PugetSoundPartnership
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Ecosystem Status & Trends

A 2009 Supplement to State of the Sound Reporting

November 2009

Acknowledgments

Scott Redman (Puget Sound Partnership staff) and Kari Stiles (Jones & Jones Architects, Landscape Architects and Planners) compiled and edited this document based on substantial contributions from subject matter experts and data providers. Authors and contributors of specific sections are credited in the body of the document.

Members of the Partnership's Science Panel directed the development of the specific indicators presented here and provided their interpretation of findings and thoughts about priorities for data collection, analyses and syntheses to further develop the desired suite of indicators.

Puget Sound Partnership's Science Panel (November 2007 to November 2009)

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1. Introduction

The Puget Sound ecosystem spans the terrestrial, freshwater aquatic, and marine systems in the area from the crest of the Cascades and Olympic mountains, down through the Puget lowlands, and into the estuarine and marine inland waters of Washington state. The Puget Sound ecosystem is the southern portion of a larger system that extends into Canadian lands and waters: the Puget Sound Georgia Basin ecosystem. This report addresses only the U.S. portion of this larger system.

The Puget Sound Partnership's report on the status of Puget Sound ecosystem provides a system-level evaluation of:

- human health and well-being – specifically those aspects of health and well-being that most depend on a functioning, viable ecosystem;
- species and food webs and habitats – including terrestrial, freshwater aquatic, and marine systems;
- water quantity and quality – to support species and habitats and human health and well-being.

Discussing the ecosystem in these terms conveys the Partnership's conception that the ecosystem incorporates human and biophysical dimensions, which depend on abundant, clean water. Discussing the ecosystem in these terms also aligns with the goals for Puget Sound ecosystem recovery specified in Washington state statute (RCW 90.71.300).

Within this human-biological-water framework, the Partnership's 2009 ecosytem status and trends reporting uses a number of ecosystem indicators to describe conditions related to the scope and span of interests described above. The Science Panel guided the selection of the specific indicators presented here by defining broad indicator categories for each of the Partnership's six legislative goals for ecosystem recovery. Panel members worked with experts, data providers and Partnership staff to identify specific indicators for each broad indicator category. The Partnership's 2009 reporting on ecosystem status and trends has two primary limitations:

- The Partnership has not yet adopted a suite of indicators that encompass and represent the Partnership's interests in the Puget Sound ecosystem.[1] The development of the Partnership's performance management system will require adoption of such a suite of

[1] Please refer to Identification of Ecosystem Components and Their Indicators 2009 Technical Memorandum.

indicators. The 2010 Puget Sound Science Update will provide a scientific synthesis of ecosystem indicators (e.g., building from hypotheses about how the ecosystem operates to identify ecosystem structures, functions, and/or processes that can serve as indicators of ecosystem condition). The Partnership's selection of indicators for evaluating can then be derived from the scientific information provided in the Puget Sound Science Update.

- As of 2009, the Puget Sound region does not have a coordinated monitoring program that provides data to evaluate ecosystem status and trends. Ongoing monitoring and assessment programs, including the Puget Sound Assessment and Monitoring Program, provide some key information, but these systems have not been updated and adapted to address the interests of the Partnership (and cannot be until the indicators recommendations and selection discussed above). The work compiled here reports on a subset of the indicators available from on-going monitoring and assessment activities, as summarized and evaluated by O'Neill et al., (2008) and Schneidler and Plummer (2009).

Even so, the ecosystem status and trends interpretations presented here reflect the Partnership's current understandings and judgments about system features most directly relevant to recovery of the Puget Sound ecosystem (six legislative goals and broad indicator categories within each). The accompanying Report on Puget Sound Ecosystem Status and a Performance Management System to Track Action Agenda Implementation (2009 Report) includes an overall summary of the status of the Puget Sound ecosystem based on a subset of the indicators presented here.

Each of the sections below was authored by a different set of topic area experts, as credited in the body of the document. Sections on future plans for each goal were developed collaboratively by Science Panel members, Partnership staff, consultants to the Partnership and topic area experts where appropriate. Members of the Partnership's Science Panel provided interpretations of ecosystem status, which are shown as blocks of text with shaded background (goal-level interpretations) or a single-line border (interpretations of individual indicators) in the sections below.

2. Human Health

People are an integral part of the Puget Sound ecosystem and the health of the people of this region depends on the condition of the Puget Sound ecosystem. Supporting human health through a viable Puget Sound ecosystem is a key concern for ecosystem recovery. This is expressed in the Partnership's authorizing statute as: “A healthy human population supported by a healthy Puget Sound that is not threatened by changes in the ecosystem.”

The health of human populations depends on clean and abundant food and water and clean air provided by ecosystems. The focus of this section is on the human health support provided by quality Puget Sound-derived seafood and clean waters for swimming and other contact recreation. This focus is consistent with Governor Gregoire's 2006 pledge to help make Puget Sound “fishable, diggable and swimmable” by 2020.

We recognize that this focus means that the evaluation in this section does not address a number of environmental conditions related to human health: abundant foods, clean drinking water and clean air. Ecosystem conditions reported elsewhere in this document relate to ecosystem support for human health. Some aspects of food production from fishing and agriculture are addressed in the human well-being, species and food webs and habitat sections below. Evaluations of water quantity and water quality provides information about the ability of the ecosystem to provide abundant, clean water for human residents.

Furthermore, the Partnership's evaluation of human health does not address aspects of human health that are not directly related to the Partnership's concerns for ecosystem recovery (e.g., quality of health care, human behaviors that increase the risks of disease and injury, and human genetic variability). While these may be key determinants of the health of Puget Sound’s human population, they are peripheral to the dependence of human health on the viability of the Puget Sound ecosystem.

What is the status of ecosystem support for human health? Seafood and water quality in some areas of Puget Sound indicate that pollution is affecting the ecosystem’s ability to support human health. Risks to human health are avoided by restricting shellfish harvest and advising limited seafood consumption in polluted areas. For example, the entire shoreline from Everett to Tacoma is closed to commercial shellfish harvest due to known pollution sources.

What affects ecosystem support for human health? The health of humans depends on the quality of goods and services provided by a healthy ecosystem, including a clean and abundant supply of food, clean water for drinking, irrigation and recreation and clean air to breathe. Stormwater inputs and other point and non-point source pollution from a growing population and continuing land development are expected to threaten human health support from the Puget

Sound ecosystem. The relative impact of legacy and new sources of contamination are not well understood.

How does ecosystem support for human health affect other aspects of the ecosystem? The following aspects of the ecosystem are affected by human health: Provisioning of seafood from Puget Sound requires water quality conditions that do not threaten human health; closure of shellfish growing areas has a direct impact on the economic benefit derived from harvesting shellfish and reduces opportunities for recreational shell-fishing; pathogens, biotoxins, and contaminants that threaten human health might also threaten the health of Puget Sound's marine mammals and other animal species.

2.1 Safety of seafood

The Puget Sound ecosystem has provided shellfish, finfish, and other foods for people for millennia. In recent years, pollution from human and animal waste and from wastewater and stormwater runoff from developed lands have threatened the healthfulness of Puget Sound seafoods. Governments protect human health by regulating harvest and providing advice about the consumption of seafood. Information from the programs used to develop these regulations and advice provide information about the ability of the ecosystem to provide clean, safe seafood.

INDICATOR: Commercial shellfish growing area closures

Data and analysis provided by Tim Determan and Cari Franz-West, Washington State Department of Health

Shellfish such as clams, oysters and other bivalves filter large quantities of water. For this reason, shellfish can accumulate bacteria, viruses or other harmful pathogens from the water. Further, since they are sessile organisms, fixed in place throughout their life span, they are good indicators of site-specific contamination. If contaminated shellfish are eaten, they can cause severe illness in humans. Shellfish growing areas require constant monitoring to ensure the waters are clean so these areas can remain open for harvesting.

Washington State Department of Health (DOH) periodically reviews water quality (fecal coliform) data and shoreline survey information and uses the information, as necessary, to adjust boundaries of classified shellfish beds to protect human health. DOH routinely samples more than 1,300 sites throughout Puget Sound. The results indicate fecal pollution impact has been generally low overall, and has remained relatively stable during the past decade. In 2008 nearly a third (30) of Puget Sound's commercial shellfish growing areas showed at least a minimal level of fecal contamination (see figure HH-1). Drayton Harbor (Georgia Strait), Burley Lagoon, and Filucy Bay (both in south Puget Sound) suffered the greatest impact from fecal pollution.

Each year, Washington State Department of Health calculates an index to evaluate fecal pollution impact on commercial shellfish growing areas. The fecal pollution index (FPI) ranges from 1.0 (all sampling stations "good") to 3.0 (all stations "bad"). Figure 1 ranks those growing areas in 2008 with FPI above 1.0.

Vibrio parahaemolyticus, is a naturally occurring pathogenic bacterium found in Puget Sound and Washington coastal waters. In summer 2009, the Washington State Department of Health confirmed over 35 cases of vibriosis caused by *Vibrio parahaemolyticus*, down from a high of 113 in 2006. Illnesses associated with *V. parahaemolyticus r*esulted in temporary closure of two commercial shellfish growing areas in summer 2009.

Since 1994, Washington State Department of Health has upgraded over twice as much growing area than they have downgraded as a result of improvements or declines in the sanitary conditions of shellfish growing areas (figure HH-2).

What activities affect fecal pollution in the Sound? "Since the early 1980s, nonpoint fecal pollution has become the key factor in closure of shellfish beds. Intensive development of rural watersheds and the marine shoreline of Puget Sound have increased the threat of nonpoint pollution." – Washington State Department of Health's Atlas of Fecal Coliform Pollution in Commercial Shellfish Areas of Puget Sound: Year 2007

What is the current status of commercial shellfish bed closures*?* Nearly a third of all commercial beds exhibited some fecal bacteria contamination Recent monitoring results indicate fecal contamination has been generally low. Since 1994, Washington State Department of Health has upgraded twice the number of growing areas that they have downgraded.

What affects commercial shellfish bed closures? Since the early 1980s, nonpoint fecal pollution has become the key factor in closure of shellfish beds. Intensive development of rural watersheds and the marine shoreline of Puget Sound have increased the threat of nonpoint pollution. Even though fecal contamination has been low, and remained relatively stable over the last ten years, increases in human population and altered land use (especially unregulated land use) could affect this trend.

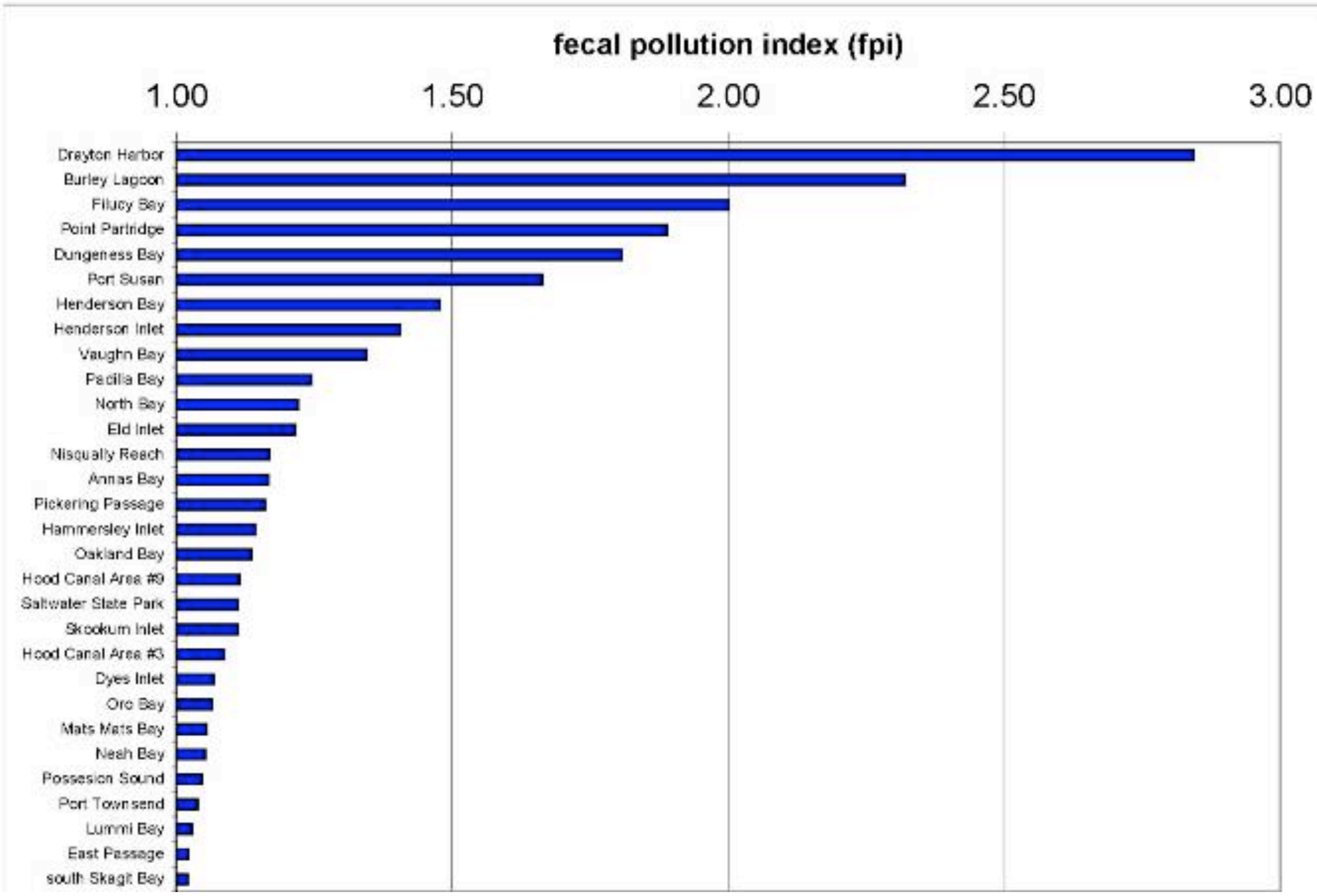


Figure HH-1a: Puget Sound Commercial Growing Areas Ranked in order of decreasing fecal pollution index for 2008 (Washington State Department of Health, 2009)

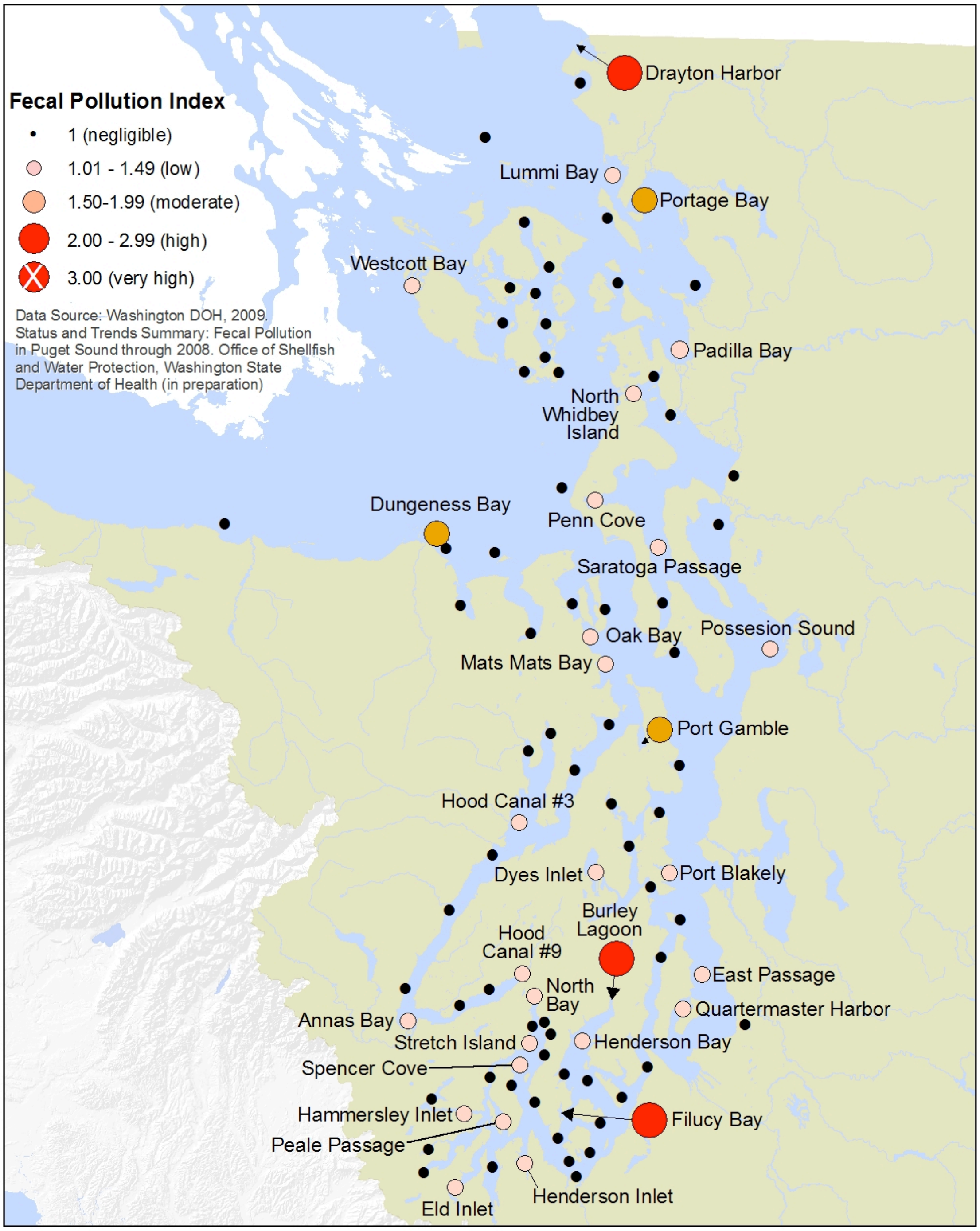


Figure HH-1b: Data from Figure HH-1 presented in map version

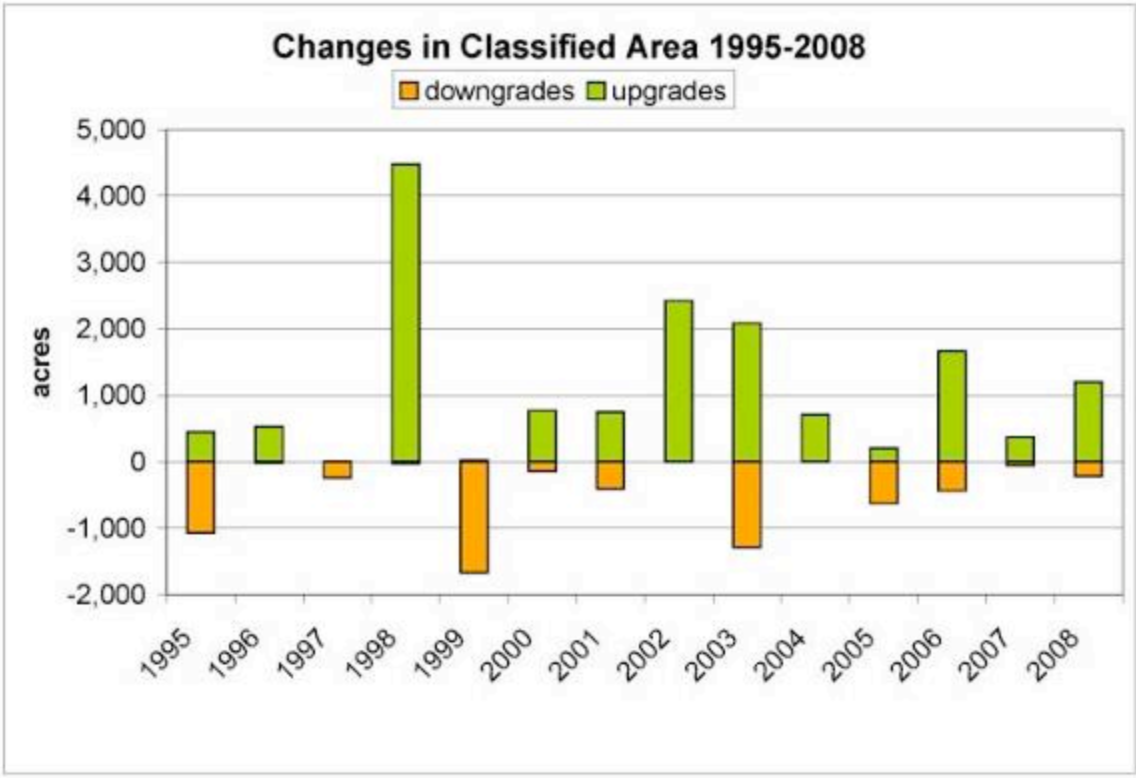


Figure HH-2: Area of Puget Sound commercial shellfish growing area classification changes resulting from improvements or declines in the sanitary conditions

What are the advantages/disadvantages of using these data as an indicator of food-related human health risks? The indicator has the advantage of addressing important social, cultural, and economic concerns of the people of Puget Sound, especially those living in rural natural resource-based communities. In most cases, the reclassifications are a direct measure of water quality. However, in some instances, Washington State Department of Health may reclassify an area for reasons other than water quality. For example, the DOH may change the size of a classified area due to change in a potential pollution source. Examples include expansion, contraction, or elimination of a marina or treated wastewater outfall.

INDICATOR: Biotoxin-related closures of shellfish harvest

Data and analysis provided by Frank Cox, Washington State Department of Health

Washington state routinely experiences seasonal restrictions on commercial and recreational shellfish harvest due to paralytic shellfish poisoning (PSP), more commonly known as "red tide." The biotoxin that causes PSP temporarily interferes with the transmission of nerve impulses in warm-blooded animals. PSP toxin is produced by microscopic organisms that naturally exist in marine water. The species that causes PSP in Washington marine waters is *Alexandrium* *catenella*. *Alexandrium* is usually present in small numbers; however, when environmental conditions are optimum, rapid reproduction occurs. WASHINGTON STATE DEPARTMENT OF HEALTH monitors PSP toxin levels in shellfish from commercial areas throughout the state. Recreational beaches are sampled as a cooperative effort between DOH, other state agencies, tribes and health departments, often utilizing citizen volunteers. Areas are closed for harvest of molluscan shellfish when PSP toxin levels equal or exceed the Food and Drug Administration standard of 80 micrograms (mg) toxin/100 grams shellfish tissue. Areas are not reopened until testing has confirmed that the PSP toxin has declined to a safe level.

Recent PSP history in Washington has shown some unusual behavior. From 1990 to 2006, PSP blooms produced many high test results for PSP toxin. However there were years since 1990 like 1995, 2007 and 2008 where PSP toxin levels remained low. It is clear that there is much that we do not understand about the dynamics that drives these toxic blooms and makes trend analysis very difficult. Weather conditions such as temperature, available sunlight, nutrients and salinity as well as algal predators, parasites and algal disease organisms no doubt play a role in the magnitude of these blooms. Much research is needed to ferret out what drives these bloom events.

In 2008, 12 samples registered more than 1,000 micrograms of PSP toxin. The highest test result was a Mystery Bay mussel sample with 2,602 micrograms of PSP toxin. In 2008, no PSP illnesses were reported although 23 sub-tidal geoduck clam tracts and two general growing areas were closed. One geoduck tract closure also had a recall of 3,368 lbs. of geoduck clams in 2008.

Domoic acid is a naturally occurring toxin produced by species of microscopic marine diatoms of the genus *Pseudo-nitzschia*. The human illness known as amnesic shellfish poisoning (ASP) or domoic acid poisoning (DAP) is caused by eating fish, shellfish or crab containing the toxin. Domoic acid was first detected on the Pacific coast in California in the summer of 1991 when a number of pelican and cormorant deaths were linked to domoic acid in anchovies. In the fall of 1991, domoic acid was detected in razor clams off the coast of Washington. This discovery brought a premature end to the recreational razor clam harvest but, not before several mild cases of ASP were associated with the consumption of razor clams. ASP has affected Washington's shellfish industry as it has lead to bans of crab export to Japan.

In Puget Sound, ASP has only caused closures in 2003 and 2005. Since ASP’s first closure on the coast in 1991, Washington State Department of Health has monitored all of Puget Sound for ASP and frequently sees low levels of domoic acid in shellfish samples. Like PSP, the dynamics that drive the blooms is not well understood and more research is needed.

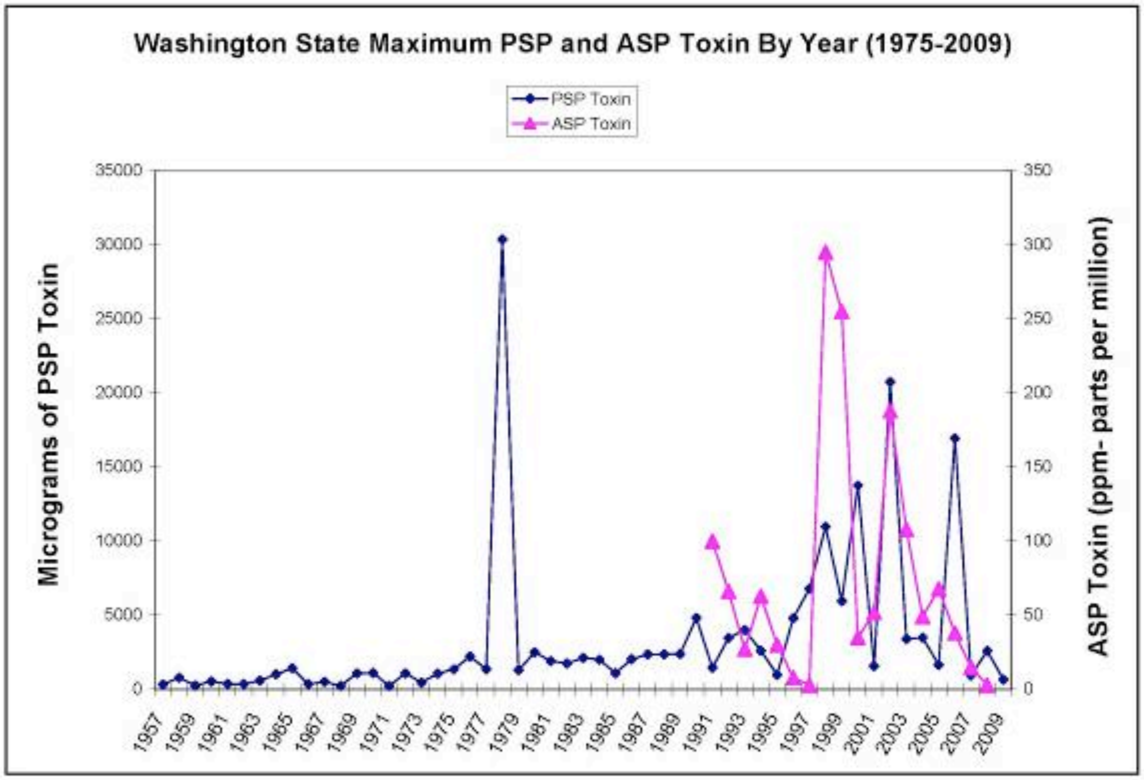


Figure HH-3: Yearly maximum concentrations of PSP and ASP toxins observed in Washington state

INDICATOR: Fish consumption advisories

Data and analysis provided by Joan Hardy, Dave McBride and Liz Carr, Washington State Department of Health

Fish is an important part of a healthy diet. It is a good protein source that is low in saturated fats and high in beneficial omega-3 fatty acids and other nutrients. Fish consumption, especially that of oily fish, decreases the risk of cardiovascular disease. Further, increased fish consumption has been shown to produce beneficial effects to pregnant and lactating women. Other reported benefits of fish consumption include a decrease in some cancers and protection against declines in brain function. DOH supports the American Heart Association's (AHA) recommendation for all consumers, including pregnant women, to eat at least 2 servings of fish per week. Research has indicated that the benefits from eating fish outweigh the risks if you choose fish low in contaminants.

Balanced against the benefits of eating fish are the possible negative effects associated with contaminants in fish. Monitoring efforts provide the required data to ascertain those risks to the public and to determine whether an advisory is warranted. As an indicator, the increase in fish consumption advisories may reflect an increase in contaminant concentrations in fish or simply reflect the result of filling data gaps where previously no data existed, not necessarily representing the trend of contaminants in Puget Sound fish.

Based on existing fish tissue contaminant concentrations, frequency of detection, and toxicity, Washington State Department of Health concluded that polychlorinated biphenyls (PCBs) and mercury pose the greatest public health concern for consumers of Puget Sound fish. Once released into the environment, these contaminants move up through the food chain into fish, marine mammals, and humans. DOH assessed Puget Sound fish tissue data to address potential health impacts to humans who eat marine fish from Puget Sound. Mercury and PCBs have been shown to cause behavioral and learning deficits in children exposed in the womb, so meal limits of certain fish are especially important for women who are pregnant, who might become pregnant, nursing mothers and young children.

Washingtonians are encouraged to choose salmon as an excellent choice for a meal due to health benefits. Current consumption advisories recommend limiting Puget Sound Chinook salmon to one meal per week and resident Chinook (blackmouth) to two meals per month. Coho caught from marine or in-river fisheries from all areas of Puget Sound can be safely eaten 2-3 times per week (no restrictions), and high-end consumers who eat more than 2 meals per week should remove the fat from the fish to reduce PCBs. Although Washington State Department of Health acknowledges that coho are not free of contaminants, they are relatively low in contaminants compared to many Puget Sound and store-bought fish. Sockeye, pink, and chum salmon were not sampled as part of the PSAMP effort but data from other sources show that sockeye, pink, and chum salmon tend to have very low PCB levels, most likely related to their life histories and diets. Therefore, DOH has no restriction on consumption of these species of Puget Sound salmon.

In general, rockfish from urban areas of Puget Sound have demonstrated higher levels of mercury and PCBs than those from non-urban Puget Sound areas. However, mercury contamination of rockfish was also higher in older fish. Washington State Department of Health recommends no consumption of rockfish from the Duwamish Waterway or from Sinclair Inlet. Other areas with more restrictive meal limits recommendations include Commencement Bay and part of the bay near Everett. The general meal limit recommendation for rockfish throughout Puget Sound is 1 meal per week (yellow areas in Figure HH-4).

English sole from non-urban areas of Puget Sound are a good choice of fish to eat. However, English sole from urban areas had higher contaminant levels (i.e., PCBs and mercury) than those from near-urban and non-urban areas. Older fish also tended to have higher mercury levels. DOH recommends no consumption of English sole in the Duwamish Waterway and no more than two meals per month in Elliott Bay, Inner Commencement Bay, and from the Mukilteo ferry dock to Everett Harbor (Figure HH-5).

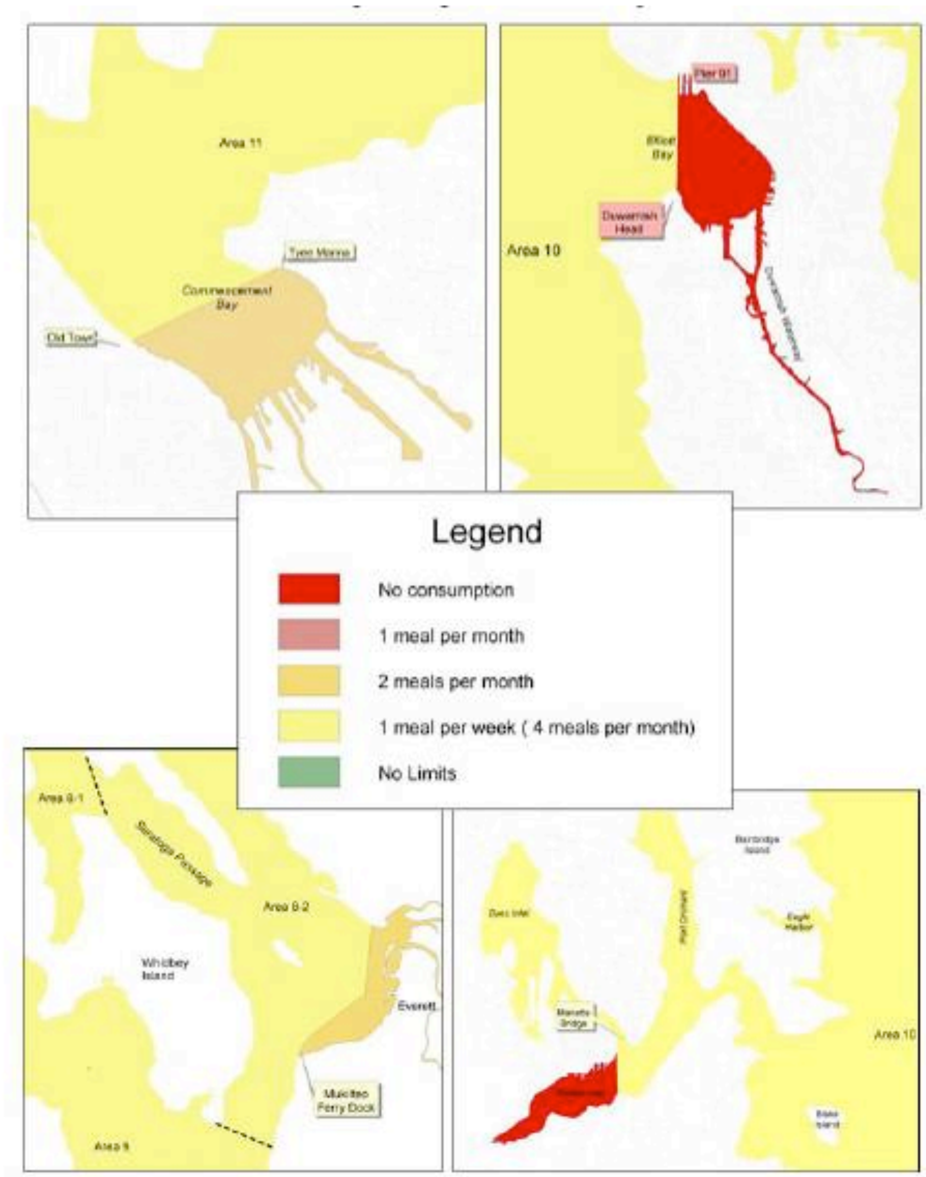


Figure HH-4: Meal limit recommendations for rockfish from urban areas of Puget Sound The general meal limit recommendation for rockfish throughout Puget Sound is one meal per week. (One meal is eight ounces of uncooked fish.)

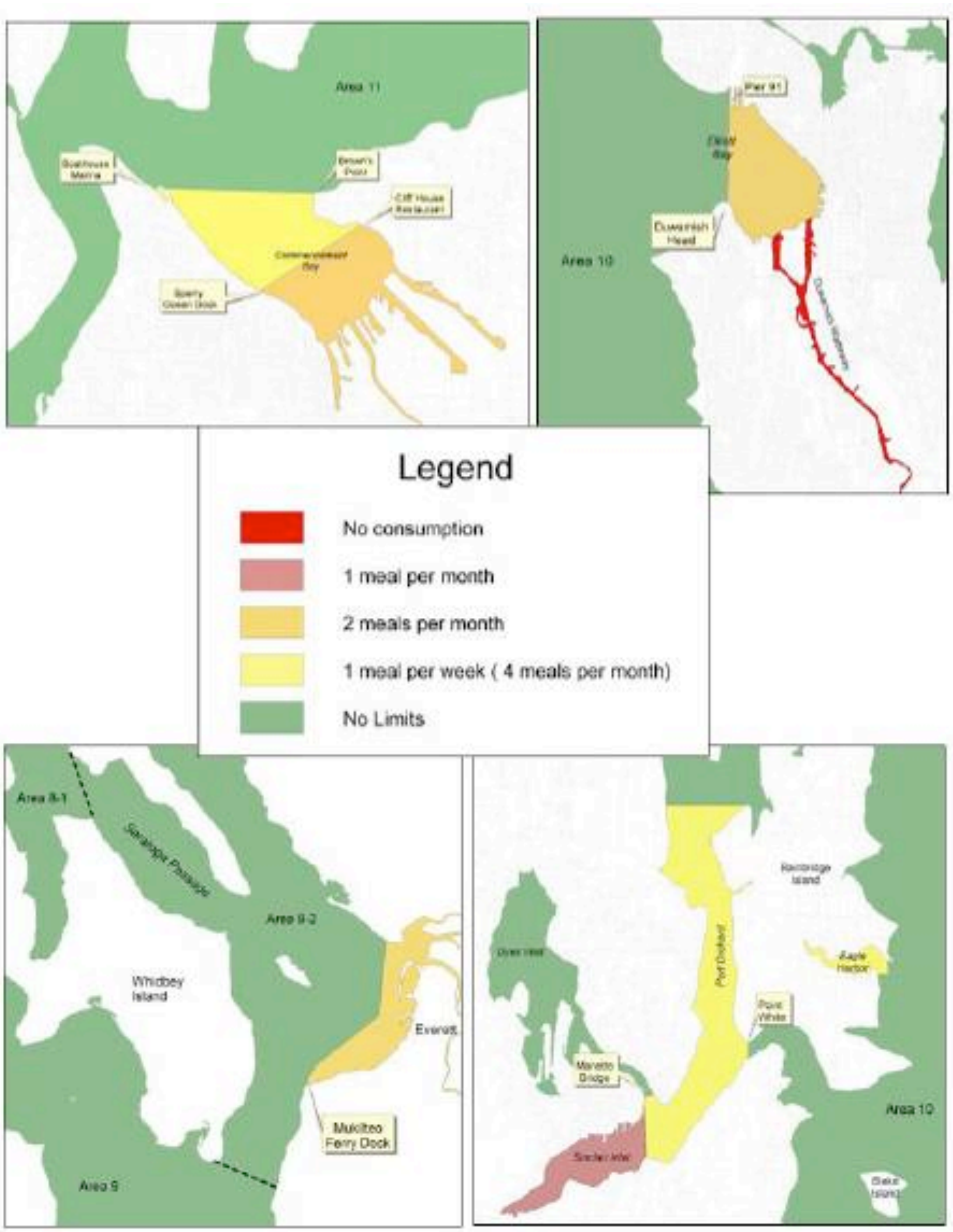


Figure HH-5: Meal limit recommendations for English sole and flatfish from urban areas of Puget Sound DOH advises no restriction on meals of English sole and flatfish from non-urban areas of Puget Sound. No restriction means you can eat 2 to 3 meals per week. (One meal is eight ounces of uncooked fish.)

Many of the contaminants that adversely affect Puget Sound marine waters are also a problem in freshwater bodies across the state. PCBs, mercury and chlorinated pesticides are responsible for fish advisories in lakes and rivers in the Puget Sound region:

- Green Lake (King County) – limit carp to one meal per month (PCBs)
- Lake Washington – do not eat carp or northern pikeminnow; limit cutthroat trout to one meal per month; limit yellow perch to one meal per week (PCBs)
- Lake Whatcom – do not eat smallmouth bass; limit yellow perch to one meal per week (mercury)

In addition to waterbody-specific advisories that may be influenced from local point and nonpoint sources of pollutants, Washington state also has a statewide advisory due to mercury: do not eat northern pikeminnow; limit smallmouth and largemouth bass to two meals per month.

For many legacy contaminants such as PCBs and DDT, concentrations appear to be on the decline. An example is illustrated by Washington State Department of Health rescinding a decades-old fish advisory for DDT in bottomfish in the Yakima River. Twenty years ago, state monitoring efforts on the Yakima River showed some of the highest DDT concentrations reported for the entire nation. Today, levels have declined based in part by local erosion control efforts as well as natural attenuation to levels that no longer warrant an advisory for DDT. Unfortunately, PBDE levels in Washington fish appear on the increase and some of the highest levels have been reported in the Spokane River. Monitoring efforts for Puget Sound will likely show similar declines in certain contaminants and increases in others.

What is the current status of fish consumption advice? Based on seafood consumption advisories, eating seafood from urban areas poses a greater risk for humans than for seafood caught from non-urban areas in Puget Sound. Puget Sound rockfish, especially older fish, from urban areas exhibit higher PCB and mercury levels than fish from non-urban areas. Advisories prohibit consumption of rockfish from the Duwamish Waterway and Sinclair Inlet and are very restrictive for fish from outher urbanized sites (e.g., Commencement Bay, Everett) throughout Puget Sound.

What affects fish consumption advisories? Chemical contaminants that affect water quality and accumulate in the marine food web drive the need to provide advice about consumption of Puget Sound finfish. Puget Sound fish consumption advisories are based on levels of PCBs and mercury.

What do we still need to know about fish consumption and contaminants in fish? Washington State Department of Health has identified a number of data gaps with regard to contaminants in Puget Sound fish. Together with Washington State Department of Fish and Wildlife, staff recommends investigating levels of toxins in crab, shrimp, and several species of bivalves. Levels of contaminants in Puget Sound sockeye, pink, and chum salmon as well as hatchery-released and pen-reared salmon should be investigated to complete the evaluation of human health impacts from eating Puget Sound salmon. Further, limited analyses of marine species such as lingcod and cabezon would be useful for answering frequent questions on human health impacts from consuming these fish.

Another issue to consider is that most consumers and anglers do not eat only one species of fish. Instead, a consumer is advised, for example, to eat either four rockfish meals per month from a marine area, or four Chinook salmon meals per month. As part of our “either/or” guidance, DOH encourages citizens to eat two fish meals per week, so a consumer should choose accordingly. Washington State Department of Health recognizes the need to conduct a “market basket” assessment of PCBs and other contaminants in foods. This would include not only fish but also beef, poultry, pork, and other foods. since available contaminant data are limited.

PSAMP data have limited information on dioxin/furan concentrations in seafood. Collection of this information is important, particularly in examining cumulative risks from dioxins/furans and PCBs with dioxin-like effects.

The widespread environmental presence of emerging contaminants such as PBDEs (polybrominated diphenyl ethers), PFCs (polyfluorinated compounds), PCPs (some components of personal care products) and pharmaceuticals are part of a new area of concern for human health. For example, PSAMP has begun sampling fish tissue for PBDEs, which are flame retardants used in a variety of consumer and industrial products. PBDEs were recently identified as bioaccumulative in the environment and have been detected in a variety of human tissues and in other organisms. Given the long life of many PBDE products and the length of time they remain in the environment, exposure can continue for years after their production. Washington state has developed a chemical action plan that resulted in a 2007 law (RCW70.76) banning products containing penta-BDE and octa-BDE. Deca-PBDE is banned in certain products sold in the state beginning in 2011, based on the identification of safer alternatives.

What are our plans for future reports? Proposed studies include investigation of contaminants in Puget Sound crab, shrimp, and bivalves. Also, Washington State Department of Health has proposed to conduct a health assessment based on PBDE levels in fish muscle tissue collected by WDFW.

2.2 Safety of water

People's health depends on clean water for drinking, irrigation and for recreation. Information about contamination of swimming beaches directly addresses the Governor’s pledge regarding swimmable waters. In future reports on ecosystem status and trends, the Partnership might report on condition at freshwater swimming areas and on the quality of freshwaters used as sources for drinking water systems. (Drinking water quality is protected by governments’ programs to ensure delivery of safe water; the Partnership's indicator will focus on the quality of ground and surface waters provided directly from the ecosystem – a measure of the service provided by the ecosystem, rather than by human capital and programs.)

INDICATOR: Pathogens at marine swimming beaches

Data and analysis provided by Jessica Archer and Jessica Bennett, Washington State Department of Ecology

Since 2003, the BEACH Program has monitored swimming beaches in Puget Sound for Enterococcus bacteria, one indicator of fecal contamination, from Memorial Day to Labor Day each year. The purpose of the program is to protect beach goers from illness resulting from feces-related pathogens (including Salmonella, Campylobacter, enterpathogenic E. coli, enterviruses).

Monitoring findings for 50 core beaches are presented in Figure HH-6. This analysis focuses on beaches that did not meet water quality standards. Beaches that did not meet EPA's water quality standards for fecal bacteria more than 8 % of the time are shown in red; from 4.1-8 % of the time, in yellow; and from 0-4 % of the time, in white. Seven beaches had bacteria levels that did not meet water quality standards >8 % of the time. Nearly all of these beaches (five) have known problems that are being addressed. Twelve of the core beaches had bacteria levels that did not meet standards from 4.1-8 % of the time. Most of these beaches (eight) have known problems that the local jurisdiction is working to address. Thirty-one of the core beaches monitored over the 6-year period did not meet EPA's criteria <4% of the time. These occurrences may result from a heavy rain event, a large bather load, or other rare events that temporarily increase bacteria levels at the beach.

Chronic bacteria water quality problems at swimming beaches typically result from ultra-local impacts ranging from dog parks and dog-use areas on beaches (Marina Beach, Edmonds and Port Williams, Clallam County), regular CSO events (Hollywood Beach, Port Angeles and numerous beaches in Kitsap County), and wide-spread failing septic systems (Bayview beaches).

Most swimming advisories occur as a result of CSO events and infrastructure failures such as pipe breaks. CSO events typically occur in the rainy season when beach use is the lowest. However, infrastructure failures can occur at any time. Many examples exist including the Memorial Day 2006 Port Angeles pipe break where six-eight million gallons of raw sewage were discharged. Even more concerning, these failures can go undiscovered or unreported for days putting the health of beach goer's at risk. An ongoing failure at the McNeil Island Prison sewage treatment facility went on for several days before it was reported to authorities, potentially putting Eagle Island residents at risk from water-borne pathogens. While most sewage failures and overflows are relatively small in volume and occur at small treatment plants, occasionally, a brief failure occurs at a large top-of-the-line facility and can have huge impacts. In 2008, a mechanical failure at the West Point treatment plant, which occurred for only 10 minutes, discharged 400,000 gallons of untreated sewage into Elliott Bay, closing local beaches. Luckily, this failure occurred in March when use is low, but the large volume in such a brief period demonstrates the potential of an enormous treatment plant such as West Point.

While improving sewage treatment plants, replacing failing septic systems, and repairing aging infrastructure is expensive, this is the clearest path towards improving water quality, protecting the public health of beach goers, and reducing swimming advisories at Puget Sound beaches.

What is the current status of marine swimming beaches? Swimming in marine waters is relatively safe in most areas and during the majority of times of the year but seven out of 50 beaches had fecal bacteria levels that did not meet EPA water quality standards greater than 8 % of the time.

What affects the status of marine swimming beaches? Runoff and discharge of human and animal waste deliver loads of bacteria and viruses that affect the safety of swimming beaches.

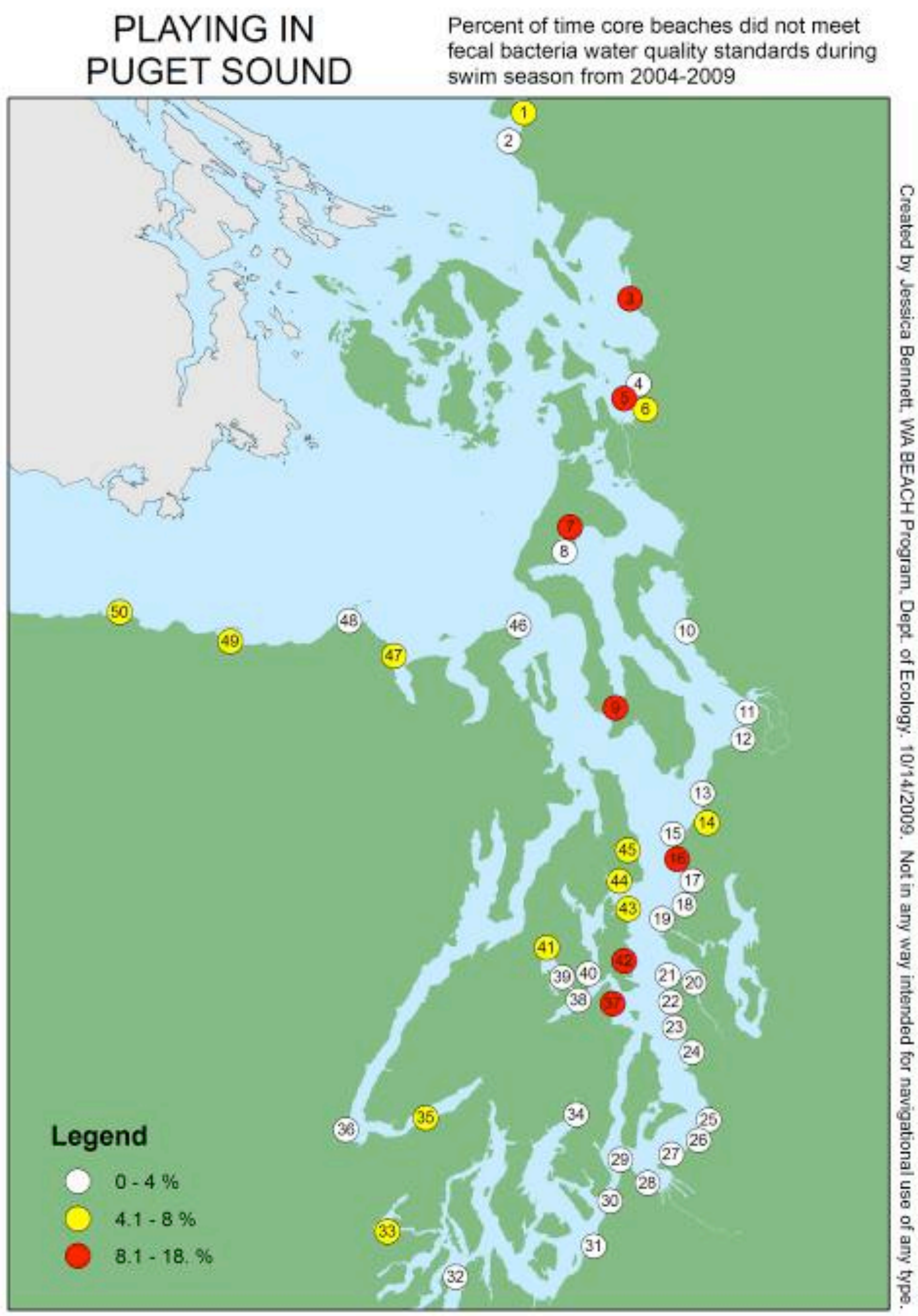


Figure HH-6: Frequency that EPA water quality standards for Enterococcus are exceeded at fifty 'core' Puget Sound marine beaches Since 2003, the BEACH Program has monitored swimming beaches for *Enterococcus* bacteria, a fecal bacteria indicator, from Memorial Day to Labor Day. Fifty core beaches are shown here. Beaches that do not meet EPA's fecal bacteria water quality standard more than 8 % of the time are shown in red; beaches from 4.1- 8 %, in yellow; beaches from 0 - 4 %, are shown in white.

LABEL	BEACH NAME	LABEL	BEACH NAME
1	BIRCH BAY COUNTY PARK	26	REDONDO COUNTY PARK
2	BIRCH BAY STATE PARK	27	DASH POINT STATE PARK
3	LARRABEE STATE PARK, WILDCAT COVE	28	WATERFRONT DOCK / RUSTON WAY
4	BAYVIEW STATE PARK	29	OWENS BEACH / POINT DEFIANCE PARK
5	BAYVIEW BOAT LAUNCH	30	TITLOW PARK
6	PADILLA BAY NATIONAL ESTUARINE RESEARCH RESERVE	31	SUNNYSIDE BEACH PARK
7	OAK HARBOR CITY BEACH PARK	32	BURFOOT COUNTY PARK
8	OAK HARBOR LAGOON	33	WALKER COUNTY PARK
9	FREELAND COUNTY PARK / HOLMES HARBOR	34	PURDY SANDSPIT COUNTY PARK
10	KAYAK POINT COUNTY PARK	35	TWANOH STATE PARK
11	JETTY ISLAND	36	POTLATCH STATE PARK
12	HOWARTH PARK	37	POMEROY PARK - MANCHESTER BEACH
13	PICNIC POINT COUNTY PARK	38	EVERGREEN PARK
14	EDMONDS UNDERWATER PARK	39	LIONS FIELD
15	MARINA BEACH PARK, EDMONDS (NO DOGS)	40	ILLAHEE STATE PARK
16	MARINA BEACH, EDMONDS (DOG PARK)	41	SILVERDALE COUNTY PARK
17	RICHMOND BEACH SALTWATER PARK	42	EAGLE HARBOR WATERFRONT PARK
18	CARKEEK PARK	43	FAY BAINBRIDGE STATE PARK
19	GOLDEN GARDENS	44	INDIANOLA DOCK
20	SEACREST PARK	45	ARNESS COUNTY PARK
21	ALKI BEACH PARK	46	FORT WORDEN STATE PARK
22	RICHEY VIEWPOINT	47	PORT WILLIAMS BOAT LAUNCH
23	LINCOLN PARK	48	CLINE SPIT COUNTY PARK
24	SEAHURST COUNTY PARK	49	HOLLYWOOD BEACH
25	SALTWATER STATE PARK	50	SALT CREEK RECREATION AREA

POSSIBLE FUTURE INDICATOR: Freshwater Biotoxins

Discussion provided by Joan Hardy, Washington State Department of Health

Washington state is in the process of determining the number of blooms and toxic cyanobacteria blooms in Puget Sound lakes through a new freshwater algae control program at the WA State Department of Ecology. In addition, Washington State Department of Health and partners (Washington State Department of Ecology, King County, Pierce County and Snohomish County) are tracking human and animal health incidents related to toxic events funded by a grant from CDC. Most toxic cyanobacteria identified regionally are microcystins (liver toxins); however, anatoxin-a (a neurotoxin) is also showing up in a number of area lakes (Figure HH-7). In the past, several dogs and cats have died after exposure to freshwater biotoxins. People, too, can become sick from recreational exposure to toxic blooms. This year, Washington State Department of Health has investigated several reports of human illness related to cyanotoxins in Puget Sound lowland lakes.

Microcystins

Year	# Counties	# Lakes	# Samples above Std.	Maximum Conc. (ug/L)
2007	5	9	22	4,810
2008	9	16	68	4,620
2009	10	19	69	187,000

Anatoxin-a

Year	# Counties	# Lakes	# Samples above Std.	Maximum Conc. (ug/L)
2007	1	1	1	4,000
2008	6	8	25	172,640
2009	2	4	21	144,000

Figure HH-7: Toxic cyanobacteria in Puget Sound counties

Testing of saxitoxin (a neurotoxin) and cylindrospermopsin (a liver toxin) in Puget Sound lowland lakes has been started in a recent project. So far, one lake has tested positive for saxitoxin, the same toxin being monitored in Puget Sound shellfish (Paralytic Shellfish Poisoning - PSP) and another has tested positive for cylindrospermopsin.

The number of lakes reporting toxic blooms has increased in the past several years due, in part, to increased awareness and sampling of lakes with blooms. Concurrently, lakes with a history of toxic blooms appear to be experiencing a higher frequency of toxic events. Increased population growth in the Puget Sound region has resulted in greater impervious surfaces that cause additional nutrient runoff to lakes. Increased nutrients and high temperatures are two factors associated with toxic algae blooms.

What is the current status of freshwater toxic algae issues in Puget Sound?
Although insufficient information is currently available to properly assess the status of freshwater toxic algae in Puget Sound, agencies are in the process of obtaining the necessary information. The data provided do not give necessary temporal or spatial information or appropriate standards to make a determination. This indicator may need additional evaluation.

What do we still need to know about toxic cyanobacteria? Washington State Department of Health and partners are in the first stages of documenting the extent, timing, and annual variability of toxic blooms in area lakes. They have started to test for two additional toxins not regularly analyzed in lake samples and are also investigating factors that may be used to predict when an algae bloom will turn toxic. One study is underway to investigate whether microcystins bioaccumulate in fish tissue, results of which may alter public health advice about consuming freshwater fish caught under bloom conditions.

What are our plans for future reports? Many reports evaluating freshwater biotoxins are planned after data from the CDC project and Ecology's ongoing tracking efforts are analyzed. Also, a report on bioaccumulation of microcystins in fish from Puget Sound lakes is planned in the near future.

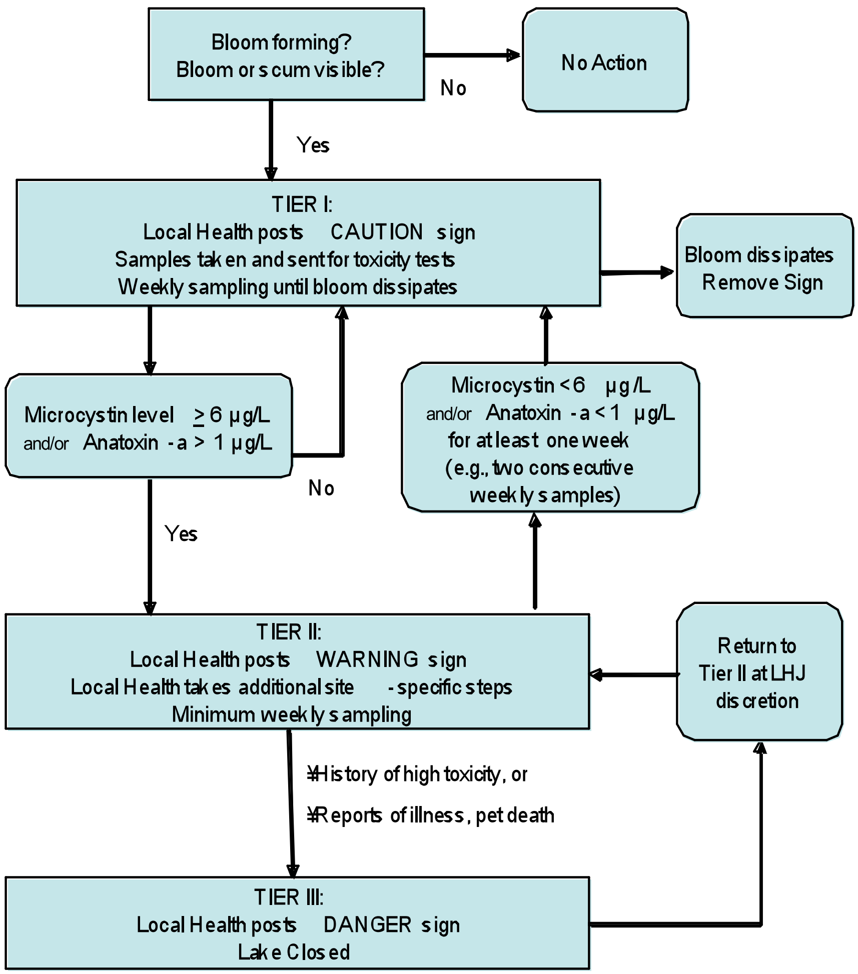


Figure HH-8: Three-tiered approach to managing Washington water bodies with cyanobacterial blooms

POSSIBLE FUTURE INDICATOR: Drinking water in Puget Sound basin

More interagency discussion is needed to decide on an approach for reporting on quality of source water for drinking water systems as another indicator of the safety of water in the Puget Sound region.

2.3 What do we still need to know about monitoring Human Health risks in Puget Sound? What are our plans for future reports?

The Partnership's concerns for human health recognize the multitude of interrelationships between human, animal and environmental health. For example, of the 1,461 infectious diseases now recognized in humans, approximately 60 % are due to multi-host pathogens characterized by their movement across species lines. Over half of all new or emerging infectious diseases since the 1940s have jumped from domestic and wild animals to humans, and it is fully expected that this trend will continue. Diseases that affect both animals and humans often result in animals serving as reservoirs for re-emerging or new diseases. Environmental degradation through pollution and contamination, or changes in the environment brought about by climate change, may result in favorable settings for expansion of existing infectious diseases, may increase the transmissibility of these diseases, or may lead to altered patterns of pathogen virulence as they rapidly adapt to new environmental cues. Animal and human migration patterns also shift in response to climate change, further leading to new routes of exposure. Beyond concern about infectious disease, the fate and effects of contamination of the environment, including chemicals, fertilizers, and antibiotics also affect human and other biological systems. An evolving " One Health" approach would incorporate the concept of sentinel species as indicators of human health, including the acquisition of pathogens infectious to humans as well as the impacts of chemical contaminants on development, reproduction and overall health.

To ensure Puget Sound waters and other natural resources are safe for eating, drinking breathing and recreating, monitoring of these resources will need to be improved and expanded. For example, novel tools and models are needed to improve our ability to forecast and predict environmental conditions that would compromise seafood quality and allow seafood managers and health officials to alert the public. Comprehensive monitoring for pathogens, biotoxins, and contaminants –including new inputs as well as existing inputs such as fecal contamination –must be maintained and improved to assure that seafood from areas in Puget Sound is safe to eat. In some areas, we will need to expand the scope and focus of monitoring efforts to address specific stressors and conditions, such as in urban areas that are exposed to different suites of stressors and require different regulatory actions. Determining trends of not only legacy contaminants such as PCBs and mercury, but also emerging contaminants of concern such as polybrominated diphenyl ethers (PBDEs) or flame retardents is warranted in assuring the health of the Sound.

The Puget Sound region is known globally for the quality and diversity of natural resource-based recreational opportunities. The region's attraction as a tourist destination and home for new businesses and residents is intimately tied to the health and availability of this resource. To ensure visitors and residents are able to continue to enjoy the Puget Sound environment without threats to their health, monitoring of potential health risks associated with recreational activities will need to be improved and expanded. In marine waters, the PSP will explore the possibility of using fecal coliform as perhaps a better marker for protection of human health at swimming beaches. In freshwaters, more data on water quality at swimming areas is needed. Although bacterial data has been collected for freshwater systems, it is very limited and was not included in this report. Expansion of indicators specific to freshwater or development of new indicators is an obvious need to properly assess conditions of freshwater systems in Puget Sound.

In order to ensure human health risks in Puget Sound are minimized, we will need to improve our understanding of the direct and indirect effects of anthropogenic and natural stressors on the environment. For example, improved tools and technology are needed to improve our understanding of conditions that influence toxic blooms. This need is more apparent when considering environmental variability and climate change, which may play a greater role in producing conditions (e.g., wind, upwelling, water temperature) that are favorable for toxin production. Improved prediction tools and modeling for forecasting of toxin events are needed to better understand the dynamics that influence occurrence of toxic blooms and allow shellfish managers to minimize the risk to humans.

3. Human Well-Being

The well-being of people in the Puget Sound region is dependent on services provided by the ecosystem: provisioning of food, water, and fiber; support for cultural, spiritual, recreation, and aesthetic values. Human well-being is equally dependent on factors less directly related to the Puget Sound ecosystem: the regional human-built environment, global and national economic conditions, large-scale natural drivers such as climate change, and so forth. Supporting human well-being through a viable Puget Sound ecosystem is a key concern for ecosystem recovery. This is expressed in the Partnership's authorizing statute as: "A quality of human life that is sustained by a functioning Puget Sound ecosystem."

The Puget Sound Partnership's selection of ecosystem indicators related to human well-being addresses the elements of human well-being as presented in the Sound Health, Sound Future report (Puget Sound Partnership, 2006):

- The Puget Sound supports thriving natural resource and marine industry uses such as agriculture, aquaculture, fisheries, forestry, and tourism.
- Aesthetic values, opportunities for recreation, and access for the enjoyment of Puget Sound are continued and preserved.
- Upland and marine resources are adequate to maintain treaty rights, as well as cultural, spiritual, subsistence, ceremonial, medicinal, and economic endeavors of the tribal communities of Puget Sound.

This memorandum covers indicators for these two elements of human well-being, which we characterize as

1) Working Resource Lands and Industries, and
2) Nature-based Recreation

Indicators for these two elements of human well-being were chosen from a much larger set of potential human well-being indicators (Schneidler and Plummer, 2009). The choice of these elements was guided by two basic criteria: (1) Data should be available or potentially available to support a well-defined measure that can be related to human well-being; and (2) a strong relation likely exists between the indicator and Partnership actions as described in the Action Agenda. While there are many aspects of human well-being not covered by the indicators presented below, the ones chosen reflect important priorities established by the Partnership. One exception is the goal of meeting tribal treaty rights and other tribal needs and interests. The set of indicators below includes a measure of tribal commercial marine harvests, however it does not address tribal communities' cultural, spiritual, subsistence, ceremonial, and medicinal needs, or the economic endeavors of the tribal communities of Puget Sound.

What is the current status of ecosystem support for human well being in Puget Sound? The Puget Sound ecosystem provides services that contribute to human well-being. Natural resources and related industries continue to support local economies in the region, though not at levels seen historically.

What affects the ecosystem's support for human well-being? The well-being of people in the Puget Sound region depends on services provided by the ecosystem: provisioning of food, water and fiber; support for cultural, spiritual, recreation and aesthetic values. Ecosystem services, in turn, depend on the health of the ecosystem's species and food webs and processes that create and maintain diverse and high-quality habitats. Therefore, stressors that affect other Partnership goals for the ecosystem also affect human well-being.

How does human well-being affect other aspects of the ecosystem? People and their behavior are typically viewed as a stressor on the Puget Sound ecosystem. A broader understanding of the relationship between people and the Puget Sound ecosystem is not currently recognized as a key aspect of ecosystem management. Human well-being is typically associated with factors such as the employment rate (a relative strength for the region) and traffic and road congestion (a detriment to well-being), and less about the benefits that people derive from the natural assets of the Puget Sound ecosystem and unintended consequences of behaviors that negatively impact the environment. Until there is a better understanding about how people value and relate to the natural ecosystem the effectiveness of actions to enhance the Puget Sound may be limited.

Human activities that generate human well-being can affect other aspects of ecosystem. Harvest of marine species and timber and agricultural production can affect the health of species, food webs and habitats. Marine harvest supports human health by providing a healthful food resource. Working lands can provide habitat characteristics that are more beneficial than developed landscapes; development of homes, businesses and transportation systems can reduce the working land base and contribute to water quantity and quality problems. Recreational activities can negatively affect wildlife habitats and stress species' populations.

3.1 Working Resource Lands and Industries

Monitoring the state of working resource lands and industries will allow the Partnership to understand whether efforts to manage for ecosystem recovery are sustaining a thriving and prosperous economy in the region. There is no expectation that the Partnership will manage these industries but rather will track them to assure that restoration efforts are not negatively impacting their status. The indicators discussed in this section report on valued aspects of working resource lands and industries in the region.

INDICATOR: Puget Sound commercial finfish and shellfish harvest, wild and aquaculture

Data and analysis provided by Mark Plummer, NOAA Fisheries

Fish and shellfish harvest indicate one aspect of a thriving marine based commercial industry — one that provides jobs, revenue, income, a tourist draw and local protein source. In addition, fish and shellfish harvest are a significant part of the culture and heritage of the Puget Sound region. Finally, fish and shellfish harvest provide both a commercial industry and well as cultural, traditional and spiritual values to local tribal nations. (The harvest of fish and shellfish and aquaculture production provide an indicator or environmental health (e.g., sustainable fisheries, harvestable shellfish) as well as human well-being.)

Figures HWB-1 to HWB-4 illustrate the historical trends in commercial (tribal and non tribal) fish and shellfish harvest in Puget Sound. For non-tribal fisheries (not including aquaculture), harvest declined from 1981 (the earliest year for which data are available from PacFIN) through the mid-1990s. The trend has been level since then, although significant annual variation exists. While groundfish accounted for a significant percentage of the total harvest for these fisheries in the 1980s, it has declined to less than 10% for the past decade. For tribal fisheries, harvest declined until 1990, after which harvest has been level, again with significant annual variation. Salmon accounted for more than 90% of the tribal harvest in the 1980s, but has dropped to around 45 - 60% over the past decade as the share of crab and other shellfish have increased significantly. Shellfish acquaculture has shown significant growth in terms of harvest since the early 1980s. This growth may be explained by increased acreage under production and introduction of new cultured species including geoduck.

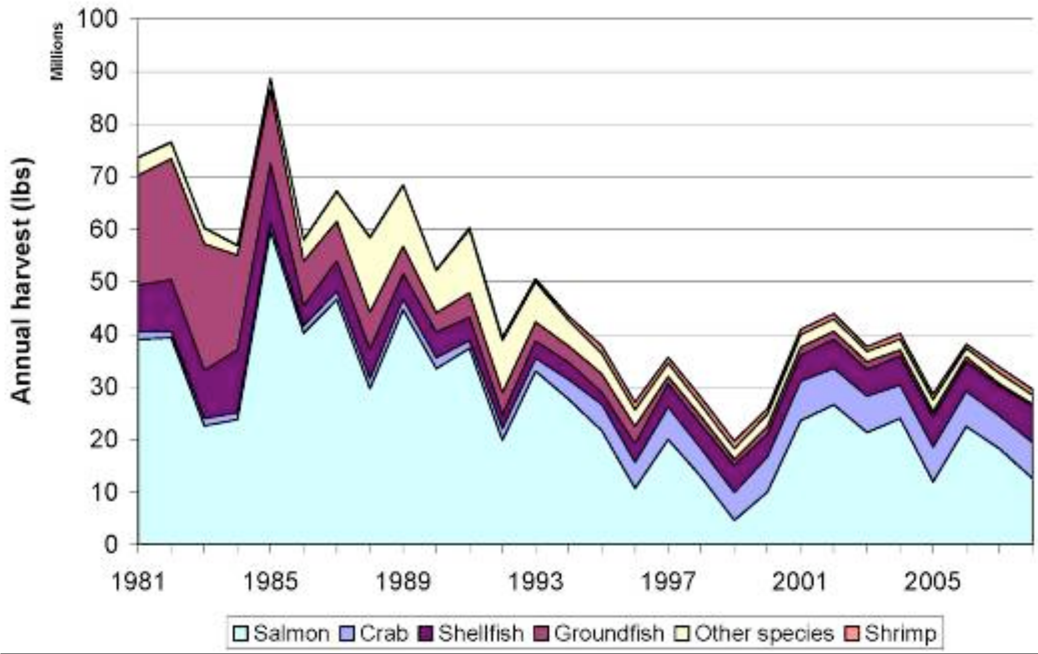


Figure HWB-1: Annual harvest in Puget Sound in all commercial fisheries (wild and shellfish aquaculture)

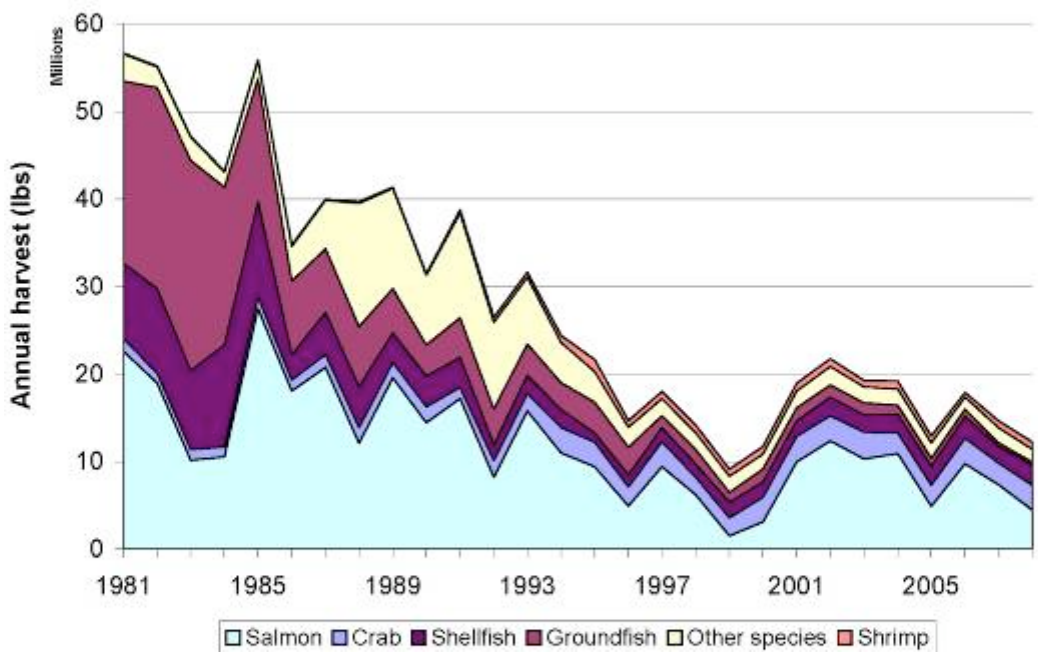


Figure HWB-2: Annual harvest in Puget Sound in non-tribal commercial fisheries (wild)

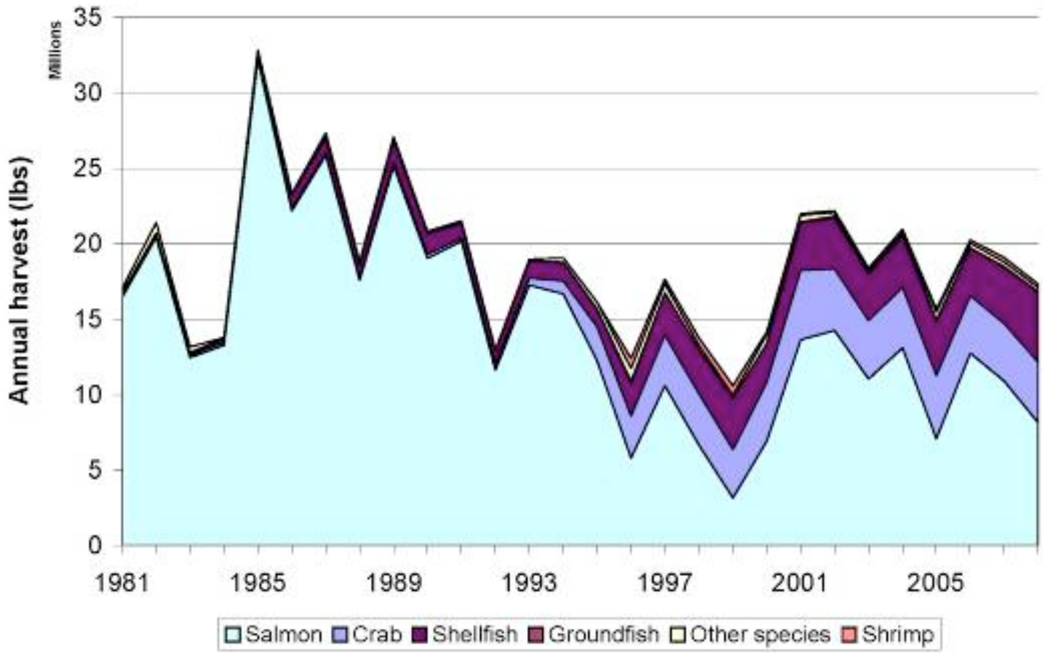


Figure HWB-3: Annual harvest in Puget Sound in tribal commercial fisheries (wild)

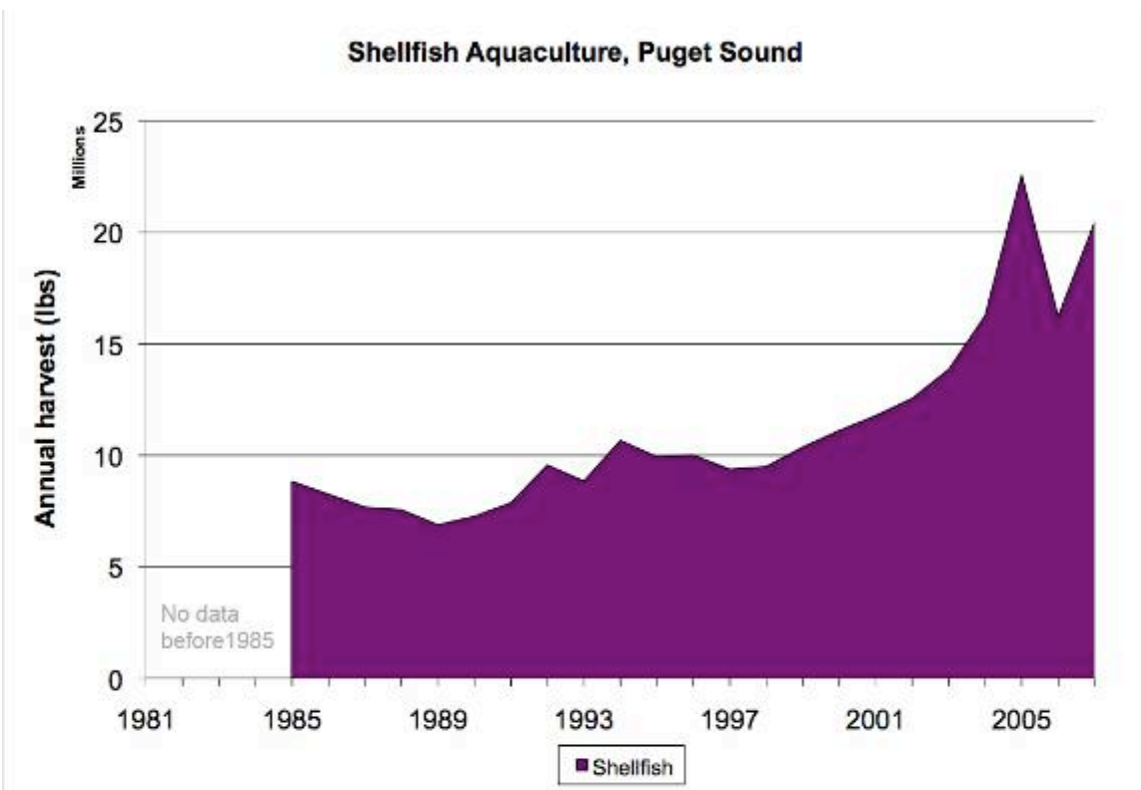


Figure HWB-4: Annual harvest in shellfish aquaculture industry

What is current status of commercial finfish and shellfish harvest? Significantly lower levels in recent years for all harvests except shellfish aquaculture.

What affects marine harvest? Marine harvest depends on markets for seafood products, the quality of waters and the resulting products, and the underlying stocks of the harvested resources (which depend on productive habitats, ocean conditions, international harvest and other factors).

INDICATOR: Forestland acreage

Data and analysis provided by Luke Rogers, Rural Technology Institute, University of Washington

Puget Sound forestlands provide services to the people of Puget Sound. Commercial forestry is a significant component of the Puget Sound region's heritage, providing the beginnings of a vibrant and stable economy. It provides jobs, tax revenue, income and fiber for both local and international use. The forest lands are also often managed to provide public access for recreational activities such as hiking, hunting and wildlife viewing. Historically, forestland ownership in Washington state has been dominated by large, vertically integrated corporations owning hundreds of thousands to millions of acres. More recently, changes in federal tax law and regulatory uncertainty regarding state forest practices have caused a massive shift in the ownership of private forestlands to smaller real estate investment trusts, timber management organizations, conservation organizations and family foresters. Coinciding with these ownership shifts are changes in the forest landscape: segmentation of once contiguous forests, land conversion, conservation easements, forestland tax exemptions and programs to enable the purchase or transfer of development rights.

Quantifying the changing ownership and structure of the forest land base is an important tool for understanding the effectiveness and consequences of forest policy over time. A regular assessment of forestlands is recommended to provide information on changes in the amount of forestland, fragmentation of the working forest land base, number of owners and economic and environmental contributions. Researchers at the University of Washington’s College of the Environment have produced this parcel-based information over the past few years and propose to continue doing so on a biennial basis.

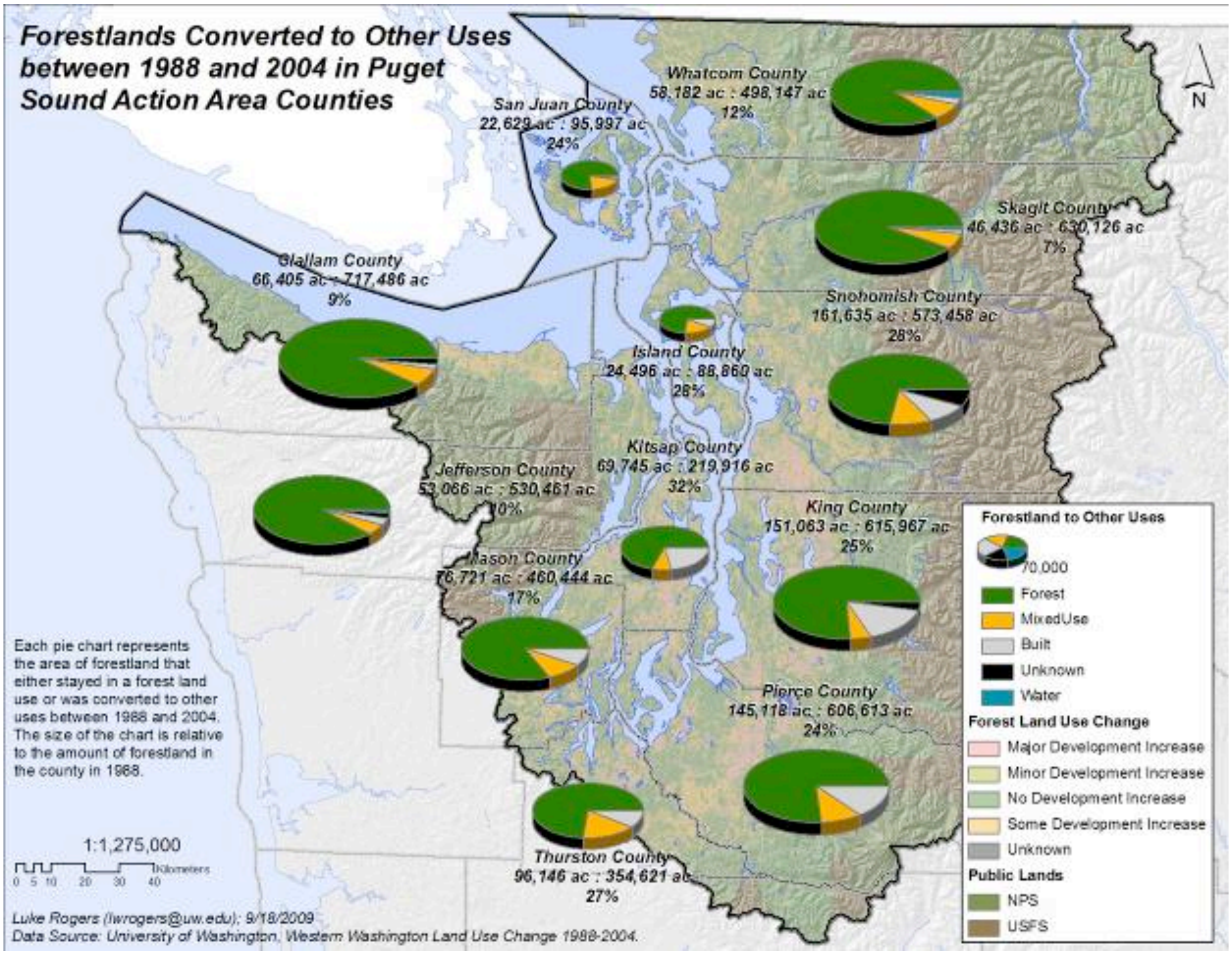


Figure HWB-5: State and Private Forest Land Use Change in Puget Sound Action Area Counties Forestland conversion driven by high real estate values and regulatory uncertainty is the dominant threat to Washington's productive forests. Between 1988 and 2004 936,000 acres of state and private forestland in western Washington were converted to non-forest uses: a 25% loss in forest lands over about 15 years. Recent research from the University of Washington indicates that nearly one million more acres of private forestland are threatened with conversion. Across all of Washington, the potential risk of conversion is highest in the Puget Sound region. From the 2006 Western Washington Land Use Change Dataset. ©2009 University of Washington.

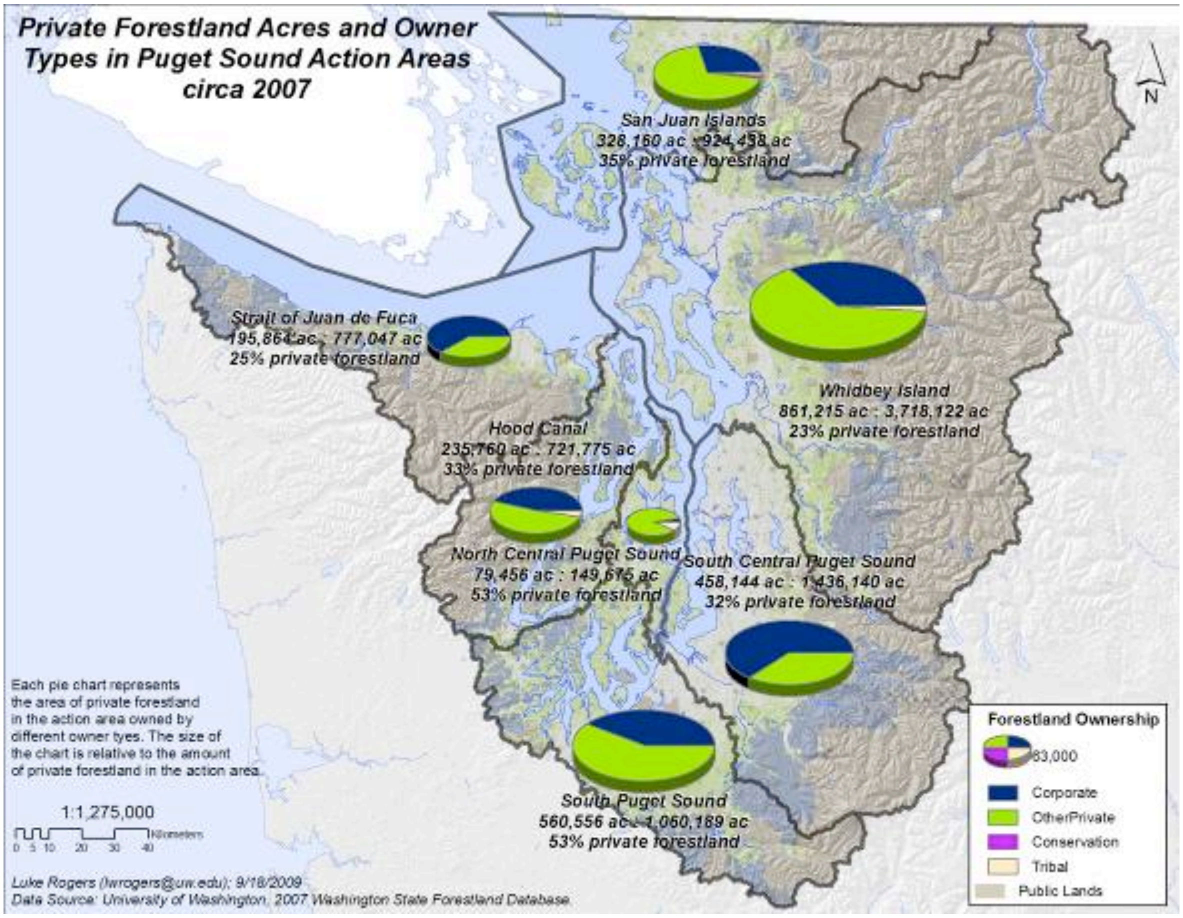


Figure HWB-6: Puget Sound Action Area Forestland Acres by Owner Type Recent trends have shifted long-held forest industry lands to other types of forestland owners. Family forests and other non-industrial groups are now the major forestland owners in the Puget Sound basin, and the state. While industry lands still produce the majority of the forest products, non-industrial owners are playing an increasing role as stewards of our natural resource lands. From the 2006 Western Washington Land Use Change Dataset. ©2009 University of Washington.

What is the current status of working forest lands in Puget Sound? Twenty-five percent loss of forest lands in about a 15-year period.

What affects working forest lands? Working forest lands are affected by markets for wood products, competing land uses, and the health of the timber stock.

POTENTIAL FUTURE INDICATOR: Agricultural land acreage

Discussion provided by Luke Rogers, Rural Technology Institute, University of Washington

Agricultural production, while relatively small in the Puget Sound region as compared to eastern Washington, is part of the basin's heritage and adds to the human well-being of local Puget Sound residents. To many it provides a traditional way of life, jobs, income and local revenue and related economic impacts through out the regional economy. In addition, agricultural production provides a local food and floral source that is of value to local residents. The agricultural sector in Puget Sound is however, facing critical challenges and an uncertain future. The Partnership needs to assure that management actions do not facilitate further decline in the industry, recognizing that farmers can be some of the best stewards of the land for future agriculture and health of the environment.

Efforts to better quantify and understand the agricultural land base in Washington state are currently underway through a partnership with the University of Washington's College of the Environment and the Office of Farmland Preservation at the Washington State Conservation Commission.

3.2 Nature-Based Recreation – For Future Development

Data and discussion provided by Mark Plummer, NOAA Fisheries, and Trina Wellman, Northern Economics

Monitoring a limited set of nature-based recreation activities in the Puget Sound basin will help the Partnership demonstrate how the ecosystem supports a sustaining quality of life for basin residents. The literature indicates that outdoor, nature-based recreation (boating, fishing, swimming, wildlife viewing, picnicing, hiking and scenic viewing) are of significant value to Puget Sound residents. With a few exceptions (e.g., Washington State Recreation and Outdoor Office, 2002), data to support indicators for these activities are not available.

Data on levels of use (based on user days or numbers of users) or availability of recreation opportunities can be collected on a regular basis for a limited set of nature-based recreation activities. The highest priority should be given to activities that have the strongest relation to Partnership goals and are likely to be affected by actions implemented through the PSP Action Agenda. An example of a possible indicator is presented in Figure HWB-7a,b.

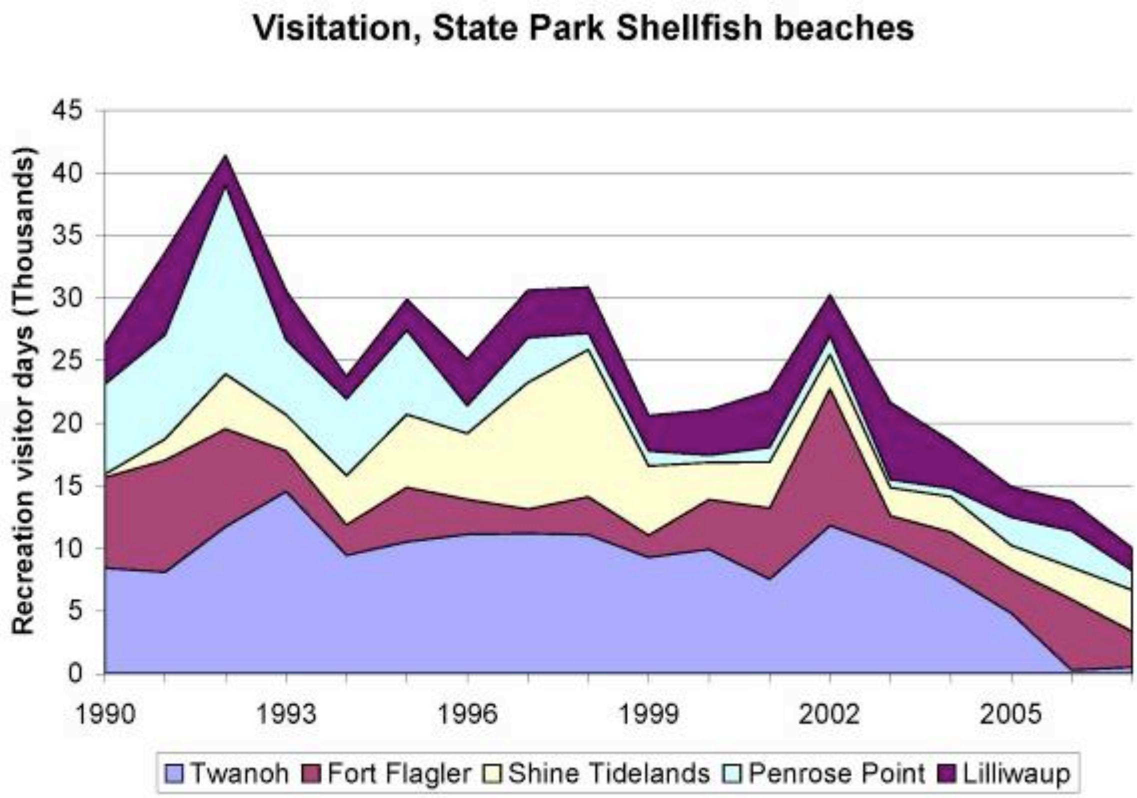


Figure HWB-7a, b: Shellfish beach visitation at select public beaches around Puget Sound

3.3 What do we still need to know about monitoring Human Well-Being in Puget Sound? What are our plans for future reports?

The indicators presented here — Working Resource Lands and Industries, and Nature-based Recreation — reflect important priorities established by the Partnership, but address only two elements of human well-being. In many cases it is very difficult to quantify and monitor the specific benefits people derive from a healthy, functioning Puget Sound ecosystem. For example, how do we begin to address the trade-offs associated with maintaining a "healthy" agricultural industry or forestry industry while improving the ecological value and function of the Puget Sound lowlands? More difficult still, how do we capture the intangible aspects of clean water and intact ecosystems such as the scenic, aesthetic and recreational value of the lands and waters comprising the Puget Sound Basin?

Despite the difficulties associated with characterizing and monitoring the elements of human well-being supported by a healthy Puget Sound ecosystem, future reporting will need to develop an approach to monitoring human well-being and expand this set of indicators to address the full component of elements supported by the Puget Sound ecosystem. Additional human well-being elements under consideration for future reporting include the following: aspects of the built environment dependent on a healthy ecosystem — such as land use, energy, water supply and flood protection; additional scenic and aesthetic resources and existence values; a broader suite of indicators characterizing working marine industries and resource lands; indicators addressing tribal communities' cultural, spiritual, subsistence, ceremonial and medicinal needs, as well as the economic endeavors of the tribal communities of Puget Sound.

4. Species and Food Webs

Stable and resilient food webs and the persistence of native species over time are key components of a healthy Puget Sound ecosystem. In a healthy ecosystem, food webs are the basis for support of many commercial, recreational, human health and aesthetic ecosystem services. On an annual to decadal scale in a healthy ecosystem, food webs are resilient to typical environmental changes and human perturbation. While populations of individual species within the food chain may fluctuate, they do not exhibit long-term decline leading to local extirpation. The health of species and food webs depends on habitat conditions, water quantity and quality, appropriate management including harvest and prevention and control of disease and deleterious exotic species (discussed in other sections).

In reporting the status and trends of Puget Sound's species and food webs, the Partnership is focusing on:

- species and communities of greatest conservation concern;
- flagship species, including ecologically important (keystone and umbrella) species as well as especially valued species;
- food web conditions.

Our knowledge of and ability to effectively manage various components of the Puget Sound food web and its individual species vary greatly. Salmon, for example, have received considerable focus, both in gaining understanding of population factors, and in carrying out restoration actions (although there is controversy about how much management is enough to achieve restoration). Less is known about nearshore marine communities, including component species and their requirements (e.g. seagrasses, forage fish spawning requirements). Riparian and estuarine environments are of high conservation concern and are highly impacted by human development—how much of these habitats are required to meet Puget Sound restoration goals?

Indicator species (sensitive to environmental change, such as the Pileated woodpecker) and keystone species (with a substantial or controlling role in the food web, such as herring) will help serve as a means to measure progress in protection and restoration. Flagship species (widely known to the public as "icons" of the Sound, such as salmon, orca) provide societal impetus for conservation — and may also themselves be keystone or indicators.

It is the lesser-known species — some of which constitute important food web components — that may present the greatest challenge. Invasive species can have huge impacts on food web composition and dynamics, and often we only discover these effects after the fact. How much do we know about the impacts of American Shad, novel pathogens (*Icthyophonus*, infecting Pacific herring), or changing water temperature as they affect food webs? The answer is very little, yet the history of biological invasions in coastal marine ecosystems (for example, San Francisco Bay) indicates that these forces can drive the food web to a completely new equilibrium with effects rippling throughout the system. Fundamentally, we know very little about even the native components of the pelagic (open water, particularly planktonic) elements of the Puget Sound food web.

Food webs are tightly linked to habitats and, hence to the maintenance of biodiversity. In both terrestrial and marine ecosystems, components of the food web *are* major components of habitats (native shrubs both feed and shelter blacktailed deer); filter-feeding bivalves both consume plankton, and serve as a substrate for other benthic organisms; phytoplankton blooms can render large areas of pelagic habitat lethal to fish and benthic species. The Partnership's approach to Puget Sound protection and restoration must take all of this complexity into account, considering the geospatial pattern of habitat connectivity needed to support native biodiversity, the functional role of food web components, population dynamics of individual valued species and the range of actions needed to lower the risk of catastrophic impacts by biological invaders.

Practically, how do we manage for ecological stability and resilience in the face of high uncertainty? A healthy functioning ecosystem consists of all of the individual species within that ecosystem, and all of the interactions between the species and the physical environment, many of which we certainly do not understand. But, generally, ecosystems are thought to be more stable when they contain a diversity of native species performing different evolved roles within the ecosystem. Therefore, it is sometimes more practical to focus restoration on individual, highly valued species, or particular, highly valued habitats, than it is to focus on the overall complexity of the system.

Individual species such as salmon and Douglas-fir are of tremendous commercial value. Bird watching and whale watching contribute significantly to our economy as well; these activities at their core are about the opportunity for people to enjoy individual species — they have a "constituency." Native species provide a foundation for our cultural heritage and our spiritual values. Washingtonians identify with salmon, Orcas, big Douglas-fir and cedar trees, starfish and anemones, salmonberries and huckleberries. Individual species are critical to the development of medicines and food crops. The native Pacific Yew is a great example of a species contributing to the on-going fight against cancer.

Ecologically, if certain species or habitats are chosen for conservation, the results can go far in protecting ecological function. Salmon restoration requires substantial protection of intact native stream and riparian communities, and has big implications for how we manage stream flow and land use (e.g. because of the impact of impervious surfaces on stream water quality and hydrology). This extends the effect of our actions far beyond just salmon.

What is the current status of Species and Food Webs in Puget Sound?
On a scale of several centuries, species composition of Puget Sound biological communities, population sizes of individual species and physical habitats that support species have been through dramatic changes. Some species formerly present are now absent from the region, and some formerly common native species have become rare. The current status of species and food webs in Puget Sound lead to three major conclusions: (1) a relatively large proportion (or number) of species in the Puget Sound ecosystem are imperiled in large part due to human activities over the last 150 years; (2) changes in species abundance can affect food webs, perhaps in dramatic and permanent ways; and (3) our knowledge of species and food web response to current threats limits our ability to predict ecosystem outcomes with great certainty.

What affects species and food webs in the Puget Sound ecosystem? Climate change and other human influences (e.g., habitat loss associated with land-use changes, pollution, harvest, non-native species introductions) contribute to rapid ecological change.

How does the status of species and food webs affect other aspects of the Puget Sound ecosystem? All species in the ecosystem are connected via a food web. Changes in the composition of species or in the abundance of a single species have the ability to change the structure of the food web. While it easy to understand how a decline in a prey item could result in decline in predators that consume that prey, less obvious changes can also occur. This phenomenon, termed “trophic cascade” represent unexpected and sometimes dramatic shifts in the system that can affect other species and humans in negative ways. Thus, declines in single species warrant concern for that species but also for the food web of which that species is part.

Declines in species can also affect other elements of the ecosystem’s structure function and process. For example, salmon transport marine-derived nutrients in the form of carcasses and eggs into nutrient limited river systems. Eelgrass provides food for a variety of herbivores, serves as habitat for a variety of fish and shellfish, and may help stabilize intertidal and subtidal sediments. Similarly, shellfish can affect the condition of bottom sediments, water clarity and nutrient cycling.

Finally, the abundance and diversity of Puget Sound species affects human health and well-being based on the system’s ability to provide quality food resources and support people’s cultural and aesthetic needs.

4.1 Species and Species Assemblages of Greatest Conservation Concern

Ecosystems are defined as collections of biological (species and species groups) and physical elements (climate, geology, soil types) and the interactions within and between these elements. Because ecosystems are complex and difficult to assess directly, simpler measures such as the number of imperiled species or groups of species are often used to assess ecosystem condition. The worldwide rate of extinction of plant and animal species has increased dramatically over background levels due in large part to human activities.

In our lifetime, Puget Sound is in danger of losing many of its plant and animal species, and the unique ecological functions they serve. Major causes include habitat loss, fragmentation, degradation, overharvest, and the introductions of exotic plant and animal species (Figure SFW-1). Climate change, increasing biological invasions, and rapid growth of the human population pose further risks to biodiversity. For example, we are expected to add almost 1.5 million people to the region by 2020. The major threats associated with rapid population growth include habitat loss, degradation and fragmentation, and disruption of natural disturbances and processes such as flows of water, nutrients and energy.
By accounting for a variety of types of species and higher-order assemblages, an indicator of number of species and groups of greatest conservation concern provides an overall picture of status addressing the Partnership goal of maintaining species in the Puget Sound basin.

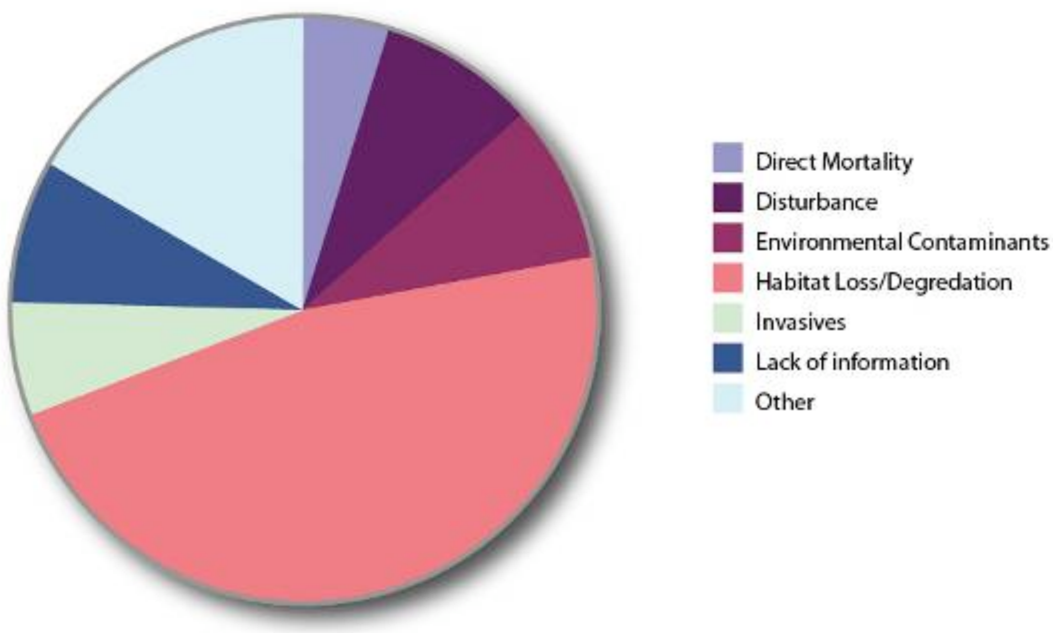


Figure SFW-1: Threats to Puget Sound biodiversity

INDICATOR: Native species and species groups of concern in the Puget Sound basin

Data and analysis provided by Rex Crawford, Washington Department of Natural Resources Natural Heritage Program, and John Pierce, Washington Department of Fish and Wildlife.
Expert advice contributed by John Gamon, Washington Department of Natural Resources Natural Heritage

Program; Tom Mumford, Washington Department of Natural Resources; and Timothy Quinn, Washington Department of Fish and Wildlife.

Figure SFW-2 depicts the number of imperiled native species and species groups (elements) in the Puget Sound ecosystem. The ratings were developed by review of available information from DNR's Natural Heritage Program and WDFW's Wildlife Program to identify the number of species or groups occuring in the Puget Sound basin that are rated as vulnerable, high risk, critical or extirpated. A considerable number of species or groups are rated as “critical” — the last stage before extirpation.

Along the x-axis of Figure SFW-2, the numbers of imperiled elements are compared to the total numbers of elements in this category. For WDFW’s evaluation of animal groups, the number of species for each taxa is a subset of all species in the region reflecting only those species with potential for concern (i.e., excluding especially common species). Future development of this indicator should improve and standardize the total numbers of species and groups included in this evaluation.

What is the current status of species of greatest conservation concern? Species with a significant portion of their range in the Puget Sound ecosystem that have been identified as global-, federal- and state-imperiled have typically experienced dramatic changes in population numbers. Even as efforts to conserve these species are underway, the list of imperiled species continues to grow. Some species, because they have minor commercial or cultural significance — or because they are obscure — are declining but have not received similar legal protection (for example under the Endangered Species Act) simply because insufficient scientific and regulatory resources prevent their formal consideration.

What affects the species of greatest conservation concern in the Puget Sound ecosystem? Threats to species of concern include: habitat loss and degradation, direct mortality (e.g., due to human harvest), environmental contaminants, disturbance, and invasive species.

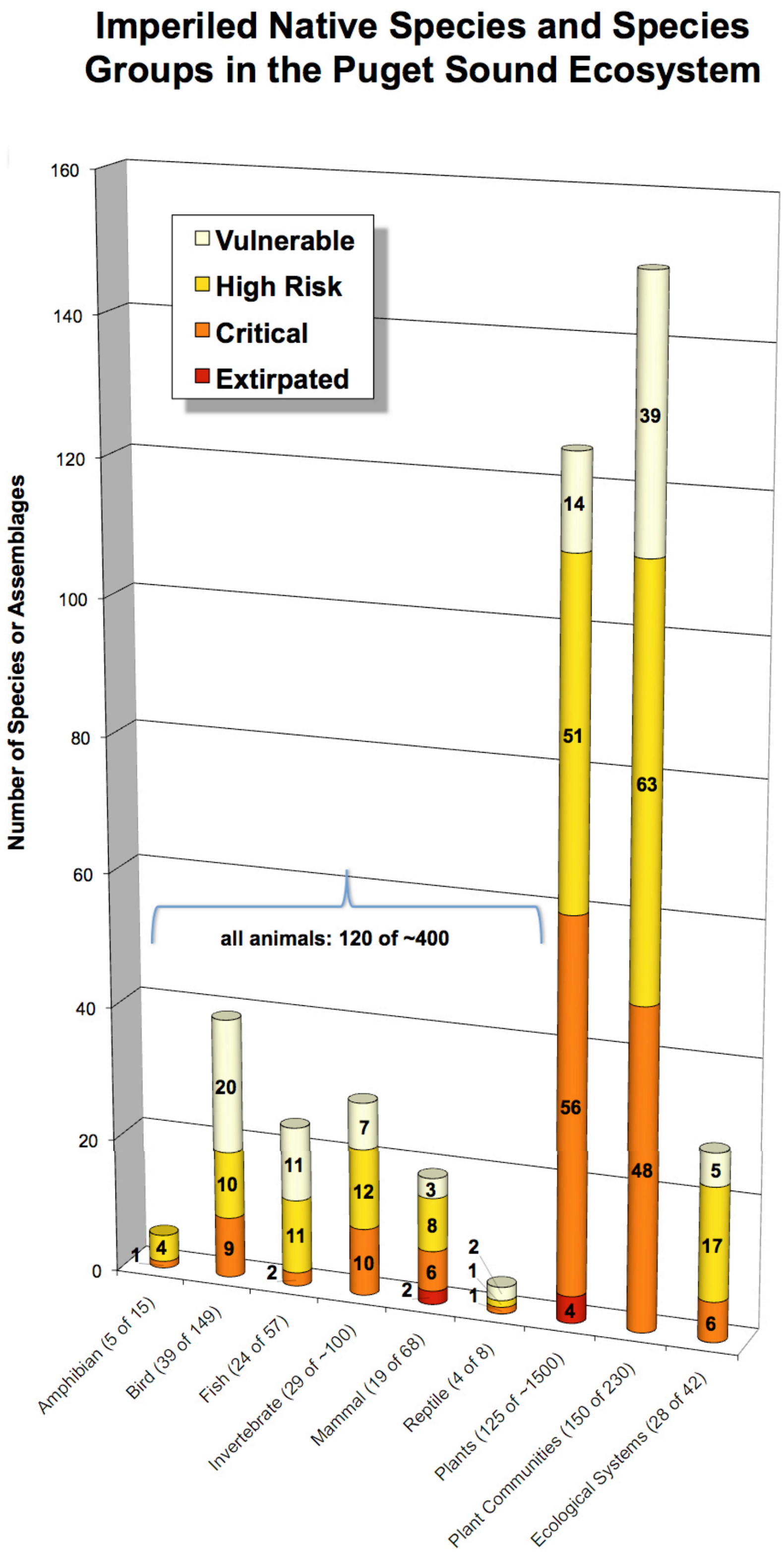


Figure SFW-2: Imperiled native species and species groups in the Puget Sound ecosystem

What do we still need to know about native species and species groups of concern? What are our plans for future reports? Figure SFW-2 reflects information on amphibians, birds, fish, invertebrates, mammals and reptiles for both marine and freshwater aquatic environments as well as terrestrial areas in the basin. However, the data for plants and plant communities do not include freshwater, estuarine or marine systems. Future development of this indicator should include data and analyses that extend it to fully represent all parts of the Puget Sound basin and all biota and biotic communities. (See section below for additional comments on marine species.)

Although all of the imperiled species and groups (elements) presented in Figure SFW-2 occur in the Puget Sound basin, some elements may occur only in the basin while others may be relatively abundant in other portions of the state. Further, the imperiled elements presented here have not yet been evaluated as to the extent that actions within the basin may affect them. In addition to expanding the scope of this analysis to include all biota and biotic communities in the basin, future development of this indicator will need to involve the collaboration of scientists and policy makers to identify those elements of greatest conservation concern and to determine which are most threatened by human actions in the basin.

Marine and estuarine organisms found in Puget Sound constitute a hugely diverse group of organisms but are not yet effectively captured in the analysis presented here. Although marine birds, fish and mammals are included in the information from the WDFW reflected in the first six columns of Figure SFW-2, other taxonomic groups of marine and estuarine species are not addressed in the indicator described above. While the taxonomy of marine plants (seaweeds and seagrasses) and plant communities has been well studied (Gabrielson et al., 2006; Hitchcock and Cronquist, 1973), with the exceptions of floating kelp and eelgrass, their abundance and distribution, and particularly their ecological function, is often poorly known. This is also true of many marine invertebrates, with the exception of the commercially important species such as crab, shellfish, etc. Marine phytoplankton and microbial (protist) biodiversity is an important element of the ecosystem. These species not only represent an important part of the lower and mid levels of the food web, but also may serve as keystone species (e.g. eelgrass, urchins). The biodiversity (species richness) provided by these marine taxa itself is important for ecosystem resilience, and can be used as an indicator of ecosystem health.

In Washington, 32 species (5% of total number) of marine algae have been listed as rare (Washington Natural Heritage Program, 2004), a number roughly in line with similar lists from Oregon (Oregon Natural Heritage Information Center, 2009) and British Columbia (BC Marine Conservation Analysis, 2007).

While some information exists for historical or baseline distribution for salt marshes, eelgrass and bull kelp, the rest are in need of careful work from herbaria, older surveys, studies and TEK.

Of 2,800 species of marine and estuarine invertebrates in 29 phyla (Kozloff, 1987), Washington Department of Fish and Wildlife's Priority Species and Habitat program (Washington Department of Fish and Wildlife, 2009) lists two marine gastropods, five mollusks, and one urchin species as “priorities for conservation and management,” about 0.3% of total species).

4.2 Flagship Species

Communities of plants and animals are composed of elements that are readily countable (e.g., number of species numbers of individual of a species) as well as more complex and thus less countable emergent properties loosely defined as elements arising from the sum of the parts (e.g., complex interactions and processes). We use species as indicators; they are the common biological currency as defined in law, but we are equally concerned with emergent properties of the communities in which species live. Flagship species include iconic animals that provide a focus for raising awareness and stimulating action for broader conservation efforts, species that we know contribute to emergent properties of communities such as keystone species, and species that are indicative of other members of the community such as umbrella species.

Flagship species refers to a single species that defines a characteristic of the environmental (keystone, umbrella) and or the role they play in the context of human systems (i.e., social, economic, religious, etc). As such they can indicate unique aspects of the ecosystem not readily measured by other simple means. Many of the flagship species listed here are sensitive to common threats within the Puget Sound and may have already been affected by past changes in the region.

The implications of status changes in flagship species should be done on a species-by-species basis and in the context of the species’ role in the environment (i.e., keystone, umbrella, icon) and the threats to the species. Some species may have a minor ecological role (for example within the food web) but be critically important as an indicator of a certain community type. Others may have a controlling role on populations of other species, but lack sufficient scientific understanding to shape effective restoration actions.

INDICATOR: Orca whales

Data and analysis provided by Ken Balcomb, Center for Whale Research

The southern resident orca whales are actually a large extended family, or clan, comprised of three pods: J, K, and L pods. Within each pod, families form into subpods centered around older females, usually grandmothers or great-grandmothers. Both male and female offspring remain in close association with their mothers for life. Three main orca populations visit the waters of Puget Sound regularly but only one – southern resident whales – return each summer to Puget Sound and the waters around the San Juan Islands. In 2005, southern resident orcas were added to the

Federal endangered species list after scientists determined they are a genetically distinct population that do not breed with other orca populations.

As of April 2009, the population totaled 85 individuals. The historic population of Puget Sound orcas, before European settlement, was estimated at 150-250 whales. All three southern residents pods were reduced in number during 1965-75 as a result of captures for marine parks. At least 13 orcas were killed during captures, and 45 were delivered to marine parks around the world, of which only Lolita (at Miami Seaquarium) remains alive.

Between 1974 and 1995, southern resident orca populations increased to 98 but dropped sharply by 2001 to 81 whales, a loss of 17 percent. Although the number of southern resident orcas has increased to 85, these animals continue to face threats to their health from a number of stresses including persistent, bioaccumulative, toxic chemicals and other contaminants and declines in prey. The whales are also at risk from major oil spills and from increased noise from whale-watching boats and other vessels.

What is the current status of southern resident orcas? What affects orcas? While the number of southern resident orcas appears stable in the most recent years, orca numbers belie the risks for the species as evidenced by fact that the species was recently listed as threatened under the Endangered Species Act. This listing was based on a 20 percent decline in the population during the 1990s, in addition to ongoing threats from boat traffic, toxic chemical contamination and declines in salmon, which is an important source of food for the species.

What activities and management activities affect southern resident orcas? The management of Pacific wild and hatchery salmon directly affects the southern resident orcas by allowing them, or denying them, adequate food supplies throughout the year (Ford et al., 2009). Other activities that affect southern resident orcas are: oil spills and pollution; detonation of explosives or production of abrupt loud noises underwater; and, usurping marine and estuarine habitats for other uses that diminish the viability of the food web.

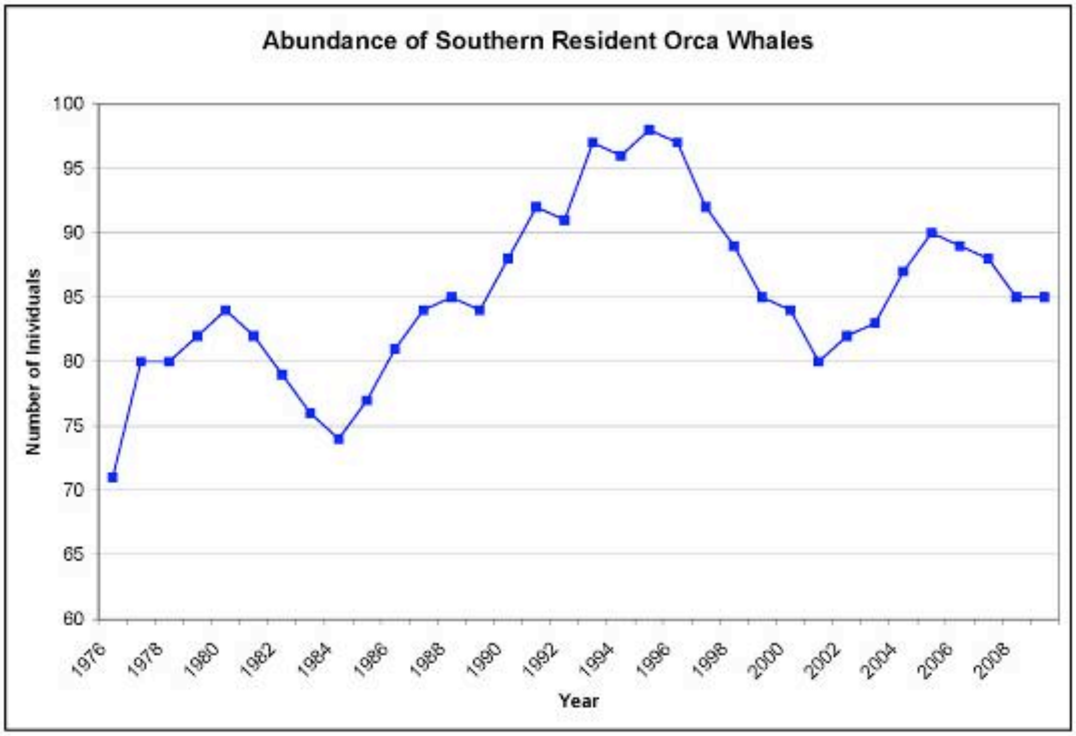


Figure SFW-3: Southern Resident Orca abundance, 1976-2009

What do we still need to know about southern resident orcas? What are our plans for future reports? We need to know the total nutritional requirement for a "recovered and sustainable" southern resident orca population, and provide for that requirement in our fisheries management programs and environmental planning. If we do not do that, we can expect future reports to document the decline of southern resident orcas to extinction, or document their absence from the Puget Sound marine habitat. In the 1970s and early 1980s when Chinook salmon were still relatively abundant seasonally in Puget Sound, we documented the southern resident orca use of that habitat during all months of the year. Currently, only chum salmon in autumn are in sufficient supply to entice the southern resident orcas into Puget Sound with any regularity.

INDICATOR: Pacific herring

Data and analysis provided by Kurt Stick and Adam Lindquist, Washington Department of Fish and Wildlife

Pacific herring are a vital component of the marine ecosystem and are a valuable indicator of the overall health of the marine environment. Many species of seabirds, marine mammals, and finfish, including chinook and coho salmon, depend on herring as an important prey item. Nearshore habitat is critical for several stages of herring life history, particularly for embryonic and juvenile phases. Status of herring populations in Puget Sound can be a measurable indicator of the productivity and health of nearshore systems. Additionally, the commercial herring bait fishery operates in Puget Sound, providing product for recreational fisheries and herring is one of the few Puget Sound marine fish species for which abundance data are available.

For the 2007-08 period, less than half (47%) of Puget Sound herring stocks are classified by WDFW as healthy (above or within 10% of the previous 25 year mean abundance) or moderately healthy (within 30% of the 25 year mean abundance). This is the lowest percentage of stocks meeting these criteria since development of the stock status summary in 1994, although similar to the status breakdown for the previous two-year periods (2003-04 and 2005-06).

Recent genetic studies involving Puget Sound herring provide solid evidence of the genetic distinctness of the Cherry Point stock. It also appears that the Squaxin Pass stock may also be genetically differentiated and all other sampled herring populations from Puget Sound are not genetically distinct.

Therefore, herring "stock" status may be most meaningful if examined with these results in mind. The Cherry Point herring stock status continues to be considered critical and the Squaxin Pass stock is considered to be healthy at this time. The spawning biomass for all Puget Sound stocks combined, excluding both the Cherry Point and Squaxin Pass stocks, would be considered moderately healthy compared to the previous 25-year sum of mean spawning biomasses for 2007-08 after a healthy status classification for 2005-06.

Due to uncertainties of stock structure, annual sampling of all known spawning populations in Puget Sound should continue and additional collection of genetic samples involving as many spawning populations as possible should be pursued.

In general, the abundance of south and central Puget Sound herring stocks in recent years is comparable to the 1970s and 1980s, while the Cherry Point stock, and cumulative north Puget Sound (excluding the Cherry Point stock) and Strait of Juan de Fuca regional spawning biomasses are at low levels of abundance (Figure SFW-5).

The North Puget Sound region herring spawning biomass, excluding the Cherry Point stock, is currently at a low level of abundance, following a cumulative peak observed in the 1990s. The Portage Bay/Samish Bay stock is the only stock in this region whose abundance is higher than the historical average in recent years.

The cumulative estimated herring spawning biomass for the herring stocks in the Strait of Juan de Fuca region continues to be very low compared to the peak period observed in the early 1980s. The Discovery Bay stock had a very large unexplained one-year increase in 2006, casting doubt on the amount of natal homing and fidelity for this stock.

The estimated spawning biomass for the Squaxin Pass stock has fluctuated drastically and recent spawning biomass is relatively high for this stock. The years of extremely low reported spawning biomass (e.g. less than 150 tons in 1977-79 and 1997-98) were generally based on spawn deposition surveys which likely underestimated abundance for this stock.

What is the current status of herring? What affects the status of herring? The species is divided into different stocks for assessment purposes. One stock (Cherry Point) has experienced relatively sizable declines in abundance, for mostly unknown reasons. Other stocks appear to be relatively stable in terms of overall abundance, although data from WDFW acoustic/trawl surveys suggests that there have been large changes in herring age distributions (fewer older fish) that may indicate increasing mortality rates among older fish. Our lack of understanding of the causes for decline in the Cherry Point stock heightens the concern for this species.

How does the status of herring affect other aspects of the Puget Sound ecosystem? This species currently supports a herring bait fishery, but has historically supported fisheries for human consumption. The herring is arguably the most important components of pelagic prey fish in the Puget Sound food web. It is an important prey species for many fish-eating predators including: whales, orcas, salmon, seals, rockfish, as well as many marine birds. Many of the species that eat herring are themselves listed (orca, certain salmon species, rockfish), or declining (rockfish).

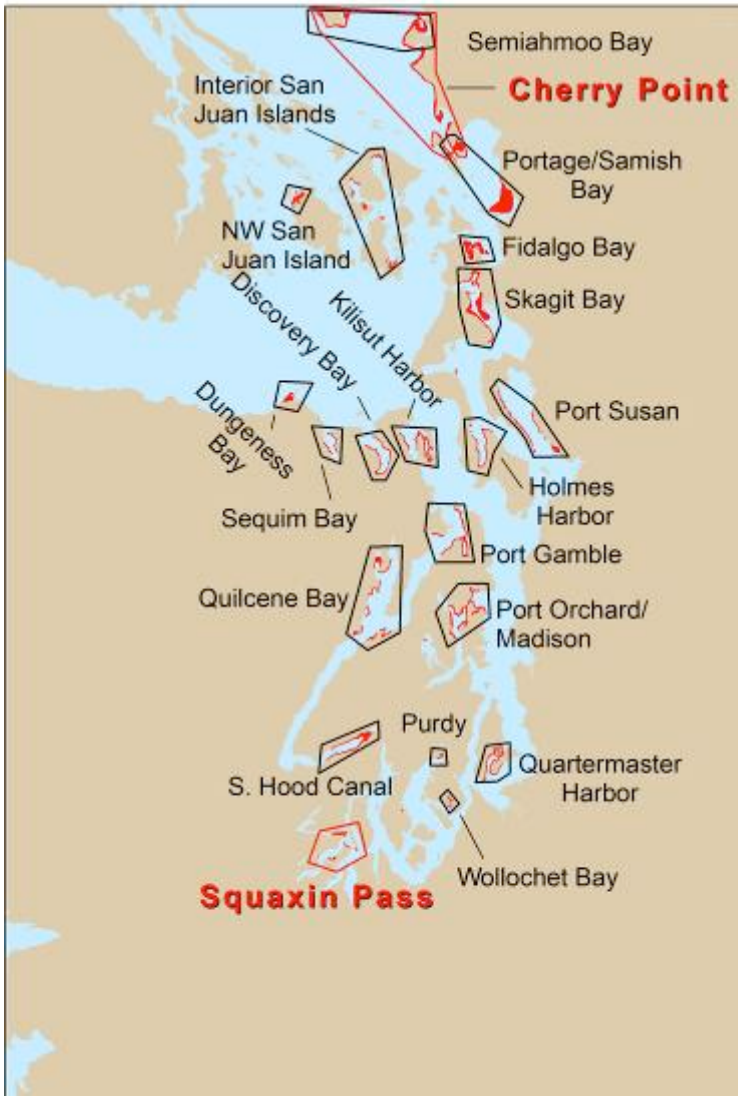


Figure SFW-4. Documented Puget Sound Herring Spawning Grounds

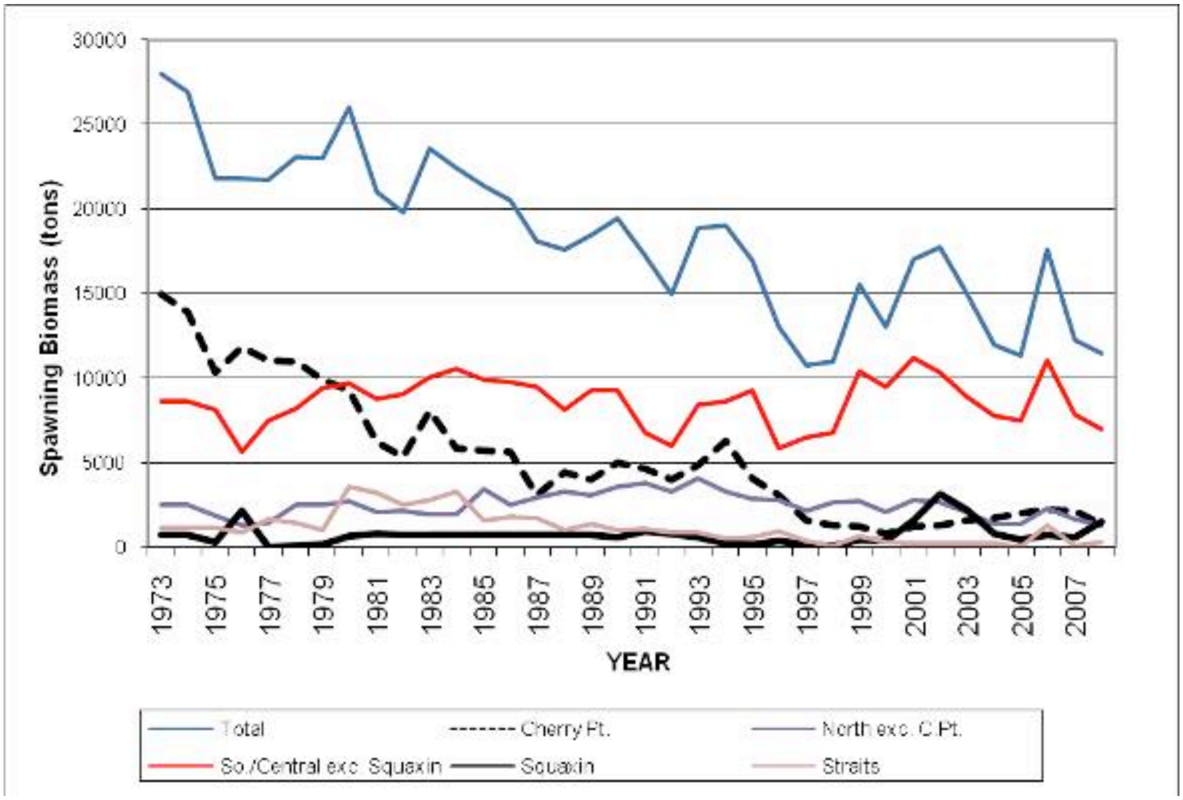


Figure SFW-5: Puget Sound herring spawning biomass estimates by selected stocks and regions, 1973-2008 (historical mean assumed if stock not sampled)

What activities and management activities affect herring spawning biomass? It is likely that herring spawning biomass is most affected by environmental conditions (e.g. water temperature, predator/food abundance, etc.) that impact natural mortality. However, human activities such as fishing, and destruction of spawning grounds due to nearshore development can also affect spawning biomass. The commercial herring bait fishery in Puget Sound is the only active herring fishery, and employs a conservative annual maximum harvest guideline that is set at 10% of the estimated cumulative adult biomass in the south/central Puget Sound region. Landings for 1998-2007 were well below the allowable catch, ranging from 2% to 6% of the total spawning biomass for the region. Continued protection of documented herring spawning grounds, and nearshore areas in general, should be a management priority.

Further information available via download from WDFW at http://wdfw.wa.gov/fish/management/saltwater.html

INDICATOR: Listed salmon

Data and analysis provided by Washington Department of Fish and Wildlife (Craig Busack, Dayv Lowry, *Erik Neatherlin, Mara Zimmerman, and numerous WDFW field staff)*

In Puget Sound, Chinook salmon, Hood Canal summer chum and steelhead are all federally listed as threatened. The availability and quality of data to inform management of individual populations varies widely. For some populations, the only directly applicable data are spawning escapement estimates (i.e., the number of fish that "escape" fisheries to make it back to the spawning grounds). In such cases, estimates of migratory pathways, entry patterns, age composition and maturation trends, age at recruitment, catch distribution and contributions must be inferred from the most closely related population for which such information is available. Obtaining the information to test and evaluate these inferences and assumptions remains a key data need.

Natural Chinook spawning abundance in Puget Sound is generally depressed, and for some specific populations, at critically low levels. The data below aggregate specific populations into broader geographical groupings called major population groups. These data show that number of spawners and total abundance (spawners + harvest and mortality) has generally increased since prior to listing in 1999. However, Puget Sound Chinook populations still remain well below the target spawning ranges needed for recovery as identified by the regional technical and scientific teams.

Hood Canal summer chum were federally listed in 1999 but conservation measures actually began as early as 1992 in response to critically depressed populations. Due to both supplementation programs and reduced harvest, Hood Canal summer chum populations have rebounded in recent years and until only very recently have remained well above the spawning goals identified by the regional technical and scientific teams. It will be important to monitor populations over the next few years to see if abundance continues to increase.

Steelhead were federally listed as threatened in 2007 because the populations were deemed critically depressed and in steep decline in recent years. The data below for steelhead are aggregated only at the Puget Sound-wide (i.e., ESU) scale because the listing is so recent that there have yet to be any priority populations or aggregate major population groupings identified.

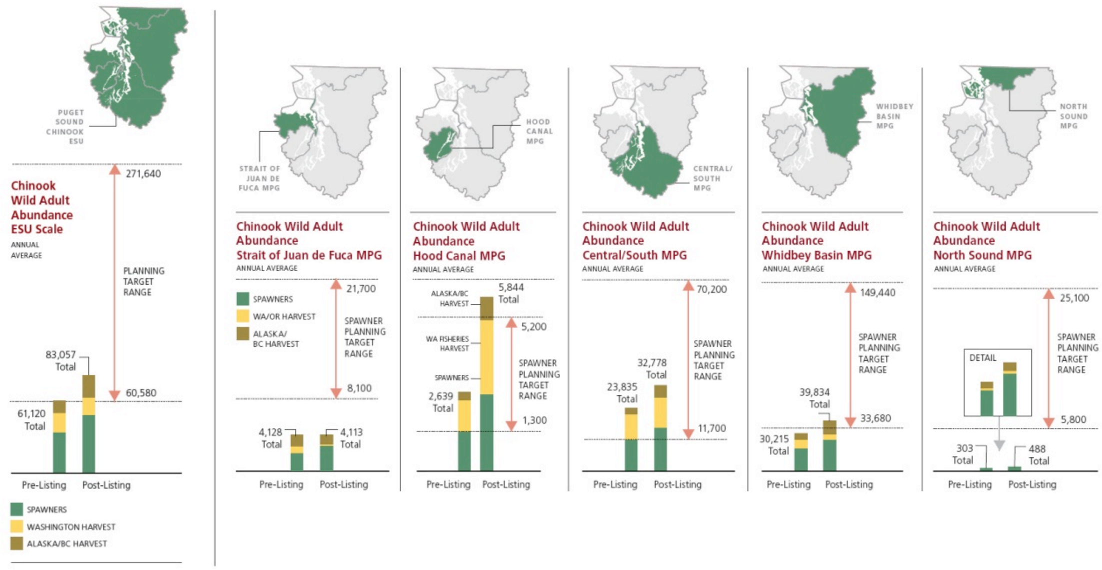


Figure SFW-6: Annual Average Puget Sound Chinook Wild Adult Abundance (as reported in 2008 State of Salmon in Watersheds)

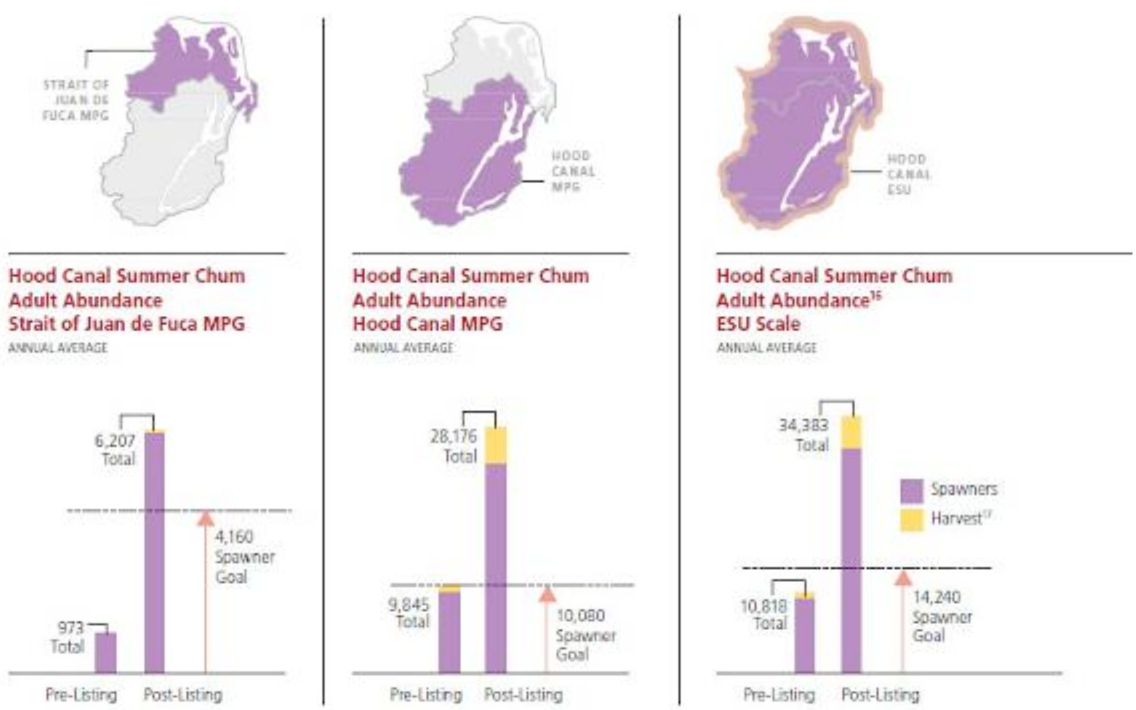


Figure SFW-7: Annual Average Hood Canal Summer Chum Adult Abundance (as reported in 2008 State of Salmon in Watersheds)

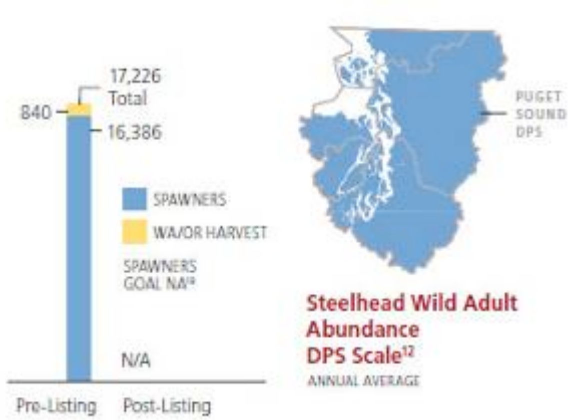


Figure SFW-8: Puget Sound Steelhead Abundance

What is the current status of listed salmon? What affects the status of listed salmon? The Puget Sound supports three species of salmon that have been listed under the Federal Endangered Species Act (ESA): Chinook, Hood Canal summer chum, and steelhead, with a fourth species, coho, under consideration. Concerted efforts to recover the Chinook and summer chum are underway, and new plans for recovering steelhead are being considered. Chinook and summer chum abundance (run size) appear to be responding to favorable ocean conditions and may be affected by concerted recovery efforts to improve harvest and hatchery practices. Factors affecting the recovery of salmon include harvest, hatchery practices and habitat, including the effects of hydropower on stream habitats.

What activities and management activities affect adult abundance of Puget Sound Chinook, Hood Canal summer chum, and Puget Sound steelhead? To reach target spawning ranges, impacts from harvest, hatchery practices and habitat loss and degradation (including changes in hydrology associated with water withdrawal, effects from hydroelectric projects, climate change) will continue to need to be addressed. Reducing the impact of harvest on Puget Sound natural populations requires accounting for all sources of fishery-related mortality in all fisheries. This is not a trivial task since directed, incidental, and non-landed mortality must all be taken into account, and since Puget Sound Chinook salmon are affected by fisheries in a large geographical area extending from southeast Alaska to the Oregon coast.

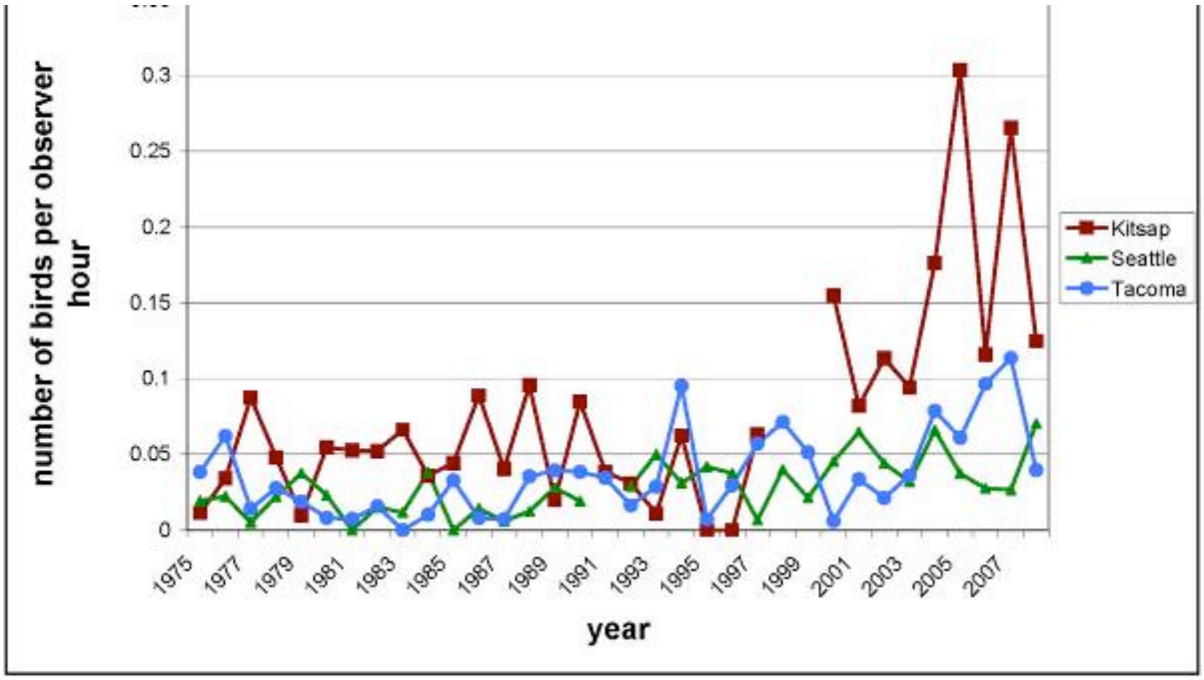
What do we still need to know about salmon stocks? We need to know to what degree habitat restoration is improving salmon population productivity at the population scale, what populations will be most impacted by climate change.

INDICATOR: Pileated woodpecker

Data and analysis provided by Joe Buchanan, Washington Department of Fish and Wildlife

Although using single species to assess landscape conditions or ecosystem health often has limited utility, some species may prove useful in this regard. The pileated woodpecker is considered a keystone species, in that its presence and use of a landscape creates habitat – through the presence of cavities it excavates – for other species. A long list of species use pileated woodpecker cavities for nesting and other purposes. In addition, this species likely accelerates the decay and conversion of snags to downed wood, therefore directly influencing recruitment of downed wood on the forest floor. Pileated woodpeckers have large home ranges (several hundred to perhaps 1000 acres). Consequently, they create opportunities for many species and potentially over large areas of the landscape.

Although the status of the pileated woodpecker has not yet been well investigated in this region, it is likely that the greatest impacts to its habitat in the region have occurred in the Puget lowlands, where most of the mature and older forest has been converted to younger forests or non-forest cover types. Many of these changes in forest cover occurred decades ago, and it would be possible to estimate the trend in Pileated Woodpecker abundance in response to those changes only by using models that link woodpecker occurrence with features of the environment that are key to woodpecker occurrence (e.g. snags). Current trends are not known, but may be stable in some areas. Where conversion continues to occur one would expect to see a decline in pileated woodpecker habitat.



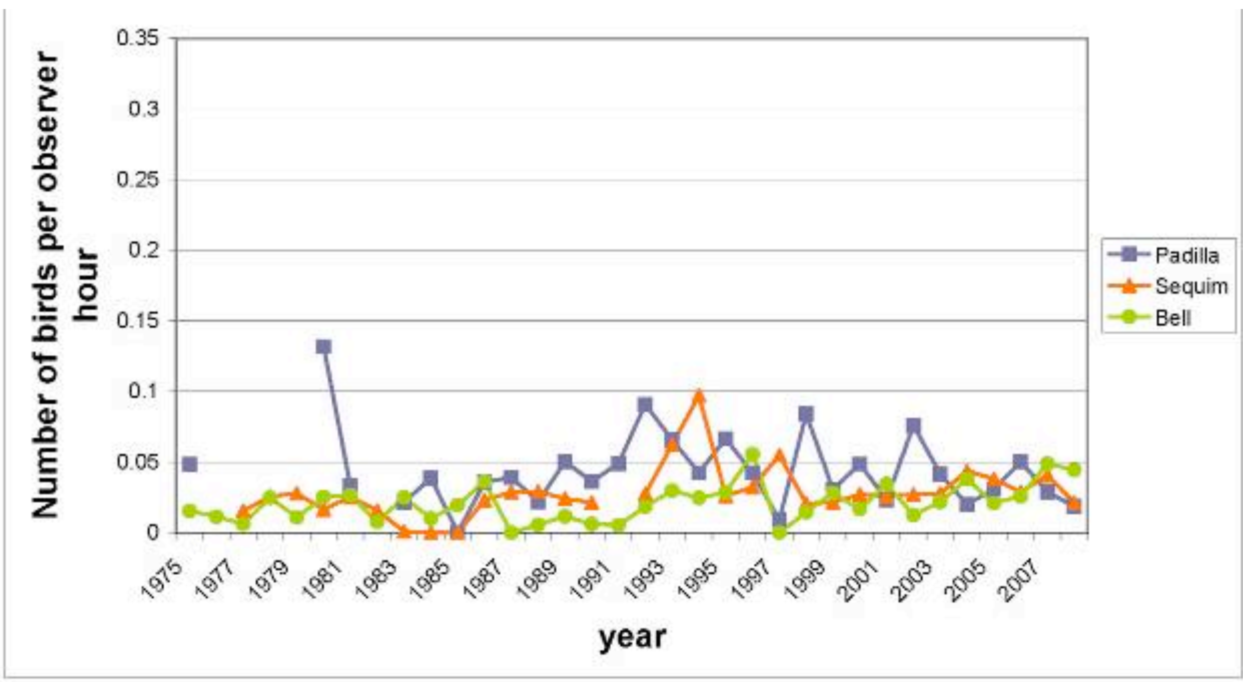


Figure SFW-9 a & b: Comparison of pileated woodpecker abundance (birds per party hour) at six Christmas Bird Counts (a: Kitsap, Seattle, Tacoma; b: Bellingham, Padilla Bay, Sequim) in the Puget Sound region, 1974-75 – 2007-08 In the top graph (a) it is apparent that more pileated woodpeckers were observed per party hour at the more rural Kitsap CBC location compared to the urban Seattle and Tacoma areas. Similarly, in the bottom graph the number of pileated woodpeckers reported per party hour was highest at Padilla Bay (rural) and lowest at Bellingham (urban). Proper interpretation of Christmas Bird Count data requires careful assessment of a variety of considerations (e.g., use of correction factors such as birds per party hour, the possibility that some individuals are double-counted).

What is the current status of pileated woodpeckers? The current status as depicted by Christmas bird counts shows that populations in the survey areas are relatively stable albeit quite variable through over recent years. It is likely that declines in pileated woodpeckers were most severe when old forests were first harvested and converted to younger industrial forests. Pileated woodpeckers appear to be tolerant of certain human activity provided that activity does not result in the loss of important habitat (forest patches) and elements (snags and downed wood) in the environment.

What does this mean for the Puget Sound ecosystem? If the human population of Washington is expected to double in the next 35-40 years and much of this population growth occurs in the Puget lowlands, this will result in a very substantial conversion of forest to non-forest cover. Without a comprehensive strategy to protect or recruit pileated woodpecker habitat, it seems likely that a decline in pileated woodpecker abundance will occur in the region. Given their role as a keystone species in the forest environment, a decline in pileated woodpecker abundance may signal declines in other species in the region.

What activities and management activities affect pileated woodpeckers? Pileated woodpeckers are probably most impacted by conversion of forest to non-forest and by the changes that generally occur when mature and older forests are replaced with younger forests which lack complex structure (e.g. large snags). These woodpeckers have large home ranges and in appear able to use small patches of habitat within that home range; there is probably a threshold beyond which the small size or isolation of suitable patches are no longer functional because it is no longer energetically feasible. Implementation of management actions that increase snag presence (directly, or via providing trees, like red alder, that decay rapidly when overtopped) should benefit the species.

What do we still need to know about pileated woodpeckers? What are our plans for future reports? Most of what we know about this species comes from studies conducted in forest landscapes. We need basic ecological information on pilieated woodpecker habitat use and home range size in various types of developing landscapes. This should help us understand the conditions needed by the species in suburban areas or the suburban-rural interface.

POSSIBLE FUTURE INDICATOR: Red-legged frog

Discussion provided by Timothy Quinn, Washington Department of Fish and Wildlife

The northern red-legged frog is one of the best sentinels or "canaries in the coal mine" that can tell us if we are reaching some of the recovery goals for the Puget Sound Partnership. Its persistence tell us about the fate of other wetland amphibian species, the availability and quality of fresh water, the connectivity between freshwater aquatic and upland forest habitat, and how climate change is affecting fragile wetland systems. Importantly, the red-legged frog serves as a flagship species that signals to the rest of the world how we in the Puget Sound region are responding to local ecosystem decline and worldwide amphibian extinction crises.

The red-legged frog is declining in the urbanizing areas across its range based on anecdotal observation form experts throughout the range of the species. This apparent decline is likely due to a variety of factors. Red-legged frogs breed in wetlands and often use forests in the adjoining uplands during late summer and fall. Development that reduces the abundance of wetlands and forests or disconnects wetlands from adjacent uplands is detrimental to the species. Introduced species such as the bullfrog and certain warm-water fish prey on the red-legged frogs or their tadpoles. In addition, changes in wetland hydrology associated with impervious surfaces and routing of stormwater (flood size and frequency during the breeding season) can also reduce survival. Finally, amphibians are in dramatic decline worldwide and although causes for this decline are complex (as above) disease has been implicated in many declines and may also be part of the story in the Puget Sound region, especially in populations stressed by other factors. We only have limited trend data for small areas of the state.

What do we still need to know about red-legged frog? What are our plans for future reports? We need a broad-scale survey that can be used to establish long-term. Ideally, these sites would be spread across a range of disturbance gradients (urban development, agriculture) that would allow us to track trends while learning more about species responses to stressors. Because this species is readily surveyed by citizen scientists, we need to train mobilize interested groups. WDFW has protocols for amphibian monitoring by citizen scientists.

POSSIBLE FUTURE INDICATOR: Pacific madrone

Discussion provided by Rex Crawford, Washington Department of Natural Resources Natural Heritage Program

Pacific madrone is sensitive to many of the common stressors found in the Puget Sound basin. As such, this species could serve as one indicator of the health of upland, dry forests near and along the Puget Sound shoreline.

Pacific madrone is native to the west coast. It occurs from southwestern British Columbia, where it is restricted to water-shedding sites on southeastern Vancouver Island, the Gulf Islands, and adjacent coastal mainland, southward through western Washington, Oregon and California in the coastal mountains and west slopes of the Sierra Nevada. It grows from near sea level to up to 3,000 feet (915 m). Pacific madrone's conservation status is considered globally secure by NatureServe and yet to be ranked in Washington.

Pacific madrone (*Arbutus menziesii*) is apparently declining throughout most of its range including Washington. Washington State University (WSU) extension estimates at least 20 years of noticeable decline in Washington. Under pre-European settlement conditions, madrone regenerated and grew in a landscape of intermittently occurring fires that reduced conifer overstory. The root systems of mature madrone trees survive fire and can resprout and re-establish more rapidly after fire than its most common associate Douglas-fir. Madrone also produces very large numbers of seeds that germinate following fire. Since the arrival of Europeans in North America, fire suppression has resulted in a reduction of the range of the Pacific madrone.

Increasing development in Pacific madrone habitat has contributed to overall decline. Madrone is extremely sensitive to change near the root crown. The species is also affected by sudden oak death, a disease caused by the fungus *Phytophthora ramorum*. Pacific madrone has low resistance to disease and is host to many pathogens that may lead to tree mortality. Pacific madrone can suffer from foliar diseases caused by a variety of fungal species and is susceptible to heart rot, butt rot and stem cankers. A fungal leaf blister disease caused by *Exobasidium vacinii* occurs on Pacific madrone leaves. This disease is not thought to significantly reduce tree growth, but it does reduce the aesthetic value of the tree. *Phytophthora cactorum* is a lethal canker disease of Pacific madrone that results in root and butt rots. Scotch broom (*Cytisus scoparius*) and gorse (*Ulex europaeus*), invasive, nonnative shrub species, compete with native forest vegetation for space, nutrients, and water.

What activities and management activities affect Pacific madrone (Arbutus menziesii)? Pacific madrone was sampled in Seattle/Puget Sound to gauge the effect of urban development and disturbance and facilitation of disease transmission and tree demise. Thinning stands, soil loss and compaction, and a host of urban impacts increased susceptibility to disease. Dense stands of Pacific madrone were less infected, and it was predicted that an increase in the proportion of seriously diseased trees would occur if forest stands were fragmented (Adams et al., 1995). Many local governments have addressed protection of Pacific madrone by enacting restrictions on grading and drainage alterations when madrone is present within development areas.

What do we still need to know about Pacific madrone (Arbutus menziesii)? What are our plans for future reports? Locations of known stands are currently limited to those in the Seattle Metro area and to forest vegetation plots. A more complete survey is needed to establish more precise distribution maps. There are no known future plans to survey madrone across its occurrence in the Puget Sound basin.

POSSIBLE FUTURE INDICATOR: Giant chain-fern

Discussion provided by Rex Crawford, Washington Department of Natural Resources Natural Heritage Program

Because giant chain-fern almost always occurs near the Puget Sound shoreline, it can serve as one indicator of impacts resulting from threats associated with terrestrial environments along the Puget Sound shoreline.

Giant chain-fern (*Woodwardia fimbriata*) occurs from Washington, in the Puget Trough area, south to southern California, and occurs as far east as Nevada. It ranges in elevations of 3 ft to 286 ft (1 to 87 m) in scattered locations in Jefferson, Pierce, Kitsap, Thurston and Mason counties. There has been one documented occurrence at about 3000 feet (915 m) in Washington's Olympic National Forest. The species occurs in mixed conifer-hardwood stands along moist stream banks and moist bluffs near salt water. It is uncommon inland of salt water in Washington. Moist bluffs it occupies are somewhat prone to slope failure. The species is limited in its distribution in Washington. Twenty-six occurrences have been reported; of these, 11 are historical records that have not been relocated for at least 35 years. In two cases the records are more than a hundred years old. Most occurrences have a small number of individuals. This species currently has sensitive status on the Washington Natural Heritage Program rare plant list; it is ranked as imperiled in the state because of its rarity. NatureServe ranks it as globally secure. At the present time we do not have monitoring data sufficient to detect trends in the species.

What activities and management activities affect giant chain-fern Woodwardia fimbriata? The giant chain-fern population in Washington is threatened by competition with invasive species and habitat loss from bluff erosion or stabilization associated with bulkheading. There may also be some collection pressure.

What do we still need to know about giant chain-fern Woodwardia fimbriata? What are our plans for future reports? To accurately assess status and trends, current population information should be updated throughout Jefferson, Pierce, Kitsap, Thurston and Mason counties. Additional inventory is also needed. The Washington Natural Heritage Program will continue to integrate new information on giant chain-fern and review its status and rank and report any changes in the biannual Washington Natural Heritage Plan.

4.3 Food Web Health – for future development

Discussion provided by Phil Levin, Sandie O'Neil and Jameal Samhouri, NOAA National Marine Fisheries Service

The Partnership's evaluation of species and food webs will require development of a framework for reporting on food web health. Indicators related to some or all of the following attributes of marine, freshwater and terrestrial ecosystems may be used to characterize food webs:

- primary production — how much "fuel" is available in the ecosystem;
- efficiency of energy flow through the ecosystem;
- food web structure — species abundance and composition (e.g. how many predators are

in the system);

- stress of the ecosystem (e.g. maintenance costs due to respiration);
- resilience — capacity of the ecosystem to absorb disturbance from threats without changing substantially .

Collectively, the flagship species indicators discussed above and indicators of these food web attributes will provide a robust view of food web health.

POSSIBLE FUTURE INDICATOR: Marine Food Web Health

Phytoplankton – This indicator is excellent at conveying information about the amount of fuel in the ecosystem, but also provides insights into the efficiency of energy flow and the resilience of lower trophic level species in the food web.
Jellyfish —This indicator is excellent at conveying information about how stressed the ecosystem is, but also provides insights into the resilience of the whole ecosystem and food web structure.
Bottomfish — This indicator is excellent at conveying information about about food web structure, but also provides information about the resilience of the ecosystem and the extent to which it is stressed.

These recommendations were informed in part by Samhouri et al. (in press).

4.4 What do we still need to know about monitoring Species and Food Webs in Puget Sound? What are our plans for future reports?

This report highlights the current state of knowledge about an important subset of species in Puget Sound. However, there remain large gaps in our understanding of the status and recent trends of many equally important species, species communities, and the diverse and dynamic relationships between species that form the foundation of healthy ecosystems. Even for those flagship species for which there has been a significant investment of research and management resources (e.g. orca and salmon), many questions remain about the effects of climate change, increased human populations and associated development, and ongoing land-use practices on the population and condition of these species. At the opposite end of the spectrum, there are still many very poorly understood species and species communities (e.g. nearshore marine communities) that are equally important to the health of Puget Sound and should be included in future monitoring and management efforts. To identify effective management actions of broad benefit to species, the Partnership will need to focus on improving assessment of species and species communities to develop a better understanding of the current status of species.

With respect to the species presented in this report, we still have a lot of questions. What are the nutritional requirements for a "recovered and sustainable" southern resident orca population? What are the causes of decline of the Cherry Point stock of Pacific herring and why has there been a Sound-wide shift in herring age structure? What are the effects of harvest, hatchery practices, and west coast fisheries on salmon?

Critical for ensuring the viability of species and food webs, understanding the stressors that negatively affect species, communities and their interactions will help us identify management actions targeted at improving the health of Puget Sound. Invasive species, habitat loss and degradation associated with development; climate change, degraded water quality and altered hydrologic regimes all affect the individual species that comprise communities and define food webs. As native habitat continues to be converted to development, how do plant and animal species respond to different types of altered land use and development practices? How sensitive are species to fragmentation of the landscape and disruption of connections between different habitat types? Determining the degree to which specific stressors affect species populations – their abundance, condition, and relationships with other species — will inform the Partnership's future reporting efforts.

In addition to understanding the health of individual species, future reporting efforts will contribute to improving our understanding of the ecological function of individual species, with respect to both ecosystem structure and processes and food web health. For example, flagship species can play critical roles in supporting the health of Puget Sound as keystone or umbrella species in specific ecosystems, as indicators of certain community types or environmental conditions, or as iconic figures that provide a focus for raising awareness and stimulating action for broader conservation efforts.

5. Habitat

The Puget Sound basin encompasses a varied and dynamic mosaic of marine, nearshore, freshwater and upland habitats for a diversity of species. A healthy ecosystem retains plentiful, productive habitats that are linked to support species and food webs. The Puget Sound Partnership's interests in the region's habitats are expressed as one of six goals for ecosystem recovery: " A healthy Puget Sound where freshwater, estuary, nearshore, marine, and upland habitats are protected, restored, and sustained."

Since statehood in 1889, Washington has lost an estimated:

- 70 % of its estuarine wetlands;
- 50 % of its riparian habitat; and
- 90 % of its old-growth forest.

Together, these native habitat types have been considered among the most diverse and productive in the state.

In reporting the status and trends of Puget Sound's habitats, the Partnership is focusing on the extent of the human footprint and on the extent and condition of focal habitats. These focal habitats include a wide array of upland ecological systems (e.g. oak grassland), which are groupings of plant associations that occur within landscapes with similar ecological processes. There is also an array of aquatic ecological systems with similar process forming attributes (e.g. eelgrass beds).

What is the current status of habitat in the Puget Sound basin? The Puget Sound basin has experienced substantial loss and degradation of native ecosystems types over the last 150 years. Much of the activity has occurred in the Puget Lowlands (below 1000 ft elevation), to provide living space (houses and associated infrastructure) for people. From 2001 to 2006, developed lands increased about 3 % with nearly two-thirds of that being impervious surface. This translates into a loss of about 10,700 acres of forest types and 4,300 acres of agricultural land over the five-year period. As of 2006, approximately 25 % of the Puget Lowland was in urban use and agriculture. Some ecosystem types, particularly those in the lowlands and along riverine and marine shorelines, have experienced more change than others. Less obvious are changes in the conditions of habitat. Much of the old forest that dominated the region in the early 1900s has been converted to younger commercial forests.

What affects the condition of habitats in the Puget Sound ecosystem? Land development is a major determinant of the extent and condition of Puget Sound habitats. Most development continues to occur in the Puget Sound lowland but is not limited to relatively undisturbed lands. Agricultural lands also appear to declining in support of more intensive land uses. In addition to development, climate change, pollution and non-native species will also affect habitat quality and quantity in the region.

How does the status of habitats affect other aspects of the Puget Sound ecosystem?
In addition to the direct effects on living space for imperiled fish and wildlife species and other valued elements of biodiversity, land conversion and use can have disruptive and degrading effects on ecosystem processes, many of which are important to maintaining a high quality of life for people. Some of these effects include an increase in flooding; reduced recharge of groundwater aquifers important for drinking, irrigation of crops, and recreation; increased transport of toxic and persistent pollutants to streams and marine areas; increased concentrations of pathogens affecting human and wildlife health; and more limited recreational opportunities. Loss of the working lands (agriculture and forests) may affect the quality, availability, and cost of food and wood fiber while decreasing the economic and cultural diversity of the region. Alteration of shoreform can alter important nearshore processes such as sediment delivery and routing as well as decrease food and habitat for the many nearshore dependent species.

5.1 Extent of Ecological Systems

INDICATOR: Conversion of upland habitats

Data and analysis provided by John Jacobson, Washington Department of Fish and Wildlife;Rex Crawford, Washington Department of Natural Resources Natural Heritage Program; and Darby Veeck, Washington Department of Ecology

The status and trends of upland habitat conversion was determined by investigating the developed areas, impervious surfaces, and agricultural areas within the Puget Sound basin. These areas were identified from National Land Cover Data (http://www.epa.gov/mrlc/), with the most recent data being from 2006. Forest Zones, Action Areas and Water Resource Inventory Areas (WRIA) were used as analysis units to summarize these conversion indicators (Hab-2a,b,c, Hab-3a,b,c, Hab-4a,b,c). The Forest Zones (Hab-1) provided a coarse grouping of ecological systems, the WRIAs provided a watershed view, and the Action Areas provided an ecological/local government view.

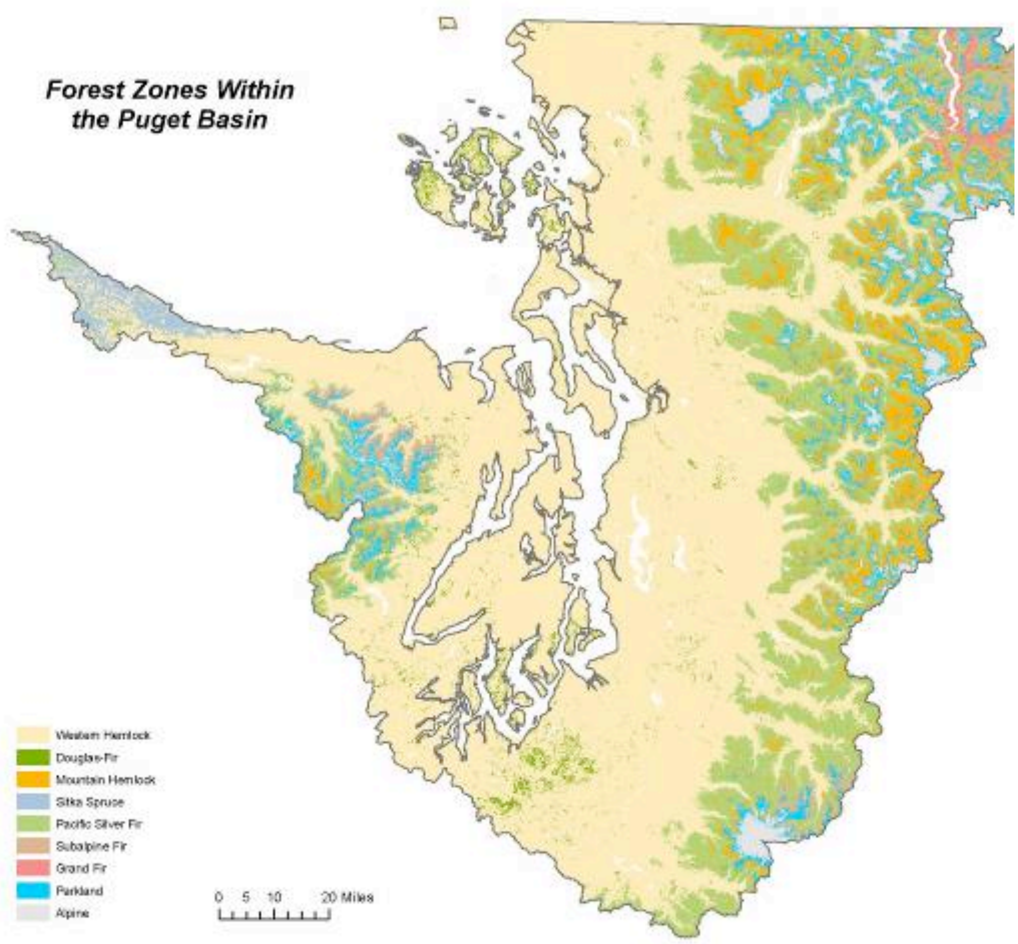


Figure Hab-1. Forest Zones within the Puget Sound basin

Status – Basin Wide:

Nearly 10 % of the Puget Sound basin is developed, with about a third of that being impervious surface. Agriculture accounts for around 4 %, therefore nearly 14 % of the Puget Sound basin has been converted from natural ecological systems since pre-settlement

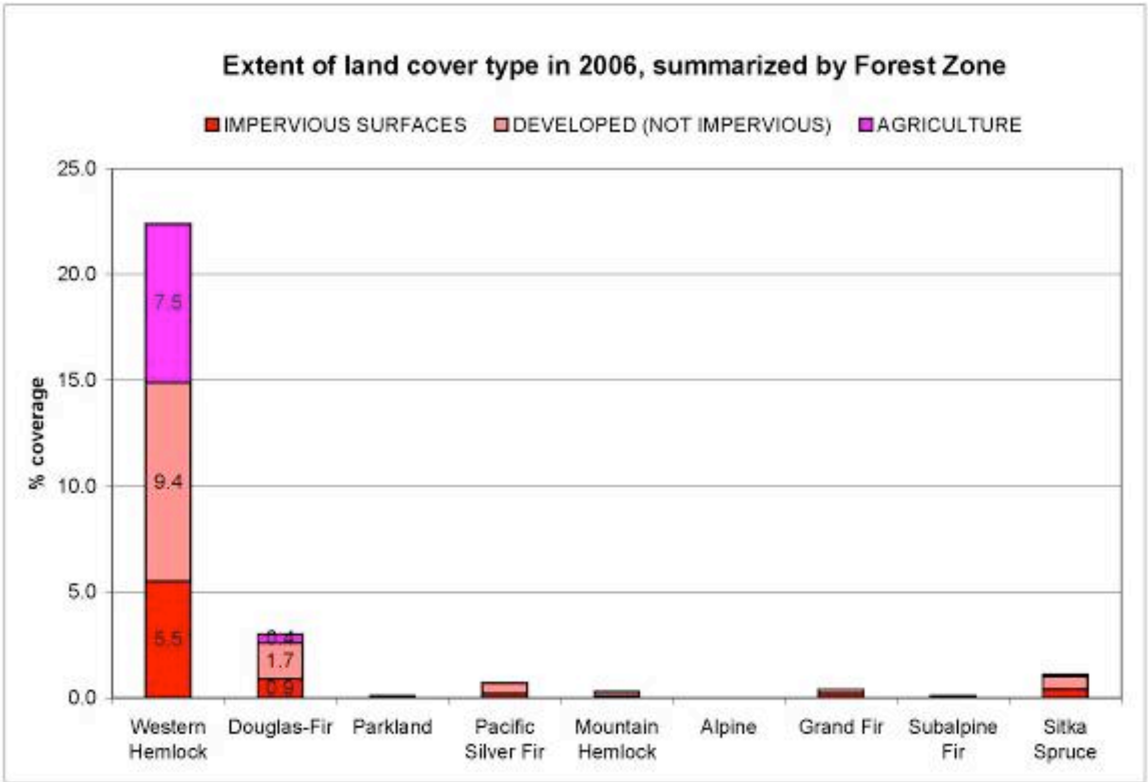


Figure Hab-2a. Status – Extent of Land Cover Type in 2006, Summarized by Forest Zones The Puget Sound basin includes nine Forest Zones (Henderson and Peter 1985); however the majority of the Puget Basin is classified as the Western Hemlock Forest Zone. This zone covers 61 % of the basin, and primarily represents the Puget Lowland region under 1,000 feet in elevation. The landcover of the Puget Lowland was one of the most changing landscapes within the country during the period of 1973 to 2000. The Puget Lowland ecoregion has the highest overall change rate of all the ecoregions studied in the western United States (http://landcovertrends.usgs.gov/west/eco2Report.html). At higher elevations, the Pacific Silver Fir Zone covers 17 % of the Basin, but all other zones cover less than 10 % area.

Fifteen percent of the Western Hemlock Forest Zone is developed, with about a third of this developed area being impervious surface. Additionally, agriculture accounts for 7.5 % of this zone, therefore nearly 25 % of the Western Hemlock Forest Zone has been converted from natural ecological systems since pre-settlement. The other zones existing at elevations greater than 1000 feet are considerably less developed, have impervious surface amounts less than 1 %, and have not been converted to agriculture in significant amounts.

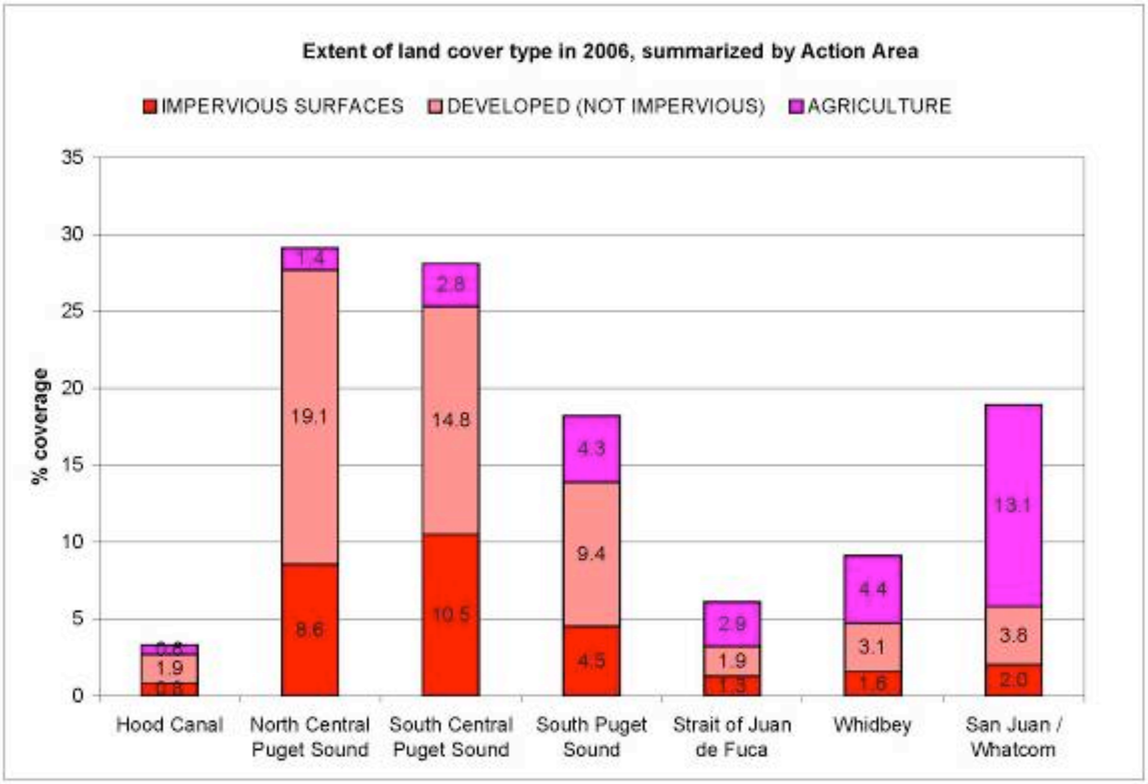


Figure Hab-2b. Status – Extent of Land Cover Type in 2006, Summarized by Action Areas. The North Central Puget Sound, South Central Puget Sound, and South Puget Sound Action Areas had roughly 28, 25, and 14 % development, respectively. These areas also had the highest amounts of impervious surface at roughly 9, 10, and 5 %, respectively. Other Action Areas had less than 6 % development and 2 % impervious surface. Noticeably, the San Juan / Whatcom Action Area had 13 % agricultural land compared to at most 4 % for the other Areas. It is important to note that four of the seven Action Areas have 18 to 29 % conversion into developed land and agricultural land since pre-settlement.

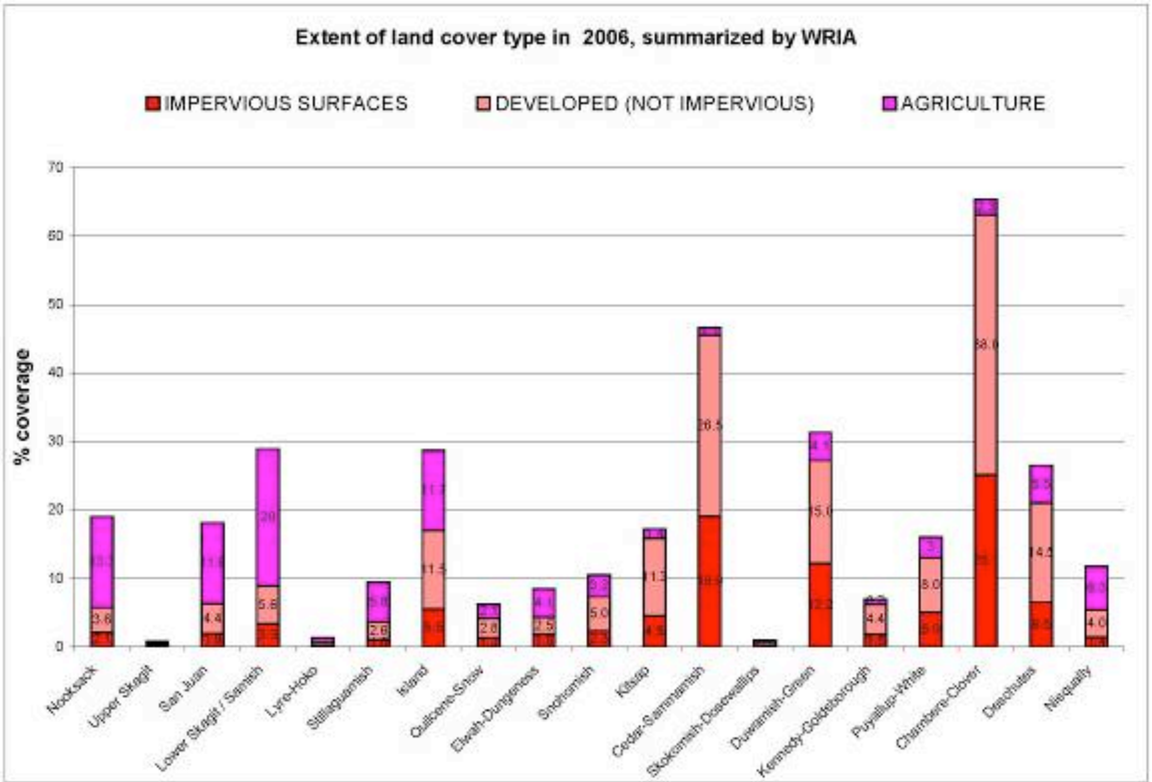


Figure Hab-2c. Status – Extent of Land Cover Type in 2006, Summarized by WRIAs. The Chambers-Clover, Cedar-Sammamish, and Duwamish-Green WRIAs had approximately 63, 45, and 27 % development, respectively. These WRIAs also had the highest amounts of impervious surface at approximately 25, 19, and 12 %, respectively. Other WRIAs had less than 17 % development and 7 % impervious surface. The Lower Skagit/Samish WRIA had 20 % agricultural land, and the Nooksack, San Juan, and Island WRIAs had similar amounts of agricultural land at around 12-13 %. All other WRIAs had at most about 6 % agriculture.It is important to note that eight of the 19 WRIAs have from 17 to 65 % conversion into developed land and agricultural land since pre-settlement.

2001 to 2006 Trends – Basin Wide

Developed land increased about 3 %, with nearly two-thirds of that being impervious surface. Agricultural land decreased by around 1 %, suggesting that there was a conversion of agricultural land to developed land. Indeed, there were nearly 4,300 acres of agricultural land converted to development, and nearly 17,000 acres have been converted from 1991 to 2006. Also important is about 10,700 acres of forest were converted to development, and about 57,000 acres have been converted from 1991-2006. With nearly 25 % of the Puget Lowland already in development and agriculture, sustained increases in development of even 3 % every five years will put strains on important ecological systems and habitats.

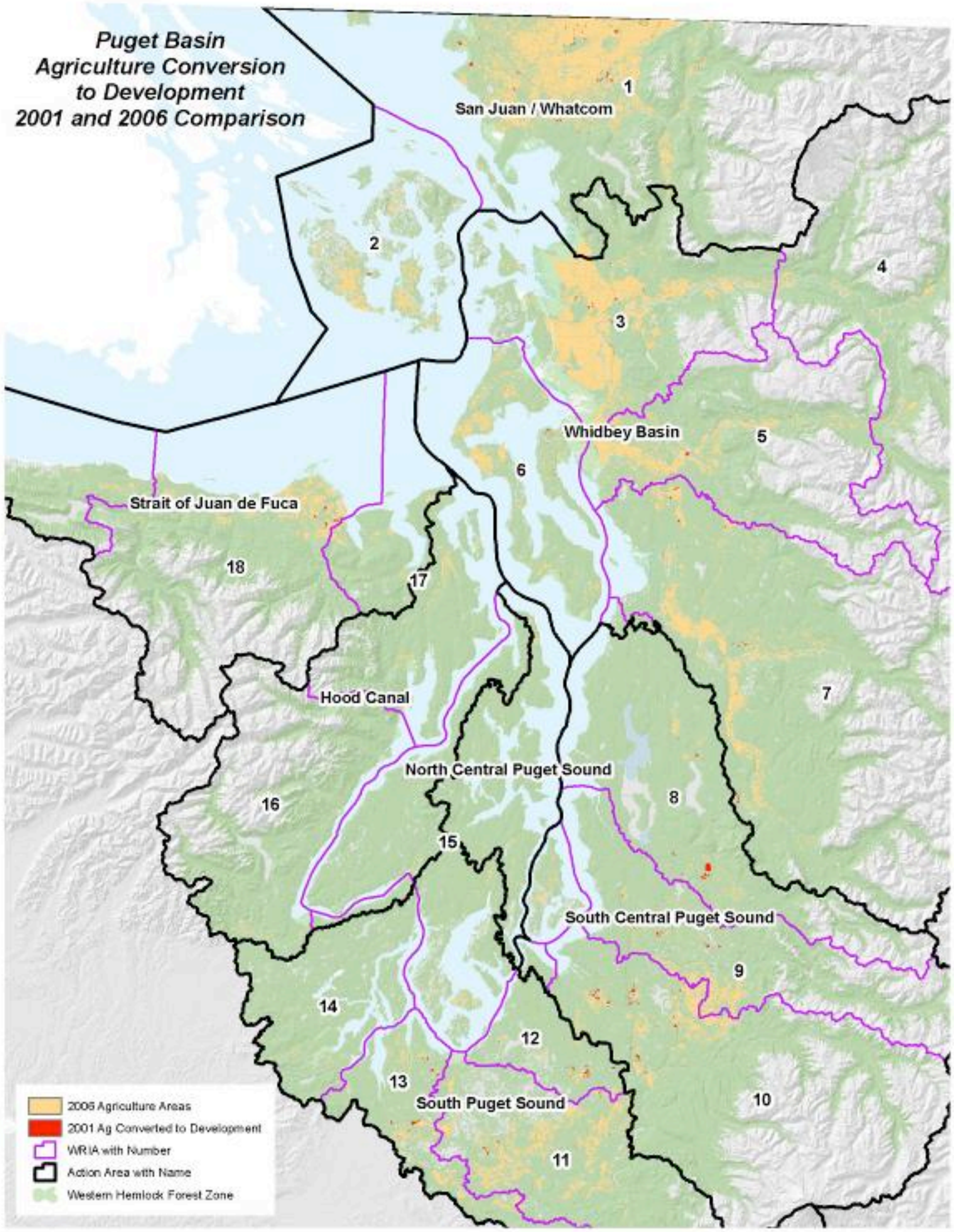


Figure Hab-3a. Agriculture conversion to development in the Puget Sound basin, 2001-2006 comparison

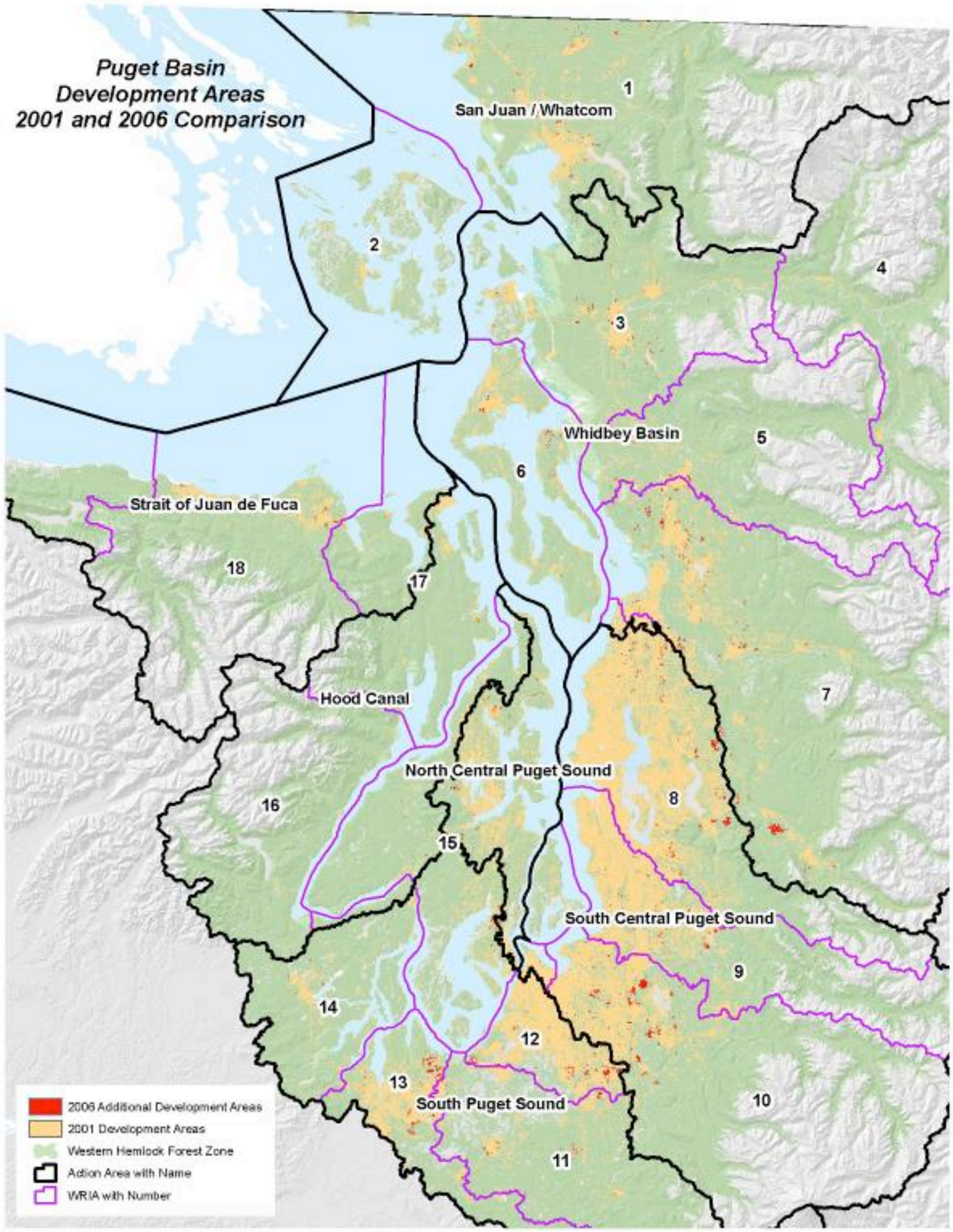


Figure Hab-3b. Development in the Puget Sound basin, 2001-2006 comparison

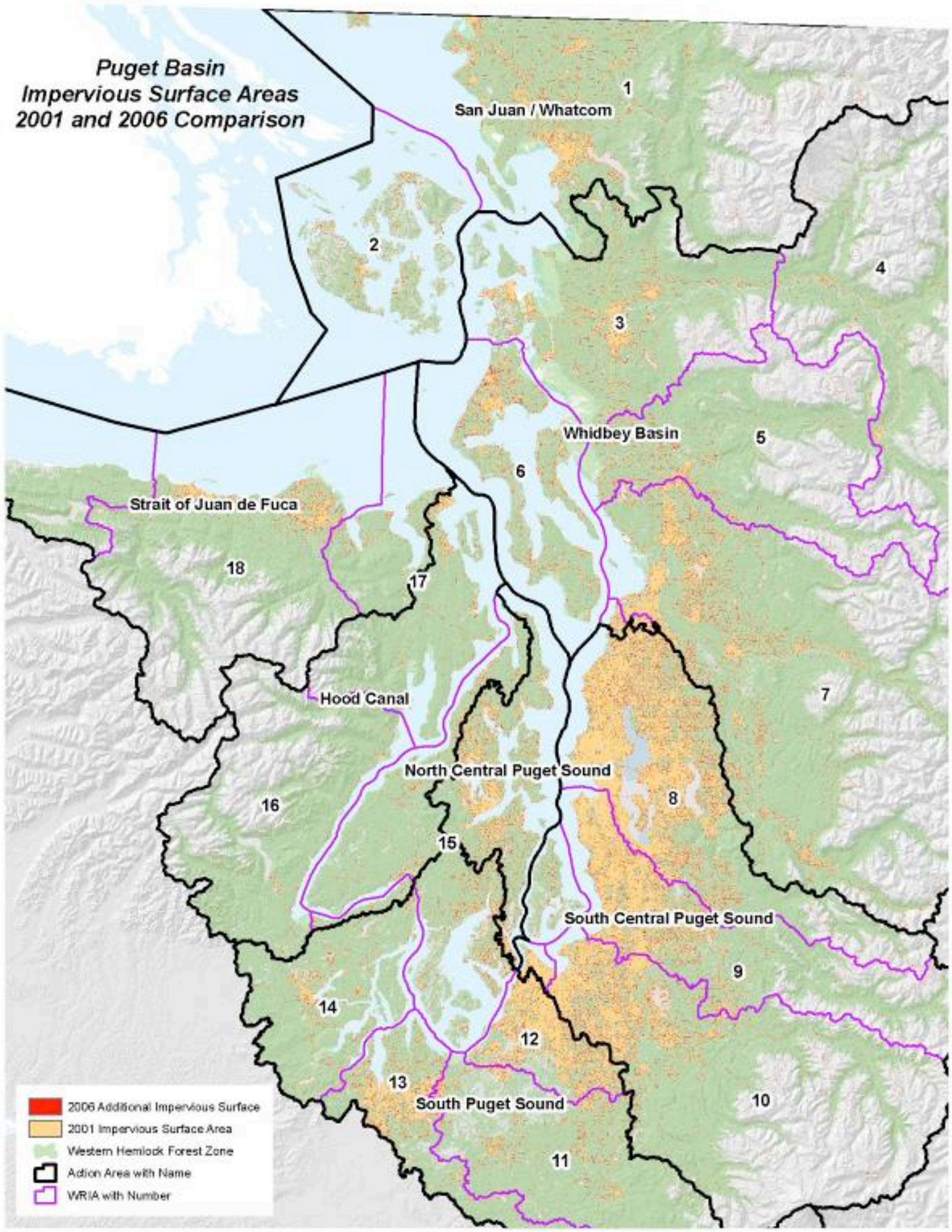


Figure Hab-3c: Impervious areas in the Puget Sound basin, 2001-2006 comparison

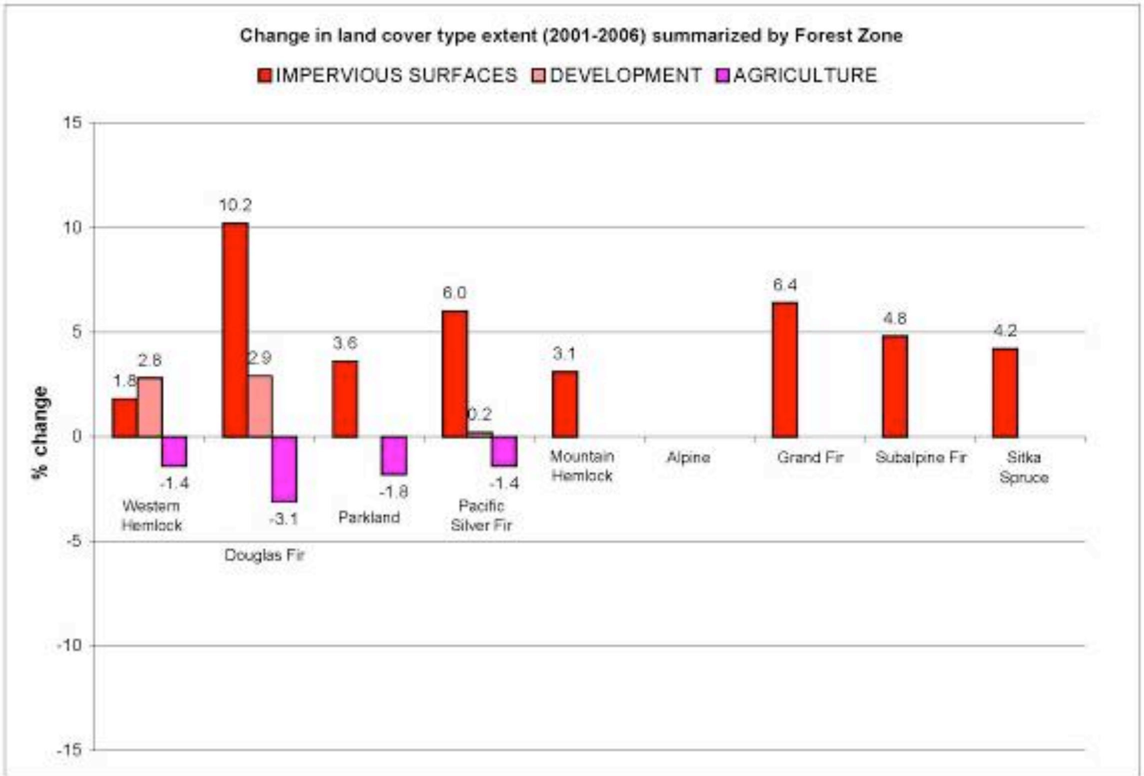


Figure Hab-4a: 2001 to 2006 Trends – Change in Land Cover Type Extent, Summarized by Forest Zones An increase of nearly 3 % in developed land occurred almost exclusively in the Puget Lowland areas below 1000 feet elevation. Within many of the Forest Zones there was a greater increase in impervious surface than development over that time period, suggesting that open/natural areas within existing developed areas experienced further development into impervious surfaces, possibly within Urban Growth Areas (UGAs). Agricultural land decreased from around 1 to 3 % in mostly the Puget Lowland where nearly all of the agricultural land exists.

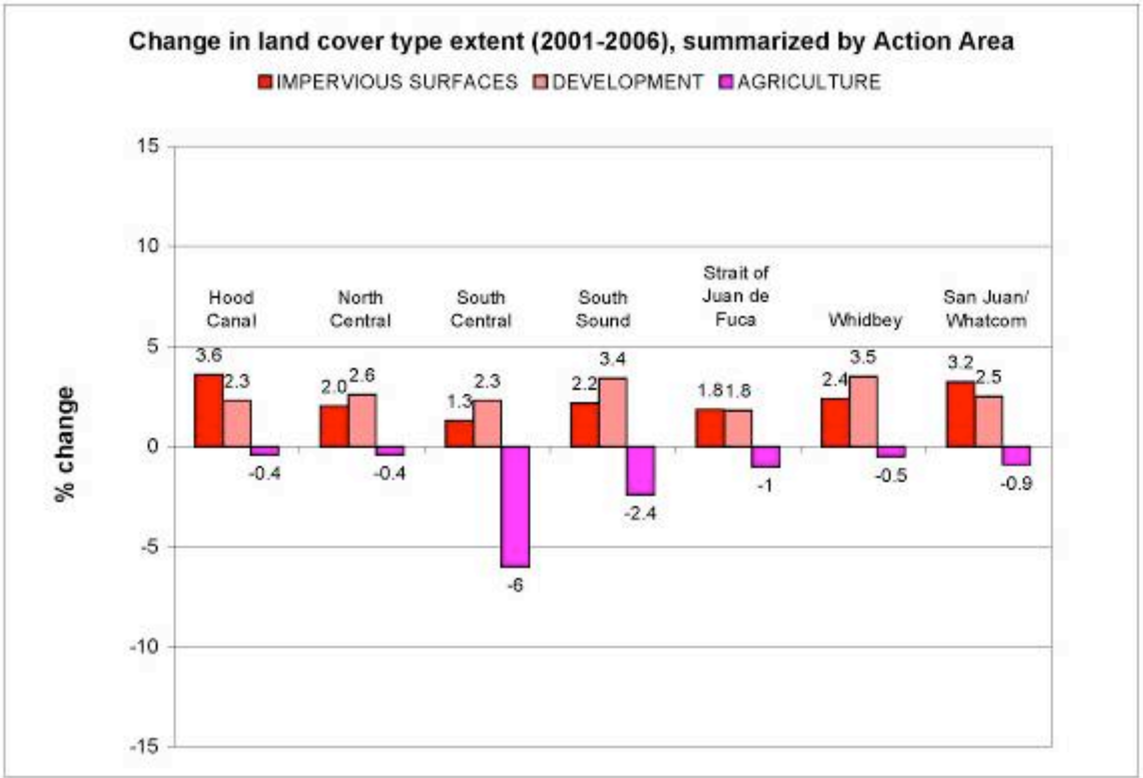


Figure Hab-4b: 2001 to 2006 Trends – Change in Land Cover Type Extent, Summarized by Action Areas The increases in developed land and impervious surface were fairly consistent across the Action Areas, ranging around 2 to 3 %. However, the San Juan and Hood Canal Action Areas had greater increases in impervious surface than development. This suggests that open/natural areas within existing developed land experienced further development into impervious surfaces, possibly within UGAs. Agricultural land decreased from about 1 to 6 %, with the 6 % loss within the South Central Puget Sound Action Area.

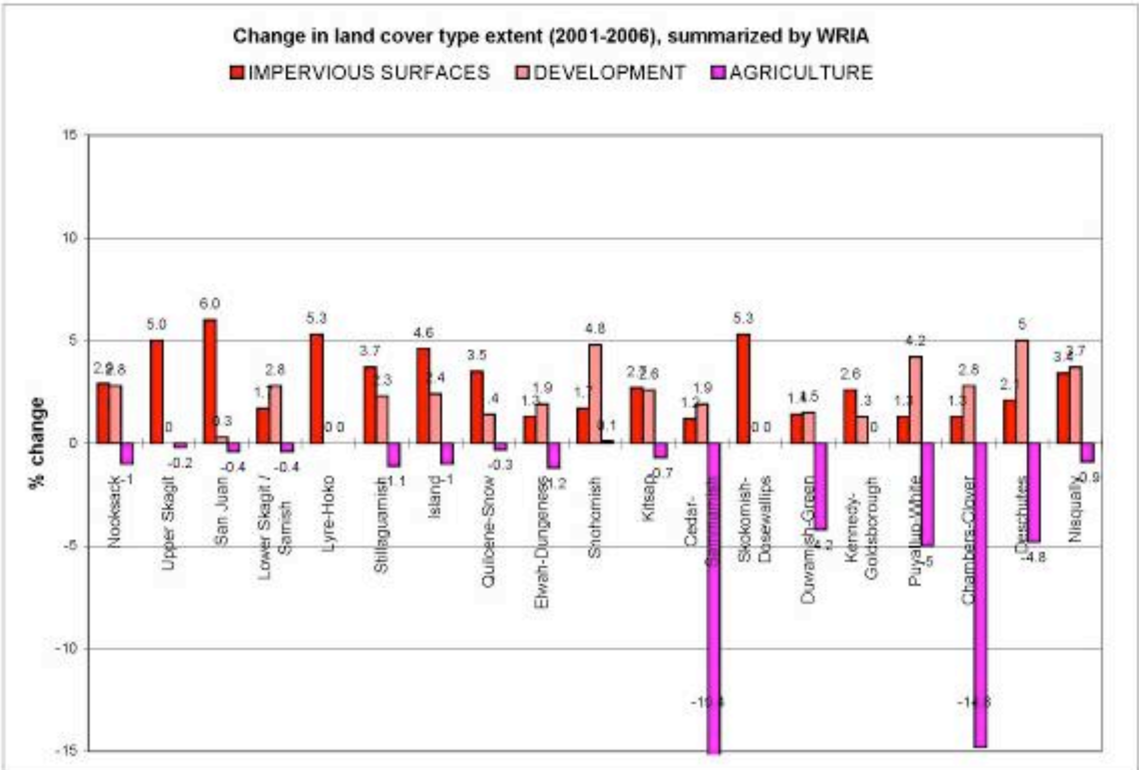


Figure Hab-4c. 2001 to 2006 Trends – Change in Land Cover Type Extent, Summarized by WRIAs The increases in developed land ranged from 0 to 5 %, and for impervious surface from around 1 to 6 % for the WRIAs. The Upper Skagit, San Juan, Lyre-Hoko, and Skokomish-Dosewallips WRIAs had significant impervious surface changes around 5 % relative to development change around 0 %. This again suggests that open/natural areas within existing developed areas had further development into impervious surfaces, possibly within UGAs. Agricultural land decreased from about 1 to 5 % in most WRIAs, but the Chambers-Clover and Cedar-Sammamish WRIAs had a decrease of about 15 and 20 %, respectively. These two WRIAs are also where about 45 and 63 % development existed in 2006, respectively, suggesting that a substantial amount of agricultural land was converted to developed land in the last few years.

What is the current status of upland habitat conversion? What affects upland habitat conversion? There has been substantial conversion and alteration of uplands over the last 50 years within the Puget Sound basin, although the rate of conversion from 2001 – 06 appears to have slowed from earlier periods. Increased awareness of the impacts to the Puget Sound ecosystem, and economic conditions that reduce development rates may have contributed to lower rate of conversion. In addition, the emphasis to develop within urban growth areas may also be contributing to reducing the rate of urban sprawl. Although upland conversion rates slowed in the most recent five-year period, forecasts for human population growth in the Puget Sound basin raises concerns for maintaining functioning upland ecosystem types, especially within the Puget Lowlands.

POSSIBLE FUTURE INDICATOR: Extent of focal upland habitats

Data and discussion provided by Rex Crawford, Department of Natural Resources Natural Heritage Program

Focal systems can be defined as systems for which we often have indirect evidence of sharp decline in extent and or quality and that warrant further investigation. These potential declines can be explored by focusing monitoring effort to better determine issues affecting the system, the extent and implications of the declines, trends through time, and solutions to significant threats.

Example – Oak Grassland Habitats. The Willamette Valley Upland Prairie and Savanna, and North Pacific Oak Woodland ecological systems (Oak Grassland habitats) are commonly found together on dry shallow bedrock soils or deep, gravelly, glacial outwash deposits, historically ranging from southern British Columbia south to the Willamette Valley in Oregon. These habitats contain numerous rare and endangered wildlife species and more than 60 plant species particular to this system. The sensitivity of the Oak Grassland habitats can serve as an important indicator of biodiversity health in the Puget Basin. Nearly all of the approximately 31 thousand acres of the Oak Grassland habitats are located in the South Puget Sound region (Figure Hab-4) and in the San Juan Islands. The South Puget Sound region supports the few remaining high quality areas of these habitats from throughout its global range.

Figure Hab-5: Current and historic extent of Oak Grassland habitats in the Puget Sound basin

The pre-settlement extent of the Oak Grassland habitats in the Puget Sound basin is estimated to have been about 121 thousand acres, by mapping the extent of soil types associated with these habitats. Therefore, nearly 75 % of the Oak Grassland habitats have been converted to other land use. Also, most of the remaining 25 % of these habitats are in fair to poor ecological condition.

The primary causes of the substantial decline in the Oak Grassland habitats are from conversion to development and agricultural land, cessation of Native American burning, and invasive plant species. These threats have the potential to decrease the current extent and degrade the ecological condition of the remaining Oak Grassland habitats.

Future Plans for Status and Trend Analysis of Focal Upland Habitats. There are 42 upland ecological systems within the Puget Sound basin, which can be related to 21 mid-level classes for more mid-scale analyses and easier display purposes (Figure Hab-6). Currently the Oak Grassland system is one of the few that has been modeled to provide an estimate of the pre-settlement status, and thus allow an analysis of the trend for this system to the present. However, there are additional imperiled ecological systems within the Puget Sound basin including: North

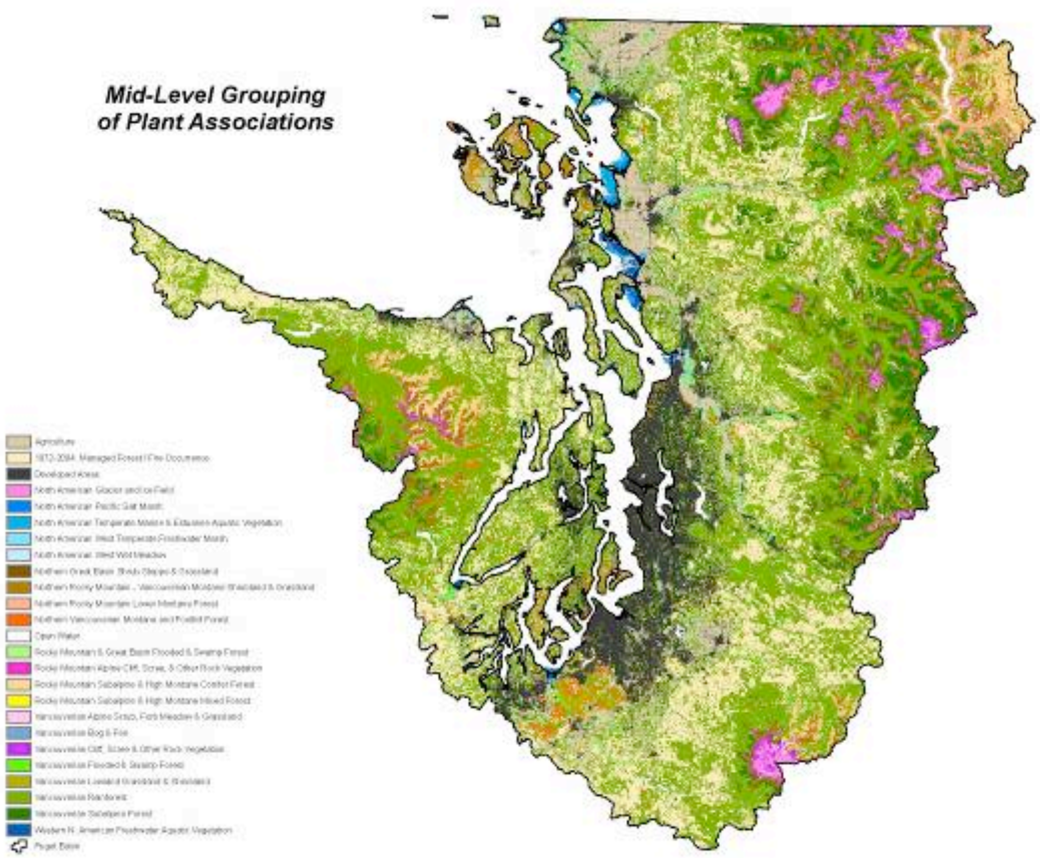


Figure Hab-6: Mid-level Grouping of Plant Associations within the Puget Basin, as a Mid-level Relationship Display of Representing the 42 Ecological Systems.

Pacific (NP) Lowland Riparian Forest and Shrubland, NP Dry Douglas-Fir Forest and Woodland, NP Oak Woodland, Willamette Valley Wet Prairie, NP Hardpan Vernal Pool and Willamette Valley Upland Prairie and Savanna. These systems as well as other upland habitats such as Old Forest, are important to understanding the state of habitat across the landscape. One way to address the need for information on ecological systems in an economical fashion is to monitor land cover/use using a multi-scale approach. This type of monitoring uses (relatively cheap) satellite data to help identify problem areas which can then assessed using more intensive (and expensive) methods such as aerial photography, and ground reconnaissance.

We have general status information on many imperiled focal systems (see species and food web indicators) from a variety of data sources and only recent change data. Some of these focal systems (e.g., Oak and grassland habitats) likely require a more detailed status review and better trend information that can reduce uncertainty associated with current and future conditions and help identify threats and specific solutions to those threats. In addition, it may be useful to map/model the historical extent of the system (e.g., Oak and grassland) as a way of calibrating threat in ways useful to policy makers.

Focal systems represent an ecologically sound method for depicting the environmental complexity and diversity of the Puget Sound Basin. System diversity is related to species diversity. Moreover, some species rely exclusively on specific systems. When the system is lost, the species associated with that system can also be lost. One common approach to conservation of systems is to ensure representation (all system types are conserved), redundancy (multiple examples of each system type are conserved) and resiliency (each example of each system type is large enough to act as a system and withstand human and natural disturbances over the long-term). Representation, redundancy, and resiliency require knowledge about the status and trends of these systems.

POSSIBLE FUTURE INDICATOR: Fresh and marine riparian vegetation

Protection of riparian vegetation via buffers is a common strategy to protect important ecological functions (e.g., Forest and Fish Agreement, President's Forest Plan). Given that landowner are asked/required to provide for these functions, and that condition of the riparian forest is useful indicator of those functions, tracking the condition of these areas may be an important indicator. Like focal upland systems, this indicator could be tracked via satellite and where more detailed information is required, existing aerial photography (NAIP data) in an economical fashion.

INDICATOR: Intertidal wetland loss

Data and analysis provided by PSNERP (Puget Sound Nearshore Ecosystem Restoration Project)

Intertidal wetlands are one of the Puget Sound habitat types most threatened by human activities. Locally, development pressures associated with a growing human population in the Puget Sound basin and the maintenance of a viable economy threaten the extent and quality of intertidal wetland habitats. Globally, warming of the atmosphere is driving local changes that impact intertidal wetlands such as changes in sea level, frequency and severity of habitat-shaping storms, volume and timing of freshwater input, and changes in water temperature and nutrient cycling. To understand changes in these critical habitat types and to begin to prioritize management actions, the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP) recently completed an intertidal change analysis. PSNERP delineated four classes of intertidal areas using current and historic data sources: tidal freshwater (TF), oligohaline transition (OT), euryhaline unvegetated (EU), and estuarine mixing (EM). Table Hab-1 presents the intertidal and wetland categories in the data sources that were binned into the four classes used in the change analysis. For the euryhaline unvegetated class, areas and percent change are reflect only those areas of EU found in areas of the Puget Sound nearshore where delta processes are predominant.

Gain or loss from historic conditions is presented for Puget Sound sub-basins as defined by the Puget Sound Nearshore Restoration Project (Figure Hab-7). Changes from historic conditions (Figure Hab-8) are represented by the difference between the sum of the area of the current intertidal area and the sum of the area of the historic intertidal area, by class, as a percentage of the historic area. A gain in the current intertidal area is positive; a loss is negative. If the historic intertidal area was 0, then the default % Gain or Loss value was 100%. If the current intertidal area was 0, then the % Gain or Loss default value was -100%.

	Change Analysis Intertidal Classes			
	Tidal Freshwater	Oligohaline Transition	Euryhaline Unvegetated	Estuarine Mixing
Intertidal/Wetland Categories in Contributing Data Sources	• Tidal-fresh channel • Riverine-tidal emergent wetland • Riverine-tidal forested wetland • Riverine-tidal scrub-shrub wetland	• Channel (in areas where appropriate) • Estuarine scrub-shrub wetland	• Areas labeled "Intertidal" • Sub-tidal channel • Cobblestone, below low-water • Cobblestone, below shoreline • Gravel • Gravel, below low-water • Gravel, below shoreline • Mud, below shoreline • Reef • Sand • Sand, below low-water	• Estuarine emergent wetland channel • Estuarine emergent wetland • Submerged estuarine emergent wetland • Closed lagoon enclosed by estuarine emergent wetland • Open lagoon enclosed by estuarine emergent wetland • Closed lagoon • Open lagoon

Table Hab-1: Intertidal and wetland categories contributing to the change analysis of intertidal classes

What is the current status of intertidal wetlands? The Puget Sound region has experienced dramatic losses of intertidal wetland types across much of the Basin in general and almost all Oligohaline Transition and Tidal Freshwater types in the last 150 years. Much of this loss can be attributed to the legacy of European settlement of the region, which was focused on development of the waterways for economic development. Loss of intertidal wetlands has contributed to the decline of Chinook salmon, which in turn may be affecting other food web elements such as Orca and other marine mammals. The importance of these wetlands has been recognized by much of the restoration community, who have initiated large-scale restoration projects in major river estuaries.

What does this mean for the Puget Sound ecosystem? Loss of intertidal wetlands has contributed to the decline of species associated with this type of habitat including some icons such as the Chinook salmon. Declines of Chinook salmon affect other food web components such as the Orca and other marine mammals. Besides providing habitat for a many species, wetlands perform many ecosystem functions from which humans benefit. Wetlands support high productivity, which contributes to the base of the food web. Wetlands accelerate nutrient recycling, help process toxic compounds and pathogens, and store carbon. The importance of intertidal wetlands has been recognized and efforts to restore estuaries are increasing in the region.

Figure Hab-7: Puget Sound Nearshore Restoration Project (PSNERP) Subbasins

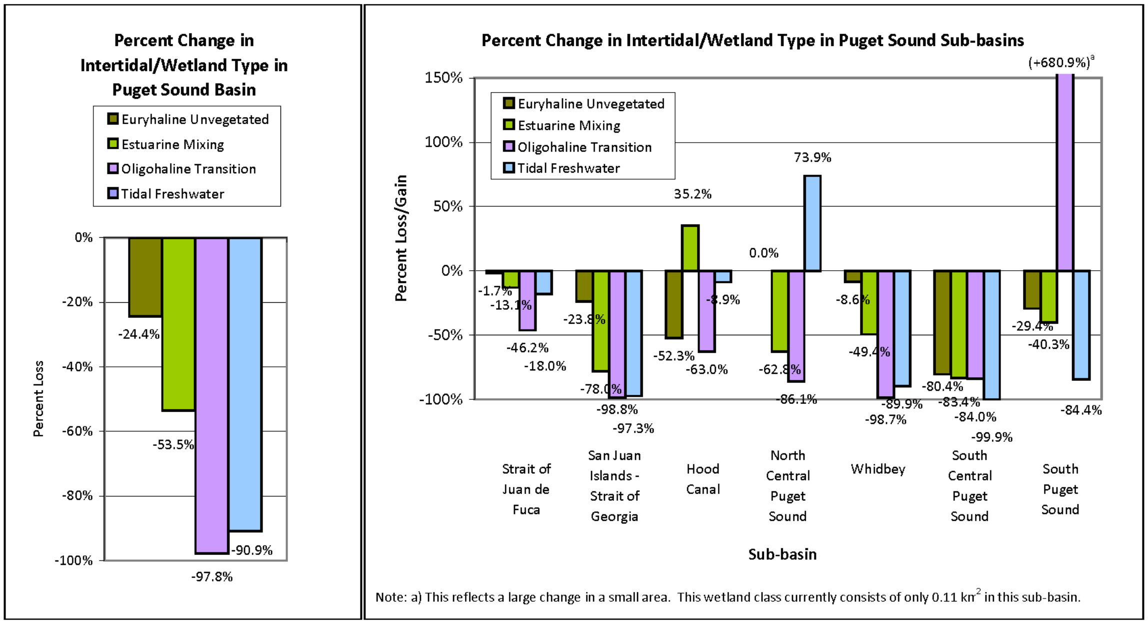


Figure Hab-8. Intertidal Wetland Change, 1850s -2006 in Puget Sound Basin and Subbasins

INDICATOR: Marine shoreform change and shoreline alterations

Data and analysis provided by Puget Sound Nearshore Ecosystem Restoration Project (PSNERP)

The shoreline of Puget Sound is shorter now (2000-2006) than it was historically (1850s-1890s), reflecting a simplification of its complex geology. Total shoreline length of all shoreforms combined declined by ~15% Sound-wide (Figure Hab-9). Additionally, the composition of geomorphic shoretypes has changed with significant gains in artificial (primarily nearshore fill) and losses in delta and embayment (barrier estuaries, barrier lagoons, closed lagoon marshes, and open coastal inlets) shoretypes. Shoreform change has been dominated by either a transition to artificial or the complete disappearance as a recognizable shoreform (i.e. filling a lagoon).

Table Hab-2 illustrates that shoreline alterations are pervasive throughout Puget Sound: armoring constitutes as much as 27% of the shoreline length, nearshore roads (occurring within 25m of the shoreline) 7.9%, and tidal barriers 10.5%. Tidal barriers are highly correlated with deltas (69%) where we have also identified significant wetland and intertidal loss. These losses are particularly striking in the upper-estuary, tidal freshwater and oligohaline transition classes, though are also notable in estuarine mixing and euryhaline unvegetated wetlands.

What is the current status of shoreform and shoreline alteration? What alters shoreforms and shorelines? Habitat loss often refers to the process of conversion of habitat to other uses (e.g., forest to agriculture, or development) under the assumption that the feature is not lost altogether but rather modified to the point of relative dysfunction to previous occupants. Development along Puget Sound over the last 150 years resulted in the true loss of shoreline (by ~15% of its original length), as well as modification of much of the remaining shoreline and shoreform features. Most significant is the increase in artificial types (nearshore fill) at the expense of barrier estuaries, barrier lagoons, closed lagoon marshes, and open coastal inlets. Nearly 27% of the shoreline length has been armored and 7.9% of the area within 25m of the shoreline consists of roads and tidal barriers. While most alterations to nearshore are heavily regulated, new and replacement shoreline armoring is still relatively commonplace for single family residences.

How does alteration of shoreforms and shorelines affect other aspects of the Puget Sound ecosystem? Similar to riparian areas along streams, marine shorelines provide a relatively unique and important suite of functions including: (1) providing shade, organic material (food), and large woody debris to the beach; (2) regulating sediment inputs; (3) improving water quality from upland sources; (4) supporting fish and wildlife species. In addition to affecting these functions, human disturbance can alter important nearshore processes such as sediment delivery and routing. If some 90% of the beach sediments is supplied by bluff erosion (current hypothesis), then armoring represents a particular challenge to restoration of the Puget Sound ecosystem.

	% of Shoreline Length					Breakwater/ Jetty (km)	Marina (km^2)	Nearshore Fill (km^2)	OWS (km^2)	Parcels (per 10 km)
	Tidal Barrier	Nearshore Road	Abandoned RR	Active RR	Armoring					
Strait of Juan de Fuca	3.7	6.8	4	0	16.1	4.7	0.23	1.58	0.2	64
San Juan Islands-Strait of Georgia	6	6.1	0.1	1.6	14	15.53	2.04	7.93	1.22	99.3
Hood Canal	7.7	12.8	0	0	21.2	0.87	0.13	0.72	0.35	157
North Central Puget Sound	3.3	3.2	0	0	9.8	1.49	0.2	1.34	0.2	171.1
Whidbey	31.3	6.7	0	1.4	22.5	8.97	1.02	9.86	0.79	170.9
South Central Puget Sound	11.7	11.2	0	2.7	62.8	8.83	3.08	20.38	3.7	210.9
South Puget Sound	3.4	6.5	0.1	2.6	34.5	0.73	0.33	3.98	0.52	166.3
Puget Sound Basin	**10.5**	**7.9**	**0.4**	**1.4**	**27**	**37.23**	**6.33**	**39.3**	**6.45**	**146.1**

Table Hab-2. Shoreline Alterations in Puget Sound Basin and by PSNERP Subbasin

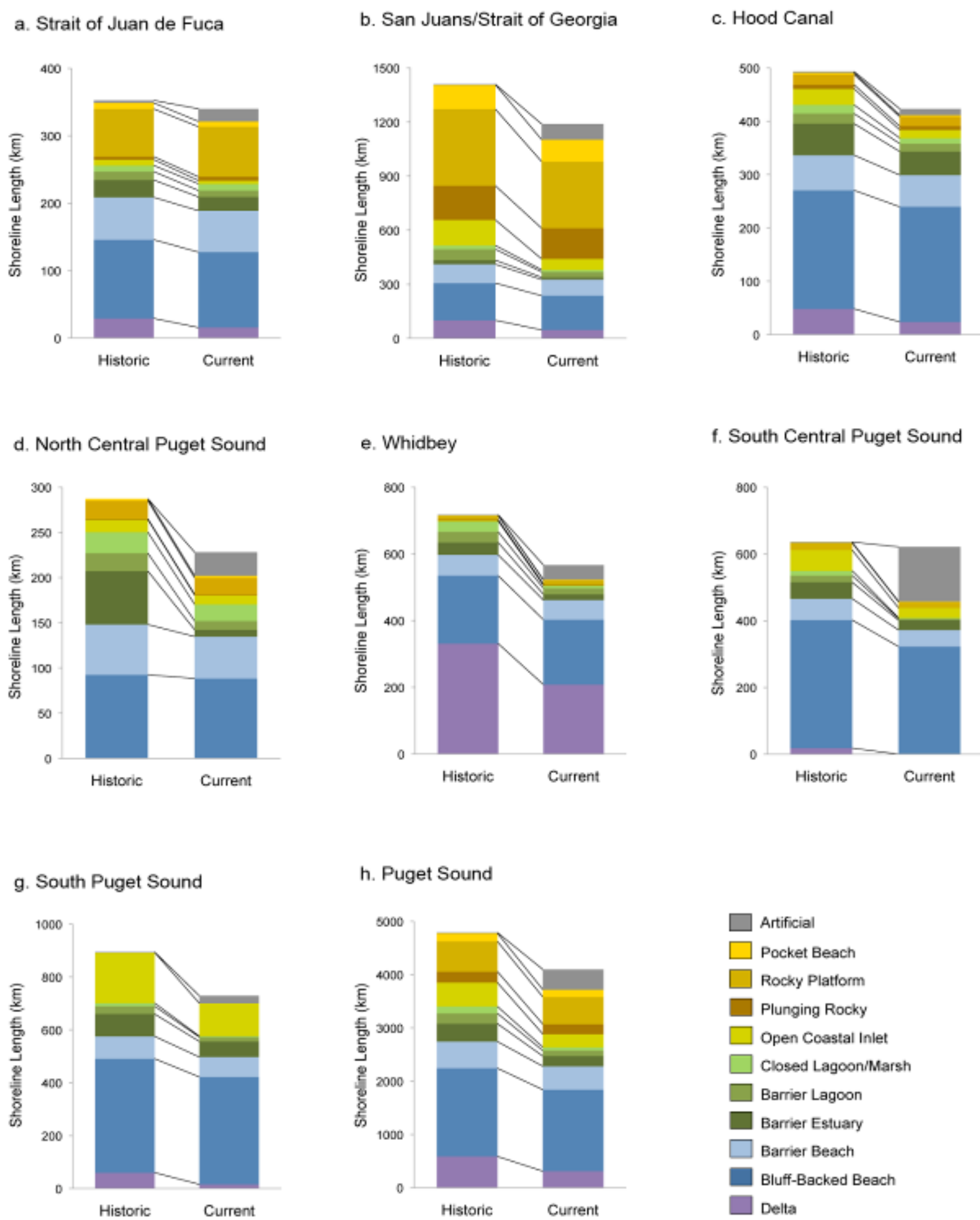


Figure Hab-9: Shoreform Change, 1850's – 2006

INDICATOR: Eelgrass area

Data and analysis provided by Helen Berry, Jeff Gaeckle, Pete Dowty and Tom Mumford, Washington Department of Natural Resources

Eelgrass (*Zostera marina L.*) is the dominant seagrass in Washington. It grows in tidelands and shallow waters along much of Puget Sound's shoreline. Eelgrass serves as a haven for many fish and wildlife species, providing them with food, breeding areas and protective nurseries. Because eelgrass habitat supports intricate food webs and diverse fauna, it plays a critical role in the health of Puget Sound.

Eelgrass is a valuable indicator of estuarine health not only because of the ecosystem functions it provides, but because it is known to be sensitive to environmental stressors. Excess nutrients, sewage and algae can reduce water clarity while storms, runoff and dredging can stir up sediment, preventing light from penetrating the water and reaching the eelgrass. Boat wakes, propellers and docks can also disturb eelgrass beds. Also, since eelgrass is protected by many regulations, its condition reflects, in part, the success of management actions.

Overall there are about 20,000 hectares (ha) (50,000 acres) of eelgrass in greater Puget Sound. It is found along approximately 43% of Puget Sound shoreline. Eelgrass commonly occurs in two different habitat — narrow beds that parallel the shoreline ("fringe" beds), and broader beds within bays ("flats"). The abundance and distribution of eelgrass varies greatly across Puget Sound (Figure Hab-10). Over 25% of all Puget Sound eelgrass is found in two expansive embayments: Padilla and Samish Bays in Skagit County.

An overall pattern of slight decline has been detected since monitoring began in 2000. The number of sites with significant annual declines has outnumbered those with increases every year in seven out of the last eight years (Figure Hab-11). Sites with long-term declines also outnumber sites with long term increases. Declines have generally occurred at smaller sites, while the extensive meadows in the region, such as Padilla Bay and Samish Bay, remained stable. As a result, the site declines are not large enough to produce a declining trend in the overall area of eelgrass in greater Puget Sound (Figure Hab-12). The regions of greatest concern for eelgrass losses are Hood Canal, and the San Juans.

Further information is available in the annual monitoring report: http://www.dnr.wa.gov/ResearchScience/Topics/AquaticHabitats/Pages/aqr_nrsh_eelgrass_monitoring.aspx

How do we define bins of status (Good, Fair, Poor) for eelgrass area?

Good: Stable or increasing eelgrass abundance and distribution (ie., no evidence of Sound-wide decline in total area or in the ratio of significantly increasing to decreasing sites, and no evidence of substantial declines in particular regions or habitat-types). Good status suggests that eelgrass continues to provide the same essential ecosystem functions as in

2000.

Fair: Sound-wide decline of small magnitude, or declines limited to specific areas or regions. Fair status suggests that eelgrass is expected to continue to provide essential ecosystem functions well into the future (decades) under the current trajectory.

Poor: Substantial Sound-wide decline (measured by proportion of increasing/decreasing sites or change in total area). Poor status suggests that the rate of decline is large enough so that provision of ecosystem functions on a soundwide scale is anticipated to be strongly diminished within 10 years.

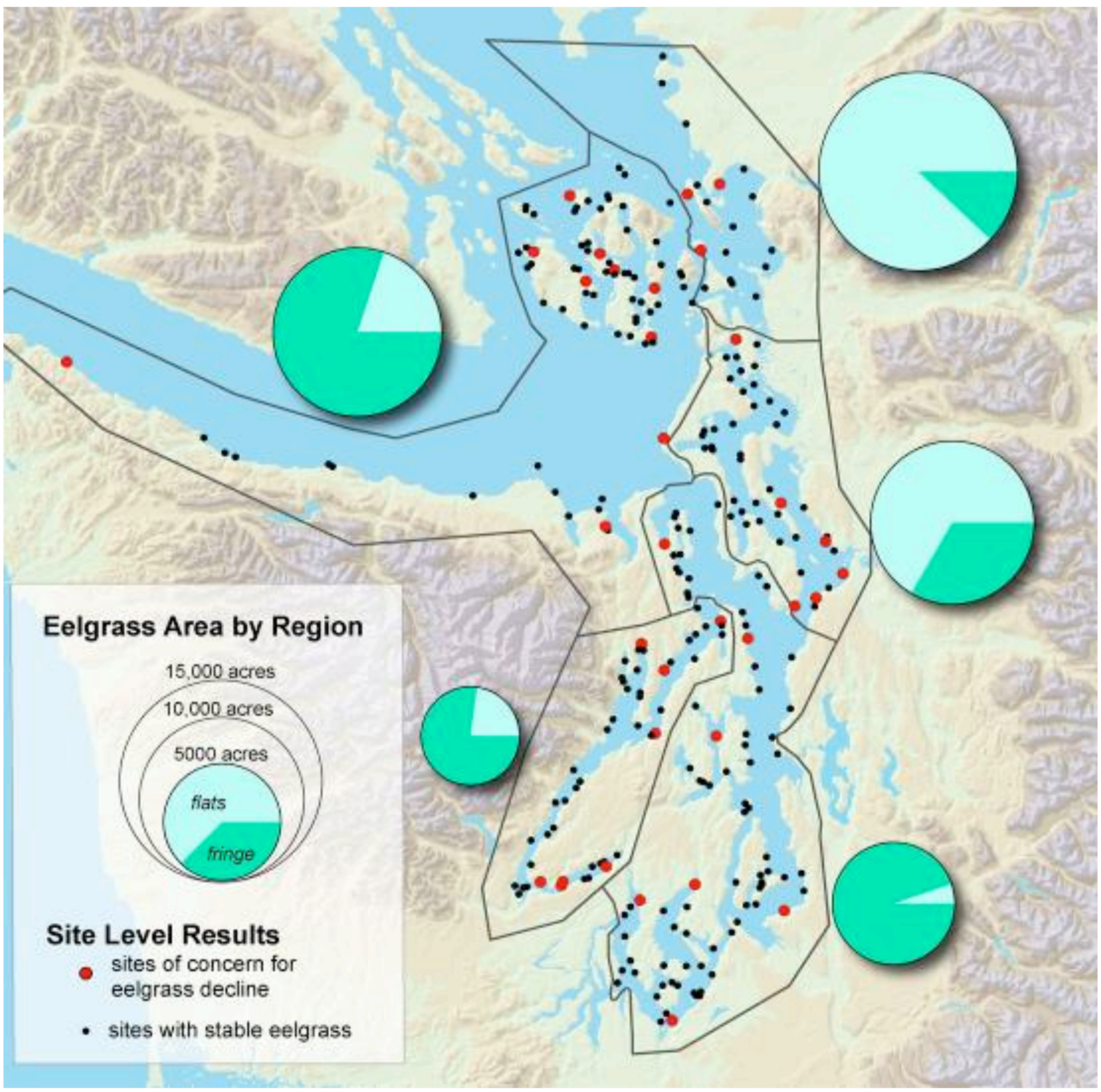


Figure Hab-10. Eelgrass area in five regions of greater Puget Sound, and the proportion of eelgrass in broad flats and narrow fringe habitat types The dots represent sites of concern for eelgrass decline (red) and stable sites (black) since monitoring began in

2000.

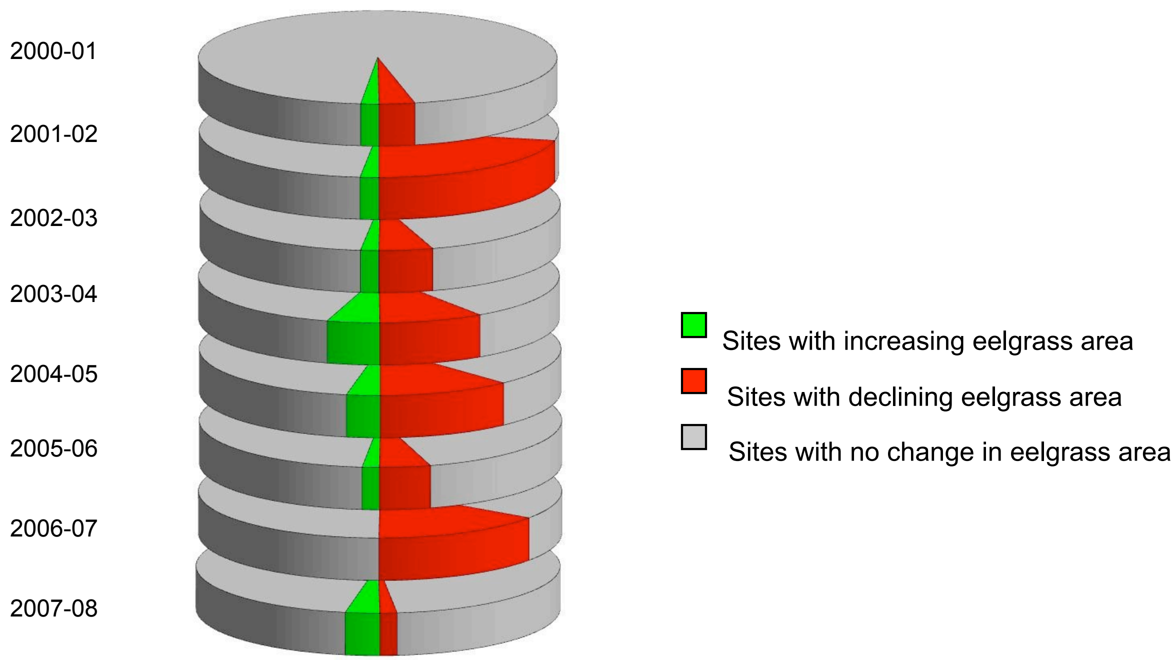


Figure Hab-11 In seven out of eight years of annual change, a greater proportion of sites showed statistically significant declines compared to increases in eelgrass area ($p<.01$).

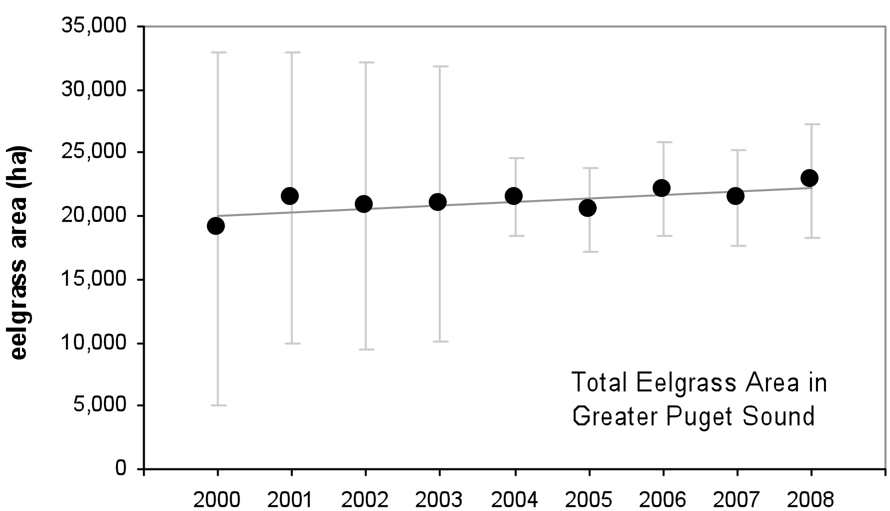


Figure Hab-12. Annual estimates of total eelgrass area in greater Puget Sound from 2000 to 2008 There is no significant trend in these data. The error bars are 95% confidence intervals. The sharp improvement in precision in 2004 is due to increasing the sampling frequency of large sites.

What is the current status of eelgrass area? What affects eelgrass area? While overall eelgrass abundance has remained stable, the number of sites with year-to-year declines has outnumbered sites with increases in seven out of the last eight years. Sites with long-term declines also outnumber sites with long term increases. These small-scale eelgrass losses are distributed at sites throughout Puget Sound. The observed eelgrass declines could reflect increased environmental stressors, such as excess nutrients, runoff, boat damage, docks, algae blooms and climate change. Because it is protected by many regulations, eelgrass condition reflects, in part, the success of management actions. Observed decreases suggest that there may be gaps in regulatory protections or their implementation.

How does the status of eelgrass area affect other aspects of the Puget Sound Ecosystem? Declines in small beds increase habitat fragmentation, reduce habitat for fish and wildlife species, disrupt food web interactions and decrease stability and biodiversity in Puget Sound.

What activities and management activities affect eelgrass area? Eelgrass abundance and distribution is influenced by natural and anthropogenic activities that occur over a range of spatial and temporal scales. Examples of natural eelgrass stressors include bioturbation, grazing, competition, disease and climatic events. Anthropogenic stressors include direct physical impacts (dredging, shoreline development, propeller scars, and vessel anchors and groundings), changes in water quality properties (eutrophication, siltation, toxic contamination), global climate change and invasive species.

Understanding the processes that lead to seagrass decline is critical to the development of management policies that target the restoration or protection of this resource. DNR established the Eelgrass Stressor-Response Program to investigate and understand causes of observed declines in eelgrass. Identifying stressors in Puget Sound will provide the essential first step toward formulating management strategies for long-term resource sustainability.

At present Washington state follows a no-net-loss policy of ecological function in eelgrass habitat through the guidelines for implementation of the Shoreline Management Act (WA State Department of Ecology), as well as policy adopted for implementation of Hydraulic Permit Approval (WA Department of Fish and Wildlife).

What do we still need to know about eelgrass? Baseline information on eelgrass abundance needs to be extended through analysis of historical data. Expanding the record of eelgrass abundance would provide a more complete understanding of the current condition of eelgrass and future restoration targets. This work would probably be restricted to certain areas within Puget Sound due to limited availability of historical data.

Stressors associated with observed losses need to be evaluated. Understanding factors causing observed declines is the crucial first step toward constructing meaningful 'results chains' that tie eelgrass condition to management actions. DNR has begun this work, but funding is limited.

DNR currently provides qualitative summary information for five regions in Puget Sound. DNR is further developing this indicator, along with more intensive five-year assessments. Guidance from the Partnership Science Panel would be helpful on the time period for change detection and whether data is required by action areas.

Further develop an assessment of eelgrass condition. While abundance is an important indicator, more advanced techniques are needed to assess bed condition and to identify predictors of losses.

POSSIBLE FUTURE INDICATOR: Freshwater wetland extent

To complement the information presented above, the Partnership may try to use the local findings from a national wetlands status and trends monitoring program (USFWS) to estimate changes in the extent of freshwater wetlands in the Puget Sound region. USFWS reports to do not present findings at the scale of the Puget Sound basin and a special analysis would need to be commissioned from the USFWS program.

5.2 Condition of Ecological Systems

POSSIBLE FUTURE INDICATOR Marine benthic index of biotic integrity

Discussion provided by Maggie Dutch, Washington Department of Ecology

Benthic infaunal indices currently used in Puget Sound: Widely accepted multi-metric benthic infaunal indices have been developed for use in estuaries around the United States (e.g., Benthic Index of Biological Integrity (B-IBI) for the eastern US; Benthic Response Index (BRI) for Southern California). These indices are used to classify benthic infaunal assemblages as impaired. The Washington State Sediment Management Standard includes methods for classifying benthos by comparing mean abundance of any major taxa groups in test sediments with those from reference sediments. Reference value ranges for selected benthic indices were also developed in the mid-1990s to represent reference area conditions. Both methods have limitations and are not widely accepted procedures for classifying benthos in Puget Sound.

Given the limitations of existing benthic indicators, Ecology's Marine Sediment Monitoring Team (MSMT) has developed alternative methods for evaluation of the condition of Puget Sound benthic invertebrate communities. A set of nine benthic metrics are calculated for each benthos sample, including total abundance, total taxa richness, evenness, dominance and abundance of annelids, mollusks, arthropods, echinoderms and miscellaneous taxa. Presence/absence and abundance of pollution-tolerant and -sensitive species are also examined. Benthos are considered to be impaired when, based on best professional judgment, the majority of calculated indices and the species composition indicate that a community is adversely different from communities in uncontaminated areas.

Benthic infaunal index data available for Puget Sound: Benthic invertebrate data have been generated from over 550 sediment samples throughout Puget Sound from 1989 through 2008 for the Puget Sound Assessment and Monitoring Program. These samples have been classified by MSMT personnel as having sediment-dwelling invertebrate communities that are either affected or unaffected by natural and anthropogenic stressors. They have been summarized in various publications separately and as part of the Sediment Quality Triad (SQT) of data (chemical contamination, toxicity, benthic infauna community structure) collected simultaneously with the benthos.

Data summaries have been generated for 10 long-term stations, eight Puget Sound monitoring regions, and for Puget Sound as a whole. Current or new summaries can be available for 2009 State of the Sound reporting.

Pros and cons of reporting a benthic infaunal index for Puget Sound

Pros:

- A Best Professional Judgment (BPJ)-based benthic index has been used to estimate the condition of Puget Sound benthos for over 550 PSAMP samples collected since 1989.
- The PSAMP benthos data set has undergone rigorous taxonomic standardization over time.
- This data set provides information for comparison within and between years, stations, and regions.
- Ecology's Marine Sediment Monitoring Team currently is working on Phase 1 of a project, funded by the Puget Soundkeeper Alliance, to develop a statistically valid, multi-metric benthic index for Puget Sound. This work won't be completed until 2010, and currently is not funded beyond Phase 1.

Cons:

- The current benthic index used by Ecology relies solely on the BPJ of a small number of Puget Sound benthic experts. A statistically rigorous index development process needs to be applied to these data, followed by a validation process and peer review both regionally and nationally.
- Recently, funding for Phase 1 of a benthic index development project has been made available by the Puget Soundkeeper Alliance, but no funding has been secured beyond Phase 1.
- Most sediment experts routinely use multiple lines-of-evidence to determine the health of aquatic sediment systems. This typically includes simultaneous collection of measures of chemical contaminant levels, toxicity, and benthic community structure (i.e., the Sediment Quality Triad), but may include other measures as well (e.g., bioaccumulation, histopathology). The PSAMP sediment component has collected the SQT of chemistry,

toxicity, and benthos for its Puget Sound sediment stations. Separate examination of these elements (i.e., sediment contamination in the *Water Quality* section and benthic indicators in the *Healthy Habitats* section of the 2009 Report) may provide a misleading picture of sediment health. These elements should be considered in tandem.

POSSIBLE FUTURE INDICATOR: Freshwater benthic index of biotic integrity

Data and discussion provided by Jim Simmonds, King County

Monitoring Overview: Stream benthic macro-invertebrates, also known as stream bugs, are animals that can be seen with the naked eye, do not have backbones and live in the stream benthos — in or near the streambed. They include insects, crustaceans, worms, snails, clams, etc. The stream benthic macro-invertebrate community structure is used to determine the ecological health of streams. Many jurisdictions, nonprofits, and state and federal agencies monitor stream benthic macroinvertebrates to assess watershed conditions and as an indicator of the biological health of stream systems. Recently, an effort to compile and manage existing stream benthic macroinvertebrate data in the Puget Sound region was completed by King County, in coordination with Pierce County, Snohomish County, City of Seattle, and Washington State Department of Ecology. The compiled data are available at http://www.pugetsoundstreambenthos.org/. Currently, about 20 entities use this site to manage, analyze and share data from their ongoing stream monitoring programs. A status report on stream benthic macroinvertebrate monitoring in the Puget Sound region is available at the above website.

Data Analysis: Stream benthic macroinvertebrate data can be analyzed using two general approaches: the Benthic Index of Biotic Integrity (B-IBI) approach, and the predictive modeling (e.g., RIVPAC) approach. The B-IBI is composed of ten metrics that measure different aspects of stream biology, including taxonomic richness and composition, tolerance and intolerance, habit, reproductive strategy, feeding ecology, and population structure. Each metric describes some aspect of the community that responds to degradation. The raw value of each metric is calculated, and from the raw value, a score of 1, 3, or 5 is assigned to the metric. The ten metric scores are then added to produce the overall B-IBI score that range from 10 to 50. The RIVPAC approach calculates the percent of species expected at a site by assessing various habitat characteristics and identifying the probability that any given species would be present. The data management system currently only calculates the B-IBI scores, not the RIVPAC scores.

Assessment of Puget Sound Stream Macroinvertebrates: Monitoring of stream benthic macroinvertebrates is conducted by multiple organizations throughout the Puget Sound region. Each organization tends to focus on specific basins, where samples are collected in an attempt to characterize water quality within the basin. There is no comprehensive sampling design that allows for comparison between basins, and each basin has different amounts of data available.

The State Department of Ecology is beginning to implement in 2009 a stratified, random status and trends monitoring program that includes stream benthic macroinvertebrates. Because of the robust nature of the design of this effort, it is expected that the results will be representative of all Puget Sound streams.

As an example of the type of presentation that might be possible, Figure Hab-12 presents the average BIBI score by WRIA from 2002 through 2008 for WRIAs 7, 8, and 9. These graphs show year-to-year variability, with no clear long-term trend. It is likely that long-term trends associated with improved watershed conditions resulting from restoration and retrofit projects would not be apparent until over 20 years of data are collected.

Possible Future Improvements: There are a number of future improvements that are possible and worthwhile for the stream benthic macroinvertebrate monitoring indicator, including:

- evaluation of relationship between BIBI and RIVPAC approaches for analyzing data
- standardization of sampling methodology to ensure data comparability
- enhancement of the existing data management system to allow for calculation of RIVPAC scores
- implementation of Washington State Department of Ecology status and trends monitoring program to ensure representative sampling of all Puget Sound streams
- better coverage in basins not currently sampled

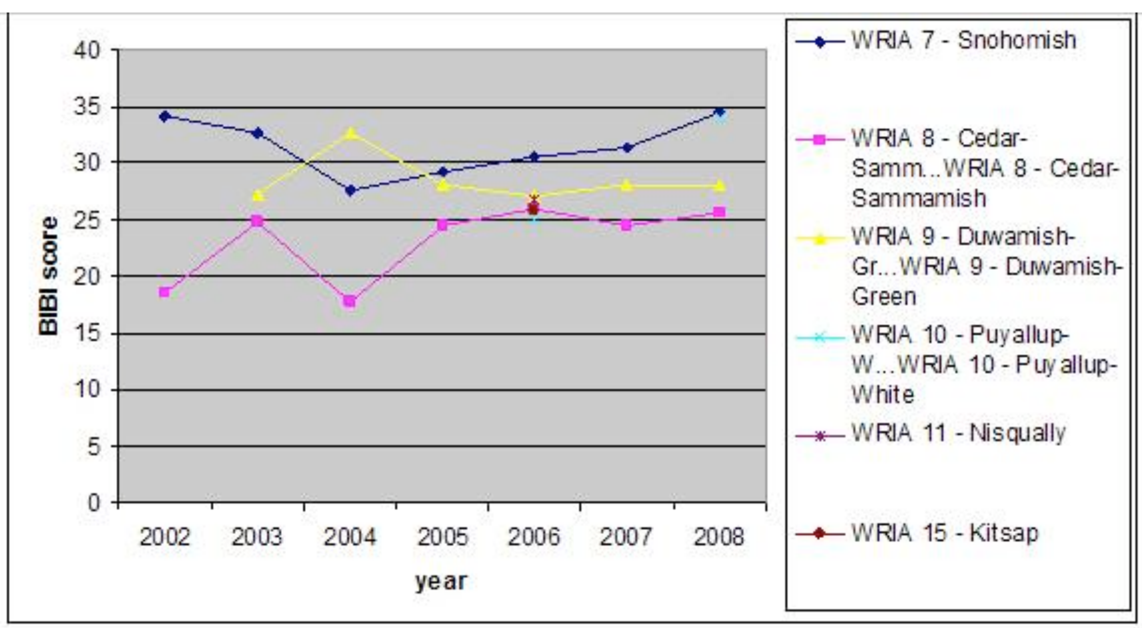


Figure Hab-13: BIBI over time in central Puget Sound streams

POSSIBLE FUTURE INDICATOR: Stillwater breeding amphibian egg masses

Discussion provided by Timothy Quinn, Washington Department of Fish and Wildlife

Wetland Amphibian Community Monitoring Overview: Stillwater-breeding amphibians produce eggs (masses) in wetlands each spring that are readily identified and easily sampled. The stillwater-breeding amphibian community is likely analogous to a stream benthic macro-invertebrate community, in that the community reflects wetland habitat conditions (including wetland and associated-stream hydrology) in addition to providing insights into surrounding uplands landscape dynamics and disturbance. The Washington Department of Fish and Wildlife has conducted two pilot studies using Citizen Scientists in 2001 and 2009 (including the direct data-gathering effort of school-aged children) to count amphibian egg masses. The value of this monitoring is related to three components of ecosystem function: (1) amphibians are ideal early-warning indicators of ecosystem decline since they live in and near water, and are exposed to both water-related insults (e.g., stormwater contaminants, elevated temperatures, altered hydrological regimes) and terrestrial disturbances (e.g., herbicide and pesticide applications, actions that produce severe sedimentation); (2) amphibians are in decline globally and amphibian monitoring within the Puget Trough-Georgia Basin Ecosystem is critically important as a benchmark for comparison to studies outside the area; and (3) amphibians are sensitive to multiple stressors ranging from upland fragmentation to changes in hydrological regime, and to toxins and pesticides in the water and ground, and are therefore a useful indicators of cumulative and synergistic effects. Finally, on-the-ground sampling of amphibians in wetlands could be easily integrated into more extended sampling system of wetlands that includes remote sensing as a key indicator ecological system.

Data Analysis: Amphibian occupancy (and richness if one desires the species suite) and relative abundance data can be analyzed using diverse general approaches. This includes developing an index of wetland biotic integrity, by species or functional species groups, as indicators of specific suites of stressors along a causal chain; or coupling amphibian data to GIS data to enable identifying thresholds of development at which species drop out. Since a lag time frequently exists in the disappearance of selected species at a particular level of development, coupling to GIS data can potentially be linked to a monitoring timeline that would ultimately identify highly precise thresholds for development that would maintain different stillwater-breeding amphibian species on the landscape and indicate different levels of biotic integrity.

POSSIBLE FUTURE INDICATOR: Freshwater habitat quality index

The Washington Monitoring Forum has endorsed a monitoring framework that includes status and trends monitoring of river and stream habitat by a probabilistic random design. The initial implementation of this framework is occurring in 2009 in the Puget Sound basin. Future reports on ecosystem status and trends can include an index (and/or individual indicator reports) developed from this monitoring. The quality assurance monitoring plan for this program (Ecology et al. 2006) suggests that following types of indicators can be developed:

- Water quality indicators, especially turbidity or suspended sediments but also addressing temperature, nutrients, dissolved oxygen, pH, conductivity, and chloride.
- Physical habitat indicators, including channel gradient; channel substrate size and type; habitat complexity, quantity and cover; riparian vegetation cover and structure; anthropogenic alterations; and channel-riparian/floodplain interaction.
- Biological indicators, including indices of biotic integrity for aquatic vertebrate assemblages (fish and amphibians) and macroinvertebrate communities.

This monitoring program is designed around a 4-year rotation. Index and/or indicator reporting should be available on a 4-year period with a baseline developed for conditions observed in 2009.

POSSIBLE FUTURE INDICATOR: Habitat connectivity

The Puget Sound basin comprises a complex and dynamic mosaic of marine, nearshore, freshwater and upland habitats. The health of these habitats and their ability to support the native species of Puget Sound is directly tied to the degree of connectivity both within and between habitat types. For many species, reductions in habitat connectivity (e.g. fragmentation of lowland forest; increased distances between pocket estuaries) significantly reduces the quality and extent of habitat available. Future plans for reporting on the health of habitats in Puget Sound include the development of indicators addressing connectivity within and between habitats.

5.3 What do we still need to know about monitoring the health of habitats in Puget Sound? What are our plans for future reports?

Although we have a good record of the extent and rate of habitat conversion to development, it is more difficult to assess the degree to which the condition and functionality of different habitat types are affected by changes in landscape condition and changes in adjacent land cover and land use. Questions remaining to be answered include:

- What is the condition of critical connections within and between focal habitats?
- How does conversion to development and fragmentation of different habitat types affect the processes — flow of water, energy and nutrients – and structures that support the diverse suite of species and communities in Puget Sound?
- How do we assess connectivity of focal habitats?
- With improvement, can Sound-wide monitoring of fresh and riparian marine vegetation be developed as an indicator of condition of important ecological functions?
- What is the current status of Puget Sound ecological systems and focal habitats?

To develop a comprehensive baseline on which to base upcoming change analyses, future reporting will include a more detailed status review and development of better trend information throughout the Puget Sound basin, including mapping of the historical extent of ecological systems and focal habitats. Future reporting could take a multi-scalar approach that focuses on a preliminary coarse-level (satellite imagery) identification of problem areas and subsequent intensive methods (aerial photography, on-the-ground research) to assess the condition of select areas. Questions that could be addressed by this approach include:

- What are the major issues affecting those upland systems for which we have indirect evidence of sharp decline in extent and or quality?
- What is the degree of decline and what are the implications of the declines?
- What are the trends through time?
- How do we begin to identify solutions to significant stressors affecting specific systems?

Similarly in our aquatic environments, future work will focus on questions about the relationship between habitat extent and condition and ecological process that support species and provide critical ecosystem services to our human populations. More specifically:

- What is the relationship between the loss and/or degradation of intertidal wetlands and the condition of important ecological processes in our nearshore and marine environments?
- How do we assess not only the extent of eelgrass areas but also their condition so we can put this information to use toward formulation of management responses with maximum effectiveness?

In freshwater environments, future reporting will address the need to understand changes in the extent of freshwater systems, changes in condition, as well as drivers of those changes. The Partnership may try to use the local findings from a national wetlands status and trends monitoring program (USFWS) to estimate changes in the extent of freshwater wetlands in the Puget Sound region. With respect to condition, an index of freshwater habitat quality could be derived from new Washington Monitoring Forum status and trends monitoring to begin answering some critical questions:

- What can indicators of the biological health of aquatic habitats, such as marine and freshwater benthic indices or stillwater breeding amphibian abundance and richness, tell us about the marine and freshwater components of our region and the actions in the uplands that affect aquatic resources?

6. Water Quantity

Fresh water supports human health and well-being, species and food webs, and functioning habitats. Streamflows support aquatic life by: moving sediments and organic matter to create and sustain a diversity of habitats in fresh, estuarine and marine waters; moderating stream temperatures; and modifying water quality by aeration and dilution. Streamflows also support withdrawals of surface waters from human uses. The hydrologic regime – the amount, timing, and variability of stream flows – of Puget Sound basin rivers and streams is a result of patterns of precipitation, snow accumulation, topography, and land use and development. The Partnership's interests in water quantity are expressed in the legislative goal for ecosystem recovery: "An ecosystem that is supported by ground water levels as well as river and stream flow levels sufficient to sustain people, fish, and wildlife, and the natural functions of the environment."

For 2009 reporting on the status and trends of freshwater quantity, the Partnership is focusing on magnitude, timing and flashiness of stream flows as a way of characterizing hydrologic regime. One section of reporting focuses on the magnitude and timing of streamflows in major Puget Sound rivers whose flows are largely unregulated. Streamflows in these systems is most affected by climate change and variability, land-use practices and water withdrawals. The second section addresses the flashiness of flows in lowland streams affected by urbanizing watersheds.

The Partnership's focused reporting on water quantity for 2009 does not include any characterization of ground water levels or ground water storage (which can be significant natural resource issues in parts of Puget Sound that depend on ground water to support ecological systems and supply water for human uses). This version of the Partnership's reporting also does not describe all aspects of surface water hydrology (especially frequency and duration of high and low flows); surface water storage in natural or human-built reservoirs; and human use of fresh waters. These aspects of water quantity may be addressed in future reports by the Partnership.

What is the current status of water quantity in Puget Sound? Streamflows in Puget Sound are affected by long-term climate influences (i.e., reduced summer flows and increased winter flows) and altered (i.e., more flashy) runoff in streams directly affected by urban development.

What affects the status of water quantity in Puget Sound? The primary influences on Puget Sound streamflows are climate, development of watersheds, withdrawals of water, and regulation of flows for flood control or power generation.

How does water quantity affect other aspects of the Puget Sound ecosystem? Water quantity affects human well-being by determining the amount of water available for human consumption and other uses. Streamflows affect species and food webs and the formation and maintenance of habitats. Water quantity can also affect water quality since it can drive circulation of marine waters and affect the distribution and concentration of pollutants in fresh and marine waters.

INDICATOR: Stream flow in major rivers

Analysis and discussion provided by Scott Redman, Puget Sound Partnership [2]

Using an analysis approach developed by UW's Climate Impacts Group (Mote et al. 2005) for the Puget Sound region, stream flow in the region's largest unregulated rivers is characterized by:

- total annual and seasonal pattern of flow to Puget Sound in 1939-1967 and 1984-2008 (See list of Snohomish, Puyallup, Nooksack, Stillaguamish, and Duckabush stations combined for this and other analysis)
- midpoint date of annual flows
- summer (June, July, August and September) fraction of annual flow
- number of high flows per year
- number of low flows per year

This assessment of the magnitude and timing of streamflows in the major, unregulated rivers includes some portion of five of 12 largest Puget Sound rivers.

As seen in Figure Wqty-1, the pattern major unregulated river flows for 1984 to 2008 shows a shift to higher and earlier fall flows, higher spring flows, and summer flows that are lower and peak earlier compared to flows from 1939 to 1967. This is consistent with prior analysis that used data through water year 2003 (Mote et al., 2005). Recent years' annual flow has been near the long-term mean values for the period.

As seen in Figure Wqty-2, the calendar date representing the mid-point of a water year's annual flow for major, unregulated Puget Sound rivers varies from mid-January (1996) to early May (2008). The overall trend is for the mid-point date to occur earlier in the year. Mote et al. (2005) notes that this pattern is an hypothesized regional effect of global climate change.Recent years have seen the lastest date on record (2008) and some of the earliest dates (2005).

The combined summer flows of Puget Sound's major, unregulated rivers show a trend decreasing trend (Figure Wqty-3; $p<0.001$ that slope = 0). Mote et al. (2005) notes that this pattern is an hypothesized regional effect of global climate change. Over the 70-year period of record the

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[2] Review provided by Nate Mantua (UW), Paul Pickett (Ecology), and Curtis DeGaspari (King County).

summer fraction varies from a low of 13 percent of the annual flow (1996) to a high of 39 percent (1955). WY 2008 had a fairly high fraction of its flow in the summer but other recent years have been nearer the long-term trend line (2004 above the long-term; 2005 to 2007 each below the long-term).

As seen in Figure Wqty-4, high flows in the 70-year record of Puget Sound region's major, unregulated rivers demonstrate a pattern of high flow years (e.g., 1996, 1991, 1990) interspersed with years without high flows (e.g., 1998-2001, 1992-1994). Mote et al. (2005) notes an increased likelihood of high daily flows, as is seen in recent years of this record, is an hypothesized regional effect of global climate change. For this analysis a high-flow occurrence is defined as a daily flow above the mean of the highest flows in each water year from 1939 to 2008. All flows depicted as counts in this chart represent combined daily flows for five major, unregulated Puget Sound rivers in excess of 81,590 cfs. The highest combined daily flow observed from 1939 to 2008 was more than 184,000 cfs (November 1990, WY 1991). Two of the highest 10 combined daily flows in this period were observed on consecutive days in November 2006 (WY 2007).

Low flows in the 70-year record of Puget Sound region's major, unregulated rivers demonstrate multi-year periods without extreme low flows (e.g., 1954-1972, 1976-1979, 1981-1985) followed by a series of years beginning in 1986 when most low flows occur (Figure Wqty-5). Since, 1986, high numbers of low-flow days occurred in 1988, 1995, 2003, 2005, and 2007. WY 1953 also had a large number of low-flow days. In six of the 70 years of this period of record, the number of extreme low flow days exceeded 15 days. Three of these six years have occurred since 2003. UW's Climate Impact Group (2005) notes that an increased likelihood of low-flow days, as is seen in the recenty years of this period, is an hypothesized regional effect of global climate change. For this analysis a low-flow occurrence is defined as a daily flow in the lowest one percentile of all combined daily flows from 1939 to 2008. All flows depicted as counts in this chart represent combined daily flows for five major, unregulated Puget Sound rivers less than 1,905 cfs. Seventy-eight of these lowest flows occurred in two water years (1953 and 1988). The lowest combined daily flow observed from 1939 to 2008 was 1,177 cfs. The lowest 25 combined daily flows on record occurred in October and November 1987 (WY 1988).

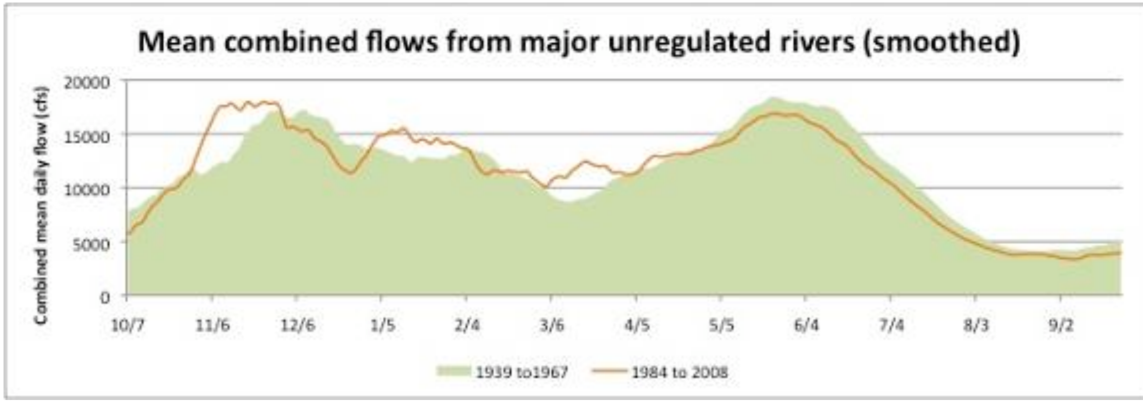

Figure Wqty-1: Seasonal pattern of runoff from Puget Sound's major rivers has shifted from conditions observed in the mid-20th century (The data presented here are moderately smoothed for presentation by using 14-day rolling averages of daily average flows.)

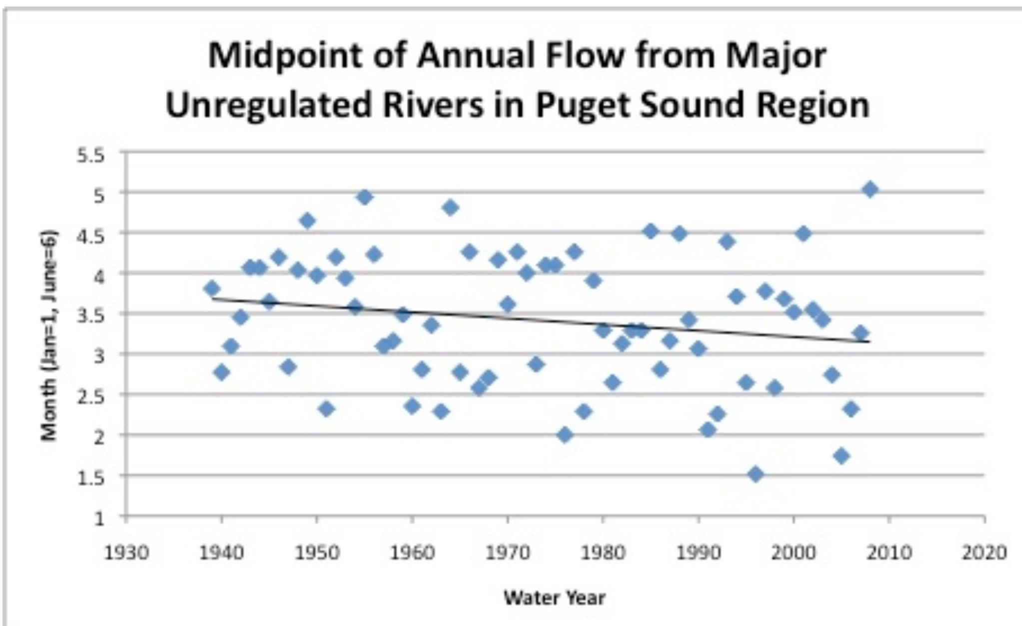

Figure Wqty-2 : The calendar date representing the mid-point of a water year's annual flow for major, unregulated Puget Sound rivers

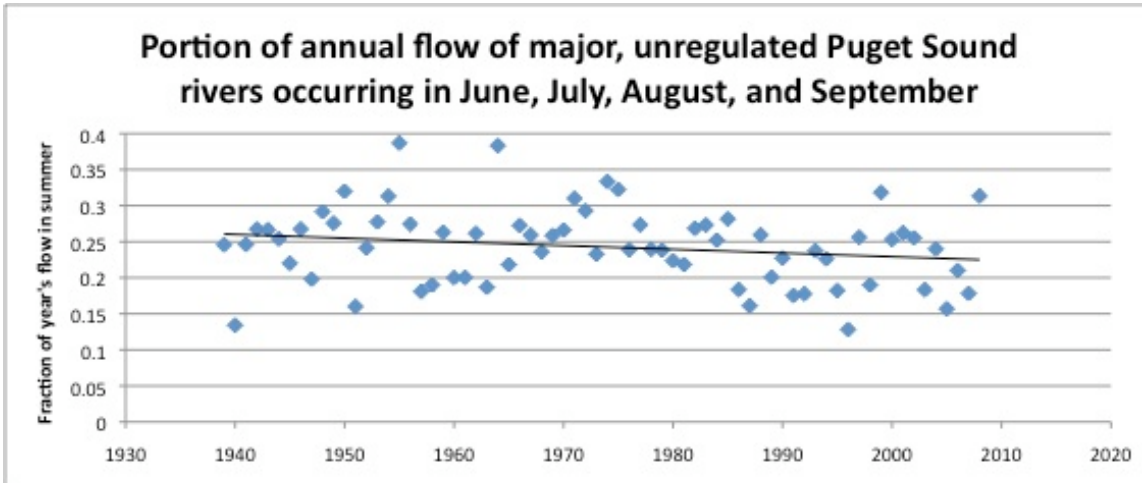

Figure Wqty-3: The combined summer flows of Puget Sound's major, unregulated rivers

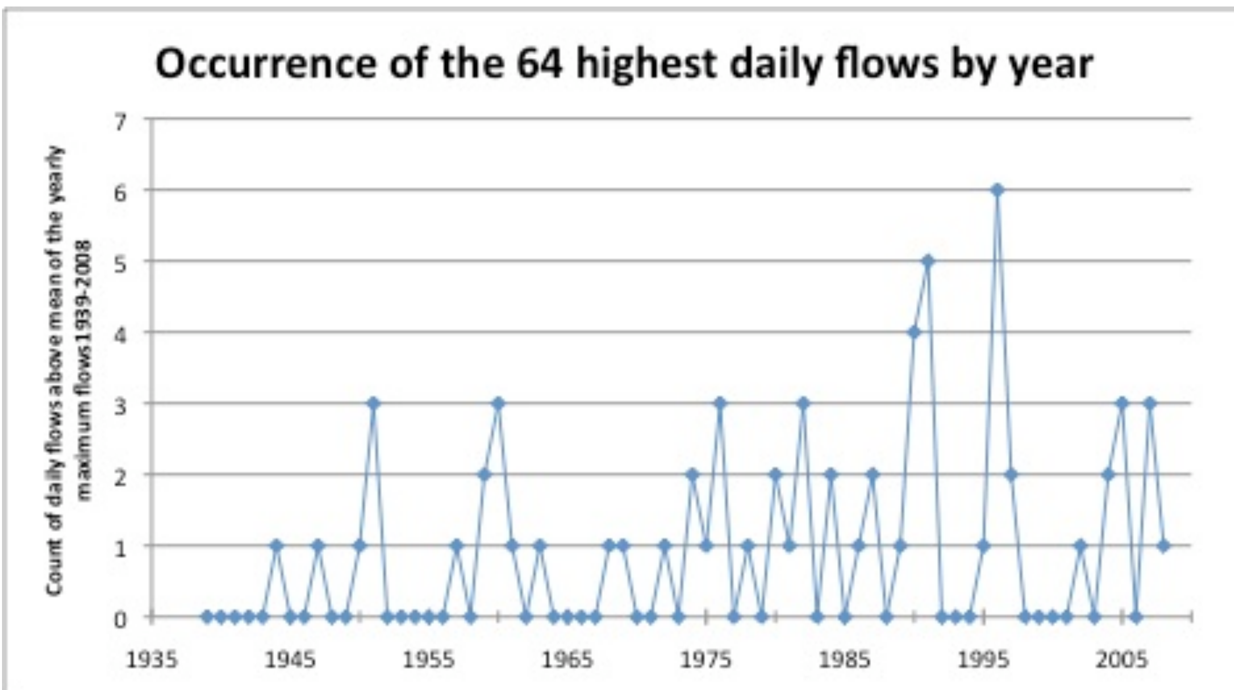

Figure Wqty-4: High flows in the 70-year record of Puget Sound region's major, unregulated rivers

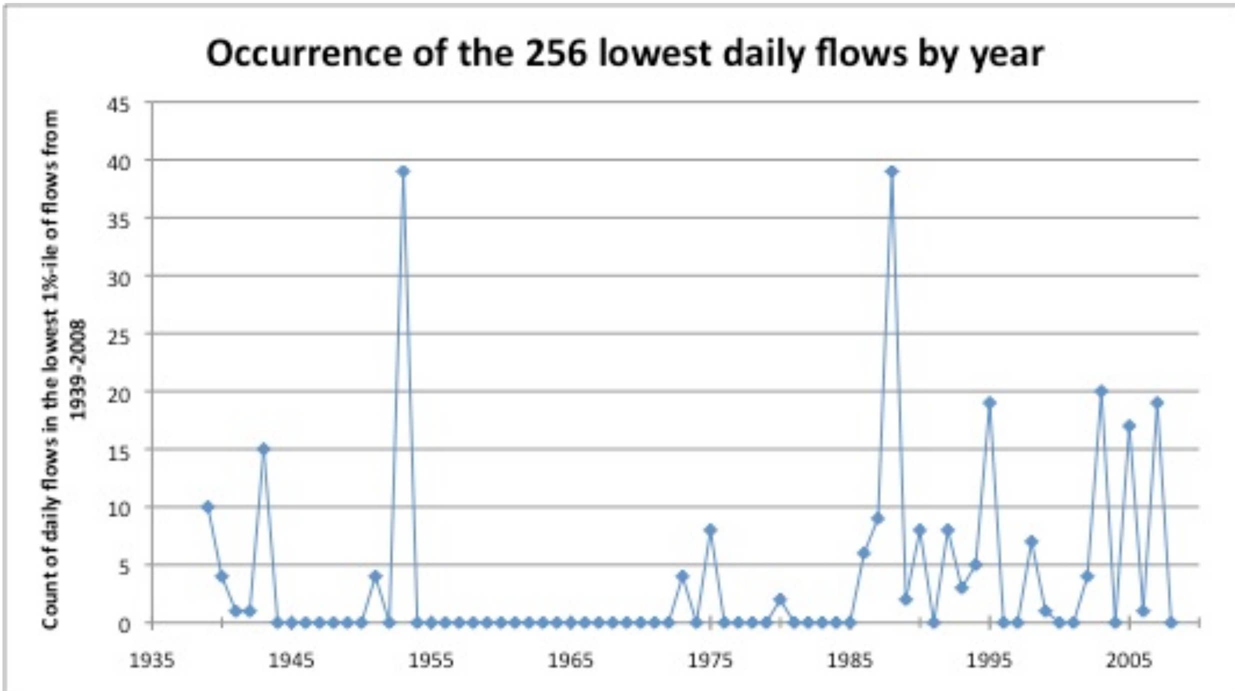

Figure 5: Low flows in the 70-year record of Puget Sound region's major, unregulated rivers

What is the current status of streamflows in major rivers? Streamflows have shifted over the past 70 years. Seasonal patterns of runoff have shifted towards higher winter stream flows and earlier and reduced summer flows supported by snowmelt.

What affects the status of stream flows in Puget Sound's major rivers? Climate and flow regulation are the primary influences on streamflows of Puget Sound's major rivers.

Methods/background: To characterize streamflows from the numerous Puget Sound rivers with stream gauging information, the Partnership has adopted an approach developed by CIG in 2005 for reporting to the Puget Sound Action Team (Mote et al., 2005). This approach combines daily flow information for Puget Sound's large rivers that are not affected by large impoundments or operations that regualte streamflow.

Table Wqty-1 lists Puget Sound's major rivers in decreasing order of average annual flow to Puget Sound as presented by CIG (Mote et al. 2005). Flows for these rivers were combined where: (1) flows appear to represent unregulated conditions; and (2) streamflow data records are continuous back to late 1938. As indicated in the table below, this assessment combines and analyzes data from six USGS gaging stations on five of these 12 rivers. This approximately follows the approach developed by CIG. Stations whose flow data are represented in this analysis are identified in the table below as are the reasons that some rivers are excluded from this analysis and the justification for deviations from the set of stations apparently used by CIG.

Station daily mean flows for the period 1 October 1938 to 30Sep2008 were downloaded from USGS (waterdata.usgs.gov), imported to a spreadsheet, and summed. This provides a 70-year record of 'combined daily flows' encompassing unregulated flows from five of 12 largest rivers discharging to Puget Sound. This does not include flows from the Fraser and Skagit rivers the two largest sources of freshwater to the marine waters of Puget Sound.

Analysis #1: Annual hydrographs represented by combined daily flows averaged by calendar date for all water years from 1939 to 2008 were developed for the first analysis. The periods selected included the first 29 years of the record (which is somewhat longer than the early period reported in Mote et al., 2005) and 1984-2008 (which extends the “recent” period as characterized in Mote et al., 2005). For graphical presentation of the hydrograph, the average combined daily flows for each date were temporally smoothed by calculation of a 14-day rolling average.

Analysis #2: A second analysis related to flow timing is the calculation of the midpoint of the combined annual flow for each water year. The midpoint is the calendar date on which one-half of a water year's total flow has occurred. Midpoint dates are plotted by water year to investigate temporal patterns in the date of occurrence of the midpoint. Mote et al., (2005) analyzed these data and calculated a trend. This presentation includes a linear trendline as calculated in Excel, this regression explains very little of the variability in midpoint date ($r^2 = 0.04$).

Analysis #3: A third analysis related to flow timing is the estimate of the fraction of the annual flow that occurs during the summer, defined as calendar months June, July, August and September. Summer fractions are plotted by water year to investigate temporal patterns in the proportion of annual flow occurring in summer. For snowmelt-dominated streams this analysis would characterize contributions to flow from the melting of snowpack. This measure provides an imperfect assessment of the proportion of snowmelt for Puget Sound rivers since some of the rivers in this analysis see substantial snowmelt runoff in April and May (Mantua, personal communication). Mote et al., (2005) analyzed these data and calculated a trend. This presentation includes a linear trendline as calculated in Excel. Although this regression explains very little of the variability in summer flow proportion ($r^2 = 0.04$), the slope is statistically significantly different than 0 ($p < 0.001$).

Analysis #4: Our fourth analysis depicts the occurrence of daily high flows across the water years of the study period. High flows are defined as daily combined flows in excess of a high flow statistic calculated from the 70-year record. Consistent with the concept as presented in Mote et al., (2005), we identified the extreme high daily flow in each water year and then calculated the mean of these 70 water-year extremes. This mean annual high flow was used as the cutoff to identify 'high' daily flows. The number of high daily flows per year is plotted by water year to display temporal patterns in the occurrence of high flows.

Analysis #5: Our fifth analysis depicts the occurrence of daily low flows across the water years of the study period. Low flows are defined as daily combined flows below a low-flow statistic calculated from the 70-year record. Consistent with Mote et al., (2005), we identified the first-percentile low daily flow, which was used as the cutoff to identify 'low' daily flows. The number of low daily flows per year is plotted by water year to display temporal patterns in the occurrence of low flows.

Major Puget Sound River	Reason to exclude from PSP analysis	Stations included	Reason to use this station	Comments/notes
Skagit	regulated at Ross Lake	--		CIG* excluded due to regulation
Snohomish		12134500 12149000	Skykomish & Snoqualmie flows offer best available data records	CIG apparently used 12150800 with record back to 1964
Puyallup		12093500	above confluence with White, which is regulated	CIG may have used 12101500 or excluded due to regulation
Nooksack		12205000	North Fork, fairly far upstream offers best available data record	CIG apparently used 12213100 with record back to 1967
Nisqually	regulated at Alder Lake	--		CIG excluded due to missing data
Stillaguamish		12167000	North Fork flow offers best available data record	CIG used same station
Green	regulated by Howard Hanson dam	--		CIG apparently used 12113000
Skokomish	regulated at Lake Cushman	--		CIG apparently excluded due to regulation
Cedar	regulated at Landsburg & Masonry	--		CIG apparently excluded due to regulation
Deschutes	missing data per 2005 CIG analysis	--		CIG excluded due to missing data

Samish	missing data per 2005 CIG analysis	--		CIG excluded due to missing data
Duckabush		12054000	best available data record	CIG used same station

Table Wqty-1: Major Puget Sound Rivers. Selection of Five Rivers for Analysis of Long-term Flow Magnitude and Timing.

* CIG = analysis presesented in Mote et al., 2005

What do we still need to know about major rivers' streamflow? What are our plans for future reports? What should we know or measure that we don't currently?

USGS (2002) recommends that indicators of water quantity include ground water levels and storage, streamflows, surface water storage, water use and characterization of water budgets. Aligning with these recommendations, we should be tracking trends in withdrawals and consumptive water use in Puget Sound's major basins. This is the most poorly known/compiled water budget component and is also the primary element of the water budget for the large basins that we can influence.

For future reporting we could focus on low streamflows using 7-day low flows. This is a good standard metric that is subject to less influence by outliers than the extreme summer low-flow day. Reporting on the proportion of time meeting instream flows would be more informative about the instream flow rules but highly correlated with 7-day low flows.

The approach of combining flows from selected rivers may provide a biased view of basin-wide conditions and trends. Future analyses should endeavor to compute high, low and timing statistics for each river by itself and then evaluate the relative coherence among watersheds for these statistics. If they do co-vary to a high degree, combining flows for a single measure of each statistic may be justified. Future analyses could include flow data from the Skagit basin (for instance, the Sauk River at Sauk, inflows to Ross Lake, and the Cascade River) in order to see how closely the basins included in this analysis track Skagit Basin flows. Other flow gauging stations on the Nooksack River should also be evaluated. Fraser River flows may not be coherent with those analyzed here (or suggested for future improvements to this analysis) because the watershed spans such a large area in British Columbia.

POSSIBLE FUTURE INDICATOR: Hydrologic alteration related to urbanization

Data and analysis provided by Curtis DeGasperi and Jim Simmonds, King County

The conversion of forested and other predominantly undeveloped land to urban and suburban land covers in the Puget Lowland has increased winter peak flows and decreased winter base flows as infiltration of rainfall is reduced and runoff from compacted soils and impervious cover is more quickly routed to receiving streams via engineered conveyance systems. Development coupled with consumptive water uses, export of water out of stream basins via regional wastewater systems or to supply water to other areas, and import of water for landscape irrigation also affects summer base flows. Hydrologic alteration is considered to be a significant cause of declining biological richness as basins become urbanized. Parallel to the concept that hydrologic change is a major driver of biological degradation in streams is the recognition that native stream biota are best adapted to the natural flow regime – the flow regime typical of the millennia prior to significant human alteration of the landscape (Poff et al., 1997). Although the historical flow regime was not without its inter and intra-annual disturbances, forest clearing and urbanization in the Puget Lowlands over the last 150 years have dramatically altered the historical flow regime, exacerbating disturbances during winter high flows and introducing disturbances during late summer when none typically occurred in the past.

A host of hydrologic metrics have been developed to provide quantitative measures of hydrologic change between pre- and post-disturbance conditions. The difficulty lies in identifying hydrologic metrics that respond to urbanization and can also be shown to be biologically relevant. Some research suggests that hydrologic metrics that capture the effect of increased flow flashiness (i.e., more frequent and rapid increases in storm water delivery to streams) resulting from land cover change – particularly an increase in the amount of impervious cover directly connected to storm water conveyance systems that deliver rainfall runoff to streams – are most strongly correlated to biological metrics (e.g., B-IBI) (Cassin et al., 2005; DeGasperi *et al.*, 2009).

Example of specific indicator: Degree of Hydrolgic Alteration (DHA).

DeGasperi *et al.* (2009) have suggested an approach to estimate a reference hydrologic metric for any particular stream location under pre-development (i.e., fully forested) conditions. This can be presented as the 25th and 75th percentile of a particular hydrologic metric under pre-development conditions. Annual hydrologic metrics calculated from observed gauging station data can be compared to these values to calculated the degree of hydrologic alteration (DHA) from these reference conditions. By assigning high, medium, or low to ranges of DHA values (e.g., <25% is Low, 25-75% is Medium, and >75% is High), maps similar to the one shown below using High Pulse Range as the hydrologic metric can be created to illustrate the status of gauged streams throughout the region.

At present, the DHA is mostly conceptual and not a fully developed and tested indicator used by King County. Figure Wqty-6 is based on output from HSPF models simulating historic (forested) condition flows and comparing the predicted historic range of variability of High Pulse Counts to current observations of High Pulse Counts based on stream gauging records. An example High Pulse Count DHA analysis is provided in Figure Wqty-7 for Bear Creek (King County gauge 02e).

Evaluation of trends in DHA or degree of hydrologic alteration using the method ilustrated here for High Pulse Count would require routinely updating historic condition models (using the most recent long-term weather data) to generate the range of responses over a long period (e.g., 1949-2008) and complete daily streamflow data for the locations represented by the models. However, other approaches might be possible that would allow comparison of modeled current conditions (using the most recent land cover data) and comparison to historical condition model results.

Technical issues aside, analysis of long-term gauging records in urbanizing basins demonstrate that indicators of flashiness are responding as expected to increasing amounts of effective (connected) impervious cover (i.e., high pulse count, duration, and range; R-B Index; and flow reversals trend upward and T_{Qmean} trends downward. As an example, trends in these six hydrologic metrics for a USGS gauging station on Mercer Creek in Bellevue, Washington is shown in Figure Wqty-8.

What is current status of hydrologic alteration? Modeling suggests that current patterns of land development have altered the hydrology of streams from pre-development conditions in ways that could have negative effects on stream biology (e.g., increase in occurrence of high-flow pulses).

What affects hydrologic alteration in Puget Sound? The benefit of comparing simulated historic and current condition modeling results is that the effect of climate is removed (the same weather data is used in both simulations) so land cover change (forest conversion and management activities that reduce the amount of effective impervious surface) are the only things that affect DHA. However, the effect of water management activities is not captured in this metric, nor is it easy to conduct trend analyses of DHA. However, comparison of annual (e.g., 2008) metrics to modeled historic variability might be amenable to trend analysis (e.g., percent of index stations in each year that are outside the expected range of variability), although the effect of interannual climate variability will weaken the ability to detect trends.

How does hydrologic alteration affect other aspects of the Puget Sound ecosystem? Hydrologic alteration affects human well-being by determining the amount of water available for human consumption and other uses. Streamflows affect species and food webs and the formation and maintenance of habitats. Water quantity can also affect water quality since it can drive circulation of marine waters and affect the distribution and concentration of pollutants in fresh and marine waters.

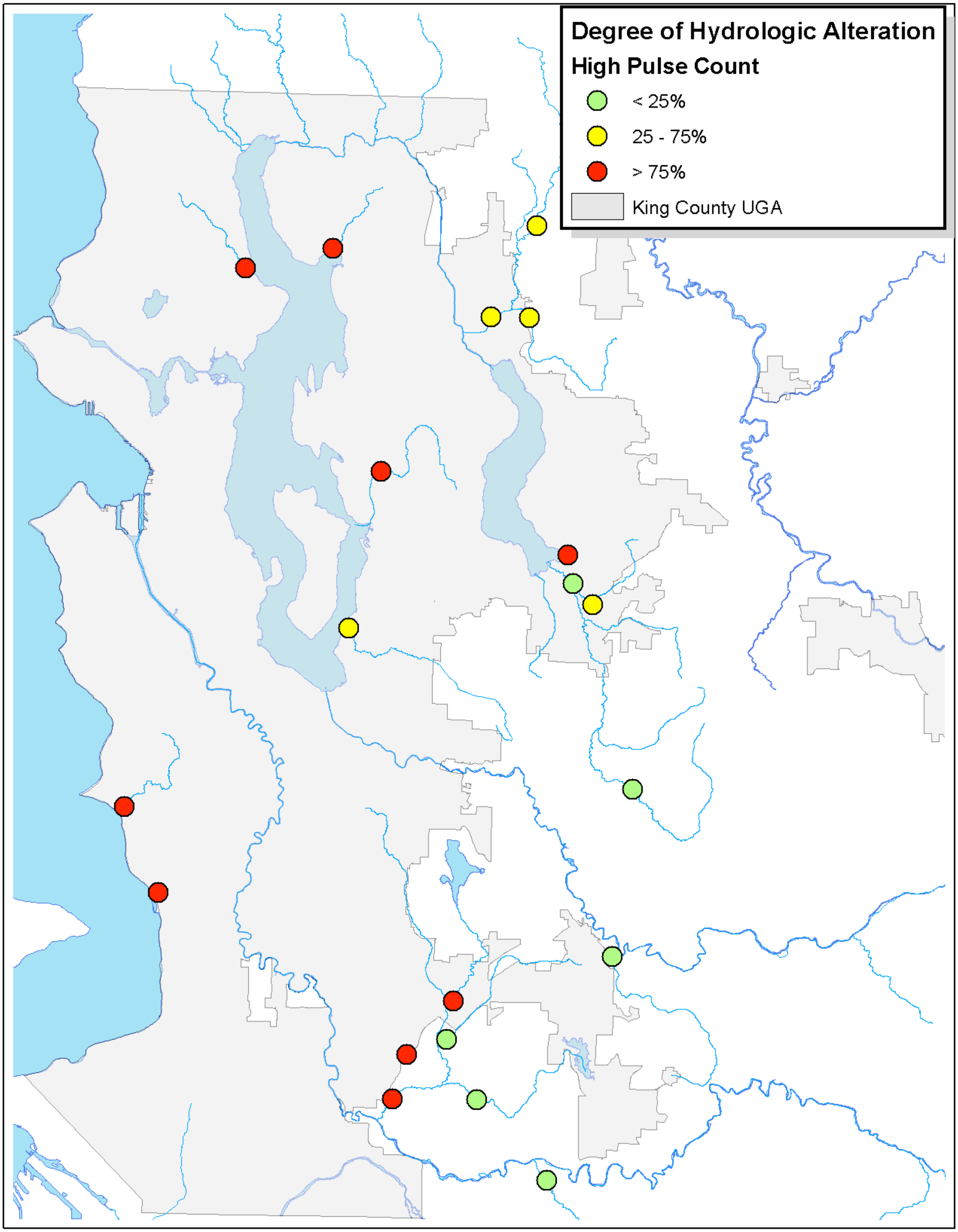

Figure Wqty-6: Demonstration of degree of hydrologic alteration

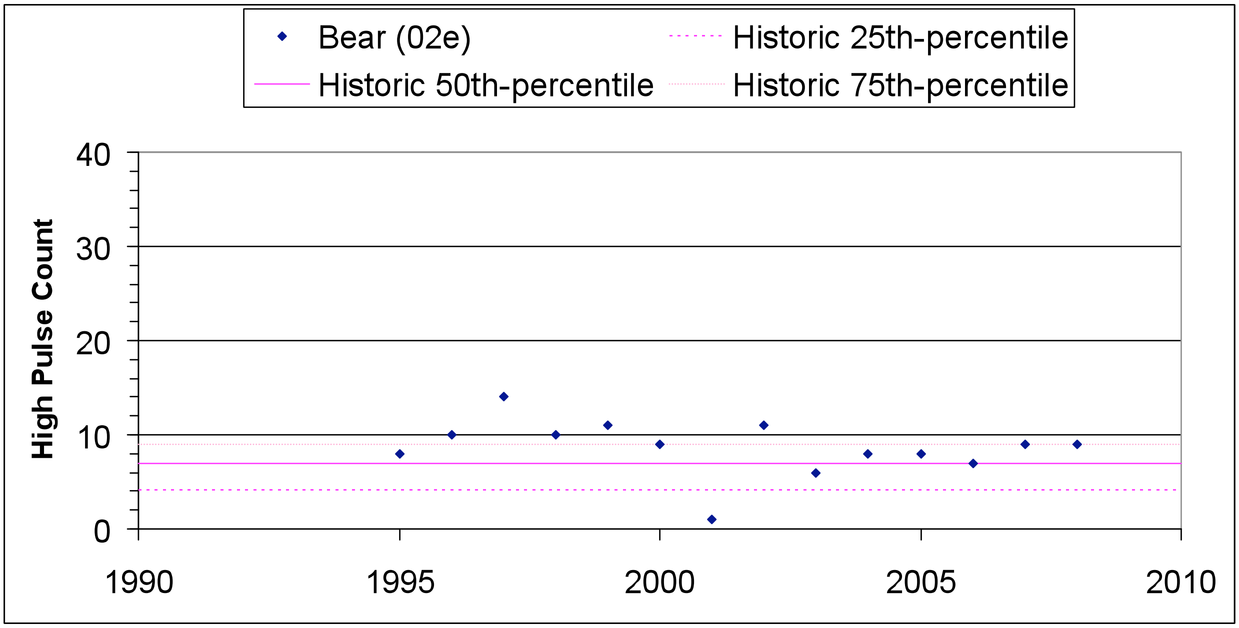

Figure Wqty-7: Demonstration of degree of hydrologic alteration calculation for Bear Creek (King County gauge 02e)

What do we still need to know about DHA? What are our plans for future reports?

There are a number of potential future improvements/enhancements that would improve the interpretation and utility of selected hydrologic indicators, including:

- expanded Puget Lowland stream gauging system designed to collect a statistically valid representation of land cover types and funded in a sustainable manner that will ensure the development of continuous long-term stream flow records. The challenge of the example presented above lies primarily in the limited extent and representativeness of the currently available stream flow data need to implement any hydrologic indicator for Puget Sound. In the Puget Sound Partnership's Phase I provisional indicator selection process (O'Neil *et al.*, 2008), an expanded flow gauging network was recommended to address this issue.
- Identify and develop models and methods for determining the degree of hydrologic alteration for a selected metric(s)
- Coordinate stream gauging and benthic invertebrate (and possibly other biological surveys – fish?) monitoring to provide for further evaluation of connections between alteration of flow regimes and biological communities.
- Further evaluation of relationship between B-IBI (and possibly RIVPAC scores) with co-located stream flow and benthic invertebrate data for the Puget Sound region

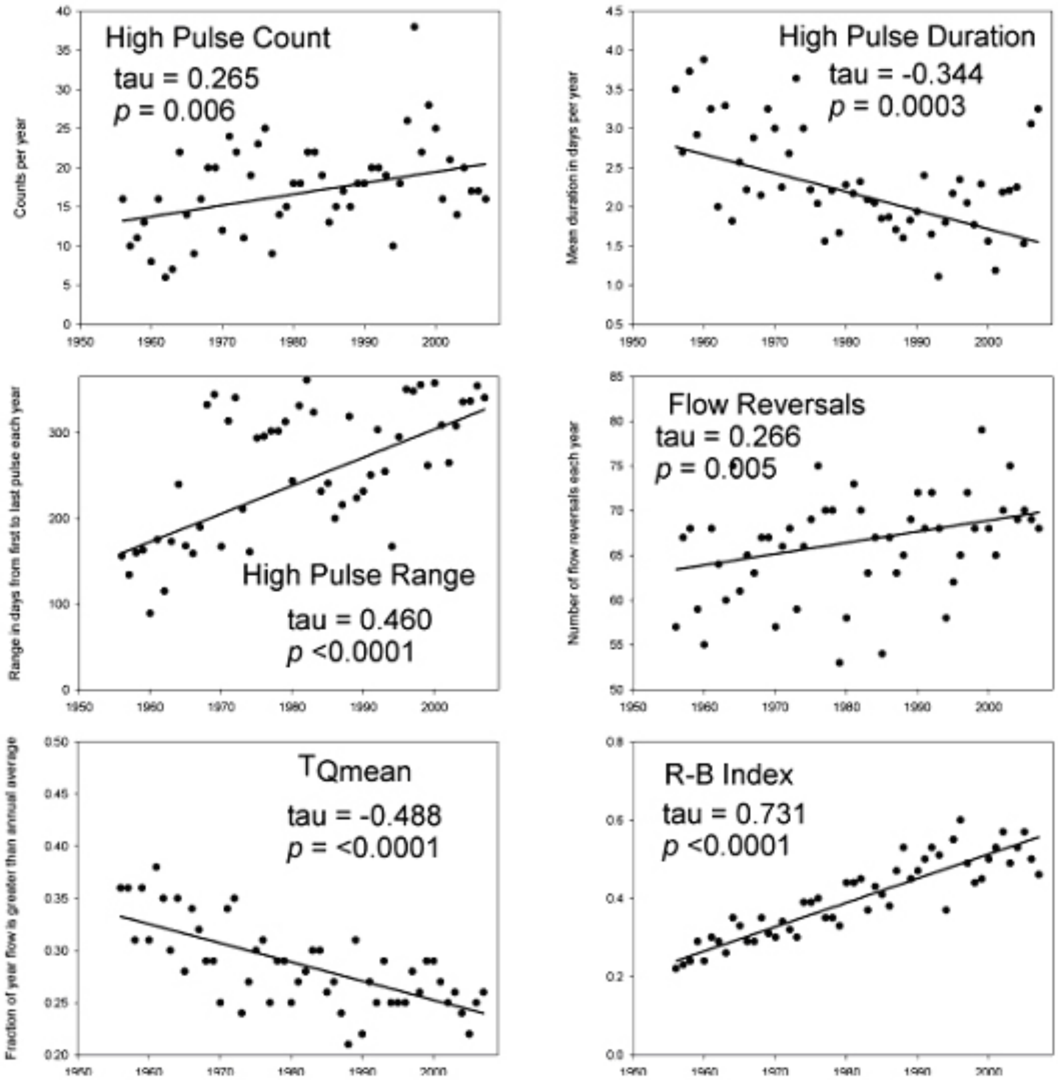

Figure Wqty-8: Trends in six hydrologic metrics (High Pulse Count, Range,and Duration; Flow Reversals, R-B Index, and T_{Qmean}) observed in Mercer Creek (USGS gauge 12120000).

6.1 What do we still need to know about monitoring water quantity in Puget Sound? What are our plans for future reports?

As mentioned above, USGS (2002) recommends that indicators of water quantity should cover a broader spectrum of water quantity issues in the Puget Sound basin than those represented by the indicators presented in this report. In future reports, the Partnership can improve water quantity reporting by including indicators that address ground water levels and storage, frequency and duration of high and low flows, storage in reservoirs, and human use of fresh waters. For example, although withdrawals and consumptive water use in Puget Sound's major basins is the primary element of the water budget for the large basins that we can influence, it is the most poorly understood water budget component.

With respect to improving those indicators presented here, future analyses focusing on unregulated streamflows should endeavor to compute high, low and timing statistics for each river by itself and then evaluate the relative coherence among watersheds for these statistics in order to avoid any potential bias present in analyses based on combined data derived from multiple rivers. Further, these analyses should expand the area covered to include flow data from the Skagit basin, one of the regions largest contributors of freshwater to the Sound, in order to see how closely the basins included in this analysis track Skagit Basin flows.

Another approach to assessing the status of unregulated streamflows could focus on reporting on low streamflows using 7-day low flows, a good standard metric subject to less influence by outliers than the extreme summer low flow day. To track management and regulatory effectiveness, reporting on the proportion of time streamflow meets required instream flow levels would be informative about the instream flow rules and also highly correlated with 7-day low flows.

In our urbanizing watersheds, primarily located in the lowlands below 1000’, streams are subject to significant changes in flow volume and flashiness of flows. For future reporting we should focus on expanding the Puget Lowland stream gauging system to provide effective monitoring of issues associated with altered land cover types (primarily development) on stream flow dynamics. This monitoring could be coordinated with benthic invertebrate monitoring to improve our understanding of the relationship between flow regimes, biological communities and habitat conditions.

7. Water Quality

Marine waters and freshwater can be degraded by the introduction of toxic chemicals, pathogens, nutrients and suspended sediments. This type of pollution can impair the beneficial use of waters by humans, aquatic life, and wildlife. A healthy ecosystem requires that levels of pollution do not harm human health or negatively affect the viability of species or habitats. The legislative goal for ecosystem recovery articulates the Partnership's interest in water quality as follows: "Fresh and marine waters and sediments of a sufficient quality so that the waters in the region are safe for drinking, swimming, shellfish harvest and consumption, and other human uses and enjoyment, and are not harmful to the native marine mammals, fish, birds, and shellfish of the region. "

In describing the status and trends of Puget Sound's water quality, the Partnership is focusing on:

- toxic chemicals in various media
- water quality indices for marine and freshwaters

The Partnership's 2009 indicators and reporting do not address chemical contamination of freshwater environments or the full array of water quality issues in marine waters. Continued development of indicators will support a more comprehensive evaluation of water quality status and trends in the future.

What is the current status of water quality (other than chemical contamination)? What affects water quality? Localized issues exist in certain areas of Puget Sound. Water quality is affected by pollutant loads, watershed and riparian habitat changes, and hydrologic, climate, and ocean conditions that affect flushing and density stratification of Puget Sound.

How does water quality affect other aspects of the Puget Sound ecosystem? Water quality affects almost every aspect of the Puget Sound ecosystem addressed by the Puget Sound Partnership. Chemical and pathogen contamination threats threaten seafood safety, safety of drinking water supplies, and affects human well-being, which depends on the provision of clean food and water. It also affects people's ability to use water for residential, agricultural, commercial and industrial purposes. Typical water quality problems such as those related to dissolved oxygen and temperature as well as chemical contamination affect the viability of species and food webs and is a key determinant of the quality of marine, estuarine, and freshwater habitats.

7.1 Chemical Contamination in Marine Environments

Discussion provided by Jim West and Sandie O'Neil, Washington Department of Fish and Wildlife, and Maggie Dutch, Washington Department of Ecology

Puget Sound and its inhabitants have been contaminated with a wide range of chemical pollutants. We monitor a short list of representative contaminants in the ecosystem, focusing on fish, invertebrate, and marine mammals that live in a broad range of habitats. We also measure these toxics in the habitats (such as sediments) where they reside, and evaluate how these toxics move from sediments or water into organisms, and measure the harm (such as disease) they cause. This section focuses on only a few of these "Indicators" which were selected as examples of where we have seen serious problems in Puget Sound, where we have seen recovery of organisms' health from reducing toxics, and how this science can inform our ecosystem managers to make the best decisions towards recovering Puget Sound's health.

Toxic contaminants have been released into the Puget Sound and its watersheds for decades by human activities. Because of concern over the possible harmful effects of these pollutants in the ecosystem, Washington's legislature established in 1989 the Puget Sound Assessment and Monitoring Program (PSAMP). PSAMP is a consortium of regional scientists from several agencies that has been monitoring and evaluating pollutants in Puget Sound since that time.

The factors that PSAMP considered in developing Indicators to evaluate the potential harm of pollutants in the ecosystem include:

- How toxic are they to organisms?
- What kind of harm do they cause?
- How long do they persist (i.e. do they break down to harmless chemicals easily)?
- Do they accumulate in organisms' bodies over time?
- How widespread are they in the ecosystem?
- Which parts of the ecosystem do they occur in?
- Which species are at greatest risk?

PSAMP scientists selected indicators based on these factors that include: (1) sediments, which give us a broad picture of how toxic bottom habitats might be, as well as where contaminants have accumulated in the system; (2) benthic, or seafloor-oriented fish, which tell us how contaminants move from the sediment reservoir to organisms; and (3) pelagic, or open-water fish or marine mammals, which that tell us how toxics move from the water to organisms.

PSAMP monitors hundreds of individual chemicals in sediment and organisms; in this report we summarize selected recent findings for three major classes:

> PAHs — polycyclic aromatic hydrocarbons, or simply "hydrocarbons", originate from oil spills or burning fuels or other organic material persistent in sediments. They cause liver cancer and other diseases in fish.

PCBs – polychlorinated biphenyls; synthethic industrial chemicals banned for production and use in the 1970s persist in the environment accumulate and biomagnify in organisms. Highest levels are found in top predators.

PBDEs – polybrominated diphenyl ethers, invented for use as flame retardants chemically similar to PCBs, with similar properties.

EDCs -- Endocrine Disrupting Compounds; a large group of chemicals from multiple sources including: medicines or pharmaceuticals personal care products e.g., soaps and shampoos a wide range of physical properties in the environment may disrupt physiologial processes such as growth and reproduction may cause feminization of male fish and altered reproductive behaviors in females.

These contaminants enter Puget Sound from a huge number of sources, carried there by by stormwater, river runoff, industrial effluents, sewage treatment plants, the atmosphere, and others. Once in the Sound, these molecules typically attach to particles in the water. Some of these particles sink to the seafloor and become part of the sediments, contributing to the reservoir of toxics there, and some particles, such as living bacteria, plankton,and other microorganisms may be consumed by any number of organisms, resulting in the enty of these toxics into the food chain (Figure Wqual-1). Contaminant molecules that bind to particle and sink to the sediments may also enter the food chain via benthic, or seafloor organisms, or may be buried by subsequent sedimentation.

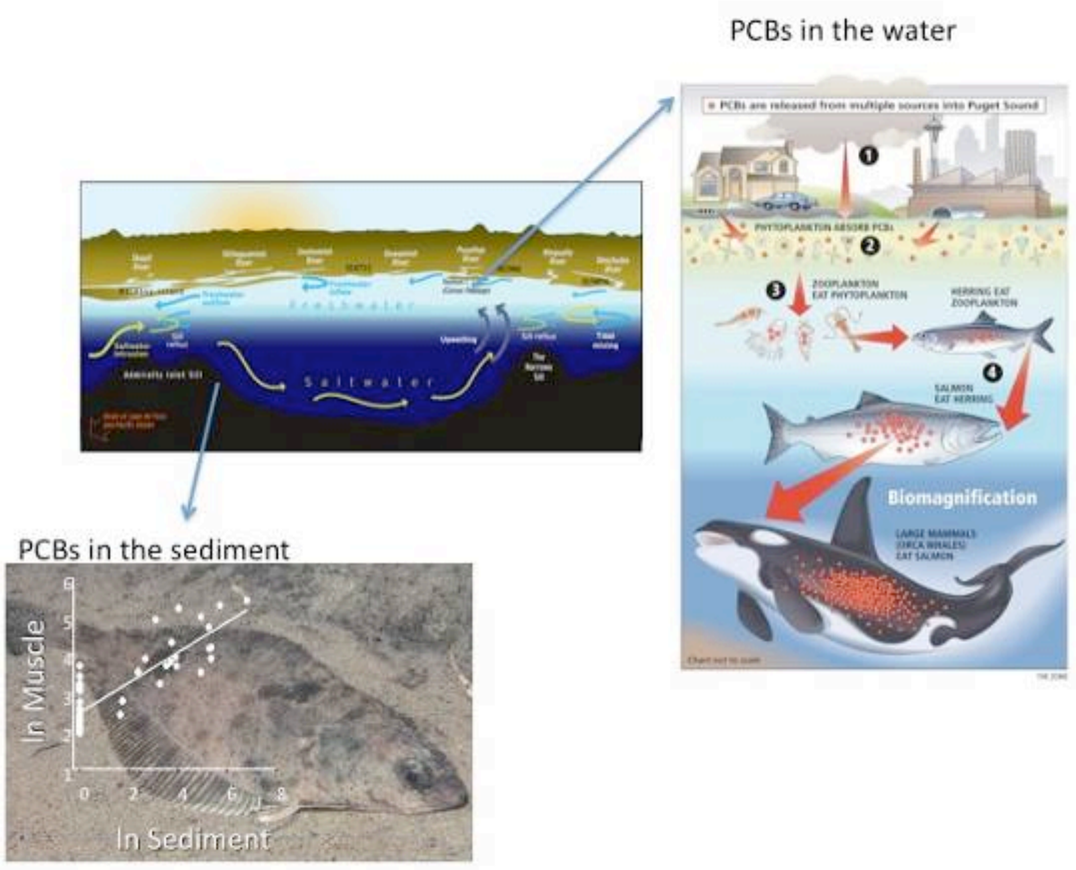

Figure Wqual-1: Sources and distribution of chemical contaminants in the marine environments of Puget Sound

INDICATOR: Contaminants in benthic environments - PAH in English Sole

Data and analysis provided by Jim West and Sandie O'Neil, Washington Department of Fish and Wildlife, Maggie Dutch, Department of Ecology

English sole, one of PSAMP's long-term indicator species, has shown us that PAH contamination may be on the decline in Elliott Bay, one of Puget Sound's most polluted bays. In the late 1990s, 20 to 40% of these bottom-feeding flatfish exhibited liver cancer related to PAH contaminants they are exposed to from consuming contaminated prey in the sediments where they live (solid line, Figure Wqual-2). In the following ten years, liver disease dropped dramatically in the population we have monitored; currently these fish show no more liver disease than those from our cleanest habitats. Also during this ten-year period, one measure of exposure to PAHs (i.e., PAH metabolites in Englis sole bile) declined significantly (dashed line, Figure Wqual-2).

This recovery of one aspect of English sole health may be related to reductions in PAHs from Elliott Bay sediments. Ecology's long-term monitoring studies in Elliott Bay showed a significant decline in sediment PAHs across the time period where we observed improvements in English sole health, especially in inner harbor areas where their population is monitored (Figure Wqual-3) (Partridge et al., 2009). We don't yet know how or why PAHs have declined; a number of sediment cleanup or capping activities have occurred in Elliott Bay during this time period, which may have been effective in protecting its inhabitats from exposure to pre-existing PAHs. Alternatively, new PAH inputs to Elliott Bay from stormwater, aerial deposition and other sources may have declined.

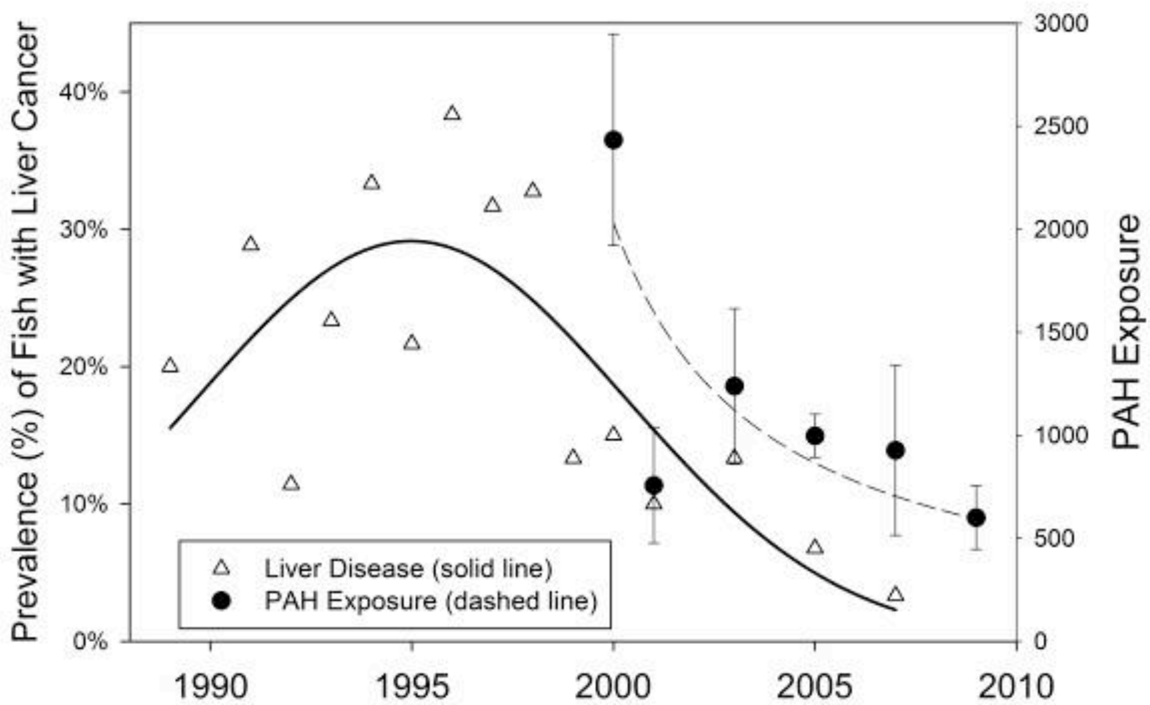

Figure Wqual-2: Liver disease and PAH exposure in English sole from Elliott Bay (Seattle)

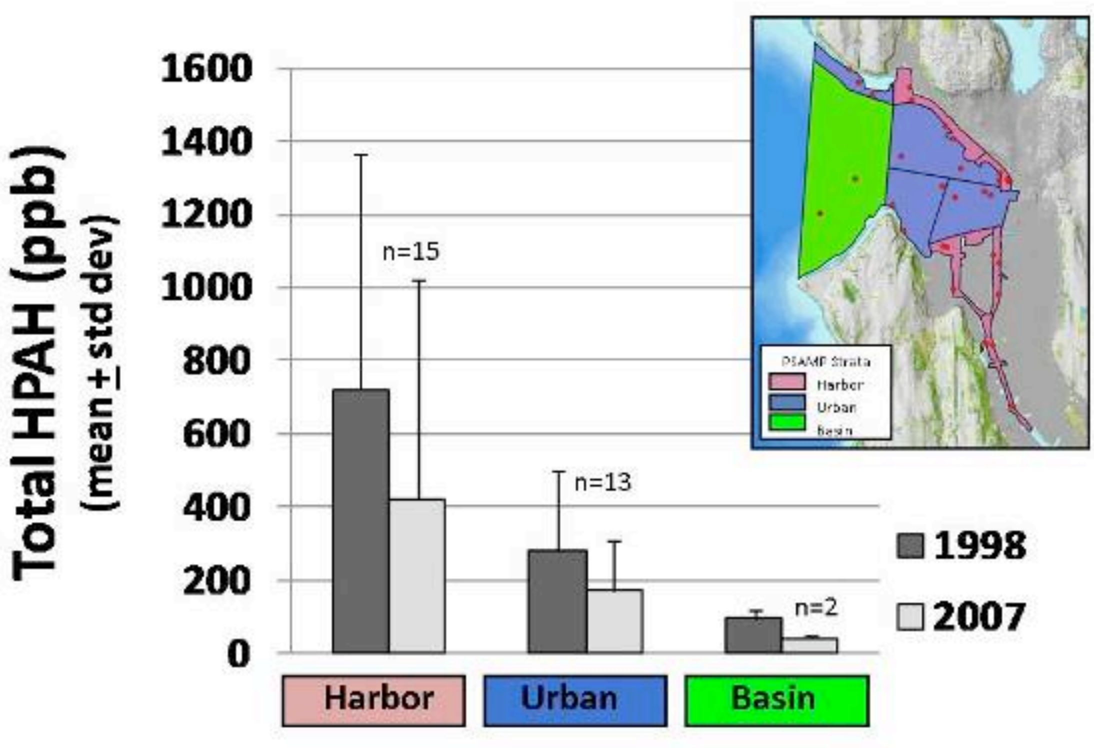

Figure Wqual-3: Change in high molecular weight PAH concentrations in Elliott Bay from 1998 to 2007. Bay is divided into three strata types – harbor, urban, and basin – developed for the PSAMP sediment monitoring component.

This recovery mirrors a remediation that was conducted in Eagle Harbor, a Superfund site located several miles away, across the Sound from Elliott Bay (Myers et. al., 2008). Sediments contaminated with PAHs at that location were covered over with clean sediments to sequester the PAH contamination. After three years of the final capping work, English sole in Eagle Harbor showed an 80 % reduction in liver cancer, and their PAH exposure metric showed a decreasing trend.

These two cases illustrate what appears to be an effective recovery strategy for fish health in a benthic species, related to their exposure to one class of toxic contaminants. Long-term monitoring of these sites will tell us whether this is a permanent recovery.

INDICATOR: PAH, PBDE, PCB and mercury in Puget Sound marine sediments

Data and analysis provided by Maggie Dutch, Department of Ecology

Although PAH levels have decreased in Elliott Bay over the past decade, levels of certain contaminants continue to exceed Washington State Sediment Quality Standards (SQS) around the Sound, most noticeably in the central Sound. These standards, adopted as part of Washington's environmental regulations, define levels at which various chemicals present in sediments become harmful to marine life (Washington State Dept of Ecology, 1995).

Concentrations of chemical contaminants in sediments have been measured in eight monitoring regions throughout Puget Sound. Highest concentrations are measured in and near urban embayments, are lower in basins, passages, and rural areas, and vary between geographic regions (Weakland et al., 2009). Contaminant levels, measured from over 500 stations between 1997 and 2008 , are displayed for PAHs, PCBs, PBDEs, and selected metals for each Puget Sound region in Figure Wqual-4. The number of stations with values exceeding SQS is also displayed.

POSSIBLE FUTURE INDICATOR: Endocrine disrupting compounds in English Sole

Data and analysis provided by Jim West, Washington Department of Fish and Wildlife

Although liver disease has declined in Elliott Bay's English sole, long-term PSAMP monitoring has shown that these same fish suffer from reproductive problems related to a different class of toxic contaminants, endocrine disrupting compounds (EDCs). Male English sole sampled from 5 Elliott Bay locations from 1997 to 2003 showed signs of becoming feminized (more than 50% in two sites, Figure Wqual-5) and females from these areas exhibited abnormal timing in their reproductive cycle.

In this case, our fish indicator species, English sole, has brought to our attention significant pollutant-related harm before we know which of the many EDCs that are present in Elliott Bay might be responsible. Current studies at NOAA Fisheries are focusing on which EDCs might be disrupting reproduction in these fish.

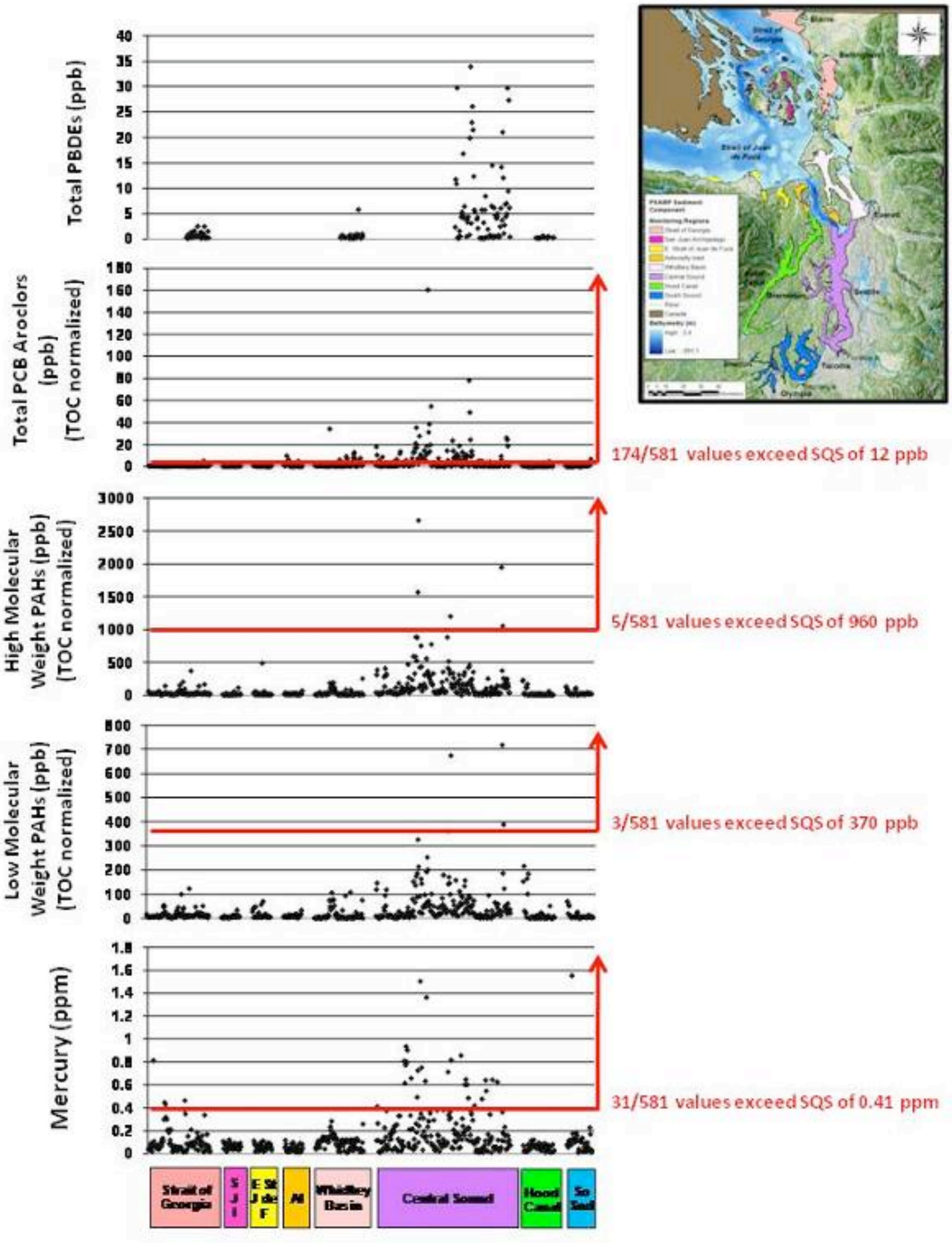

Figure Wqual-4: Status and spatial distribution of selected chemical contaminant concentrations in Puget Sound sediment monitoring regions (1997-2008)

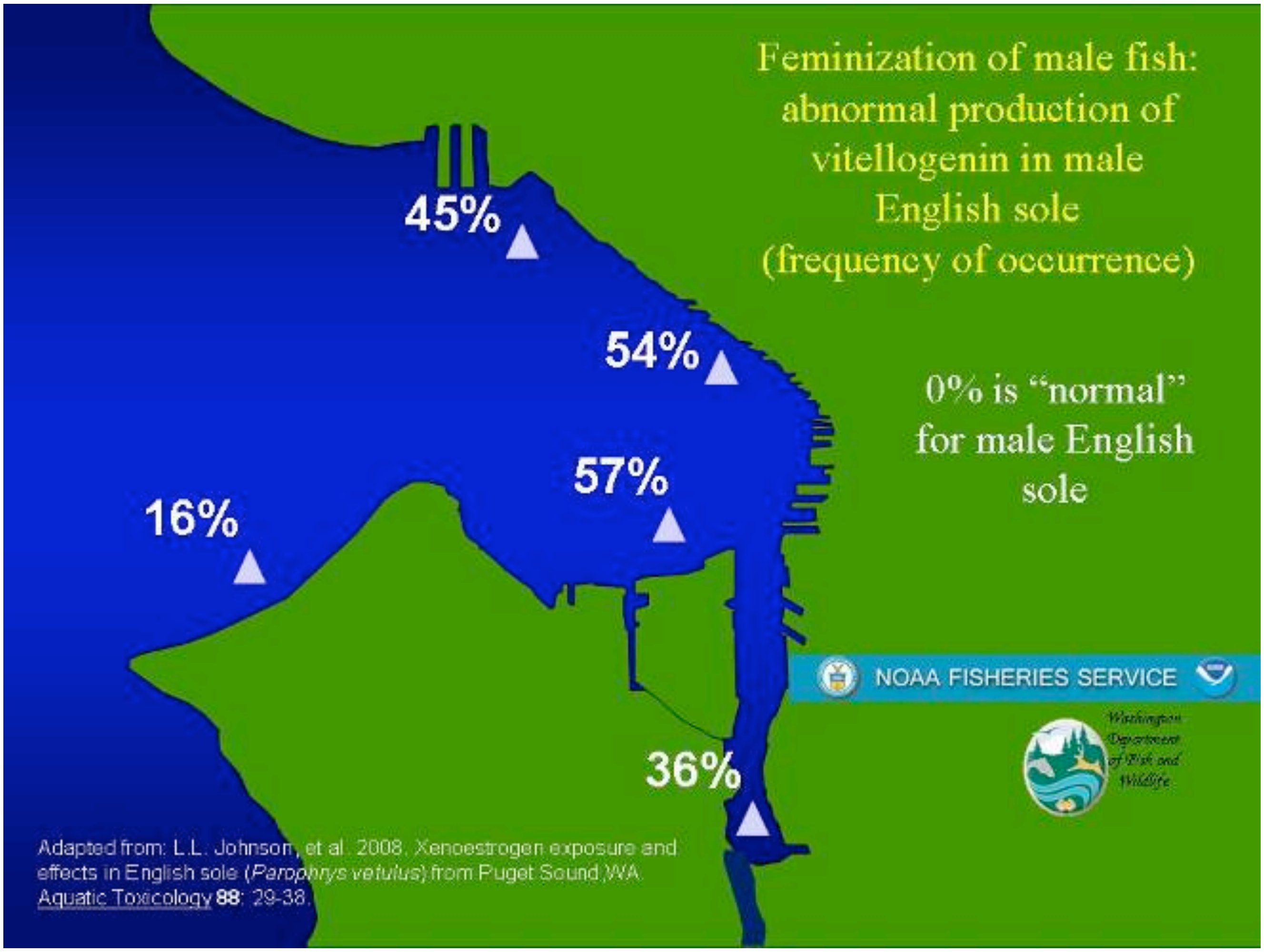

Figure Wqual-5: Endocrine disrupting chemicals in Elliott Bay English sole

What is the current status of chemical contamination in benthic environments? Though PAH levels and English sole liver disease have declined in Elliott Bay over the past ten years, a problem still exists with this group of contaminants because concentrations still exceed Washington State sediment quality standards.

What affects chemical contamination of benthic environments? Chemical contamination in Puget Sound's benthic environments reflects the remants of historic loads and current day loads. For PAHs historic and current day contamination might arise from combustion of oil and/or wood and spills or seeps of oil or petroleum products. An improvement similar to that reported for Elliott Bay was seen in Eagle Harbor in response to contaminated sediment site clean up but cause of the improvement in Elliott Bay has not been investigated.

INDICATOR: PBDEs (Flame Retardant Chemicals) in Pacific herring and harbor seals

Data and analysis provided by Jim West and Sandie O'Neil, Washington Department of Fish and Wildlife

Herring populations in Southern and Central Puget Sound have for the past eight years exhibited levels of PBDE flame retardant chemicals two to three times greater than those from the less urbanized Northern Puget Sound (Figure Wqual-6). This result mirrors our observations of other persistent organic pollutants in herring such as PCBs, illustrating how pelagic food webs can be contaminated by their proximity to human sources.

Currently, PBDE levels in herring from Puget Sound are roughly 30% of their PCB levels; however PBDEs are projected to increase, whereas PCBs have declined in many marine species since the ban on their use in the U.S. in 1976 (not shown here). PBDEs were already present in one northern Puget Sound herring population by 1994; however any PBDE trends we have observed in herring since that time are weak or insignificant. A longer PBDE time series from harbor seals, a major predator of herring, indicate that PBDEs were probably rare in the pelagic food web in the early 1980s, but rapidly increased at least through 2004 (Figure Wqual-6).

Herring have shown us that the Central and Southern Puget Sound basins have been receiving greater loads of this relatively new contaminant, especially over the past two decades, than less urbanized or developed regions. These results, combined with current research on regional patterns of PBDE uptake by marine plankton (herring's food source), will help us to understand how and where such contaminants enter Puget Sound's ecosystem. This in turn will help us to develop better strategies aimed at preventing PBDEs and other pollutants from being taken up by Puget Sound's food chain.

What is current status of chemical contaminants in pelagic environments? Flame retardants have only recently been recognized as a class of compounds that are increasingly showing up in aquatic ecosystems. Other contaminants, such as PCBs, which persist in the environment as a legacy of historic uses, are present but not increasing in pelagic food webs. Due in part to difficulties in measuring chemical contaminants in pelagic environments, little information exists about concentrations of many classes of pollutants, including pharmaceuticals, personal care products, flame retardants other than PBDEs and plasticizers.

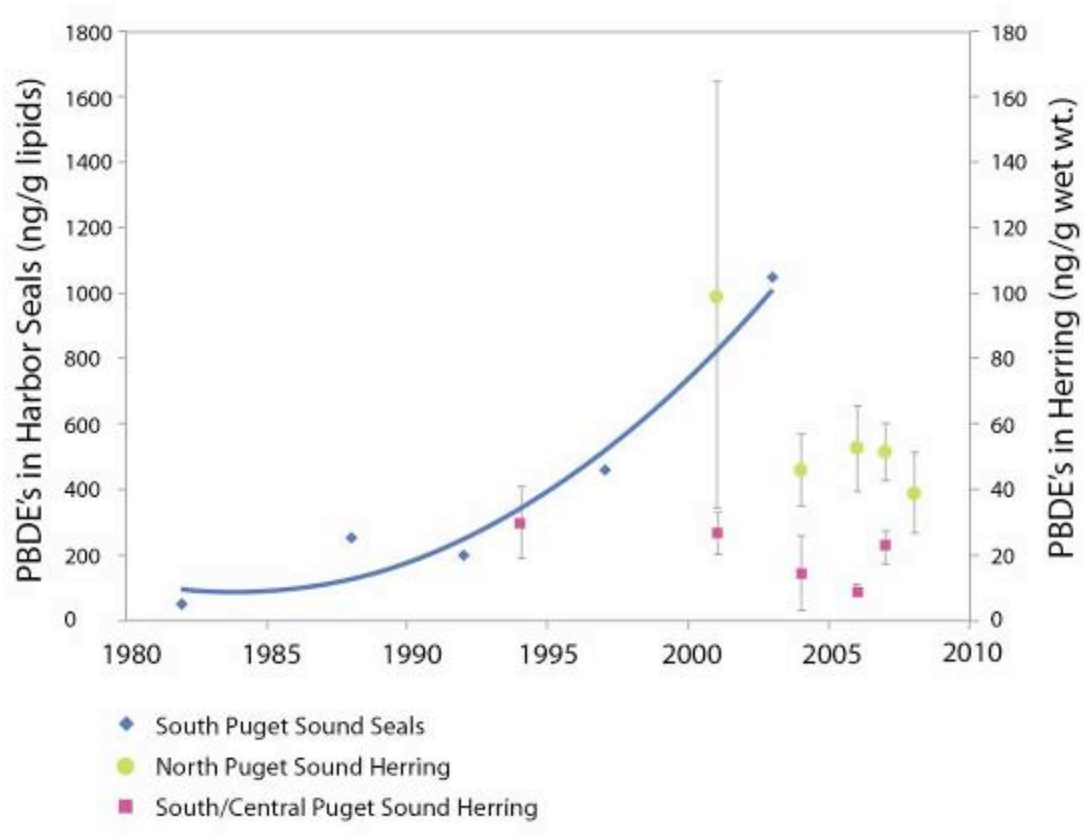

Figure Wqual-6: PBDEs in harbor seals and Pacific herring in Puget Sound

7.2 Water Quality in Fresh and Marine Waters

INDICATOR: Spatial distribution of hypoxia in Puget Sound

Data and discussion provided by Christopher Krembs, Washington Department of Ecology, and Kimberle Stark, King County. [3]

Dissolved oxygen (DO) is critical for supporting the life of marine species. Water holds less oxygen than air and concentrations can vary between sites, between different water masses, with depth, with tides, and within a day and the seasons. The concentration of oxygen is the result of a delicate balance between many processes including changes in water temperature the consumption of oxygen by organisms as well as chemical processes, the production by aquatic plants, the atmosphere-ocean oxygen exchange, and ocean currents.

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[3] Review provided by Jan Newton (UW).

Low oxygen concentrations (hypoxia) can be temporary or chronic and stress the environment according to severity and duration of the event. Factors resulting in hypoxia include: (1) the increased buildup and decay of organic material due to optimal algae growth conditions (sunlight and nutrients); (2) changes in ocean properties that lead to local accumulation of organic material and subsequent microbial oxygen consumption; (3) intrusions of water with low oxygen content, e.g. upwelled ocean water; and (4) stratification, which often occurs in stagnant brackish water near rivers where oxygen cannot be replenished from the atmosphere and decaying organic material continues to accumulate near the bottom.

These locations often coincide with places of human activity and use of natural resources, and are thus under the combined influence of land, ocean and human processes. In addition, low DO can hasten the release of toxins and nutrients from sediments into the water column.

Many of the factors affecting oxygen concentrations in Puget Sound are influenced by the bathymetry and the dynamic watersheds that discharge into Puget Sound. Other factors, such as nutrient loading and river flow alteration, are directly influenced by human actions and compounded, albeit on a large scale, by climate change. It therefore remains a key goal and challenge to address the cause and remediation of low oxygen in the marine environment appropriately.

Puget Sound, with its fjord-like topography, shallow sills, bays and estuaries, displays a very complex pattern of chronic hypoxia (Figure Wqual-7). Chronic hypoxias are found in Hood Canal, Budd Inlet, Sequim Bay and increasingly in areas of Whidbey Basin and Quartermaster Harbor. These patterns are partially caused by local factors, such as eutrophication and poor water circulation resulting from large-scale oceanographic processes such as coastal upwelling and large scale climatic variability such as the Pacific Decadal Oscillation (PDO). As a result, oxygen concentrations greatly fluctuate over the years yet consistent problem areas remain and observations of low oxygen concentration become more numerous in restricted areas.

What the current status of marine water? What affects marine water quality?

Based on hypoxia alone, this is a fairly localized problem but with areas of strong concern. Natural processes, such as local biological production driven by ocean and climate driven influences, are responsible for much of the hypoxia observed in Puget Sound, but human contributions of excess nutrients in some areas are exacerbating the duration and intensity of the hypoxia.

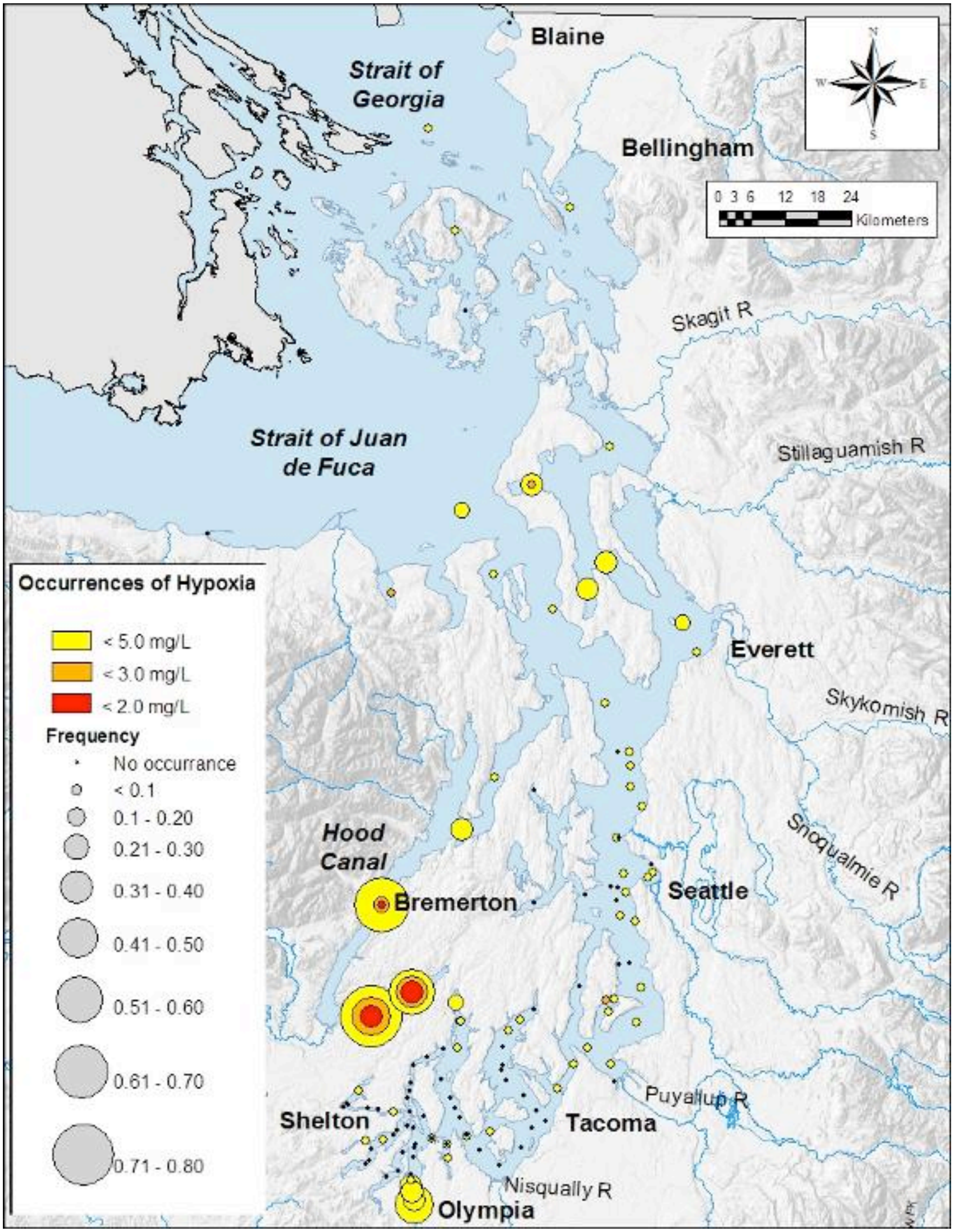

Figure Wqual-7: Surface map of Puget Sound illustrating the spatial patterns of chronic low oxygen concentration from 2003-2008
An upper concentration threshold of 5 mg of oxygen per liter was selected in accordance with WA Department of Ecology's marine water quality oxygen criteria indicating a level at which marine organisms begin to become stressed. Fish and other organisms may start to die when levels fall to less than 2 mg oxygen per liter.

What do we still need to know about marine water quality in Puget Sound?

Quantitative studies and continued assessment of the importance and interactions of factors that contribute to low oxygen and degradation of water quality in context of climate change are central to the successful understanding and management of the marine environment. A new marine water quality index provided by the Washington State Department of Ecology will be used to track and report changes in Puget Sound's water quality and other properties in the context of a suite of important environmental factors including near shore and large scale oceanic and climatic factors.

INDICATOR: Fresh water quality index

Data and analysis provided by Dave Hallock, Washington Department of Ecology

In 2008, most freshwater monitoring stations received Water Quality Index (Hallock, 2002) scores of "fair" or "good" (Figures Wqual-8 and -9). Stations with the lowest scores tended to have high nitrogen concentrations. Nitrogen contributes to algae growth, particularly in the marine environment. Some stations, like the Skagit River at Marblemount, were considered "fair" rather than "good" because of naturally occurring sediment from glaciers in the watershed. No long-term stations had "poor" overall WQI scores in 2008. Leach Creek near Steilacoom, where bacteria and nitrogen concentrations were both extremely high, was the only station we monitored in 2008 that received a "poor" score.

Since 1995, overall water quality in major Puget Sound rivers has been steady or even improving (Figures Wqual-9 and -10). Assessment of trends requires a consistent set of stations from year to year, hence only WA Department of Ecology's long-term monitoring stations are included in the analysis. Annual bar plot of percent of stations in good/fair/poor categories (Figure Wqual-9) is not a sensitive measure of trends because it requires a station's score to cross a category boundary before change is seen. A plot of the average of scores (Figure Wqual-10) is more sensitive to trends but doesn't provide information about numbers of stations with good/fair/poor status. WA Department of Ecology's long-term monitoring stations are sentinel stations, which are downstream of most human impacts. Trends at these stations may reflect the good work being done by individuals and organizations to protect water quality in watersheds all around the Sound. As the population in Puget Sound continues to grow, so will the pressures on our aquatic resources.

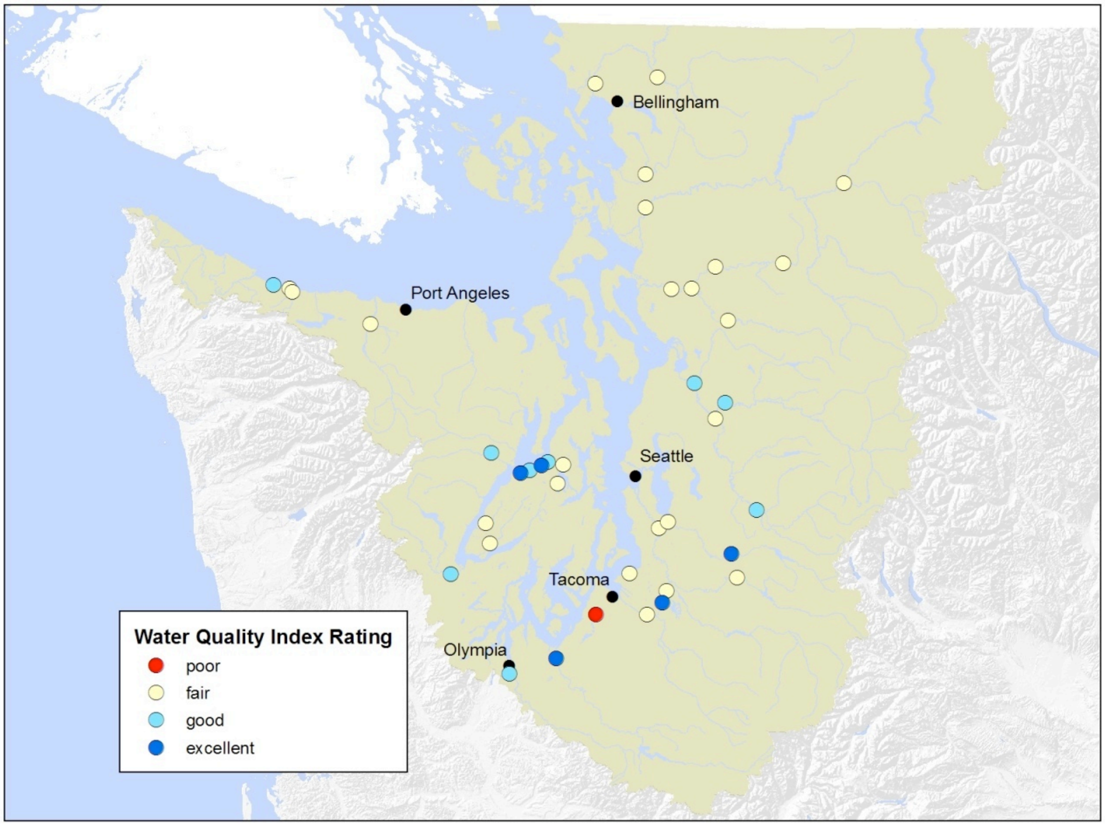

Figure Wqual-8: 2008 water quality index ratings for freshwater stations in the Puget Sound basin

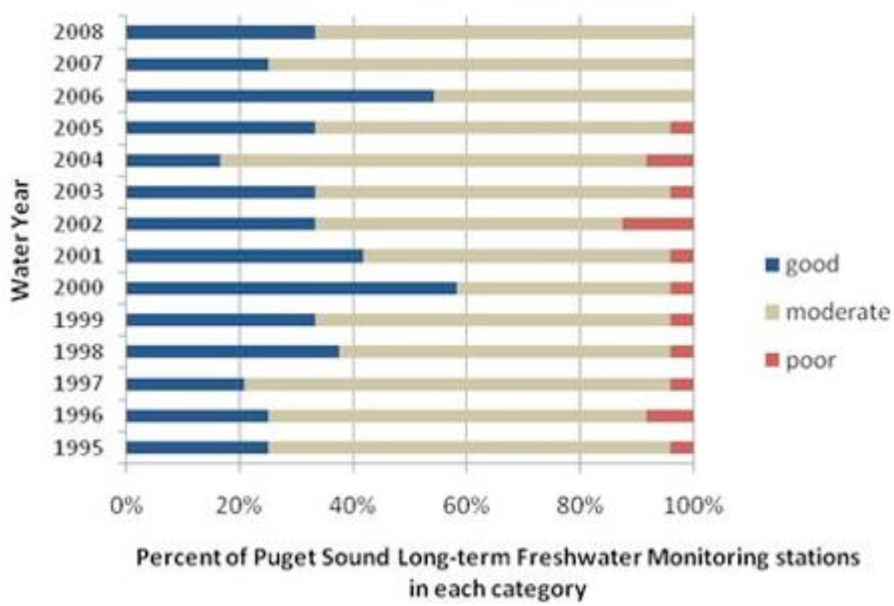

Figure Wqual-9: WQI category rating over time at Puget Sound's long-term freshwater monitoring stations

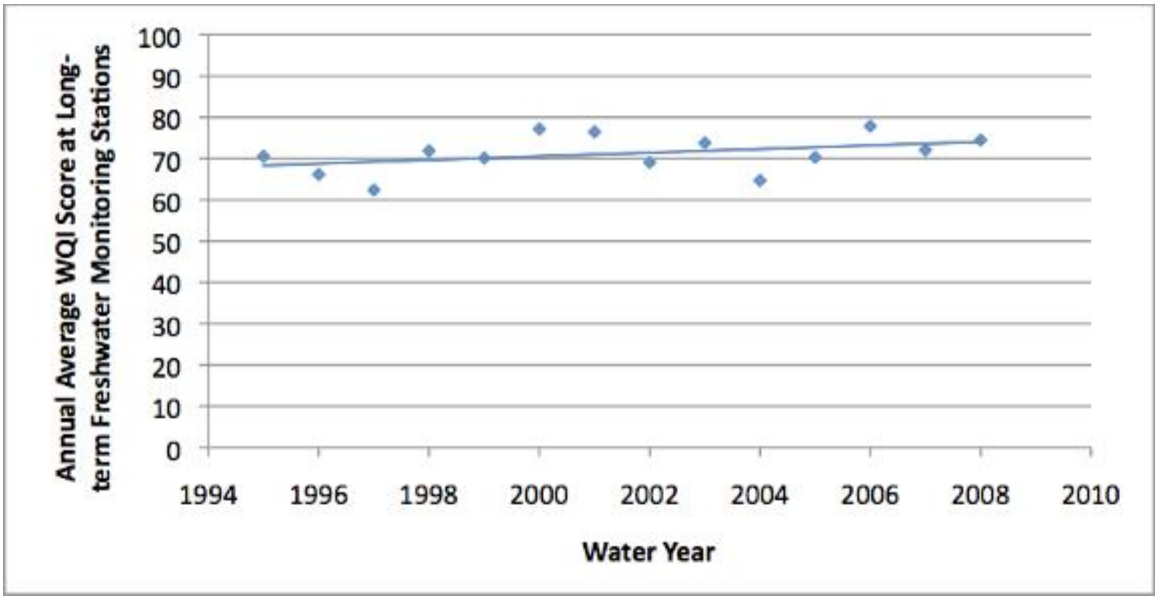

Figure Wqual-10: Average freshwater WQI scores at Puget Sound region long-term monitoring stations

What is the current status of freshwater quality? Freshwater quality is quite variable, with some rivers, streams and lakes showing impacts and others not. The majority of the long-term sites are rated as moderate with respect to water quality. There may be a slight trend to improvement in the overall rating of Puget Sound rivers and streams.

What affects freshwater quality? Freshwater quality is affected by pollutant loadings from point and non-point sources and by alteration of watershed and, especially, riparian habitats.

What activities and management activities affect the freshwater WQI? All human activities have the potential to affect the quality of our waters. Impervious surfaces from roads, parking lots, and homes can change flow regimes, increase temperatures, and carry contaminants to surface water. Sewage, even when treated, adds nutrients, especially nitrogen, to our waters. Livestock can contribute fecal contamination and more nutrients. The removal of riparian vegetation increases water temperatures and adds sediment. Draining wetlands removes natural filtration systems. Management activities are designed to reduce or mitigate the impacts of human actions on water quality.

What do we still need to know about freshwater WQI? What are our plans for future reports? Many organizations collect water quality data in the Puget Sound area. Data consistent with WQI calculations should be included in future reports to give as broad a view as possible of the status of freshwaters in Puget Sound. Participation in WA Department of Ecology's "Side by Side" program will allow results collected using different procedures and methods to be compared.

Data summarized in this report are from stations selected for monitoring for specific reasons. As a result, conclusions about average watershed health may be biased, especially towards streams lower in the watershed. In future reports, data from probabilistic monitoring being implemented by WA Department of Ecology and others (see discussion in the habitat section of a new freshwater habitat quality index from the new proababilistic monitoring program) may allow an unbiased assessment of the status of Puget Sound's freshwater resources.

In addition, in the future presentations on the freshwater WQI could be adjusted to account for interannual changes in discharge. Similar graphs of key parameters captured in the freshwater WQI could also be made.

7.3 What do we still need to know about monitoring water quality in Puget Sound? What are our plans for future reports?

To ensure water and sediment quality support species, habitats, and human health and well-being we must improve our understanding of the effects of both legacy and emerging contaminants. For example, we must develop a better understanding of the short-term and potential long-lasting effects of PBDEs (fire retardants) and other chemicals of emerging concern on ecosystems. Further, as ecosystem processes shift in response to climate change and development pressures and practices, we will also need to increase studies of contaminant transport and accumulation as related to ecosystem processes such as flushing rates in Puget Sound.

Development of effective management approaches and solutions to specific contaminant issues requires that the Puget System is assessed holistically — freshwater, marine water, and climate. Evaluation of current status, identification of recent and emerging trends will increase our understanding of water quality issues and allow identification of actions that will be helpful in protecting marine and fresh waters and the species that depend on these waters.

In particular, additional areas of study should include areas with sensitivity to nutrient loading and evidence of hypoxia. Focus on these areas will inform our understanding of anthropogenic causes or contributors to decreased water quality. Studies of long-term water quality trends in Puget Sound as a basin, how climate variation and climate change affect hypoxia, and how biota are being impacted will be essential to ensure development of a comprehensive management framework and specific management strategies that restores and protects the health of Puget Sound.

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