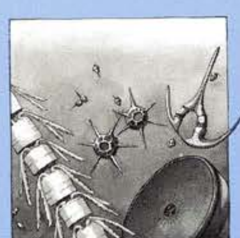
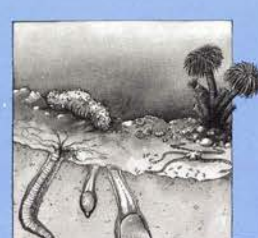
PUGET SOUND WATER QUALITY AUTHORITY

Puget Sound Update

FIRST ANNUAL REPORT OF THE PUGET SOUND AMBIENT MONITORING PROGRAM





Bill Curia

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FIRST ANNUAL REPORT OF THE PUGET SOUND AMBIENT MONITORING PROGRAM

May 1990

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SUMMARY

The Puget Sound region is a place of great scenic beauty and abundance of natural resources. It is the most frequently visited and heavily populated area of the Pacific Northwest. The Sound's attractions have led to rapid population growth, development, and industrialization. Over the past 100 years, the human population in the Puget Sound basin has increased 100-fold, and it is continuing to grow at a rapid pace. Development can lead to poor water quality, sediment contamination, and the degradation and destruction of fish and wildlife habitat; the decline and disappearance of valuable and cherished resources can result from these human activities.

In order to understand the threats which the Sound is facing now and will face in the future, it is necessary to examine the status of natural resources, how they change over time, and the environment that affects them. We also need accurate environmental information to determine whether our source control activities and cleanup efforts are effective. We have never established a consistent and comprehensive system for measuring the condition of Puget Sound and its watersheds, and for gauging the effectiveness of preventive and cleanup actions. The Puget Sound Ambient Monitoring Program (PSAMP) has been initiated to answer this need.

PSAMP is intended to monitor ambient, or background, conditions in Puget Sound, which include the cumulative effects of contamination and habitat degradation from many individual actions. PSAMP is not intended to measure the effects of specific discharges. PSAMP is a comprehensive, long-term monitoring program for measuring components of the Puget Sound ecosystem that might be affected by pollution. The program is achieved through the coordinated efforts of state government agencies, with support and cooperation from other government agencies, business, industry, volunteer citizen monitors, and the public.

The purpose of PSAMP is to characterize over time the condition of the water, sediments, plants, animals, and habitats in Puget Sound and its watersheds. This information will help water quality and natural resource managers make appropriate management decisions to protect and preserve the quality of the Puget Sound ecosystem. PSAMP data collection began in 1989 with investigators collecting samples for sediment quality, toxics in fish tissue, liver disease in fish, and contaminants in shellfish. State agencies are also carrying out some limited surveys for populations of marine mammals (harbor seals) and birds as well as investigations into marine and fresh water quality.

Puget Sound includes the waters of the Strait of Juan de Fuca east of Port Angeles and the Strait of Georgia to the Canadian border, Puget Sound "proper" (south of Admiralty Inlet), and the surrounding watersheds. The Straits of Juan de Fuca and Georgia provide the links between Puget Sound and the Pacific Ocean.

Developed estuaries in other parts of the country and abroad provide examples of breakdowns in the ecosystem due to degraded water quality, habitat loss, and chemical spills. These breakdowns include losses of fish, shellfish, and plant life, and foul-smelling algal blooms. Some similar disruptions are already visible in Puget Sound.

The health of Puget Sound is generally good, with serious contamination and degradation problems restricted to fairly small areas near the shorelines and urban bays. However, widespread destruction and contamination of natural shoreline areas has decreased the quality and quantity of critical fish and wildlife habitat. There are early warning signs of problems emerging in many areas, such as contaminated sediments, liver tumors in bottomfish, shellfish bed closures due to fecal contamination, and reductions in wild salmon runs and other populations of fish and wildlife.

Virtually no area of Puget Sound is pristine and free from contamination. The worst chemical contamination problems show up in the bottom sediments, where particles associated with toxic chemicals settle. The urban bays contain areas of the most contaminated sediments, which are associated with harm to biological populations living in the sediments, bottomfish disease, and contamination in the flesh of fish and shellfish.

During their 1989 survey, PSAMP investigators detected toxic chemicals (metals and organics) at all 50 sites in Puget Sound, with the highest concentrations in the urban bays. Rural bays and the deep basins of the Sound showed lower levels, although the deep basin sediments were found to have higher concentrations of certain organics than had previously been measured. The only Puget Sound sediments that were toxic to laboratory test organisms during the 1989 PSAMP survey were from Dyes Inlet in Kitsap County. Scientists looked for unusual patterns of bottom-dwelling animals in the sediment at the same 50 stations; most patterns that they found were probably the result of naturally occurring environmental factors. PSAMP managers need additional years of information to confirm these patterns.

The marine waters of Puget Sound are generally clean, but there may be many chemical contaminants in the water at low or immeasurable levels. Some water quality problems are already apparent in areas with restricted water circulation, and there are contaminated shellfish beds in many bays. During 1989 PSAMP investigators found fecal coliform bacterial contamination and elevated levels of dissolved ammonia in several South Sound bays. Both these pollutants are indicators of sewage contamination from sewage treatment plants (particularly LOTT in Budd Inlet), failing septic systems, agricultural runoff, and stormwater runoff.

Human activities may be responsible for changes in population levels of fish, marine birds, waterfowl, and marine mammals in Puget Sound. Some fish populations are declining, especially Pacific cod and other marine fish. Many species of marine birds appear to be thriving in the Strait of Juan de Fuca and near the San Juan Islands, but have almost ceased to breed in the Main Basin of the Sound. Some populations of waterfowl, notably the diving ducks like goldeneye, are declining, probably due to habitat loss. Some resident marine mammals like harbor seals are thriving in the North Sound, South Sound, and Hood Canal, but no longer breed in the Main Basin. Harbor porpoises are almost never seen south of Admiralty Inlet anymore.

The accumulation of toxic chemicals in the flesh of fish, shellfish, birds, and marine mammals should be taken as a warning sign of potential damage to our resources and as a threat to human health. During 1989 PSAMP investigators measured toxic chemicals in the flesh of bottomfish (English sole) from several locations in the Sound. They found metals and some organic contaminants in many locations, particularly the urban bays. Bottomfish from Sinclair Inlet in Kitsap County carried the heaviest load of toxic chemicals in their flesh. The highest levels of toxic chemicals seen in Puget Sound fish may pose a health risk to humans who consume them.

Shellfish in many areas of Puget Sound are contaminated by chemicals, bacteria, and paralytic shellfish poisoning (PSP). Public health officials have closed many areas to shellfish harvest due to these contaminants, both seasonally and year round. For example, the entire eastern shore of the Main Basin of the Sound, from Tacoma to Everett, cannot be certified for commercial shellfish harvest due to contamination from point source discharges. During 1989 PSAMP investigators detected fecal coliform contamination above the standard allowable for commercial shellfish harvest at three nonurban locations in the Sound: Walker State Park (near Shelton), Belfair State Park (Hood Canal), and Dosewallips State Park (Hood Canal). All three are affected primarily by nonpoint sources of pollution and are popular recreational shellfish beaches. PSP is a potentially deadly toxin caused by a naturally-occurring algae which blooms at unpredictable intervals in Puget Sound. Closures of shellfish beaches in Puget Sound due to PSP contamination vary each year. In 1988 and 1989 public health officials closed shellfish areas south of the Tacoma Narrows for the first time due to PSP.

There are very few areas of vegetated nearshore estuarine habitats left in Puget Sound. Over the past 100 years there have been great losses of nearshore eelgrass and salt marshes in the urbanized estuaries and heavy losses of nearshore and upland wetlands throughout the basin. As these losses continue, they eliminate more and more of the critical refuge, feeding grounds, and nursery areas for fish and wildlife. During 1988-89 PSAMP investigators have been examining ways to accurately measure the extent of the remaining nearshore estuarine habitat. They may use remote sensing techniques to inventory Puget Sound habitats in future.

The rivers and streams of Puget Sound suffer from many localized water quality problems, including habitat destruction, chemical contamination of fish flesh, and reductions in the populations of fish and wildlife supported by the freshwater corridors. During 1989 PSAMP investigators measured conventional pollutants at several locations on the 10 major rivers of the Puget Sound basin. They found fecal coliform bacteria that exceeded state water quality standards on the Samish and Nooksack rivers, and heavy particle loads on several rivers. These results imply that source control measures to reduce sedimentation in the watersheds are not particularly successful. Decreased levels of several water quality pollutants were also seen, including lower levels of fecal coliform bacteria, nutrients, and ammonia in the Green-Duwamish River, and lower ammonia levels in most Puget Sound rivers except the Skagit, Stillaguamish, and the Skokomish.

The ecosystem approach of PSAMP will give us the most accurate and cost-effective information on the status of Puget Sound waters, sediments, and biological populations. PSAMP managers will make some changes to the PSAMP design in upcoming years, based on information gathered in the first years of the program.

The PSAMP design concentrates largely on levels of contamination in Puget Sound sediments, waters, habitats, and biological populations, and generally does not address population estimates of Puget Sound animals. Further emphasis on biological population levels is needed in the future.

In 1990 the Washington State Legislature passed legislation that requires the implementation of PSAMP by state agencies. Funding has not yet been assured, however. There are many portions of PSAMP which are not currently funded, including estimates of marine mammals, birds, and the extent of estuarine nearshore habitat. Other portions of the program have inadequate funding to assess the status and trends of resources throughout the Sound, including contamination levels in fish, shellfish, sediments, and marine and fresh waters.

Without adequate information in these parts of the ecosystem, major changes in resource populations, levels of contamination, risks to human health, and environmental conditions could go unnoticed until a crisis strikes. Without PSAMP information, managers would be hampered from preventing the same problems from recurring in the future. The cost of future restoration of some of our unique and valuable marine populations could be extremely large. Other natural resources, particularly sensitive habitats, can never be replaced once they have been lost. Information collected by PSAMP about these resources and Puget Sound environmental conditions will play a critical role in preventing some of these losses.

INTRODUCTION

PURPOSE OF THIS REPORT

This is the first annual report of the Puget Sound Ambient Monitoring Program (PSAMP); it briefly describes PSAMP, explains the significance of each type of measurement, and provides initial interpretation of the results. The report provides a background on the history of contamination problems and solutions, as they have unfolded in Puget Sound, and explains the interaction of different parts of the Sound's natural ecosystem. In addition, this report touches on the significance of contamination, source control and prevention programs, cleanup activities, and the protection of critical habitats.

PSAMP is intended to monitor ambient, or background, conditions in Puget Sound, which include the cumulative effects of contamination and habitat degradation from many individual actions. The scientists who designed PSAMP purposely located sampling stations away from the influence of single sources of contamination. The results of PSAMP cannot be used to estimate the amount of contamination or change that is occurring as the result of individual discharges, development projects, or other human-induced disturbances. PSAMP was developed to collect baseline and long-term information which will be used to detect long-term trends and changes in the Puget Sound environment.

This report is organized around the many parts of the Puget Sound ecosystem which are monitored by PSAMP. The sediments, marine waters, fish, shellfish, marine mammals, birds, nearshore habitat, and freshwater rivers and streams of the Puget Sound basin are described and 1989 PSAMP information is discussed, where it is available. We have attempted to describe the results of PSAMP in pictures and graphics wherever possible.

We compare data that have been collected in Puget Sound over time to the current PSAMP data, and discuss the implications of the information. Data collected by other organizations in the basin, such as fisheries harvest, are discussed as they relate to PSAMP results. Finally, we draw conclusions about the overall status of Puget Sound waters, sediments, and biological populations, and make some recommendations for future monitoring.

PUGET SOUND IS VALUABLE – AND THREATENED

Figure 1. Puget Sound Basin.

The Puget Sound basin (Figure 1) is the most frequently visited and heavily populated area of the Pacific Northwest. Visitors and residents alike revel in the natural scenic beauty and abundance of marine resources that inhabit the Sound and its watersheds. The variety of plants and animals—including salmon, bottomfish, crabs and shrimp, waterfowl, marine birds, and marine mammals—as well as the numerous opportunities for boating, fishing, shellfishing, beachcombing, and hunting, make the Puget Sound area of particular importance to the economy of the state, the region, and the nation.

The very attractions that make Puget Sound and its watersheds a desirable place to live and visit have led to rapid population growth and development. Over the past 100 years, the population in the Puget Sound basin has increased 100-fold, and it is continuing to grow at a fast pace. Effects of increased human development threaten to degrade the quality of many of the Sound's sediments, biological resources, and pristine waters. Resource managers and decision makers have been aware of the growing threats to the health of Puget Sound for years, and have been taking increasingly aggressive action to protect the area. The protection of vulnerable fish and wildlife habitats, the cleanup of the most contaminated areas, and source control programs to limit the discharge of toxic chemicals and other pollutants into the Sound are gaining increasing attention and support. These actions are critical if we are going to maintain the quality of life in this area.

WHY DO WE NEED TO STUDY PUGET SOUND?

Poor water quality, sediment contamination, and the degradation and destruction of fish and wildlife habitat can all lead to the decline and disappearance of valuable and cherished resources. In order to understand the threats which the Sound is facing now and will face in the future, it is necessary to examine and record the status of natural resources and the environment that affects them, and to examine how those natural resources are changing over time. In addition, accurate information on the status and trends of the environment will help us understand whether, and where, our source control and remedial action efforts are being most effective, and to ensure the cost-effective use of public and private dollars devoted to cleaning up Puget Sound and preventing its future contamination.

HASN'T PUGET SOUND BEEN ADEQUATELY STUDIED?

Many aspects of the biology, physics, and chemistry of Puget Sound have been studied. However, we have never established a consistent and comprehensive system for measuring the condition of Puget Sound and its watersheds, and for gauging the effectiveness of preventive and cleanup actions. Most past studies have been of short duration and have given us a snapshot of conditions in the Sound, but have not allowed us to follow trends and changes in the environment over time. By the early 1980s there were research tools and techniques available to measure many parts of the ecosystem, including the chemicals of concern in the environment (especially low concentrations of toxicants). By the mid-1980s, resource managers in the Puget Sound region saw the need for a permanent program to measure important environmental indicators year after year in a consistent fashion. In answer to this need a Soundwide monitoring program (PSAMP) was designed and initiated.

WHAT IS THE PUGET SOUND AMBIENT MONITORING PROGRAM?

PSAMP is a comprehensive, long-term monitoring program for measuring numerous aspects of the Puget Sound ecosystem that might be affected by pollution. The program is achieved through the coordinated efforts of state government agencies, with support and cooperation from other government agencies, business, industry, and the public.

The purpose of PSAMP is to characterize the condition of the water, sediment, plants, animals, and habitats in Puget Sound and its watersheds. PSAMP will collect and record information on the Sound and its inhabitants now and in the future. This will allow PSAMP managers to document the status and trends in contamination and the effects of contamination on the Sound's natural resources, as well as changes in the Puget Sound ecosystem due to natural causes. As PSAMP continues into the future, we will have a solid record with which to assess conditions in the Sound, and to make decisions about the cleanup of contaminated areas and the protection and prevention of further harm to valuable resources.

PSAMP was designed with the help of a consultant to the Environmental Protection Agency (EPA) and was refined by the Monitoring Management Committee (MMC) using accepted scientific and statistical methods. The MMC was appointed by the Puget Sound Water Quality Authority and is made up of environmental professionals representing federal, state, local, and tribal government agencies, as well as universities, citizens' groups, business, and industry. PSAMP is managed by the PSAMP Steering Committee which represents the five state agencies involved in collecting samples (the state Departments of Ecology, Fisheries, Health, Natural Resources, and Wildlife), the Puget Sound Water Quality Authority, EPA, local government, and tribes. The Puget Sound Water Quality Authority coordinates and provides data management support for PSAMP.

Citizens' monitoring

Citizens' monitoring plays an important role in PSAMP. There are great educational and public involvement benefits to having citizens involved in the monitoring program. In addition, citizens' monitoring provides a unique opportunity to collect information in a less expensive way, allowing the limited PSAMP resources to fund additional portions of the program.

The Puget Sound Water Quality Authority has contracted for administrative costs with two citizens' groups (Adopt-A-Beach and Chautauqua Northwest) to provide volunteers for sample collection and other duties under PSAMP. All PSAMP monitoring carried out by citizens is under the direct supervision of staff at one of the state agencies participating in the program. Agency staff are responsible for providing training, necessary equipment, supervision, and follow-up reporting to the citizens' groups.

During 1988-89 citizen monitors participated in several key parts of PSAMP: volunteers worked with technicians from the state Department of Natural Resources during a nearshore habitat inventory; they dug clams for paralytic shellfish poisoning (PSP) and bacterial analysis under the direction of the state Department of Health; and they participated in the collection of rockfish for tissue chemistry analysis for the state Department of Fisheries.

During 1990 citizen monitors will help catch Pacific cod and salmon for tissue analysis; dig clams for further bacterial, chemical, and PSP analysis; and work with the state Department of Ecology in collecting water quality samples. Further involvement of citizens in PSAMP is planned for the future.

PSAMP investigators measure the ambient or background conditions of Puget Sound which are the result of both natural processes and the accumulation of impacts from many human-related (anthropogenic) activities. Over time, PSAMP will collect information on long-term trends in environmental conditions. The program will allow us to see changes over time at set locations in the Sound, but will not necessarily allow us to compare different areas of Puget Sound to one another.

PSAMP is not intended to measure the effects of specific discharge pipes, storm drains, areas of highest sediment contamination ("hot spots"), or individual dredging and filling projects. Monitoring programs linked to the granting of permits for wastewater discharges and studies associated with regulations for shoreline development, dredged material disposal, and other activities provide information about the impact of individual projects. Natural resource managers and water quality planners also need information about the larger Soundwide impacts of numerous human-induced changes; PSAMP has been designed to provide this information.

PSAMP was designed during 1987 and 1988; the first year of data collection under PSAMP was 1989. State agencies are carrying out portions of PSAMP within their existing funding, and the Washington State Legislature allocated a small amount of additional funding to PSAMP for the period July 1989 through June 1990. As of this writing, only about 30 percent of PSAMP has been funded. Until the program is fully funded, information on many parts of the environment, natural resource populations, and fish and wildlife habitats will not be gathered. Specific important information that will not be collected in 1989 and 1990 will be discussed in this report. The participants in PSAMP are seeking additional sources of funding for the future.

WHAT DOES PSAMP MEASURE AND WHY?

In designing PSAMP, the environmental professionals of the MMC examined the major components of the Puget Sound ecosystem and decided which ones would give the best all-around picture of past, present, and future environmental conditions. They considered the technical feasibility and cost of each type of data collection, the results of past monitoring studies, and the ability of agencies and other organizations to carry out each monitoring task. The MMC members had to make some difficult choices because monitoring all of the important ecosystem components would be excessively expensive. They settled on gathering information from eight separate compartments of the ecosystem, each represented by a PSAMP sampling and analysis task. The full design of PSAMP, the rationale behind each type of sample collection, and the frequency of sample collection are summarized in Table 1. Due to funding limitations, the state agencies are able to carry out considerably less than the full PSAMP design; Table 2 indicates the monitoring that is being carried out during 1989-1990.

Additional information collected

Agencies, other organizations, and individuals collect many kinds of information in the Puget Sound area that are useful in interpreting the data collected by PSAMP. This information includes: weather and climate data, commercial and recreational harvests of fish and shellfish, aquaculture production, research monitoring of some ecosystems, and measures of the increase in human activities in the region (as shown by changes in population and employment numbers and by the number of development permits granted in each area). PSAMP managers will use these data to help in the interpretation of PSAMP results.

WHAT HAPPENS TO ALL THE PSAMP DATA?

The primary purpose of gathering data under PSAMP is to help water quality and natural resource managers determine whether environmental conditions and resources throughout Puget Sound are getting better, getting worse, or remaining stable. This information will allow managers to make appropriate management decisions to protect and preserve the quality of the Puget Sound ecosystem.

Table 1. Description of full PSAMP design.

Task	Rationale for Sampling	Number of Stations/Surveys	Frequency of Sampling	Agency
Sediment quality	Site for contaminant buildup	75 throughout Puget Sound	Annually - spring	Ecology
Sediment chemistry				
Bioassays				
Benthic invertebrates				
Marine water column	Water quality changes			Ecology
Long-term trends		10-12 throughout Puget Sound	Monthly	
Known water quality problems		5-10 in selected bays	Seasonally	
Algal growth		5-10 in selected bays	Summer & winter solstices	
Fish	Fish health & human health risk			Fisheries
Tissue chemistry (bottomfish)		21 stations	Annually - early summer	
Liver histopathology (bottomfish)		21 stations	Annually - early summer	
Tissue chemistry (cod, rockfish, salmon)		5-10 stations	Annually, depending on species	
Shellfish	Human health risk			Health
Abundance		35 beaches	Annually	
Bacterial contamination		35 beaches	Quarterly	
Tissue chemistry		35 beaches	Annually	
Paralytic shellfish poisoning		35 beaches	Monthly (or more often)	
Birds	Ecosystem indicator	Surveys throughout Puget Sound	Monthly, annually	Wildlife
Marine mammals	Ecosystem indicator	Surveys throughout Puget Sound	Monthly, annually	Wildlife
Nearshore habitat	Inventory & health of habitat	One-third of Puget Sound	Annually	Natural Resources
Freshwater	Input of contaminants to Puget Sound	75 throughout watersheds	Monthly	Ecology

After collection of samples in the field and careful laboratory analysis, information gathered by PSAMP is screened for quality and entered into specially designed computer databases. PSAMP designers have developed a data management system that will provide useful tools for natural resource management, planning, and measuring the effectiveness of pollution control programs. All PSAMP computer work is carried out on microcomputers (desktop or personal computers), with links built between the computers of each of the state agencies involved in PSAMP. The Puget Sound Water Quality Authority maintains the central version of PSAMP data. The state agencies carrying out PSAMP monitoring, and other federal, local, and tribal agencies, industry and business groups, scientific researchers, and the public have access to PSAMP information through the Authority's central database.

PSAMP data that are best represented by maps, such as the size and location of eelgrass and kelp beds, will be stored in a geographic information system (GIS) which is being developed for the Puget Sound region. The Puget Sound GIS will be kept on a large mainframe computer.

In addition to the annual Puget Sound Update (of which this is the first), each of the state agencies carrying out PSAMP tasks will write an annual technical report documenting and interpreting the previous year's monitoring results. The technical reports will be available through each of the responsible state agencies upon request. Currently, the only 1989 PSAMP technical report available covers sediment quality monitoring.

Table 2. 1989-1990 PSAMP implementation.

Task	Rationale for Sampling	Number of Stations/Surveys	Sampling Dates/Frequencies	Agency
Sediment quality Sediment chemistry Bioassays Benthic invertebrates	Site for contaminant buildup	50 throughout Puget Sound	March - April 1989, 1990	Ecology
Marine water column Long-term trends	Water quality changes	24 throughout Puget Sound	Monthly	Ecology
Fish Tissue chemistry (bottomfish) Liver histopathology (bottomfish) Tissue chemistry	Fish health & human health risk	10 stations 10 stations 4 stations	May 1989 May 1989 September 1989 - rockfish February 1990 - Pacific cod April 1990 - salmon	Fisheries
Shellfish Abundance Bacterial contamination Tissue chemistry Paralytic shellfish poisoning	Human health risk	10 beaches 10 beaches 4 beaches 16 beaches	May 1990 Quarterly April 1990 Monthly (or more often)	Health
Birds	Ecosystem indicator	No activity		Wildlife
Marine mammals	Ecosystem indicator	No activity		Wildlife
Nearshore habitat	Inventory & health of habitat	No activity		Natural Resources
Freshwater	Input of contaminants to Puget Sound	75 throughout watersheds (limited parameters)	Monthly	Ecology

HOW DOES THE PUGET SOUND ECOSYSTEM WORK?

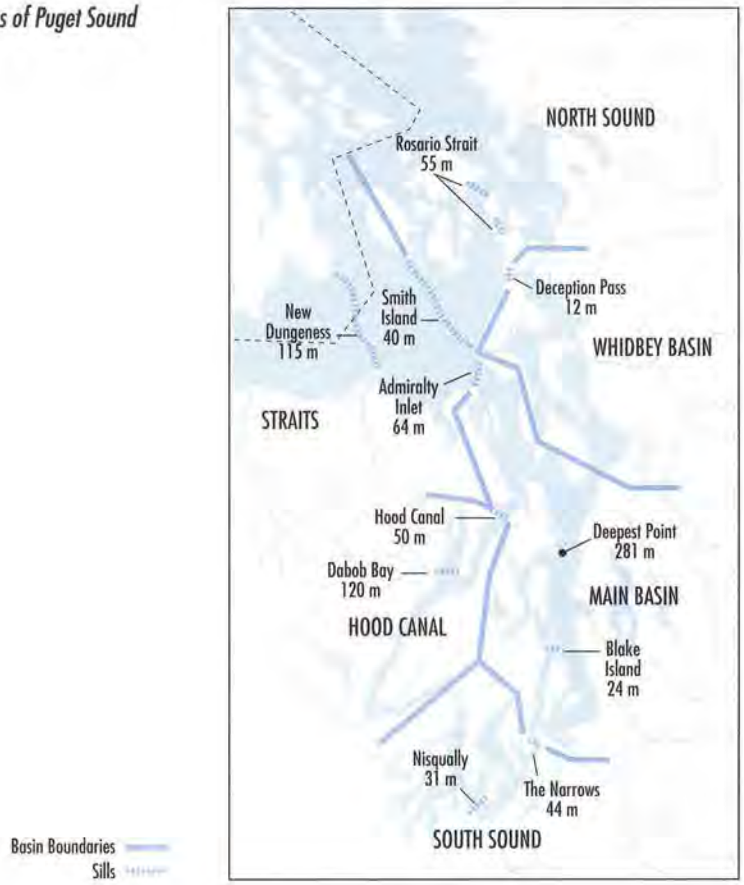
In order to manage the ecosystem, decision makers have defined Puget Sound to include the waters of the Strait of Juan de Fuca east of Port Angeles and the Strait of Georgia to the Canadian border, Puget Sound "proper" (south of Admiralty Inlet), and the surrounding watersheds (Figures 1 and 2). The Straits provide the link between Puget Sound and the Pacific Ocean (the Strait of Juan de Fuca connects directly to the ocean at Cape Flattery, and the Strait of Georgia connects to the ocean north and west of Vancouver Island).

The portion of Puget Sound which lies south of Admiralty Inlet is a deep fjord-like estuary which was carved by glaciers in past ice ages. There are four major basins in the Sound (Main Basin, South Sound, Whidbey Basin, and Hood Canal), which are separated from one another by relatively shallow sills (there is no sill separating the Whidbey Basin and the Main Basin) (Figure 3). Another shallow sill at Admiralty Inlet separates Puget Sound from the Straits of Juan de Fuca and Georgia. Although the sills separating the basins of Puget Sound are shallow as compared to the deep basins of the Sound, they are approximately 50 to 80 meters deep—far deeper than the deep portions of most other estuaries. The depth, sills, and strong tidal currents in Puget Sound make this estuary unlike any other major estuary in this country; Puget Sound most closely resembles the fjords of northern Norway and British Columbia. However, unlike most fjords, the deep water of Puget Sound is well mixed and seldom stagnates.

Ten major rivers and many smaller streams contribute large volumes of fresh water and particles to the surface layer of Puget Sound, which flows slowly towards the ocean. Saltier water which originated in the north Pacific Ocean enters the Sound via the Straits and Admiralty Inlet, and remains underneath the fresher layer. Much of the natural chemistry and biology of the Sound depends on both the physical movement of water in and out of the Sound and water circulation patterns within the Sound.

Figure 2. Location map.

Figure 3. Oceanographic basins of Puget Sound and major sills.



The great depths of Puget Sound and the shallowness of the sills prevent much of the water and almost all of the particles of sediment, plankton, and debris from leaving the Sound. We might think of Puget Sound as a large bathtub in which water sloshes back and forth due to the tides but only a fraction escapes. The sills act as giant mixers, mixing and recirculating water back into the basins of the Sound (Figure 4). Because the average time that water stays in Puget Sound (about 155 days) is much longer than the time that it takes the average particle to sink out of the water column (about 15 days), most particles sink and are trapped in the sediments before they are washed out of the Sound (Duxbury, 1988).

The trapping of water and particles is the major reason that natural resource managers and water quality planners are concerned about the amount of contaminated material that is discharged into the Sound by human activities. Many contaminants cling to particles, sink out of the water column, and remain in the Sound. The heaviest particles settle close to their sources, but many of the smaller particles can be widely distributed throughout the Sound before they settle into the sediments, causing the spread of low levels of contaminants far from their origin.

The Puget Sound ecosystem can be thought of as a pressurized water system with pipes, valves, and pumps. The plants, animals, water, and sediment are the pipes, valves, and pumps, and the water flowing in the pipes at high pressure represents the interactions and flow of energy or food among them (Figure 5). Minor leaks in one part of the piping may not cause obvious harm, but in time will show up as a loss of water in the system and lower water pressure. As more and more parts of the piping are stressed, the balance and operation of the pipes, valves, and pumps may break down and lead to serious damage.

There are many cases of breakdowns in the ecosystem in developed estuaries and waterways in this country and in other parts of the world. Examples include dramatic losses of blue crab, oysters, clams, fish, and submerged vegetation in the Chesapeake Bay due largely to degraded water quality; large foul-smelling algal blooms in the Adriatic Sea caused by excessive waste discharges from humans and farm animals; and the loss of most plants and animals in the Rhine River due to a major chemical spill. Disruptions are

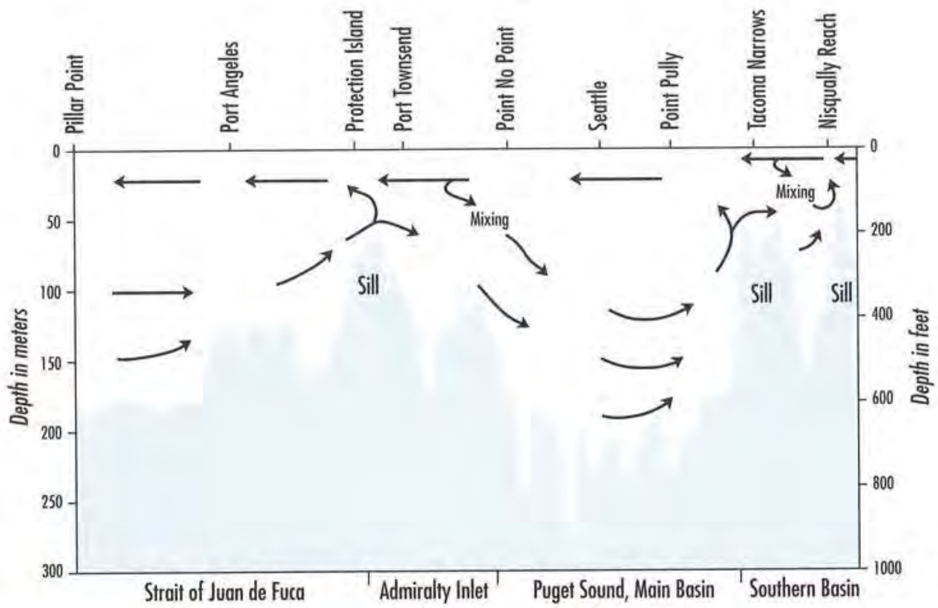


Figure 4. Simplified cross-section of circulation in Puget Sound.

Reference: Adapted from Ebbesmeyer and Barnes, 1980.

already visible in Puget Sound, including occasional fish kills during the late summer due to low oxygen levels, liver tumors in bottomfish in the urban bays, and habitat loss—resulting in damage to wild salmon stocks—due to development. In order to avoid further breakdown of the Puget Sound ecosystem, we must strive to understand and protect the most vulnerable portions while seeking to restore the damaged parts.

The various compartments of the Puget Sound ecosystem (the plants, animals, water, and sediment) have been identified and targeted for PSAMP monitoring. In some cases, the commercial importance of a species, or the vulnerability of a habitat, have helped to single it out for PSAMP monitoring. Also, the technical feasibility, cost, and coverage by other monitoring programs have led the designers of PSAMP to target or to exclude specific ecosystem compartments for PSAMP monitoring.

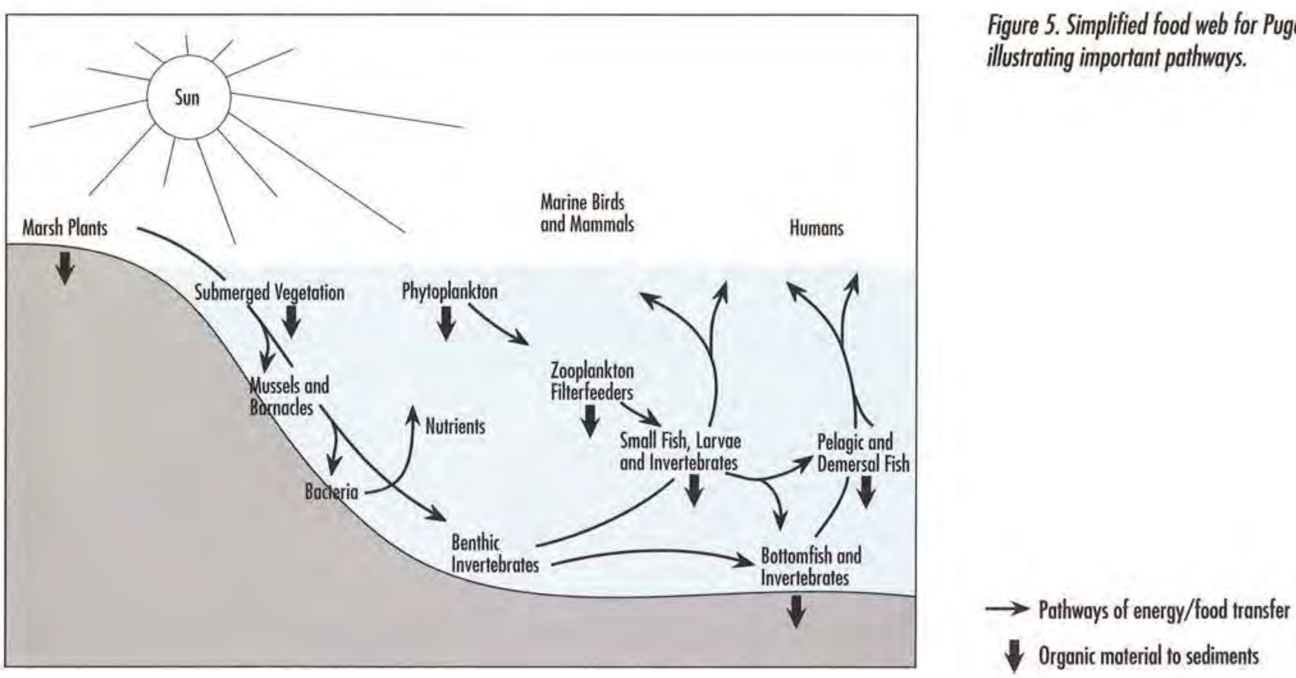
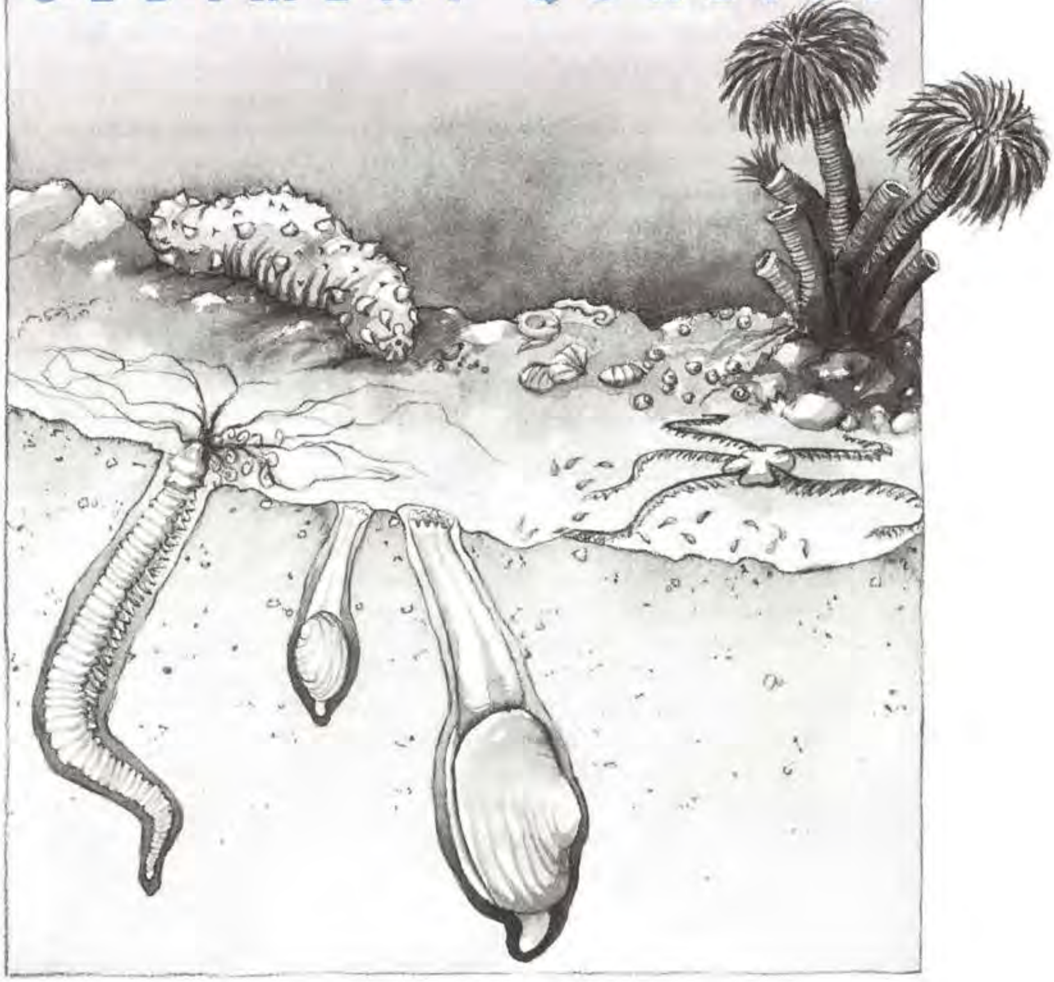


Figure 5. Simplified food web for Puget Sound illustrating important pathways.

SEDIMENT QUALITY



BACKGROUND

Sediments, the sand and mud that lie on the bottom of Puget Sound, are an important part of the Sound's ecology; they provide food, shelter, and rearing grounds for marine plants and animals. Many of the benthic plants and animals (those living on or near the bottom) form the base of a food web which supports commercially and recreationally important species such as juvenile salmon, cod, rockfish, and Dungeness crab.

Generally, the major sources of sediment to Puget Sound are rivers, bluff and shoreline erosion, and underwater erosion and slumping. Sediment resulting from biological activity in the water column, from atmospheric sources, and from wastewater appear to be relatively small (Lavelle et al., 1985). Sediments may become contaminated by toxic organic compounds and metals which come from human-related (anthropogenic) sources, such as municipal and industrial wastewater, stormwater runoff, and spills. Certain toxic chemicals from the land bond readily with particles in water and are washed into Puget Sound by rivers and from discharge pipes. Most of the particles and contaminants which do not dissolve in water sink out of the water and join the Sound's sediments. Scientists measure concentrations of chemicals in the sediments as an indicator of the chemical enrichment and environmental degradation resulting from human activities.

Bottom sediments are the final resting place of much of the contamination that enters the Sound. In some areas benthic animals accumulate contaminants from consuming sediments and from living in contact with these sediments. The health of the benthic communities that live in and on the sediments is a measure of the cumulative effects of that contamination.

Sediments and benthic communities have been most extensively studied in Puget Sound's urban bays. Major investigative efforts have been undertaken in Elliott Bay (Seattle), Commencement Bay (Tacoma), Everett Harbor, Sinclair Inlet (Bremerton), and Bellingham Bay (Figure 2, page 11). In general the sediments in the nearshore areas of urbanized bays show higher levels of contamination, greater toxicity to test organisms, and greater incidences of abnormal communities of benthic animals than those in less developed areas (Long, 1985). Urban bays show the results of stormwater and sewage discharges, as well as past and present industrial practices, which contribute many different chemicals to the sediments. Shoreline modifications and dredging are common in urban bays, causing disturbances in the supply of natural sediments. The deep basins of the Sound show much lower contamination levels than the urban bays.

Sediments in the nearshore areas of the "non-urban" bays may also be contaminated due to past and present industrial, stormwater, and sewage discharge practices. Among these areas are the Guemes/Fidalgo channel (near Anacortes), Crescent Harbor (at Whidbey Island's Naval Air Station), Richmond Beach (north Seattle), Shilshole Bay (at the mouth of the Lake Washington ship canal), and Liberty Bay (on the Kitsap Peninsula) (Tetra Tech, 1988a).

PROBLEMS ASSOCIATED WITH MEASURING SEDIMENT QUALITY

Contamination of Puget Sound bottom sediments is extremely patchy—that is, highly contaminated areas, or "hot spots", can be located in proximity to "clean" areas. Similarly, robust populations of bottomfish and benthic invertebrates may exist next to degraded or impoverished communities. Even in the urban bays, areas of clean sediments are commonly found.

Sampling and analyzing sediments for chemicals and benthic animals is extremely expensive and difficult. Specialized equipment is needed, including a ship, sampling gear, and electronic positioning equipment. Trained laboratory experts are needed to correctly analyze for toxic chemicals, perform bioassays, identify hundreds of species of marine life, and evaluate benthic communities. These difficulties explain why we have had, prior to PSAMP, information from a relatively small number of bottom sediment samples from all over the Sound. Only those areas which are considered highest priority for becoming contaminated, or those areas being considered for nearshore development, the disposal of dredged material, capping of contaminated sediments, or dredging, are likely to be extensively sampled. PSAMP is the first comprehensive effort to examine sediments at a distance from anthropogenic sources.

WHY WORRY ABOUT SEDIMENT QUALITY?

In order to preserve healthy plant and animal populations in Puget Sound, we must protect their habitats and food supplies. Sediment contamination may affect not only the health of the organisms living in direct contact with the sediment, like bottomfish and invertebrates, but also animals that prey on the benthic creatures. Similarly, the predators of these animals may be affected, and so on up the marine food web, affecting pelagic fish like salmon and cod, birds, and marine mammals like seals, sea lions, and whales. Ultimately, humans can also be affected by eating contaminated seafood.

SEDIMENT CONTAMINATION

Many contaminants are bound to particles released into the Sound from discharge pipes, storm drains, and rivers, and settle out of the water column close to their point of origin. These sediments form the most contaminated areas, the so-called "hot spots", in the urban bays and near other known sources of past and present contamination. Contaminants bound to small particles and those which remain dissolved in the water are spread further from their sources.

Clean sediments are washed from shorelines and down rivers before accumulating on the bottom of the Sound. Sediments do not build up in areas of the Sound where currents are swift. The fast-moving and recirculating waters of Admiralty Inlet and the Tacoma Narrows are examples of areas where we cannot sample fine sediments. These swiftly flowing waters act as pumps or sluices to shift water and sediment from one basin of the Sound to another, spreading both contaminants and clean sediments away from their point of origin.

Many different toxic chemicals find their way into the Sound. Wastewater, stormwater, and runoff from land can contain many types of chemicals depending on the industry or municipal treatment plant that they are discharged from, the type of land use being drained, the weather, and/or the time of year. The bottom sediments receive an ever-changing and evolving mixture of chemicals due to the complex variation of chemical inputs from different sources and the chemical interactions that occur between the toxics and seawater and among the chemicals.

The primary chemicals that may be toxic in Puget Sound are heavy metals and organics. Many heavy metals (such as lead, copper, and mercury) exist naturally, are harmless to marine life in low concentrations, and may be needed in small quantities by some organisms for growth. However, some metals alter their form in the presence of other chemicals. In these altered forms, the metals may accumulate in the tissues of plants and animals, resulting in injury or death. For example, mercury is harmless until it forms methyl mercury which accumulates in the liver and muscle of marine animals. Above certain concentrations, methyl mercury may cause disabilities and death.

There are two types of organic molecules found in the sediments of Puget Sound: those which are naturally occurring and those which have been created by humans (synthetic organics). The naturally occurring organics are the fuel upon which the marine system runs, but they can cause harm to

How can we improve the Sound's sediment quality?

Cleaning up sediment contamination is extremely costly. For example, preliminary estimates for removing or capping contaminated sediments in some of the nearshore areas of Commencement Bay (a federal Superfund site) are $32 million (EPA, 1989). Removing and disposing of contaminated sediment, or capping those sediments in place, are technically viable options for cleanup.

The most cost-effective and environmentally responsible method of dealing with sediment contamination is to prevent it in the first place. Contaminants which will eventually find their way into the sediments are most easily controlled at their source. Sources of these contaminants include municipal and industrial wastewater, storm drains, combined sewer overflows, and runoff.

Source control measures, while considerably cheaper than cleanup activities, are still expensive. Considerable effort and many millions of dollars are already being spent on source control measures and cleanup actions. We need an accurate picture of past and present levels of sediment contamination, patterns of movement of contaminants to the sediments, the effects of contaminants on organisms, and rates of natural burial and cleanup of sediments in order to understand the damage that discharges are doing to our resources and to spend our pollution prevention and cleanup dollars in the most effective manner.

marine life when their supply to the sediments is greatly increased through anthropogenic or other means. For example, the petroleum hydrocarbons, such as oil, are naturally occurring organic molecules. These molecules only become harmful in the marine environment when they are introduced in large quantities. The synthetic organics are not naturally occurring and can be absorbed by organisms, accumulate in the tissues, and cause injury or death. Unlike most metal complexes, toxic forms of synthetic organics can be very long-lasting. Well-known examples of synthetic organics that may cause harm in the marine environment are polychlorinated biphenyls (PCBs) and organochlorine pesticides like DDT.

PSAMP AND THE SEDIMENT TRIAD

PSAMP has been designed to establish baseline conditions for sediment quality in Puget Sound and to track changes over time at set sampling stations. Cost constraints dictate that only a few sites in each Puget Sound bay or area will be sampled. PSAMP investigators will use PSAMP sediment quality data to compare changes over time at each station location, and will not attempt to compare different areas of Puget Sound.

The approach to measuring sediment quality that PSAMP has taken is known as the sediment quality triad (Chapman and Long, 1983; Long and Chapman, 1986) because there are three interrelated parts. The first part is the measurement of chemical contaminants in sediment—metals and organics, including those that exist naturally and those that are introduced by humans. The second is bioassays—the measurement of the reaction of test organisms to sediment exposure in a laboratory setting. Several bioassays can be used simultaneously and each measures a different reaction of the organisms to contaminants—mortality, embryonic malformation, cellular or body system malfunctions. The third part of the triad is the identification and enumeration of the inhabitants of the sediments—the benthic invertebrates.

The data from each portion of the sediment triad provides a vital piece of information, and, when taken together, can be used to determine the level of sediment contamination and its effects on Puget Sound species. Chemical concentrations alone do not tell us whether actual harm is being done to living resources. Toxic effects on laboratory animals or plants do not necessarily indicate whether the inhabitants of the sediments are being affected in Puget Sound. Studies of benthic communities alone are not sufficiently sensitive to allow us to estimate harm to other natural resources in the area. The combined results of all three parts of the sediment triad provide us with a comprehensive picture of the quality of the sediments. This comprehensive picture may allow us to distinguish between natural changes in the environment (such as those caused by an El Nino event—the large-scale warm water event which periodically brings tropical species into our waters) and those caused by humans.

Unfortunately, we cannot currently benefit from all the information that the sediment triad measures due to constraints of technology, cost, and interpretation of the information. We may not have identified all the chemicals of concern to the Sound; the "perfect" bioassay organisms that adequately measure all effects of contamination are not available; enumerating samples of benthic organisms is extremely costly; and the interpretation of the information is very complex. Improvements in these areas are the subject of research studies and investigations in Puget Sound and around the world.

During 1989 PSAMP investigators with the Department of Ecology and their consultants sampled 50 sediment stations throughout Puget Sound, using the sediment triad (Figure 6). The 1989 survey represents about 65 percent of the total number of stations that the full PSAMP design calls for. During 1989 stations were placed to act as integrators of contamination from many sources but at a distance from any single source of contamination (such as a major discharge pipe). By examining stations away from immediate sources of contamination, and generally away from known "hot spots", PSAMP managers will be able to tell whether overall conditions in the Sound are changing. Samples were taken at water depths of 20 meters and in the deep basins of the Sound (approximately 100 to 250 meters deep) in order to examine sediments from many environments of Puget Sound.

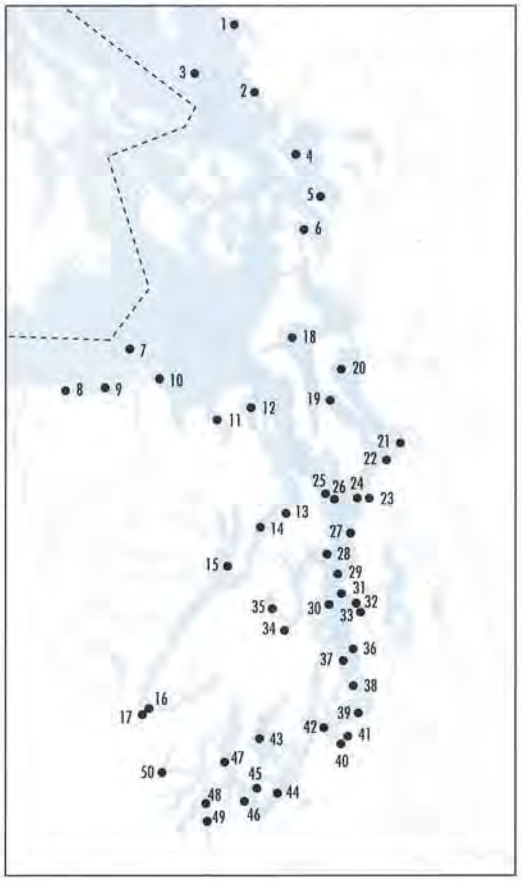


Figure 6. Locations sampled in 1989 for sediment quality monitoring.

CONTAMINATION OF SEDIMENTS – METALS

Almost all of the 1989 PSAMP sediment samples had low levels of several heavy metals that have been identified as priority pollutants by the Environmental Protection Agency (EPA). These findings confirm those of many previous Puget Sound studies (Long, 1982; Dexter et al., 1985). The only metal that was found at relatively high concentrations is mercury (Figure 7), which was found in Sinclair and Dyes Inlets (stations 34 and 35) at levels exceeding those that managers believe cause harm to organisms (i.e., above the low Apparent Effects Threshold [AET] levels, Tetra Tech, 1986). The AETs are levels of toxic compounds that help natural resource managers determine whether chemical concentrations found in the sediments are causing problems. Somewhat elevated levels (but below the AETs) of one or more of the metals arsenic, copper, lead, and zinc were also found at sites in Sinclair Inlet (station 34), Dyes Inlet (station 35), Point Pully (station 38), Duwamish Head (station 33), Budd Inlet (stations 48 and 49), and the Great Bend in Hood Canal (stations 16 and 17) (Figure 8). Each of these stations, with the exception of Point Pully in East Passage and the Great Bend, is in proximity to urban sources of contaminants (but not within known "hot spots" of contamination). Researchers at the National Oceanic and Atmospheric Administration (NOAA) and the University of Washington have shown that East Passage may be the primary area for the deposition of suspended particles transported by

Figure 7. Concentrations of mercury at 1989 PSAMP urban bay and deep basin stations.

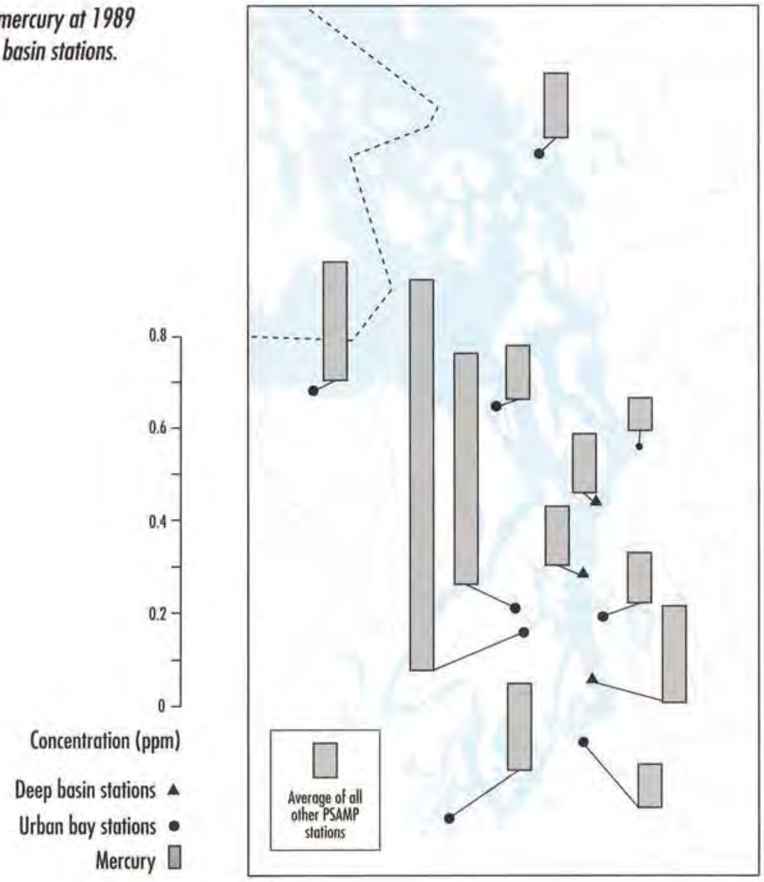
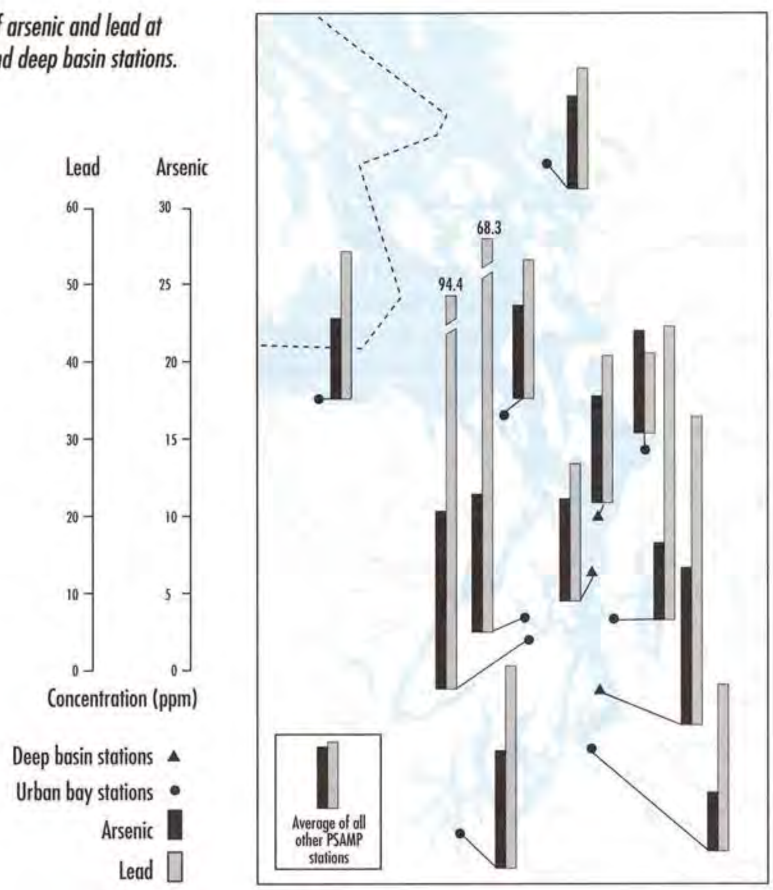


Figure 8. Concentrations of arsenic and lead at 1989 PSAMP urban bay and deep basin stations.

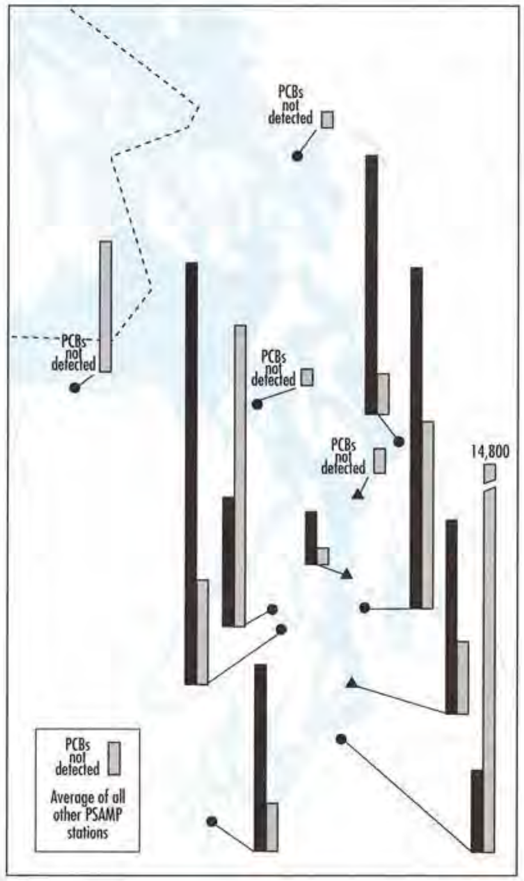


currents from Commencement Bay and Elliott Bay—both urban bays with areas of highly contaminated sediments (Stober and Chew, 1984; Curl et al., 1987).

PSAMP investigators measured several naturally occurring metals during the 1989 survey at concentrations which have not been associated with toxic effects. Among these metals are vanadium, cobalt, cadmium, aluminum, and nickel. Relatively high concentrations of several of these metals (compared to background conditions in Puget Sound) were found at stations in areas which are considered to be non-urban and relatively uncontaminated. These include stations 16 and 17 in the Great Bend in Hood Canal (cobalt, iron, vanadium, and aluminum) and stations 18, 19, and 20 in Possession Sound (chromium, nickel, and cobalt). The sea water which moves back and forth between the Great Bend and Lynch Cove in Hood Canal can cause certain metals to precipitate from seawater and fall to the bottom as particles (Paulson, personal communication), including those seen at elevated levels in the 1989 PSAMP data (cobalt, iron, and vanadium). Outflow from the Stillaguamish River has been shown to contribute nickel to Possession Sound (Paulson, personal communication). In the future, PSAMP investigators will take samples close to the mouth of the Stillaguamish River to confirm the source of the chromium and cobalt.

CONTAMINATION OF SEDIMENTS – TOXIC ORGANIC COMPOUNDS

During the 1989 survey PSAMP investigators found low levels of toxic organic compounds at all of the PSAMP sediment stations, with the highest levels found in the urban bays. The findings confirm the results of many previous studies in Puget Sound (Long, 1982; Dexter et al., 1985). The most common organic contaminants found were the polyaromatic hydrocarbons (PAHs) (Figure 9). PAHs are a mixture of compounds including low molecular weight PAHs (which are derived from petroleum fuel and oil) and high molecular weight PAHs (which result from the combustion of hydrocarbons).



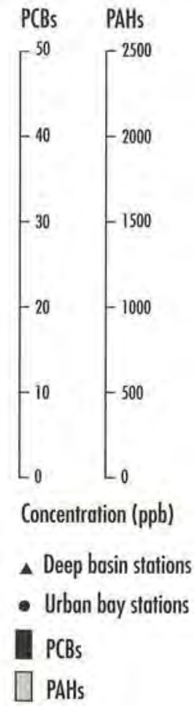


Figure 9. Concentrations of PCBs and PAHs at 1989 PSAMP urban bay and deep basin stations.

Polychlorinated biphenyls (PCBs) were found at many of the 1989 PSAMP stations (Figure 9) in the same general areas as they have been found in past studies (Long, 1982; Evans-Hamilton, 1987). These compounds were used extensively as coolants and frequently mixed with oils and greases in electrical transformers and cooling units. PCB manufacture and sale has been illegal since the 1970s, but they persist in the environment for many years. Although differences in sampling locations make it difficult to look at trends in toxicant levels between past studies and the 1989 PSAMP results, the 1989 PSAMP PCB levels appear to be lower than levels previously found (Malins et al., 1980), which may indicate that we are beginning to see a general decrease of PCBs in Puget Sound sediments. Similarly, the withdrawal from use of organochlorine pesticides such as DDT during the 1970s may be reflected in the 1989 PSAMP survey which detected these pesticides less frequently than in past Puget Sound studies (Malins et al., 1980). Additional years of PSAMP data are needed to confirm these trends.

The 1989 PSAMP survey confirmed patterns of contamination by organics found in other studies (Malins et al., 1982; Pacific Northwest Marine Laboratory, 1986; Crecelius et al., 1989), including the ubiquitous presence of byproducts of plastics manufacture (phthalates), the presence of pulp mill-associated chemicals (resin acids and retene) in areas adjacent to pulp mill discharges, and indicators of human and animal sewage (beta-coprostanol) close to developed areas.

The most surprising result from the 1989 PSAMP organics investigations is the discovery of volatile organic compounds in the deep sediments of the main basin (station 29), East Passage (station 38), Possession Sound (station 19), and the Strait of Georgia (station 3). These compounds are generally unstable and quickly evaporate in air. The volatiles seen in the 1989 sediment sampling included acetone and xylene, which can be produced under certain conditions by the bacterial breakdown of organic material. The origin of the volatile organic contaminant methylene chloride, which was also found in these areas, is a mystery. The presence of these volatile organics in deep basin sediments in the Sound has not previously been recorded, and will be investigated further by PSAMP in the 1990 field sampling.

OTHER SEDIMENT PARAMETERS

The amount of organic matter which accumulates in the bottom sediments is dependent on water currents and on the size of sediment particles (grain size). Grain size information collected during 1989 by PSAMP confirmed that fine grain sediments are seen in areas with slow tidal currents such as shallow bays and the deep basins of the Sound. Coarser sediments, including sand, rocks, and boulders, were found in areas more strongly swept by currents such as the Straits of Juan de Fuca and Georgia (stations 7, 9, and 3) and the mouth of Hood Canal (station 13). The 1989 PSAMP sediment data demonstrate that toxic chemicals are most likely to be attached to smaller size particles (Figure 10).

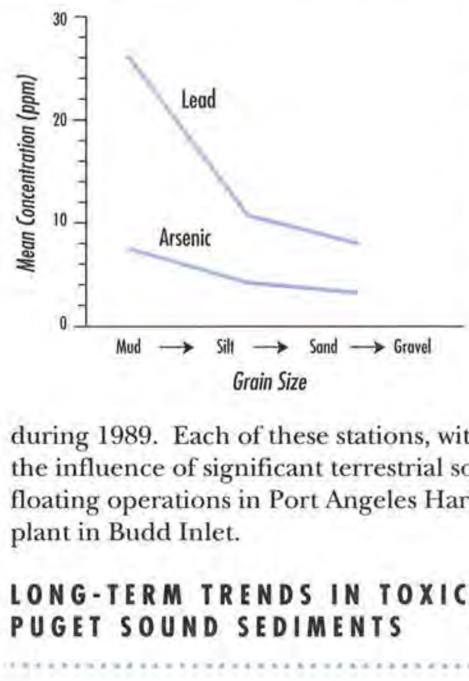


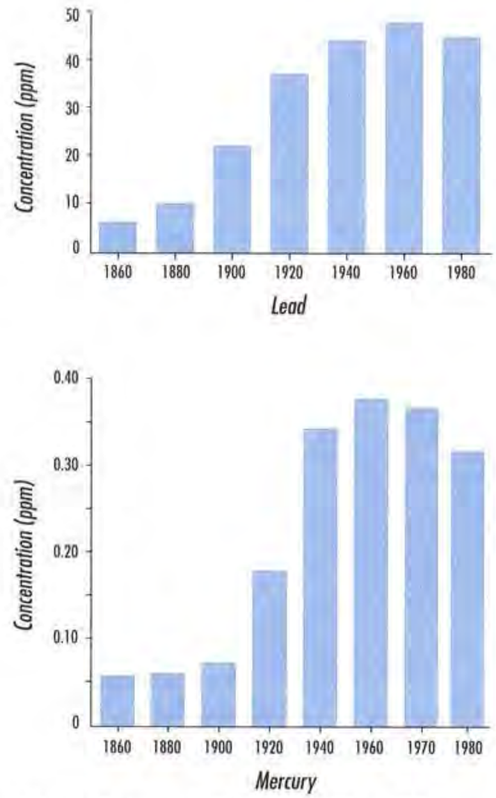
Figure 10. Changes in average PSAMP arsenic and lead concentrations with grain size.

The 1989 PSAMP investigators measured the total amount of organic material at each station, and confirmed that the finer sediments contained greater amounts of organic matter. PSAMP investigators found that sediment sampling stations in Port Angeles Harbor (stations 8), Dyes Inlet (station 35), Sinclair Inlet (station 34), Budd Inlet (stations 48 and 49), and near Point Pully (station 38) had the highest content of organic matter during 1989. Each of these stations, with the exception of Point Pully, is under the influence of significant terrestrial sources of organic matter, including log floating operations in Port Angeles Harbor and a large wastewater treatment plant in Budd Inlet.

LONG-TERM TRENDS IN TOXICS FROM PUGET SOUND SEDIMENTS

The results of the 1989 PSAMP sediment sampling contribute additional detailed sediment contamination information to the long-term trend that has been recorded by researchers at the University of Washington and other academic institutions and by agencies, including NOAA, EPA, Ecology, and Metro, and their consultants, since the late 1970s and early 1980s.

Sediment chemists examine present day and historical sediment contamination by taking long sediment cores from the bottom of the Sound, and, using specialized tools and techniques, determine the age of the layers of sediment and their contaminants. In general throughout Puget Sound, metal levels show a gradual increase from the start of industrial times (about 1860), reach a peak between 1930 and 1950, and have shown a decrease in the past 10 to 20 years (Romberg et al., 1984; Bloom and Crecelius, 1987). Many factors may have contributed to this decrease, including the gradual switch to unleaded gasoline (for lead), the decrease in production and eventual closing of the ASARCO smelter in Tacoma (for arsenic), and the pretreatment of industrial waste by industry prior to release to municipal sewer systems (for many metals). For example, results from Metro's toxic pretreatment planning study and other studies (Romberg et al., 1984; Crecelius and Bloom, 1988) showed a decrease in lead and mercury concentrations over time in the main basin of Puget Sound (Figure 11).



References: Romberg et al., 1984; Crecelius and Bloom, 1988.

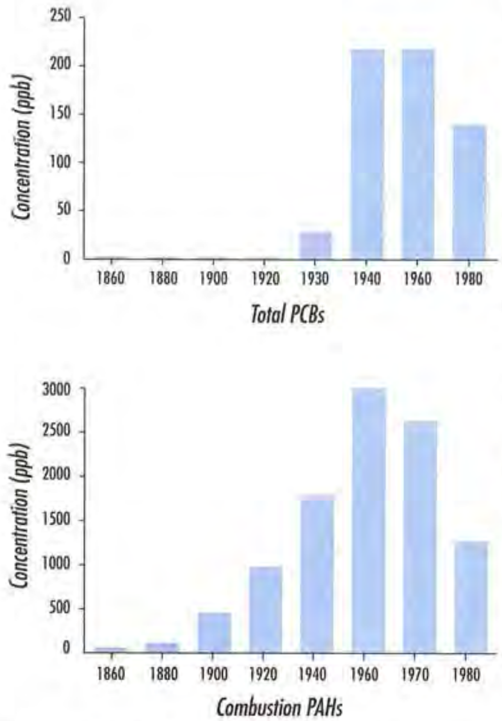
Figure 11. History of sediment contamination by lead and mercury in the deep Main Basin of Puget Sound.

The accumulation of synthetic organics in the sediments of Puget Sound started after the Second World War and, in general, is continuing (Dexter et al., 1985). The concentration of a few synthetic organic compounds has decreased in Puget Sound sediments in recent years, largely due to bans on the production and sale of those compounds (Dexter et al., 1985). Chlorinated pesticides (DDT) and PCBs are most notable in this category. Figure 12 shows information from sediment cores collected in the Main Basin of Puget Sound for historical changes in PCBs and combustion polyaromatic hydrocarbons (HPAHs) from 1850 to 1980 (Galvin et al., 1984; Crecelius and Bloom, 1988). Future sediment chemistry sampling will help to determine whether these trends in decreasing contamination over time are continuing, or are being reversed by increasing human development in the Puget Sound basin.

SEDIMENT BIOASSAYS IN PUGET SOUND

The need for reliable measures of the effects of sediment contamination on animals in Puget Sound has been the focus of development work by many researchers since the late 1970s. The most widely-accepted benthic bioassays for Puget Sound were chosen for PSAMP. They are: tests for mortality, using an amphipod (a small shrimp-like creature which lives in the sediment); tests for abnormal embryonic development, using bivalve (oyster or mussel) larvae; and tests for changes in cell physiology using a luminescent bacterium (the Microtox test). Because of limited funds during 1989, investigators were able to apply only the amphipod and Microtox tests. For most metals and organic toxicants, the amphipod bioassay is thought to be more sensitive than the Microtox.

Figure 12. History of sediment contamination by PCBs and PAHs in the deep Main Basin of Puget Sound.



References: Galvin et al., 1984; Barrick and Prahl, 1987.

During 1989 PSAMP bioassay results showed very few toxic effects from sediments collected at the 50 Puget Sound stations. Only one station, in Dyes Inlet (station 35), had sediment containing sufficient toxicity to kill an unacceptable number of the amphipods, while none of the 50 stations showed toxicity to Microtox bacteria.

PSAMP stations were purposely placed at some distance from known sources of pollutants, so this result is not surprising. However, large variability in the test results at several stations, including Port Susan (station 20), the deep Main Basin (station 24), and Point Pully (station 38), may have obscured the presence of sediment toxicity at those stations. In addition, bioassays cannot identify stations where toxic chemicals are approaching levels which will harm animals—they can only point to those stations where toxic chemicals levels are already causing harm.

Previous studies have shown mortality to test organisms from sediments in the urban bays and other areas near potential contaminant sources including East Passage (Stober and Chew, 1984), while sediments taken from the deep basins and non-urban bays have generally shown no toxicity (Long, 1985; Crecelius et al., 1989)

MEASUREMENTS OF BENTHIC INVERTEBRATE POPULATIONS

The third part of the Puget Sound sediment triad is the study of benthic invertebrate populations. In order to count the benthic invertebrates, a sediment sample is sieved through a mesh. The animals caught on the mesh are preserved, allowing for the unhurried task of sorting, identifying, and counting them. All these steps must be painstakingly done by hand, and a high degree of experience and skill is needed to accurately identify each animal from among several thousand species of marine invertebrates found in Puget Sound. Although many hundreds of samples have been collected for benthic invertebrate analysis over the years in Puget Sound, very few results are available which cover a wide geographic area in detail, or where samples were repeatedly taken at the same locations over several years.

The vast numbers of Puget Sound benthic species presents another problem: how to display or describe the patterns of occurrence and abundance seen from one location to another or from one year to another. Many factors affect the number of species and the number of individuals per species found in the benthos, including sediment grain size, water depth, amount of organic matter present, salinity of the water between the sediment particles, degree of contamination, and interactions among species. These factors further complicate the task of determining geographic and temporal trends in benthic populations.

Scientists describe a benthic invertebrate community by reporting the number of species (species richness), the number of individuals of each species (abundance), and the dominance of the community by one or more species groups (dominance). In addition, scientists have developed complex systems of statistical analyses and have calculated indices to describe the similarity of one community of invertebrates to another, the position that is occupied in the marine food web by each grouping, or the tolerance of each species or community to pollution.

After they accounted for natural factors such as grain size and water depth, the PSAMP investigators calculated that, for the benthic populations sampled at the 1989 PSAMP stations, there was lower species richness in the urban areas and generally more species richness in less contaminated areas. No single species or small group of species was dominant throughout the Sound.

The 1989 PSAMP samples showed that the Puget Sound benthic communities were grouped according to whether sediments were constantly deposited in an area (depositional environment) or were swept away frequently by currents (erosional environment). Also, the number of benthic species decreased going from north to south in Puget Sound due to decreasing salinity of the overlying water—a common pattern seen in estuaries. There were no clear trends of benthic species associated with toxic chemicals, although the pattern of species followed that of total organic carbon and sediment grain size rather closely.

The patterns of benthic communities found in 1989 by PSAMP agree with previous studies of benthic communities in the Sound. Past studies in the very contaminated areas of the urban bays have shown the absence of many of the typical Puget Sound crustaceans and echinoderm species, and greater numbers of pollution-tolerant species of polychaetes (worms) and molluscs (Chapman et al., 1984). PSAMP investigators could not determine whether the benthic communities sampled during the 1989 PSAMP studies have been directly affected by contamination (based on indices calculated from the number of species and abundance of each species). PSAMP investigators feel that further years of PSAMP data may yield correlations between benthic invertebrates and contaminants at the PSAMP stations.

Dr. Fred Nichols (U.S. Geological Survey) has been collecting benthic invertebrate samples at three stations in Puget Sound since 1969. This is the longest running and most comprehensive set of benthic invertebrate data for Puget Sound (Nichols, 1985). Nichols has observed changes in the populations of several benthic species over time, including increases in the total abundance, total weight, and number of species of benthic invertebrates, and shifts in dominance among both rare and abundant Puget Sound species. Scientists do not know whether these changes are due to natural cycles, are caused by contamination, or are the result of recovery from contamination. PSAMP investigators will continue to monitor Nichols' stations, which should help identify the cause of changes seen in Puget Sound benthic communities.

1989 PSAMP RESULTS AND THE SEDIMENT TRIAD

The purpose of using the sediment triad to estimate the sediment quality in Puget Sound is to be able to verify, through three independent measures, whether contaminants are accumulating in the sediments and whether they are doing harm to the biological populations of the Sound. The presence of potentially toxic chemicals in sediments from many of the 1989 PSAMP stations indicates that contaminants are accumulating in the sediments. Results of the bioassays and the lack of clear patterns of benthic community alterations indicate that there are few toxic effects at those station locations. A single year's worth of data is often inconclusive, however, except to show whether major problems exist with benthic communities. It is apparent that PSAMP managers need several more years of sediment triad data before a reliable baseline of sediment quality can be established. Also, before making an evaluation of the overall sediment quality of Puget Sound, PSAMP investigators should sample many additional locations within Puget Sound.

FUTURE PSAMP SEDIMENT QUALITY MONITORING

The second PSAMP sediment quality survey will take place during March-April 1990. PSAMP managers will make some changes to the sediment sampling scheme during 1990 based on some of the 1989 results.

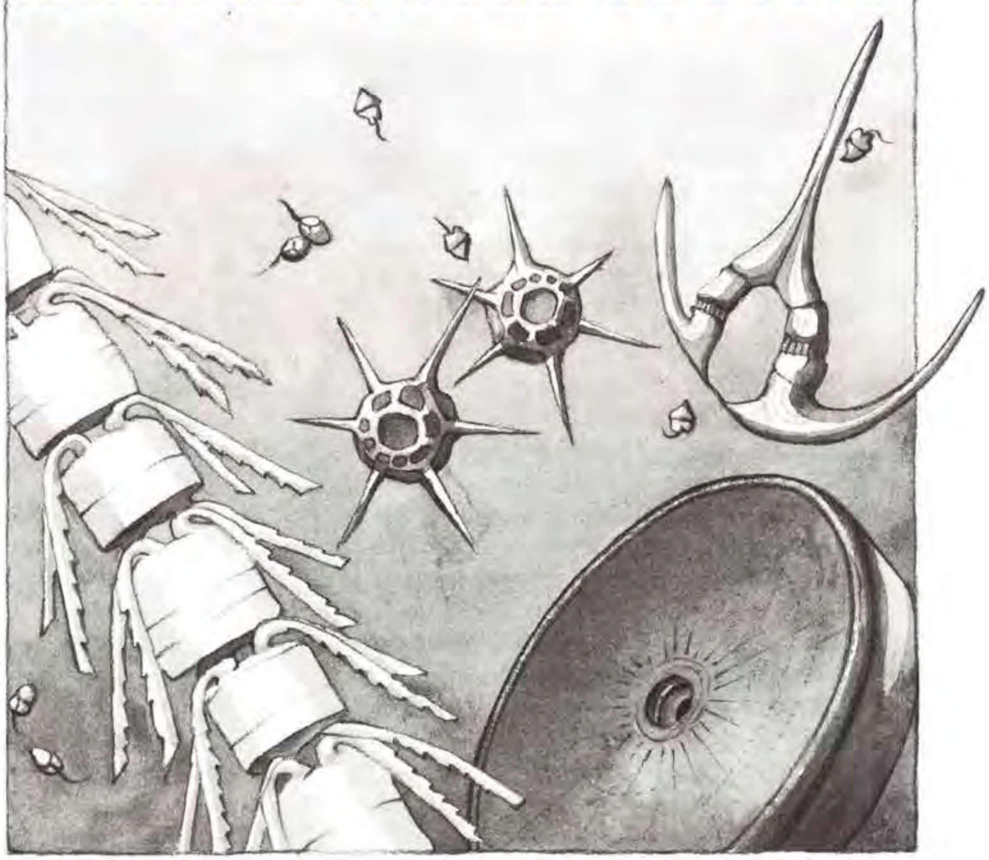
Many of the areas sampled by PSAMP during 1989 have not been surveyed before. The 1990 sampling will help to confirm (or refute) whether chemicals found during 1989 PSAMP sampling were present in higher or lower concentrations than in previous years, including the elevated concentrations of volatile organics in the deep basins, the presence of elevated levels of metals contributed to the Whidbey Basin by the Stillaguamish River, and the apparent lower levels of PCBs in Elliott Bay. Repeated sampling of many of the 1989 PSAMP stations during 1990 may also confirm the 1989 toxicity levels and will add information about benthic invertebrate community patterns.

During the 1990 sampling, some changes will be made in station locations. In general, river mouths and areas which produced unexpected results will be examined in more detail.

Thirty-two of the 50 stations sampled in 1989 will again be sampled as part of the fixed station network. PSAMP investigators will establish a rotating network of 18 stations which will allow more intensive sampling in one area of the Sound each year. The rotating stations will be placed in the South Sound in 1990, north Puget Sound in 1991, and the central portions of the Sound and Hood Canal in 1992.

Current PSAMP funding does not allow investigators to collect enough samples to determine fine-scale patterns of sediment contamination, toxicity, and effects on the benthic community. The full PSAMP design calls for 50 percent more stations to be sampled each year. Until this level of funding is reached, we will have to rely on guesses about sediment quality levels in many of the smaller bays and other areas of the Sound. Unexpected results and emerging trends will not be confirmed as quickly as they might, and more years of sediment sampling will be needed to establish a baseline of Puget Sound sediment quality. During this time, managers may not have sufficient information to recognize ongoing changes in sediment quality in Puget Sound.

MARINE WATER COLUMN



BACKGROUND

The water that overlies the bottom of Puget Sound is known as the marine water column. This water transports dissolved gases, nutrients and chemicals, particles, and small plants and animals incapable of swimming against currents (plankton) throughout Puget Sound. The water column is home to free-swimming (pelagic) fish like salmon, cod, and rockfish and mammals like seals, sea lions, and whales. Sediment washed from the land by rivers, particles and their contaminants discharged from pipes and storm drains, and young forms of many marine animals pass through the water column on their way to the sediments.

The health of the marine water column is often referred to as the water quality of a body of water. Water quality problems are those which affect the water column and its inhabitants, or which diminish the usefulness of water column and nearshore resources to humans (beneficial uses). Examples of water quality problems in Puget Sound include the contamination of shellfish beds, floating mats of odorous algae, fish kills due to low oxygen levels, and discolored water from spills and discharges.

The marine waters of Puget Sound move back and forth with each change of the tide. Salty ocean water enters the Strait of Juan de Fuca at Cape Flattery with each flood tide, and flows east and south into the basins of Puget Sound via Admiralty Inlet. Because the ocean water is cold and salty, it stays in the deep basins of Puget Sound, mixing partially with less salty water above. The 10 major rivers of Puget Sound, and numerous smaller rivers and streams, discharge about 10 billion gallons of fresh water into the Sound each year, mostly during the winter rainy season or after the snow pack melts from the Cascade and Olympic Mountains. The fresh water stays mainly on the surface, gradually mixing with the underlying saltier water, and flows northward toward Admiralty Inlet and the Straits. Puget Sound has a very large tidal prism (the volume of water exchanged on each tidal cycle). The Sound's two billion gallon tidal prism moves water swiftly over great distances. Tidal currents distribute the marine water and its associated particles and contaminants, as well as many of its plants and animals, throughout the Sound.

HOW DO CONTAMINANTS GET INTO THE WATER COLUMN?

As contaminants enter the Sound from the land or from outfalls, they are either attached to particles (particulate phase) or they are dissolved in the water (dissolved phase). Those attached to particles sink out of the water column to join the bottom sediments. These particles settle at varying distances from their source, depending upon their size and density and the speed of the water currents. The dissolved contaminants remain in the water column to be distributed throughout the basins and waterways of Puget Sound. Fortunately for the inhabitants of the water column, most toxic chemicals which enter the Sound are in the particulate phase and are quickly removed from the water column, although some particles (and their associated contaminants) are resuspended from the bottom sediments into the water column. The volume of Puget Sound water rapidly dilutes most dissolved contaminants to harmless levels. For this reason, we seldom attempt to measure toxicants dissolved in the water or in plankton. Instead we search for them in the sediments and bottom-dwelling plants and animals as well as in some Puget Sound fish, marine mammals, and wildlife.

Contaminants other than toxics can affect marine and estuarine waters such as Puget Sound. The so-called conventional pollutants such as particles (suspended sediments), dissolved nutrients, material which draws oxygen from the water (biological oxygen demand, or BOD), and temperature and salinity changes, can upset the natural balance of plant growth, resulting in water quality problems. These problems may include large overgrowths of algae (known as blooms). After marine algae have bloomed, they die and decompose, robbing the water of life-sustaining oxygen. Foul odors and fish kills can result.

Disease-causing bacteria and viruses (pathogens) associated with sewage from humans and animals are also a threat to the beneficial uses of Puget Sound. In general, these pathogens do not affect the health of marine organisms, but they are a health threat to humans who come into contact with contaminated water or who eat shellfish from contaminated waters. Fecal coliform bacteria (which are found in the intestines of warm-blooded animals) are monitored by public health officials in water and in shellfish to indicate the presence of these bacteria and viruses.

ARE THERE WATER QUALITY PROBLEMS IN PUGET SOUND?

Algal blooms, fish kills, beach closures, shellfish harvest restrictions, and fishery bans have plagued many other developed estuaries across the country and abroad. These problems may be caused by chemicals, nutrients, and particles from land runoff or discharges from industrial and municipal sewage plants. Fortunately, strong tidal exchange in Puget Sound prevents most areas of the Sound from suffering similar problems.

However, some areas of Puget Sound have experienced water quality problems in the past, particularly areas affected by lumber and pulp mill wastes. These problems included fish kills and widespread toxicity to developing oyster larvae (Cardwell and Woelke, 1979). During the 1970s strong source control programs were put in place to reduce the amount of waste from the forest products industry. These controls were very effective in curbing the release of excessive amounts of organic matter into the water, reducing problems with biological oxygen demand as well as eliminating the toxicity of the water to oyster larvae. Similar controls, in the form of permits issued to municipal and industrial dischargers of wastewater, are in place to reduce the discharge of conventional pollutants to Puget Sound. These permits are presently being strengthened to reduce the discharge of toxic pollutants into the Sound.

Despite these efforts, some areas of Puget Sound (non-urban as well as urban areas) still experience water quality problems. Problems may include eutrophication (the overgrowth and die-off of algae due to excessive nutrients) and fecal contamination from human and animal sources during warm weather, following heavy rains, or whenever a spill, broken sewer line, or storm drain pours untreated waste into the Sound. Many areas are closed to shellfish harvest due to excessive fecal coliform bacteria in the water. As the human population in the Puget Sound basin grows, increased nearshore and watershed development and the need to dispose of escalating quantities of waste will increase the burden put upon the natural systems of the Sound.

PSAMP MARINE WATER COLUMN MONITORING

PSAMP was designed to measure water quality parameters over time throughout Puget Sound in a three-part scheme. The first part involves sampling a limited number of open water stations, once a month, to evaluate long-term water quality trends. The second part looks at specific areas with known or suspected water quality problems, and the third part documents the dynamics of algal growth, related to nutrients, light, and water column stability.
The purpose of the PSAMP water column design is to collect baseline and long-term water column data in many areas of Puget Sound to see if there are changes in water quality conditions over time. Managers will also make some limited use of PSAMP data to compare the water quality among areas of Puget Sound, allowing them to set priorities for management actions among the bays, inlets, and open basins of the Sound.

LONG-TERM WATER QUALITY TRENDS

Under the full PSAMP design, investigators will monitor 10 to 12 stations in the open waters of Puget Sound throughout the year to learn about the movement of the marine water and dissolved contaminants (by measuring temperature and salinity), the nutrient and dissolved oxygen content, the level

What can the PSAMP water column data be used for?

Water column data collected by PSAMP as well as by earlier studies could be analyzed to show whether gradual changes in the surface and deep waters of the Sound are occurring which indicate a Soundwide increase in contaminants such as nutrients. From these results, water quality managers might conclude that more aggressive source control measures are needed. Also, scientists might recognize large-scale climatic changes from the PSAMP information, including such phenomena as El Nino and global warming. By recognizing global and large-scale changes, scientists could correctly interpret changes seen in short-term studies or in nearshore areas. In turn, the scientists could advise water quality managers when changes to source control or remedial action programs would be effective in reversing water quality trends.

of algal growth (chlorophyll), and the presence of fecal contamination (fecal coliform bacteria). The open basin stations are intended to represent overall water quality conditions in Puget Sound, so they are located away from the shoreline (generally in mid-channel) and away from the influence of individual point sources. Data from these stations will be added to information that has been collected extensively around the Sound since the 1930s, and long-term trends will be examined.

During 1989 PSAMP investigators sampled a total of 24 stations monthly in the open basins and in selected South Sound locations, but were unable to carry out other necessary portions of the program due to funding limitations.

RESULTS OF 1988-89 PSAMP WATER COLUMN MONITORING

PSAMP environmental scientists with the state Department of Ecology sampled the surface and near surface waters at 19 long-term water column stations in the deep basins of Puget Sound, and five stations in South Sound bays, monthly from October 1988 to September 1989 (Figure 13). Traditionally, the South Sound has not been monitored for water quality as frequently as the Main Basin; water quality managers are now discovering that bays in the South Sound have some of the worst water quality problems in Puget Sound.

In general, the 1988-89 PSAMP water column results show that the water quality in many parts of Puget Sound is good. However, samples from several South Sound bays, notably Budd Inlet (in West Bay, near the Port of Olympia), and Oakland Bay (near Shelton) showed intermittent high levels of fecal contamination. Past studies have also measured fecal coliform bacteria at both these locations. The fecal coliform bacteria probably enters Budd Inlet from the LOTT sewage treatment plant outfall and nonpoint pollution carried by the Deschutes River, and enters Oakland Bay from forest products industry waste, stormwater carried by streams, and failing septic tanks.

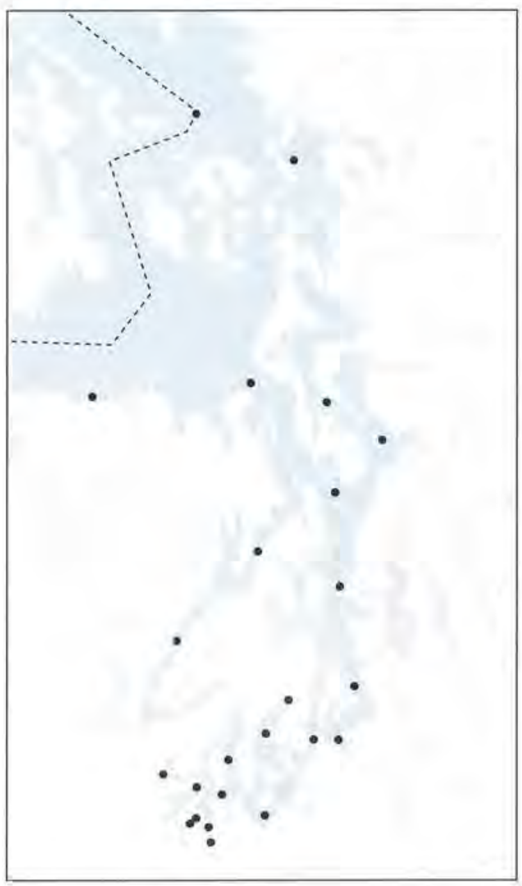


Figure 13. Locations sampled in 1989 for marine water quality monitoring.

PSAMP investigators found few fecal coliform bacteria at stations in the main basin of Puget Sound, except for samples taken off the West Point sewage treatment plant outfall (October 1988) and in East Passage (January 1989). The East Passage result was unexpected; PSAMP investigators will examine the area more closely to better understand the source of this contamination.

Water samples from several South Sound bays had dissolved ammonia levels which are well above Puget Sound Main Basin concentrations (considered to be "background levels"), including stations in Budd Inlet (West Bay and mid-bay), Eld Inlet (near Flapjack Point), Totten Inlet (near Windy Point), and Oakland Bay (near Shelton). In most of the South Sound bays excessive amounts of ammonia are probably being supplied by a combination of sewage treatment plants, rivers and streams, failing septic systems close to the shore, and other nonpoint runoff.

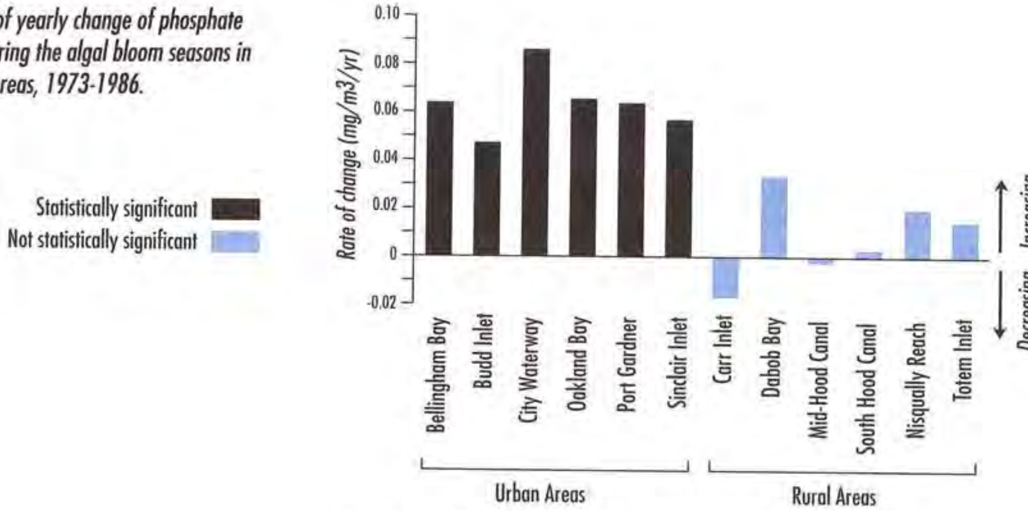
Environmental scientists seldom find dissolved ammonia in seawater because marine algae remove it very rapidly when they are growing. High ambient levels of ammonia indicate that there is a strong and continuous source of ammonia to the water; extremely high levels of ammonia are toxic to many marine animals including juvenile fish. During the algal growing season (May through September), algae generally remove most ammonia supplied to them.

Ammonia levels in most of the South Sound bays declined during the 1988-89 growing season and increased again once the marine algae were no longer growing rapidly. The West Bay station in Budd Inlet (which is close to the LOTT outfall and within the Deschutes River delta) did not show a decrease in ammonia levels during the growing season, which indicates that ammonia inputs to that station must be extremely large and continuous. Very high algal growth rates and large algal blooms leading to eutrophication and low dissolved oxygen levels have been recorded in that part of Budd Inlet in past studies (URS, 1986). PSAMP investigators did not measure algal growth levels or oxygen depletion during 1988-89, but they did note visible signs of eutrophication, such as floating algal mats. Eutrophication events typically last for only a few days. During 1989 PSAMP investigators were able to sample Budd Inlet only once a month, which would allow them to catch only a few of these events. More frequent sampling is needed to better discern short-term changes in water quality; parts 2 and 3 of the PSAMP water column work have been designed to carry out this sampling.

LONG-TERM TRENDS IN WATER QUALITY—OTHER STUDIES

The 1989 PSAMP results add to the long-term database of marine water column information on the Sound. Small changes have been seen in several water column parameters from the 1950s to the present, although no major Soundwide trends have been found (Tetra Tech, 1988b). The small changes include: a small rise in surface water temperature in almost all areas of the Sound, a decrease in biological oxygen demand from pulp mill effluent, a decrease in deep water salinity, and both decreases and increases in dissolved nutrients and dissolved oxygen in localized areas (Dexter et al., 1985; Tetra Tech, 1988b). Also, an increase in concentrations of phosphate (a dissolved nutrient) has been observed in the urban areas between the early 1970s and the mid 1980s (Figure 14), which might be the result of increased human population growth and development in the Puget Sound basin. The toxicity of water to oyster larvae from the vicinity of pulp mills reached a peak during the 1960s and has declined drastically since the 1970s due to major improvements in the quality of the wastewater from the mills (Cardwell and Woelke, 1979).

Figure 14. Rates of yearly change of phosphate concentrations during the algal bloom seasons in urban and rural areas, 1973-1986.



Reference: Adapted from Tetra Tech, 1988b.

The presence of fecal coliform bacteria on Puget Sound urban beaches or in shallow water is directly related to the proximity of sewage outfalls and/or storm drains (Metro, 1988b, 1989). Improvements in municipal waste treatment methods have resulted in overall decreases in fecal coliform counts in urban areas such as Elliott Bay, Sinclair Inlet, and Dyes Inlet (Figure 15) (Galvin et al., 1984; Tetra Tech, 1988b). However, significant increases in fecal coliforms have been seen in rural areas where contamination comes from agricultural runoff and other nonpoint sources (Galvin et al., 1984). Other urban areas, such as Golden Gardens in north Seattle, also continue to be affected by high fecal coliform counts, probably related to stormwater discharges and nonpoint activities (Metro, 1988b, 1989). There are other nonpoint sources of fecal coliform bacteria to the water column, including discharges from marinas and boats, which are generally difficult to document (Department of Health, 1989b).

AREAS WITH KNOWN OR SUSPECTED WATER QUALITY PROBLEMS

Based on previous Puget Sound studies (Campbell et al., 1976; Anderson et al., 1984), PSAMP designers recognized the need to monitor water quality changes which occur on short time scales and in localized areas.

Under the full design, the second part of PSAMP marine water column monitoring involves the selective and comprehensive measurement of water quality parameters in bays and inlets with restricted water circulation and where water quality problems are known or suspected. These special ambient studies will allow managers to make predictions of the impacts of waste discharges and to tailor wastewater permits and other actions appropriately. In some cases, PSAMP data will be able to pinpoint the causes of water quality problems.

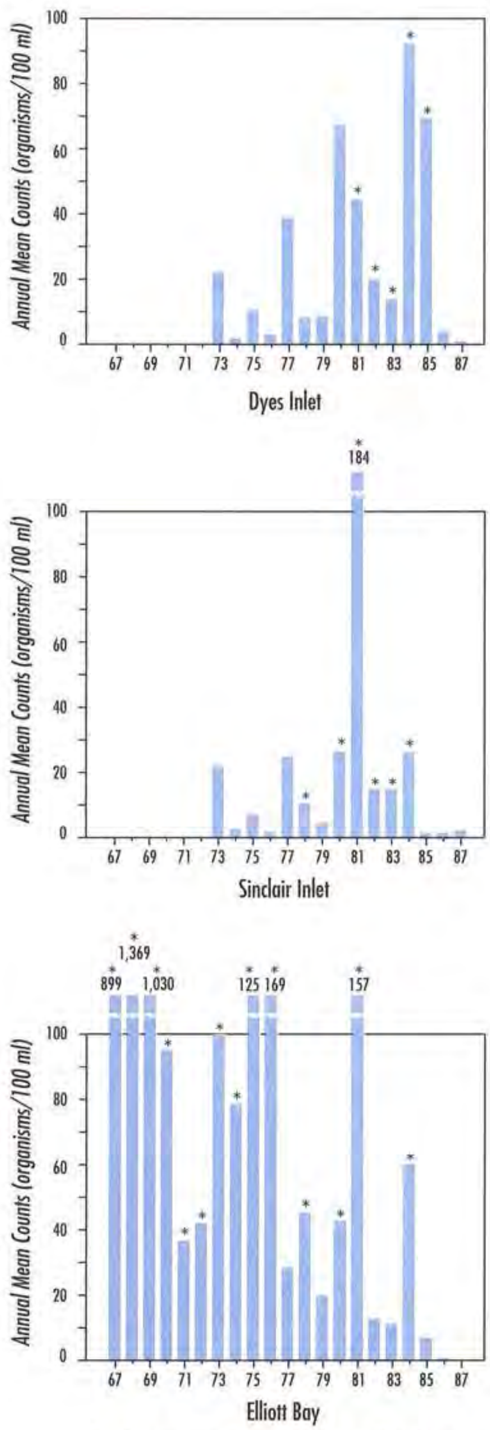
Past studies in Puget Sound have shown that decreased water circulation in many bays and small inlets of the Sound allow the build-up of nutrients, algae, and fecal coliform bacteria. These sorts of problems plague many estuaries in other parts of the country. Serious water quality problems have been observed in recent years in Budd Inlet in the South Sound. Other areas with suspected water quality problems include Fauntleroy Cove (at the edge of the Main

Basin), which suffers from an accumulation of seaweed which dies off and causes foul odors, and Quilcene and Oakland Bays (northern Hood Canal and South Sound, respectively) which have high levels of fecal coliform bacteria causing shellfish bed closures. Many other bays and inlets in Puget Sound are closed to shellfish harvesting due to fecal coliform contamination, as well.

Due to funding limitations, PSAMP investigators were unable to initiate the second part of the marine water column program during 1989.

PREDICTIONS OF ALGAL GROWTH

Under the full PSAMP design, the third and final part of PSAMP marine water column monitoring is "solstice monitoring". For two weeks on either side of the winter and summer solstices (December 21 and June 21, respectively), samples will be taken from several locations around Puget Sound for analysis of dissolved nutrients, algae populations (chlorophyll), and sunlight (incident radiation). Measuring these parameters at the time of the solstices allows for the prediction of the maximum levels of algae that can be expected in the Sound during that year (Anderson et al., 1984). This information can aid water quality managers in predicting which bays may be most at risk for eutrophication, allowing them to take long-term source control actions, such as amending wastewater permits or relocating poorly sited discharges.



*Exceeds marine water quality standards at least once during the year.

Figure 15. Changes in annual mean of fecal coliform levels in surface water of three urban bays.

Due to lack of funding, PSAMP investigators were unable to carry out any "solstice monitoring" during 1989. As PSAMP managers are able to secure future funding, the "solstice monitoring" program will be initiated with the help of citizen monitors.

FUTURE PSAMP WATER COLUMN MONITORING

During 1989 PSAMP concentrated on establishing an up-to-date system of water column monitoring, using electronic equipment, at several stations in the open basins and larger bays of Puget Sound. Beginning in 1990, the number of open water stations will be reduced (from 24 in 1989 to 12 in 1990-1991). This will allow PSAMP investigators to initiate the second part (areas with known or suspected water quality problems) and third part (predictions of algal growth) of the program.

The current PSAMP marine water column monitoring is being carried out by environmental scientists with the state Department of Ecology using existing Ecology funds; no new funds have been allocated for PSAMP water column monitoring for the 1990-1991 period. At present, less than 30 percent of the necessary PSAMP water column program is being carried out. The overall health of Puget Sound's marine water column appears to be good, although deterioration is notable in some areas. Without comprehensive monitoring of the water column, water quality managers may not detect emerging problems until there is serious damage done to natural resources.

FISH

BACKGROUND

When many people think of Puget Sound, they think of fish. Salmon, steelhead, rockfish, halibut, cod, and other sportfish are plentiful. Fishing played a key role in sustaining the early Native American people in the Puget Sound basin, attracted early settlers to the area, and has continued as an important economic factor to the present day. The state Department of Fisheries determined that commercial landings of salmon and marine fish in the Puget Sound basin in 1986 accounted for over $130 million. The value of the recreational fishery is estimated to be even greater.

There are more than 220 species of fish in Puget Sound, living many different lifestyles, and occupying many different positions in the marine food web. Anadromous fish, like salmon, steelhead, and searun trout, hatch in fresh water, migrate long distances to marine water to feed, and return to fresh water to spawn. Marine fish live in a number of different habitats in Puget Sound, never entering fresh water at all. Some rockfish, for example, spend their lives on a single reef while other marine fish, like herring, swim through wide-ranging areas of marine and estuarine waters. Flatfish, like sole, flounder, and halibut, spend most of their adult lives on or near sandy or muddy bottoms.

Many Puget Sound fish populations, such as salmon and lingcod, are thriving (Sekulich, 1990; Schmitt, 1990). Populations of Puget Sound salmon, as well as other anadromous fish, are maintained at robust levels through fish hatcheries and other enhancement programs. Wild stocks of some of these fish, as

How do contamination levels of Puget Sound fish compare with other areas?

As part of their National Status and Trends program (NS&T), investigators from the National Oceanic and Atmospheric Administration (NOAA) measure contaminants in bottomfish tissue and look for certain liver disorders as an indicator of the health of the fish. There are many reasons that the data collected at different locations are not equivalent (such as sampling different fish species with different feeding habits and collecting samples at varying distances from point sources of pollution). It is interesting nonetheless to note that levels of several toxic chemicals measured in fish tissue from Puget Sound are among the highest on the West Coast (although lower than levels elsewhere in the country). During 1984 and 1985, Puget Sound bottomfish from Elliott Bay and Commencement Bay had lower levels of DDT in their livers, higher levels of PCBs in their livers, and higher PAHs in their bile (an excretion product from the liver which accumulates chemicals when the fish's internal organs are exposed to them) than fish at most other West Coast sampling locations (NOAA, 1987). Although different fish species were sampled at different West Coast locations, bottomfish from Elliott Bay and Commencement Bay had a higher incidence of liver disease than fish from other stations sampled on the West Coast (Varanasi et al., 1988). Bottomfish from Nisqually Reach (a non-urban area of Puget Sound), had a lower incidence of liver disease than those from the Puget Sound urban areas (Varanasi et al., 1988).

well as many marine fish species, are not doing as well. Populations of cod, whiting, and other marine fish are depressed or declining (Schmitt, 1990). These declines are the result of natural and anthropogenic pressures, including overfishing, increased marine mammal predation, poor environmental conditions, chemical contamination, and shoreline development. Fisheries managers cannot easily separate the effects on fish populations of contamination and related disease from those of habitat loss, poor environmental conditions, and overfishing. They need good estimates of fish population abundances, detailed knowledge of the life history of many fish species, and information on the effects of contamination, in order to protect and preserve healthy stocks of Puget Sound fish.

THREATS TO PUGET SOUND FISH

Human development in the Puget Sound basin has brought with it many threats to fish populations. Like all living creatures, fish need adequate, uncontaminated food supplies and an abundance of natural habitat in which to thrive.

The human population in the Puget Sound basin has centered largely around bays with large navigable rivers (commonly called the urban bays). Pollution from residential and industrial development is more concentrated in the water and sediments of these urban bays than in other areas of Puget Sound. Fish that live in the urban bays are more likely to be exposed to degraded habitats and contamination than those that live in less contaminated areas. For example, flatfish living in close contact with contaminated sediments and feeding on contaminated benthic organisms are at greater risk for accumulating toxic chemicals in their tissues than those living in more pristine areas.

Researchers have shown that the thin upper layer between the water and the air (called the sea-surface microlayer) may concentrate toxic chemicals (Hardy, 1987). Some flatfish and other marine fish release eggs which float in the upper water column. Because fish eggs and larvae are especially sensitive to chemical contaminants, eggs and larvae living in the upper water column may suffer harm from the sea-surface microlayer (Hardy, 1987). Pelagic or free-swimming fish may also be at risk. Juvenile salmon and marine fish like rockfish and cod may accumulate toxicants in their bodies from eating contaminated animals in nearshore estuarine areas or from absorbing low levels of toxic chemicals dissolved in the water (Landolt et al., 1987; McCain et al., 1988b).

Many fish can metabolize and excrete chemical contaminants. However, this action creates toxic intermediate products which are filtered from the fish's body through the liver (Chapman et al., 1983). Researchers have shown that flatfish livers can concentrate these intermediate products and suffer damage, including cancerous tumors, pre-tumors, and other diseases (Malins et al., 1980, 1984; McCain et al., 1982; Myers et al., 1988). English sole—the most commonly studied Puget Sound flatfish—suffering from liver disease tend to reproduce at lower rates than healthy fish (Johnson et al., 1988; McCain et al., 1988a). Fisheries managers do not have sufficiently detailed information about English sole populations to know whether these reproductive problems are affecting the population levels in the urban bays. Soundwide, the population of English sole appears to be reasonably stable (Figure 16).

University of Washington researchers have found that Pacific cod in the Sound have higher levels of some contaminants in their tissues than most other Puget Sound species examined (Landolt et al., 1985, 1987). Pacific cod populations in both central and southern Puget Sound have seriously declined (Figure 17), but fisheries biologists are uncertain whether contamination is responsible for this decline. Poor environmental conditions (especially warm water temperatures for the past several years) and overfishing have probably had major effects on the Pacific cod population (Palsson, in review).

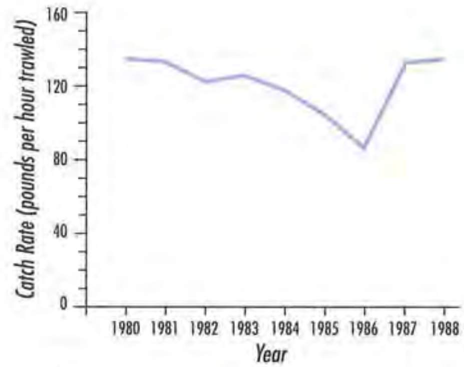


Figure 16. Commercial catch rates of English sole in central Puget Sound.

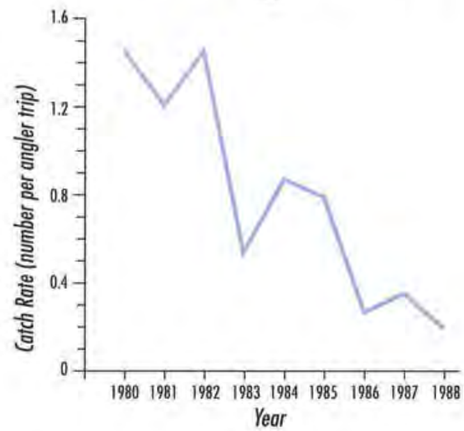


Figure 17. Recreational catch rates of Pacific cod in central Puget Sound.

WHY SHOULD WE WORRY ABOUT CONTAMINATED FISH?

There are two major concerns associated with contaminated fish in Puget Sound: the health of the fish themselves and the threat that they may pose to humans and other animals who eat them. Fisheries managers are concerned because high disease rates and reproductive failures can threaten whole fish populations. Public health officials are concerned about the risks to humans from eating contaminated fish. Natural resource managers are concerned because many marine and terrestrial animals (including birds, other fish, and marine mammals) eat fish. These animals can accumulate the fish's toxicants, pass them up the food web, and pose an additional health risk to humans and other predators.

Humans may be at risk for illness and serious disease if they consume enough contaminated fish; it is often difficult to say how much is enough, however. An Environmental Protection Agency study has shown that the potential lifetime cancer risk from eating about 30 servings of Puget Sound bottomfish a year from contaminated areas is similar to the risk from eating other foods which are known to contain carcinogens (Tetra Tech, 1988c). These foods include diet soda, peanut butter, charcoal broiled steaks, and whole milk. Heavy consumers of contaminated fish can face higher risks. PSAMP managers will evaluate the contamination level of Puget Sound fish to determine whether this risk is increasing, decreasing, or remaining stable over time.

PSAMP FISH MONITORING

PSAMP investigators monitor Puget Sound fish for the presence and effects of contamination, not for population trends. They look for indicators of the health of bottomfish in Puget Sound as well as for indicators of the human health risk of eating Puget Sound fish.

PSAMP has been designed to monitor English sole for the occurrence of liver disease (as a measure of the health of the fish), and to measure tissue contamination levels (as a measure of the threat to human health from eating English sole). Because few people eat a steady diet of English sole, PSAMP investigators also measure contaminants in five species of fish that are caught by many recreational and commercial anglers: copper and quillback rockfish, chinook and coho salmon, and Pacific cod.

Rockfish may live for 30 years or longer and spend much of their lives in one area. PSAMP investigators believe that toxic chemicals measured in rockfish tissue have been accumulated in a localized area. Also, the longevity of rockfish ensures that contaminants which are known to accumulate in fish tissue will show up in their muscles.

Salmon and Pacific cod are relatively shorter-lived and highly migratory. Muscle tissue contamination levels in these species are representative of conditions that fish may encounter throughout Puget Sound rather than in one small area. PSAMP investigators monitor so-called resident salmon (those that spend most of their time feeding in Puget Sound), rather than those that favor the north Pacific Ocean, to ensure that toxic chemicals in the salmon tissue represent Puget Sound conditions. Pacific cod swim throughout Puget Sound but generally do not migrate to the open ocean. This species, as well as being one of the most commonly caught by recreational anglers, has been shown to contain high levels of arsenic and PCBs as compared to other Puget Sound fish (Landolt et al., 1985, 1987).

Figure 18. Locations sampled in 1989 for English sole and rockfish.

English sole •
Rockfish ▲

PSAMP RESULTS FROM 1989

PSAMP investigators from the state Department of Fisheries collected English sole from 10 stations in Puget Sound during May 1989 (Figure 18), many of which were located in or near the urban bays. The 1989 PSAMP fish survey covered a larger geographic area than most previous studies. PSAMP investigators examined the English sole for parasites and other obvious health problems (such as fin erosion), and noted their length, weight, sex, and reproductive maturity. Chemists analyzed muscle tissue from the fish for four metals (arsenic, copper, lead, and mercury) and for many organic compounds, including PCBs and pesticides which have been found at elevated levels in fish in past studies. Fish pathologists cut sections of the fish livers and examined them microscopically to detect tumors and other signs of liver disease. The results of the liver microscopic analyses will be available during spring 1990.

PSAMP investigators also sampled rockfish for muscle tissue contaminants at two locations in the Sound during September 1989 (Figure 18). Chemists will be analyzing these samples in 1990.

RESULTS OF 1989 PSAMP BOTTOMFISH TISSUE ANALYSIS – METALS

PSAMP investigators found low levels of lead, copper, mercury, and arsenic in English sole tissue at most of the 1989 PSAMP stations. In general, fish caught in the urban bays had higher levels of metals than those from the rest of the Sound. Sinclair Inlet fish consistently had the highest levels of metals, particularly lead and arsenic. English sole collected from Discovery Bay—a non-urban area—had comparably high levels of arsenic in their tissues. Naturally occurring sources of arsenic in Puget Sound (including Pacific Ocean water, shoreline erosion, and river input) may be high enough to account for the fish tissue levels seen in Discovery Bay.

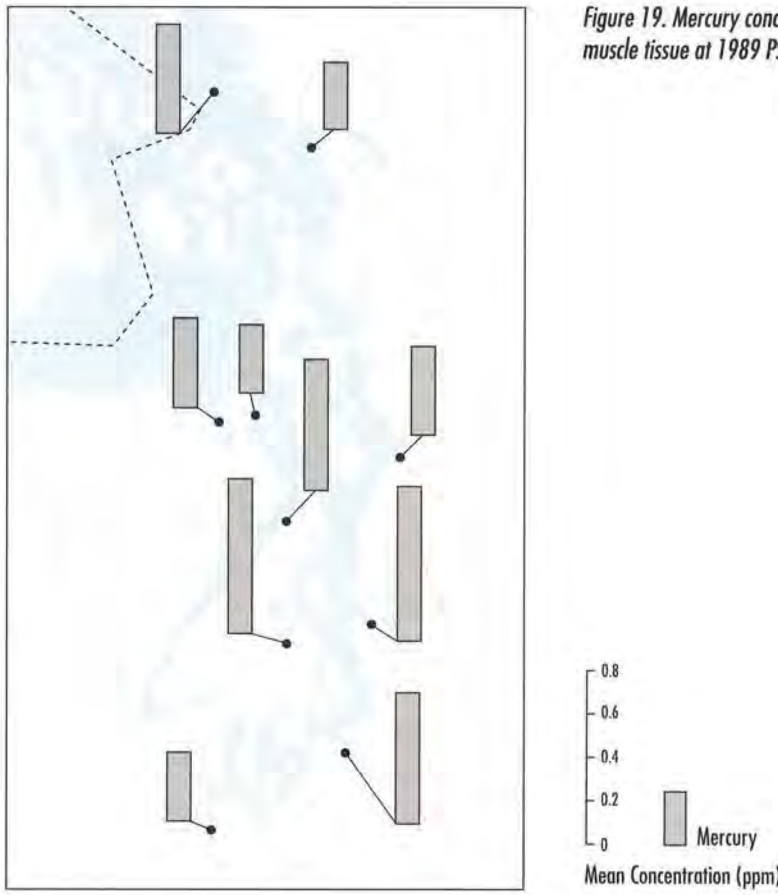
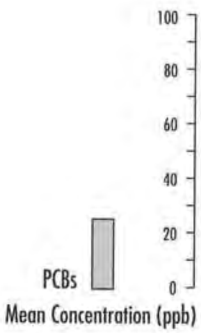


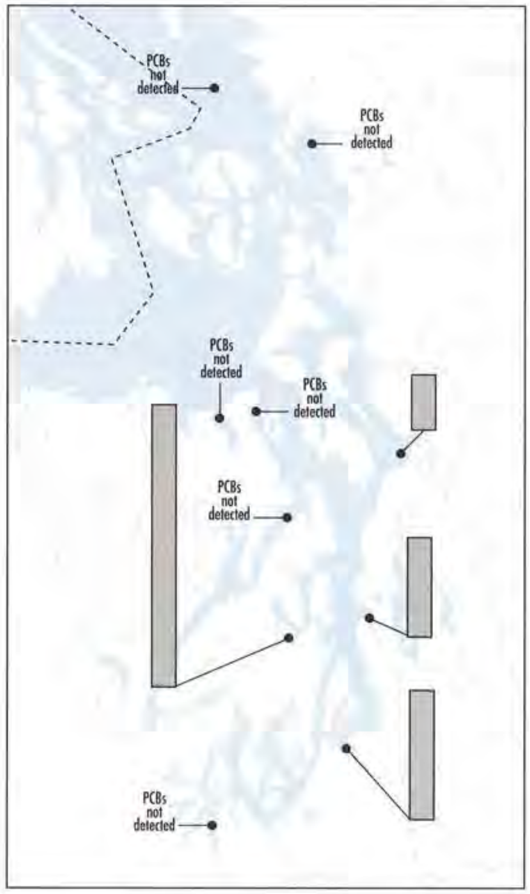
Figure 19. Mercury concentrations in English sole muscle tissue at 1989 PSAMP stations.

The 1989 PSAMP English sole tissue levels of all four metals are similar to those that have been found in previous studies in the urban bays (Landolt et al., 1985; Tetra Tech, 1985; Crecelius et al., 1989). Mercury levels in fish collected from the nearshore stations in Sinclair Inlet, Elliott Bay, and Commencement Bay were twice as high as those in most nonurban areas (Figure 19), suggesting that industrial activities in the urban bays are a major source of mercury. Mercury levels in fish may have increased at the Elliott Bay stations compared to samples collected in 1986 (PTI and Tetra Tech, 1988). Investigators with the National Oceanic and Atmospheric Administration (NOAA) have previously measured high concentrations of mercury in sediment and organisms from Bellingham Bay (NOAA, 1987). Industrial discharges of mercury to Bellingham Bay have decreased significantly in recent years. PSAMP managers are cautiously optimistic that the lower levels measured during 1989 may indicate a recovery of the sediments and organisms.

RESULTS OF 1989 PSAMP BOTTOMFISH TISSUE ANALYSIS – TOXIC ORGANIC COMPOUNDS

Figure 20. Concentrations of PCBs in English sole muscle tissue at 1989 PSAMP stations.





The English sole muscle tissues measured during 1989 contained very few toxic organic compounds. PSAMP investigators found PCBs at low levels in all of the urban bay samples, with the highest concentrations in Sinclair Inlet and Commencement Bay (Figure 20). Recent studies of PCBs in bottomfish (Landolt et al., 1985; Crecelius et al., 1989) showed similar levels; measurements of PCBs in English sole made during the late 1970s and early 1980s were substantially higher (Malins et al., 1980, 1982; Gahler et al., 1982). This trend suggests that the removal of PCBs from manufacture in the 1970s is beginning to reduce levels of PCBs in bottomfish tissue.

Organochlorine pesticides were not found in any of the 1989 English sole samples, although they have been detected in other fish species from Puget Sound (Landolt et al., 1987). PSAMP investigators again are cautiously optimistic that we may be beginning to see a decrease in these pesticides in organisms. Previous studies have suggested that there has been such a decrease in fish from Elliott Bay over time (Matta et al., 1986; Mearns et al., 1988).

PSAMP investigators were somewhat surprised to find the organic compounds benzoic acid and benzyl alcohol in almost all of the 1989 bottomfish samples, with the highest levels in the South Sound. Bottomfish from Discovery Bay and Port Townsend (areas away from urban impacts) also had high concentrations of benzoic acid in their muscle tissue. These compounds typically come from atmospheric deposition of combustion products (from cars and open burning) and from the breakdown of lignins and tannins, which are naturally occurring chemicals found in wood (Brown, personal communication). The potential effects of benzoic acid and benzyl alcohol on the fish, or as a threat to human health, are unknown. Future PSAMP monitoring of fish tissue will look for these two compounds in an attempt to confirm their presence and significance in the environment.

FUTURE PSAMP FISH MONITORING

PSAMP managers were able to fund about 25 percent of the necessary PSAMP fish work during the 1989-1990 period. The funds are being used to collect English sole and the five species of recreational fish (two rockfish species, two salmon species, and Pacific cod) at a few locations once during the two-year period. As additional funding becomes available, state Department of Fisheries biologists will sample the bottomfish and recreational fish each year at an increased number of locations. PSAMP managers will place increased emphasis on collecting and interpreting data on fish abundances, aquaculture yields, and fish harvest records to determine the production of Puget Sound fish. Also, beginning with the next PSAMP annual report, data analysis efforts will focus on evaluating changes over time of risks to humans from consuming contaminated fish from Puget Sound.

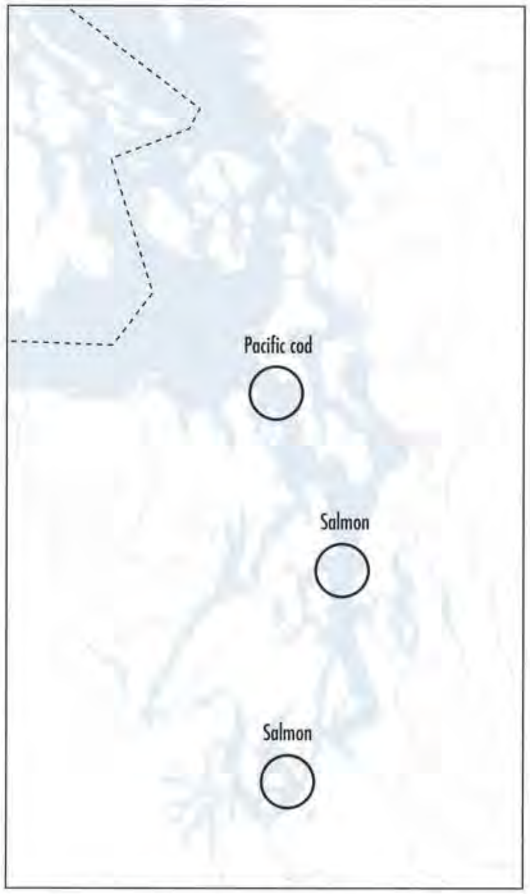


Figure 21. Salmon and Pacific cod stations to be sampled in 1990.

During 1990 PSAMP will collect Pacific cod off Port Townsend in February and two salmon species at two locations in April (Figure 21). Investigators will complete the analysis of toxic chemicals in rockfish tissue collected in September 1989 and microscopic analysis of bottomfish livers collected in May 1989.

Until a greater amount of funding is available for PSAMP fish work, we will know very little about the health of fish populations in most locations in the Sound and the risk that those fish may pose to humans who eat them.

SHELLFISH

BACKGROUND

Shellfish are a multi-million dollar commercial and recreational fisheries resource to the Puget Sound region. Puget Sound shellfish include clams, oysters, mussels, scallops, geoducks, crab, and shrimp. The abundance of shellfish has represented the high quality of life and richness of nature in this region to the earliest communities of Native American people, the European settlers, and today's Puget Sound residents. Shellfishing, more than any other part of the region's economy, depends on good water quality and is vulnerable to degradation of the Puget Sound environment.

Most bivalve shellfish (such as clams and oysters) are sedentary animals which live their adult lives in one spot on the floor of Puget Sound. (The exception is the scallop which swims freely from time to time.) Bivalves filter enormous quantities of water (for example, oysters can filter 25 to 50 gallons of water per day) to extract tiny particles of plankton and debris which provide them with nourishment. This filtering process places bivalves at risk for accumulating contaminants from the water column. Even though the contaminants may be very dilute in the water, shellfish can accumulate them in high concentrations in their tissues. Also, most bivalves live on the bottom sediments of Puget Sound; this may expose them to contaminants that have accumulated in the sediments.

The non-bivalve shellfish (crab and shrimp) spend most of their lives consuming plants, animals, and debris from the bottom of Puget Sound or capturing free-swimming and floating animals from the water column. Crab and benthic shrimp (generally bottom scavengers) can accumulate chemicals from contaminated sediments. Free-swimming predatory shrimp may be exposed to some contaminants in the water column, but they are generally at lower risk for contamination than the bottom-dwellers.

Resource managers and public health officials are concerned about shellfish contamination because harm may occur to the shellfish themselves and because humans may face health risks from consuming contaminated shellfish.

PUBLIC HEALTH CONCERNS ABOUT SHELLFISH

Threats to public health from consuming contaminated shellfish fall into three categories: pathogens (disease-causing organisms such as bacteria and viruses), paralytic shellfish poisoning (PSP), and chemical contamination.

In Puget Sound commercial shellfish growers raise shellfish mostly in the non-urban areas. Monitoring of commercial shellfish is required to ensure that the shellfish meet strict standards for bacterial, PSP, and chemical contamination before the shellfish reach the market. The state Board of Health has recently adopted bacterial standards for the recreational harvest of shellfish; however, there is very little monitoring of recreational shellfish areas for contamination. Public health officials are concerned about public health risks to recreational harvesters, and are expanding their monitoring programs to include recreational beaches.

Pathogens can be transmitted to water and to shellfish from infected humans (and other animals) via their feces. Sources of pathogens include discharges of wastewater from sewage treatment plants, stormwater runoff, runoff from failing septic system drainfields, and the release of animal feces into water from farms, forests, and developed areas. Heavy rainfall can wash fecal material from the land and cause contamination of nearshore shellfish beds. Generally, pathogens that can infect humans are very few and far between in water (although the effect of a very few organisms on humans can be serious), so we cannot accurately measure them. Instead, we measure indicator bacteria, usually fecal coliforms (and sometimes others) which are found associated with pathogens. The presence of indicator bacteria show that fecal contamination (and possibly pathogens) is present in the water or shellfish tissue.

Commercial shellfishing is prohibited all along the eastern shore of the Main Basin, from Tacoma to Everett (and in other areas of the Sound) due to potential bacterial and chemical contamination caused by discharges from storm drains, residences, sewage treatment plants, and industries. Department of Health officials believe that recreational beaches are also being affected by these discharges, although present regulations do not require that these beaches be posted or closed to shellfish harvest. Shellfish monitoring under PSAMP and other programs will provide public health officials with the information they need to selectively restrict shellfish harvesting at recreational beaches when a public health threat is found to exist.

During the 1950s and 1960s a number of areas of the Sound were closed to commercial shellfish harvesting due to bacterial contamination, including all of Dyes and Sinclair Inlets and portions of Budd Inlet, Oakland Bay, Liberty Bay, and Port Susan. Since 1981 the state Department of Health has closed many other areas due to bacterial contamination as well (Table 3, Figure 22).

Year	Area	Contaminant Source(s)	Species Affected	Acres Affected
1981	Burley Lagoon	Rural NP	Pacific oysters Manila clams	480
1982	Minter Bay	Rural NP	Pacific oysters	93
1983	Penn Cove	Point/STP	Blue mussels	500
1983	Lower Eld Inlet	Rural NP	Pacific oysters Manila clams	600
1984	N Quilcene Bay	Rural NP	Pacific oysters	200
1984	Henderson Inlet	Rural NP	Pacific oysters Manila clams	300
1986	S Skagit Bay	Rural/Ag NP	Softshell clams	2900
1987	Port Susan	Ag NP/STP	Pacific oysters Manila clams	6100
1987	Dosewallips Tidelands	Seals	Pacific oysters Manila clams	180
1987	Oakland Bay	Urban Pt/NP	Pacific oysters Manila clams	820
1987	Lynch Cove	Rural/Urb NP	Pacific oysters Manila clams	630
1988	Duckabush Tideland	Rural NP	Pacific oysters Manila clams	210
1988	Drayton Harbor	Rural NP	Pacific oysters Manila clams	500
1989	N Skagit Bay	Rural NP	Softshell clams	2500

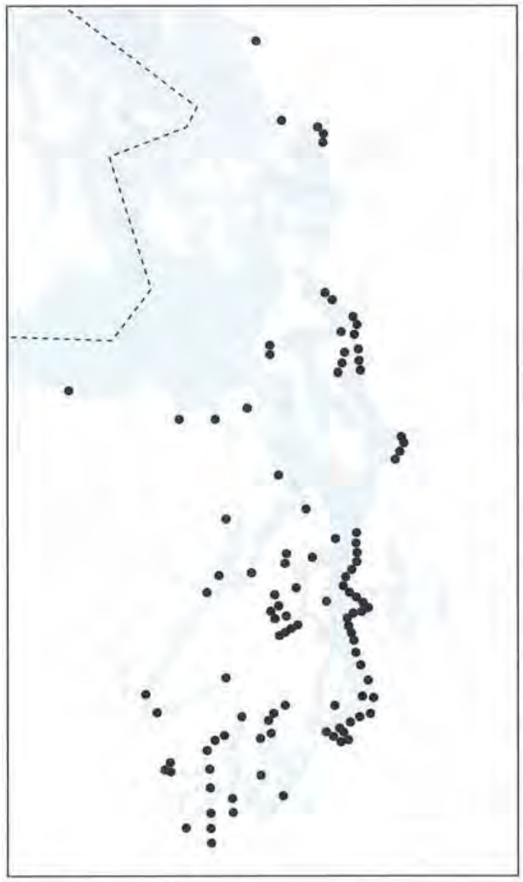
STP = Sewage Treatment Plant; Ag = Agricultural; NP = Nonpoint Source; Urb = Urban; Pt = Point Source

Table 3. Shellfish growing areas where commercial harvest has been restricted.

Paralytic shellfish poisoning (PSP) is the result of a nerve toxin which can accumulate in the tissues of shellfish that filter certain algae (*Protogonyaulax catenella*) from the water. The algae which is responsible for PSP grows rapidly in our waters on a frequent but unpredictable basis. When sufficient levels of the algae are present in the water, the shellfish can concentrate enough toxin to make the shellfish meat dangerous, if not fatal, to humans and other animals. Because of the potential life-threatening nature of PSP, shellfish from commercial and recreational shellfish areas are routinely monitored for PSP, and numerous beaches are closed for shellfish harvesting every year when the PSP toxin is detected.

Shellfish tissue can concentrate chemical contaminants from filtering large amounts of water as well as from material resuspended from contaminated sediments. Both the public health effects and the effects on the shellfish themselves are not well known, although we have some information on the risks to humans from consuming shellfish contaminated by arsenic and PCBs (Tetra Tech, 1988c). Public health officials realize the need for careful monitoring of chemicals in shellfish and for further information on the effects that chemical contaminants have on shellfish. In future years, PSAMP managers and public health officials will use information on toxic chemicals to estimate the risk to human health from consuming Puget Sound shellfish.

Figure 22. Shellfish beds where commercial harvest has been restricted.



Reference: Department of Health, 1989a.

PSAMP SHELLFISH MONITORING

The focus of PSAMP shellfish monitoring is on the threat to human health from consuming contaminated shellfish. Because commercial growers and harvesters of shellfish must have their shellfish checked regularly for PSP and bacterial contamination, PSAMP investigators focus their sampling on public recreational beaches where countless Puget Sound residents harvest shellfish.

PSAMP investigators with the state Department of Health sample certain species of bivalves (native littleneck clams, manila clams, butter clams, and blue mussels) for bacterial contamination (fecal coliform indicator bacteria). Every three months they collect shellfish tissue samples at beaches in areas of heavy public harvesting, which often correspond to rural areas suffering from nonpoint source pollution.

Tissue from the same species of shellfish are collected for PSP analysis at many recreational beaches, with the help of citizen monitors, every other week, for six months of the year. During the winter months (October through March) samples are collected once a month. Technicians and citizen monitors collect shellfish tissue samples for toxic chemical analysis at several beaches in areas of known or suspected sources of toxic chemicals once during the spring.

Shellfish experts from the state Department of Fisheries survey recreational beaches for the abundance of harvestable shellfish during the spring. Public health officials can use information on the abundance of harvestable shellfish to determine where to focus their monitoring efforts for shellfish contamination. Department of Fisheries shellfish biologists also fly over the beaches and conduct creel surveys (checking how many shellfish have been harvested by people on certain beaches) to estimate how many people are digging shellfish and how many shellfish are being harvested.

PSAMP SHELLFISH RESULTS FROM 1989/1990 – BACTERIAL CONTAMINATION

PSAMP investigators sampled shellfish tissue for bacteria during November 1989 and February 1990 from 10 recreational beaches around Puget Sound (Figure 23).

During both sampling periods, samples from seven of the 10 beaches showed low levels of fecal contamination. In November 1989 three beaches showed fecal contamination levels which are above commercial shellfish standards: Walker State Park near Shelton (South Sound), Belfair State Park near Lynch Cove on Hood Canal, and Dosewallips State Park on Hood Canal. Public health officials consider that the contamination problems at Walker State Park are due to failing septic systems and discharges of municipal sewage and stormwater, while those at Dosewallips State Park are due to an increasing population of harbor seals (Faigenblum, 1988; Calambokidis et al., 1989). State Department of Health officials believe that high fecal coliform levels in shellfish at Belfair State Park are caused primarily by failing community on-site septic systems in the town of Belfair. Samples of shellfish tissue analyzed for fecal coliform bacteria in February 1990 showed levels that were slightly lower than the November samples (but still above commercial shellfish standards) at Walker State Park, Belfair State Park, and Dosewallips State Park.

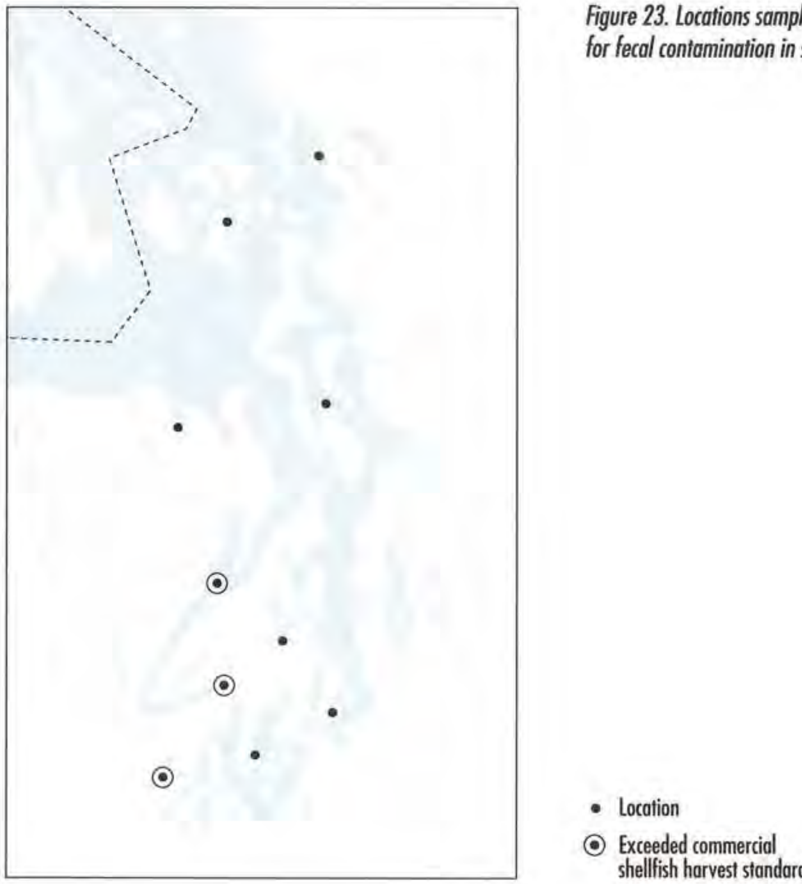


Figure 23. Locations sampled in 1989 and 1990 for fecal contamination in shellfish.

In addition to shellfish monitoring carried out by PSAMP investigators, there have been many previous studies of bacterial contamination of shellfish, as well as several ongoing monitoring programs. County health departments around the Sound collect samples for Department of Health analysis of fecal coliform bacteria in water near shellfish beds as a measure of contamination of shellfish. Metro analyzes shellfish tissue and water for fecal coliform bacteria at several beaches in the Seattle/King County area, and frequently reports levels above the commercial standard for harvest (Metro, 1988b, 1989). University of Washington scientists sampled several recreational shellfish beaches in East Passage between 1982 and 1984. They found that shellfish meat from these beaches had high levels of fecal coliform bacteria during rainy weather, particularly during the winter and early spring (Stober and Chew, 1984).

Public health officials at the state Department of Health sampled a number of recreational shellfish sites in Puget Sound in 1988 and found (as they did in 1989) high levels of fecal coliform bacteria at Dosewallips State Park and Walker State Park. The same study also showed high bacterial levels in shellfish near the urban bays and all along the eastern shore of the main basin of Puget Sound (Faigenblum, 1988). During the 1988 study public health officials found consistently low levels of fecal contamination in more rural areas, including Birch Bay, Oak Harbor, Quartermaster Harbor, and Camano Island (Faigenblum, 1988).

The role of citizen monitors in collecting shelfish

During 1989 citizen monitors played their most significant role in PSAMP by collecting shellfish samples. Without their help, many of the recreational beaches throughout the Sound would not have been monitored for PSP toxin at all. In addition, help from citizen monitors allows PSAMP managers to use limited funds for bacterial and chemical analysis rather than field collection of samples. This savings allows scientists to monitor a greater number of recreational shellfish beaches for contamination.

Figure 24. Selected locations sampled in 1989 for PSP in shellfish.

Location •
Closure due to PSP levels ⦿

PSAMP SHELLFISH RESULTS FROM 1989 — PSP

During 1989 PSAMP investigators found PSP in shellfish on beaches in many parts of the Sound during the late fall (Figure 24). This was unusually late in the season for high PSP levels; these levels generally peak during the late summer and early fall. Public health officials closed beaches to shellfish harvest throughout King County and parts of Pierce County, as well as parts of Carr Inlet in the South Sound, in response to the PSP levels. Beaches were also closed for shellfish harvest due to PSP in Skagit, San Juan, Jefferson, and Clallam Counties. Pink scallops, which live in deep water, were found to have high levels of PSP during 1989 as well.

TOXIC CHEMICALS IN SHELLFISH

Scientists have analyzed for a limited number of chemicals in Puget Sound shellfish, and no routine monitoring of either metals or organics has been undertaken. During the late 1960s and early 1970s scientists found low levels of organochlorine pesticides in Puget Sound mussels (Butler, 1973).

A few shellfish tissue samples collected in 1974 showed high levels of PCBs in shrimp from Elliott Bay and in mussels from Commencement Bay; lower levels were found in mussels from Nisqually Reach in the South Sound (Matta et al., 1986). In 1984 NOAA researchers found PCBs in shellfish tissue in the same general areas, although the concentrations appear to have dropped in Elliott and Commencement Bays (NOAA, 1987; Mearns et al., 1988). Based on shellfish tissue samples collected from Budd Inlet, NOAA researchers believe that levels of PCBs in certain species of South Sound shellfish may have increased between 1974 and 1984 (Matta et al., 1986). Scientists collected mussel samples from Elliott, Bellingham, and Commencement Bays during 1986, and found elevated levels of PCBs, PAHs, and the toxic metals zinc (Elliott and Commencement Bays) and chromium, mercury, and nickel (Bellingham Bay) (NOAA, 1987; Mearns et al., 1988). Other studies looked at the prevalence of metals in shellfish tissue at several locations around the Sound and found low levels of many trace metals (Romberg et al., 1984; Faigenblum, 1988). During 1988 scientists surveyed shellfish tissue at several recreational beaches in the Sound, most of which were remote from the urban bays. They found low levels of toxic organics and metals in shellfish meat from most areas (Faigenblum, 1988).

FUTURE PSAMP SHELLFISH MONITORING

During 1990 PSAMP investigators will continue to sample shellfish as they did in 1989. Due to a limited budget, only about 30 percent of the shellfish portion of PSAMP will be carried out. Fewer samples of shellfish tissue can be collected than was planned by the PSAMP designers; during 1990 the state Department of Health scientists will sample shellfish tissue at 10 beaches for fecal coliform analysis during May, August, and November. Shellfish will be collected at four beaches in May for toxic chemical analysis. PSP sampling and analysis will continue on samples collected from many recreational, as well as commercial, beaches. PSAMP sampling for shellfish abundance will cover 10 beaches during May 1990. Analysis of PSAMP shellfish data in future years will focus on assessing the risk to human health from eating contaminated shellfish from Puget Sound.

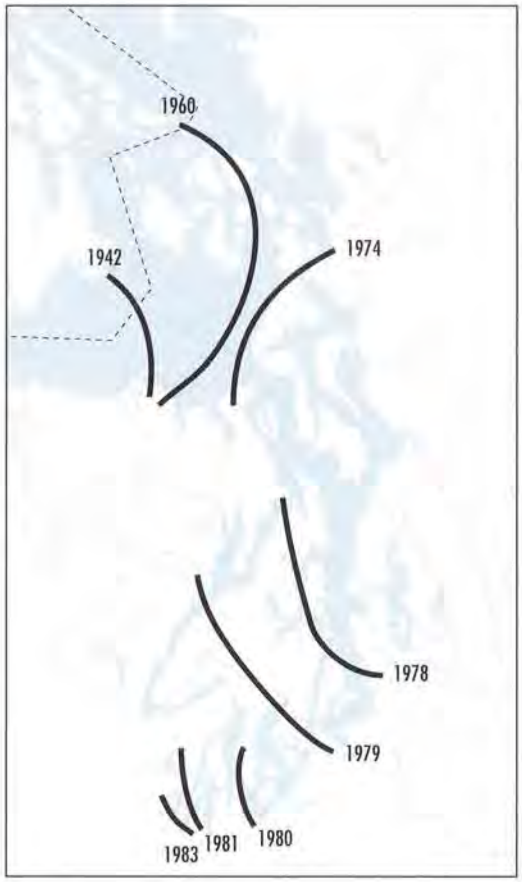


Figure 25. Progression of PSP into Puget Sound.

Until funding levels for PSAMP increase, public health officials and environmental scientists will not be able to monitor the 35 shellfish sites throughout the Sound that the designers of PSAMP felt were necessary. Without this information, we will have only a sketchy idea of the levels of bacterial and chemical contamination, PSP toxin, and shellfish abundance in the Sound.

The history of PSP in Puget Sound

The spread of PSP in Puget Sound has been unpredictable and inconsistent (Figure 25). Measurements of the toxin in shellfish have been made off the coasts of Washington, Oregon, California, British Columbia, Alaska, and in the western part of the Strait of Juan de Fuca since the 1930s. Shellfish near Dungeness Spit were found to contain the toxin in 1942, but no PSP was seen east of the spit until the late 1960s, when the San Juan Islands were first affected. In 1974 PSP was found for the first time in Bellingham Bay. In 1978 the toxin reached as far south as Des Moines (south of Seattle) during a major outbreak, with record levels seen in Penn Cove (Whidbey Island).

PSP was first seen in the Tacoma Narrows and northern Hood Canal in 1979, the Nisqually area in 1980, Budd and Totten Inlets in 1981, and Skookum Inlet in 1983 (Cheney and Mumford, 1986). There have been periods of time, such as 1984, when PSP has not been detected in Puget Sound (Dexter et al., 1985). In 1988 and 1989 the northern parts of Puget Sound enjoyed unusually low levels of PSP, while shellfish in the South Sound were heavily affected. During September 1988 the Department of Health ordered the first PSP-related beach closures for shellfish harvesting south of the Tacoma Narrows.

MARINE MAMMALS

BACKGROUND

Most people stop to admire the graceful movements and playful antics of the marine mammals that live in Puget Sound. Officers of the Washington state ferries announce the presence of porpoises, and frequently slacken speed at sighting a killer whale (orca).

Marine mammals are heavily dependent on good environmental conditions and undisturbed habitat for their health. In addition to their aesthetic appeal, monitoring of top predators like marine mammals will give us information on the passage of contaminants through the Puget Sound food web. Because marine mammals resemble humans physiologically, monitoring of marine mammals may provide information on potential health problems which we may encounter from eating contaminated fish from Puget Sound.

Twenty-one species of marine mammals—whales, porpoises, dolphins, seals, and sea lions—live in Puget Sound (Table 4). Of those, one seal (harbor seal) and four whales (minke whale, Dall's porpoise, harbor porpoise, and killer whale) are considered to be year-round residents, while many other species are seasonal, accidental, or rare visitors, attracted by the rich food supply (Table 4). Some of the visiting marine mammals (most notably the population of young male California sea lions sighted near the Hiram Chittenden locks in Seattle, in Everett, and near Edmonds) have become nuisances and are posing a threat to some fisheries resources. The resident harbor seal population has also lost favor with many of the human inhabitants of the Puget

Table 4. Puget Sound marine mammals.

Common Name	Occurrence
Seals and sea lions	
Harbor seal	Common, resident
Northern elephant seal	Occasional, migrant
California sea lion	Common, migrant
Stellar sea lion	Occasional, migrant
Northern fur seal	Rare, migrant
Whales, dolphins and porpoises	
Baleen Whales	
Minke whale	Common, resident
Gray whale	Common, migrant
Humpback whale	Accidental, migrant
Fin whale	Accidental, migrant
Sei whale	Accidental, migrant
Toothed Whales	
Dall's porpoise	Common, resident
Harbor porpoise	Common, resident
Killer whale	Common, resident
Pacific white-sided dolphin	Occasional
False killer whale	Rare
Pilot whale	Rare
Risso's dolphin	Rare
Pygmy sperm whale	Accidental
Northern right whale dolphin	Accidental
Common dolphin	Accidental
Beaked whales (several species)	Accidental

Resident = Lives year-round and breeds in Puget Sound
Migrant = Migrates to or through Puget Sound
Occasional = Regular occurrence in low numbers
Rare = Very few but steady numbers of sightings
Accidental = Only a few known sightings in Puget Sound

Sound basin due to the increasing amount of fecal waste produced by the seals and the threat that the waste poses to nearby shellfish resources.

In general, most resident Puget Sound marine mammal populations are thriving, but in recent years biologists have seen some changes in their distribution and numbers, and have observed some reproductive problems that could be due to human disturbances. Harbor porpoises have virtually disappeared from the area south of Admiralty Inlet (Everitt et al., 1980; Calambokidis et al., 1985). Harbor seals no longer breed in the Main Basin; however, their numbers are increasing in other parts of the Sound. Harbor seals are using more haulout sites (areas where seals and sea lions leave the water to rest on land) and pupping sites than they have in the past (Calambokidis et al., 1985; Jeffries, 1990).

THREATS TO MARINE MAMMALS

Human activities in Puget Sound can affect marine mammal populations directly and indirectly. Direct effects include the killing and capture of marine mammals. From 1900 to 1960 the state offered a bounty on all seals and sea lions, which led to the killing of an estimated 17,000 animals (Newby, 1973). At that time, seals and sea lions were thought to be a threat to salmon resources.

In 1976 the Washington State Legislature prohibited the capture of killer whales in state waters; before 1976 almost half of the killer whale population in Puget Sound was captured for display in aquariums and zoos—or killed in the process.

Humans indirectly interfere with marine mammals through commercial and recreational fishing, which can alter the marine mammals' food supply; by shoreline development projects, which may destroy and degrade marine mammal habitat; and by dumping toxic chemicals into Puget Sound, which may accumulate in marine mammal tissue.

Both the state of Washington and the U.S. Congress adopted legislation during the 1970s (a state resolution and the Marine Mammal Protection Act) to halt the killing and taking of marine mammals. The direct exploitation of marine mammals is no longer a concern in Puget Sound, but human development and pollution pressures may have replaced earlier threats to marine mammal populations.

PSAMP MARINE MAMMAL MONITORING

The design of PSAMP calls for monitoring the abundance and reproductive success of marine mammal populations, and tracking chemical toxicant levels in their tissue. This information will allow natural resource managers to assess the status and changes in marine mammal populations. The designers of PSAMP chose resident marine mammals so that they could identify effects that are related to Puget Sound contamination levels and other anthropogenic threats. Monitoring of migrant marine mammals, and those that are occasional visitors, would not distinguish effects of Puget Sound conditions from those that the animals might have encountered elsewhere.

The first phase of PSAMP marine mammal monitoring will focus on population estimates of the resident harbor seal. Harbor seals were chosen for PSAMP because they have been extensively studied in Puget Sound, they cover much less territory than other resident species, and they tend to stay in the region where they were born. Also, some subpopulations of harbor seals feed in areas influenced by industrial activities. Using toxicant information from seal subpopulations, environmental managers will be able to differentiate areas of Puget Sound where the seals are most vulnerable to chemical contaminants.

In the future, PSAMP investigators will measure the reproductive success of harbor seals by monitoring pupping success and causes of pup mortality in seal populations. PSAMP investigators will also collect and analyze tissue from stranded marine mammals for toxics. In the meantime, PSAMP will collect data on toxicant levels in marine mammal tissue samples taken from animals washed up on beaches, caught in nets, or measured by other organizations. Monitoring of other resident marine mammal species is also planned for a future phase of PSAMP.

No funds are available for PSAMP marine mammal monitoring during the 1989-1990 period. Currently the state Department of Wildlife is carrying out surveys to estimate population size and reproductive rates of harbor seals. Their program is not adequate to monitor marine mammal abundance and reproductive success Soundwide, however. Biologists with the Cascadia Research Collective in Olympia have been monitoring some harbor seal populations in Hood Canal and Puget Sound for the state Departments of

Health, Ecology, and Wildlife. Because there is no routine collection or analysis of marine mammal tissue for toxic chemicals in Puget Sound at this time, we do not know if marine mammals are presently suffering from high levels of toxicants in their tissues. Researchers have found elevated tissue contaminant levels and reproductive failures in Puget Sound marine mammals in the past (Calambokidis et al., 1985).

POPULATION ESTIMATES OF HARBOR SEALS

Wildlife biologists presently take photographs during annual aerial surveys to count the number of adult harbor seals and pups in Puget Sound. The surveys are carried out at the major haulout sites in Puget Sound (Figure 26) during the peak pupping period (mid-September in the South Sound and mid-August in the North Sound). Researchers studying Puget Sound harbor seals also observe the animals from the land. PSAMP managers will begin to collect these data and will compare them with past studies in order to document trends in population abundance.

Figure 26. Harbor seal haulout sites in Puget Sound.

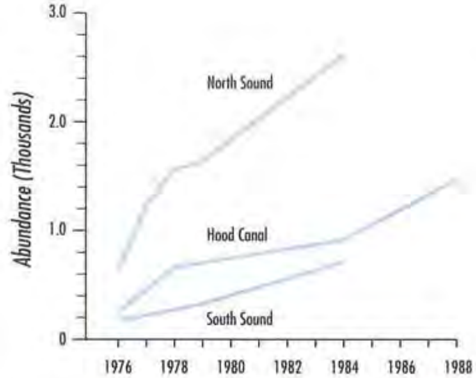
References: Calambokidis et al., 1978; Everitt et al., 1979; Osborne et al., 1988.

Researchers have found that there are three distinct subpopulations of harbor seals in Puget Sound: in the South Sound, Hood Canal, and the North Sound/Strait of Juan de Fuca region. Studies have shown increases in all three subpopulations since the 1970s, although the South Sound residents did not begin to increase in number until the late 1970s. During the early 1980s harbor seals in Hood Canal increased by 5 percent per year, North Sound seals by 14 percent per year, and South Sound residents by 19 percent per year. Recent counts at some sites indicate that the populations are continuing to grow (Figure 27) (Calambokidis et al., 1988).

Bounty hunting may have decreased the population of harbor seals in the South Sound more than in other areas, but they are now growing at the fastest rate. Hood Canal and North Sound harbor seals may not have been as strongly affected by bounty hunting, but they are presently increasing at a lower rate than those in the South Sound.

REPRODUCTIVE SUCCESS OF HARBOR SEALS

Despite increases in the harbor seal populations throughout the Sound, scientists have seen high incidences of premature births and the death of pups in some areas (Steiger et al., 1989). These harbor seal reproductive failures may be caused by contaminants in their flesh or in their internal organs, as well as other factors (Newby, 1973; Calambokidis et al., 1988).



Data from Everitt et al., 1979, 1980; Calambokidis et al., 1979, 1985, 1988.

Figure 27. Harbor seal abundances in Puget Sound.

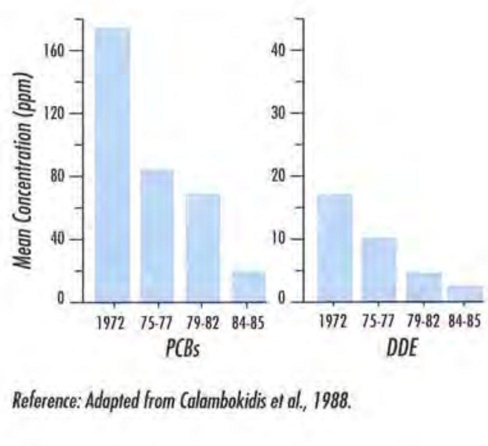
Seals living in Hood Canal and the North Sound have had reproductive problems which scientists do not fully understood. Harbor seals from the Skokomish delta (Hood Canal) have a low reproductive rate, which may be a natural method of limiting their own population size. However, these seals pup almost year-round, which has never been documented elsewhere, suggesting that there is some stress on the population (Calambokidis et al., 1979; 1985). The North Sound seals have suffered from premature births and high pup mortalities (Steiger et al., 1989).

MEASURING CONTAMINATION IN MARINE MAMMALS

Puget Sound marine mammals accumulate toxic chemicals from their food supply. Some of the highest tissue levels of PCBs in the world were measured in blubber from Puget Sound harbor seals during the 1970s (Calambokidis et al., 1985). Tissue samples that were analyzed during the mid-1980s showed lower levels (Calambokidis et al., 1984, 1985); there have been few recent analyses of marine mammal tissue for contaminants.

Between 1976 and 1989, researchers measured PCBs, organochlorine pesticides (particularly DDT and DDE), and metals in the livers and kidneys of killer whales that had been stranded on the coasts of Washington, British Columbia, and Alaska (Calambokidis et al., 1990). The levels of PCBs and pesticides that they found were comparable to those that have been found in the organs of other marine mammals—high enough that they may be posing a threat to the killer whales. Levels of metals (particularly mercury) in these animals' livers were variable and are probably not as harmful to their health as the PCB and pesticide levels reported (Calambokidis et al., 1990).

Researchers have noted a decrease in PCBs and organochlorine pesticides (notably DDE, a breakdown product of DDT) in harbor seal tissue in the last 20 years (Figure 28). PCBs and organochlorine pesticides have not been produced since the 1970s, but they are persistent in the environment and will



Reference: Adapted from Calambokidis et al., 1988.

Figure 28. Concentrations of PCBs and DDE in harbor seal pups from Puget Sound.

continue to be detected in the fatty tissue of marine mammals well into the future. Scientists have not looked as extensively for other contaminants in marine mammal tissue; detection of other organics and metals in future studies may give us insight into the impacts that industrialization and other human activities are having on marine mammal populations.

FUTURE PSAMP MARINE MAMMAL MONITORING

In the future, if funding becomes available, PSAMP managers plan to initiate Soundwide abundance monitoring for harbor seals and other resident species including killer whales, harbor porpoises, and minke whales. Each of these species relies on somewhat different food sources; estimates of their abundances could help managers understand the threats to the marine food web. PSAMP managers also plan to monitor reproductive success and tissue contaminant levels of harbor seals and other resident marine mammals.

Until adequate funding is available for PSAMP marine mammal monitoring, we will continue to have very limited information on the populations, reproductive rates, and contamination levels of Puget Sound marine mammals. Extensive losses of some marine mammal species, and population explosions of others, could go unnoticed without accurate information on the present marine mammal population sizes. In order to explain the causes of large fluctuations in marine mammal numbers, managers need information on the size and health of these populations.

BIRDS

BACKGROUND

Marine birds and waterfowl are very much a part of the scenic vista of Puget Sound shorelines and waters. Hunters place a high value on many species of ducks and geese, while other human residents of the Puget Sound basin spend increasing amounts of time in the "non-consumptive" pursuit of birdwatching.

Many species of marine birds (those that spend most of their lives on marine waters) and waterfowl (ducks, geese, and swans that spend much of their lives on fresh and salt water) are residents of the Puget Sound basin. An even greater number use the Sound seasonally as a stopping and feeding ground on the Pacific flyway. Birds are treasured by many of the human residents of the Puget Sound basin and are extremely vulnerable to harm by humans, yet we know very little about most Puget Sound resident and migratory bird species.

THREATS TO PUGET SOUND MARINE BIRDS AND WATERFOWL

Resident and migratory bird populations are vulnerable to harm from human activities including hunting, contamination of food supplies, destruction of critical habitat, and elimination of food supplies. There are examples from around the world of bird species that have been drastically reduced in numbers by actions and consequences of human development.

As human development and industrialization in the Puget Sound basin increases, birds suffer direct and indirect losses. Direct threats to bird populations include hunting, death from oil spills, poisoning from the ingestion of lead shot (although hunting regulations have recently forbid the use of lead shot in Puget Sound), and tangling of marine birds in fishermen's gill nets. Indirect threats—with potentially greater impact—include reproductive threats from the accumulation of toxics and the loss of habitat critical to bird rearing, feeding, and refuge.

Waterfowl are particularly vulnerable to the loss of critical habitat due to nearshore development. Waterfowl experts do not believe that current regulations adequately protect against these losses, and more waterfowl habitat is destroyed each year than is replaced by enhancement programs (Kraege, 1990). In addition, waterfowl that spend only part of the year in Puget Sound may be threatened by habitat losses in other areas along their migration route.

WHY SHOULD WE MONITOR BIRDS IN PUGET SOUND?

Birds are an important aesthetic and recreational resource for many of the human residents of the Sound, and their numbers will be sorely missed if they are not protected from anthropogenic losses. Without good estimates of the population sizes and health of marine birds and waterfowl made throughout the year, wildlife managers cannot hope to adequately manage and protect Puget Sound bird populations.

By monitoring Puget Sound birds, we can examine the condition of mid-level and top predators in the ecosystem, which may be at risk from the accumulation of contaminants through the food web. Each bird species lives a unique lifestyle, and may suffer different effects from human development. By monitoring different bird species, scientists gain information about different pollutant pathways and food web links through the ecosystem. This information can be used to protect Puget Sound birds and other natural resources. While birds are not as closely related to humans as are marine mammals, contamination levels in birds can give us a glimpse into the problems that could ultimately affect human health.

PSAMP BIRD MONITORING

Wildlife biologists have carried out monitoring surveys for birds in Puget Sound for many years, primarily associated with the harvest of waterfowl. There have been very few actual population estimates of marine birds and waterfowl, however. The object of PSAMP bird monitoring is to gain accurate estimates of the population of all major Puget Sound bird species, including those which are not targeted by hunters. The PSAMP designers also felt that an estimate of the health of bird populations, as measured by reproductive success and the accumulation of toxic chemicals in their tissues, was needed to adequately protect common and threatened species of Puget Sound birds.

No funding is available for monitoring Puget Sound birds under PSAMP for 1989-90. However, the state Department of Wildlife, the U.S. Fish and Wildlife Service (USF&WS), and volunteers involved in the National Audubon Society Christmas Bird Count are collecting some bird data in the Sound.

The state Department of Wildlife and USF&WS perform surveys to monitor the abundance of waterfowl in different parts of the Sound. Marine birds are only counted incidentally during these surveys. The Department of Wildlife also collects information on the harvest of waterfowl from hunters.

The Christmas Bird Count, which was organized as an alternative to a Christmas hunting contest, has become an annual count of birds across North America; it is the longest time series of data for any animal species in the country. Each year for the past 90 years, groups of volunteer bird watchers, under the auspices of the National Audubon Society, count all the birds they sight in one day during late December.

We gain different types of information from surveys for waterfowl and marine bird abundances, waterfowl harvest data, and the long-term trends supplied by the Christmas Bird Count data. Natural resource managers need all three types of information to estimate the abundance of Puget Sound bird populations. The amount of information currently being collected is inadequate to provide population information on most common and threatened Puget Sound bird species. The health of Puget Sound bird species cannot be measured from any of the surveys presently being conducted. Future surveys must include measures of reproductive success and toxic chemical content in bird tissues in order to provide this information.

PUGET SOUND BIRD POPULATIONS – WATERFOWL

Twenty-six species of ducks, 10 species or subspecies of geese, and two species of swans use Puget Sound for some portion of the year . Some species breed in Puget Sound during the summer; others spend much of the winter feeding here (Figure 29); while others use the Sound as a stop along Pacific Flyway migratory routes. Almost nothing is known about levels of toxic chemicals in the tissues of Puget Sound waterfowl.

Wildlife managers strictly control hunting of waterfowl in the state of Washington and believe that existing regulations adequately protect waterfowl populations (Kraege, 1990). The number of each species of waterfowl shot by hunters is not strictly related to the abundance of that species, however (Figure 29). This factor, along with natural population shifts due to weather conditions, further complicates our understanding of the causes of waterfowl population changes. We need to monitor population levels of several waterfowl species at frequent intervals to differentiate among the effects of nature, hunting, and loss of habitat.

The highest wintering populations of waterfowl in Puget Sound are found in the estuaries and uplands of Port Susan and Skagit, Padilla, and Samish Bays. In these areas, dabbling ducks (primarily mallard, wigeons, green-winged teal, and northern pintail) frequent large

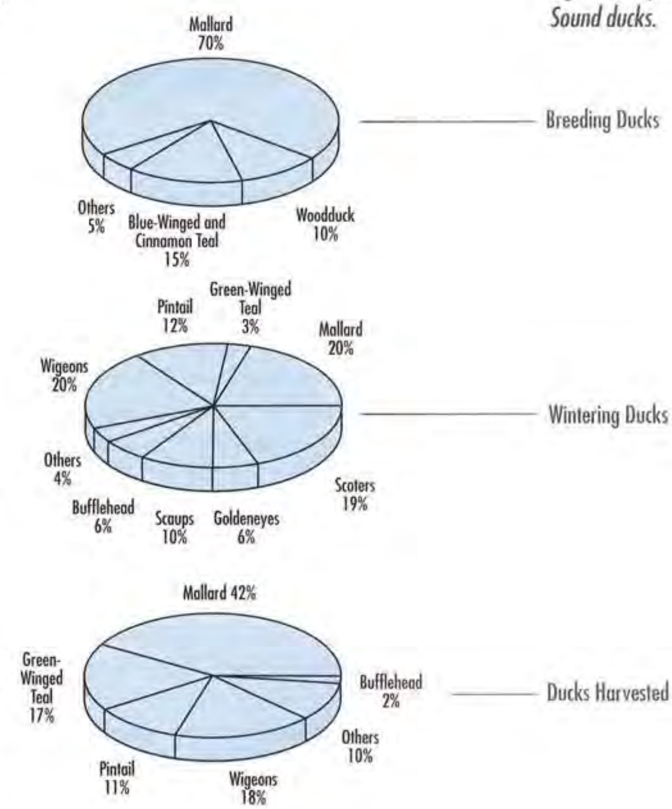
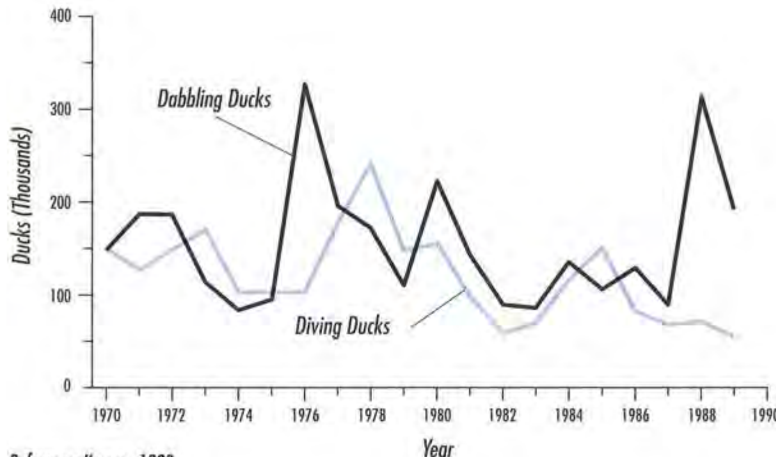


Figure 29. Species composition of Puget Sound ducks.

areas of emergent vegetation (wetlands) and forage in diked agricultural areas. The diving ducks (primarily scoters, goldeneyes, scaups, and bufflehead) are found throughout Puget Sound, particularly south of Port Susan. They tend to be found in deeper waters than the dabblers and feed almost entirely in saltwater.

Populations of dabbling ducks have varied in number over time, but the overall trend has been stable (Figure 30). The abundance of diving ducks has decreased since 1978 (Figure 30). Hunters shoot diving ducks only incidentally to the dabblers, so this decline is probably not associated with hunting in Washington state. The greatest losses in diving ducks have been among goldeneye, which have decreased by over 500 a year (total losses of roughly 11,000 over the past 20 years) (Kraege, 1990). Brant and snow geese have increased in numbers, probably due to natural population increases and the tightening of hunting regulations over the last 10 years.

Figure 30. Abundances of ducks in Puget Sound.



Reference: Kraege, 1990.

Links between marine birds and their prey

Because marine birds are wholly dependent on the marine environment for food, changes in their prey may be reflected in the stability and health of the bird populations. For example, many alcids (a family of seabirds with several species that breed in Puget Sound, including rhinoceros auklets, pigeon guillemots, tufted puffins, and marbled murrelets) feed almost exclusively on baitfish including sandlance and herring. By monitoring alcids and baitfish, we might see a link between habitat loss and tissue contamination levels of the prey (sandlance and herring) and population levels of the predator (alcids). This information may lead scientists to a better understanding of how to protect baitfish and marine birds from the worst human effects of habitat degradation and pollution.

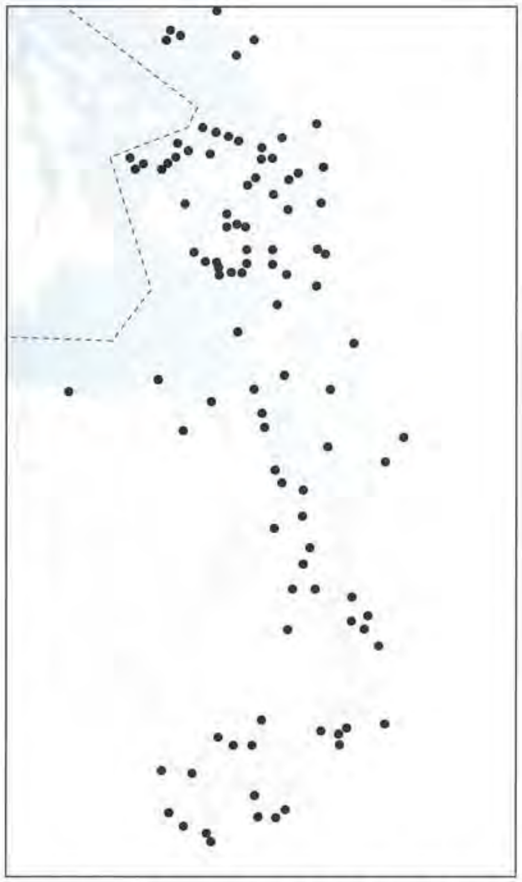
PUGET SOUND BIRD POPULATIONS – MARINE BIRDS

Marine birds in Puget Sound are generally more vulnerable to human disturbances than are waterfowl. Although they once frequented large areas of the Sound, marine birds are presently found nesting primarily on protected islands and other inaccessible areas; the birds have been driven away from other sites by the presence of humans and other disturbances. Marine birds are entirely dependent on the marine environment for food, and many spend their entire lives on the water. They dive below the surface to feed and sleep on the surface at night, returning to land only to breed.

The USF&WS and Department of Wildlife conduct annual surveys of breeding birds at each of the national wildlife refuges in Puget Sound. Almost all of the resident populations of marine birds and the largest concentrations of glaucous-winged gulls in Puget Sound live in these refuges. Because marine birds live several years, mature late in life, and do not necessarily breed every year, these breeding surveys may not accurately reflect the population levels of all Puget Sound marine birds, which include non-breeding birds (Cummins et al., 1990).

The largest concentrations of all species of marine birds are in the northern Sound; some species are also found in lower numbers south of Admiralty Inlet (Figure 31). The population level of most marine bird species has stayed the same or has increased over the last 20 years, but the number of breeding sites has decreased due to disturbances by humans.

Researchers have seen a dramatic decrease in numbers of two marine bird species: marbled murrelets, which nest in old-growth forest, and tufted puffins (Cummins et al., 1990). Glaucous-winged gulls have increased in number and may have caused decreases or displacements in the populations of two species of surface nesting cormorants by moving into their nesting grounds (Cummins et al., 1990). Populations of marine birds that breed on Protection Island in the Strait of Juan de Fuca have all increased over the last few years, with the exception of the rhinoceros auklet population which may have decreased. These changes are due mostly to changes in the local populations and partly to immigration from other areas (immigration has been documented for double-crested cormorants) (Henney et al., in press).



Data from Salo, 1975; Manuwal et al., 1979; Wahl et al., 1981; Wahl and Speich, 1984; Calambokidis et al., 1985; Speich and Wahl, 1989.

Figure 31. Breeding colony sites for marine birds in Puget Sound.

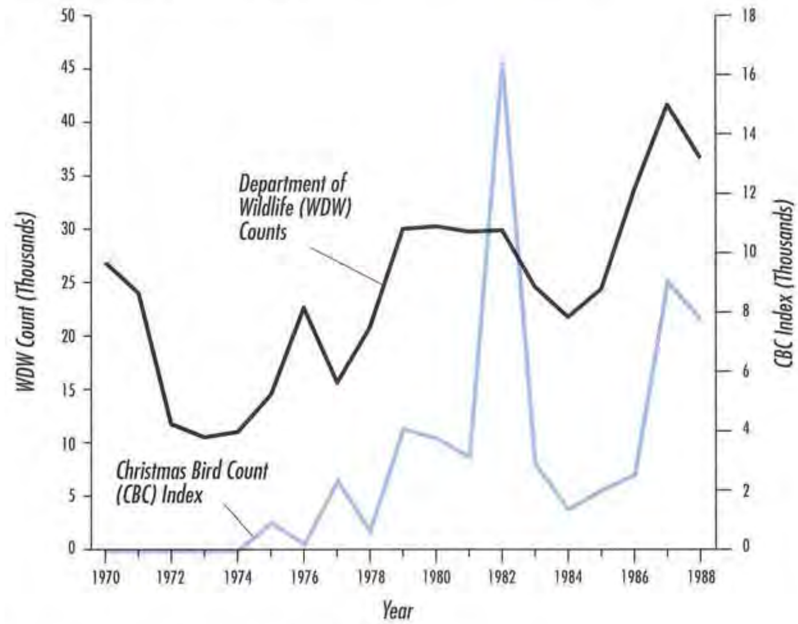
Researchers in Puget Sound have investigated the relationship between reproductive problems and toxic contamination in marine birds. At several locations in Puget Sound, investigators have seen eggshell thinning and reproductive failures in glaucous-winged gulls, pigeon guillemots, and great blue herons (Calambokidis et al., 1985; Fry et al., 1987; Speich et al., 1988), which has been tied to organochlorine pesticides like DDT in other areas (Faber et al. 1972; Cooke et al., 1976). Researchers in Puget Sound have found some of the world's highest levels of DDT in the tissue and eggs of these three species (Riley et al., 1982; Calambokidis et al., 1985). There have been no recent estimates of toxicants in the tissues of Puget Sound marine birds.

CHRISTMAS BIRD COUNTS

Each December, groups of Audubon Society volunteers count birds within a designated area about 15 miles in diameter. In the Puget Sound region there are 14 such designated sites which have remained largely constant throughout the years. There have been some inconsistencies in the amount of survey effort over the years, however, which make it difficult to use these data for quantitative trend analysis.

Despite their earlier skepticism, an increasing number of scientists agree that the Christmas Bird Counts provide good qualitative estimates of marine birds and waterfowl (Bock and Root, 1981). Christmas Bird Count data have been summarized in previous studies (Dexter et al., 1985), and PSAMP managers have gathered Christmas Bird Count data from 1961 through 1988. The data, such as those for snow geese, appear to compare favorably with those collected by professionals at the state Department of Wildlife (Figure 32). In addition, the USF&WS has documented increases in Puget Sound bird populations, including pelagic cormorants and pigeon guillemots, which are reflected in the Christmas Bird Count data.

Figure 32. Comparison of snow goose counts in Skagit River area.



FUTURE PSAMP BIRD MONITORING

If funds become available for PSAMP bird monitoring, the state Department of Wildlife will increase the area covered by and the frequency of their abundance surveys for waterfowl, and they will initiate a comprehensive summer survey for marine birds. PSAMP managers will continue to collect additional data from other bird sampling programs including the Department of Wildlife's waterfowl harvest and the Christmas Bird Count.

Until more information becomes available on population levels of Puget Sound birds, and funding is provided, PSAMP will be unable to monitor the reproductive success of threatened species, or to examine toxicants in bird tissue. Other bird populations, including shorebirds like plovers and sandpipers, are good candidates for PSAMP bird monitoring as they forage within a small area throughout the winter, accumulate toxic chemicals in their tissues, and are eaten by other Puget Sound birds, including merlin and the endangered peregrine falcon (Shick et al., 1987; Buchanan, 1988). If future funding allows, PSAMP managers will consider monitoring population levels of shorebirds.

Without additional funding, several very important questions about Puget Sound birds will not be answered, including whether pollution, habitat loss, or reduction in food sources are affecting population levels, and how bird populations respond to contaminants and other human-related impacts in the environment. Without information of this type on marine birds and waterfowl in Puget Sound, we may risk losing several important populations of birds (especially those that rely on relatively small areas of specialized habitat), and our actions may cause serious depletion of other bird populations.

NEARSHORE HABITAT

BACKGROUND

The sharp slopes of the Cascade and Olympic Mountains continue downhill into Puget Sound, creating steep underwater contours. Because the nearshore areas of Puget Sound slope steeply, the area of the seafloor that is reached by light is relatively narrow. All green plants are dependent on light, so the Sound's seagrasses and attached seaweeds must grow in this narrow band. Estuaries elsewhere in the country are generally shallower and have much wider expanses of submerged vegetation.

There are few pristine coastal wetlands left in Puget Sound; however, there are a number of systems which resemble the native wetlands that the first people saw when they migrated to this area. Puget Sound once had broad expanses of salt marshes in the Puyallup, Skagit, and Duwamish deltas, but they have been largely eliminated through diking, dredging, and filling for farming and development. The only broad areas of vegetated nearshore habitat (habitats are areas that provide a home, shelter, and food) that still exist in Puget Sound include the sweeping eelgrass meadows of Padilla Bay, kelp and eelgrass beds in the vicinity of Dungeness Spit (Strait of Juan du Fuca), and the salt marshes of the Skagit, Nisqually, and Stillaguamish deltas.

Beaches without seaweeds or sea grasses are also important in Puget Sound. Many commercial and recreational species of fish release their eggs on mud and sand flats, including the extensive mudflats of the Skagit and Nisqually

Changing threats to nearshore habitats

The earliest threats to vegetated nearshore habitats were from shoreline logging, log storage, and milling operations. It was the custom to dispose of mill wastes in the intertidal areas. Logging allowed very heavy loads of silt to travel down Puget Sound rivers and streams, burying nearshore riverine and estuarine habitat and smothering the animals and plants living there. Later, wetlands in the river mouths and bays of the Sound were filled to provide port facilities and to satisfy the demand for urban and industrial growth. Many river deltas were diked to produce extensive agricultural lands. Today, some of the greatest threats to vegetated nearshore habitats include: commercial, industrial, recreational, and residential development along the shorelines; disturbances of beaches for public access to shorelines, particularly in isolated areas; dredging activities and the increased sedimentation caused by dredging; and harvesting of nearshore resources, such as kelp.

river deltas. Juvenile salmon and shorebirds also feed on these flats. Human residents of the Puget Sound basin use these unvegetated beaches extensively for recreational activities such as clam digging, walking, and beachcombing.

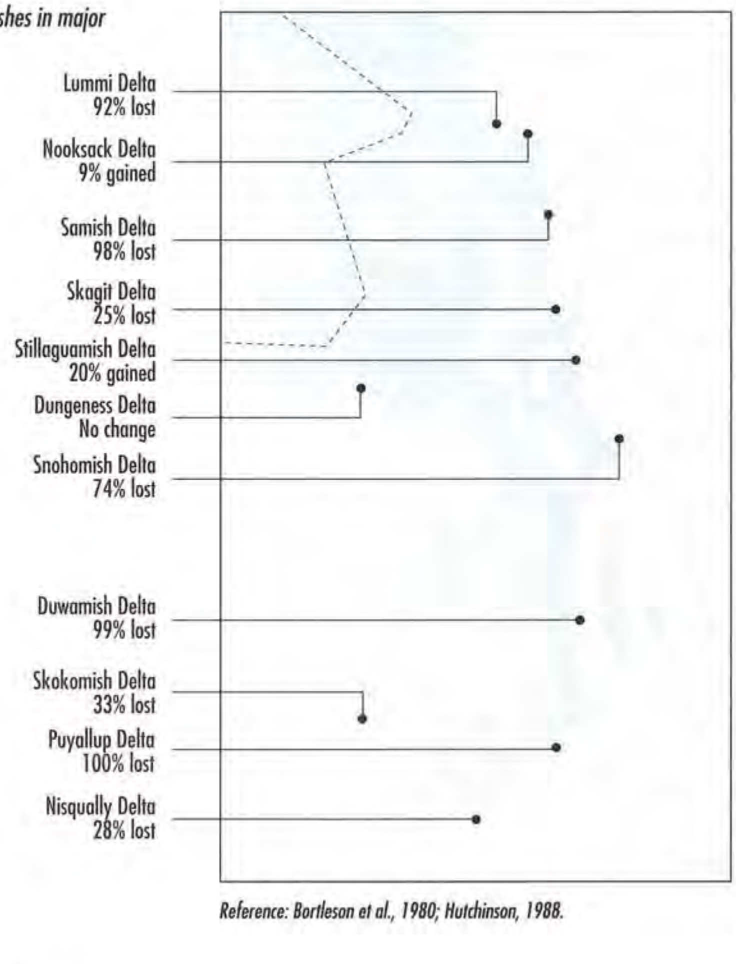
Other critical nearshore habitats are not influenced by saltwater. Upland wetlands (those that are away from the coast, on higher ground), as well as wetlands associated with rivers and lakes, all provide vital habitats for fish and wildlife species in the Puget Sound basin. These wetlands help to maintain the abundance and diversity of native Northwest species in the Puget Sound region. Many fish and birds (such as salmon and herons) use both saltwater and upland wetland habitats at different stages in their lives.

WHY ARE ESTUARINE NEARSHORE HABITATS IMPORTANT?

Many types of Puget Sound sea creatures spend at least part of their life cycles dependent on the narrow fringing eelgrass meadows, kelp beds, and salt marshes of Puget Sound. These vegetated nearshore habitats provide feeding and nursery grounds for juvenile salmon and other fish, food and refuge for many marine invertebrates which form the base of the benthic food web, and refuge, feeding, and stopping grounds for ducks, geese, and marine birds.

Salt marshes also perform a number of other vital functions. They reduce flooding in coastal and lowland areas, control shoreline erosion, filter pollutants from stormwater, and provide recreational and scenic opportunities for the inhabitants of the Puget Sound basin.

Figure 33. Changes in salt marshes in major river deltas.

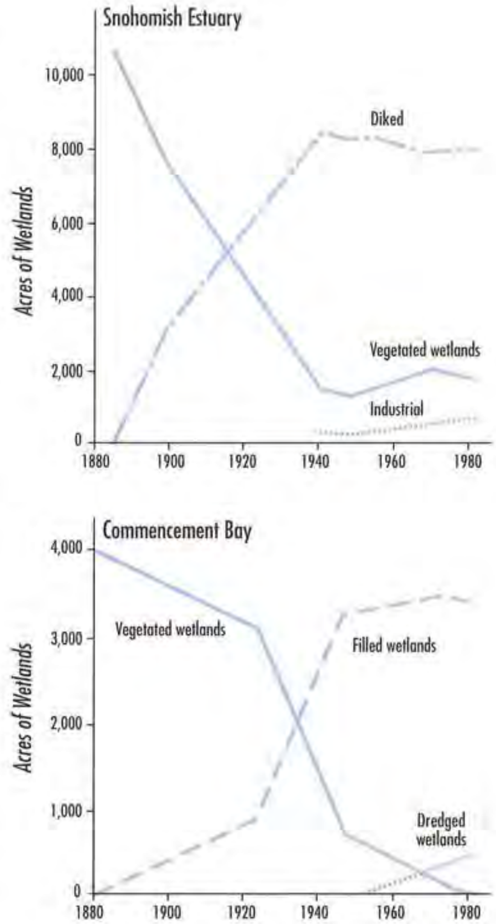


Reference: Bortleson et al., 1980; Hutchinson, 1988.

THREATS TO NEARSHORE HABITATS

The growth and development of the Puget Sound area over the past hundred years has severely reduced areas of nearshore habitat, particularly in the deltas of the largest rivers.

Dredging and filling for nearshore development projects, building of seawalls and bulkheads to reduce shoreline erosion, and dumping of debris on beaches diminishes both the quantity and the quality of valuable nearshore habitat. Development has reduced the area of salt marsh by 99 percent in the Duwamish delta, by 74 percent in the Snohomish delta, and eliminated it altogether in the Puyallup delta (Figure 33). Between 1900 and 1940 agricultural lands replaced 150 acres of nearshore wetlands associated with the Snohomish River each year, while filling of wetlands for industrial development around Commencement Bay claimed 75 acres a year (Figure 34). Natural sedimentation and a minimum of diking, dredging, and filling account for a 20 percent and 9 percent increase in the area of salt marshes in the Stillaguamish and Nooksack river deltas, respectively. Natural processes which replenish salt marsh and other nearshore habitats are not rapid enough to compensate for the permanent loss of wetlands due to development in the Puget Sound basin. Diking of deltas also prevents the depositing of sediment by rivers. Sediment deposition nourishes and enlarges salt marshes.



Reference: Adapted from Boulé et al., 1983.

Figure 34. Losses in wetlands at two urban estuaries.

Native Northwest fish and wildlife populations are dependent on the availability of abundant high quality habitat for their feeding, refuge, and raising young. The invasion of species from other places, many of which can outcompete the native species, poses a serious threat to the native species. Ever since the European settlers began importing goods to Puget Sound, exotic plants and animals have been intentionally and accidentally introduced. In some cases, the exotic species have fit well into the ecosystem and caused little apparent harm to native species, while others have wreaked havoc with native populations. Examples of harmful invaders include the introduced species of cordgrass (*Spartina species*) which has invaded the natural marshes of another seagrass (*Scirpus species*), changing the food available to several species of animals; and the introduction of a non-native species of eelgrass which appears to be competing with the native species, and which has taken over unvegetated mudflats where fish and shorebirds once fed, leaving these animals with fewer places to forage for food (Thom and Hallum, in preparation).

PSAMP INVESTIGATIONS INTO NEARSHORE HABITAT

Natural resource managers know very little about estuarine nearshore habitats, including how many acres of each type of habitat exists, the natural functions of these habitats, or how these habitats change over time. However, managers recognize that these habitats play an important ecological role in the functioning of the Puget Sound ecosystem, and that we must act quickly to prevent further loss of these habitats.

The design of PSAMP calls for an inventory of the estuarine nearshore habitat of Puget Sound every three years. Surveying and mapping the roughly 2,000 miles of Puget Sound shoreline is an awesome task that could take scientists and technicians years to complete. There are no PSAMP funds available for surveying nearshore habitat during the 1989-1990 period.

The Environmental Protection Agency, the state Department of Natural Resources, and the Puget Sound Water Quality Authority funded a pilot project to explore the use of remote sensing for coastal habitat inventories. Scientists are considering several methods, including aerial photography and the use of digital sensors borne on low-flying aircraft (similar to some types of satellite sensors). Trained technicians and observers check the photographic and sensor information and create computerized maps, which will be stored on a GIS computer system. Use of this approach could drastically reduce the amount of time and money spent on completing the Puget Sound habitat inventory. The habitat inventory maps will be a useful tool for natural resource managers and planners in evaluating impacts from proposed shoreline development, dredging, and diking and in managing leases of public aquatic lands. Preliminary results of the 1988 remote sensing pilot project show that the experimental inventory methods are very promising and could provide us with an accurate and cost-effective inventory of Puget Sound vegetated nearshore habitats over the next few years. Efforts to complete and update this inventory, however, will not be possible without further funding.

PSAMP designers specifically targeted estuarine nearshore habitats for monitoring. Upland wetlands, and those associated with rivers and lakes, were excluded from the PSAMP design as their impact on Puget Sound processes was thought to be less direct than those in estuarine areas. Natural resource managers recognize the importance of upland wetlands for fish and wildlife habitat, flood and erosion control, groundwater recharge, and recreational opportunities for humans. Efforts to inventory, monitor, and manage these wetlands are underway through many different Puget Sound programs. These programs include: countywide inventories carried out by local governments, tribes, and trained volunteers, and coordinated through the state Department of Ecology; forested habitat inventories carried out by participants in the Timber/Fish/Wildlife program; and monitoring of natural and recreated wetlands associated with development projects by developers and their consultants.

HISTORICAL CHANGES IN KELP, EELGRASS, AND SALT MARSHES IN PUGET SOUND

At one time, salt marshes were extensive in the Puget Sound basin. Since the early 1900s development has eliminated approximately 70 percent of the original salt marshes (Hutchison, 1988; Thom and Hallum, in preparation).

The Duwamish River, which empties into Elliott Bay, is an example of the extensive alteration of salt marsh and other intertidal habitat in the basin. Using old photographs and geological evidence, researchers at the Port of Seattle and the University of Washington have documented the alteration of the salt marshes in the Duwamish estuary from 1854 to the present (Blomberg et al., 1988). In order to provide a navigable waterway from the Seattle waterfront into the industrial district, engineers dredged the river channel, filled salt marshes, straightened the river, and created Harbor Island at its mouth.

In 1854 there were approximately 1500 acres of salt marsh and another 1450 acres of tide flats and shallow nearshore areas in the Duwamish estuary. In 1985 the only salt marsh remaining in the estuary were two tiny areas (Kellogg Island and another area upriver); the tide flats and shallows had been totally eliminated (Figure 35) (Blomberg et al., 1988).

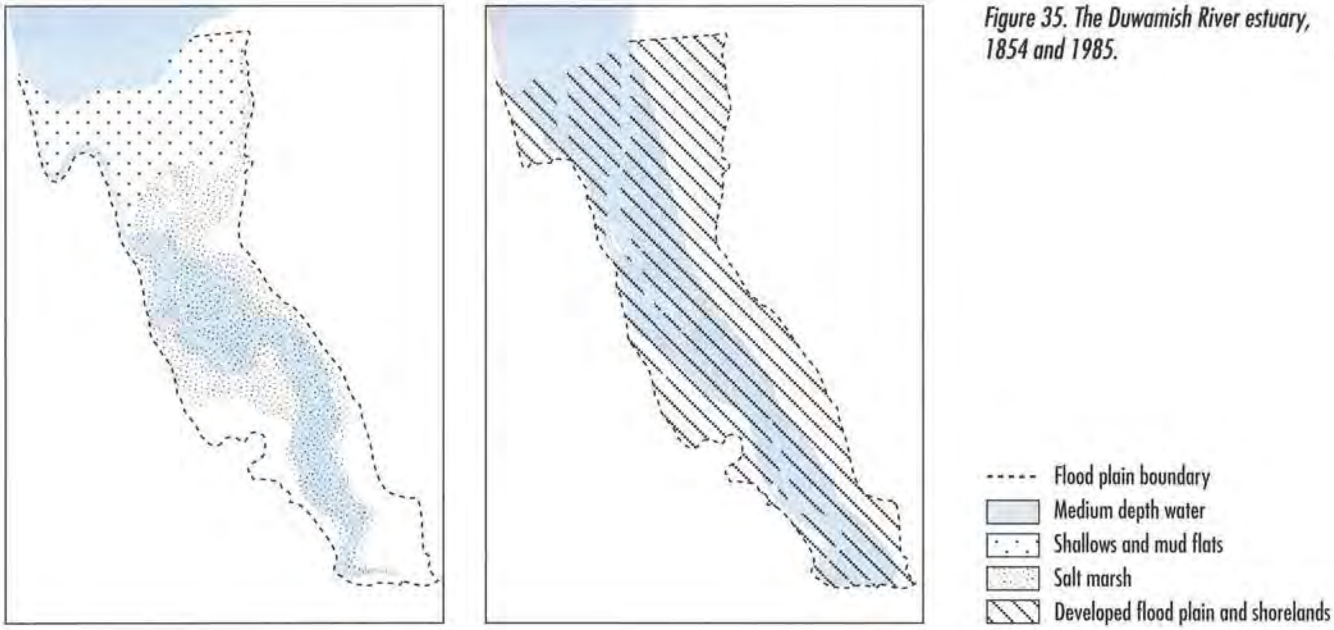


Figure 35. The Duwamish River estuary, 1854 and 1985.

Reference: Blomberg et al., 1988.

There are no good quantitative historical data on the extent of eelgrass meadows throughout the Puget Sound basin. However, anecdotal and other information from a few areas indicate that there have been extensive losses in Bellingham Bay and in the Snohomish delta and an increase in Padilla Bay. In addition, University of Washington researchers believe that some existing eelgrass beds are showing signs of stress, including excessive growth of algae on their blades, which could be a sign of nutrient enrichment due to pollution (Thom and Hallum, in preparation).

University of Washington researchers have calculated the extent of kelp beds in 1912 and in 1978 in many parts of the Sound (Thom and Hallum, in preparation). In areas where apparent changes had occurred between the 1912 and 1978 measurements, the researchers visited the sites during 1989 to determine if the changes were continuing. Their results show that there appears to have been an overall increase in Puget Sound kelp beds. Table 5 shows the changes in the distance of shoreline covered by kelp beds in different portions of the Sound. Researchers do not know whether kelp beds actually increased between 1912 and 1978, because no other measurements were taken in between those two dates. Additional years of data are needed to verify whether changes in kelp beds are occurring in the Sound. University of Washington researchers believe that, in some areas, the increase may be attributed to the building of bulkheads and seawalls which alter the natural movement of water and sediment near the shoreline. The kelp plant grows very quickly from a stalk which dies back each fall. It is relatively pollution-tolerant and may rapidly dominate shallow subtidal areas. The apparent increased presence of kelp in Puget Sound may indicate changes in the stability of nearshore sediments and perhaps increased loads of dissolved nutrients to the system (Thom and Hallum, in preparation).

Table 5. Changes in shoreline covered by kelp beds in Puget Sound from 1912 to 1978.

Area	% Change in Extent of Kelp
North Sound	+128.3
Main Basin	+482.7
South Sound	+332.4
Hood Canal	-42.9
Strait of Juan du Fuca	+ 6.4
Total	+52.7

Data from Thom and Hallum, in preparation.

FUTURE PSAMP NEARSHORE HABITAT MONITORING

The design of PSAMP calls for continuing the inventory of vegetated nearshore habitat every three years. Future phases of PSAMP will examine the functions that each type of habitat provides to fish and wildlife, and will examine the value of each type of habitat in different areas of the Sound.

The 1988 pilot study to inventory nearshore eelgrass meadows, kelp beds, and salt marshes is scheduled for completion by 1991. Until funding becomes available through PSAMP, there will be no further inventories of nearshore habitat in Puget Sound. The initial 1988 pilot study covered approximately 65 percent of the Sound's shorelines. Without further surveys at frequent intervals, we will have no idea of the extent or condition of vegetated nearshore habitat in the remaining 35 percent of Puget Sound shorelines, nor will we know whether there are changes occurring in the valuable nearshore habitat throughout the Sound.

F R E S H   W A T E R

BACKGROUND

The freshwater rivers and streams of the Puget Sound basin drain approximately 16,000 square miles of upland and lowland terrain. In addition to providing important habitat for many species of fish and wildlife within their corridors, the rivers and streams transport billions of gallons of water each year into Puget Sound. This water carries a diverse mixture of particulate and dissolved material, including sediment, dissolved nutrients, toxic chemicals (like pesticides, herbicides, and metals), oil and grease, and miscellaneous organic matter. Maintaining good water quality in the rivers and streams of the Puget Sound basin is necessary for the health of the inhabitants of the watersheds, and is critical to protecting the health of Puget Sound.

WHY SHOULD PSAMP MONITOR RIVERS AND STREAMS?

Because the focus of PSAMP is on characterizing and tracking changes in Puget Sound, PSAMP managers are interested in the quality of freshwater rivers and streams as they affect Puget Sound water quality, sediment quality, habitat, and biological populations. The large volume of fresh water which enters the Sound (in addition to acting as one of the driving forces of the Puget Sound oceanographic regime), and the large deltas created by many of the Puget Sound rivers, have an influence on many nearshore areas of the

Sound. The freshwater information gathered by PSAMP will not allow managers to calculate the total mass loadings of sediment and contaminants from rivers into the Sound because not enough stations are monitored, but it will show trends in river water quality and sediment loadings over time. Using this information, managers will be able to estimate the risk to nearshore resources (such as shellfish beds threatened by fecal coliform contamination) and take the appropriate source control measures in the watersheds.

PSAMP designers did not intend to collect detailed freshwater monitoring data about the water quality, sediment quality, habitat, and biological resources in the watersheds. Other monitoring programs in the Puget Sound basin are designed to provide necessary information for watershed and nonpoint source control activities. These programs include: long-term monitoring by the state Department of Ecology and the U.S. Geological Survey; habitat and stream corridor monitoring by Timber/Fish/Wildlife; water quality and stream corridor monitoring by Metro; long-term water quality assessments by the watershed management committees under the Puget Sound Water Quality Management Plan; intensive surveys and surface water investigations by the Department of Ecology; as well as numerous other programs by local governments, tribes, schools, colleges, and citizens' groups. Most of these monitoring programs measure conventional pollutants (such as fecal coliform bacteria, nutrients, suspended solids, and oil and grease) and/or habitat quality in the watersheds; a few measure toxic chemicals in river water, sediment, and biota. At full implementation, PSAMP will provide additional toxic chemical information which should be useful to watershed and natural resource managers.

THREATS TO WATER QUALITY IN RIVERS AND STREAMS

Water quality and habitat in Puget Sound rivers and streams are threatened by physical scouring of the streambeds by sediments, burial of critical habitat and biological resources by excessive sedimentation, and contaminants carried by excessive runoff (often the result of vegetation removal and development by humans in upstream areas). In fresh water, water quality managers must be concerned about both toxicants (metals and organics) and conventional pollutants, as each has a role in threatening critical resources and beneficial uses.

Excessive input of dissolved nutrients, in particular, can cause major algal blooms and eutrophication in rivers and streams. Differences in the natural chemistry and circulation of fresh water versus marine water can cause eutrophication in fresh water which we seldom see in Puget Sound. Scientists monitor additional parameters in the rivers (including suspended sediment and flow rate) in order to judge water quality and to predict potential water quality problems.

The majority of pathogens (as indicated by fecal coliform bacteria) which enter the nearshore area of Puget Sound are carried by rivers and streams, or by storm drains—which are essentially human-made rivers. Urban, suburban, agricultural, rural, and managed forest areas all contribute bacteria and viruses which affect the use of nearshore shellfish beds and recreational beaches.

Environmental managers are also concerned about toxic chemicals in rivers and streams. The chemicals of greatest concern include those released to rivers from industrial and wastewater treatment plants, and pesticides and herbicides from agriculture, forestry, and home gardening.

Freshwater sediments are the major resting place of toxic chemicals in rivers and streams, just as marine sediments are in Puget Sound. However, due to the swiftly moving water and shallow depths of rivers and streams, freshwater sediments accumulate in only a few locations. Particles and their associated contaminants are generally suspended in the rivers and streams, or settle briefly in quiet pools, only to be carried further downstream during the next freshet, or flooding period, and eventually into Puget Sound. Scientists seldom monitor freshwater sediments in Puget Sound rivers and streams for toxic chemicals. Also, suspended particles are rarely measured for toxics due to technological difficulties and high costs. Similarly, scientists and managers seldom measure toxic chemicals dissolved in the water, which, although more concentrated in fresh water than in Puget Sound, are still found at levels usually too low to detect. Environmental managers measure some fish and freshwater invertebrates for toxic chemicals to determine if biological resources are becoming contaminated.

PSAMP FRESHWATER MONITORING

The object of PSAMP freshwater monitoring is to determine the influence that freshwater rivers and streams are having on Puget Sound water and sediment quality.

The PSAMP design calls for sampling conventional pollutants and metals at 75 freshwater stations in the Puget Sound basin. Tissue from resident fish will also be collected for toxic chemical analysis. Currently only a small portion (about 20 percent) of the necessary PSAMP program is being funded. During 1989-1990 PSAMP investigators will sample conventional pollutants and some fish tissue at a limited number of stations on major rivers.

Water quality managers use these data, along with information on sediment and water column monitoring near the river mouths, to predict water and sediment quality in nearshore areas of Puget Sound. These data allow managers to assess the impact that source control measures are having on reducing toxic and conventional pollutant loadings carried to the Sound by rivers.

RESULTS OF 1988-1989 FRESHWATER MONITORING

PSAMP investigators from the state Department of Ecology sampled stations on each of 10 major rivers in the Puget Sound basin monthly between October 1988 and September 1989. The rivers are: the Nooksack, Skagit, Samish, Stillaguamish, Snohomish, Cedar, Green-Duwamish, Puyallup, Nisqually, and Skokomish (Figure 36). PSAMP investigators measured many physical and chemical parameters in the river water, including fecal coliforms, nutrients, suspended sediment, temperature, and dissolved oxygen.

In general, for the conventional pollutants sampled by PSAMP, water quality at most of the stations in the Puget Sound rivers was good. Samples from only a few rivers exceeded the state water quality standards (the legal definition of good water quality). Levels of fecal coliform bacteria were regularly above the state water quality standards for stations on the downstream portions of the Nooksack and Samish Rivers during 1988-89. Fecal coliform levels never exceeded the standards in the Skagit, Stillaguamish, Snohomish, Nisqually, and Skokomish Rivers. Very few of the 1988-89 river samples exceeded state

Figure 36. Rivers of the Puget Sound basin monitored for water quality.

water quality standards for dissolved oxygen, temperature, and pH (a measure of acidity of water). When freshwater areas exceed the state water quality standards, Department of Ecology managers use the information to direct additional monitoring and investigative efforts into tracking the source of contamination.

PSAMP investigators also measured the amount of particulate material in the major rivers (suspended sediment). The Nooksack River carries the heaviest load of particles to the Sound for its volume of water. During 1988-89 the Nooksack (which is glacier-fed) contributed about 10 percent of the Sound's fresh water and 25 percent of the particles introduced by the major rivers. Three other rivers also contributed heavy particle loads to the Sound during 1988-89 (Skagit River—22 percent; Stillaguamish—17 percent; Snohomish—27 percent); each of these rivers contributes particles in about the expected proportion for its volume of water. There is no apparent trend in the suspended sediment load in the Puget Sound rivers, despite watershed management activities which are aimed at reducing suspended sediment loading. Water quality managers feel that increased development in the watersheds is probably offsetting any gains in decreased sediment load from management activities.

Water quality managers have noticed several differences between the 1988-89 PSAMP freshwater data and past results. Dissolved oxygen levels, particles, and fecal coliform bacteria were slightly higher in the Green-Duwamish River during 1988-89 than the average has been since 1983. The Skagit River showed slightly higher levels of dissolved oxygen and particles, and slightly lower levels of fecal coliform bacteria, during 1988-89 than the average found since 1983. None of these changes is sufficient to indicate a definite trend in water quality; water quality managers will be watching closely for future changes.

Metro collects freshwater data from many rivers and streams in the Seattle/King County area, including the Green-Duwamish River. Metro investigators have seen a dramatic change in the water quality of the Green-Duwamish after the diversion of the Renton sewage treatment plant wastewater from several miles upstream in the river to a marine outfall in Elliott Bay. Levels of ammonia dropped between 90 percent and 95 percent, nutrient levels (total phosphorus) dropped about 85 percent, and dissolved oxygen levels rose slightly in the year following the diversion (Metro, 1988a).

During the 1980s, PSAMP investigators with the state Department of Ecology noticed an apparent trend of decreasing ammonia concentrations in all of the major Puget Sound rivers except the Skagit, Stillaguamish, and the Skokomish. Lower summertime ammonia levels are the cause of the downward trend, while ammonia concentrations during the fall have remained the same. In rivers draining primarily rural land, ammonia concentrations during the summer are generally due to a combination of natural processes and anthropogenic inputs from nonpoint sources including runoff from agricultural fields, animal-keeping practices, septic systems, forest practices, and stormwater. Fall concentrations of ammonia are more likely to be caused by natural than anthropogenic sources, as part of the natural breakdown cycle of plants dying off in the winter. PSAMP managers believe that this decreasing trend of ammonia levels during the summer may indicate that nonpoint source controls are having some effect in many of the Puget Sound watersheds.

PSAMP investigators are in the process of evaluating trends in other freshwater parameters. As more PSAMP freshwater data become available, PSAMP managers will examine the effects that Puget Sound river water quality and sediment loading are having on the nearshore areas of Puget Sound.

FUTURE PSAMP FRESHWATER MONITORING

Freshwater monitoring under PSAMP is currently funded through existing Department of Ecology programs; PSAMP managers do not expect that additional funds will be available until at least 1991.

PSAMP freshwater sampling during 1989-90 will continue the work that has been done in 1988-89. When further PSAMP freshwater monitoring funds become available, investigators will sample additional stations on Puget Sound rivers and streams, analyze river water samples for metals, and measure toxic chemicals (metals and organics) in suspended sediment and in the tissue of resident fish to determine if there is a human health risk from eating them.

Without further funding for freshwater monitoring, we risk knowing very little about the water quality and contaminant contribution to Puget Sound from the smaller rivers and streams in the basin. Also, we will have virtually no information on levels of toxic chemicals in water and fish found in Puget Sound's watersheds and the cumulative effects of source control programs to control freshwater pollutants.

OTHER PROGRAMS

Many agencies and research programs collect data on water quality, sediment quality, and other environmental parameters in the Puget Sound basin. Few, however, plan to collect them on a long-term continuous basis, as PSAMP has committed to do. In this section, we highlight several monitoring programs and other studies which are comparable to PSAMP in the type of information collected, the methodologies used, the geographic extent of sampling, or other factors. As more PSAMP funding becomes available in the future, PSAMP managers will attempt to incorporate results from some of these ongoing programs into the PSAMP database and into the annual Puget Sound Update.

PUGET SOUND DREDGED DISPOSAL ANALYSIS (PSDDA)

PSDDA is a consortium of state and federal agencies who have identified open water sites for the disposal of material dredged from the bottom of Puget Sound. PSDDA has developed a process whereby dredgers test their dredged material for toxic chemicals and (in some cases) for toxicity to bioassay organisms before it is accepted at PSDDA sites. PSDDA sites are the only areas in Puget Sound where dredgers can dispose of dredged material in open water; material that fails to meet PSDDA criteria must be capped (covered with clean sediment in deep water) or disposed of on land. The process of selecting PSDDA open water disposal sites included baseline monitoring of potential disposal sites for sediment quality, using methods of sampling and analysis that are very similar to those of PSAMP. Follow-up monitoring of PSDDA sites will use the same techniques, making the data comparable to those of PSAMP.

OTHER PUGET SOUND ESTUARY PROGRAM STUDIES

The Puget Sound Estuary Program (PSEP) is a part of the Environmental Protection Agency's National Estuary Program (NEP). The NEP identifies estuaries of national significance across the country, and supports the development of action plans for their protection and preservation. All of the major federal and state agencies, as well as tribal and local governments, which have responsibilities for Puget Sound are part of PSEP; the program is co-managed by EPA Region 10 (Seattle), the state Department of Ecology, and the Puget Sound Water Quality Authority. PSAMP is the program which provides direct PSEP involvement in monitoring Puget Sound. In addition, many technical studies carried out under PSEP, and many technical tools developed under PSEP for use in Puget Sound, are useful to PSAMP and other monitoring programs. PSEP has provided financial and technical support for the development and initial implementation of PSAMP.

Among the studies and tools developed by PSEP, those most relevant to PSAMP include: the Puget Sound Protocols (accepted methods for the collection and analysis of environmental samples in Puget Sound); the Puget Sound Environmental Atlas (computerized maps of many types of Puget Sound environmental data); the Urban Bay Studies (data collection and action plans for improving the water and sediment quality in Elliott Bay, Everett Harbor, Bellingham Bay, Sinclair/Dyes Inlet, and Budd Inlet); the Seafood Risk Assessment Study (for determining the risk to human health from consuming Puget Sound seafood); and numerous other studies on specific topics concerning the quality of Puget Sound water, sediment, biological populations, and habitats.

DISCHARGER MONITORING IN THE ENVIRONMENT

Under the National Pollution Discharge Elimination System (NPDES) and the State Wastewater Discharge Permit and Rules, Washington state dischargers of wastewater from sewage treatment plants, industrial facilities, and other sources must obtain a discharge permit from the state Department of Ecology (or in some cases from EPA). Each discharge permit specifies the location and design of the wastewater outfall, places limits on the amounts of many types of contaminants that can be discharged from the outfall, and specifies monitoring requirements for the wastewater from each facility. Currently very few NPDES permits in Puget Sound have requirements for monitoring in the environment (that is, at the end of the pipe and beyond); under the Puget Sound Water Quality Management Plan, the state Department of Ecology is in the process of adding environmental monitoring requirements to NPDES permits. The types of samples collected and the analyses performed by dischargers will depend on factors unique to each wastewater facility and the water body into which it discharges. However, collection and analysis of all samples will follow the Puget Sound Protocols, and the data will be comparable to PSAMP data, thus expanding our knowledge of conditions in Puget Sound.

NOAA NATIONAL STATUS AND TRENDS PROGRAM (NS&T)

As a part of a nationwide program, investigators from the National Oceanic and Atmospheric Administration (NOAA) collect and analyze bottomfish, sediment, and shellfish from several sites in Puget Sound once a year. The investigators analyze the samples for toxic chemicals and examine the bottomfish livers for disease. The types of samples, the methods for sampling and analysis, and data analysis techniques are standardized as much as possible across the country, although different species of fish and shellfish must often be collected at different locations. NOAA investigators examine the data, compare the results among regions of the country, and publish periodic reports of the results. Sample collection and analysis methods are not identical between NS&T and PSAMP. Some NS&T results have been discussed in previous sections of this report.

OTHER FEDERAL PROGRAMS

Many federal agencies carry out monitoring programs in and around the Puget Sound basin, several of which are peripherally related to PSAMP.

EPA and their contractors carry out studies and monitoring associated with the Comprehensive Environmental Response, Compensation and Liability Act (Superfund) program as a part of the evaluation and cleanup of hazardous materials at Superfund sites. In Puget Sound Superfund studies are ongoing in Commencement Bay (Tacoma), in Eagle Harbor (on Bainbridge Island),

and at a site on Harbor Island (Seattle). Most of the Puget Sound Superfund sampling is for sediment and biological populations. Methods for sample collection and analysis are very similar to those used by PSAMP.

The U.S. Navy monitors the water, sediments, biological populations, and habitat at all or some of their facilities on Puget Sound. Most notably: monitoring before, during, and after dredging, dredged material disposal, and construction of the Navy Homeport at Everett; and monitoring of water, sediment, and shellfish at the Naval Submarine Facility at Bangor on Hood Canal. Methods for sample collection and analysis vary somewhat from those of PSAMP, but the Navy has expressed interest in standardizing their monitoring through use of the Puget Sound Protocols.

The U.S. Geological Survey, the U.S. Forest Service, and the U.S. Fish and Wildlife Service carry out monitoring programs in the watersheds of Puget Sound. Each agency collects information which relates most directly to their mandate, including monitoring of water, sediments, biological populations, and habitat. Methods of collection and analysis differ somewhat from those of PSAMP.

OTHER STATE AND LOCAL GOVERNMENT PROGRAMS

There are numerous state and local agency programs that collect information related to Puget Sound and its watersheds. In many cases, the investigators are using sampling and analysis methods that differ from those of PSAMP. Some examples of these programs (some of which have been briefly described in this report) include:

- Intensive surveys of areas with conventional and toxic contamination problems in water and sediment (state Department of Ecology).
- Investigations of areas with hazardous wastes, including state Superfund sites (state Department of Ecology).
- Monitoring of fish and wildlife populations and habitat in marine and fresh water (state Departments of Fisheries and Wildlife).
- Monitoring of geoduck tracts and other aquatic lands for biological populations (state Department of Natural Resources).
- Monitoring of commercial and recreational shellfish beaches for fecal coliform contamination of water (state Department of Health, Metro, and county health departments).
- Stream corridor monitoring in Puget Sound watersheds (Timber/Fish/Wildlife and watershed management committees under the Puget Sound Water Quality Management Plan).
- Wetlands inventories and monitoring (county and city governments, in cooperation with the state Department of Ecology).
- Freshwater (and some marine) water quality monitoring (volunteer groups including schools, community groups, and environmental groups).

MONITORING RELATED TO SHORELINE DEVELOPMENT

Under the Clean Water Act, the Coastal Zone Management Act, the Shoreline Management Act, and a host of other federal, state, and local laws, shoreline and nearshore development projects require a series of federal, state, and local permits. It is increasingly difficult to obtain permits for shoreline and nearshore development. Currently, almost all permits granted have stringent monitoring requirements that the developer must carry out as a part of the construction project. The developer is responsible for the monitoring requirements in each permit; the monitoring is usually carried out by the developer's consultant, often under the supervision of a local agency. Information collected under development permits is usually very localized and detailed, and sometimes consists of a single sampling effort. Other development monitoring, particularly that associated with wetland mitigation projects, consists of ongoing monitoring efforts. Most development monitoring uses methods that differ from those of PSAMP; PSEP managers are working with state and local agencies to ensure the expanding use of the Puget Sound Protocols for development monitoring.

CANADIAN MONITORING PROGRAMS

Both the Canadian federal government (Environment Canada, Fisheries and Oceans Canada) and the British Columbia government (Ministry of the Environment) carry out monitoring of water, sediment, biological populations, and habitat for numerous purposes in their waters. Because the waters of Puget Sound, the Straits, and British Columbia are interconnected, information gathered on the Canadian side of the border may have direct relevance to Puget Sound water quality trends. PSEP managers have been working with Canadian environmental managers, particularly those associated with the Fraser River Estuary Management Plan, to standardize the collection and analysis of samples on both sides of the border. Several Canadian (federal and provincial) representatives participate on the Monitoring Management Committee and in PSEP.

LONG-TERM WATER QUALITY MONITORING IN PUGET SOUND

There are a number of marine laboratories, aquariums, and educational institutions scattered around the Sound which collect long-term water quality information. Generally, these institutions monitor their saltwater intakes or nearby ambient water for temperature, salinity, dissolved oxygen, and a few other parameters. In most cases the data collected are of sufficient quality to be used for long-term trends in nearshore water. PSAMP managers have contacted many of these institutions; each has expressed an interest in upgrading the quality of the data collected and cooperating with PSAMP in data-gathering efforts. In all cases, the institutions are unable to make many changes to their programs due to lack of funding.

In the future, PSAMP managers will work with these institutions, providing technical assistance and guidance to ensure that the data collected are comparable and useful to environmental managers and that these data are included in the PSAMP annual report.

CONCLUSIONS

In this report, the PSAMP managers have attempted to provide an overview of the PSAMP design and first-year results, to compare those results with historical information, and to provide some background on the Puget Sound ecosystem. In future reports PSAMP managers will focus more attention on PSAMP data as they become available. In this last chapter, we attempt to summarize the condition of Puget Sound waters, sediments, biological populations, and habitats, using the results of PSAMP and other studies. In addition, we make recommendations for future monitoring and explain the price of not monitoring the waters and resources of the Sound. Following this chapter, we include the references used in preparing this report for those who wish to seek more information along with a list of contacts for finding out more about PSAMP or for getting involved with citizens' monitoring.

THE OVERALL STATUS OF PUGET SOUND

The health of Puget Sound is generally good, with serious chemical and pathogen contamination and degradation problems restricted to fairly small areas near the shorelines and the urban bays. The problems that we encounter in the urban bays and a few other areas, however, are often severe. In addition, widespread degradation of natural shoreline areas has diminished the quality and quantity of critical fish and wildlife habitat. There are early warning signs of problems emerging in many other areas also, such as contaminated sediments, liver tumors in bottomfish, shellfish bed closures due to fecal contamination, and reductions in some populations of fish and wildlife.

Virtually no area of Puget Sound is pristine and free from contamination. The 19th century influx of immigrants and the gradual development and industrialization of the Puget Sound basin has spread low levels of contamination to all parts of the Sound and the Straits of Juan de Fuca and Georgia (although our information for these latter areas is not as good as for Puget Sound south of Admiralty Inlet).

Many areas of Puget Sound still remain in a reasonably uncontaminated condition, however, including many of the rural bays, the deep basins, and many parts of the Straits. Between these relatively clean areas and the contaminated urban bays lies the majority of Puget Sound, with low levels of assorted contaminants, many of which may not cause direct harm to plant, animal, or human inhabitants of the basin. However, we know very little about the cumulative effects of human activities on Puget Sound biological populations, including the accumulation of contaminants, habitat destruction, and interruption of food supplies.

SEDIMENT CONTAMINATION

The worst chemical contamination problems show up in the bottom sediments, where particles associated with metals and organics settle. The urban bays contain the worst areas of contaminated sediments; rural bays and the deep basins of the Sound collect contaminants in their sediments as well, although generally at lower concentrations. Harm to biological populations, as suggested by bioassays, changes in indigenous benthic invertebrate populations, bottomfish tumors, and reproductive problems, are greatest in areas of high sediment contamination.

MARINE WATERS

The marine waters of Puget Sound are generally clean, due to the tremendous volume, tidal mixing, and exchange with ocean water. However, there may be many chemical contaminants in the water at low or immeasurable levels. Water quality managers are keeping a sharp watch on areas of restricted water circulation and have discovered eutrophication problems in Budd Inlet (URS, 1986), contaminated shellfish beds in many bays, and potential problems in other areas.

EFFECTS ON BIOLOGICAL POPULATIONS

Changes in population levels of fish, marine birds, waterfowl, and marine mammals may be caused by human activities. Development, waste disposal, habitat destruction, overharvesting, and other factors may cause damage to these resources. The accumulation of toxic chemicals in the flesh of fish, shellfish, birds, and marine mammals does not necessarily mean that the animals are being harmed, but these chemicals must be taken as a warning sign of potential damage to our resources and a threat to human health.

HABITATS

The vegetated nearshore estuarine habitats in Puget Sound are a mere shadow of their former selves. Over the past 100 years there have been staggering losses of nearshore eelgrass and salt marshes in the urbanized estuaries and heavy losses of nearshore and upland wetlands throughout the basin. We cannot accurately document the extent of fish and wildlife losses due to habitat destruction, but evidence from other regions, and some local information, suggest that the impacts have been enormous. The loss of Puget Sound vegetated nearshore habitat, despite many regulatory constraints, continues at an alarming rate. Losing the nearshore habitat eliminates more and more of the critical refuge, feeding grounds, and nursery areas for the fish and wildlife which help make the Puget Sound area such a desirable place to live.

FRESH WATER

The rivers and streams of Puget Sound suffer from many localized water quality problems, but the systems are resilient and no recent widespread degradation of water quality has been seen. However, riverine habitat destruction, reductions in the populations of fish and wildlife supported by the freshwater corridors, and the press of human development in the watersheds are indications that we are stressing the system and that further breakdowns in the health of rivers and streams may follow.

RECOMMENDATIONS FOR FUTURE MONITORING

The first year's information collected by PSAMP confirms the expectations of the program's designers: the ecosystem multi-compartment approach of PSAMP will give us the most accurate and cost-effective information on the status of Puget Sound waters, sediments, and biological populations. During 1989 PSAMP investigators have collected good baseline information for some compartments of the ecosystem, including sediments, fish, shellfish, and marine and fresh waters. In order to build on this foundation, and to include those ecosystem components where PSAMP monitoring has not been fully initiated (marine mammals, birds, and nearshore habitat), additional funding of PSAMP is needed.

PSAMP managers will make some changes to the PSAMP design in upcoming years. These changes will be based on information collected by PSAMP and other programs, technological advances which will make the measurement of some environmental variables easier and less costly, the need to monitor emerging environmental problems, and the availability of funds for monitoring. In the future, PSAMP managers may relocate some monitoring stations, fill in geographic station coverage, add or delete some parameters, and sample additional ecosystem compartments. Beginning with the next annual PSAMP report, PSAMP managers will evaluate the effects of eating contaminated seafood on human health, using risk assessment techniques.

There are many portions of PSAMP which are not currently funded, or where funding is inadequate to assess the status and trends of resources throughout the Sound. Managers have had to make tough choices about which parts of the ecosystem will not be sampled, and what areas of the Sound will not be monitored, until more funds are available.

Early in the PSAMP design process, members of the Monitoring Management Committee decided to concentrate on levels of contamination in Puget Sound sediments, waters, habitats, and biological populations. The PSAMP design generally does not address population estimates of Puget Sound animals; the exceptions are the marine mammal and bird tasks. The designers of PSAMP felt that the state Departments of Fisheries, Wildlife, and Natural Resources, as well as several federal agencies (notably the National Oceanic and Atmospheric Administration and the U.S. Fish and Wildlife Service), already had responsibility for assessing and protecting marine populations in Puget Sound. Unfortunately, state and federal funding has not been sufficient to allow these agencies to adequately protect many populations of fish, shellfish, birds, marine mammals, and other resources. PSAMP will continue to stress the importance of monitoring biological populations in the Sound and will seek the necessary resources to fund these measurements. In future reports, PSAMP managers will attempt to include the latest information from appropriate state and federal agencies on the status of Puget Sound populations.

In 1990 the Washington State Legislature passed legislation that requires the implementation of PSAMP by state agencies. Funding has not yet been assured, however. The Puget Sound Water Quality Authority and other PSAMP managers (including the state agencies responsible for implementing PSAMP, EPA, tribes, and local government) are working hard to obtain the necessary funding for PSAMP.

WHAT HAPPENS IF WE DON'T MONITOR?

Certain components of the ecosystem are receiving minimal monitoring under PSAMP or any other program. Scientists and managers are measuring contamination in fish and shellfish resources in only a few areas of the Sound, and will probably not inventory estuarine nearshore habitats again in the near future. There is inadequate monitoring of marine and fresh water, marine mammals, and birds to keep track of changing conditions. Without information in these parts of the ecosystem, major changes could occur and shifts in resource populations or levels of contamination could go unnoticed until a crisis strikes. Alternately, changes in ecosystem compartments could occur and managers would have inadequate information to explain whether the changes were due to natural or anthropogenic causes. Lack of information of this type could hinder managers from preventing the same problems from occurring in the future.

By collecting little or no information in some compartments of the ecosystem, the public may incur staggering future costs to restore affected resources, or we may see great reductions or even total loss of some of our unique and valuable marine populations. There are many worldwide examples of over-exploitation of resources, decimation of biological populations by pollution, and human illnesses from eating contaminated seafood that must be an example to us in the Puget Sound area. In addition, managers will continue to have only limited information with which to evaluate the effectiveness of source control and cleanup programs.

The information that PSAMP investigators are collecting, and the actions that will be taken as a result of PSAMP, will provide a level of protection for Puget Sound, its biological resources, and human health that is critical for maintaining a healthy and diverse Puget Sound. The money spent on PSAMP is an excellent investment in the future of Puget Sound.

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