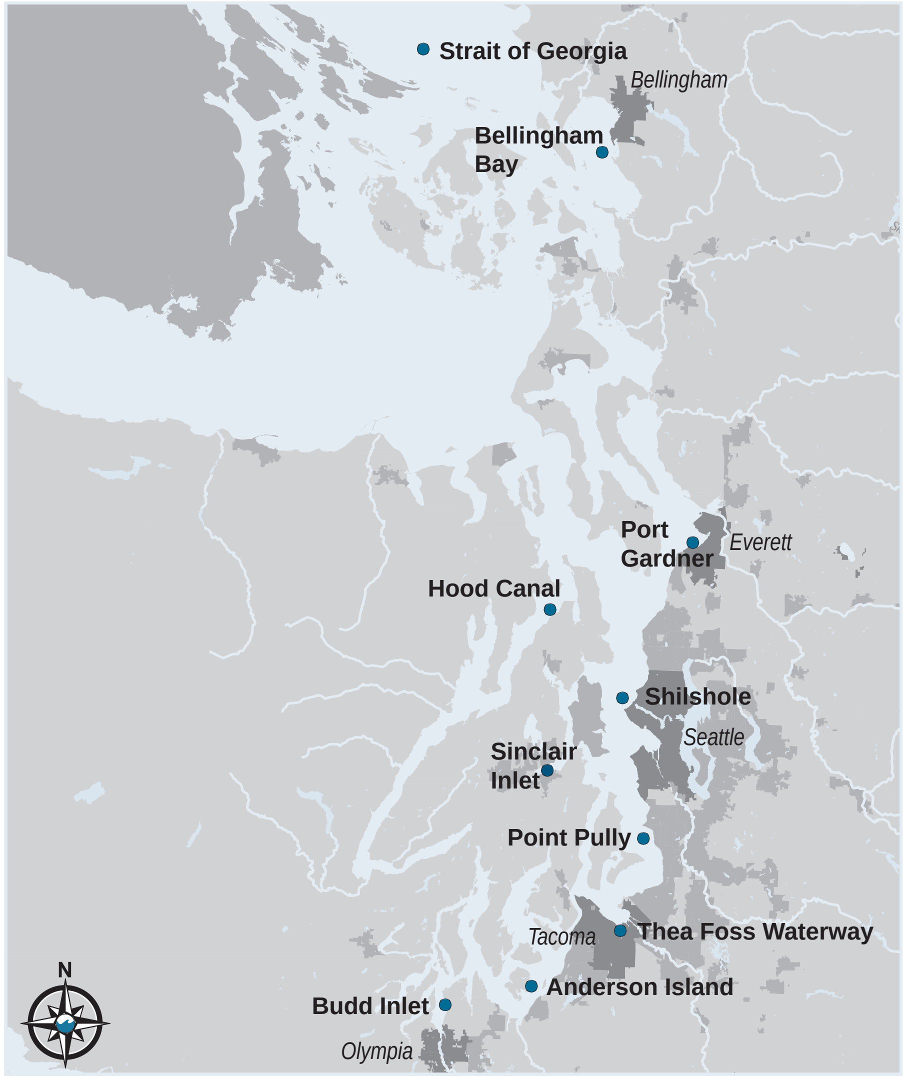


Figure 4-25. Location of PSAMP's 10 long-term monitoring sites in Puget Sound.
(Source: Ecology)

i. PAHs in Mussels

Since 1986, NOAA's National Status and Trends Mussel Watch Program has been monitoring contaminants in mussels from Puget Sound, the Strait of Juan de Fuca, and the Pacific Ocean coast of Washington. The Mussel Watch Program analyzes nearly 150 separate chemicals in whole soft tissue from composites of two mussel species collected at each of 12 sites in Puget Sound and four sites on the Pacific Ocean coast. Samples were collected annually until 1994 and every other year since then. The Mussel Watch program data can help track changes in contaminants, including PBTs, PAHs, and metals that accumulate in mussel tissue, providing a gauge of water quality near monitoring sites.

Status and Trends

Median concentrations of PAHs[3] in mussel tissue from Puget Sound sites range from 200 to 4,000 parts ppb dry weight (dw). These concentrations range from one to more than 10 times the national median value of 220 ppb dw.

The pattern of PAH concentrations in mussel tissue in Puget Sound has varied over the last two decades. PAH levels declined in the mid-1980s, then increased

[3]TPAHs in ppb dry weight is the sum of 18 parent compounds of dry tissue weight.

PAH Compounds	Station Change 1989-1996 vs. 2000											Station Trend 1989-2000										
	Strait of Georgia	Bellingham Bay	Hood Canal	Port Gardner	Port Gardner[oc]	Shilshole	Sinclair Inlet	Point Pully	Thea Foss WW	Anderson Island	Budd Inlet	Strait of Georgia	Bellingham Bay	Hood Canal	Port Gardner	Port Gardner[oc]	Shilshole	Sinclair Inlet	Point Pully	Thea Foss WW	Anderson Island	Budd Inlet
LPAHs																						
2-Methylnaphthalene	↑	↑		--	--	--	--	--	↑			↑	--	--	--	--	--	--	--	--	--	--
Acenaphthene				--	--		--		--						--	--	--	--	--	--		--
Acenaphthylene				--	--		↑	--	--					--	--	--	--	--	--	--	--	--
Anthracene	--	--		--	--	--	--	↓	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Fluorene	--	--		--	↑	--	--	--	--		--	--	--		--	↑	--	↑	--	--	--	--
Naphthalene	--	↑		--	--	--	--	--	↑	--	--	↑	--	--	--	↑	--	--	--	--	--	--
Phenanthrene	--	--	--	--	--	--	--	↓	--	↑	--	--	--	--	--	--	--	--	--	--	--	--
Retene	--	--		--	--	--	--	--	↑	--	--	--	--	--	--	--	--	--	--	↑	--	--
Total LPAH	↑	↑	--	--	--	--	--	--	--	↑	↑	↑↑	--	--	--	↑	--	--	--	--	--	--
HPAHs																						
Benzo(a)anthracene	--	↑		--	↑	--	--	--	--	↑	--	--	--	--	--	--	--	--	--	--	--	--
Benzo(a)pyrene	--	--		--	--	--	--	--	--	↑	↑	--	--	--	--	--	--	--	--	--	--	--
Total Benzofluoranthenes	↑	↑	--	--	↑	↑	--	--	--	↑	↑	--	--	--	--	--	--	--	--	--	--	--
Benzo(g,h,i)perylene	--			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Chrysene	--	--		--	--	--	--	↓	--	↑	--	--	--	--	--	--	--	--	--	--	--	--
Dibenzo(a,h) anthracene						--	--	--	--						--	--	--	--	--	↓		
Fluoranthene	--	--	--	--	--	--	--	↓	--	↑	--	--	--	--	--	--	--	--	--	--	--	--
Indeno(1,2,3-c,d)pyrene	--	--		↑	↑	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Perylene	↑	↑		--	--	↑	--	--	--	--	--	--	--		--	--	--	--	--	--	--	--
Pyrene	--	↑	--	--	↑	--	--	↓	--	↑	↑	--	--	--	--	--	--	--	--	--	--	--
Total HPAH	--	↑	--	--	--	--	--	--	--	↑	--	↑	--	--	--	--	--	--	--	--	--	--
Total PAH	--	↑	--	--	--	--	--	--	--	↑	↑	↑	--	--	--	--	--	--	--	--	--	--

Table 4-4. Changes and trends in both low- and high-molecular-weight PAH compound concentrations in sediments collected from 1989 through 2000. While most PAH compounds did not change significantly during the study period, those that did change generally increased in concentration. Blank boxes indicate insufficient data. Double arrows at the Strait of Georgia indicate greater change, compared to the other sites.
(Source: Ecology)

↑,↓......... increase, decrease (α = 0.05)

↑↑, ↓↓ ... increase, decrease (α = 0.01)

-- .... no change

blank...... insufficient data

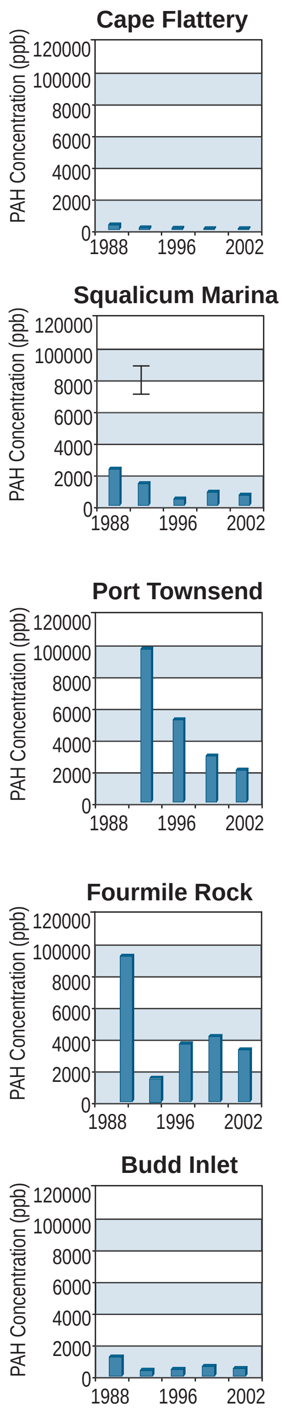
Shaded results indicate changes for all stations combined for a single compound or for all compounds combined for a single station, at α=0.05 (dark) or α=0.10 light.

oc = data normalized to organic carbon.

slightly in the mid-1990s. Overall, PAHs in mussel tissue appears to be in decline. Everett Harbor had the highest concentration in 2000, at 31,750 ppb (off the scale in Figure 4-26); however, concentrations at that site were not consistently that high over the years. A second site with high mussel PAH concentrations was Port Townsend. The Port Townsend Mussel Watch site is located at the south side of the marina and sampling did not begin here until 1990. Nevertheless, this site had the highest concentrations in 1990—8,000 to 12,000 ppb dw. Those concentrations fell to about 2,500 ppb dry weight by 2002.

Elsewhere throughout Puget Sound and the Strait of Juan de Fuca, PAH concentrations were about 1,000 to 2,000 ppb dry weight in the mid-1980s. Concentrations had declined to below 1,000 ppb dry weight by 2002; however, as with PCBs, there was an increase in PAH concentration in the mid-1990s, most notably at Fourmile Rock, Everett Harbor and Duwamish Head. Generally, during

Figure 4-26. **Total PAHs in Puget Sound mussel tissue.** PAH levels have generally declined, with highest concentrations in Everett and Fourmile Rock near Seattle. Median tPAH levels from all national sites sampled 2002/2003 was 220 ppb dry weight). (Source: NOAA)



the past two decades, sites with the lowest TPAH concentrations (<200 ppb dry weight but as low as 10 to 20 ppb dry weight) were along the Pacific Ocean coast and in northern Puget Sound.

ii. Crabs and Fish

PSAMP scientists have previously described PAH-exposure of English sole, Pacific herring, rockfish, and Dungeness crab in the *2000* and *2002 Puget Sound Updates*. Combining results for all species for multiple years between 1998 and 2005[4] indicates that the greatest exposure to PAHs generally occurs in urbanized embayments or shorelines (Figure 4-27). Concentration of PAHs was six times greater in Dungeness crab from one urban location (Thea Foss Waterway) than two non-urban locations (Vendovi Island and the Cherry Point shoreline). The bottom-dwelling fish species (English sole and rockfish) also exhibited three to four times greater exposure (as measured by the PAH metabolic biliary phenanthrene) to PAHs in the Thea Foss Waterway, Elliott Bay, Sinclair Inlet, and

[4]Sampling occurred in the following years for the following species:
Dungeness crabs - 2001
Pacific herring - 1999, 2000, 2001, 2002, and 2004
English sole - 1998, 1999, 2000, 2001, 2003, 2005
Rockfish - 1998, 1999, 2002 and 2001 however, not all rockfish species were sampled in all years.

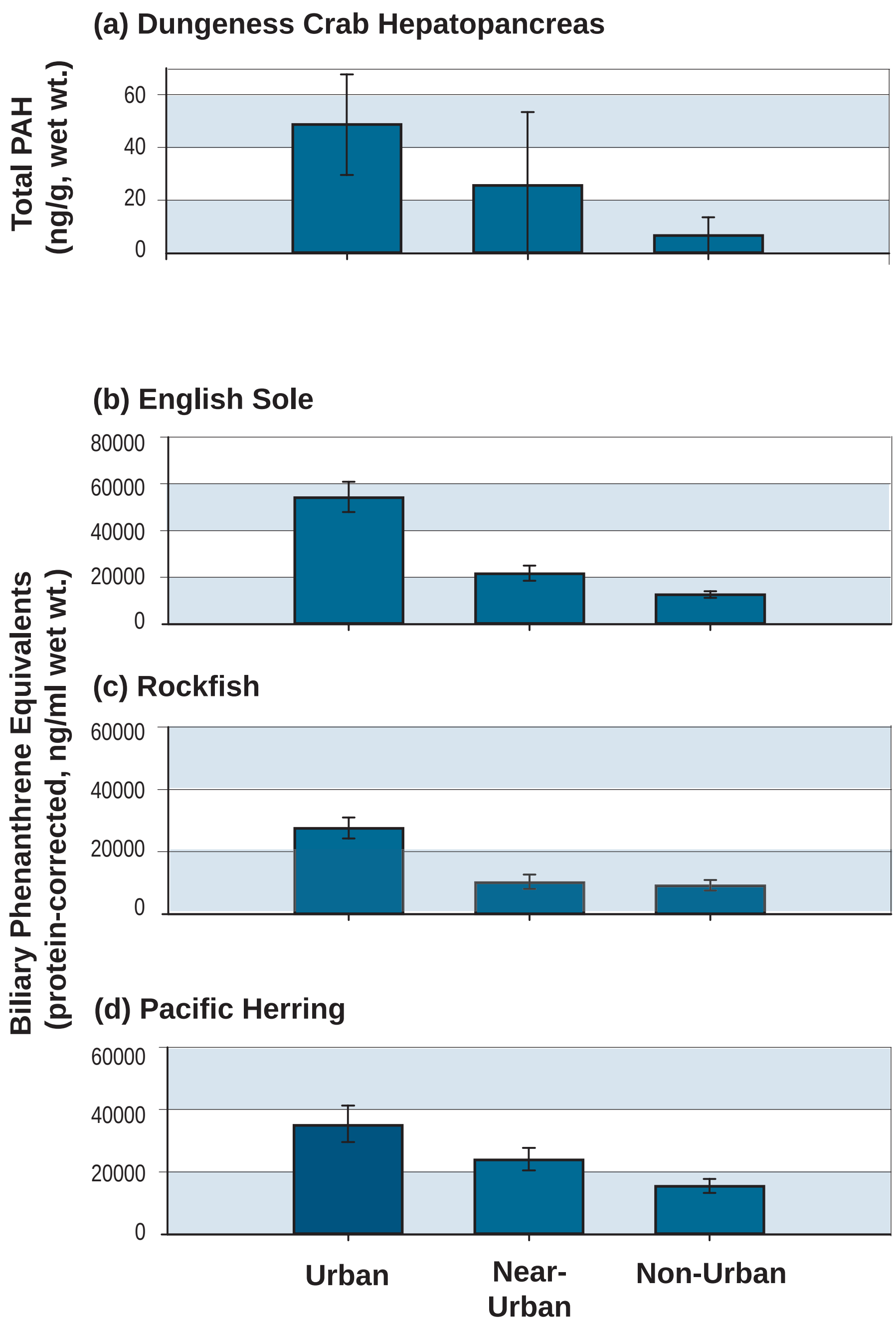


Figure 4-27. **Exposure to PAHs in urban embayments**. Exposure to PAHs (as indicated by the presence of the biomarker biliary phenanthrene in the bile) is greatest in urbanized embayments or shorelines for bottom-dwelling species (Dungeness crab, English sole, and rockfish), or in urbanized basins (Central Puget Sound) for a pelagic species such as Pacific herring. PAHs were measured directly in crab tissue and as PAH-metabolites in fish bile. (Source: WDFW)

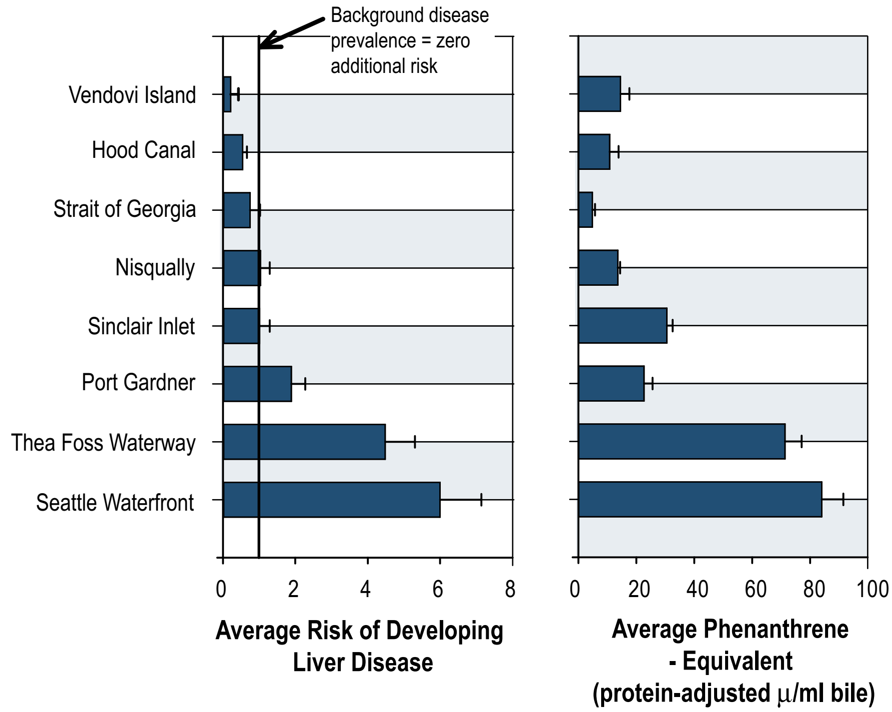
Port Gardner, than at non-urban sites. For the pelagic species (Pacific herring), PAH exposure of an urban population (Port Orchard/Madison stock in central Puget Sound) was more than twice that of a non-urban herring (Semiahmoo stock in the Strait of Georgia).

c. Effects of PAHs on Biota

i. English Sole

In previous editions of the *Puget Sound Update*, PSAMP, WDFW and NOAA scientists have described the connection between PAH exposure and its effects, primarily liver disease and reproductive impairment in English sole. PSAMP scientists have been monitoring both exposure and effects in English sole as an indicator of the health of bottom-dwelling fishes in Puget Sound.

Figure 4-28. Risk of developing liver disease and exposure to PAHs in English sole. Study was conducted at eight long-term monitoring stations. English sole from two urban locations exhibited a high risk of developing liver disease. The Seattle waterfront had six times the risk and the Thea Foss Waterway had four times the risk relative to uncontaminated baseline stations. Both urban locations had relatively high exposures to PAHs as reflected in the measured phenathrene, a byproduct of PAH metabolism (>60 ug/ml). Port Gardner exhibited a relatively small risk (two times the baseline) and relatively low PAH-exposure, while all other locations exhibited risk equivalent to or less than baseline and low PAH exposure. Risks were averaged over a 17-year period, and PAH exposure was averaged over an eight-year period. (Source: WDFW)



Status and Trends

Observations for PAH-related liver disease in English sole for a period spanning 17 years, from 1989 through 2005, from six locations, and for slightly shorter periods from two additional locations are summarized in this update. PAH exposures have been measured since 1998 in sole from these eight locations, which represent a range of conditions from highly urbanized or industrialized to more remote uncontaminated locations.

Of the eight long-term English sole stations that PSAMP scientists monitor, both PAH exposure and the risk[5] of developing liver disease have been consistently greatest in individuals taken from two urban locations—the Seattle waterfront and Thea Foss Waterway (Figure 4-28).

English sole from another urban location, Sinclair Inlet, have consistently exhibited low prevalences of liver disease and PAH exposure, even though these fish exhibit high concentrations of PCBs and other toxics characteristic of Puget Sound's urban habitats (Figure 4-27). Sole from Port Gardner exhibited disease risk of two times the baseline, while sole from five other sites exhibited disease risk equivalent to or less than baseline. PAH exposure was low in all six locations, relative to that of the Seattle waterfront and Thea Foss Waterway.

High prevalence of liver disease in English sole has also been reported in Eagle Harbor, where PAH source control and cleanup have occurred, and where NOAA scientists have documented the recovery of English sole health over the past decade. (See Focus Study: Eagle Harbor Capping on page 172.)

[5] Risk is calculated using logistic regression to compare the prevalence of liver disease (i.e., the number of fish exhibiting any disease, as a percentage of the total) at a location, to prevalence of disease in English sole from 19 uncontaminated background, or baseline locations. The risk at baseline locations is 1.0, and the risk at other locations is expressed as the increased or decreased predicted likelihood of developing disease relative to that baseline (e.g., 10x). The analysis accounts for the natural increased likelihood that English sole will develop liver disease as they age, even in the absence of PAHs and other toxic compounds.

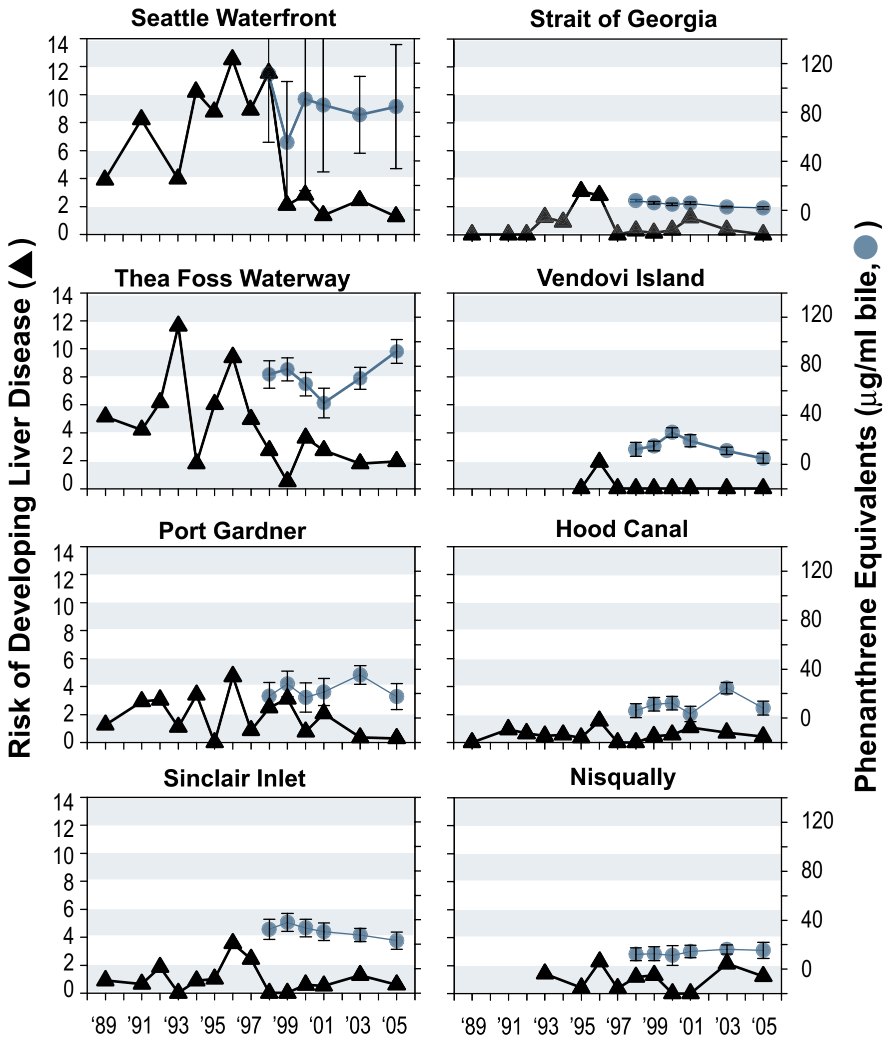


Figure 4-29. Trends in liver disease risk and exposure to PAHs in English sole. Long-term trends in risk of developing liver disease (triangles), 1989–2005, and in exposure to PAHs (circles), as measured by the biomarker biliary phenanthrene equivalents in the bile, 1997-2005. Both the Seattle waterfront and Thea Foss Waterway had higher risk of developing liver disease, compared to other locations in Puget Sound. Analysis is based on six composite samples per year. (Source: WDFW)

In the 17 years that liver disease has been monitored in Puget Sound's English sole, decreasing trends have been observed at the Seattle waterfront and Thea Foss Waterway—the two urban locations that have historically exhibited the greatest overall disease prevalences (Figure 4-29). Risk at the Seattle waterfront increased over the first 10 years of monitoring (1989-1998), with an average of 8.5 times the baseline in that period and a peak in 1996 of 12.5 times the baseline. Risk at the Seattle waterfront declined sharply from 1999 through 2005, with an average of two times the baseline risk during this period. A similar decline occurred at the Thea Foss Waterway, with average and peak risks of six times the baseline and 12 times the baseline prior to 1998, and an average of two times the baseline from 1998 through 2005.

It is difficult to correlate time trends in PAH exposure with liver disease, because PSAMP's monitoring of PAH exposure in English sole bile began in 1998, missing the period of high liver disease prevalence in the early to mid-1990s. It is possible that slowing declines in liver disease at the Seattle waterfront and Thea Foss Waterway result from localized sediment cleanup measures and source controls; however, this is not clear from PAH exposure measures. This could result from the time lag that occurs between source removal (exposure) and recovery from liver disease. In addition, English sole probably forage over a larger range than is encompassed by individual recovery (e.g., sediment capping) efforts. Hence,

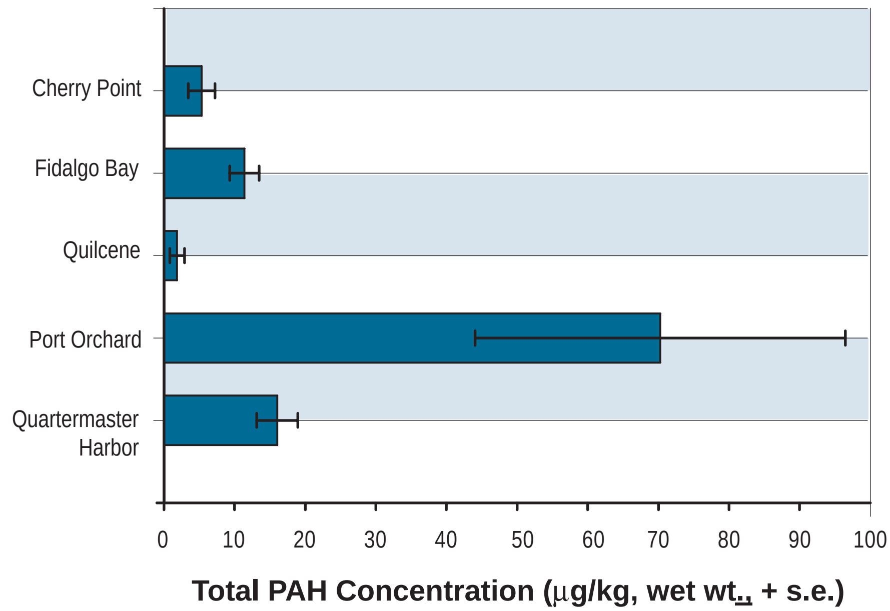


Figure 4-30. PAHs in herring eggs. Total PAHs were greatest in spawned herring eggs sampled from the Port Orchard/Madison spawning grounds. (Source: WDFW)

during sediment years when sediment cleanup is occurring, variability in PAH exposure may increase, while overall exposure decreases. This appears to be the situation at the Seattle waterfront.

ii. Herring Eggs

PSAMP scientists have assessed PAH exposure in developing embryos of Pacific herring. This otherwise pelagic species spawns adhesive eggs on intertidal and shallow subtidal structures, especially on algae and seagrasses. Shoreline habitats are particularly susceptible to large and small oil spills and to PAH inputs from shoreline sources, such as runoff and river inputs. PSAMP scientists sampled developing herring embryos from five locations throughout Puget Sound in 1999, 2001, and 2002, representing five of the Sound's major spawning stocks.

Status and Trends

Embryos of Port Orchard/Madison herring in their typical spawning habitats (along the northern and western shore of Bainbridge Island and northern Port Orchard) exhibited five to 15 times the concentrations of Total PAH (TPAH) than those from four other locations throughout the Sound, including two near oil refineries or transfer stations (Fidalgo Bay and the Cherry Point shoreline) (Figure 4-30). Port Orchard/Madison embryos also exhibited a high variability in TPAH concentrations, which was related to differences in specific collection locations and developmental stages of the embryos (Figure 4-31). One Port Orchard/Madison spawning location, Point Bolin, exhibited low TPAH, while another, Hidden Cove, exhibited relatively high TPAH. In addition, TPAH increased in Hidden Cove embryos as they aged: samples of 10-day-old embryos had up to four times the TPAH concentrations of three-day-old embryo from the same location, collected a week prior. TPAH concentrations observed in embryos from Hidden Cove were high enough to suspect toxicological impacts. In one experiment (Carls et al. 1999), developing herring embryos were exposed to aqueous PAHs at concentrations of TPAH between 22 and 108 ng/g (embryo tissue, wet weight) and became malformed or died. Total PAH concentrations in four of five Hidden Cove samples were well above the 22 ppb lower threshold, and samples from Point Bolin, as well as all others from the four other spawning stocks (Figure 4-30), were well below this threshold.

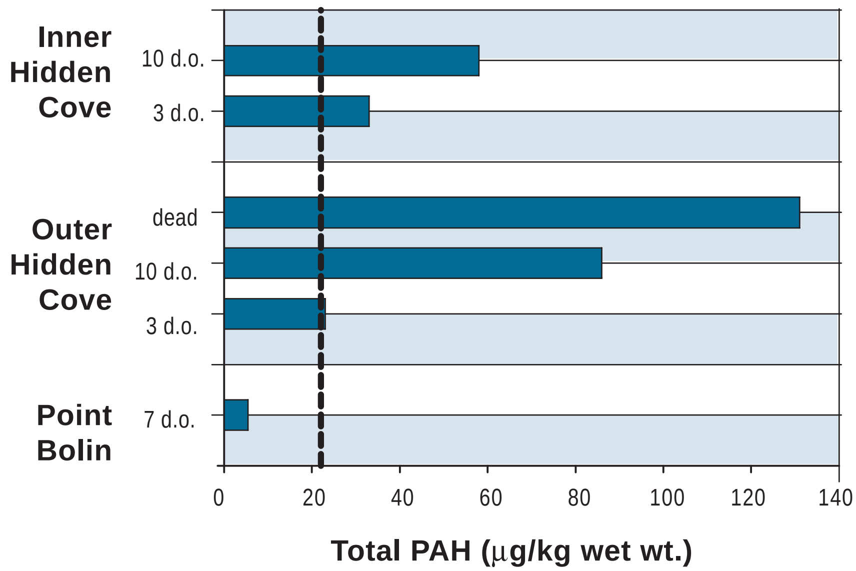


Figure 4-31. Variability in herring eggs from Port Orchard. High variability in Total PAH (TPAH) from Port Orchard/Madison spawned eggs is related to specific spawning location and age of embryos. High TPAH concentrations were observed in embryos taken from two locations within Hidden Cove, but not from Point Bolin, 5.5 miles (9 km) away. In addition, 10-day-old embryos had greater TPAHs than did those recently spawned (three-days-old), indicating that PAHs accumulated in embryos as they developed. Greatest TPAH levels were observed in dead embryos (probably older than 10 days). The vertical dashed line indicates a total PAH concentration, or threshold, beyond which exposed embryos begin to die.
(Source: WDFW)

d. PAHs and Creosote

Creosote is an effective tar-based wood preservative that has been in use for over 100 years, to preserve railroad ties, telephone and power poles, wharf and pier pilings, beach access stairways, railings, and other landscaping features. There are a variety of commercial creosote formulas containing as many as 300 different chemicals, a large portion of which are PAHs, known to be toxic. PAHs are associated with disease and other health problems in English sole and other marine fish. Researchers at NOAA's Northwest Fisheries Science Center state that failure to achieve acceptable minimum levels of PAHs in sediments will result in impaired productivity of fish stocks (Johnson, Collier, and Stein 2002).

Creosote wood debris has been observed on beaches throughout Puget Sound. Whether freshly washed up or buried in the intertidal zone for decades, this debris can leach creosote continually. Researchers with the Skagit Marine Resources Committee found that even 60-year-old pilings are leaching creosote daily into the marine environment, and a scratch with a finger nail can bring fresh chemicals to these pilings' surfaces (Dinnel 2005). One cubic foot of creosote-treated wood contains at least 20 pounds (9 kg) of creosote.

Status and Trends

NWSC and DNR have identified creosote removal as a high priority and are actively surveying and removing creosote debris from beaches. Marine Resources Committees in Whatcom and Skagit counties and the Padilla Bay National Estuarine Research Reserve organized a creosote removal program between 2002 and 2005. The goals of the program are to inventory and remove creosote debris on Northern Puget Sound and the Strait of Juan de Fuca beaches, better understand the rate of deposition of creosote debris on the beaches, and identify sources of creosote contamination. To date, the program has resulted in the removal of 275 tons (124 kg) of debris from 112 miles (180 km) of shoreline in Whatcom, Skagit, and Island counties and in Padilla Bay (Table 4-5, Page 174). Large removal projects at Dungeness Spit National Wildlife Refuge, Lake Hancock, Jetty Island, and San Juan Historical Park are scheduled to occur in late 2006.

Focus Study

Restoration of English Sole Health Following Capping of Contaminated Sediments in Eagle Harbor

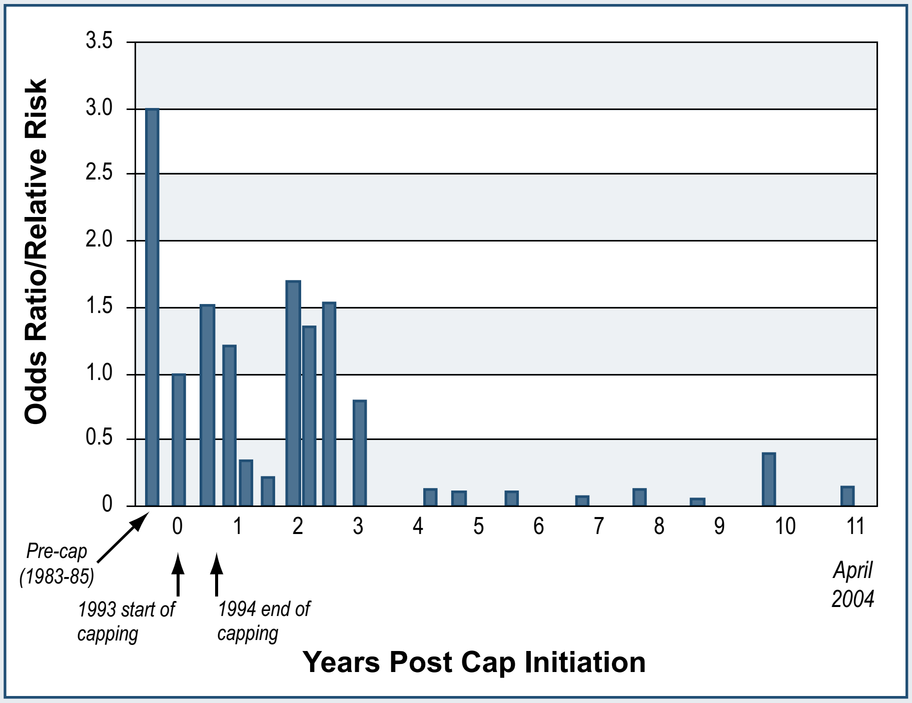


Figure 4-32. **Risk of liver lesions in English sole in Eagle Harbor, 1983-2004.** Risk of lesion occurrence defined as 1.0 at start of capping. Relative risks at other sampling timepoints determined by stepwise logistic regression, after accounting for fish age. (Source: NOAA)

Eagle Harbor on Bainbridge Island was designated as a Superfund site by the EPA in 1987 because of high sediment concentrations of PAHs released chronically from a nearby creosoting facility. These high levels of PAHs were associated with adverse biological effects in resident fish species. Earlier studies (1983-1986) by NOAA scientists on English sole from this site showed high prevalence (up to 80 percent) of liver lesions, including tumors in resident fish.

Scientists have demonstrated in multiple field studies that these lesions are strongly and consistently associated with PAH exposure, and have also shown that liver lesions can be induced in sole by injections of a PAH-rich fraction extracted from Eagle Harbor sediment. Further studies from 1986 through 1988 incorporated biochemical biomarkers of PAH exposure and effects. Prior to site remediation, liver lesion occurrence and biomarker values in English sole from Eagle Harbor were among the highest in Puget Sound.

As part of a combined EPA/Army Corps of Engineers effort, a cap of clean sediment was placed over the most contaminated portions of Eagle Harbor in 1993 and 1994 in an attempt to immobilize PAH-contaminated sediments. NOAA Fisheries scientists found that liver lesion prevalences and biomarker values just before capping were somewhat reduced, compared to historical data, consistent with the closure of a creosoting facility and implementation of shore-based source controls.

English sole were collected immediately before and after capping, and at regular intervals for 128 months after sediment capping. Scientists found that toxicopathic

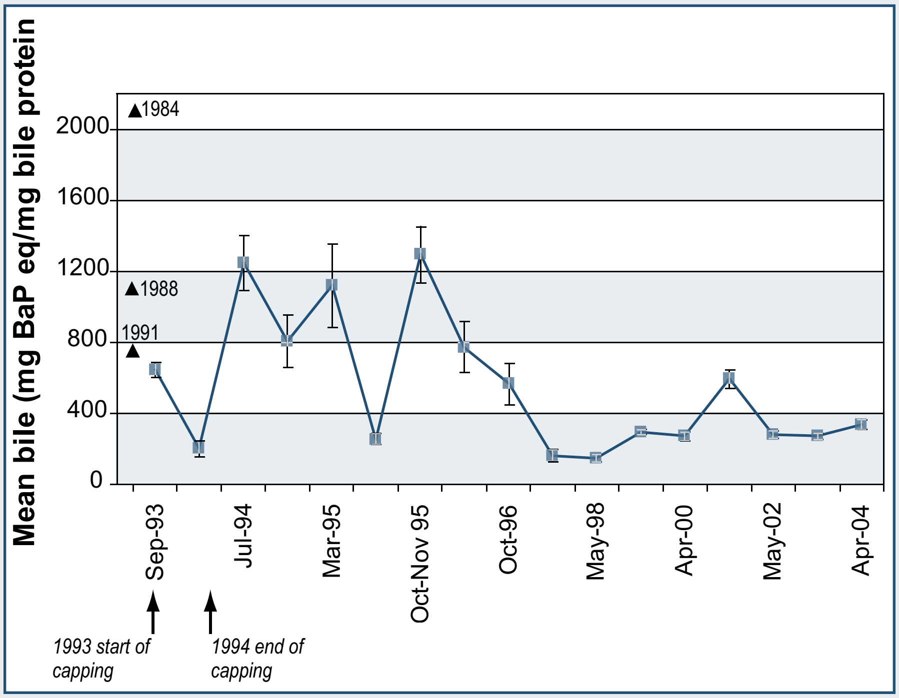


Figure 4-33. Biliary FACs (a biomarker for PAH exposure) in English sole from Eagle Harbor. Biliary FACs have declined since the late 1990s following capping. (Source: NOAA)

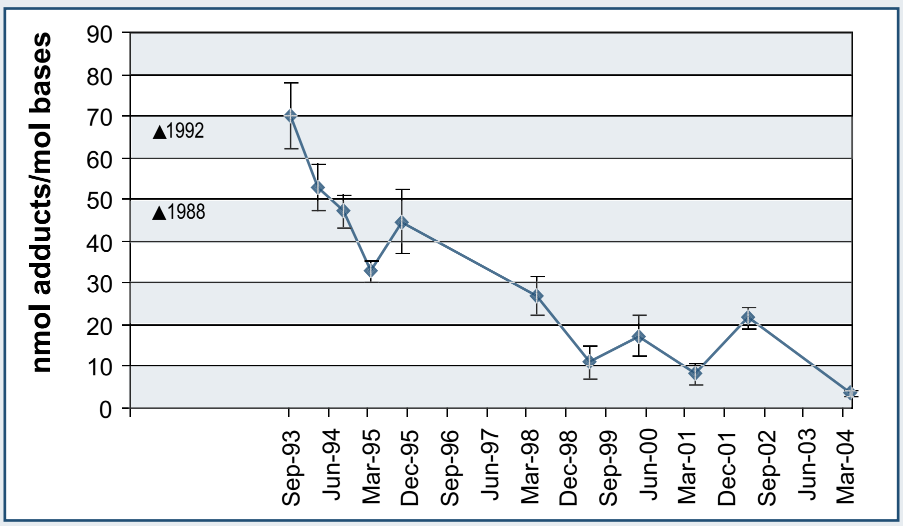


Figure 4-34. DNA adducts (a biomarker for PAH exposure) in English sole from Eagle Harbor. The prevalence of this biomarker has declined in English sole since capping took place in 1993. (Source: NOAA)

liver lesion risk (a calculated parameter that is based on lesion prevalence and fish age), and levels of two biomarkers—metabolites of PAHs that bind to the DNA in liver cells (hepatic DNA adducts) and fluorescent aromatic compounds (FACs) or metabolites of PAHs found in bile (biliary FACS), were highly variable over the first two to three years following sediment capping, relative to values prior to cap placement. Over the entire monitoring period there was an overall decrease in risk for hepatic lesions in English sole (Figure 4-32). There was also a decline in the two biomarkers; biliary FACs (Figure 4-33); and hepatic DNA adducts (Figure 4-34). In particular, the risk of hepatic lesion occurrence in English sole has been consistently low (> 0.20), compared to lesion risk at cap initiation (1.0), from approximately four years after sediment cap placement through April 2004.

These results show that the sediment capping process has been relatively effective in reducing PAH exposure and associated biological effects in resident flatfish species.

Table 4-5. Creosote wood debris removal in northern Puget Sound, between 2002 and 2005. In total, 275 tons of creosote were removed from 112 miles of beach. (Source: Northwest Straits Commission).

Site	Creosote debris removed	Shoreline in project area
Whatcom County shoreline	100 tons	
Padilla Bay	30 tons	26 miles
Skagit County	35 tons	80 miles
Island County	210 tons	6 miles, plus Double Bluff Beach

Impacts to the Ecosystem

Studies with herring embryos demonstrated that water-diffusible compounds from creosote-treated pilings disrupted normal development, and proximity to the pilings was directly correlated to survival (Vines et al. 2000). Northwest Straits beaches are frequently spawning sites for surf smelt and sand lance—two of the local forage fish that are important prey for salmon, marine birds, and other wildlife.

5. Oil Spills

Each year, commercial ships transport about 15.8 billion gallons of crude oil and refined petroleum products through Puget Sound. The total number of vessels and the amount of oil that each vessel can carry have both increased, therefore increasing the risk of oil spills in Puget Sound. For example, newer container ships can now carry up to 3.8 million gallons of fuel, while oil tankers carry upwards of 40 million gallons. Additional sources of potential oil spills are large marine oil terminals, refineries, oil pipelines, land transportation and smaller commercial or recreational boats. A major oil spill in Puget Sound could be catastrophic for Puget Sound marine life and shorelines.

The following section summarizes the overall oil spill statistics for Puget Sound.

Status and trends

Since 2005, there have been no **major** spills (10,000 gallons or more). There have been 19 **serious** spills (25 gallons or more) with about 4,000 gallons reaching Puget Sound. Of this amount, commercial vessels spilled at least 3,160 gallons. Figure 4-35 shows locations of oil spills in Puget Sound since 1998.

Since 1998, Puget Sound and its tributaries experienced one major spill (in 1999), and 165 serious spills, totaling at least 350,000 gallons (Figure 4-36). During each of the last nine years, the total number of oil spills reported to Ecology has stayed about the same, while the number of serious spills has decreased from 23 to about 13 spills per year (Figure 4-37). Spills larger than 25 gallons are included in this tally.

While it is difficult to characterize trends in these low-probability high-impact events, it appears that the volume of oil released from large spills has steadily declined in the last 15 years.

a. Dalco Oil Spill, 2004

An estimated 1,000 gallons of unknown oil product was released to the waters of southern Puget Sound on October 14, 2004, in the vicinity of Commencement Bay and Dalco Passage near Vashon and Maury islands. Oiled beaches were reported on the southern ends of both Vashon and Maury islands, and oil was reported on Puget Sound waters in Colvos Passage and central Puget Sound.

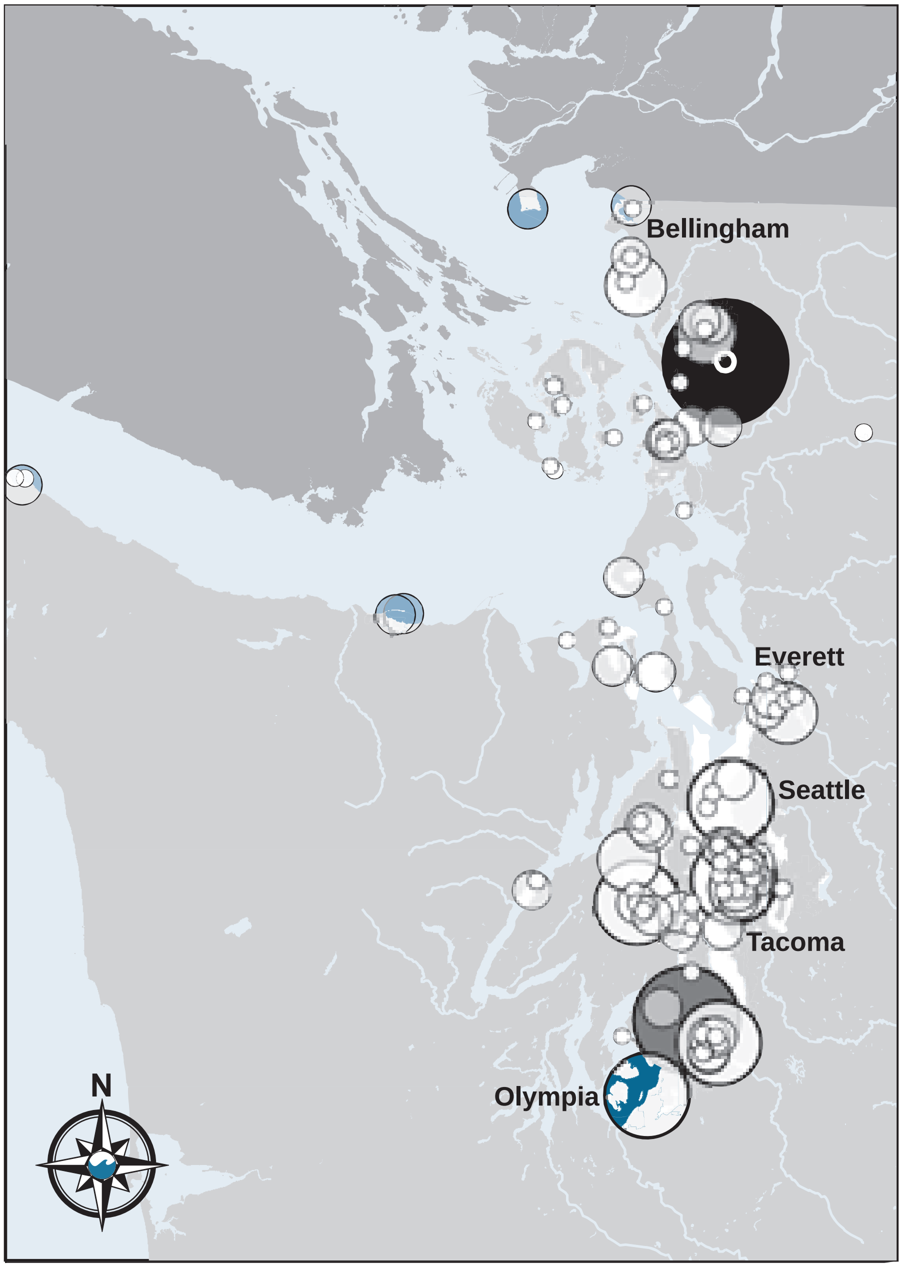
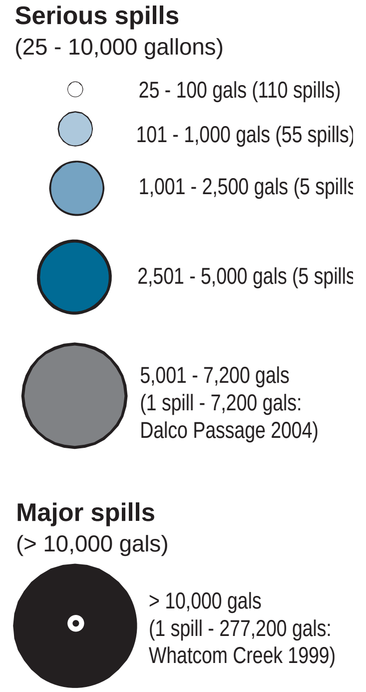


Figure 4-35: **Map of location and volume of oil spills in Puget Sound 1998-2006**. The cumulative volume of oil spilled into Puget Sound during this period is approximately 350,000 gallons, from 165 serious and one major spill.
(Source: Ecology)

Location and volume of oil spills, 1998-present (in gallons)



Ecology and WDFW staff collected intertidal sediment samples, along with some tissue and water samples, from the area of immediate impact, as well as from other areas in King, Pierce, and Kitsap counties.

Status and Trends

King County conducted a reconnaissance survey of intertidal sediments to aid in evaluating impacts to both King County properties and other properties located within its borders. The survey involved the collection of 30 intertidal sediment samples from 18 stations located on Vashon and Maury islands and along the mainland shoreline of south King County (Figure 4-38). The samples were analyzed for a variety of chemical and physical parameters to aid in evaluating impacts to Puget Sound shorelines from the oil spill.

Figure 4-36. Total volume of oil spilled per year from 1998-2006. (Source: Ecology)

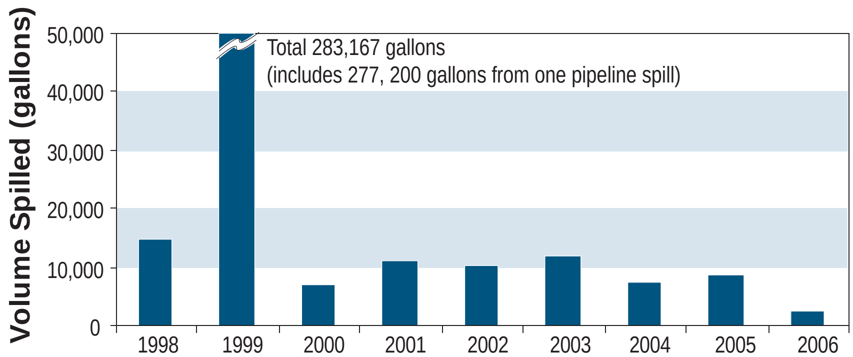


Figure 4-37. Total number of oil spilled in Puget Sound from 1998-2006. Spills of 25 gallons or more are included in this total. (Source: Ecology)

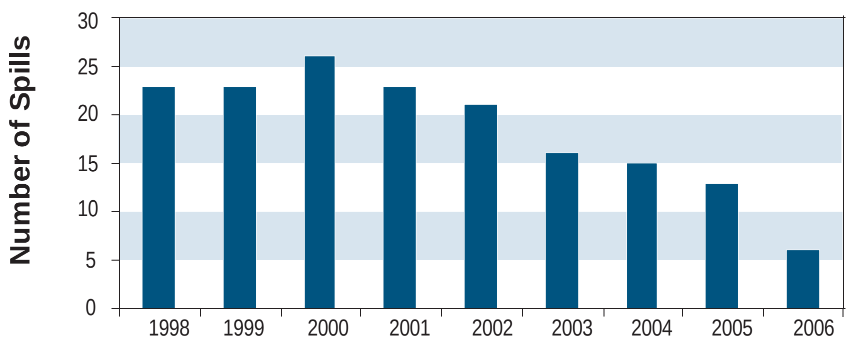
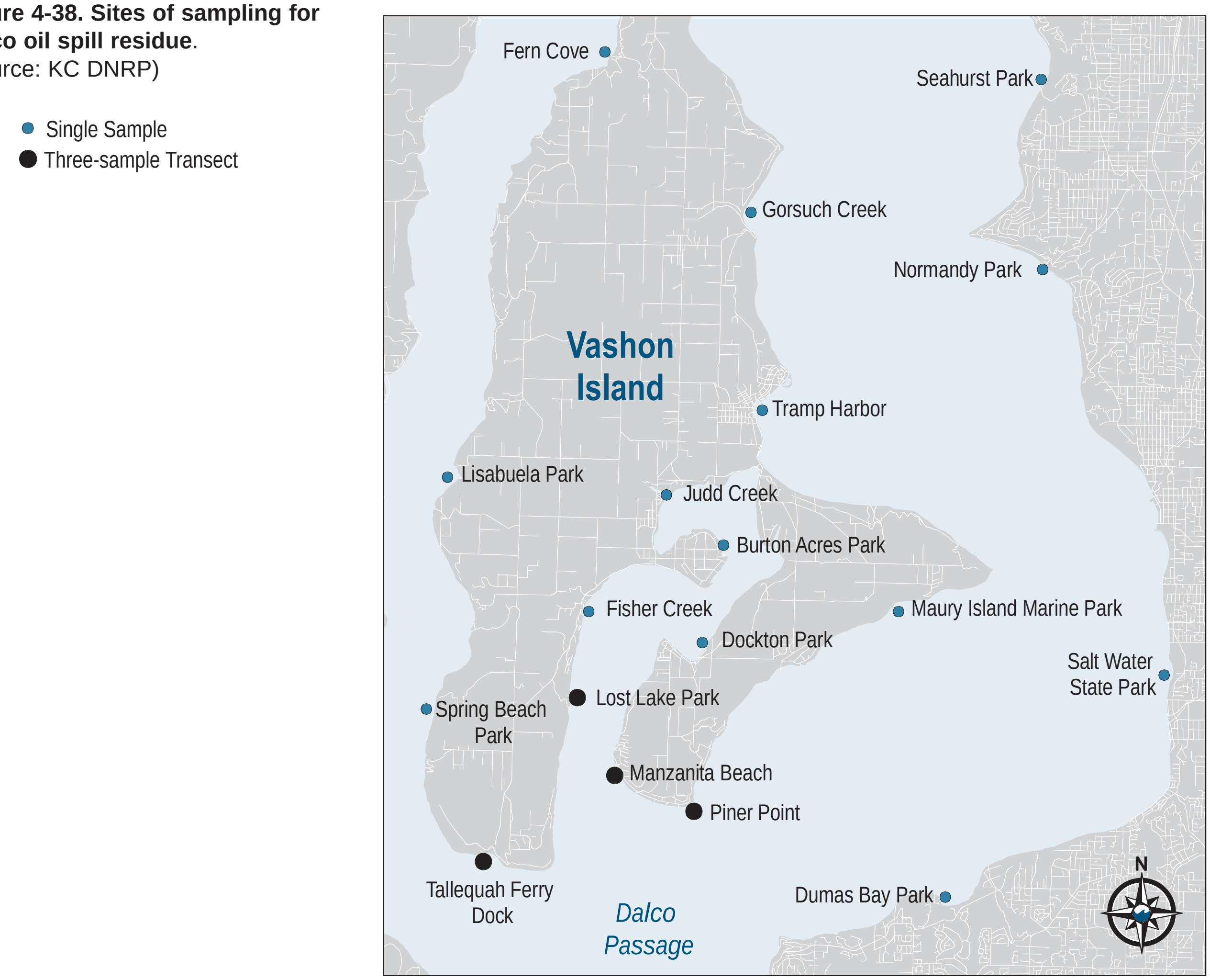


Figure 4-38. Sites of sampling for Dalco oil spill residue. (Source: KC DNRP)



Single samples were collected from the plus 7-foot-tide height (referenced to mean lower-low water) at 14 of the sampling stations. A three-sample transect was performed at each of the other four stations, with samples collected from the previous high water mark (indicated by the wrack line), the plus 7-foot-tide height, and the water line at the time of sampling.

All 30 samples were analyzed for petroleum hydrocarbons and PAHs, and those samples collected from the four southernmost stations were also analyzed for PCBs.

Petroleum hydrocarbons were not detected at any of the 18 stations sampled. Trace levels of several PAH compounds were detected at many of the stations sampled. Elevated PAH concentrations were detected at the Tahlequah ferry dock station; however, these concentrations were still well below the Puget Sound Apparent Effects Thresholds[6]. It appears that elevated PAH concentrations detected at the Tahlequah station are the result of legacy contamination from the dock and normal ferry operations. PCBs were not detected at any of the four stations sampled, and PCB analysis was not performed on samples collected from the other 14 stations, based on petroleum hydrocarbon and PAH analytical results.

Based on the results of this intertidal sediment reconnaissance survey, it does not appear that the Dalco Passage oil spill had a lasting impact on intertidal sediment quality at the 18 locations from which King County collected samples.

b. Oil Spill at Point Wells, 2003

On December 30, 2003, nearly 5,000 gallons of diesel oil spilled into Puget Sound at Point Wells near Richmond Beach. Over the next two days, the oil came ashore along 1.5 miles of the northern shore of Port Madison, between Point Jefferson and Indianola. The pristine beach and an adjacent marsh were heavily oiled, and shellfish and other intertidal organisms were contaminated. Cockles, native littleneck, butter, manila, and eastern softshell clams had elevated levels of PAHs, particularly near the marsh. PAH levels ranged from 173 to 17,000 parts per billion.

Status and Trends

During the week following the oil spill, federal and state agencies, the Shoreline Cleanup Assessment Team (SCAT) and the Responsible Party (RP) carried out wildlife surveys from boats and helicopters and on foot along 30 miles of shoreline. Survey teams attempted to rescue 23 animals, including six birds that were oiled. Only two of the birds survived. One oiled seal pup was captured but subsequently died of pneumonia.

DOH's Office of Food Safety and Shellfish immediately closed the shoreline to shellfish harvest, due to concern for public health risks. By one month later, about 700 gallons of oil were recovered and 180,000 pounds of solid waste were removed, including 14 tons of oil-coated pea gravel from the upper intertidal zone.

There are no accepted international or federal limits for oil-related contaminants in shellfish. Seafood contaminated by oil is considered adulterated, meaning the contaminant may impart a taste or smell. Consumption of adulterated seafood is not regarded as an acute health risk.

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[6] The Apparent Effects Thresholds (AFT) is the concentration of a contaminant above which statistically significant likelihood of adverse affects is expected (EPA 1988).

6. Endocrine Disrupting Compounds

Endocrine disruptors are compounds that interfere with the normal actions of hormones in humans, fish, and wildlife. Environmental estrogens are an especially troublesome class of endocrine disruptors. These compounds include naturally occurring estrogens in plants and in animal waste, as well as synthetic estrogens and estrogen-like compounds (xenoestrogens) that are structurally similar to natural hormones. Xenoestrogens, which include some chlorinated pesticides, birth control pills, plastics and plasticizers, and surfactants in soaps and other personal care products, act as hormone mimics and may block natural hormone functions.

a. Monitoring for Endocrine Disrupting Compounds in Puget Sound

King County initiated a pilot monitoring study in 2003 to determine if Endocrine Disrupting Chemicals (EDCs) are present in surface waters of King County and, if so, at what concentrations. The County also wanted to better understand the potential for EDCs to effect aquatic life, and King County's data were compared to data from laboratory exposure studies. Samples were collected from marine waters, large lakes, rivers, and smaller streams, from stormwater discharges on Seattle's State Route 520 Bridge, and from stormwater discharges in the Sammamish River valley. These initial surveys were not intended to provide a comprehensive assessment of EDCs in King County waters. These data will be used to determine if future monitoring is warranted, and if so, to guide development of such a monitoring program.

Data for 16 EDCs were collected (Table 4-6). Five chemicals were never detected: estrone, methyltestosterone, progesterone, testosterone, and vinclozolin. Six chemicals were detected in greater than 20 percent of the samples: bisphenol A (BPA—a plasticizer), 17-β estradiol (a natural hormone known as E2), and 17α ethynylestradiol (a synthetic hormone, EE2), and three phthalates (bis (2-ethylhexyl) phthalate, diethyl phthalate, and di-N-octyl phthalate). The remaining five chemicals—nonylphenol (NP) (surfactant breakdown product), the phthalates benzyl butyl phthalate, bis(2-ethylhexyl) adipate, dimethyl phthalate, di-N-butyl phthalate—were detected less frequently. Many of the detected phthalates were also commonly detected in laboratory and field blanks, suggesting that their results be interpreted with caution.

Overall, the maximum detected concentrations for several chemicals were in undiluted stormwater runoff; other chemicals were detected at relatively similar concentrations across all water types. For the purposes of this preliminary study, and based on the limited data for some water types, only coarse differences between marine, lake, stream, and limited point-sources were distinguishable.

b. Effects of Endocrine Disrupting Compounds on English sole

Recent studies reveal that environmental estrogens are present in Puget Sound, based on monitoring vitellogenin induction in male English sole. Vitellogenin is the egg yolk protein produced by female fish during the reproductive season. Male fish, whose natural estrogen levels are low, don't normally produce vitellogenin. However, male English sole from several sites in Puget Sound have detectable levels of vitellogenin in their blood, signaling that these residential bottom-feeding fish are experiencing significant exposure to estrogenic compounds in their habitat.

Table 4-6 Maximum detected endocrine disrupting compound concentrations by water type. (Source: KC DNRP)

Chemical (µg/L unless noted)	N	FOD (%)	Marine	Lakes	Stream/ River-Dry weather	Stream/ River-Wet weather	100% Road/ Bridge Runoff	100% Storm-water
Benzyl Butyl Phthalate	72	12.5	0.01	ND	0.011	ND	0.96	2.06
Bis(2-ethylhexyl)adipate	127	9.4	ND	ND	1.02	ND	0.65	0.036
Bis(2-Ethylhexyl)Phthalate	30	100	40.5	13.1	15.8	4.61	20.3	--
Diethyl Phthalate	67	23.9	--	ND	ND	0.55	2.55	ND
Dimethyl Phthalate	164	15.2	--	0.014	0.02	0.022	0.193	1.71
Di-N-Butyl Phthalate	55	9.1	--	--	0.31	ND	0.9	ND
Di-N-Octyl Phthalate	163	29.4	--	0.0396	0.06	0.68	3.36	0.5
Bisphenol A	181	24.9	ND	0.046	0.44	0.934	9.14	1.57
Total 4-Nonylphenol	272	15.8	0.254	0.149	0.46	0.836	44.2	8.9
17-β Estradiol (ng/L)[1]	362	0.3	ND	ND	13.0	ND	ND	ND
17-β Estradiol (ng/L)[2]	344	27.9	0.5	0.6	1.1	0.5	N/A	1.2
Estrone	362	0	ND	ND	ND	ND	ND	ND
17α Ethynylestradiol (ng/L)[1]	362	0	ND	ND	ND	ND	ND	ND
17α Ethynylestradiol (ng/L)[2]	343	23.9	ND	0.9	0.63	2.0	ND	5.9
Methyltestosterone	362	0	ND	ND	ND	ND	ND	ND
Progesterone	362	0	ND	ND	ND	ND	ND	ND
Testosterone	362	0	ND	ND	ND	ND	ND	ND
Vinclozolin	362	0	ND	ND	ND	ND	ND	ND

—	No usable samples for matrix
Bold	Maximum of all detections
ND	All values non-detect in matrix
N	Number valid samples, by chemical, all matrices
FOD	Frequency of detection based on usable samples.
1	Analysis by GCMS
2	Analysis by ELISA
NA	Not Analyzed

PSAMP monitoring studies have shown that, of all the sites sampled, those in Elliott Bay have the highest number of males (over 30 percent samples) with detectable levels of vitellogenin in their blood.

Female sole are also affected by exposure to the estrogenic compounds at the Elliott Bay sites. Researchers have found that some females begin spawning at a younger age and demonstrate altered reproductive timing. Over time, these physiological changes induced by increase exposure to estrogen compounds in the environment, coupled with other stressors, may challenge the future reproductive success of English sole.

As yet, we are unsure about the specific compounds that are responsible for vitellogenin induction and other reproductive abnormalities in English sole. Monitoring studies are beginning to characterize various pharmaceutical and wastewater compounds in the Puget Sound and its associated watersheds that could have estrogenic activity.

Laboratory studies are underway with salmon, sole, and other species to determine the sensitivity of fish species to xenoestrogens. In one study, male salmon were exposed to ethinyl estradiol, the synthetic estrogen found in birth controls pills, at concentrations within the range that has been measured at Puget Sound sites. These fish showed changes in reproductive hormone levels that could disrupt their reproductive cycles. Effects were found in English sole exposed to the natural estrogen, 17-beta estradiol. In another study, zebrafish were exposed to similar concentrations of ethinyl estradiol, and their sexual behavior was observed. Exposed males became less aggressive, and their mating success was reduced. Laboratory exposure studies with English sole are also helping to identify industrial chemicals that might be causing vitellogenin production in male sole. Male sole exposed to the plasticizer bisphenol A or the surfactant nonylphenol produced vitellogenin; those exposed to phthalates did not.

Table 4-7. Summary of trace metal results at Station LTDF01, 1988-2004
(Source: KC DNRP)

Metal	Frequency of Detection	Detection Limit Range[1]	Concentration Range[1]	SQS[1]
Arsenic	10/12	3.1 – 12	9.8 – 15.2	57
Cadmium	7/12	0.18 – 0.70	0.23 – 0.49	5.1
Chromium	12/12	0.31 – 1.2	27.9 – 47.8	260
Copper	12/12	0.23 – 0.93	37.4 – 65.2	390
Lead	12/12	1.8 – 7.0	48.0 – 69.7	450
Mercury	12/12	0.033 – 0.047	0.425 – 0.911	0.41
Silver	10/12	0.23 – 0.93	0.63 – 1.68	6.1
Zinc	12/12	0.31 – 1.2	74.4 – 100	410

[1]All values reported in mg/kg DW.

7. Metals in Puget Sound

a. Metals in Elliott Bay Subtidal Sediments

King County has monitored sediment quality at one station along the Seattle waterfront as part of its ambient sediment monitoring program. Subtidal sediment samples have been collected from Station LTDF01 (Table 4-7) and analyzed for metals, among other chemicals since 1988.

Samples were collected annually from 1988 through 1993, in 1995, and biennially from 1996 through 2004. Included in the suite of metal analytes have been the eight trace metals regulated under the Washington State Sediment Management Standards: arsenic, cadmium, chromium, copper, lead, mercury, silver, and zinc. Table 4-7 summarizes analytical results for these eight trace metals. It includes the frequency of detection, the range of detection limits, the range of detected metal concentrations, and the Sediment Quality Standard (SQS) chemical criterion for each metal. Data in the table are presented in units of milligram per kilogram, normalized to dry weight.

Arsenic, cadmium, and silver were not detected in every sample, and detected concentrations of these three metals have generally been just above the analytical limit of detection. Concentrations of arsenic, cadmium, chromium, copper, lead, silver, and zinc have been consistent over the 16-year monitoring period, and all detected sediment concentrations of these metals have been well below their respective SQS chemical criteria.

Concentrations of mercury, however, have consistently been above the SQS chemical criterion of 0.41 mg/kg. Figure 4-39 presents sediment mercury concentrations at Station LTDF01 between 1988 and 2004.

Mercury concentrations exceeded the Cleanup Screening Level (CSL) in sediment samples collected during the first eight monitoring events. The CSL is the higher of the two Sediment Management Standards chemical criteria. Since 1998, however, sediment mercury concentrations have been below the CSL but still exceeding the SQS. The data indicate a possible downward trend in mercury concentrations at Station LTDF01 (Figure 4-39).

b. Metals in Puget Sound Sediments

As part of PSAMP, Ecology sampled sediments at 10 fixed stations each spring, from 1989 through 2000 (Figure 4-40). Stations were chosen from a variety of habitats and geographic locations in Puget Sound. Sediments from each station

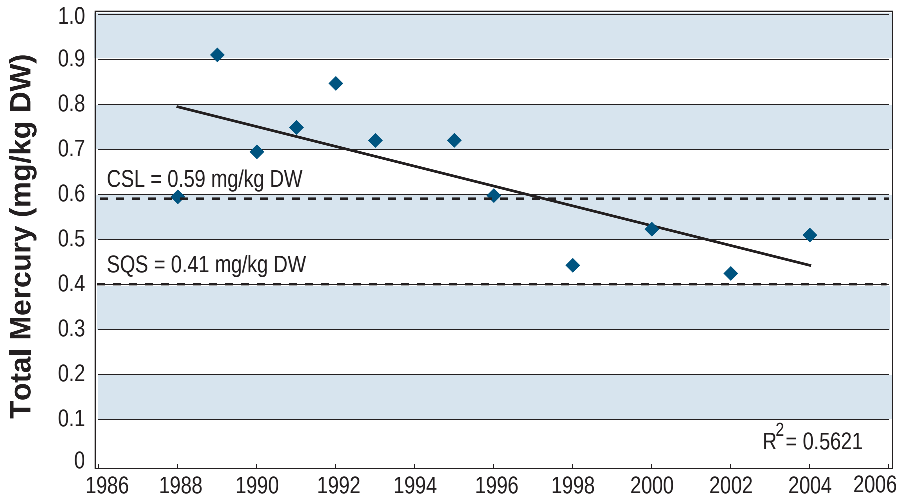


Figure 4-39. Mercury concentrations at King County's Elliott Bay station, 1988-2004. Dry-weight mercury concentrations along with Sediment Quality Standard (SQS) and Cleanup Screening Level (CSL) chemical criteria, and line of regression showing a downward trend in concentration.
(Source: KC DRNP)

Figure 4-40. Location of 10 long-term PSAMP sediment monitoring stations in Puget Sound.
(Source: Ecology)

were analyzed for particle size, organic carbon content, and the presence of more than 120 chemical contaminants, as well as the types and abundances of sediment-dwelling organisms.

Chemical contaminants in the sediments were measured yearly from 1989 through 1996 and again in 2000. The contaminants examined included priority pollutant and ancillary metals, as well as organic compounds, such as PAHs, chlorinated pesticides, and PCBs. Changes in sediment condition over this time period included decreases in levels of metals at some stations.

Status and Trends

The concentrations of most metals did not change significantly over the study period. Those that did change generally decreased. There was a significant decrease in copper across all stations and significant decreases in metals in general at stations in Port Gardner and Budd Inlet (Table 4-6).

Impacts to the Ecosystem

Toxic metals enter the environment as waste from industrial manufacturing and mining, municipal wastewater, combustion products, and agricultural pesticides (Newman and Unger 2003). Nationwide, metal concentrations in fresh water and estuarine sediments have exhibited declines, similar to those observed in this study, since the mid-1970s. These trends may reflect decreases in emissions to air and water from municipal and industrial sources, following the implementation of federal clean water and air regulations. However, despite these improvements, metal concentrations remain above sediment quality guidelines in many urban bays of Puget Sound, emphasizing the need for continued monitoring and cleanup (Lefkovitz et al. 1997, Mahler et al. 2004).

The PSAMP long-term monitoring program provides a vital record of sediment conditions in Puget Sound and gives insight into the effects of both natural and human-driven stressors on the estuary.

c. Metals in Biota

Since 1986, NOAA's National Status and Trends (NS&T) Program has been monitoring contaminants in mussels from Puget Sound, the Strait of Juan de Fuca and the Washington coast. The NS&T Program analyzes nearly 150 separate chemicals in whole soft tissue from composites of mussels (*Mytilus edulis* and *M. californicus*) collected at each of 17 sites in Washington and one at the Columbia River south jetty. Samples were collected annually to 1994 and every other year since then. In this report, five of the 17 sites in Washington are summarized.

Status and Trends

Trends for five metals from five locations (Budd Inlet, Port Townsend, Squalicum Marina in Bellingham, Fourmile Rock near Seattle, and Cape Flattery near Neah Bay on the outer coast) are shown in figures 4-41 a through e. From 1988-1990, three samples per site were collected annually. After 1990, the sample size dropped to one sample per site every two years. Data shown is the median concentration of metals.

Average mercury levels in Puget Sound mussels are 20 percent higher than the national median of 0.1 ppm dw. Mercury concentrations are highest in Bellingham Bay, where the median concentration rages between 1.5 and 2.6 ppb dry weight. Cape Flattery, the closest to the coast, had levels ranging 0.9 and .2 ppb. The remaining three sites have lower mercury levels, with some variability across the 17 year monitoring period.

Metals	Station Change 1989-1996 vs. 2000										Station Trend 1989-2000									
	Strait of Georgia	Bellingham Bay	Hood Canal	Port Gardner	Shilshole	Sinclair Inlet	Point Pully	Thea Foss WW	Anderson Island	Budd Inlet	Strait of Georgia	Bellingham Bay	Hood Canal	Port Gardner	Shilshole	Sinclair Inlet	Point Pully	Thea Foss WW	Anderson Island	Budd Inlet
Priority Pollutant																				
Antimony						--	--		--							--	--	--	--	
Arsenic	--	--	--	--	↓	↓	--	↓	↓	--	--	--	--	--	--	--	--	--	--	--
Cadmium						--				↓	--	--	--	--	--	--	↑	--	↑	--
Chromium	--	--	--	--	↑	--	--	↑	↑	↓	--	--	--	--	--	↓	--	--	--	--
Copper	--	↓	--	↓	↓	--	↓	--	↓	↓	--	--	--	--	--	↓	↓	--	--	--
Lead	--	--	--	--	--	--	--	↓	--	↓	--	--	--	--	--	--	--	--	--	↓
Mercury	--	↓		--	--	--	--	↓	--	↓	--	--	--	--	--	--	↓	--	↓	--
Nickel	--	--	--	↓	--	↓	--	--	--	↓	--	--	--	--	--	--	--	--	--	--
Silver	--	--	--	↓	--	--	↓	--		--	--	--		--	--	--	--	--	--	--
Zinc	--	↓	--	↓	--	--	--	↓	--	↓	--	--	--	--	↓	↓↓	↓	--	--	--
Ancillary																				
Aluminum	--	--	--	↓	--	--	--	↓	--	↓	--	--	--	--	--	--	--	--	--	--
Iron	--	↓	--	↓	--	--	↓	--	↑	↓	--	--	--	--	--	--	--	--	--	--
Manganese	--	--	--	--	--	↓	↓	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 4-6. Changes and trends in metals concentrations in sediments. Samples were collected from 1989 through 2000 for the PSAMP sediment monitoring program. Most metals declined in concentrations during this period, except for chromium and cadmium, which showed increases in some locations.
(Source: Ecology)

↑,↓ .... increase, decrease (α=0.05)
↑↑, ↓↓ ..... increase, decrease (α = 0.01)
-- .... no change
blank .... insufficient data

Shaded results indicate changes for all stations combined for a single compound or for all compounds combined for a single station, at α=0.05.

Puget Sound mussel samples are close to the national median of 2.1 ppb with the exception of Budd Inlet, where levels reached approximately 12 ppb in 2002-2003. The high variability in cadmium levels at this site may be due in part to the small sample size (one sample every two years) may account for the large inter-year variability seen in lead at this site. But local sources of cadmium may be causing this site to have overall higher levels than other Mussel Watch sites in Puget Sound.

Lead concentrations in mussels from the five sites is close to the national median of .77 ppb, with the exception of Budd Inlet and Cape Flattery which both had peaks in the mid-1990s (3.7 and 1.7 ppb respectively). Since this time, the levels at these two sites have returned levels below 1.0 ppb.

Since the Mussel Watch program began, zinc levels in Washington mussels from the five sites have exceeded the national median of 110 ppb dry weight for all sites. Budd Inlet has only slightly exceeded the national median (approximately 140 ppb in the late 1980s) but in recent decades has hovered near 100. Bellingham and Fourmile Rock have had the highest zinc levels, ranging in the 150-250 ppb concentration over the past two decades.

Copper levels in mussels have been fairly steady at Budd Inlet, Port Townsend, Fourmile Rock and Cape Flattery, showing little change since 1985. In Bellingham Bay, however, copper levels have increased steadily in the past 6 years, with currently levels about twice the national median for copper (8.0 ppb dry weight). Levels in Bellingham have been higher than other sites since monitoring began in the early 1980s.

Copper disrupts sense of smell in fish

The sense of smell in salmon is controlled by the olfactory sensory organ, a delicate structure appropriately called a “rosette” for its radial arrangement of folded tissue. The organ is designed to detect odors as they are carried by water through the olfactory cavity. Studies have shown that exposure to dissolved copper at levels close to those measured in stormwater can impair a fish’s sense of smell. This can cause critical behavior changes in fish, affecting predator avoidance, natal stream imprinting, homing, and mating synchronization.

Figure 4-41a. Trends of metals in mussel tissue in Puget Sound. Mussel Watch data for five metals (mercury, lead, copper, zinc and cadmium) from four sites throughout Puget Sound and one at Cape Flattery near the outer coast is shown. The Squalicum Marina in Bellingham had the highest median mercury, zinc and copper levels.
(Source: NOAA National Mussel Watch Program).

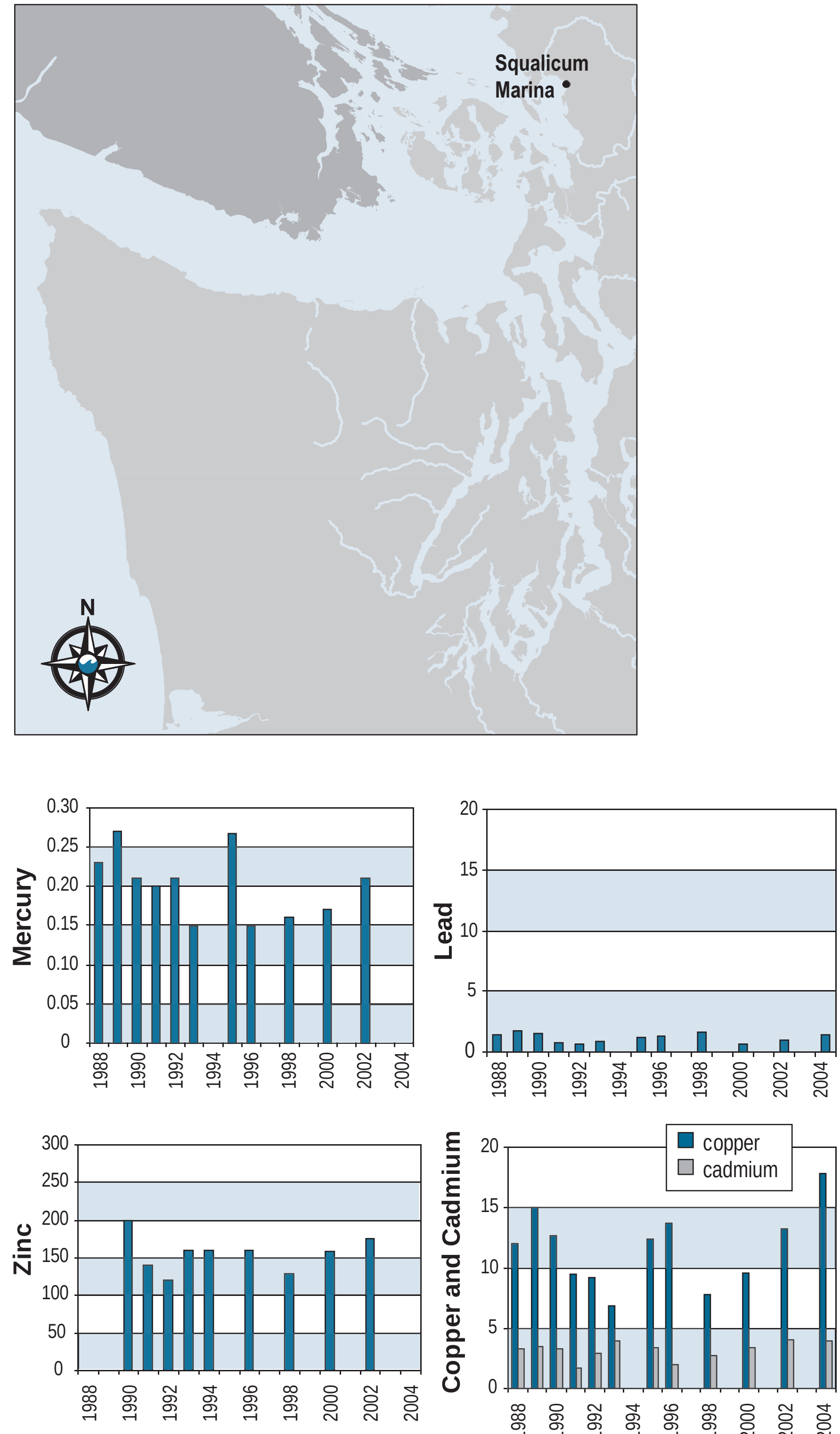


Figure 4-41b. Trends of metals in mussel tissue at Cape Flattery.

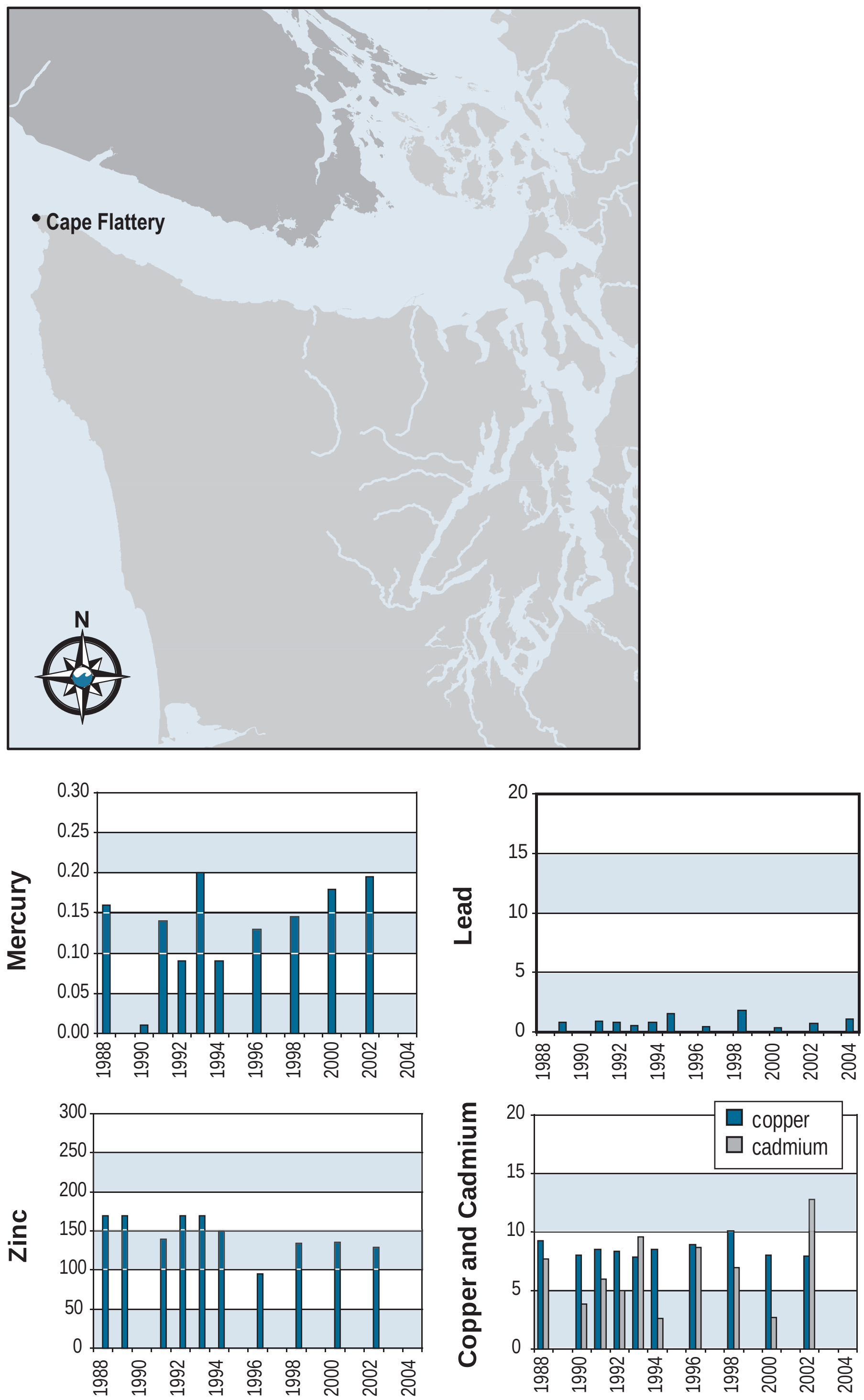


Figure 4-41c. Trends of metals in mussel tissue at Port Townsend in Puget Sound.

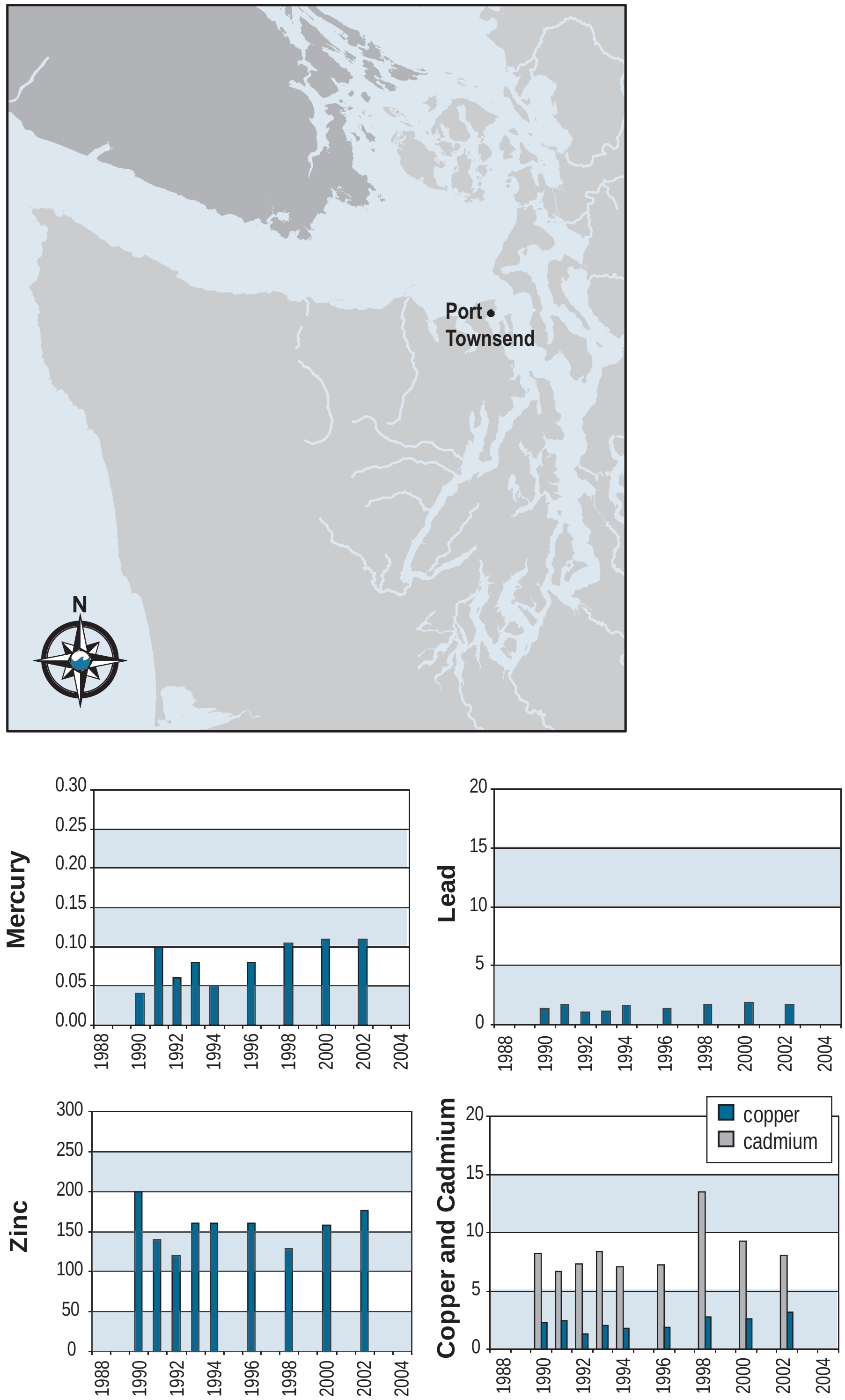


Figure 4-41d. Trends of metals in mussel tissue at Fourmile Rock in Puget Sound.

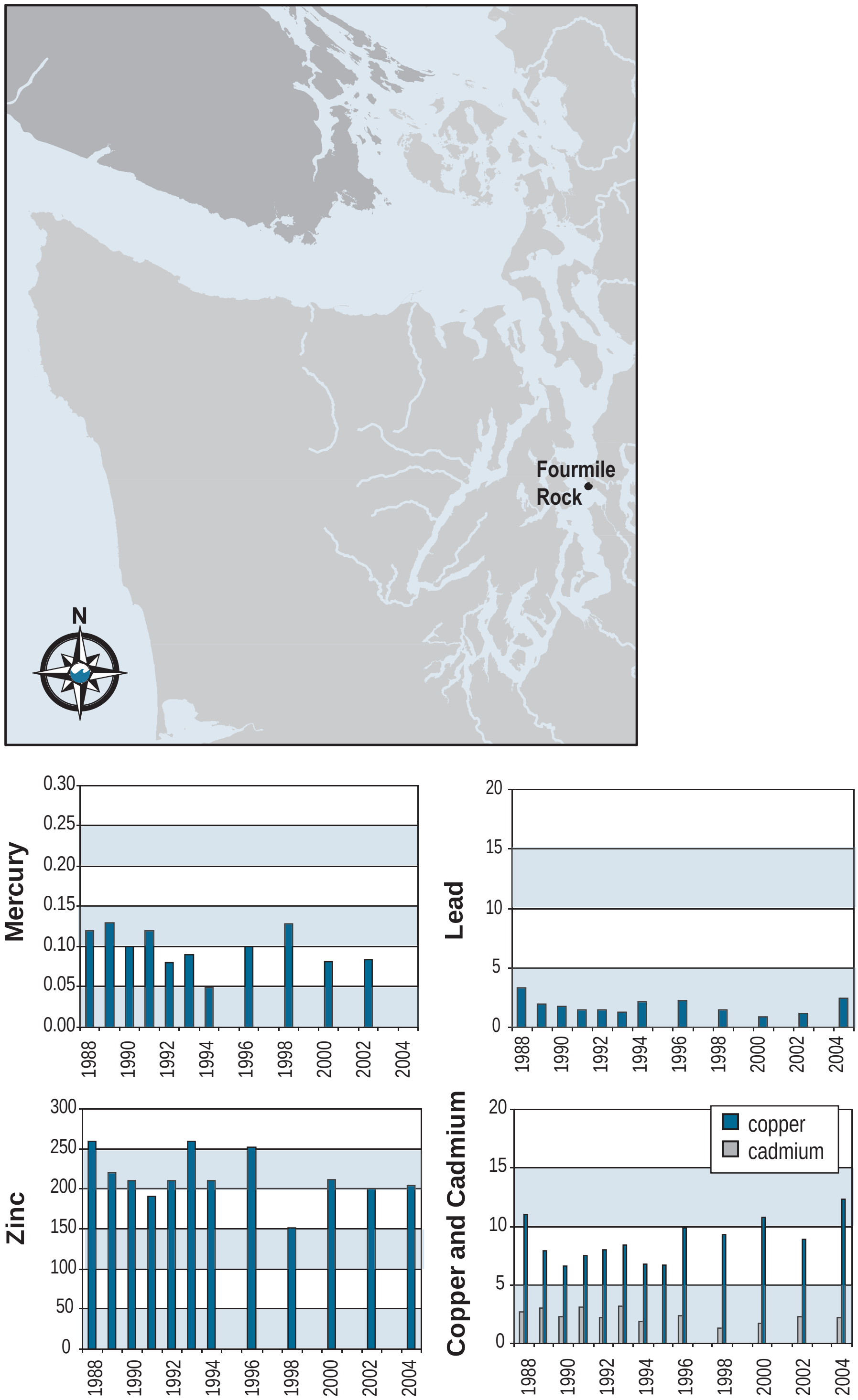


Figure 4-41e. Trends of metals in mussel tissue at Budd Inlet in Puget Sound.

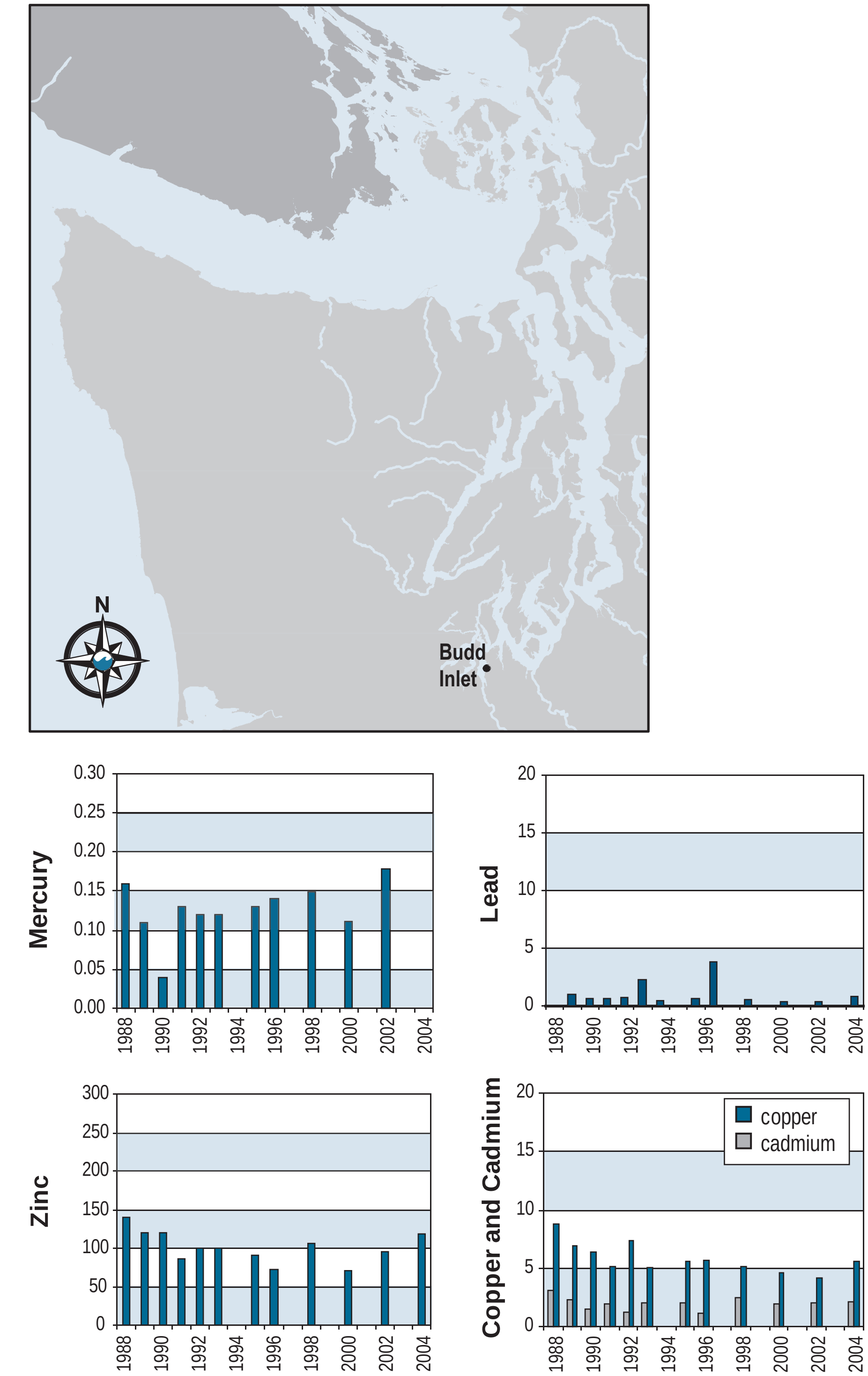


Figure 4-42. Dead coho salmon with 100 percent egg retention. (Courtesy of Sarah McCarthy, NOAA Fisheries).

8. Effects of Urban Runoff on Biota in Freshwater Systems

Many restoration projects in Puget Sound focus on streams running through urban areas that have barriers to fish passage or unsuitable physical habitat for spawning salmonids. Beginning in the late 1990s, agencies in the greater Seattle area began conducting salmonid spawner surveys to evaluate the effectiveness of local stream restoration efforts. These surveys detected a surprisingly high rate of mortality among migratory coho salmon females that were in good physical condition but had not yet spawned (Figure 4-42). In addition, adult coho from several urban streams showed a similar progression of symptoms (disorientation, lethargy, loss of equilibrium, gaping, and fin splaying) that rapidly led to death of the affected animals. This phenomenon was termed pre-spawn mortality (PSM). Researchers from NOAA Fisheries' Northwest Fisheries Science Center, in partnership with City of Seattle - Seattle Public Utilities and USFWS's Western Washington Fish and Wildlife Office, have been studying adult coho spawners in Puget Sound streams to determine the causes and geographical extent of these acute fish die-offs.

Status and Trends

PSM has been consistently observed over the past several years in many lowland urban streams in the Puget Sound region, with overall rates ranging from approximately 25 to 90 percent of females returning to spawn. Coho die-offs in these streams are generally associated with large rain events. Continuous daily surveys over the past four years in a representative urban stream in West Seattle have revealed female coho PSM rates ranging from 66 to 89 percent, compared with less than one percent in a forested reference stream (Table 4-9). Although the precise cause of PSM in urban streams remains unknown, conventional water quality parameters (e.g., temperature and DO) and disease do not appear to be causal. The weight of evidence suggests that adult coho, which enter small urban streams following fall storm events, are acutely sensitive to pollutants in nonpoint source stormwater runoff. Research is underway to investigate potential linkages between land-use patterns and PSM, as well as the effects of degraded stormwater on other life history stages of coho. Additional studies are being conducted to predict the population-level impacts of PSM on coho stocks that return to spawn throughout the Puget Sound region.

Table 4-9. Pre-spawn mortility in urban and rural streams from 2002-2005. Neither disease nor conventional water quality parameters (temperature and dissolved oxygen) appear to be the cause of the mortality, suggesting that pollution sources in stormwater may be the culprit. (Source: NOAA Fisheries)

	Year	N	PSM
Longfellow Creek (urban)	2002	57	86%
	2003	18	66%
	2004	9	89%
	2005	75	72%
Fortson Creek (non-urban)	2002	114	<1%

Impacts to the Ecosystem

Collective results to date suggest that stormwater runoff has important negative impacts on both the survival and reproductive success of coho salmon in urban and urbanizing watersheds. The current aim is to determine the consequences of spawner and embryo mortality on healthy populations of wild coho throughout the Puget Sound Basin.

9. Recommendations

In the *2002 Puget Sound Update*, recommendations were provided based on the results from the studies summarized in the report. The recommendations for toxic contaminants work and progress made through 2006 on those recommendations are summarized below:

Recommendation from the *2002 Update* for Toxic Contaminants	Progress made through 2006 on recommendations in the *2002 Update*
As much as possible, studies should be interdisciplinary in nature such that the 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.	Progress is difficult to document. However, WDFW and NOAA continue to collaborate on studies of PAH exposure in English sole and PTB concentrations in fish species in Puget Sound.
Further pilot studies are needed to assess toxic contaminant impacts in previously understudied species, to fully evaluate ecosystem effects of these contaminants.	No progress to report.
Continued monitoring is needed for biota affected by contaminants, even when contamination 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.	• Continued studies of the affects of PAHs on English sole (WDFW). • Continued studies on vitelloginin levels in male English sole (NOAA).
Further studies are needed to better understand sources of the recent increases in benzoic acid in sediments and shellfish as well as the ecological implications of these increases.	No progress to report.
For contaminants that are increasing in Puget Sound sediments, scientists need to quantify sources, and policy-makers need to determine if current controls are inadequate to control these pollutants.	Efforts are underway by Ecology and EPA to conduct a limited assessment of loadings for key contaminants.
WDFW needs to further investigate the sources and pathways of contaminants in Pacific herrings. Emphasis should be on assessing whether dredged material management, contaminated sediment cleanup, or wastewater discharge control could reduce herring contaminant exposure.	This activity was not funded. No progress to report.

Recommendation from the *2002 Update* for Toxic Contaminants	Progress made through 2006 on recommendations in the *2002 Update*
Scientists need to use developing food web models for the Strait of Georgia and South Puget Sound Basin 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 bald eagles. These studies can identify gaps and encourage additional studies to fill them. This work can also identify the leading opportunities to reduce the accumulation of toxics in the food web.	No efforts to develop and apply food web models have been initiated as of August 2006 but discussions have begun about projects that if funded, could begin in early 2007 or the 2007-2009 biennium.
Scientists need to continue efforts to relate fish contamination and disease to sediment contamination, especially at areas such as the Seattle waterfront and Thea Foss Waterway, to try and learn more about how fish respond to cleanup efforts and sediment disturbances.	Studies of the risk of developing liver lesions in English sole continued at the Seattle waterfront, Thea Foss Waterway, and other sites in Puget Sound. Linkage to clean up or capping efforts is implied. (NFSC/WDFW)
More focused monitoring is needed to measure the effectiveness of alternative contaminant control measures.	This activity was not funded. No progress to report.

Moving Forward on Puget Sound Science

In looking ahead to what recommendations to report in future editions of the *Puget Sound Update,* it makes sense to focus on the goals and strategies that have been recommended in *2006 The Puget Sound Partnership Final Report*, the PSAT *2007-2009 Conservation and Recovery Plan for Puget Sound,* and the 2006 PSAMP Review. Collectively, these three sources provide targets and goals developed and supported by a large scientific community and reflect both short-term (two year) and long-term considerations for protecting and restoring Puget Sound's health.

The following bullets summarize the goals and strategies put forth by the Puget Sound Partnership, PSAT, and PSAMP that are related to toxic contaminants (Chapter 4 of this report). Progress towards these goals and strategies will be reviewed in the next edition of the *Puget Sound Update*.

Puget Sound Partnership Final Report (from Appendix A)

Goal: Puget Sound species and the web of life thrive.

- Terrestrial, aquatic and marine species exist at variable levels into the future and biodiversity of the overall ecosystem is naturally maintained.
- Invasive species do not significantly reduce the viability of native species and the functioning of the food web.
- The harvest of fish, wildlife, shellfish and plants is balanced, viable, and ecosystem based.

2007-2009 Conservation and Recovery Plan for Puget Sound

Priority 1. Clean up contaminated sites and sediments

- Continue to identify and clean up contaminated sites.
- Manage navigation dredging operations to clean up contaminated areas whenever possible and prevent contamination of unconfined disposal sites.

Priority 2. Prevent Toxic Contamination

- Reduce the use and generation of toxic chemicals.
- Reduce the release of toxic chemicals to the environment.
- Improve spill prevention and response.
- Educate residents to change behaviors to reduce toxic contamination.
- Study toxics in Puget Sound.

The Role of Science

Strategies:

- Continue ongoing monitoring of the status and trends of key components of the Puget Sound ecosystem.
- Provide scientific information to stakeholders, decision-makers and the public.
- Direct new monitoring activities to focus on the effectiveness of management activities and policy initiatives.
- Develop a roadmap to prioritize, finance and conduct focused research on emerging topics or research questions that are brought forth through PSAMP and science programs.

Detailed recommendations for further research and monitoring

Many of the following recommendations are an outcome of the 2005-2006 PSAMP review and have been included as actions in the *2007-2009 Puget Sound Conservation and Recovery Plan*. Progress towards these and previous recommendations will be reported in the next *Puget Sound Update*.

Toxics assessment

- Threats to human and marine wildlife health from exposure to major contaminants (PCBs, PBDEs, mercury, PAHs, metals, and pesticides) and new, emerging contaminants (such as pharmaceuticals and personal care products) are identified and measured in key indicators in the food web, including mussels, Pacific herring, salmon, and seals.
- The sources and contribution of key toxic contaminants from terrestrial, atmospheric, and marine discharge sources are determined. This information is used to determine toxic loading in sediment and key fish, mammals, and water bodies in Puget Sound.
- PSAMP status and trends monitoring of sediments is continued to determine spatial extents of contamination, toxicity, and benthos impairment within regions of Puget Sound.
- Develop a new urban embayment layer to PSAMP regional and strata layers for spatial extent calculations, as well as an assessment of sediment quality to measure success of contaminated site cleanup. Monitor sediment quality at multiple scales (Soundwide, regional, strata, and bay) for conventional contaminants and newly emerging contaminants. Also monitor sediment quality on intertidal lands.

Toxics Management

- Develop comprehensive and extensive integrated contaminant monitoring plans to track pathways and burdens and to link to human consumption advisories.

Modeling

- Develop a quantitative model to determine baseline levels of inputs and the fate of toxics in Puget Sound with explicit consideration of forage fish (by age, class, and location), birds, fish, and mammals.
- Develop a conceptual model of Puget Sound, using data from PSAMP, the Puget Sound Nearshore Partnership, and other science programs, to communicate and organize scientific information, relationships, and results.

Processes and Connections

- Develop biological indicators (invertebrates, fish, birds and mammals) of toxic exposure and effects at multiple taxonomic levels.
- Monitor effects of mixtures and interactions of nutrients, organics, and metals, not isolated contaminants.

5 Nutrients and Pathogens

Driftwood Beach on Blakely Island in San Juan County. | *Jim Johannessen*

1. Overview

Water quality is a primary factor affecting the health of marine and freshwater species in the Puget Sound region. As Washington's population grows and urbanization of the Puget Sound area continues, freshwater and marine ecosystems are under rising pressure from human activities that increase nutrient and pathogen pollution. Inputs of nutrients and pathogens affect ecosystem functions, the health and habitat of aquatic species, including economically important species (such as salmon and shellfish), and human health.

Nutrients consist of a variety of natural and synthetic substances that stimulate plant growth and enrich aquatic ecosystems. As a general rule, phosphorus tends to be the limiting nutrient in freshwater systems, and nitrogen tends to be the limiting nutrient in marine systems. This means that increased loadings of these nutrients can have significant effects on the character and condition of these respective systems.

Human activities have had a profound effect on the cycling of nutrients worldwide and nutrient pollution in the Puget Sound Basin. Nutrient availability in Puget Sound involves inputs from natural and human sources, such as upwelling and inflow of oceanic waters, flows from rivers and streams, stormwater runoff carrying fertilizers and other materials, discharges from sewage treatment plants, atmospheric deposition, and numerous other sources. It also involves uptake by phytoplankton and other aquatic vegetation and export to oceanic waters. Monitoring of nutrients is critical for assessing and understanding both short- and long-term changes in water quality and their effects on the Puget Sound marine ecosystem. Increased nutrient loading can dramatically change the structure and function of freshwater and marine ecosystems by altering biogeochemical cycles and producing cascading effects throughout the ecosystem and food web, such as prolonged algae blooms, depressed oxygen levels, fish kills and losses of aquatic vegetation. Eutrophication, as these nutrient-driven changes are known, is one the most important challenges facing Puget Sound and coastal ecosystems worldwide.

Pathogen pollution is an equally significant water quality problem in the Puget Sound Basin. Pathogens are disease-causing microorganisms that include a variety of protozoa, bacteria, and viruses. Some pathogens occur naturally in the marine environment (e.g., *Vibrio parahaemolyticus*). Most, however, are carried by host organisms and are associated with human and animals feces from such sources as onsite sewage systems and municipal sewage treatment plants, stormwater runoff, and boat waste. Pathogen pollution causes a range of environmental, human health, and economic impacts that include the contamination of shellfish beds, recreational waters and beaches, drinking water supplies, and other water-related resources. Pathogens also disrupt ecosystem functions and affect populations of freshwater, marine, and terrestrial species.

Increases in development around Puget Sound have prompted many investigations into the sources, loadings, pathways, and effects of nutrient and pathogen pollution. This information is needed to better understand the nature and scope of the problems and to inform management plans and efforts to prevent and control the pollution sources.

Key findings reported in this chapter include:

Fresh Water

- In Ecology's 2004 Water Quality Assessment, 58 freshwater sites were identified with **dissolved oxygen** problems in Puget Sound because of excessive nutrients (phosphorus and nitrogen) in the streams. Nutrients sources include drainage from agricultural, forestry, and residential activities and other sources.
- Twenty-five of 38 freshwater stations were scored "Good" according to the **total nitrogen** Water Quality Index. Ten stations scored "Fair." Three stations (in Hood Canal and on the Deschutes River near Olympia) scored "Poor."
- In 2005, freshwater stations were nearly equally divided between "Good" and "Fair" for **phosphorus** and were stable in water years 2000 through 2005.
- The WQI for **fecal coliform** rated "Good" at 28 of 38 freshwater streams for fecal pollution. The remainders were "Fair." Fecal conditions appear to be stable since 2000.

Marine Waters

- Hood Canal, Budd Inlet, Penn Cove, Saratoga Passage, and Possession Sound are locations of highest concern, based on Ecology's **index of water quality** for Puget Sound.
- Stations in Hood Canal, Penn Cove, Possession Sound, and Saratoga Passage had very high sensitivity to **eutrophication,** suggesting that these locations are at greatest risk for further declines in water quality due to human additions of nutrients.
- The most recent Water Quality Assessment lists 76 water bodies in Puget Sound with **fecal coliform** problems. However, fecal coliform data collected at marine ambient stations suggest a general decline in fecal coliform contamination from 2001 through 2005. The highest levels of fecal contamination occurred in Budd Inlet, Commencement Bay, Elliott Bay, and near West Point (north of Elliott Bay), Possession Sound, and Port Angeles harbor.

- DOH determined that 31 of 98 shellfish growing areas in Puget Sound experienced significant **fecal pollution** in 2005. Those with the greatest impact were Drayton Harbor, Dungeness Bay, and Henderson Inlet. Samish Bay and Burley Lagoon show no evidence of change in fecal pollution since 2002.
- Between 1995 and 2005, over 12,500 acres of **shellfish growing areas** were upgraded and 5,000 acres were downgraded, for a net increase of 8,500 acres. As a result of Kitsap County's Pollution Identification and Correction Program, parts of four shellfish harvest areas have been cleaned up and reopened for harvest; Burley Lagoon, Cedar Cove (part of Port Gamble), Illahee State Park, and Dyes Inlet.
- Twenty percent of 428 recreational beaches in 12 Puget Sound counties are threatened by **fecal pollution**. Five percent of these beaches are closed because of **biotoxins**. Within King County, trends at 21 recreational beaches indicate that fecal pollution has declined since 1997. Ecology's Beach Environmental Assessment, Communication and Health (BEACH) Program indicates that central Sound beaches typically have the highest measured bacterial pollution, most notably in Dyes and Sinclair Inlets.
- Eighteen of 29 **paralytic shellfish poisoning** (PSP) sampling sites (62 percent) had at least some PSP impact in 2005. Burley Lagoon ranked highest in PSP impact in 2005. The year 2003 appeared to be lowest in PSP activity throughout Puget Sound.
- In 2003, a short-lived ***Pseudo-nitzschia*** bloom occurred at Fort Flagler near Port Townsend. Mussels from the sentinel monitoring cage contained domoic acid slightly above the U.S. Food and Drug Administration's (FDA's) action level, and DOH closed the area to shellfish harvest. In October 2005, *Pseudo-nitzschia* blooms occurred at four places in north Puget Sound (Sequim Bay, Port Townsend, Holmes Harbor, and Penn Cove). Several shellfish species were affected. All four areas were closed to shellfish harvest.

2. Nutrient and Pathogen Monitoring in Puget Sound

Nutrients and pathogens are monitored at freshwater and marine sites by state agencies, local and tribal governments, and other organizations. The findings reported in this chapter come primarily from Ecology, DOH, and selected local governments.

With nutrients, water quality data is collected for different forms of phosphorus and nitrogen (e.g., ammonium and dissolved inorganic nitrogen) and combined with other information (e.g., marine water circulation and stratification) to provide a more complete picture of the effects in the receiving waters. Because of the difficulty and expense associated with the direct detection of pathogens in freshwater and marine environments, fecal coliform and enterococci bacteria are monitored as indicator organisms or surrogates that signal the possible presence of feces and waterborne pathogens. PSAMP scientists have developed a number of indices to consolidate and represent complicated data sets and, if possible, findings are presented both in terms of status (most recent conditions) and trends (changes over time).

State and local agencies use different monitoring strategies to meet their management goals. For example, Ecology is responsible for ensuring that water quality meets standards established by the federal Clean Water Act. Their monitoring programs are designed to assess the status of waters and to detect long-term changes from both natural and human causes using a range of physical, biological, and chemical parameters in fresh waters and marine waters in both urban and rural areas. Their data reported in this chapter are mainly from ambient monitoring conducted under PSAMP and recreational beach monitoring.

DOH's monitoring program is designed to classify shellfish growing areas under the National Shellfish Sanitation Program and to protect shellfish consumers from illness caused by pathogens and biotoxins. DOH uses water quality data from multiple sampling stations within each growing area, shoreline surveys, and other information to classify the different growing areas. Despite the narrower focus of the DOH program, the results have been adapted by PSAMP to measure water quality conditions and trends in the Sound.

Local and tribal governments and other organizations also monitor nutrients and pathogens in coordination or, in some instances, under contract with the state agencies to gauge conditions and trends and to guide shorter-term management actions. Results from a few of these local programs are included in this chapter to provide a more complete picture of the issues.

3. Impacts of Nutrients and Pathogens

a. Nutrients

Nutrients come from a variety of human activities and pollution sources, ranging from fossil fuel combustion to sewage discharges to forest practices, and they reach the receiving waters along a number of pathways (direct discharges, surface runoff, groundwater flow, and air deposition). There are also natural sources of nutrients that include the upwelling of coastal waters and runoff from the region's heavily vegetated landscapes, transporting large amounts of biomass to the waters of Puget Sound.

The effect of human activity on the global cycling of nitrogen in recent decades has been immense, and the rate of change in the pattern of use has been extremely rapid. One of the consequences associated with these changes has been the dramatic increase in nitrogen loadings to estuaries and coastal waters. So profound are these changes and loadings that some scientists contend that nutrients are now the largest pollution problem in the country's estuarine and coastal waters. The problem is likely to continue to worsen globally in concert with the expanding use of fossil fuels and inorganic fertilizers (National Research Council 2000, Howarth et al. 2002, 2000).

Under the right conditions, nitrogen inputs to marine waters can fuel algal blooms which, in turn, can reduce oxygen levels and harm marine life when the phytoplankton die back and decay in the lower water column. Sustained loadings of nitrogen and other organic matter can enrich and alter the marine ecosystem in many other ways. The direct and indirect effects of eutrophication are numerous and interconnected and range from reduced oxygen levels and biological diversity to altered food webs (Rabalais 2002, Diaz 2001, Cloern 2001, National Research Council 2000). The more enclosed areas of Puget Sound, including Hood Canal and the South Puget Sound and Whidbey basins, are vulnerable to eutrophication, due to slow flushing rates, limited stratification, and a number of other factors.

b. Pathogens

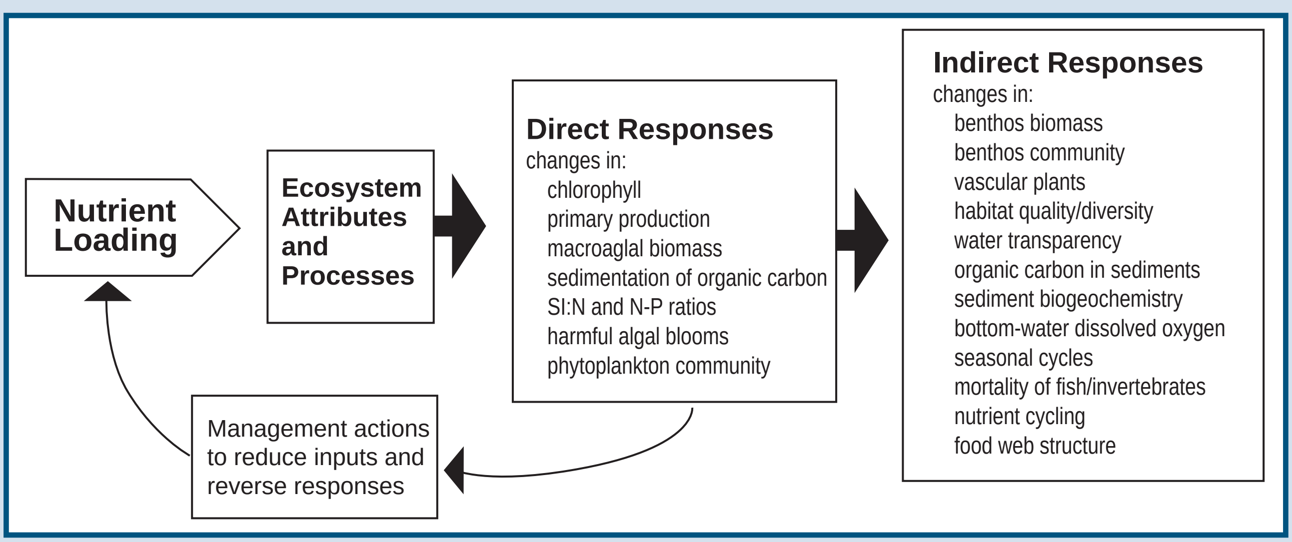
Pathogen pollution is a significant public health problem that also carries with it notable social and economic consequences. Pathogens are disease-causing microorganisms that include a variety of viruses, bacteria, and protozoans, most of which originate in the digestive tracts of humans and animals. Most waterborne pathogens make their way to the broader environment from such sources as sewage treatment systems, combined sewer overflows, stormwater runoff, and domestic animal and wildlife wastes. Pathogen pollution contaminates and affects the beneficial use of shellfish growing areas, recreational beaches, drinking water supplies, and other water resources. A leading disease risk to shellfish consumers are enteric viruses, especially a subgroup known as noroviruses that are frequently implicated in shellfish-related illnesses. Risks associated with swimming and other primary contact recreation include respiratory, ear, eye, and skin infections, gastrointestinal diseases, and other more serious conditions, such as meningitis and hepatitis.

Focus Study

Conceptual Model of Coastal Eutrophication

In his review of conceptual models of coastal eutrophication, James Cloern (2001) describes the evolution of these issues and explains several fundamental differences in the responses of freshwater and coastal ecosystems to nutrient enrichment. He describes coastal eutrophication as a "myriad of biogeochemical and ecological responses to human fertilization of ecosystems at the land-sea interface" and offers the flow chart below to help explain the cascading effects associated with coastal eutrophication.

All estuarine and coastal ecosystems have unique attributes that determine their sensitivity to eutrophication, and a number of management strategies can be used to mitigate and reverse the effects of pollution. Cloern also lists several challenges to the scientific community on the topic, including the need to develop nutrient budgets for different systems, to develop better indices to measure sensitivity to nutrient inputs, and to devise innovative ways to synthesize information from multiple sources to guide management plans.



Other pathogens occur naturally in the marine environment. Most notable among these in the waters of the Pacific Northwest is *Vibrio parahaemolyticus*, the most common cause of seafood-associated bacterial gastroenteritis in the U.S. Disease outbreaks associated with *V. parahaemolyticus* are most common in late summer months, when intertidal shellfish waters become warmer. Areas of Hood Canal and south Puget Sound are most susceptible to these conditions.

Biotoxins also present serious public health risks and can contaminate shellfish growing areas, leading to closures. Biotoxins are poisons produced in certain species of algae that, when they proliferate, are referred to as harmful algal blooms. The most common of these in Puget Sound is paralytic shellfish poison (PSP), which is produced by the phytoplankton *Alexandrium catenella* and can cause sporadic but widespread closures in Puget Sound. Common on the outer coast but only recently detected at a few sites in north Puget Sound is another biotoxin called domoic acid, the cause of amnesic shellfish poison (ASP), which is produced by the dinoflagellate *Pseudo-nitzschia*. First detected on Washington's Pacific Ocean coast in the in the early 1990s, domoic acid has resulted in lengthy closures of the coastal razor clam fishery. If organisms containing domoic acid were to move further into Puget Sound, the economic and public health implications could be dramatic.

Pathogens and biotoxins also pose serious risks to the health of marine wildlife. Coastal runoff containing the protozoan, *Toxoplasma gondii*, which is found in cat feces and is infectious to humans, has caused extensive infection and mortality in southern sea otter populations along the California coast (Jones et al. 2003, Miller et al. 2002, Gaydos et al. 2004) identified over 40 potential infectious diseases and listed morbilliviruses and herpesviruses as the highest infectious disease risks to the southern resident orca population of Puget Sound. Marine distemper viruses, such as phocine distemper virus or cetacean morbillivirus, have caused large die-offs of seals and whales in some parts of the world (Osterhaus et al.1995) but have not been documented in Puget Sound. Canine distemper virus has been transmitted from dogs to seals and has caused large-scale die-offs in Antarctica, Lake Baikal, the Caspian Sea, and other areas (Kennedy et al. 2000, Kennedy 1998). Having never been exposed to distemper viruses, harbor seals in Puget Sound would be very susceptible to infection if a canine distemper virus were to cross from domestic dogs to seals. Other protozoa such as *Cryptosporidium* and *Giardia*, which have long been thought of as terrestrial and freshwater pathogens, are also emerging as marine wildlife pathogens. Outbreaks of biotoxins have been implicated in the mortality of sea birds, sea lions, sea otters, cetaceans, and other wildlife on the West Coast (Lowenstine 2004, Trainer 2002). Additional research is needed to more fully understand the effects of these and other pathogens and toxins on the food web and the health of marine wildlife.

4. Fresh Water

Water quality characteristics of freshwater inputs are important controlling factors on the Puget Sound marine environment. As part of PSAMP, Ecology monitors 12 water quality parameters on a monthly basis at 24 long-term and 10 to 15 rotating river and stream sampling stations in Puget Sound. Ecology initiated its freshwater sampling program in 1970. These 12 parameters include nutrients (total nitrogen, ammonia, nitrate plus nitrite, total phosphorus, and orthophosphorus), pathogens (fecal coliform bacteria), temperature, DO, pH, conductivity, total suspended solids, and turbidity (Hallock et al. 2004). Ecology also monitors biological conditions (benthic invertebrates) and the spread of invasive, non-native aquatic plant species.

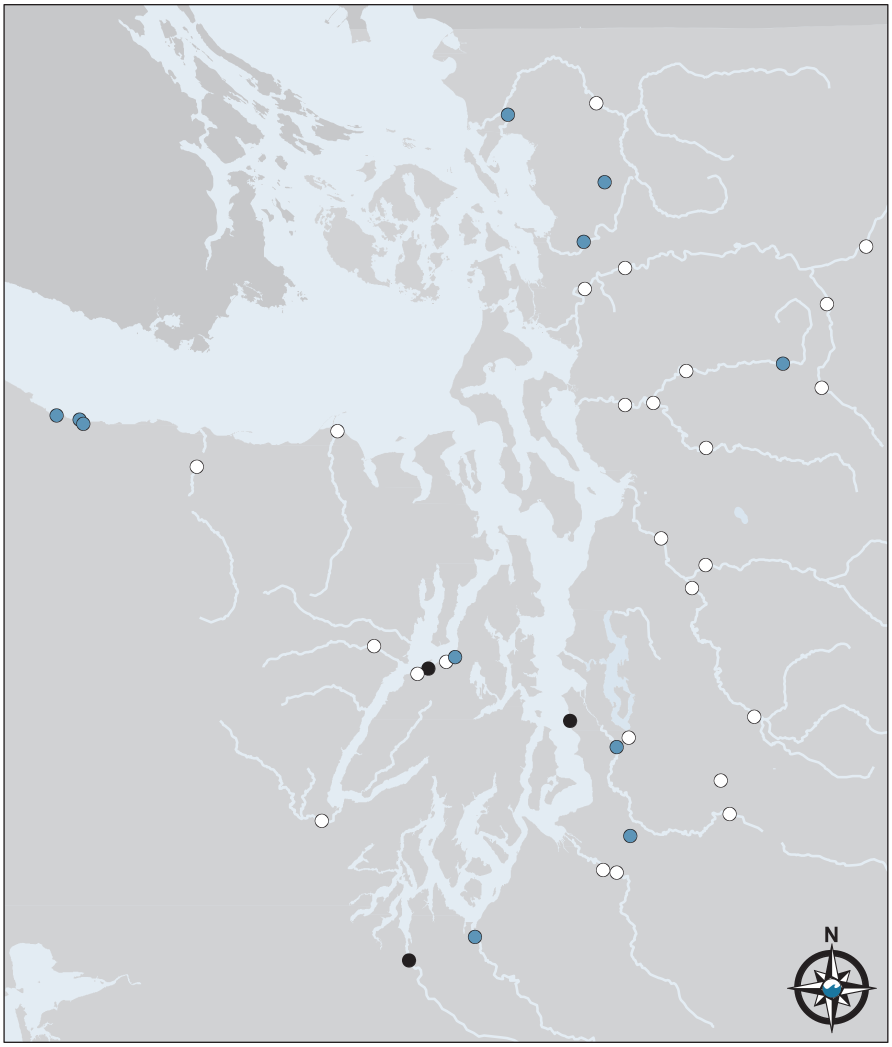


Figure 5-1. Ecology's freshwater core ambient monitoring stations and WQI scores for total nitrogen, 2000-2005. Fifty-six percent of the monitoring stations demonstrated good water quality, with low concentrations of nitrogen; 36 percent of the stations demonstrated fair water quality; and eight percent of the stations demonstrated poor water quality, as measured by high nitrogen concentrations.
(Source: Ecology)

a. Nutrients

The State regularly assesses the condition of the state's water bodies. In the 2005 Water Quality Assessment, lack of oxygen was identified as a concern at six freshwater locations in the Puget Sound region. Other locations were deemed to be waters of concern for other indicators. One score of the Water Quality Index (WQI) assesses the nutrient status of rivers and streams based on concentrations of total nitrogen and phosphorus (Hallock et al. 2001). When concentrations of nitrogen and phosphorus are elevated significantly over background levels, this indicates a likely pollution problem. Common sources include: runoff from agricultural or residential areas where fertilizers are used; discharges from wastewater treatment plants or subsurface flows from shoreline onsite sewage systems; or runoff and sedimentation from logging practices.

Status and Trends

Figure 5-1 shows the total nitrogen WQI for sampling stations within the Puget Sound Basin based on 2000-2005 data. The results indicate good conditions at 22 of 39 freshwater stations. The remaining stations are in fair (14 stations) and poor (three stations) conditions. The stations with poor conditions were located in central Puget Sound, Hood Canal, and south Puget Sound.

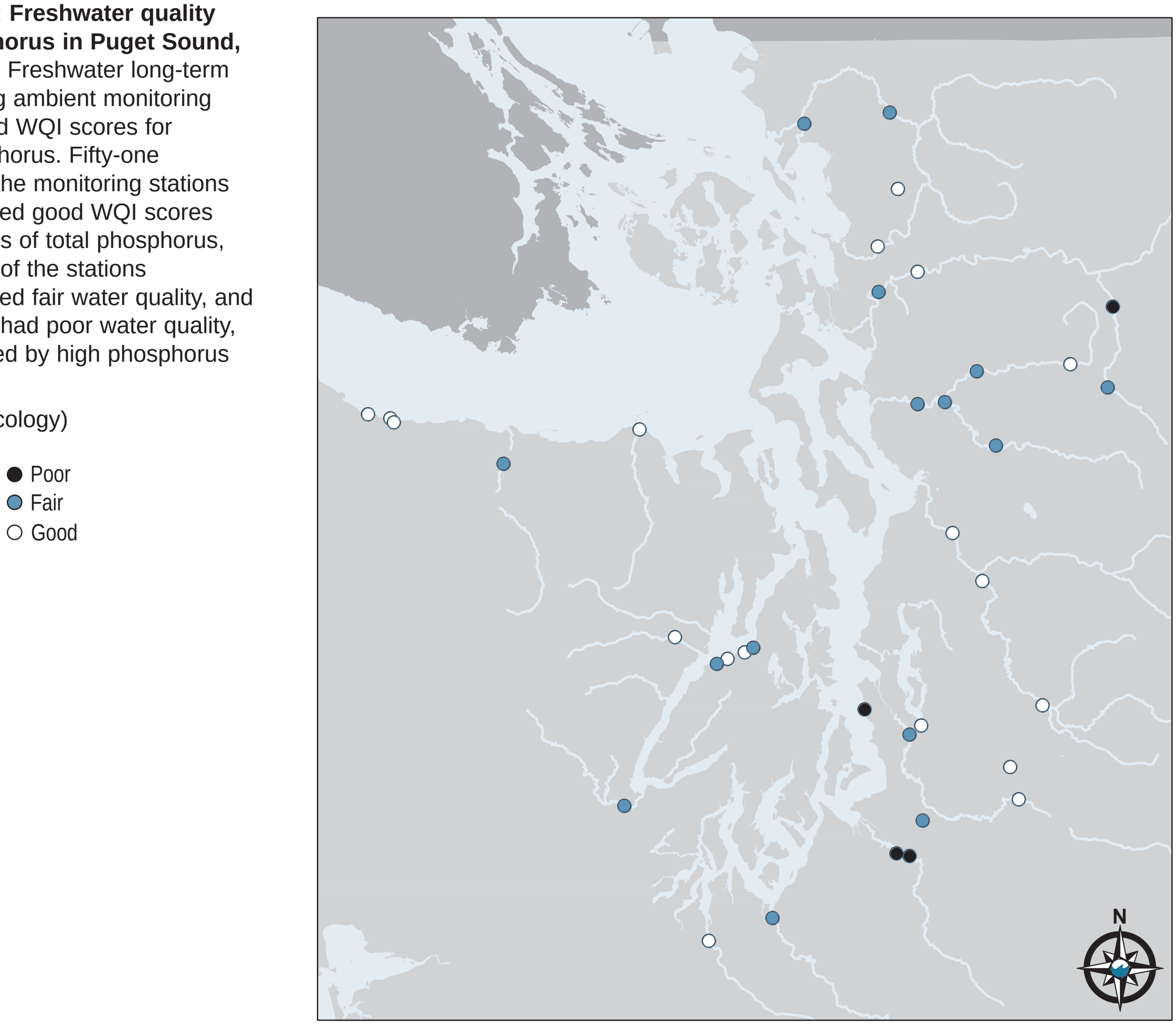


Figure 5-2: Freshwater quality for phosphorus in Puget Sound, 2000-2005. Freshwater long-term and rotating ambient monitoring stations and WQI scores for total phosphorus. Fifty-one percent of the monitoring stations demonstrated good WQI scores or low levels of total phosphorus, 36 percent of the stations demonstrated fair water quality, and 13 percent had poor water quality, as measured by high phosphorus levels.

(Source: Ecology)

Results for the total phosphorus WQI (Figure 5-2) show a different pattern than the nitrogen WQI. Five stations were rated poor for high phosphorus concentrations, 14 stations were rated as fair, and the remaining 20 stations were rated as good. The stations with the highest levels of phosphorus included Fauntleroy Creek (a small creek in West Seattle), the lower mainstem of the Sauk River, the White River, and two stations on the lower Puyallup River.

b. Fecal Bacteria

Fecal coliform bacteria are used as indicators of the potential presence of water-borne pathogens that are associated with human and animal wastes. The WQI for fecal coliform bacteria showed good conditions at most freshwater stations in the Puget Sound Basin.

Status and Trends

Freshwater long-term and rotating ambient monitoring stations and WQI scores for total fecal coliform for 2005 data are provided in Figure 5-3. The majority of stations (29 of 39) demonstrated good conditions and the remaining stations were rated fair.

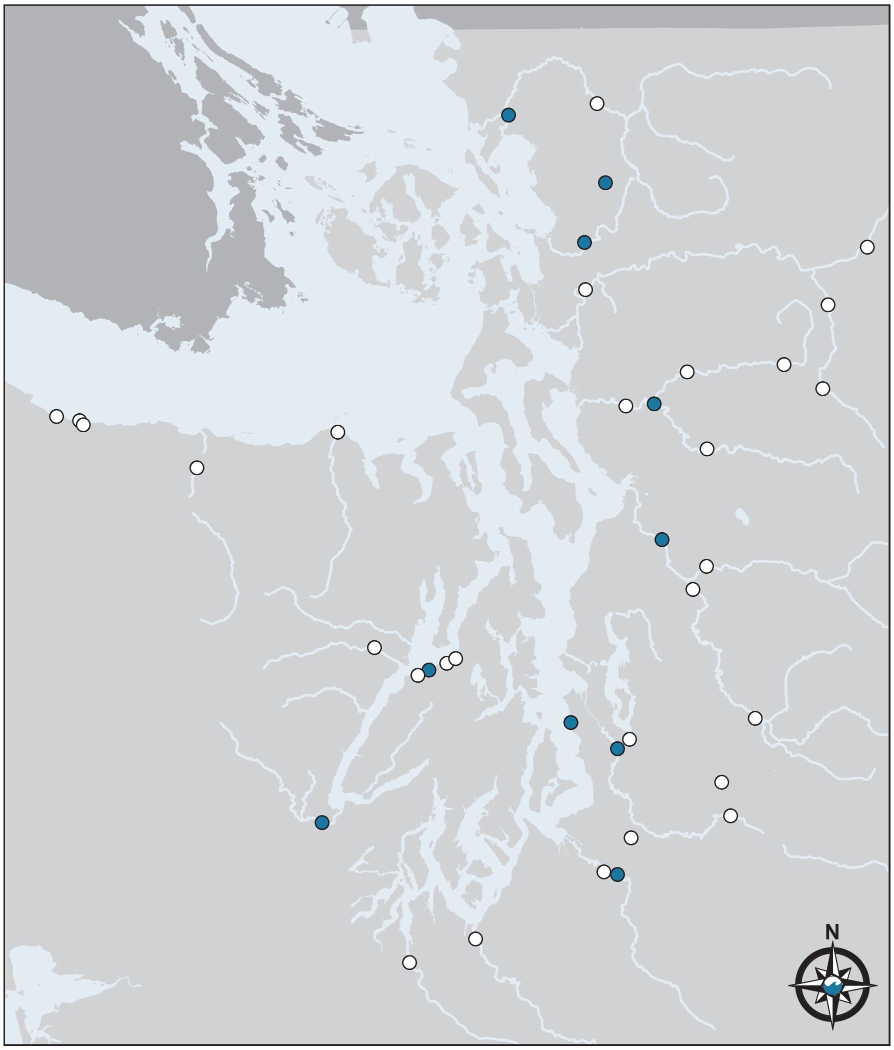


Figure 5-3. Freshwater quality for fecal coliform in Puget Sound, 2005. Ecology freshwater long-term and rotating ambient monitoring stations and WQI scores for fecal coliform based. Seventy-four percent of the monitoring stations demonstrated good conditions for fecal coliform, while 26 percent demonstrated fair conditions for fecal coliform. None of the stations demonstrated poor ratings for fecal coliform.
(Source: Ecology)

● Poor
● Fair
○ Good

5. Marine Water

a. Water Quality Status

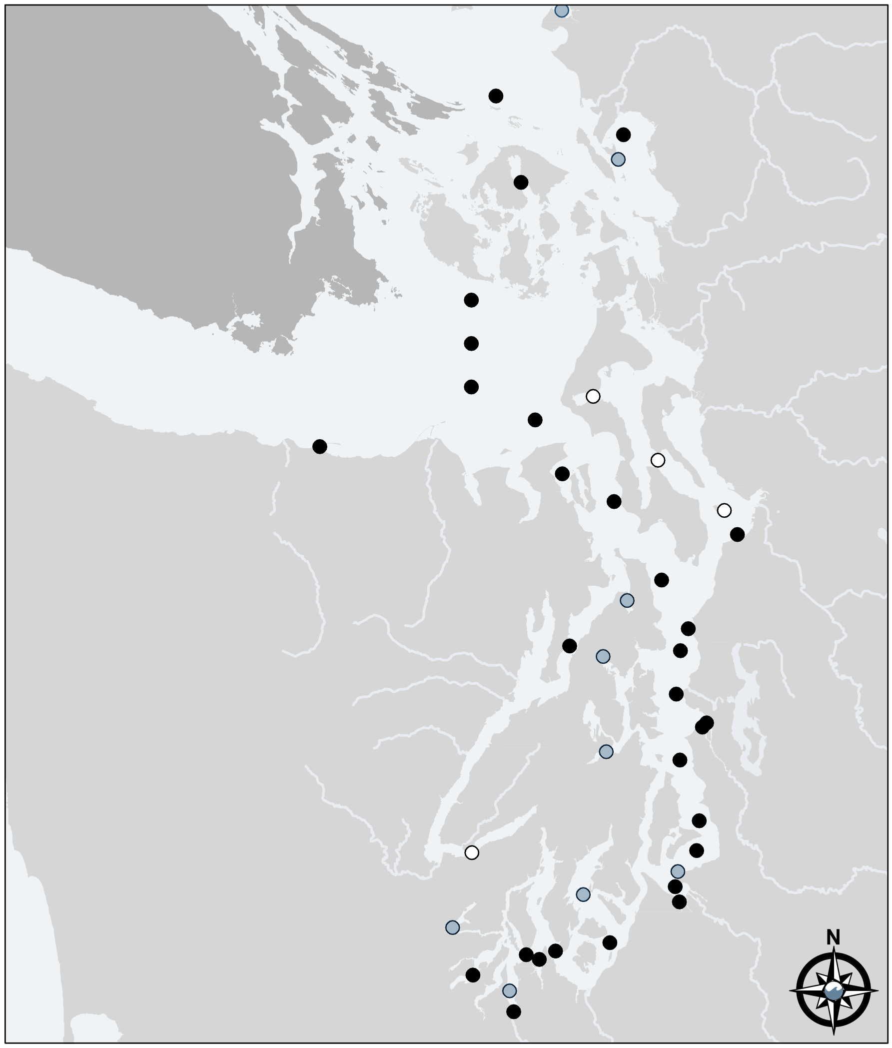
Ecology monitors marine water quality at long-term stations located throughout Puget Sound and in the coastal estuaries of Grays Harbor and Willapa Bay. In addition, the King County Department of Natural Resources and Parks conducts similar monitoring at a series of stations located in the Central Puget Sound Basin as part of PSAMP. Water quality variables measured by these programs include temperature, conductivity, salinity, density, DO, light transmission, nutrients (nitrate, nitrite, phosphate, silicate, and ammonia), and fecal coliform bacteria concentrations. The following section includes monitoring results for nutrients and fecal coliform bacteria and an index of sensitivity to eutrophication for locations monitored from 2001 through 2005.

Status and Trends

In marine ecosystems, nitrogen is usually the limiting nutrient for phytoplankton growth, so dissolved inorganic nitrogen (DIN), which includes nitrate, nitrite, and ammonium, is used as an indicator of nutrient availability. Figure 5-4 shows the distribution of DIN at stations throughout Puget Sound. Stations were classified by calculating the number of months with DO less than 1.0 micromoles/liter in each year between 2001 and 2005 and reporting the highest value. Chronically

Figure 5-4. Occurrence of low dissolved inorganic nitrogen at marine monitoring stations in Puget Sound, 2001-2005. Nitrogen is usually a limiting resource for phytoplankton growth, so chronically low DIN levels indicate that a water body may be susceptible to eutrophication. (Source: Ecology)

- ○ **Low** = <1.0 µM 5 month or more in a year
- ● (grey) **Moderate** = <1.0 µM 3-4 months or more in a year
- ● **High** = <1.0 µM 0-2 months in any given year



low concentrations of DIN in marine waters indicate that nutrient availability may be limiting phytoplankton production and, therefore, that the waters may be susceptible to eutrophication if additional nutrients are added.

Between 2001 and 2005, four stations had low DIN (< 1.0 µM) for five months or more. Two of these, south Hood Canal and Penn Cove, also had low DIN from 1998 through 2000. The other two stations, Saratoga Passage and Possession Sound, have had moderate DIN from 1998 through 2000. Overall, however, the number of stations that experienced an increase in low DIN occurrences equaled the number of stations that experienced a decrease in low DIN occurrences.

Ammonium is the form of nitrogen most easily taken up by phytoplankton. It enters marine waters from a variety of human and animal sources. Therefore, it provides an indication of nutrient availability and the proximity of an ammonium source that could cause eutrophication. Figure 5-5 shows the distribution of maximum ammonium concentrations measured at Puget Sound monitoring stations from 2001 through 2005.

Between 2000 and 2005, three stations had high (> 10 µM) ammonium concentrations: Budd Inlet's South Port station (which had high ammonium in 1998 through 2000), Quartermaster Harbor (which previously had moderate

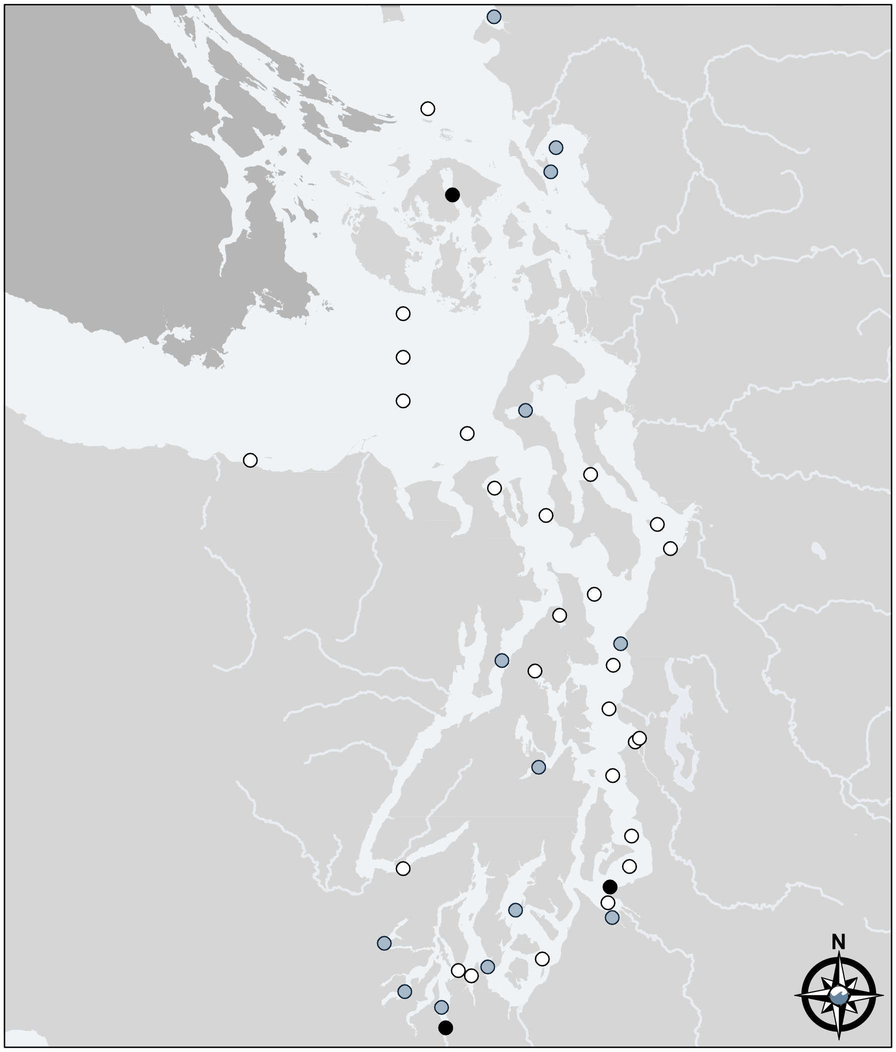


Figure 5-5. Maximum ammonium concentrations at marine monitoring stations in Puget Sound, 2001-2005. Ammonium is a nutrient that stimulates phytoplankton growth but can be toxic to marine life in high concentrations. Elevated concentrations of ammonium indicate the proximity of a nutrient source that could contribute to eutrophication. (Source: Ecology)

- **High** = >10.0 µM
- Moderate = 5.0 - 10.0 µM
- Low = < 5.0 µM

ammonium), and East Sound (which was not sampled in 1998 through 2000). Overall, eight stations had increases in ammonium concentrations: Penn Cove, Bellingham Bay (Pt. Frances), Nisqually Reach, Hood Canal (Bangor), Carr Inlet, Commencement Bay, Quartermaster Harbor, and Drayton Harbor. Five stations had decreases: Budd Inlet (Olympia Shoal), Possession Sound, Dana Passage, Port Orchard, and Bellingham Bay (Nooksack). As a result of these changes, stations with moderate ammonium concentrations were distributed throughout the Sound, rather than being clustered in the south Sound, as observed in 1998 through 2000. All levels measured are below the national water quality standards for ammonium. Trend analysis has not been done on the sites to determine overall changes over time. However, eight stations did show improvements in condition for ammonium while five declined during this period.

b. Eutrophication

The potential for eutrophication in Puget Sound depends on a variety of factors, including the strength and persistence of stratification, background concentrations of DO, and the susceptibility of the waters to increased phytoplankton growth due to nutrient additions. As a result, the risk of eutrophication can vary significantly in different parts of the Sound.

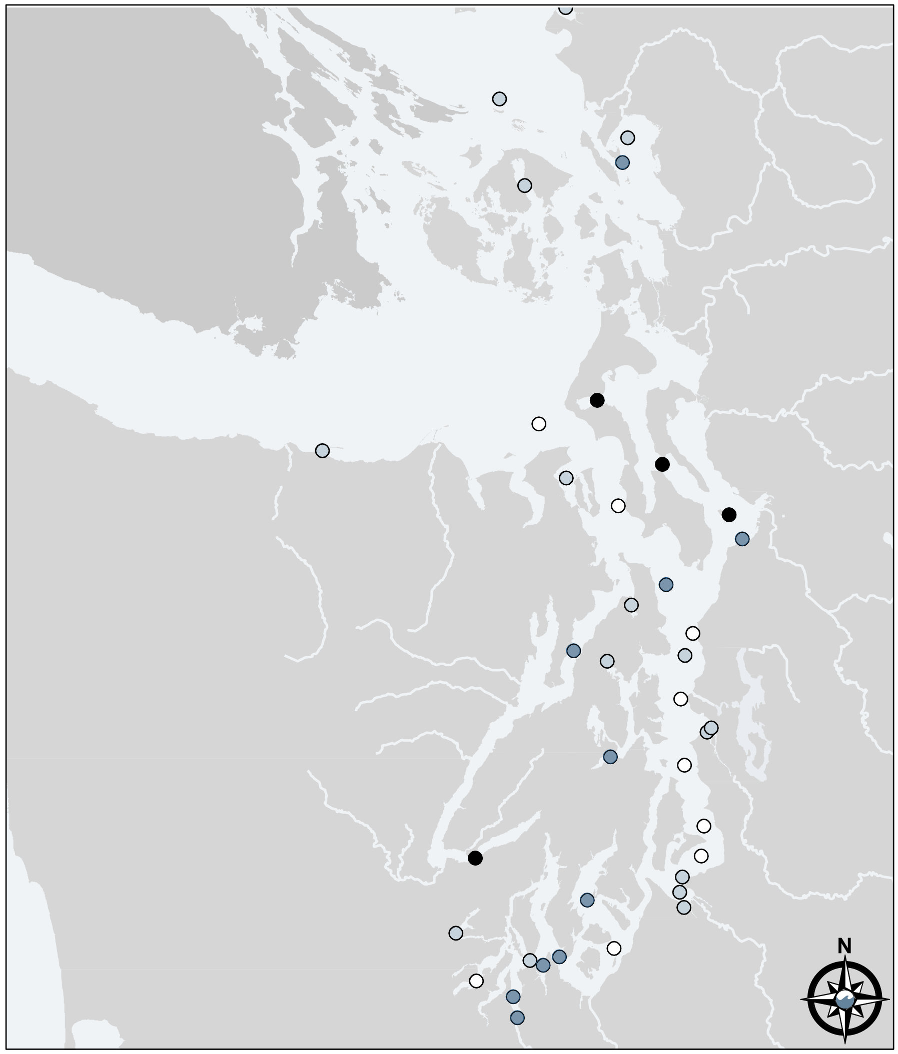


Figure 5-6. Index of sensitivity to eutrophication for Puget Sound marine water monitoring stations, based on 2001-2005 data. Stations are scored by assigning values to each of three indicators. Highest values are given to very low DO, strong stratification, and low DIN. Rankings of some stations were adjusted to reflect the influence of local factors, such as flushing time or susceptibility to eutrophication. Stations with very high sensitivity scored in all three indicators. (See Table 5-1 for individual station rankings.) This index provides a relative measure of sensitivity to water quality changes due to nutrient additions. In contrast, the water quality concern index (Chapter 3, Section g) combines the indicator results used here with information on maximum nutrient and fecal coliform concentrations to provide a measure of existing water quality conditions.
(Source: Ecology)

As discussed earlier, waters with chronically low DIN concentrations are usually more sensitive to nutrient additions than those with higher concentrations. In a stratified water column, high nutrient availability in surface waters can result in excessive phytoplankton growth, which sometimes takes the form of highly visible blooms. As the phytoplankton die and sink, their decomposition consumes oxygen, driving DO concentrations lower. Because strong, persistent stratification inhibits mixing, DO levels at depth can continue to decline until they harm other marine life in these areas. (The causes and consequences of low DO and strong stratification are presented in more detail in Chapter 4.)

Status and Trends

To assess differences in sensitivity to eutrophication and to highlight locations most at risk, PSAMP scientists used Ecology and King County data from 2001 through 2005 on DIN, stratification intensity and persistence, and DO concentrations to calculate each station's condition. Figure 5-6 shows an index of the susceptibility to eutrophication for these locations. To calculate the index, numerical scores were assigned to two threshold values for each indicator, and a total score for the three indicators was calculated (see Table 5-1 legend). Stations were then assigned to one of four risk categories. In a few instances (noted in the Table 5-1's footnote), stations were placed in higher or lower categories than the numerical results indicated, because of special considerations. These include the effects of high flushing rates, which are not incorporated into the index at this time. (Future revisions of the indices will incorporate more of these factors into the index.) Categorical values for the indicators at each station are shown in Table 5-1.

Stations in south Hood Canal, Penn Cove, and Possession Sound are at very high risk for eutrophication, as in the previous assessment. Saratoga Passage, which was formerly classified as high risk, is now considered to have very high risk because of declines in DO concentrations and an increase in the frequency of low DIN. Stations with high sensitivity included many enclosed or semi-enclosed urban bays with slow flushing, such as Budd Inlet, Port Gardner, Bellingham Bay, Nisqually Reach, Carr Inlet, Case Inlet, and Henderson Inlet.

In contrast to Puget Sound, most stations in Grays Harbor and Willapa Bay, on Washington's outer coast, have low to moderate risk of eutrophication (Table 5-1), even though some of them rank relatively high in the water quality concern index, presented in (Chapter 3, Section 6g). These differences reflect the impact of strong tidal flushing and relatively high exchanges of water with the Pacific Ocean coast, which reduce the residence time of water in the estuary and prevent or slow the build-up of very high nutrient concentrations. Nonetheless, if inputs of nutrients were to increase substantially, eutrophication could become a problem.

Table 5-1. Indicator results and sensitivity to eutrophication index for Puget Sound marine monitoring stations, 2001-2005. Index calculations are described in Figure 5-6 and text. Stratification rankings are Strong and Persistent (SP), Strong and Intermittent (SI), Moderate and Intermittent (M Int), Moderate and Infrequent (MI), and Weak and Infrequent (WI). (Source: Ecology)

Location	DO	DIN	Stratification	Sensitivity to Eutrophication
Saratoga Passage	Very Low	Low	SP	Very High
Possession Sound	Very Low	Low	SP	Very High
Penn Cove	Very Low	Low	SP	Very High
Hood Canal - Sisters Pt.	Very Low	Low	SP	Very High
Bellingham Bay - Pt. Frances	Very Low	Mod	SI	High
Budd Inlet - South Port	Very Low	High	SI	High
Budd Inlet - Olympia Shoal	Very Low	Mod	MI	High
Admiralty Inlet South	Very Low	High	SI	High
Port Gardner West	Low	High	SP	High
Nisqually Reach	Very Low	High	WI	High
Hood Canal - Bangor[1]	Low	High	M Int	High
Sinclair Inlet[2]	Low	Mod	MI	High
Carr Inlet[2]	Low	Mod	WI	High
Henderson Inlet[2]	Low	High	WI	High
Willapa Bay - S. Jenson Pt.	High	Low	WI	Moderate
Willapa Bay - Nahcotta Channel	High	Low	MI	Moderate
Strait of Georgia	Low	High	SI	Moderate
Quartermaster Harbor	Low	Mod	MI	Moderate
Port Gamble	Low	Mod	MI	Moderate
Point Jefferson	Low	High	SI	Moderate
Elliott Bay	Low	High	SI	Moderate
Commencement Bay - Browns Pt.	Low	High	SI	Moderate
Commencement Bay	Low	High	SI	Moderate
Bellingham Bay - Nooksack	Low	High	SI	Moderate
Willapa River - Raymond	High	High	SI	Moderate
Willapa River - John. Slough	High	High	SI	Moderate
Port Townsend	Low	High	MI	Moderate
Port Orchard	High	Mod	WI	Moderate
Port Angeles Harbor	Low	High	WI	Moderate
Oakland Bay	High	Mod	MI	Moderate
East Sound	Low	High	MI	Moderate
Drayton Harbor	High	Mod	M Int	Moderate
Dana Passage	Low	High	WI	Moderate
Willapa Bay - Toke Point[3]	High	Mod	MI	Low
Willapa Bay - Naselle River[3]	High	Mod	MI	Low
Grays Harbor - Chehalis River[3]	High	High	SP	low
Grays Harbor - Damon Pt. [3]	Low	High	MI	Low
West Point[4]	Low	High	MI	Low
East Passage[4]	Low	High	MI	Low
Admiralty Inlet - Quimper Pn.[4]	Low	High	MI	Low
Admiralty Inlet - Bush Pt. [4]	Low	High	MI	Low
Totten Inlet	High	High	MI	Low
Point Wells	High	High	MI	Low
Grays Harbor - South Channel	High	High	MI	Low
Gordon Point	High	High	WI	Low
Dolphin Point	High	High	MI	Low

[1]Station has been moved, because of Navy security restriction. Alternate sampling sites are located in areas with different physical characteristics, which may impact water quality observations. Station believed to be higher-risk, based on historical observations.

[2]Station located in enclosed or semi-enclosed water body; increased risk due to reduced circulation.

[3]Station located in shallow, well-flushed areas; reduced risk.

[4]Station located in well-mixed, well-flushed passage or basin; reduced risk.

c. Fecal Pollution in Shellfish Growing Areas

DOH classifies commercial shellfish beds according to requirements set by the National Shellfish Sanitation Program and conducts its water quality monitoring program in conjunction with PSAMP. This long-term monitoring data has been used to determine status and trends of shellfish growing areas in Puget Sound. The shellfish growing area classifications are based on intensive and systematic sampling of fecal coliform bacteria and shoreline surveys to identify significant sources of fecal pollution. DOH also conducts comprehensive monitoring for biotoxins and performs other targeted monitoring activities.

Status and Trends

DOH calculated growing area statistics (geometric means and 90th percentiles)[1] from more than 1,300 marine water sampling sites in 98 shellfish growing areas collected in 2005. Sites were grouped by year and by category—"Good," "Fair," or "Bad." 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 fecal pollution in the various shellfish growing areas of Puget Sound (Figure 5-7). There were 31 shellfish growing areas with significant fecal pollution impact.

A Fecal Pollution Index, (FPI) was calculated for each growing area. (For detailed information on how FPIs were calculated, see Determan, 2005). Figure 5-8 shows FPIs for the 31 shellfish growing areas with scores greater than 1.0 in 2005 (approximately a third of all areas). In 2005, Drayton Harbor showed the greatest fecal pollution impact (FPI = 2.75), followed by Port Susan (FPI = 2.40), and Padilla Bay (FPI = 2.19). These FPIs help confirm the visual information displayed in Figure 5-7. The ranking may be a useful tool in prioritizing resources for remedial action. Figure 5-9 shows FPI values for the six basins in Puget Sound.

Fecal Pollution in Historically Important Shellfish Areas.
A number of shellfish growing areas have received substantial federal, state, and local resources for remedial action for over a decade. FPIs were used to examine trends in several long-term project areas. Figure 5-10 shows annual standardized FPIs[2] from seven shellfish harvest areas in Puget Sound, ordered according to their 2005 FPIs. Henderson Inlet and Portage Bay show evidence of reduced fecal impact in recent years. This may be in response to several factors, including remedial action, annual rainfall, and changes in land use. For example, fecal pollution impact in Henderson Inlet closely follows annual rainfall and may be a stronger influencing factor than remedial action. However, the strength of interacting factors in fecal pollution has not yet been examined.

Annual standardized FPIs were also calculated from pooled results from all standardized stations throughout Puget Sound. The results suggest that overall fecal pollution impact in Puget Sound from 1998 through 2005 has been low and stable.

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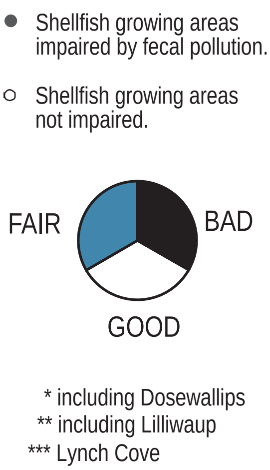
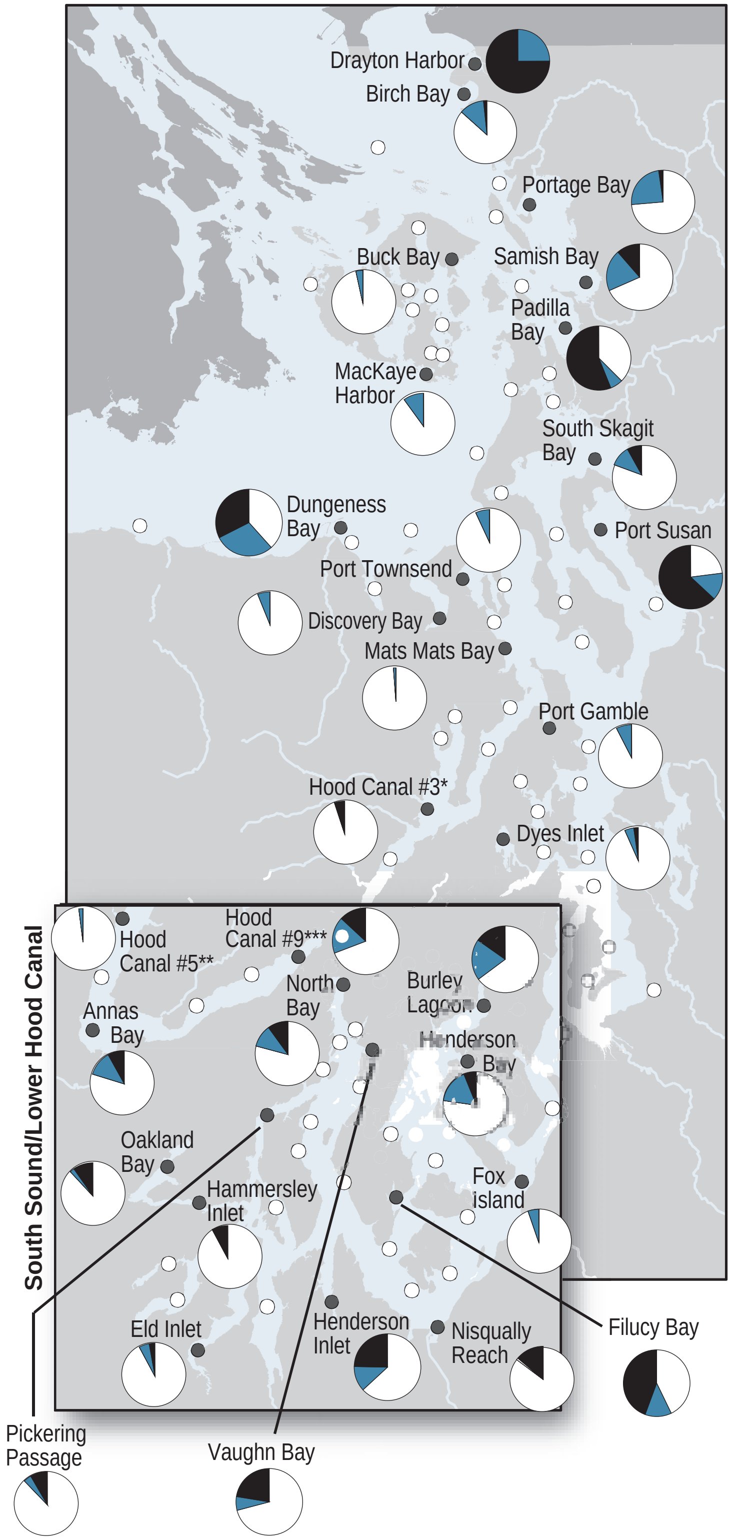
[1] The status of each growing area for calendar year 2005 was determined by sorting 90th percentiles from all sampling sites and sampling dates during the year into three categories: Good, Fair, or Bad. Each category is defined as follows:

- Good (0-30 MPN per 100 ml)
- Fair (31-43 MPN per 100 ml)
- Bad (greater than 43 MPN per 100 ml

[2] In order to assure accurate among-years comparison, each area was standardized, with only stations consistently sampled over the entire period of record used for FPI calculations. Thus, stations that were recently added or terminated were eliminated before FPIs were calculated. The annual FPIs were plotted as standard FPIs.

Figure 5-7: Status of fecal pollution in shellfish growing areas throughout Puget Sound and associated waters in 2005. The pie charts with greater proportions of black and gray represent areas most affected by fecal pollution. Thirty-one of the 98 shellfish growing areas were affected by fecal pollution. The most affected areas include three growing areas in north Puget Sound: Drayton Harbor, Port Susan, and Padilla Bay. Across the region, fecal pollution is generally low but widespread and highly variable.
(Source: DOH)





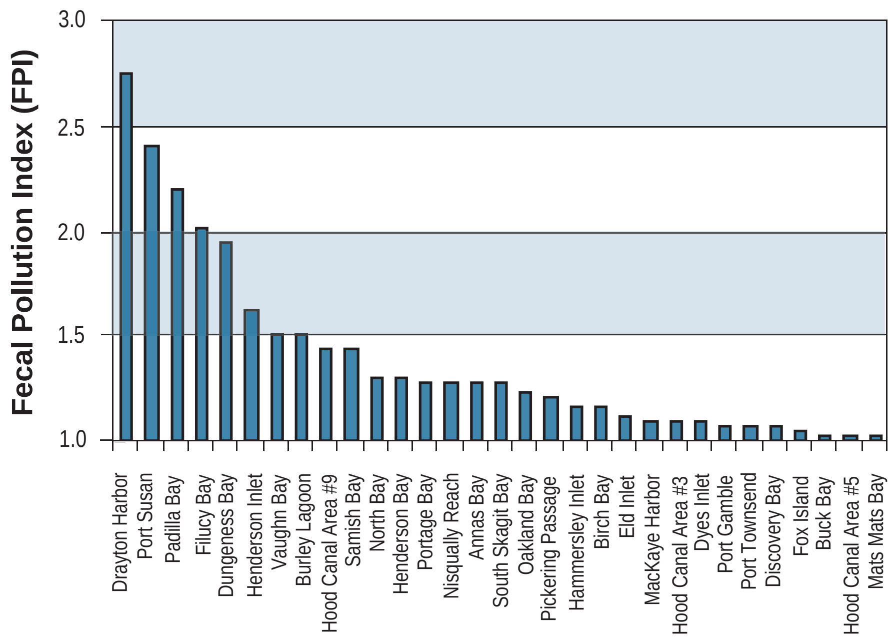


Figure 5-8. Index of fecal pollution in Puget Sound. A fecal pollution index (FPI) was used to rank 31 shellfish growing areas experiencing significant fecal pollution in 2005. The individual growing areas are ranked according to the degree of fecal coliform pollution impact, with Drayton Harbor showing the highest fecal pollution levels in Puget Sound.
(Source: DOH)

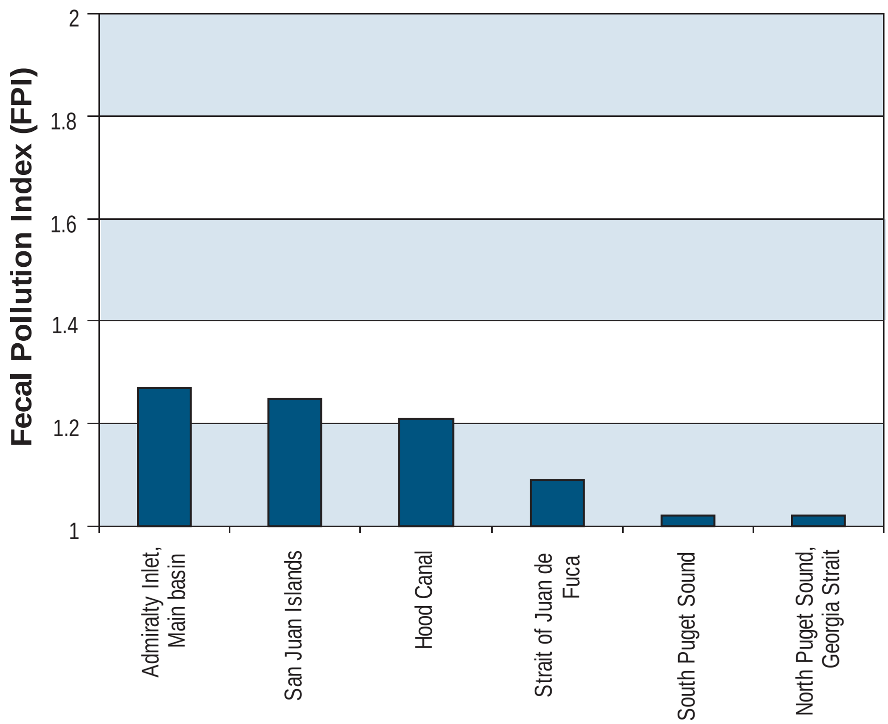


Figure 5-9. Fecal Coliform Index values for six major basins or regions in Puget Sound. North Puget Sound had the greatest impact, while Admiralty Inlet - Central Puget Sound the San Juan Islands were the lowest.
(Source: DOH)

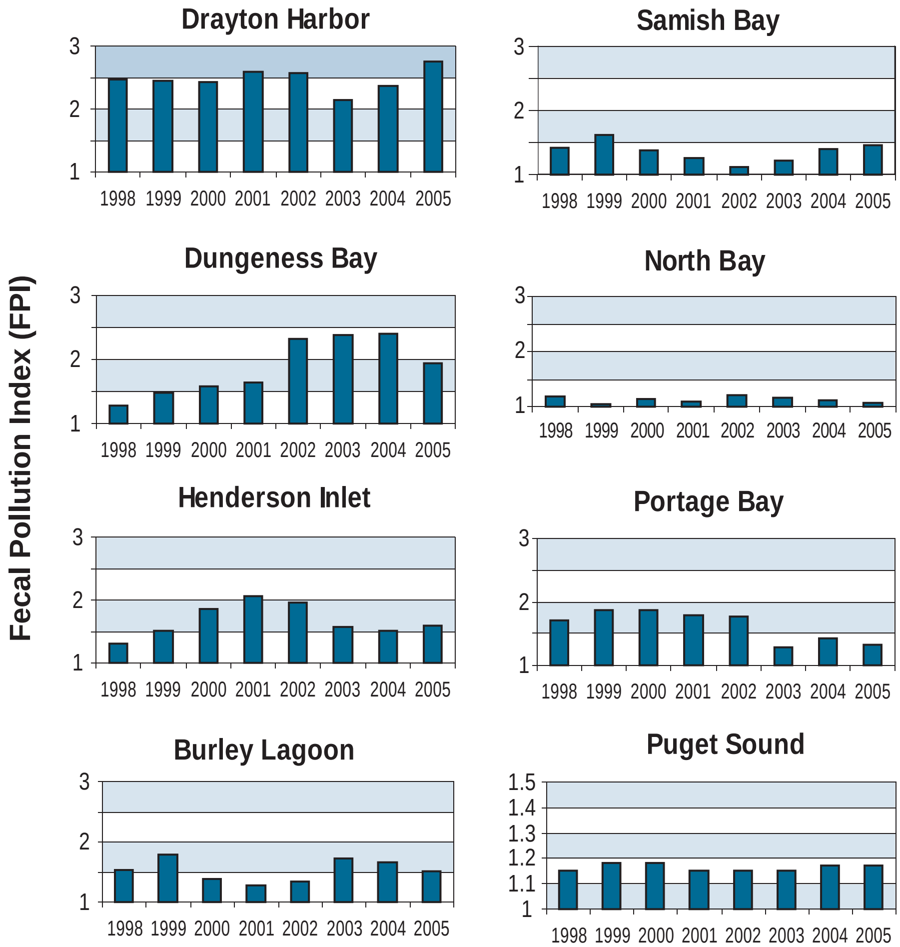


Figure 5-10. Fecal coliform index trends in Puget Sound, 1998-2005. Standardized FPIs were used to indicate temporal trends in fecal pollution in eight shellfish growing areas that received remedial action over the years 1998-2005. Changes in fecal pollution impact are attributed to various interacting factors, including local rainfall patterns, change in land use, and intensity of remedial action**.** (Source: DOH)

Shellfish Growing Area Reclassification

During the past two decades, numerous growing areas have been downgraded by DOH, because of nonpoint fecal pollution. Local and state agencies subsequently investigated fecal sources in each associated watershed. Various processes have been undertaken to address pollution issues, including watershed management, intervention by local health authorities and conservation districts, shellfish closure response efforts, and Ecology's Total Maximum Daily Load program. In some instances, remedial action has led to upgrades of growing areas. Figure 5-11 summarizes reclassifications of shellfish growing areas in Puget Sound from 2001 to 2004 and also notes the key pollution sources.

Between 1995 and 2005, DOH reclassified more than 20 commercial shellfish growing areas in Puget Sound (Figure 5-12). During that period, over 12,500 acres (5,059 hectares) were upgraded and more than 5,000 acres (2,023 hectares) were downgraded, yielding a net gain of approximately 8,500 (3,440 hectares) commercial acres. The increase in harvestable acreage is the result of targeted efforts to protect and restore the Sound's valuable shellfish growing areas. The successes during this period take on added significance when compared with the region's population growth and development that continued to expand during this time frame.

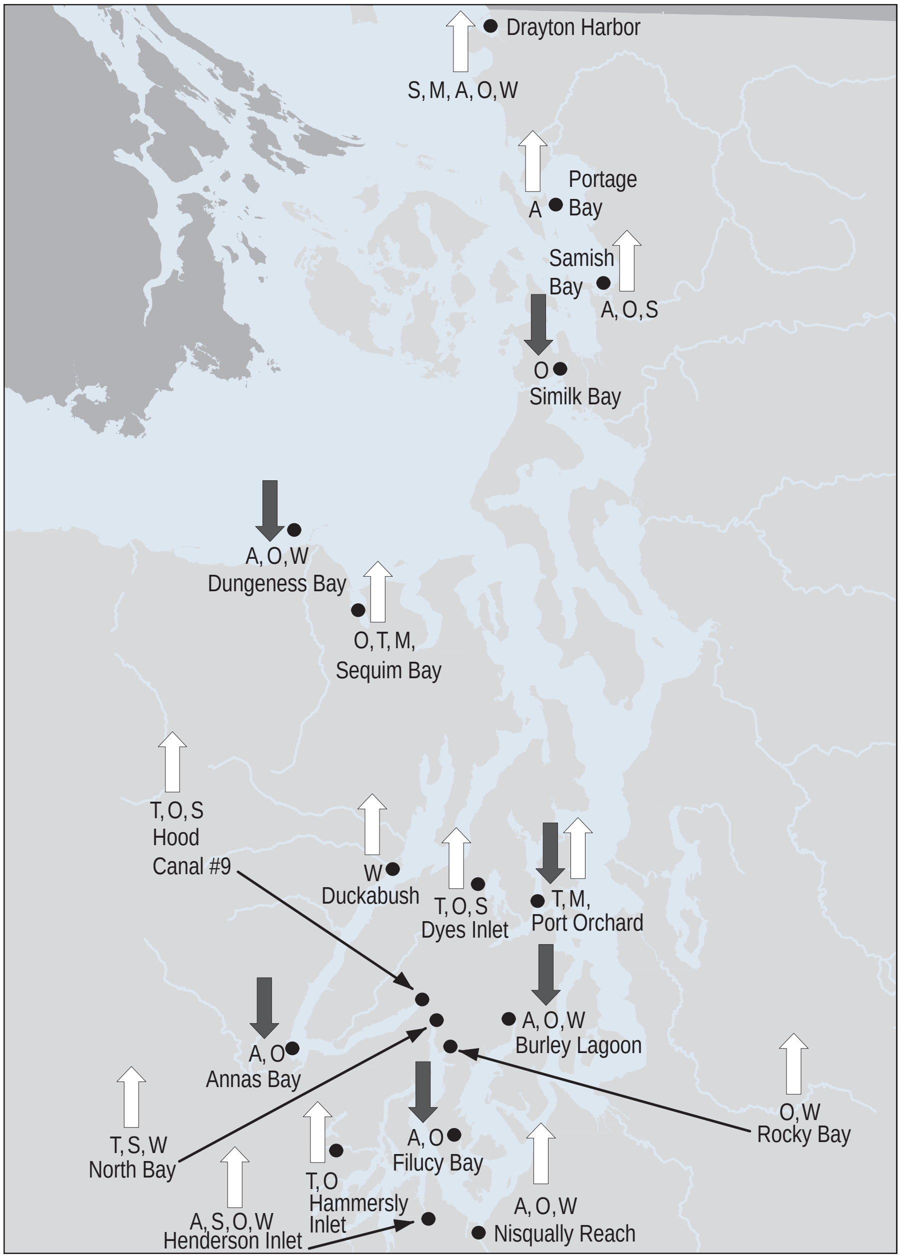


Figure 5-11. Shellfish growing areas in Puget Sound that have been reclassified or listed as threatened between 2001 and 2004. All areas are affected by nonpoint pollution sources (i.e., stormwater, agricultural runoff, and failing onsite sewage systems), therefore, conditions vary throughout Puget Sound. Some areas have improved because of local remedial action programs. Pollution sources listed have been identified and tracked. (Source: DOH)

Pollution Sources

O - Onsites
T - Treatment Plant
S- Stormwater
A- Agriculture
W- Wildlife
M - Marinas

Reclassification Type

Downgrade

Upgrade

d. Kitsap County pathogen study

Kitsap County Health District (KCHD) began water quality monitoring in 1996 in 10 watersheds throughout Kitsap County. The program included monitoring for fecal coliform bacteria in 55 streams, 67 marine stations, and 28 beaches. In addition, KCHD's Pollution Identification and Correction (PIC) Program was created to assist communities in the clean up of surface waters that had documented fecal coliform pollution problems. PIC staff visit homeowners and help identify potential pollution sources. They also educate homeowners on how to avoid contributing to pollution loads, including proper maintenance of onsite sewage (septic) systems. Over the past 10 years, PIC staff have inspected 4,827 individual properties and discovered 737 failing onsite sewage systems.

As of result of this program, four polluted shellfish harvesting areas were cleaned up and reopened: Burley Lagoon, Port Gamble Bay (Cedar Cove), Illahee State Park, and Dyes Inlet. To prevent additional inputs of fecal contamination, four sewage control devices were installed at Kitsap County marinas.

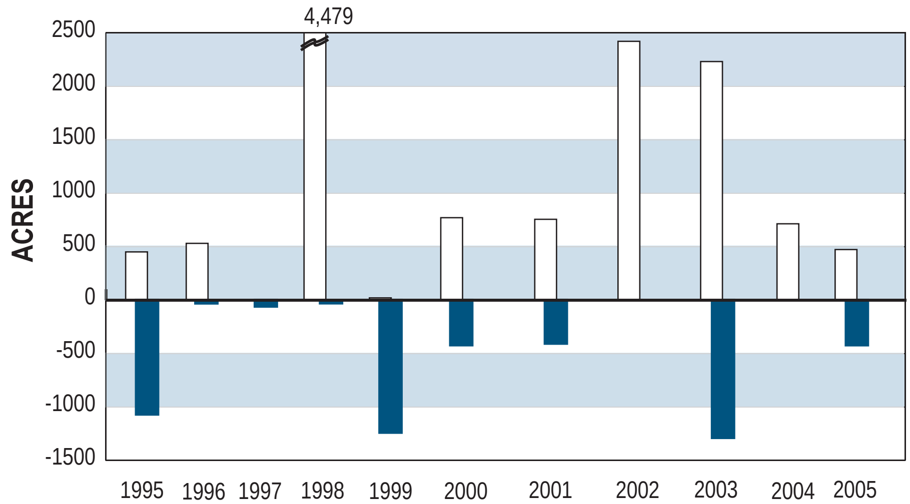


Figure 5-12: Puget Sound commercial shellfish reclassification, 1995-2005. The figure shows names and relative sizes of commercial shellfish growing areas reclassified by DOH (adapted from DOH 2005). Improvements in water quality and sanitary conditions allow DOH to reduce or remove harvest restrictions (upgrades), and declining conditions require DOH to restrict or close areas to harvesting (downgrades). The graph shows significant variability from year to year, but the trend in Puget Sound over the 11-year period has been generally positive, as restoration efforts have successfully outpaced downgrades in other areas. (Source: PSAT)

☐ Upgrades

■ Downgrades

** reclassifications associated with changes in sanitary conditions*

e. Monitoring for Fecal Pollution along Puget Sound Beaches

Ecology and DOH jointly administer the Beach Environmental Assessment, Communication and Health (BEACH) Program, an EPA-funded effort that monitors for fecal bacteria (enterococcus) at saltwater beaches used for swimming, surfing, scuba diving, wind surfing, and other water contact activities. The program also notifies the public if a beach is believed to have an increased risk of disease. The BEACH Program coordinates its activities with DOH's shellfish monitoring program.

King County also monitors its beaches for fecal contamination, mainly focusing on shellfish consumption risk. Although the health risks for consuming shellfish are evaluated differently than the risks for water contact activities, the BEACH Program and King County programs complement each other by providing comprehensive bacteria monitoring and public health evaluations at Washington's heavily used saltwater beaches.

i. Ecology's BEACH Program

The BEACH Program was developed in 2002 and full implementation began in 2004. Each year a risk-based system that considers use patterns and the proximity to significant sources of fecal pollution is used to select approximately 70 beaches for weekly monitoring during the summer, from Memorial Day through Labor Day. From 2002 through 2005, nearly 200 beaches have been evaluated and 104 beaches have been monitored. Figure 5-13 shows sampling locations in 2004 and 2005 and the number of exceedances during each season.

Status and Trends

In north Puget Sound, 25 beaches were sampled during the 2004-2005 period. This area does not usually have high bacterial counts, because of the existence of exposed beaches with strong currents and short retention times. Beaches that did have exceedances tended to be in communities that were largely on septic systems (Birch Bay County Park and Bayview State Park) or in small, enclosed bays, such as Freeland.

In the central Sound, 28 beaches were sampled in 2004 and 2005. This area tends to have the highest bacteria counts, primarily due to combined sewage overflows, aging infrastructure, and small enclosed bays with long retention times. Specifically, Dyes and Sinclair Inlets tend to have high numbers of exceedances.

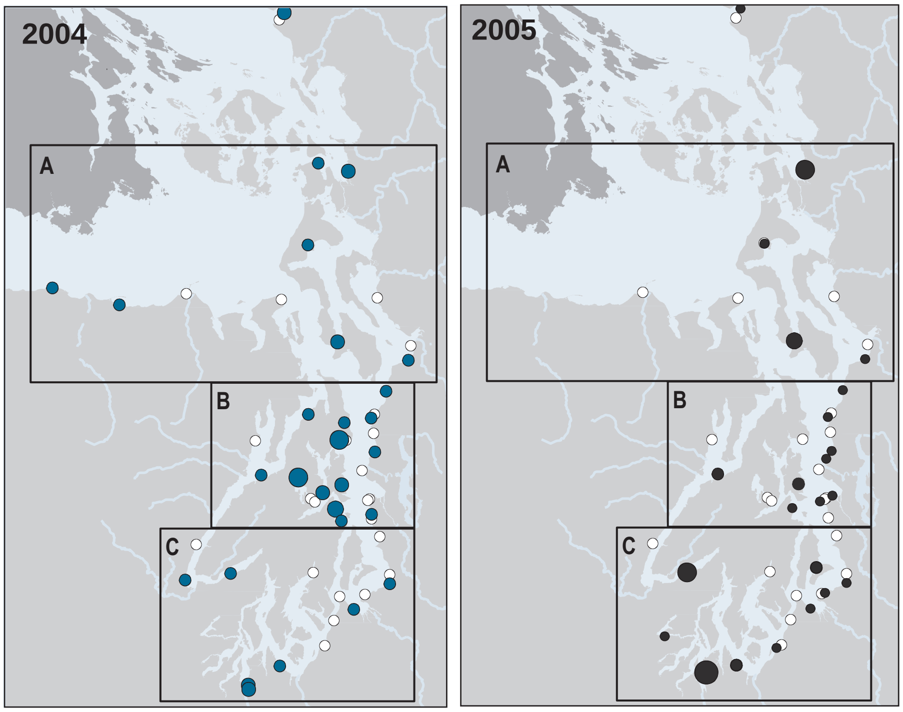


Figure 5-13. Beach monitoring in Puget Sound. This map indicates beach monitoring sites and locations with enterococcus bacterial exceedances from Ecology's BEACH Program. Sampling took place during the summer months of 2004-2005. Central Sound typically has more bacteria exceedances owing to combined sewer overflows, aging infastructure and the numerous small, enclosed bays with long retention times.
(Source: Ecology)

Number of enterococcus exceedences

2004	2005
No exceedence	No exceedence
1	1
2	2
3	3
4	4
5	5
6	6

Twenty-three beaches in the south Sound were monitored during 2004 and 2005, and the results indicate patchy bacterial exceedances attributed to site-specific problems. A failing septic pipe was identified as a source of high bacteria at Twanoh State Park in Hood Canal, and a failing treatment plant was identified as a source in Thurston County.

Human Health Implications

The BEACH Program notifies the public whenever high levels of bacteria or sewage spills are affecting monitored beaches. The number of beach closures caused by sewage spills has increased dramatically since 2003, which may be partly the result of better communication between state and local agencies, rather than an increase in the number of spills.

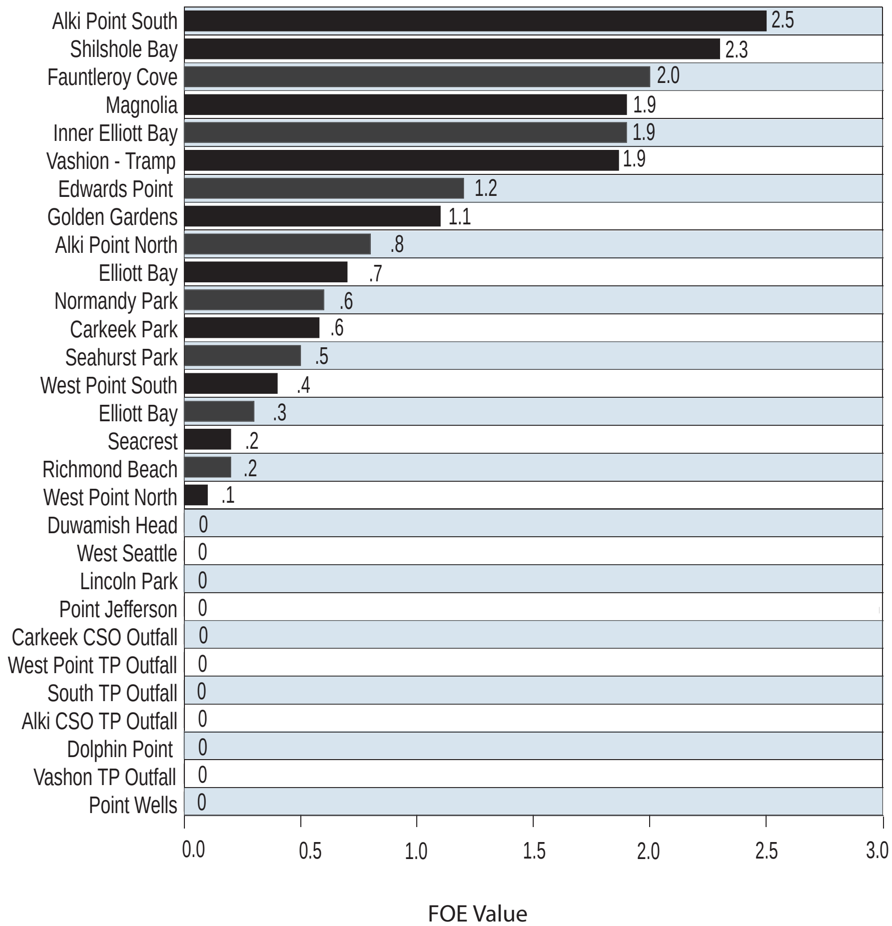
ii. King County's Beach Monitoring Program

Status and trends

Trend analyses of fecal coliform geometric mean values from more than 20 beach stations monitored by King County indicate that fecal pollution at these sites has been lessening since 1997. This may be attributable to changes in annual rainfall patterns. Seattle's Carkeek and Golden Gardens Parks, located north of the Ship Canal, consistently exceeded the water quality guidelines until mid-2002 and have since improved to acceptable levels. Stations in Magnolia, Alki Point, and Fauntleroy Cove show similar trends but still exceed water quality guidelines.

To rank the extent of fecal coliform levels at King County marine monitoring stations, a Frequency of Exceedence (FOE) Index was calculated for 20 King County beach and offshore stations sampled in 2004 (Figure 5-14). The FOE index is based on Washington State Department of Ecology water quality guidelines and represents the frequency with which a station exceeds fecal coliform bacteria state guidelines. The higher the value of the FOE Index, the more frequently a station has exceeded state guidelines for fecal coliform bacteria. The

Figure 5-14. Frequency of Exceeding (FOE) fecal coliform ranking at King County beaches. Sites are ranked according to their frequency of exceeding state guidelines for fecal coliform at King County beaches and offshore stations in 2004. The higher the value of the FOE Index, the more frequently a station has exceeded state guidelines for fecal coliform bacteria.
(Source: KC DNRP)



results of ranking stations by FOE index can be seen in Figure 5-14. Station LSKS01 near Alki Point is ranked as King County's most polluted station with respect to fecal coliform contamination. This station was persistently in exceedance of water quality guidelines by greater than two times for the entire year. With the exception of LTEH02 and LTED04, both in Elliott Bay, all offshore and outfall stations had the lowest FOE index for fecal coliforms.

Monitoring for Fecal Coliform at Public Shellfish Beaches

In addition to monitoring water quality at beaches for fecal pollution to protect human health, the State also monitors beaches for fecal coliform bacteria and biotoxins in shellfish harvest areas. In 2005, over 450,000 recreational shellfish licenses were sold in Washington. DOH works cooperatively with WDFW, local health jurisdictions, tribes and other stakeholders to classify beaches and educate the public regarding their personal responsibility for safe shellfish harvests and consumption.

Currently, 251 recreational beaches are classified as "Open," "Conditionally Open," "Advisory," or "Closed." Monitoring and classification efforts focus on areas with significant shellfish resources and harvest activity (more than 500 people per year). Between 2004 and 2005, seven local health jurisdictions requested that DOH classify 13 recreational shellfish beaches. As with commercial shellfish areas, recreational classification must meet the standards of the National Shellfish Sanitation Program.

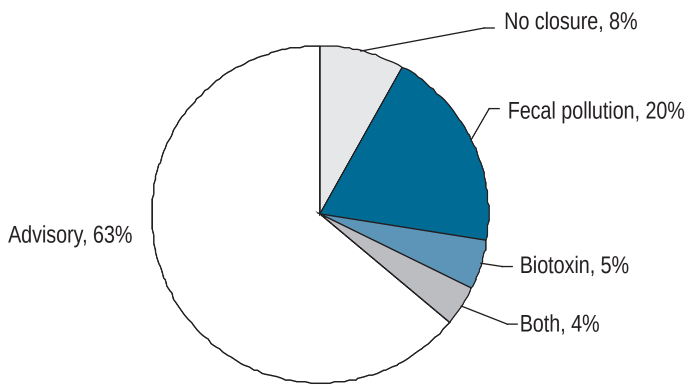


Figure 5-15. **Closure status of all Puget Sound recreational shellfish beaches as of May 31, 2006**. Status can change daily because of marine biotoxin or pollution events.
(Source: DOH)

County	total	No Closure	Pollution	Biotoxin	Both	Advisory
Clallam	29		5	4	8	12
Island	56	5	17			34
Jefferson	47	5	7	3	1	31
King	22		13		3	6
Kitsap	30	3	11	3	2	11
Mason	36	4	9			23
Pierce	33	8	6			19
San Juan	123	3	1			119
Skagit	21		4	10		7
Snohomish	7	1	4		2	
Thurston	6	2	3		1	
Whatcom	18	3	4			11
Total	428	34	84	20	17	273

Table 5-2 Closure location and status of recreational shellfish beaches in 12 Puget Sound counties as of May 31, 2006. The table indicates the wide range of available recreational beaches and the diversity of factors controlling their availability for shellfish harvest. (Source: DOH)

Notes: Status can change daily due to marine biotoxins or pollution events.

No Closure: Beaches that were currently not closed as of May 31, 2006.

Pollution: Beaches that are closed due to known or likely sources of contamination from human or animal waste as of May 31, 2006.

Biotoxin: Beaches that were closed due to biotoxins (PSP, domoic acid) as of May 31, 2006.

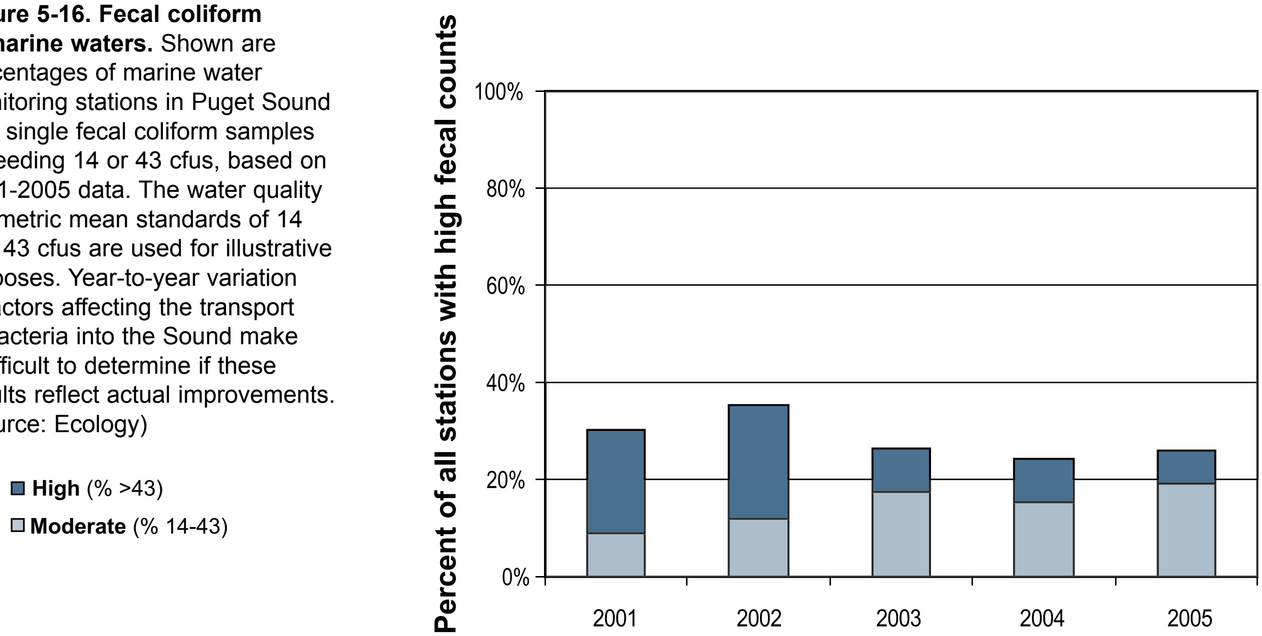
Both: Beaches closed by both health threats as of May 31, 2006.

Advisories: Beaches that are unclassified; possess seasonal closures (i.e., marinas, *Vibrio)*; or pollution events are too unpredictable (rainfall, combined sewer overflows, etc.).

All 12 local health jurisdictions in Puget Sound manage the recreational shellfish beaches in their areas. DOH works closely with the jurisdictions, parks administrators, and other stakeholders to provide program guidance, beach signs, and educational materials.

The current closure status for 428 recreational shellfish beaches in Puget Sound is listed in Table 5-2. Figure 5-15 summarizes this information for all beaches in Puget Sound, indicating that about 20 percent of shellfish on recreational beaches are affected by fecal pollution. Fecal pollution tends to be somewhat localized in adjacent uplands and, thus, can be controlled. In contrast, marine biotoxins (such as domoic acid) and diseases (such as vibriosis from *Vibrio* bacteria) are subject to more regional or global factors and, thus, are unlikely to be eliminated by remedial action. More than 60 percent of beaches have advisories, due to a variety of factors, including a lack of information (unclassified status), seasonal closures, or pollution events that are too unpredictable (e.g., rainfall or combined sewer overflows).

Figure 5-16. Fecal coliform in marine waters. Shown are percentages of marine water monitoring stations in Puget Sound with single fecal coliform samples exceeding 14 or 43 cfus, based on 2001-2005 data. The water quality geometric mean standards of 14 and 43 cfus are used for illustrative purposes. Year-to-year variation in factors affecting the transport of bacteria into the Sound make it difficult to determine if these results reflect actual improvements. (Source: Ecology)



f. Fecal Coliform Bacteria in Marine Waters

Ecology uses individual monthly samples, collected at open-water stations, to identify high fecal coliform concentrations for its long-term marine monitoring program. State standards for fecal coliform bacteria in marine waters dictate that the mean (geometric) of multiple samples cannot exceed 14 colonies/100 ml, and that not more than 10 percent of these samples can exceed 43 colonies per 100 ml. For simplicity of presentation, these limits are used to categorize fecal coliform, based on individual samples in this document.

Status and Trends

The percentage of stations with moderate (14-43 cfu[3] per 100 ml) or high (>43 cfu per 100 ml) maximum fecal counts from 2001 through 2005 are presented in Figure 5-16. These results are consistent with a general decline in fecal coliform contamination noted in the *2002 Puget Sound Update*, but, because there is considerable year-to-year variation in factor affecting the transport of bacterial pollution into Puget Sound, further monitoring is required to determine if these results represent actual improvements.

The maximum fecal coliform bacteria concentrations observed at stations throughout Puget Sound between 2001 and 2005 and classified using the same criteria discussed previously are shown in Figure 5-17. The highest levels of fecal contamination were observed in Budd Inlet, Commencement Bay, Oakland Bay, Port Angeles Harbor, Possession Sound, Elliott Bay, and off West Point. Moderately high levels of contamination were observed in Admiralty Inlet, Bellingham Bay, Sinclair Inlet, and off Point Jefferson. In general, these results are similar to those from 1998 through 2000 and reflect the fact that fecal coliform contamination is typically associated with large urban areas, those areas adjacent to intense shoreline development, or near enclosed or semi-enclosed inlets with slower flushing times.

[3] Colony forming unit

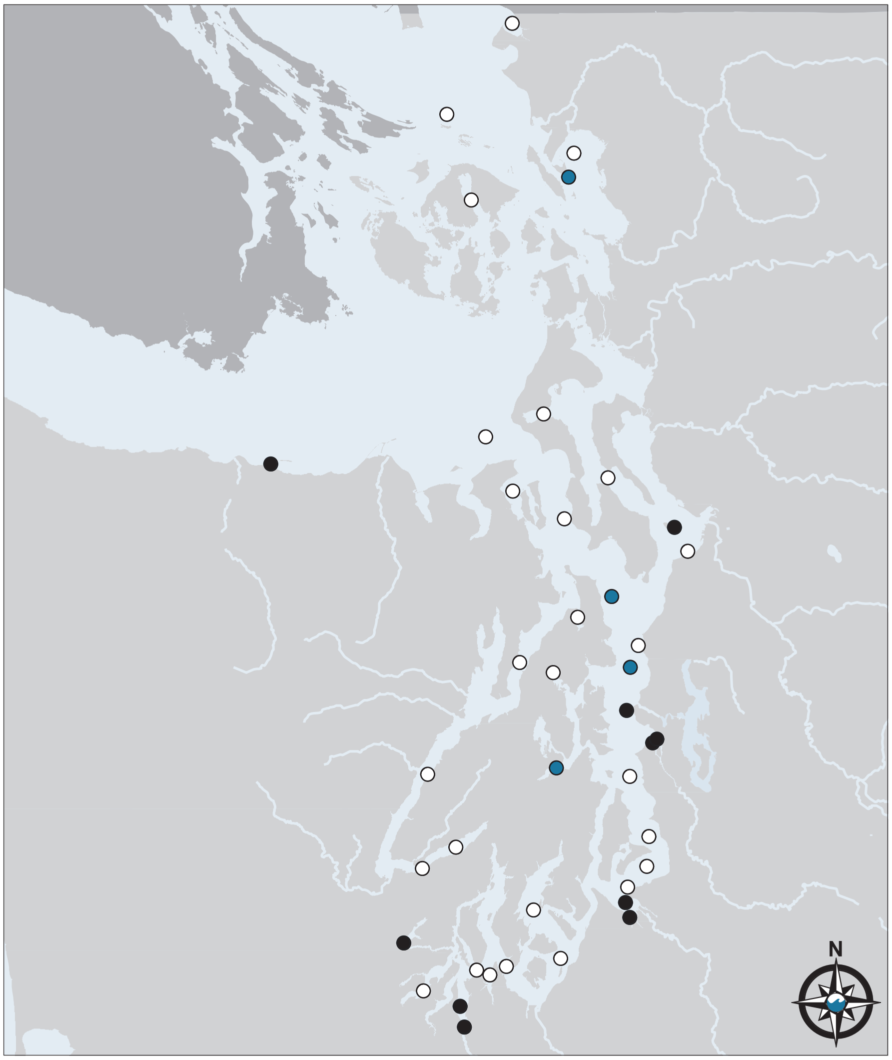


Figure 5-17. Distribution of maximum fecal coliform bacteria counts at marine monitoring stations in Puget Sound, 2001-2005. High fecal coliform counts indicate the presence of a nearby source of fecal coliform bacteria and, possibly, other contaminants. (Source: Ecology)

- High (> 43 cfu/100ml)
- Moderate (14-43 cfu/100ml)
- Low (< 14 cfu/100ml)

Declines in both fecal coliform and ammonium, both byproducts of animal waste, were observed at DOH's Bellingham Bay-Nooksack station. In 2003, DOH upgraded a portion of Portage Bay in Bellingham Bay as a result of reduced fecal pollution. This upgrade could be related to a remediation program involving a number of agencies and organizations to prevent and control fecal pollution from many sources, with control measures including better management practices at dairies in the Nooksack River watershed.

g. Circulation Modeling in Oakland Bay and Hammersley Inlet

The City of Shelton needed to increase the discharge from its wastewater treatment plant but did not want to compromise economically important shellfish harvest areas. DOH approached Ecology in 2002 to develop a computer model of Hammersley Inlet and Oakland Bay that could be used to evaluate the effectiveness of various discharge scenarios. The use of computer circulation models provides an excellent, cost-effective way to evaluate the possible outcomes of different management actions on marine water bodies.

To address DOH's request, Ecology developed the three-dimensional Hammersley Oakland Bay Oceanographic circulation model. The approach taken to evaluate discharge scenarios also included a dye-release study to determine the amount of of dilution between the existing outfall and the boundaries established to protect the shellfish beds (See Figure 5-18 in Appendix C, Color Figures). The model was tuned to recreate the amount of dilution observed during the dye experiment and used to determine if various discharge scenarios would meet required water standards for fecal coliform bacteria.

The study, which was also supported by FDA and the City of Shelton, was a factor in DOH's decision to reopen a portion of the shellfish growing area in Hammersley Inlet. It also provided guidance for planned treatment plant upgrades, which include improvement of the outfall, installation of an effluent detention basin for controlling the timing of discharges, and a permit limit on the amount of effluent that could be discharged.

6. Harmful Algal Blooms

a. Biotoxins

Harmful algal blooms (HABs) in Puget Sound are those that can cause PSP and ASP. To detect the occurrence of these forms of poisoning, DOH monitors biotoxins in shellfish species from many locations throughout Washington's marine waters. In Puget Sound, DOH samples mussels biweekly for PSP and domoic acid at sites that are part of its Sentinel Monitoring Program. When shellfish show harmful levels of either biotoxin, DOH issues warnings to commercial and tribal growers, recreational beach managers, and local health agencies.

Status and Trends

There has been a documented spread in the occurrence of PSP throughout Puget Sound (Trainer et al. 2003) and formal shellfish closures that first began in the 1950s in areas of north Puget Sound in Sequim Bay, Discovery Bay, and the San Juan Islands. The first closures inside the main basin of Puget Sound were reported in 1978 when a large bloom event followed a late-summer warm spell and heavy rains. PSP illnesses were reported from Saratoga Passage to Vashon Island. The gradual, southward spread of PSP closures continued with increased incidents during the 1980s and 1990s. In 2000, seven people were stricken with PSP from mussels collected in Carr Inlet in South Puget Sound.

Diatoms in the genus *Pseudo-nitzschia* can produce the ASP-causing toxin domoic acid, which can accumulate in shellfish and other organisms to levels dangerous to human and marine life. In the fall of 1991, DOH found domoic acid in razor clams along Washington's ocean coast. Shellfish closures due to domoic acid levels are presently not uncommon and can be fairly chronic on Washington's ocean coast. Prior to 2003, domoic acid had not been detected at closure levels within Puget Sound, although *Pseudo-nitzschia* and domoic acid had been documented in Hood Canal (Horner et al.1996). In 2003, the first shellfish closure attributed to domoic acid occurred near Port Townsend in north Puget Sound.

In 2005, elevated levels of domoic acid prompted shellfish closures in Sequim Bay, Penn Cove, Saratoga Passage, and Holmes Harbor. The factors prompting such blooms and domoic acid production are current topics of research, to better understand, for example, why the concentrations of *Pseudo-nitzschia* do not correlate with the amounts of domoic acid found in shellfish (Trainer et al. 2000; 2002).

Harmful algae in Puget Sound

Phytoplankton are single-celled, free-floating plants (algae) in marine waters. A harmful algal bloom contains species of algae that produce biotoxins. When sunlight and nutrients are optimal, blooms of phytoplankton occur. Shellfish may concentrate dangerous levels of biotoxin while feeding during a bloom. Blooms of certain phytoplankton are known to harm humans, marine mammals, and birds. Two harmful algae are found in Puget Sound. The dinoflagellate *Alexandrium catenella* produces a family of saxitoxins, known collectively as PSP toxin. Symptoms of PSP range from numbness of the lips, face, and extremities, to respiratory arrest and death. There is no known antidote.

The second harmful algae is *Pseudo-nitzschia,* which produces domoic acid. Diatoms of this genus are an unfortunate recent arrival to Puget Sound from Pacific Ocean coastal waters. Gastrointestinal distress occurs within 24 hours after eating domoic acid-contaminated shellfish. Other reported symptoms include dizziness, headache, disorientation, and permanent short-term memory loss. In severe cases of ASP, seizures and death may occur.

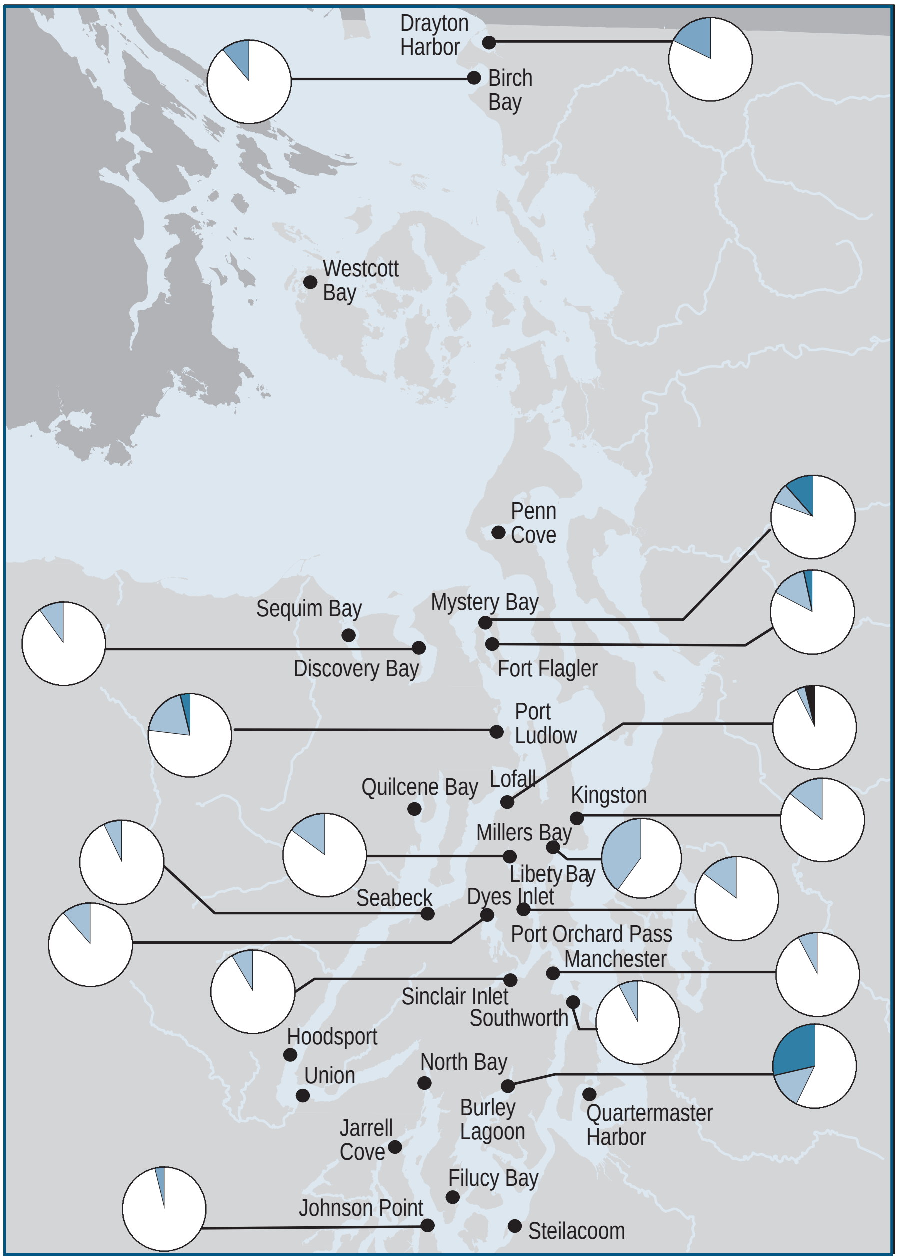


Figure 5-19. Paralytic Shellfish Poisoning (PSP) activity at PSP monitoring sites in Puget Sound. Pie charts estimate time per year each site was within a PSP impact category. Those sites with no pie chart did not experience PSP in 2005. (Source: DOH)

PSP Impact Categories

- None (PSP less than 80 ppb)
- Low (PSP 80 -499 ppb)
- Moderate (PSP 500 -999 ppb)
- High (PSP greater than 1000 ppb)

b. Paralytic Shellfish Poisoning

Status and Trends

In 2005, DOH examined results from 29 sentinel monitoring sites for spatial and temporal trends in PSP. The spatial distribution of PSP in Puget Sound is shown in Figure 5-19. Results were sorted into PSP impact categories (defined in the figure's legend) at each site. A pie chart summarizes the fraction of results in each impact category. Eighteen of 29 sites (62 percent) had at least minimal PSP impact.

The 18 sites affected by PSP were ranked, using a PSP Impact Index[4], which ranges from 1.0 (100-percent "Low" results) to 3.0 (100-percent "High" results).

[4] To calculate the PSP Impact Index, PSP results were sorted according to impact category (Low, Moderate, and High). The fraction in each category was then weighted (i.e., Low fraction x1; Moderate fraction x 2; High fraction x 3). The PSP Impact Index is the sum of the weighted values.

Figure 5-20. Ranking of 18 of 29 individual paralytic shellfish (PSP) poisoning sampling sites impacted in 2005. The PSP Impact Index ranges from 1.0 (100=percent Low results) to 3.0 (100=percent High results). Most sites fall within Medium to Low impact ranges. (Source: DOH)

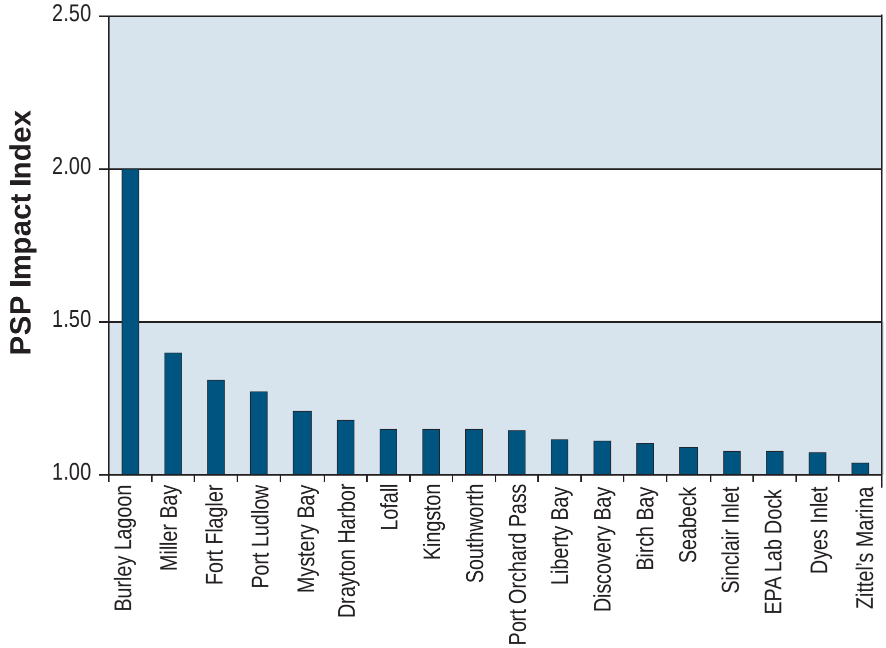


Figure 5-20 ranks the 18 sites according to the intensity of PSP activity. Burley Lagoon (in the South Puget Sound Basin) ranked highest in 2005, according to the PSP Impact Index.

The concept of the PSP Impact Index was extended to describe temporal tends in PSP activities in Puget Sound from 2001 through 2005. PSP impact indices were calculated, using results from all sites within each of five regions of Puget Sound and Soundwide (Figure 5-21) for each year from 2001 through 2005. The data suggest that, over the past five years, PSP activity was lowest in 2003 in four of five regions and overall in Puget Sound. PSP activity appears to have dropped significantly in 2005 in the Strait of Juan de Fuca, Admiralty Inlet, and the Central Puget Sound Basin. However, PSP activity was higher in 2005 in Georgia Strait and south Puget Sound. PSP activity in Hood Canal recently occurred for the first time in five years with blooms in Lofall and Seabeck.

c. Domoic Acid in Puget Sound

Status and Trends

In September, 2003, a *Pseudo-nitzschia* bloom occurred near Fort Flagler State Park on Marrowstone Island in Jefferson County. Subsequently, domoic acid was detected in mussels from the sentinel mussel cage at Fort Flagler, at levels slightly above the FDA domoic acid action level of 20 ppm in shellfish. DOH initiated closures for commercial and sport shellfisheries in the Fort Flagler area. Although the bloom was short-lived, low levels of domoic acid were detected as far west as Port Angeles, as far east as east Whidbey Island, and as far south as Port Ludlow (Figure 5-22).

In October 2005, levels of domoic acid detected in mussels from Penn Cove and clams from Holmes Harbor exceeded the FDA standard for PSP, prompting new closures. This time, levels were higher than first recorded in 2003. Domoic acid was also detected in Dungeness crab, below the FDA action level of 30 ppm for crab meat. Consequently, the crab fishery was not closed.

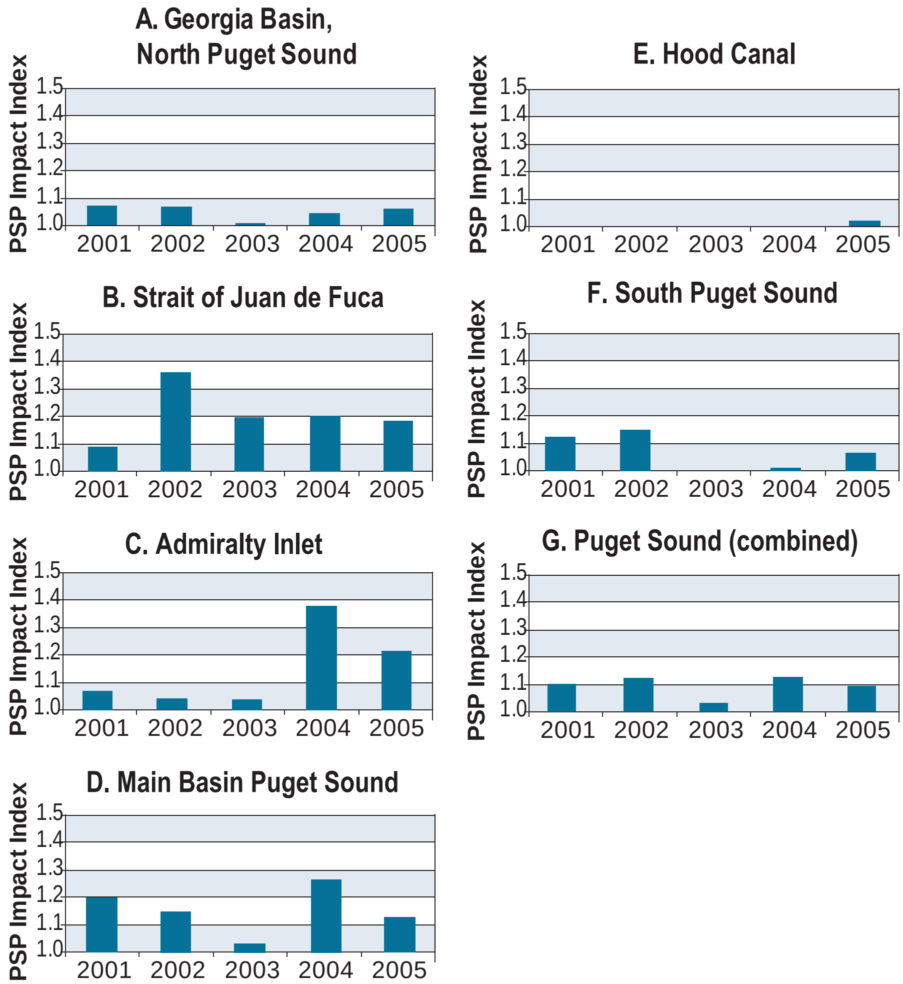


Figure 5-21. Trends in Paralytic Shellfish Poisoning (PSP) in Puget Sound. Temporal trends in PSP intensity from 2001 through 2005 in five regions of Puget Sound and through all of Puget Sound combined. The data suggest that PSP activity in the last five years was lowest in 2003 in regions a, s, d, and f and overall in Puget Sound. PSP activity appears to have dropped significantly in 2005 in the Strait of Juan de Fuca, Admiralty Inlet, and the Central Puget Sound Basin. However, PSP activity was higher in 2005 in the Georgia Strait and Puget Sound. (Source: DOH)

7. Natural Pathogens

a. Vibrio

Vibrio parahaemolyticus is a bacteria that naturally inhabits coastal marine waters. Its pathogenic mechanisms are not completely understood. DOH routinely analyzes oyster samples for presence of *V. parahaemolyticus* colony.

From May through September, DOH obtains oyster samples for laboratory analysis at least every other week from selected harvest sites in Puget Sound. Sites are located in Samish Bay, north, central, and south Hood Canal, Hammersley Inlet, and Willapa and Quilcene bays (Figure 5-23). These sites represent areas that were sources of two or more confirmed *V. parahaemolyticus* illnesses annually within the past three years.

Status and Trends

In 2006, a Washington record was set for the numbers of *Vibrio parahaemolyticus*-associated illnesses and laboratory confirmed cases of vibriosis was set. Among Washington residents and visitors to Washington who consumed local oysters during the outbreak, 113 cases of vibriosis were reported, with 71 of these cases being laboratory confirmed. The year-to-date total, which includes sporadic cases, is 124 cases, with 75 being laboratory confirmed. This reported outbreak surpasses that of 1997 and establishes a record that no one is anxious to soon exceed.

Figure 5-22. Domoic acid blooms in Puget Sound. The first major incursions of domic acid in Puget Sound occurred in 2003. The FDA domoic acid action level is 20 ppm. Above this level, shellfish are considered unsafe for human consumption.
(Source: DOH)

1. Littleneck clams - 36 ppm
   Sept. 15, 2005
2. Blue mussel - 26 ppm
   Sept. 19, 2005
3. Manila clams - 36 ppm
   Pacific oysters - 30 ppm
   Sept. 12, 2003
4. Blue mussel - 29 ppm
   Sept. 2, 2003
5. Manila clams - 68 ppm
   Blue mussel - 46 ppm
6. Dungeness crab - 28 ppm
   Oct. 26, 2005
7. Manila clams - 32 ppm
   Oct. 17, 2005

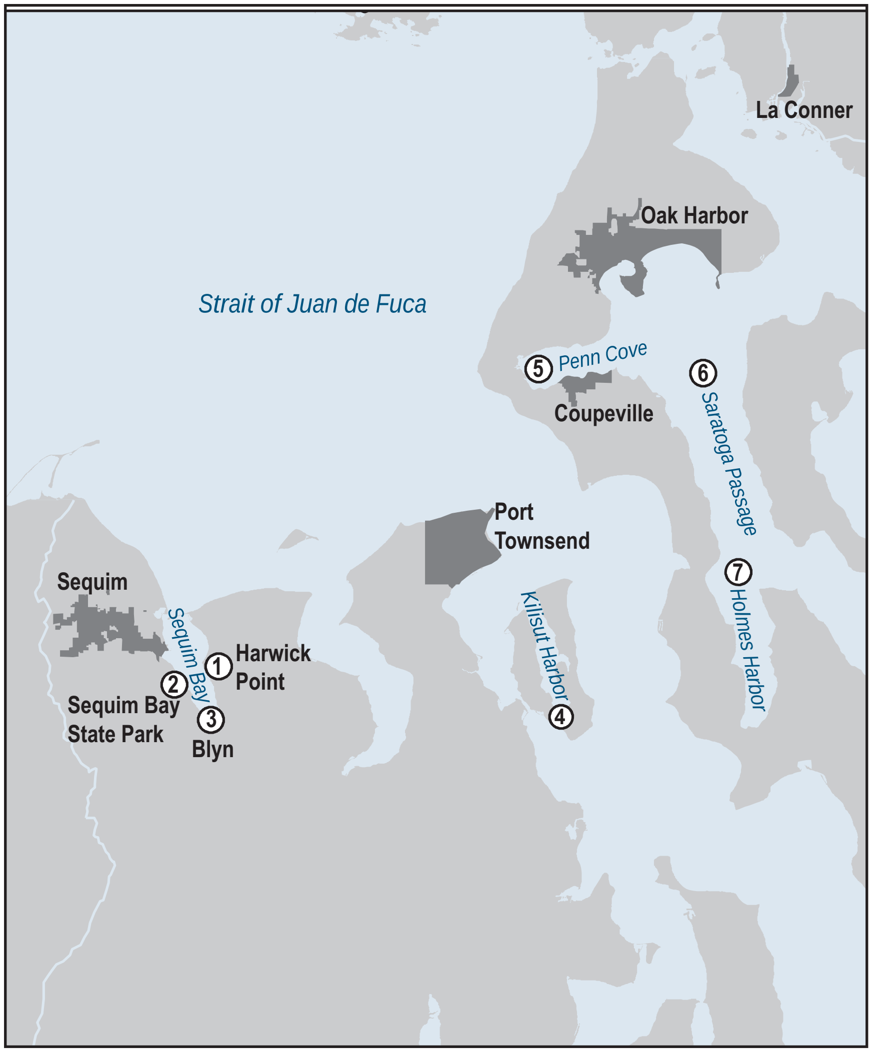
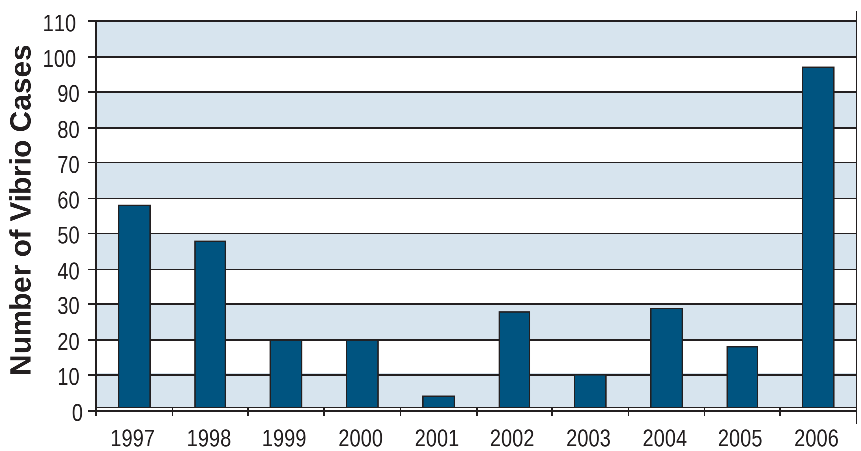


Figure 5-23. Vibriosis occurrence in Puget Sound. Confirmed cases of vibriosis from the disease's documented onset in Puget Sound in 1997 through 2006.
(Source: DOH)



8. State Controls

a. TMDL Process Overview

The federal Clean Water Act requires that a Total Maximum Daily Load (TMDL) be developed for each of the water bodies on the 303(d) list—the State's list of polluted water bodies. Also known as a water quality improvement project, a TMDL identifies how much pollution needs to be reduced from sources to achieve compliance with the state's water quality standards. Many of the water quality improvement projects are being conducted in the Puget Sound region to control and prevent pathogen and nutrient pollution. These include projects for the Skokomish, Nooksack, Union, Deschutes, Stillaguamish, and Dungeness rivers and numerous streams and other water bodies.

Ecology and other agencies provide technical expertise for the scientific analysis of each TMDL and related cleanup plans. Community residents have knowledge about their watersheds that helps to identify the pollution sources and the best management practices to fix the problems. Because solutions for water pollution problems require action on the parts of many people in a watershed, public participation in producing and implementing TMDLs is extremely important. By working together to produce the TMDL and identify solutions, local governments and citizens tend to take ownership of the plans and have stakes in their successful implementation to improve water quality within their communities.

b. 303(d) Listings in Puget Sound

Under the Clean Water Act, every state has its own water quality standards, designed to protect, restore, and preserve water quality. Every two years, states are required to prepare a list of water bodies that do not meet water quality standards. This list is called the 303(d) list or water quality assessment. To develop the list, Ecology compiles its own water quality data, along with data submitted by local, state, and federal governments, tribes, industries, and citizen-led monitoring groups. All data are reviewed to ensure that they were collected with appropriate scientific methods, before they are used to develop the 303(d) list.

There are currently 76 303(d) listings for fecal coliform contamination in Puget Sound marine waters (Figure 5-24).

Within the 303d list, there are several categories of impairment:

- Category 1: Meets tested standards for clean waters.
- Category 2. Water of concern.
- Category 4: Polluted waters that do not require a TMDL:
  - 4a: Waterbodies that have an approved TMDL.
  - 4b: Water bodies that have a pollution control plan in place.
  - 4c: Water bodies that are impaired by a non-pollutant.
- Category 5: Polluted waters that require a TMDL.

In the 2004 Water Quality Assessment, 58 locations were identified in Puget Sound marine waters where low levels of DO are problems (Figure 5-25). Many other locations were deemed to be waters of concern. Excess nutrients (nitrogen, specifically) are a main cause of low DO levels, but also important are the low levels of nutrients in incoming oceanic water. Human sources of nitrogen come from both point sources and nonpoint sources. Outside of Hood Canal, the most significant, immediate DO issues are in the South Puget Sound Basin. Carr,

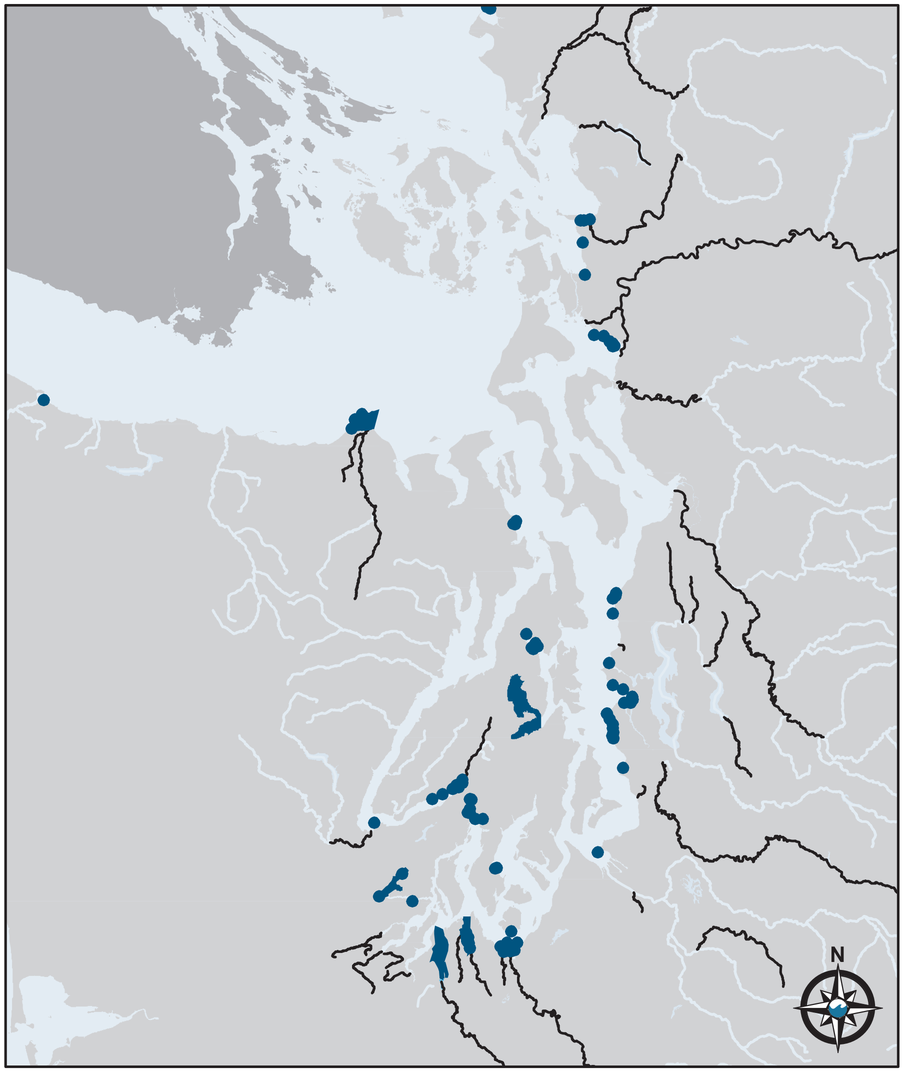


Figure 5-24. Locations of 303(d)-listed sites for fecal coliform contamination in Puget Sound. Most are located near urban areas, including Olympia, Seattle, Everett and Port Angeles. Hood Canal also has significant numbers of listed areas.
(Source: Ecology)

Fecal Coliform TMDLs
Listed Marine Area

Case, and Budd inlets are the locations of greatest concern. There are also DO problems in more localized areas of central and north Puget Sound (see Chapter 3, Section e).

Ecology and other agencies have been working on TMDLs to start addressing these problems. In the Puget Sound region, Ecology has started or completed TMDLs in 14 watersheds (Figure 5-26). Additional TMDLs will be needed to resolve some 303(d) listings that have not been addressed.

c. Point Sources and NPDES Permits

Under federal law, all states are required to address stormwater as a point source discharge. Phase I of the federal municipal stormwater program focused on large-sized municipalities. In 2000, Phase II of the federal municipal stormwater program imposed new requirements for smaller municipalities. There are now over 100 municipalities in Washington that require stormwater permit coverage under Phases I or II of the municipal National Pollutant Discharge Elimination System (NPDES) stormwater permit program. These municipalities vary in size, state of their existing stormwater programs, and funding abilities. This diversity makes development and implementation of stormwater permits challenging.

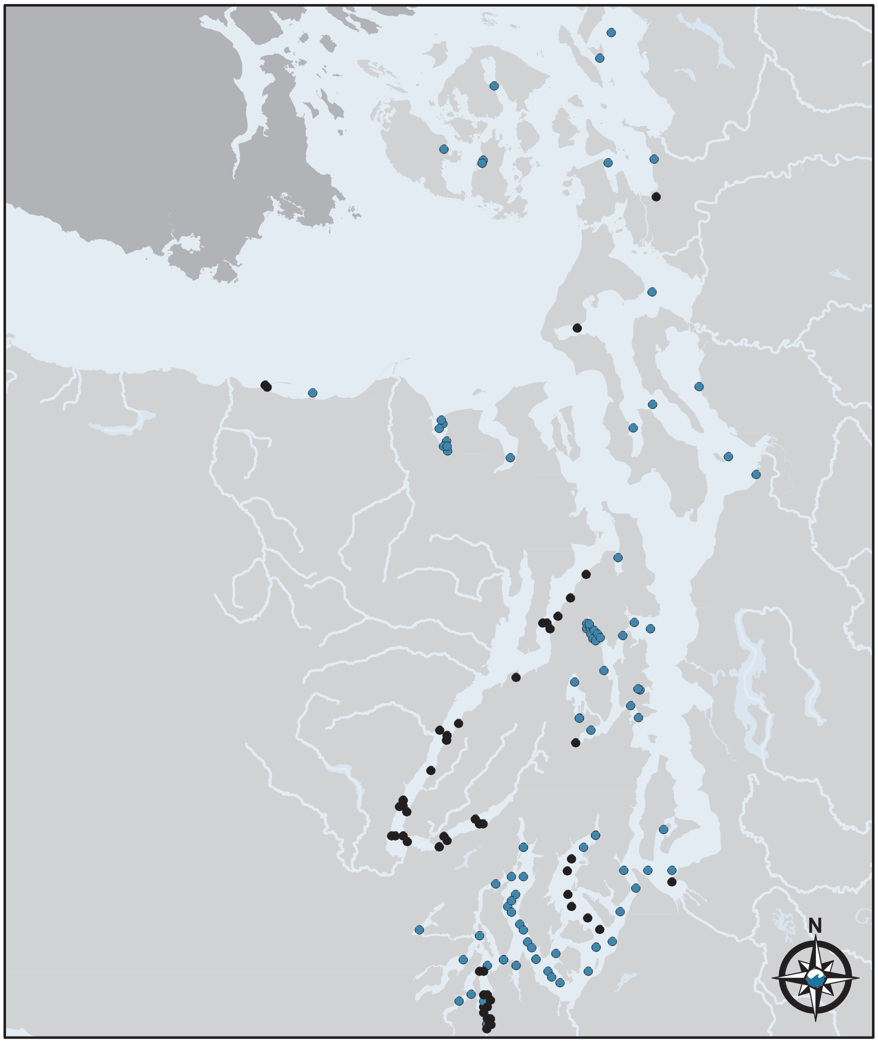


Figure 5-25. 303(d) listings for dissolved oxygen in Puget Sound. These data are from a variety of sources, including state, local, tribal, and citizen monitoring efforts. Most of the areas of highest DO concern are in Hood Canal and bays within central and south Puget Sound.
(Source: Ecology)

- Category 5: Impaired Water
- Category 2: Waters of Concern

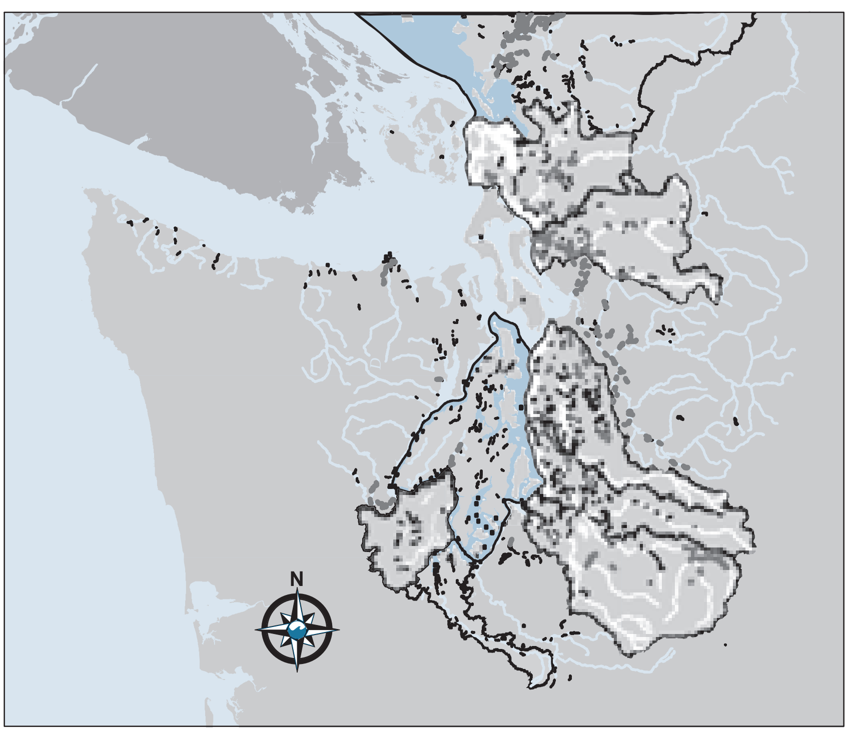


Figure 5-26. TMDLs and 303d listed fresh water and marine water bodies in Puget Sound. Every two years, Ecology assesses the quality of the surface waters of Washington state. Water bodies that do not meet the state's water quality standards because of human-caused problems are identified as "impaired" and assigned a category for further study and clean up. In 2004, there were approximately 1,474 listings of impaired waters in Puget Sound's fresh and marine waters. Most of the impairments are the result of toxic contamination, pathogens, low dissolved oxygen, and high temperatures.
(Source: Ecology)

- **Category 4A:** TMDL in place
- **303(d) List-Category 5:** Impaired waters
- Puget Sound WRIAs with TMDLs under development

9. New Approaches to Pathogen Control

a. Land Use Analysis

Efforts to protect and restore water quality in shellfish growing areas have generally focused on identifying and controlling pollution from individual sources, such as sewage treatment plants, failing onsite sewage systems, and livestock. This approach has been quite successful in the Puget Sound region, achieving a net upgrade of more than 8,000 commercial shellfish acres in the 11 years between 1995 and 2005. While these approaches must be maintained, there are a number of reasons why additional strategies should be pursued and efforts to more permanently safeguard the region's shellfish growing areas should be increased:

- The tenuous condition and classification of the restored shellfish areas and the need for ongoing attention.
- Relentless growth pressures in the region (population, development, land cover change).
- Increasing number of shellfish areas added to DOH's annual list of threatened shellfish areas.
- Increasing prevalence of stormwater impacts, making the pollution problems more complicated to assess and costly to correct.
- Greater understanding that many conventional pollution control practices do not fully mitigate impacts or fully protect the health and function of aquatic habitats.
- Better awareness that efforts and investments are often reactive and focused more on symptoms and short-term fixes than on underlying causes and lasting preservation.

Studies indicate that shellfish growing areas are vulnerable to contamination at relatively low levels of development, especially if watershed hydrologic processes are disrupted and there is high connectivity between the pollution sources and receiving waters. These impacts can worsen as population and development levels increases in the adjacent shorelines and watersheds. Contamination is not simply a function of the pollution sources; it is also a function of the landscape change. More development and modification of the landscape invariably increase the potential for contamination because of the efficient delivery of pollutants and the loss of native land cover and hydrologic features (e.g., wetlands) that effectively attenuate flows and contaminants.

Landscape analysis techniques have been used to assess the relationship between different landscape metrics (e.g., population density or percent land cover) and bacterial levels in commercial shellfish growing areas in the Puget Sound region. Research by Alberti and Bidwell (2005) examined relationships at the watershed and shoreline scale, using cross-sectional analyses (comparing different areas at the same point in time) and longitudinal analyses (comparing changes over time at different areas). The study concluded that different landscape patterns correlate strongly with bacterial levels in shellfish growing areas. (See Figure 5-27 in Appendix C: Color Figures.) Most notably, the researchers identified the amount and aggregation of forest cover as the best predictors of nearshore water quality (more forest cover correlated with lower bacterial levels) and also strongly correlated the amount and aggregation of impervious cover with water quality (more impervious cover correlated with higher bacterial levels).

10. Recommendations

In the *2002 Puget Sound Update*, recommendations were provided, based on the results from the studies reported. The recommendations for nutrients and pathogens work and progress made through 2006 on those recommendations are summarized below:

Recommendation from the ***2002 Update*** for Nutrients and Pathogens	Progress made through 2006 on recommendations in the ***2002 Update***
Intensive and coordinated local efforts can reduce fecal pollution problems as evidenced by successes in the Nooksack basin and seen in previous results for Eld Inlet and Oakland Bay, presented in the *2000 Puget Sound Update.*	• Skagit County Health Department created an Area of Special Concern for the Dewey Beach area of Fidalgo Island and mandated regular inspection of onsite sewage systems. • Thurston County Health Department created the Henderson Inlet Shellfish Protection District and mandated regular inspection of onsite sewage systems. • Kitsap County Health District sampled shoreline seeps along a portion of the Hood Canal, identified malfunctioning onsite systems and worked with owners to obtain repairs.
Such efforts should be initiated at all areas where DOH's analysis indicates worsening trend, 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, and south Skagit Bay.	See above.
Wherever possible, monitoring should adopt an interdisciplinary approach that integrates sampling of pathogens and nutrients with physical parameters of the receiving water body 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.	• The Hood Canal Dissolved Oxygen Program established a coordinated monitoring effort to characterize water quality in the Hood Canal and determine the sources, transport, and fate of nitrogen. • Ecology has routinely sampled nutrients, fecal coliform bacteria and physical parameters at its long-term marine monitoring stations since 1973. These data are also collected during most other marine monitoring activities.
Decisions about the discharge of nutrients to Puget Sound from point and non-point 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 sensitivity to eutrophication would be managed accordingly.	• Onsite sewage treatment devices were installed at Hood Canal sites by the Puget Sound Action Team and are being monitored to characterize nitrogen removal. • The Legislature funded research being conducted by the University of Washington to study the movement of nitrogen from onsite sewage systems into Hood Canal marine waters. • Ecology recently received funding to collect data needed to determine how much nitrogen from a variety of sources affects DO levels in South Puget Sound. This supports Ecology's efforts to continue development of an existing South Sound model as a tool for identifying the impacts of increased nutrient loading.

Moving Forward on Puget Sound Science

In looking ahead to what recommendations to report on in future editions of the *Puget Sound Update,* it makes sense to focus on the goals and strategies that have been recommended in *2006 The Puget Sound Partnership Final Report*, the PSAT *2007-2009 Conservation and Recovery Plan for Puget Sound* and the 2006 PSAMP Review. Collectively, these three sources provide targets and goals developed and supported by a large scientific community and reflect both short-term (two year) and long-term considerations for protecting and restoring Puget Sound's health.

The following bullets summarize the goals and strategies put forth in by the Puget Sound Partnership, PSAT and PSAMP that are related to nutrients and pathogens (Chapter 5 of this report). Progress towards these goals and strategies will be reviewed in the next edition of the *Puget Sound Update*.

Puget Sound Partnership Final Report (from Appendix A):

Goal: Puget Sound marine and fresh waters are clean

- Toxics and pathogen levels in marine mammals, fish, birds, shellfish, and plants do not harm the persistence and health of these species.
- Loadings of toxics, nutrients and pathogens do not exceed levels consistent with health ecosystem functions.
- The waters in Puget Sound region are safe for drinking, swimming, and other human uses and enjoyment.

2007-2009 Conservation and Recovery Plan for Puget Sound

Priority 4. Reduce nutrient and pathogen pollution

- Focus efforts and resources in high-risk areas most vulnerable to the effects of pathogen and nutrient pollution.
- Enhance state agency coordination and implementation of programs and projects.
- Support effective and innovative implementation of regulatory and non-regulatory approaches.
- Enhance the capacity of local jurisdictions to design and implement effective and comprehensive programs using a range of regulatory and non-regulatory approaches.
- Educate and involve residents and others to enhance stewardship activities.
- Enhance monitoring, modeling and other assessment activities to better understand the pollution problems and guide management activities.

The Role of Science

Strategies:

- Continue ongoing monitoring of the status and trends of key components of the Puget Sound ecosystem.
- Provide scientific information to stakeholders, decision-makers and the public.
- Direct new monitoring activities to focus on the effectiveness of management activities and policy initiatives.
- Develop a roadmap to prioritize, finance, and conduct focused research on emerging topics or research questions that are brought forth through PSAMP and science programs.

Detailed recommendations for further research and monitoring

Many of the following recommendations are an outcome of the 2005-2006 PSAMP review and have been included as recommended actions in the *2007-2009 Puget Sound Conservation and Recovery Plan*. Progress towards these and previous recommendations will be reported in the next edition of the *Puget Sound Update*.

Water quality and biota assessment

- Assess the factors causing the intermittent production of domoic acid.
- Monitor water quality including nutrients and DO levels in the Strait of Juan de Fuca, the source of marine water for greater Puget Sound, including Hood Canal.
- Monitor PSP with sentinel mussel program to protect human health.
- Enhance monitoring of pathogens in swimming areas.
- Take steps toward developing a comprehensive assessment of nutrient inputs to Puget Sound and identify priority geographical areas and strategies to prevent and control those inputs.

Modeling

- Build and populate models for the transport and fate of nutrients in the Puget Sound ecosystem, based on the Puget Sound conceptual model.

Appendix A: Threatened and Endangered Species in Puget Sound

State and federal listed species in Puget Sound

(As of October 2006)

This list includes marine-dependent species that live all or part of their life cycle in the waters of the Strait of Juan de Fuca, San Juan Islands, Hood Canal, and central and south Puget Sound. Not included are species that live in fresh water and upland of the shoreline.

Group	Common Name	State Status	Federal Status
Marine Mammals	Northern Pacific Humpback Whale	E	E
	Steller Sea Lion	T	T
	Orca	E	E
	Pacific Harbor Porpoise	C	
	Northern Sea Otter	E	Co
Birds	Bald Eagle	T	
	Canada Goose, Aleutian	M	Co
	Golden Eagle	C	
	Marbled Murrelet	T	T
	Tufted Puffin	C	Co
	Brandt's Cormorant	C	
	Cassin's Auklet	C	Co
	Common Murre	C	
	Western Grebe	C	
	American White pelican	E	
	Brown pelican	E	E
	Snowy Plover	E	T
Marine and Anadromous Fishes	Chinook Salmon (Puget Sound)	C	T
	Chum Salmon (Hood Canal/E. Strait of Juan de Fuca)	C	T
	Coho Salmon (Puget Sound/Strait of Georgia)		C
	Bull Trout (Coastal/Puget Sound)	C	T
	Pacific Hake	C	C
	Pacific Cod	C	
	Walleye Pollock (South Puget Sound)	C	Co
	Pacific Herring (Cherry Point/Discovery Bay)	C	C
	Brown Rockfish	C	
	Copper Rockfish	C	
	Greenstriped Rockfish	C	
	Widow Rockfish	C	
	Yelloweye Rockfish	C	
	Quillback Rockfish	C	
	Black Rockfish	C	
	China Rockfish	C	
	Tiger Rockfish	C	
	Bocaccio Rockfish	C	
	Canary Rockfish	C	
	Redstripe Rockfish	C	
	Yellowtail Rockfish	C	
	Eulachon	C	
	River Lamprey	C	Co
	Pacific Lamprey		Co
	Coastal Cutthroat		Co
Invertebrates	Olympia Oyster	C	
	Newcomb's Littorine Snail	C	Co
	Pinto (Northern) Abalone	C	

E – Endangered
T – Threatened
C – Candidate
Co – Concern
M - Monitor

Appendix B: Common and Scientific Names of Species Reported in the *2007 Puget Sound Update*

Scientific names are used at the first mention of a species, then referred to by common name throughout the remainder of the report.

Common Name	Scientific Name
Amnesic shellfish poison dinoflagellate	*Pseudonitzschia*
Arctic brant	*Branta bernicla*
Asian colonial tunicate	*Didemnum spp.*
Atlantic salmon	*Salmo salar*
Bald eagle	*Haliaeetus leucocephalus*
Barrow's goldeneye	*Bucephala islandica*
Biotoxic protozoa	*Toxoplasma gondii* *Cryptosporidium* *Giardia*
Black oystercatcher	*Haematopus bachmani*
Black scoter	*Melanitta perspicillata*
Blue mussel	*Mytilus edulis; M.californicus*
Bonaparte's gull	*Larus philadelphia*
Brandt's cormorant	*Phalacrocorax penicillatus*
Bull kelp	*Nereocystis luethkeana*
Bull trout	*Ssalvelinus confluentus*
California gull	*Larus californicus*
California sea lion	*Zalophus californianus*
Caspian tern	*Sterna caspia*
Chinook salmon	*Oncorhynchus tshawytscha*
Chum salmon	*Oncorhynchus keta*
Club tunicate	*Stela clava*
Coho salmon	*Oncorhynchus. kitsutch*
Common goldeneye	*Bucephala clangula*
Common loon	*Gavia immer*
Common merganser	*Mergus merganser*
Common murre	*Uria aalge*
Copper rockfish	*Sebastes caurinus*
Dall's porpoise	*Phocoenoides dalli*
Dinoflagellate	*Alexandrium catenella*
Dolly Varden trout	*Salvelinus malma malma*
Double-crested cormorant	*Phalacrocorax auritus*
Dungeness crab	*Cancer magister*
Eelgrass	*Zostera marina*
English sole	*Parophrys vetulus*
European green crab	*Carcinus maenas*
Geoduck	*Panopea abrupta*
Giant kelp	*Macrocystis integrifolia*
Glaucous-winged gull	*Larus glaucescens*
Gray whale	*Eschrichtius robustus*
Great blue heron	*Ardea herodias*
Greater Scaup	*Aythya marila*

Common Name	Scientific Name
Green sea urchin	*Stronglyocentrotus droebachiensis*
Harbor porpoise	*Phocoena phocoena*
Harbor seal	*Phoca vitulina*
Harlequin duck	*Histrionicus histrionicus*
Heermann's gull	*Heermanni philadelphia*
Herring gull	*Larus argentatus*
High arctic brant	*Branta bernicla*
Horned grebe	*Podiceps auritus*
Humpback whale	*Megaptera novaeangliae*
Knotweed	*Polygonum spp.*
Large burrowing Pacific clam	*Panopea abrupta*
Large dinoflagellate	*Noctiluca scintillans*
Lingcod	*Ophiodon elongatus*
Long-tailed duck	*Clangula hyemalis*
Mallard duck	*Anas platyrhychos*
Marbled murrelet	*Brachyramphus marmoratus*
Market squid	*Loligo opalescens*
Minke whale	*Balaenoptera acutoraostrata*
Non-native dwarf eelgrass	*Zostera japonica*
Non-native sea grass	*Spartina species*
Northern anchovy	*Engraulis mordax*
Northern pintail	*Anas acuta*
Nutria	*Myocastor coypus*
Olympia oyster	*Ostreola conchaphila*
Orca	*Orcinus orca*
Pacific cod	*Gadus macrocephalus*
Pacific hake	*Merluccius productus*
Pacific herring	*Clupea pallasi*
Pacific loon	*Gavia pacifica*
Paralytic shellfish poison (plankton)	*Alexandrium catenella*
Pelagic cormorant	*Phalacrocorax pelagicus*
Pigeon guillemot	*Cepphus columba*
Pink salmon	*Oncorhynchus. gorbuscha*
Pinto abalone	*Haliotis kamtschatkana*
Purple loosestrife	*Lythrum salicaria*
Purple sea urchin	*Stronglyocentrotus purpuratus*
Quillback rockfish	*Sebastes maliger*
Rainbow trout	*Oncorhynchus mykiss*
Red-necked grebe	*Podiceps grisegena*
Red sea cucumber	*Parastichopus californicus*
Red sea urchin	*Stronglyocentrotus franciscanus*
Red-throated loon	*Gavia stallata*
Rhinoceros auklet	*Cerorhinca monocerata*
Ruddy duck	*Oxyura jamaicensis*
Sea otter	*Enhydra lutris kenyoni*
Sixgill shark	*Hexanchus griseus*
Sockeye salmon	*Oncorhynchus. nerka*
Solitary tunicate	*Ciona savignyi*
Spiny dogfish	*Squalus acanthias*
Stalked kelp	*Pterygophora californica*
Steelhead	*Oncorhynchus mykiss*

Common Name	Scientific Name
Stellar sea lion	*Eumetopias jubatus*
Surf scoter	*Melanitta perspicillata*
Surf smelt	*Hypomesus pretiosus*
Thayer's gull	*Larus thayeri*
Vbrio (biotoxin)	*Vibrio parahaemolyticus*
Walleye	*Sander vitreus vitreus*
Walleye pollock	*Theragra chalcogramma*
Western grebe	*Aechmophorus occidentalis*
Western gull	*Larus occidentalis*
Western High Arctic black brant	*Branta bernicla*
White-winged scoter	*Melanitta fusca*
Zebra mussel	*Dreissena polymorpha*

Appendix C: Color figures

Chapter 3: Physical Environment and Habitat

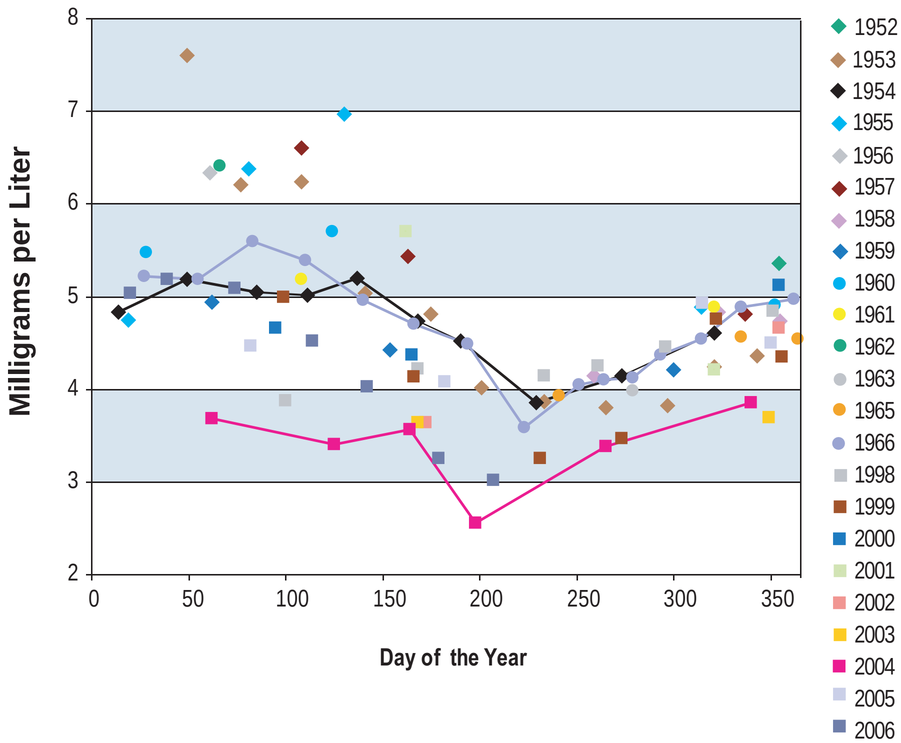
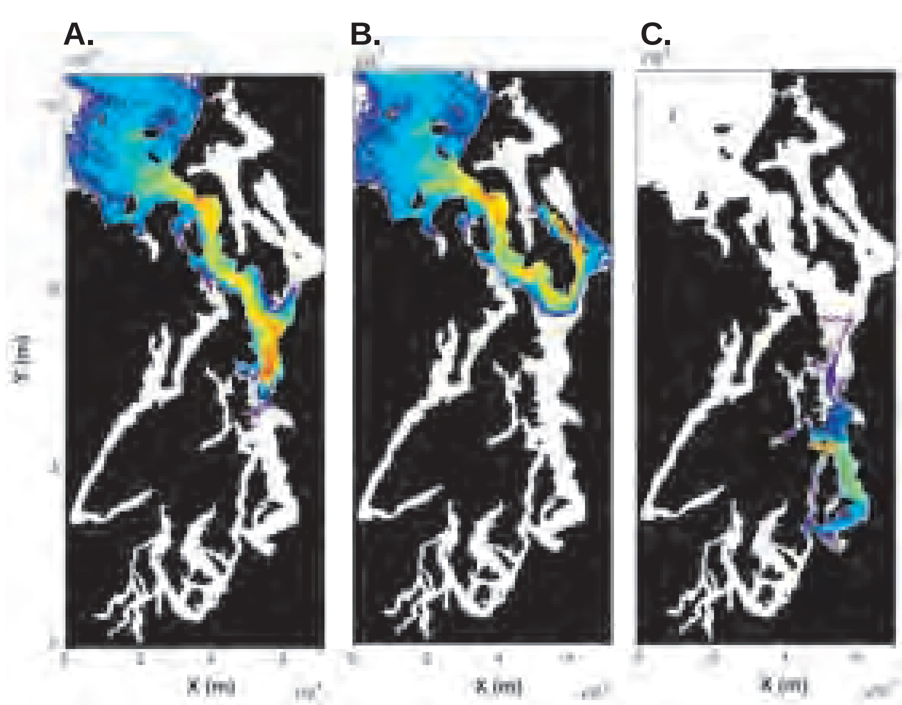


Figure 3-13. Average dissolved oxygen concentrations from Hood Canal. Waters deeper than 65 feet (20 m) from Dabob Bay to the Great Bend indicate that although oxygen typically reached hypoxia or even anoxia during summer throughout the recorded periods, more recently hypoxia is lasting longer and persisting throughout the entire year. This is likely to have serious consequences for marine organisms within Hood Canal that can survive short periods of low dissolved oxygen but may not survive prolonged periods of oxygen deprivation. (Source: University of Washington: Mark Warner, analysis; Collias and PRISM, data).



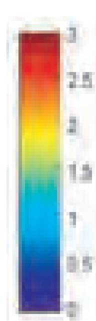


Figure 3-17. Track densities of particles released from a single point in the Puget Sound model. (A) Point Jefferson release, (B) Saratoga release, and (C) Alki Point release. The color bar indicates density of particle tracks in arbitrary units (it's scaled logarithmically—that is, a unit increase corresponds to a tenfold increase in track density). Particles are tracked over three weeks. The colored portion in each map shows the extent of the overall spread, and the warmest colors show the most popular paths. Over three weeks, water movement from a given point tends to flow primarily in the direction of the warmest colors. (Source: Kawase, UW)

Figure 3-18. A side view of track densities of particles in Admiralty Inlet released at the surface and tracked over a 24-hour period. The purple line depicts the approximate center-channel bathymetry. The color bar indicates particle-track density in arbitrary units. Vertical mixing of the surface-released particles, can be seen downwards in the sill region, which is indicated by the solid line. (Source: Kawase, UW)

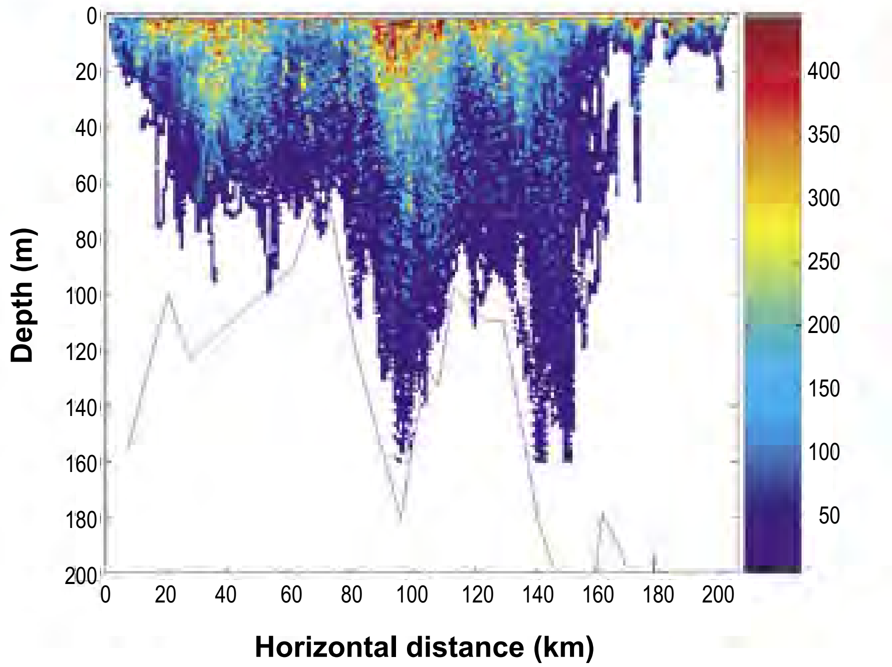
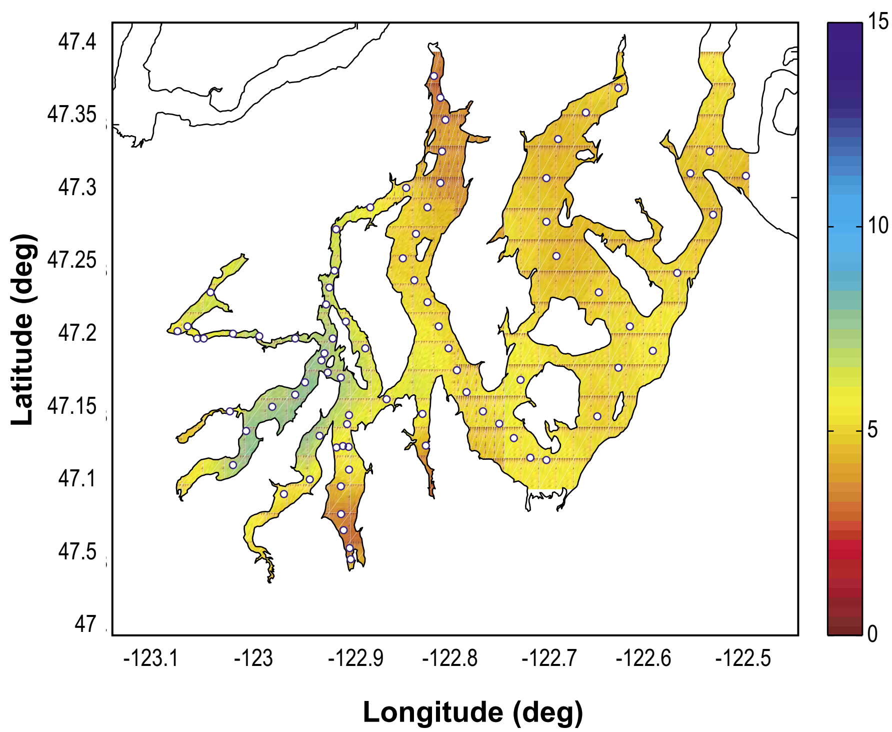


Figure 3-19. **Distribution of DO in South Puget Sound during a fall 2003 sampling cruise.** Case, Carr, Budd, and Henderson Inlets all had relatively low DO concentrations. Areas in dark orange and red generally correspond to the areas with moderate to high sensitivity to eutrophication, noted in Table 5-1 and Figure 5-6 (eutrophication index). (Source: Ecology)



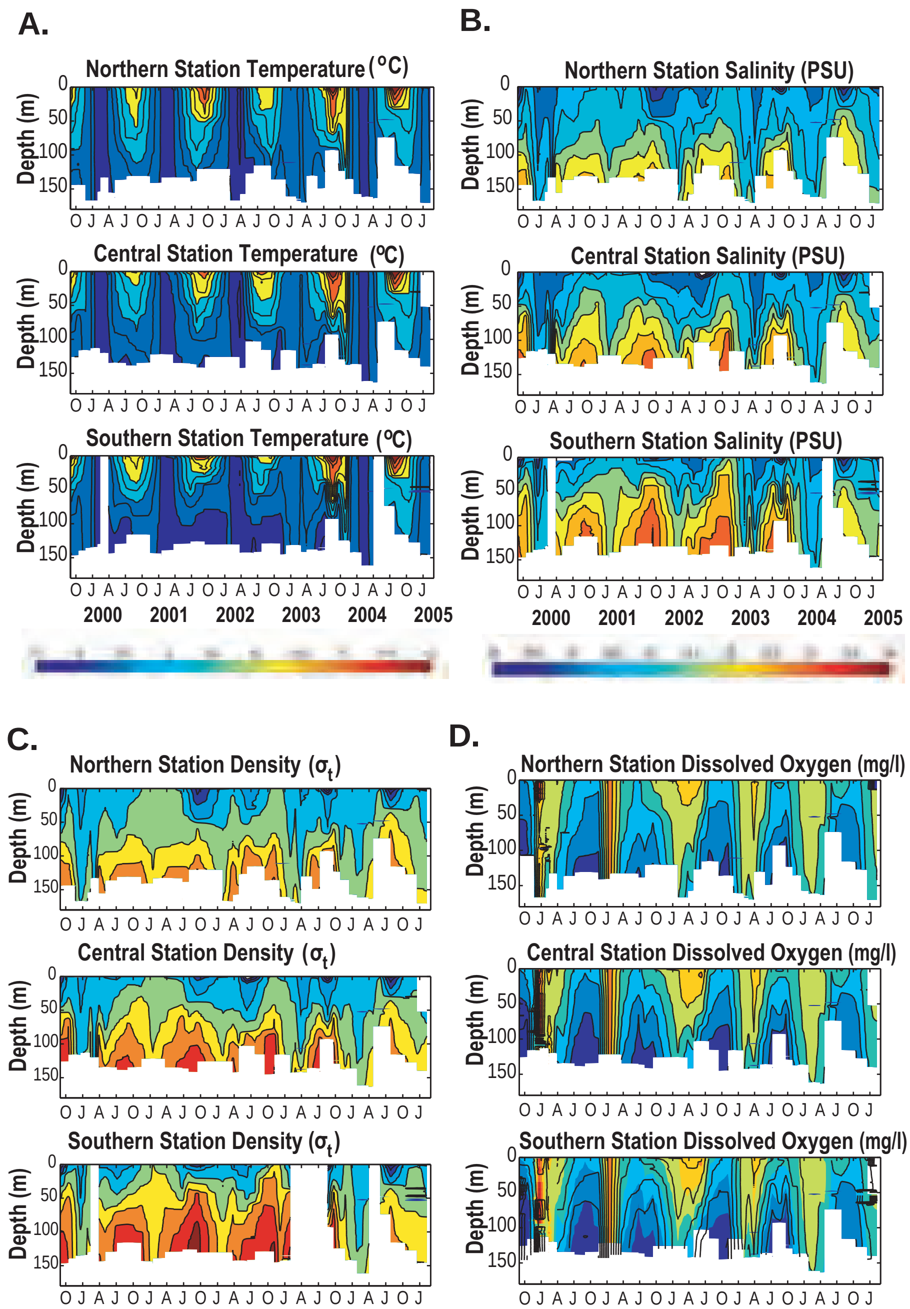


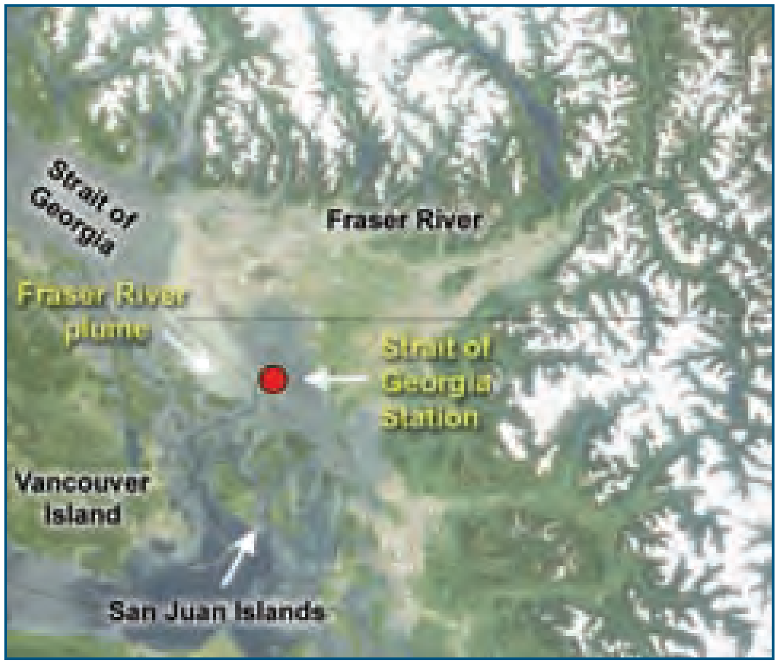
Figure 3-20: Joint Effort to Monitor the Straits (JEMS). JEMS time-series data showing:

A. Temperature
B. Salinity
C. Density
D. Dissolved oxygen

Data were collected at the three stations positioned across the Strait of Juan de Fuca, between San Juan Island and Port Angeles. Shown are contours of monthly data from September 1999 through December 2004.

Aside from seasonal cycles, there is distinct inter-annual temperature variation, which mirrors the El Niño Southern Oscillation (ENSO)-driven climate pattern (colder 2000, 2001 and 2002, warmer 2003, 2004). Also, the higher salinity signal from the 2000-2001 drought is clearly seen in the record. Both temperature and salinity affect seawater density, which controls the degree of stratification or layering of water in Puget Sound. There is also considerable inter-annual variation in the oxygen record. (Source: Ecology and UW)

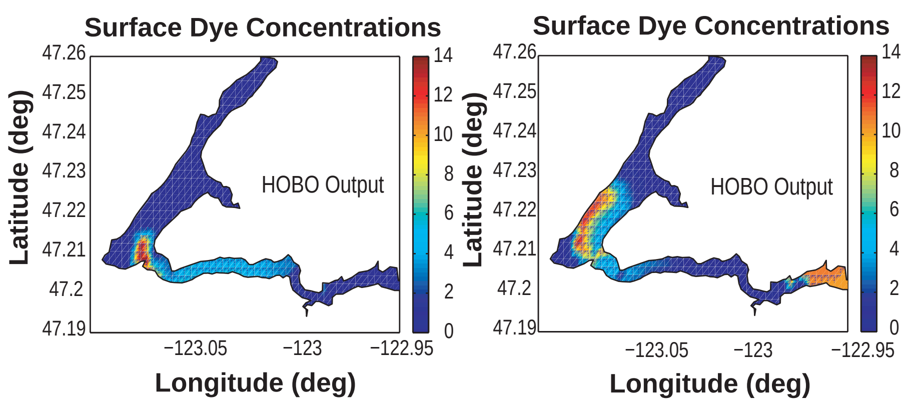
Figure 3-26. Satellite image of the Strait of Georgia. This photo shows a sediment plume from the Fraser River and the location of the PSAMP monitoring station, June 2003.
(Source: Ecology)



Satellite photo courtesy of SeaWiFS Project, NASA/Goddard and ORBIMAGE

Chapter 5: Nutrients and Pathogens

Figure 5-18. Circulation in Hammersley Inlet, South Puget Sound. Model results showing the distribution of simulated effluent (dye) in Hammersley Inlet at one hour after slack low tide (left figure) and two hours after slack low tide (right). The results demonstrated the effects of discharge location on effluent dilution and indicated that extending the diffuser across Hammersley Inlet could reduce the concentration of effluent reaching the shellfish beds. Minimizing effluent during slack tides, when mixing with seawater is least effective, could also reduce the concentration of effluent.
(Source: Ecology)



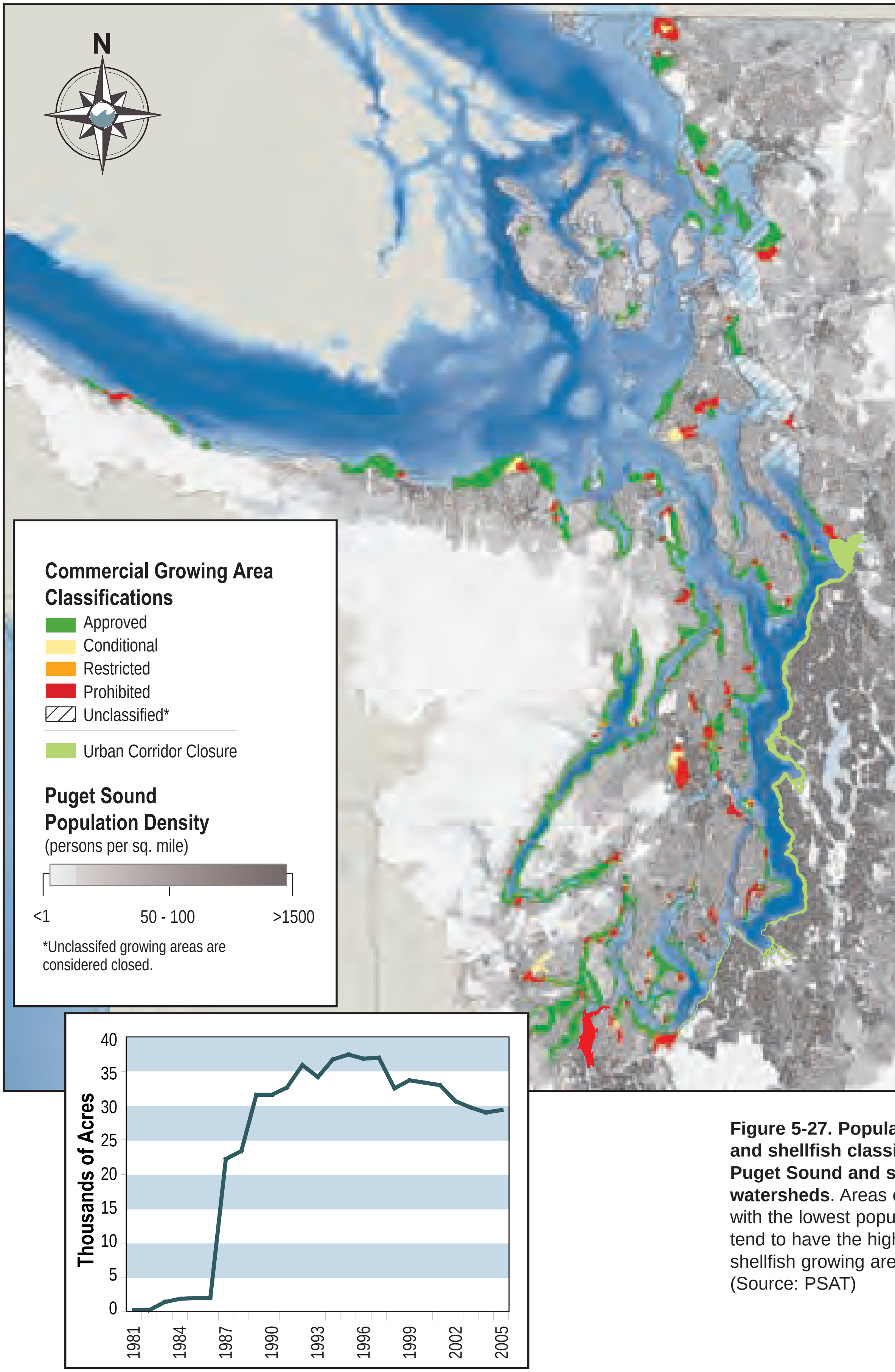


Figure 5-27. Population density and shellfish classification in Puget Sound and surrounding watersheds. Areas of Puget Sound with the lowest population densities tend to have the highest classified shellfish growing areas. (Source: PSAT)

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