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Puget Sound: Issues, Resources, Status, and Management

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The NOAA Estuarine Programs Office

presents

AN ESTUARY-OF-THE-MONTH-SEMINAR

PUGET SOUND

ISSUES, RESOURCES, STATUS, AND MANAGEMENT

January 21, 1987

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Preface

Alyn C. Duxbury
Washington Sea Grant Program

In September 1986, Dr. Howard S. Harris, Ocean Assessments Division, NOAA, and I met in Seattle with Dr. James Thomas, NOAA Estuarine Programs Office, to discuss featuring Puget Sound in the Estuary-of-the-Month Seminar Series. As a result, I volunteered to assemble a one-day program of speakers and to coordinate the publication of their papers.

Puget Sound Studies

Like many major estuarine environments, the Puget Sound Region is a place of intensive study in many fields. To what extent the Sound has been used or abused often seems to be a function of whom one talks to and his or her particular interests. Political and resource management interests abound in the Pacific Northwest and frequently bring together Federal, state, county, and municipal agencies, as well as public and private industries to address issues, uses, problems, and solutions.

Seminar Topics

A one-day seminar is not long enough to cover all the activities, groups, and research effort presently ongoing in this dynamic marine arena. Therefore, it was necessary to select among many possible topics. This does not mean, however, that those topics not included are unimportant.

In organizing the seminar we decided to showcase two problems that have received much attention and that are considered to be most important to the conservation and development of the Sound and its resources:

- Toxicants - their presence and distribution in the Sound's urban bay sediments, their point and non-point sources, and their resulting biological impacts; and

- Sewage Contamination - the bacterial contamination from sewage treatment plant effluent and from non-point land runoff that does not destroy shellfish resources, but does preclude commercial sales from contaminated beds.

In the sessions that resulted from these plans, speakers reviewed ways that agencies--Federal, state, and local--have responded to these problems and described management strategies to counter-act them. They also described ways that management policies are creating useful interactions among agencies at different levels of government.

We are pleased to provide this information about Puget Sound and in doing so, we hope that it will foster a better understanding of Puget Sound as a unique estuarine environment with unique problems and solutions.

PUGET SOUND, A FJORD-LIKE ESTUARY

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In the Pacific Northwest there are a series of glacially scoured, interconnected channels that form the Strait of Juan de Fuca, Georgia Strait in Canada, and Puget Sound in the State of Washington. Puget Sound is the southernmost portion of this system and centers on 47^{o} N latitude.

Documentation of Puget Sound dates back to Captain George Vancouver's exploratory visit in 1792. He penetrated the Sound as far south as Blake Island with the HMS Discovery and anchored. He then sent his young lieutenant, Peter Puget, in a small boat to explore farther inland. As a reward for Puget's efforts, the area south of the present Tacoma Narrows was named Puget's Sound. The main basin or channel between the Narrows and the entrance at the north was named Admiralty Inlet. Port Gardner, Possession Sound and Hood's Canal completed the roster of the principal components of this inland sea.

No one has been willing to leave the original names alone or to retain their geographical relationships. Today the commonly accepted nomenclature and subdivisions of the Sound based on defensible oceanographic and geographic criteria use Puget Sound to refer to the total body of water south and east of a line between Partridge Point on Whidbey Island and Point Wilson at Port Townsend.

This body of water is then subdivided into Hood Canal, South Sound, Whidbey Basin and the main or central basin. Even this is not sacred and with each new law or regulation that pertains to the Sound, the writers are compelled to redefine the boundaries for Puget Sound. At present some legislation expands Puget Sound north and west to the Canadian boundary and half way out the Strait of Juan de Fuca.

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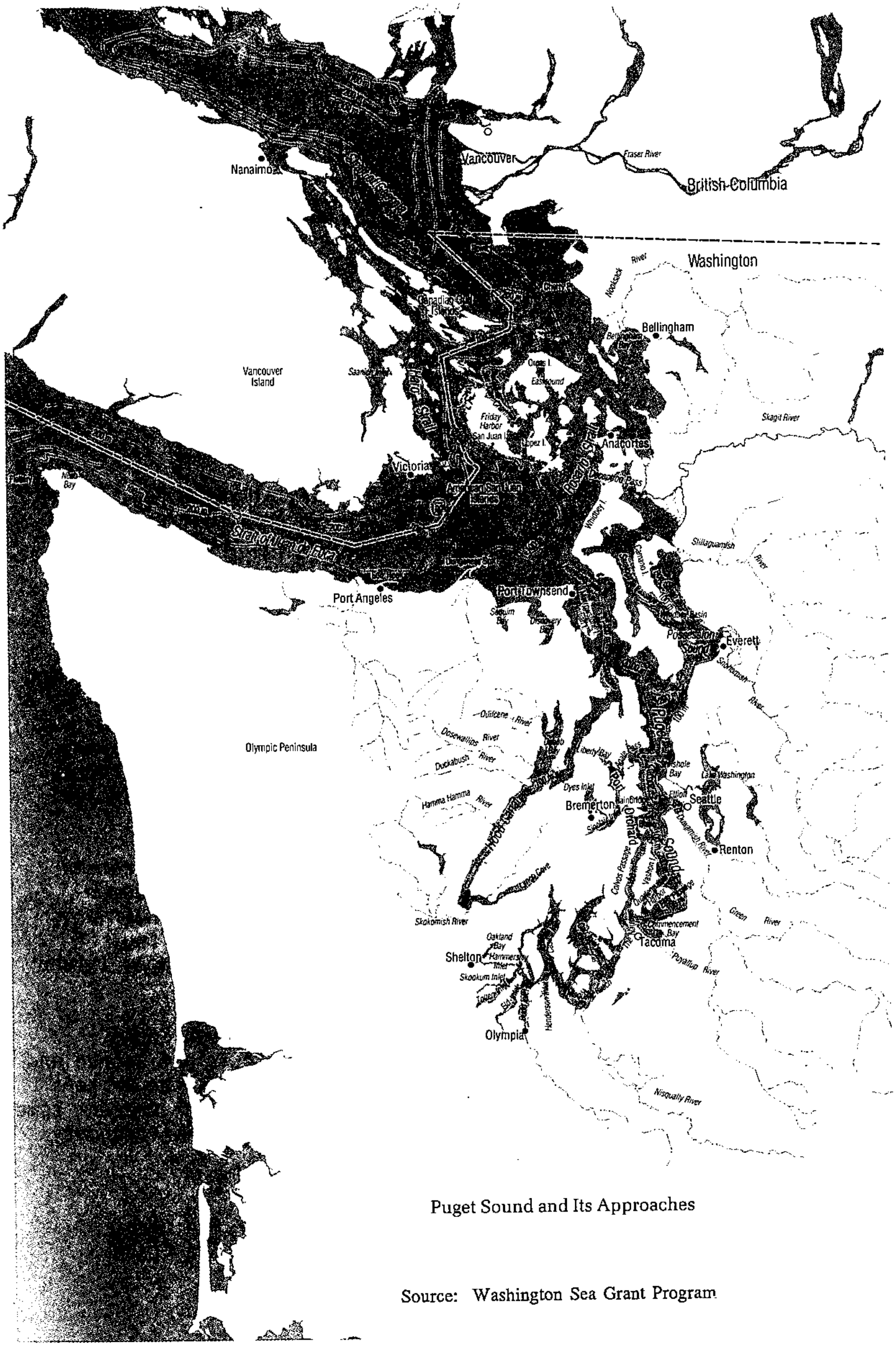


Puget Sound and Its Approaches

Source: Washington Sea Grant Program

In view of the ever-changing limits of the Sound, quoted numbers for volume, surface area, mean depth, miles of shoreline and number of islands mean little unless the boundaries are carefully and accurately specified. Hereafter, any reference to Puget Sound in this paper means that body of water bounded at Deception Pass and the north end of Admiralty Inlet. If a greater region is to be referred to, then descriptors such as Puget Sound and adjacent waters, the greater Puget Sound region, or specific names for adjacent areas will be used.

Puget Sound proper has a shoreline length of 1,157 nautical miles. Its surface area at mean high water is 767.6 sq. nautical miles. It contains a volume of 26.5 cu. nautical miles at mean high water and gains and loses a mean intertidal volume of 1.27 cu. nautical miles each change of the tide (McLellan, 1954). These numbers give the initial clues to why Puget Sound is unique among all estuarine systems in the continental United States and why Puget Sound responds in its own way to both natural and anthropogenic stress.

The volume and surface area can be used to determine the mean depth of the Sound, 210 ft. This depth takes into consideration all the small, shallow, appended inlets as well as the deeper main channels, Table 1. If the mean depth of the main basin alone is calculated it is found to be 329 ft. Main basin depths range from 0 to 930 ft. maximum with typical midchannel depths of 600-800 ft. The small appended inlets attached to the main channels have mean depths that are in tens of feet, e.g. 12.0 ft. for Eld Inlet.

Table 1
Area, Volume Table for Puget Sound

Region	Area MHW n. mile^2	Volume MHW n. mile^3	Mean Depth ft.
South Sound	130.7	2.49	116
Main Basin	223.5	12.1	329
Hood Canal	113.2	3.92	210
Whidbey Basin	184.9	4.58	150
Admiralty Inlet	115.3	3.41	179
Total Sound	767.6	26.5	210

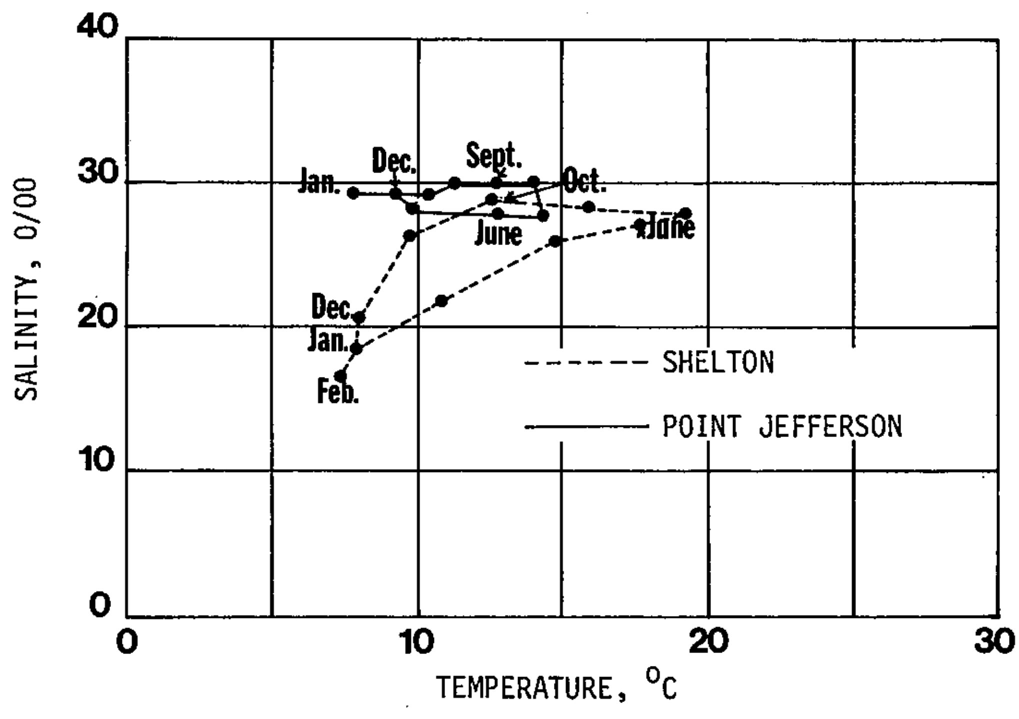
Source--McLellan, 1954

These values point out that for Puget Sound in general over half of the volume of water lies below the photic zone judged to be effective to about 100 ft. depth. In the main basin about 80 percent of the water volume is below the photic zone, whereas nearly all the water in the shallow appended inlets may be completely within the photic zone. This coupled with the annual variation in solar radiation at 47° N and the infamous cloud cover associated with our region causes seasonality in plant growth as well as fostering one type of marine plant life over another. The main deep channels have only small areas of sea floor within the photic zone. This coupled with minimal presence of hard stable rock substrates limits the overall abundance of macrophytes and rooted higher plants. Instead primary production on which the food webs are built is principally supplied by phytoplankton. In the shallow inlets both phytoplankton and benthic plants are important if suitable substrate is present.

The shallow appended inlets of Puget Sound have characteristic patterns of changing properties that are similar to those found in the shallow temperate zone estuaries of the east coast of the United States. A dissimilarity is that many of our shallow inlets do not have extensive areas of adjacent low-lying land to form bordering marshlands. Further, our shallow inlets for the most part do not have large streams or rivers at their heads. This, coupled with being dead end arms of water, reduces the ability of these inlets to exchange water with the main body of the Sound and diminishes their tidal currents and turbulent mixing.

The reduced advective and diffusive exchanges allow <u>in situ</u> changes in these appended embayments to play an important role in their observed changes in water properties. Large annual changes in water temperature are common due to surface heating and cooling, and if small streams are present, surface salinities can vary widely with stream flow (Fig. 2).

Figure 2. Variation in surface salinity and temperature over the annual cycle of a shallow inlet station, Shelton, and a main basin station, Point Jefferson.



Primary production due to phytoplankton can be very high in these shallow embayments over the entire water column during spring and summer. This process can utilize nutrients faster than they can be supplied by a net water exchange with the main parts of the Sound. During the periods of high primary production the surface waters become supersaturated with dissolved oxygen. As this production wanes due to die off and grazing, dissolved oxygen can decrease at depth while nutrients increase.

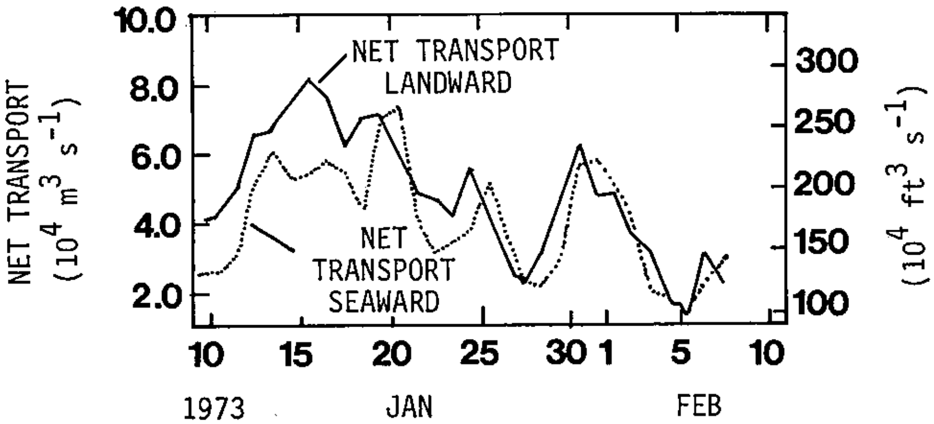
The sediments in the heads of these quiet protected bays are generally fine and high in organic content. Other regions of these bays have mixed coarse to fine sediments that are representative of the adjacent land materials and little wave or current energy is present to erode and sort beach material. It is in these bays that the native shellfish are found and shellfish aquaculture occurs.

Because primary production appreciably depletes soluble nutrients in these shallow appended embayments and natural water exchange rates are reduced, anthropogenic sources of nutrients can play a significant role in increasing primary production above normal levels to cause eutrophication. These inlets are poor sites for sewage treatment plant outfalls or drainage systems that conduct water laced with nutrients from land areas of intensive human use. Fortunately for Puget Sound most of these shallow embayments are surrounded by rural rather than urban and industrialized land usage. However drainage from the land, even under rural conditions, can supply coliform bacteria having its source in failing septic tank systems or hobby farms. Coliform bacteria derived from fecal matter of warm-blooded animals is not normally detrimental to the valuable shellfish resources, but its presence above certain concentration levels can cause health risk concerns and result in the closure of shellfish beds to commercial and recreational harvest.

The reduced net exchange of water between these shallow inlets and the main channels of the Sound not only restricts the natural supply of nutrients for in situ primary production, it also restricts the exporting of phytoplankton from the embayments. This is why the shellfish have such a good food supply and why sediments in these bays are high in organic content. The sediments, being high in organic content, are often anoxic a few inches below their surface. Over the fall and winter period, when light levels and productivity are reduced and stream flow and wave activity increases, these inlets gradually regain reasonable levels of dissolved oxygen and nutrients in readiness for a new spring bloom.

The main channels of Puget Sound function quite differently than the small appended embayments. In the main basin of Puget Sound the direct measurement of currents and their integration over tidal months as well as water and salt budget analysis (Cannon, 1983, Collias, 1977, Friebertshauser and Duxbury, 1972, and Barnes and Ebbesmeyer, 1978) indicate that a net two-layer estuarine circulation exists. There is a net seaward flux in the upper 150 ft. of the water column and a landward flux between 150 ft. depth and the channel bottom at 600 to 800 ft. depth. It must be appreciated that depths of 600 ft. or greater are equivalent to the depth of the outer edge of the continental shelf but are found in the main basin at distances of less than 1 mile from the beach. Measured net fluxes in the main basin are variable over the annual cycle. Observed values range between 0.7×10^6 ft.^{3}/sec. and 2.9×10^6 ft.^{3}/sec. (Cannon, 1983) (Fig. 3).

Figure 3. Measured fluxes in the middle of the main basin



After Cannon and Ebbesmeyer (1978)

The seaward surface flux should exceed the landward flux at depth by the freshwater inflow which has an annual average value of about 39×10^3 ft.^{3}/sec. The magnitude of these net fluxes can be put in perspective by comparing them with the annual mean discharge of the Columbia River which is about 0.26×10^6 ft.^{3}/sec. (Pruter and Alverson, 1972).

Considerable interest has been generated in the fact that a portion of the seaward surface layer flux is mixed with the oceanic water in the Strait of Juan de Fuca at the entrance sill in Admiralty Inlet. It is this mixture that then enters at depth to produce the landward-moving flux in the main basin. This process recycles some of the surface flow. Present estimates of the percent of recycling of surface water are between 50 to 60 percent (Barnes and Ebbesmeyer, 1978, Cannon and Ebbesmeyer, 1978 and Ebbesmeyer and Barnes, 1980). The percent of recycling and rates of inflow of mixed water are believed to be related to stability of the water column and spring and neap tide cycles. However a clear understanding of the process has not yet evolved (Geyer and Cannon, 1982).

If 50 percent recycling of the net seaward surface flow is assumed then the flux of water escaping the Sound is one-half the main basin surface flux rate. This escaping flux rate when divided into the Sound's volume yields a flushing time for the whole Sound of approximately 155 days.

At the sound end of the main basin the orientation and dimensions of the channels cause the tidal currents on the rising flood tide to prefer the East Channel route on their way to the Tacoma Narrows. The turbulent mixing in the Narrows during the flood mixes the surface water and water from depth in the East Channel together sending it into South Sound. On the ebb this well-mixed water is preferentially discharged into Colvos Passage which is narrow and shallow. This water exits this channel as a surface flow to rejoin the main basin opposite Alki Point.

This constitutes tidal pumping that produces a net clockwise circulation about Vashon-Maury Islands and selectively forces deep water up from depth at the south end of East Channel converting it to a surface water seaward flow near Alki Point. Tidal pumping combined with recycling at the entrance sill increases the two-layer net circulation in the main basin above what is required in and out of the Sound to maintain salt and water budgets. This circulation also assures that waters of the main basin in contact with the urban centers can move elsewhere in the Sound to exchange with any of the appended basins or small embayments.

The rapid two-layer net circulation in the main basin plays a significant role in controlling primary production. In the spring and early summer the addition of snowmelt runoff and surface heating combine to produce stability in the top 100 ft. of the water column. This enhances bloom conditions for phytoplankton and dissolved oxygen levels increase as nutrients in the surface layer decrease. This surface layer of the main basin, however, is actively being advected towards the mixing sill at Admiralty Inlet. If 50 percent recycling occurrs, then the surface water with its high density of phytoplankton population, lowered nutrients and high oxygen values is being mixed downward and returned to the main basin. This distributes phytoplankton advectively to the 500 to 700 ft.-thick deep layer at about 1/2 the average concentration found in the 100 ft.-thick surface layer. This means that below the photic layer there can at times be about 3 times the total plant biomass found in the surface layer. Much of the phytoplankton is exported to the Strait. The tidal pumping action at the Tacoma Narrows sends the main basin deep water with its suspended phytoplankton and nutrients back to the surface layer and the photic zone.

The strong net advective processes in the main basin, sill mixing, and tidal pumping, export of phytoplankton and its advection to depth, act to ventilate the deeper waters of the main basin and continually supply nutrients to the surface layer. These natural flux rates of dissolved oxygen and nutrients are so large that anthropogenic sources of nutrients and BOD in the main basin are insignificant if well dispersed. At 930 ft. in the main basin the percent saturation of dissolved oxygen rarely drops below 65 percent whereas the percent saturation at 200 - 300 ft. depth in the Strait and along the coast can be less than 30 percent when upwelled type oceanic water is present in the summertime.

Particulates other than plankton are present in Puget Sound. They come from rivers, shore erosion, and urban sources. An annual average value of particulates in suspension is about 1 g/m^3 of estuarine water. When this is combined with the estimate of rate of input of particulates a mean residence time for particulates in the water column is found to be about 15 days. This is about 1/10 of the estimated residence time for water in Puget Sound. This means that particulates are more apt to settle out within the system than to be exported by the net circulation fluxes. Thus Puget Sound is a sediment trap.

Because many toxicants have an affinity for particulates, absorbing on their surface, the Sound can also be a trap or sink for toxicants. Size and chemical nature of the particles controls in part the scavenging of toxicants out of the water colum. This and the circulation within the estuary determines where they eventually settle out.

In the main basin rivers, shoreline, and urban discharges are sources for particulates. The pattern of their deposition is that finer and lower density particles in the sediments are at the greater depths along the central axis of the basin furthest from sources with coarser sediments along the edges closest to sources. A discrete source of mixed particle sizes or fines at the the shore edge or a wave-protected area can locally disrupt the general pattern. Concentrations of toxicants in the sediment are generally higher at depth in the fine sediments than in the coarser sediments of the near shore zone. If a localized source of toxicants and mixed-size particulates exists an elevated concentration of toxicants may be found in the near field of the source. If a localized source of clean particulates exists then their near field accumulation can reduce concentration levels of toxicants in the sediments (Fig. 4).

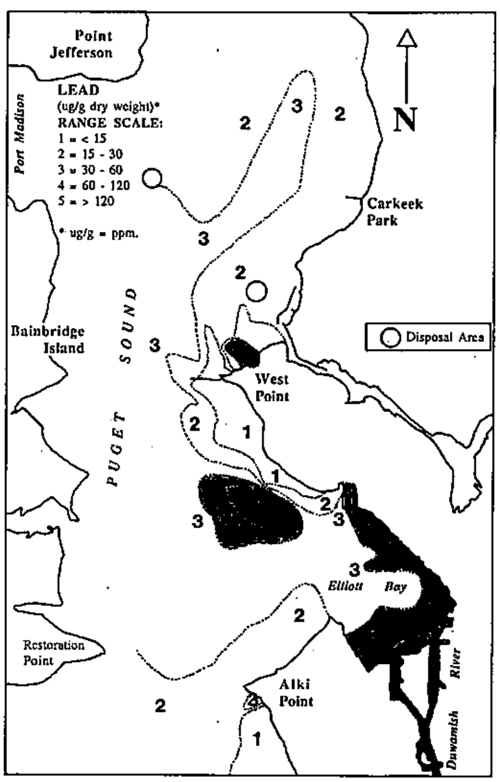


Figure 4. Concentrations of lead in surface sediments are highest around Harbor Island and parts of the Elliott Bay waterfront, at the four mile rock dredge disposal site and at the site of the old north trunk sewer outfall between West Point and Shilshole Bay.
(After: Metro TPPS Study)

Some discharges are sources of toxicants only. If they are dispersed they tend to go far afield until particulates from other sources send them eventually to the sea bed. If the toxicant is not dispersed it leaves its signature in the near field sediments as a "hot spot."

Toxicants attached to very fine grain or low density materials can be carried anywhere in the Sound by the net circulation and kept in suspension by the tidal current turbulence. These materials may wander into the rural appended embayments far from urban sources. However, if the local sources of clean sediment material in these rural embayments is large in comparison to the advected supply, these embayments will have low concentrations of toxicants in the sediment.

The laying down of toxicants in the sediments is a physical mechanism for cleansing the Sound. Eventually the toxicants are forced to sufficient depth that they no longer interact with the water or the biota. As the input of toxicants is decreased natural sedimentation processes will tend to decrease the concentration of toxicants at the sediment-water interface providing humans do not interfere with the sediment supply. Increasing the clean sediment supply increases the sedimentation rate and also decreases the sediment toxicant levels. The depth of the Sound allows much of the sedimentation processes to progress with no interference to shipping. In the urban industrailized port areas sediment and toxicant accumulation may produce shoaling that requires dredging. It is in these areas that disturbance of the sediments makes toxicants again available to the water and biota. Special handling is required to minimize impacts of dredging and dredged material disposal.

Puget Sound is a magnificent and dynamic estuarine environment. Annually it receives enough river water to form a layer 65 ft. thick over its entire surface. This fresh water is combined with seawater by turbulent mixing derived from tidal currents. The presence of this fresh water requires that a net circulation exists that transfers a diluted surface layer seaward and allows seawater in at depth to replenish the seawater carried out in the surface mixture. There is also the driving force of denser oceanic water at depth on the Strait side of the entrance sill trying to displace the less dense water at depth in the main basin. Both the rates of addition of river water and the supply rate and density of the oceanic waters have seasonal cycles. The Sound continually tries to adjust its properties towards an equilibrium as fresh water input and oceanic water supply changes in time. This makes the net circulation flows variable in time. In the attempt to keep up with the circulation driving forces, Puget Sound reaches its most diluted stage in February about one month after the maximum wintertime precipitation period. At this time about 1 cubic nautical mile of its total of 26.5 cu. nautical miles is stored fresh water. In late October or early November before river flow has appreciably increased the Sound is at its saltiest having given up its stored fresh water and replaced it with the upwelled oceanic type water that entered at its maximum rate in August and September displacing the resident water upwards and seaward.

Every part of the Sound is different. One can not generalize and apply rules of use appropriate in the main basin to the smaller shallow appended embayments. Neither can one apply rules of use to the main basin that are derived from an understanding of the appended embayments. Although we should try to use a holistic approach to Puget Sound as a system, as every part is dependent on another part, we must also use site-specific criteria to determine how we should or should not capitalize on the Sound as a multiple resource.

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SOURCES OF CONTAMINATION IN PUGET SOUND

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Introduction

Effective management decisions concerning the control of toxic chemicals which enter Puget Sound require the identification of the contributing sources and the quantification of the total input associated with these sources, (i.e., the contaminant mass loading). Quantitative knowledge of chemical contaminant inputs into the Sound coupled with a good understanding of the transport and or fate of these materials in the receiving waters of the Sound is critical to: 1) the estimation of the net toxic chemical loading that remains following inputs, losses via sedimentation or degradation and outflows (i.e., the chemical mass balance); 2) the determination of the relationship between contaminant input, environmental distribution and effects; and 3) establishment of a realistic control, compliance, and enforcement strategy.

The total contaminant loading associated with an input source is calculated from the contaminant concentration in the discharge and the total flow or material volume of the source entering into Puget Sound. Although this type of calculation may appear to be straight forward, it is in fact quite difficult to characterize the concentration of all toxicants in all source discharges to Puget Sound. As an example, consider that there are hundreds of chemicals that could potentially be discharged from over 350 point sources that discharge either directly into Puget Sound or to rivers draining to the Sound. As discussed below, other sources of toxicants to Puget Sound are equally difficult to characterize.

The reader is cautioned to remember that the total loadings emphasize the relative contribution of different input sources but do not indicate the potential for impacts associated with a source. In other words, a small loading may be associated with high concentrations that could cause localized impacts. Conversely, large contaminant mass inputs are not necessarily detrimental when they are associated with a large material or inflow volume that has low concentrations. Computation of total toxicant inputs represents only the first step in understanding the overall significance and effect of pollution in Puget Sound.

Three recently completed studies supported by EPA, the Municipality of Metropolitan Seattle (Metro), and NOAA in Puget Sound provide "first cut" estimates of mass loading for selected contaminants. These studies include Water Quality Management Program for Puget Sound (Jones and Stokes, 1983); Metals/Toxicants Pretreatment Planning Study (Romberg et al., 1984); and Toxic Chemicals and Biological Effects in Puget Sound (Quinlan et al., 1985).

In the Jones and Stokes, 1983 report only pollutant loadings associated with municipal and industrial discharges were considered. The information reported was primarily for conventional pollutants; organic pollutant data was sparce. Due to these limitations, total pollutant loading and the relative importance of each source was not assessed in this report. In the TPPS report (Romberg et al., 1984), the main basin of Puget Sound was the primary focus of the contaminant loading estimates. Loading data was presented for both metals and synthetic organic components.

Quinlan et al. 1985 developed contaminant loading estimates for five source categories and three major classes of chemical contaminants, including metals, polynuclear aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs). Sources included: rivers, shoreline erosion, atmospheric deposition, municipal sewage effluents and industrial waste effluents. This report presents the most complete picture of contaminant inputs to Puget Sound available to date and is the basis of loading values that will be presented here. However, calculated loadings are considered only as preliminary estimates due to the lack of detailed concentration data available to perform the computations. Substantial information gaps exist for concentrations of metals and organic constituents in all sources discharging to Puget Sound.

Although the historical data base is limited, the estimated loading for a number of chemical contaminants which occur in high abundance in Puget Sound has been quantified as a first approximation. This report briefly summarizes the existing information and provides an overview of the type of sources contributing to the contamination of the Sound, the quantities of contaminants emitted by these sources, and the main subregions of Puget Sound receiving these inputs. The main subregions of Puget Sound for which contaminant loadings have been calculated are indicated on Figure 1. In addition, a summary of EPA's ongoing efforts to expand the database available for contaminant source characterization is presented.

Sources of Toxic Chemicals

Toxic chemicals entering Puget Sound originate from two types of sources: point sources and nonpoint sources. Point sources are most readily identified and monitored as they are associated with an outfall pipe. Point sources include inputs such as municipal and industrial outfall discharges. There are over 350 permitted discharges in the Puget Sound basin (USEPA, 1985). Approximately 180 discharge directly to the Sound with the remainder discharging to rivers that drain to the Sound (USEPA, 1985). Nonpoint sources are not associated with an outfall pipe; rather they are spread out over a large land area. These sources include riverine flow, urban runoff, agricultural runoff containing animal wastes as well as agricultural chemicals, runoff from logging operations, shoreline erosion, atmospheric inputs from car exhausts or industrial emissions (atmospheric deposition), contaminated groundwater entering the Sound, septic systems, sewer overflows, spills, and boat discharges. Point sources and some nonpoint sources such as runoff from dairy farms are regulated under the National Pollution Discharge Elimination System (NPDES) permit system.

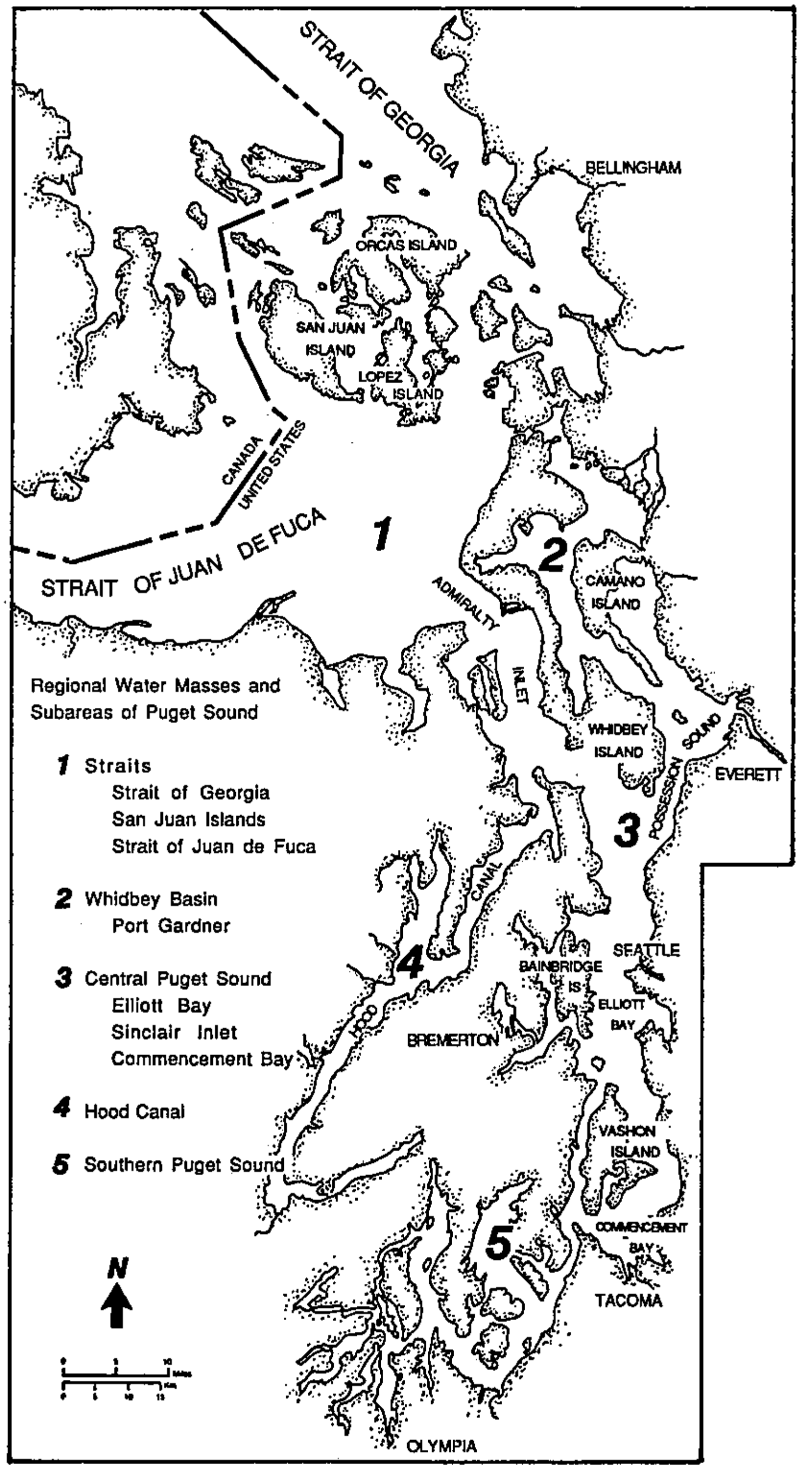
Relative Source Contributions

Preliminary estimates of toxic chemical mass loadings have been computed for the following five subcategories: municipal; industrial; riverine; shoreline erosion; and atmospheric deposition. Loadings have been computed for select metals, for the polychlorinated biphenyls (PBCs), and for polynuclear aromatic hydrocarbons (PAHs). The results of these loading computations are presented below. First, however, the limitations of available contaminant concentration data will be summarized to emphasize the preliminary nature of the computed contaminant loadings. Estimates of inflow and material input are subject to similar limitations which will not be detailed in this report.

Riverine

Available metals data were limited both in the numbers of rivers sampled and in the numbers of samples per river. The available data were used to develop single values for riverine metals concentrations. A crude estimate of the possible organic concentration in Puget Sound rivers was obtained from limited data available for the upper Duwamish (Green) and Puyallup Rivers and the Lake Washington Ship Canal.

FIGURE 1
MAJOR PUGET SOUND SUBREGIONS



Shoreline Erosion

Metals composition has been measured in very few soil samples. Data from three studies were used in conjunction with the reported composition of "average earth's crust" to determine representative values of Puget Sound shoreline soils. Concentrations of PAH's and PCB's in regional soils were assumed to be equal to zero.

Atmospheric Inputs

Inputs of metals and organics resulting from atmospheric transport and deposition have received very limited study. Lead and total suspended particulate data are most readily available for a number of Puget Sound stations. Metals data available for airborne dust collected at the University of Washington were also available. The ratio of lead to other metals in this dust was used to estimate ambient metals concentrations in other areas. PAH concentrations were also estimated from a single study and the assumption that the PAH input is proportional to the input of atmospheric lead.

Municipal Discharges

Considerably more data are available for the major municipal sewage effluent discharge then for other sources. However, little data exist for many of the smaller discharges. Therefore the concentrations of metals and organics reported in the Metro TPPS report were considered to be representative of all Puget Sound Municipal discharges.

Industrial Discharges

Available NPDES monitoring and inspection reports were used to estimate metals concentrations in industrial discharges. Available data were not adequate to estimate industrial inputs of organic compounds. It should be noted that the major contribution of metals to Puget Sound from industrial effluents was the ASARCO smelter near Tacoma. Which is now closed. Other significant industrial inputs were the pulp and paper mills which may have made an even greater contribution prior to implementation of secondary treatment facilities in the mid-1970's (Quinlan et al. 1985, pg. 74).

The total Puget Sound inputs for the selected priority metals and synthetic organic chemicals associated with the various sources are presented in Tables 1 and 2. It is apparent that metal inputs are dominated by the major nonpoint sources (riverine and shoreline erosion). The large contributions of metals from shoreline erosion reflect the fact that the metals are natural elements present at

Table 1

Estimated Trace Metals Inputs to Puget Sound (Mt/yr)

Metal	Source Type: Rivers	Shoreline	Atmospheric	Municipal	Industry
Arsenic (As)	64	34	11	1.5	63
Cadmium (Cd)	19	17	0.5	1.5	2
Chromium (Cr)	89	68	ND*	16	18
Copper (Cu)	108	75	32	24	56
Lead (Pb)	55	54	121	25	15
Mercury (Hg)	4	3	0.1	0.2	0.1
Silver (Ag)	4	1	0.1	3	2
Zinc (Zn)	384	305	27	51	47
Total	726	557	192	119	203

* **ND** = No Data

Source: *Quinlan, E.A. et al. 1985.* NOAA Technical Memorandum: *Toxic Chemicals and Biological Effects in Puget Sound: Status and Scenarios for the Future,* Table 23, pg. 74.

Table 2

Estimated Inputs for Synthetic Organic Compounds into Puget Sound* (Mt/yr)

Constituent	Riverine	Shoreline Erosion	Atmospheric	Municipal	Industry
CPAHs	**4.8**	**0**	**1.77**	**0.38**	**NQ**
PCBs	**0.12**	**0**	**NQ**	**0.36**	**NQ**

* *Advective inputs are excluded.*

NQ = *Not Quantified (insufficient data).*

Source: *Quinlan, E.A. et al. 1985.* NOAA Technical Memorandum: *Toxic Chemicals and Biological Effects in Puget Sound: Status and Scenarios for the Future,* Table 25, pg. 77.

background concentrations. These natural background concentrations are generally at low, nontoxic levels; however, low concentrations associated with a large material volume result in a high mass loading.

Riverine loadings reflect natural loadings as well as loadings from human activities occurring upstream. The relative contribution of natural versus human-induced loadings is unknown at this time. As for shoreline erosion, contaminant concentrations in riverine inflows generally occur at low, non-toxic concentrations. Moderate inputs of metals are exhibited by atmospheric and industrial sources with relatively low contributions from point discharges.

For the selected organic compounds, the total inputs are substantially lower than for the metals. Polynuclear aromatic (PAH) compounds appear to be associated with riverine and atmospheric sources, while polychlorinated biphenyls (PCBs) appear to originate primarily from point sources. It should be noted however that the uncertainty in the reported numbers may be large enough that these differences are insignificant. Additionally, the result that high PAH loadings are associated with riverine and atmospheric inputs is due, in part, to the way that source concentrations were estimated and is probably not totally accurate given the lack of major known sources to most rivers and the fact that loadings calculated for atmospheric inputs in nonurban areas were also high.

Areas of Puget Sound Receiving the Largest Input of Toxic Chemicals

To illustrate the relative contribution of each source to the contaminant loading in each Puget Sound subregion, the total loading for six metals (arsenic, copper, lead, mercury, silver, and zinc) and two classes of synthetic organic compounds (combustion polynuclear aromatic hydrocarbons - CPAH and polychlorinated biphenyls-PCBs) corresponding to each source was computed as shown in Figures 2 and 3. It is apparent that in Whidbey Basin which receives greater material (water and suspended sediments) from river discharges than other basins, the riverine inputs dominate the remaining nonpoint source inputs and the point source contributions. Recall that the same concentrations are used to calculate riverine loadings to all basins, differences in total loading therefore reflect only the differences in river inflow volume. For the Main Basin of Puget Sound where most of the industrial, commercial and residential development occurs, the point source contributions are enhanced with respect to the nonpoint sources. The southern Sound and Hood Canal receive comparatively reduced contaminant loadings due to both the decrease in nonpoint source contributions and the low population density, commercialization

Figure 2
Total Mass Loading for Selected Metals (Mt/yr)[1]

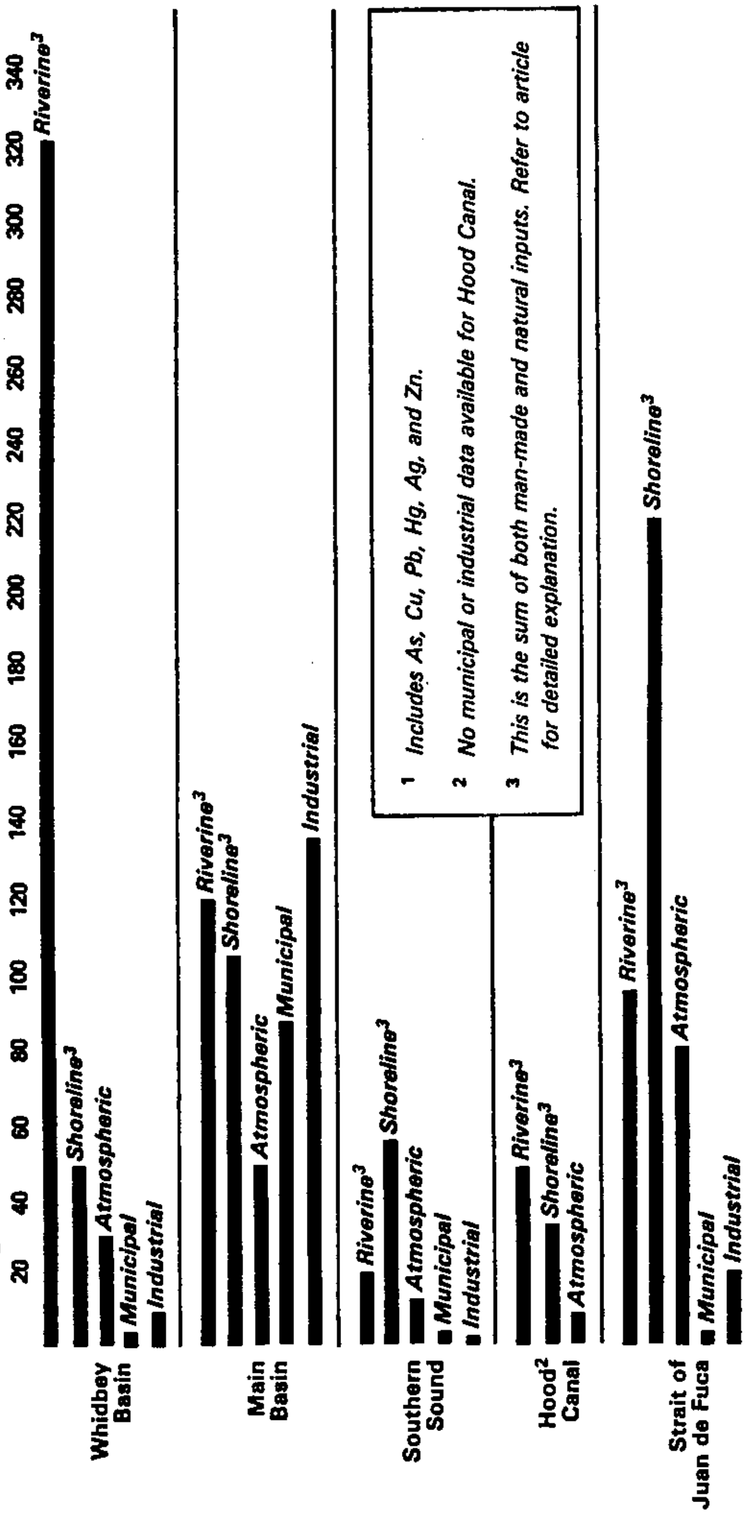
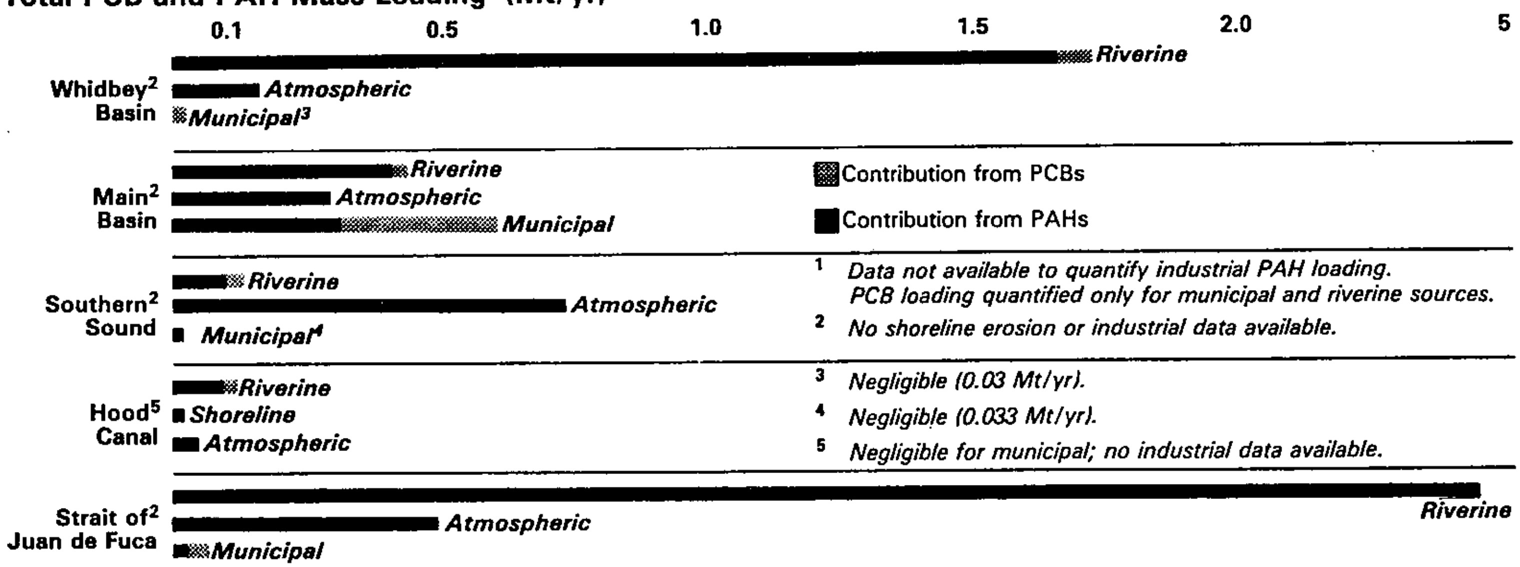


Figure 3
Total PCB and PAH Mass Loading[1] (Mt/yr)



1 *Data not available to quantify industrial PAH loading. PCB loading quantified only for municipal and riverine sources.*

2 *No shoreline erosion or industrial data available.*

3 *Negligible (0.03 Mt/yr).*

4 *Negligible (0.033 Mt/yr).*

5 *Negligible for municipal; no industrial data available.*

and industrial activity. Due to dynamic water transport through relatively narrow channels, shoreline erosion provides the highest contribution to the total metal loading in the Straight of Juan de Fuca.

For the synthetic organic compounds, the CPAHs are the largest contributors to organic contaminant loading for all subregions except for the Main Basin where municipal inputs appear to contribute equal loadings of PAHs and PCBs. Again, for the northern Puget Sound regions, riverine inputs exceed by far any other nonpoint and and point source input. However, for the Main Basin, municipal discharges appear to be responsible for the majority of the organic contaminant loading (relative to nonpoint sources; recall that loadings from industrial sources are not well-known at this time). It is also interesting to note that the atmospheric contributions to the CPAH loading is noticeable in areas where fossil fuel consumption is increased from industrial and residential activity.

Quantifying Nonpoint Source Contributions

As pointed out earlier, nonpoint sources are diverse and difficult to quantify; loading estimates to date have been based upon limited data. Available means by which nonpoint source contributions may be more accurately quantified are discussed below.

Nonpoint source inputs can be estimated in a number of ways with increasing levels of complexity. The simplest method is applicable in subregions where major nonpoint source loadings is via riverine inflow. In this instance, it is possible to monitor concentrations of contaminants in the rivers or other drainage systems and measure their flows. Multiplying the two together will yield the contaminant mass flux (loading) from this source into the Puget Sound region under consideration. This type of approach was used to calculate the nonpoint source loadings presented earlier.

A more detailed method is to catalog contaminant sources within a given area and quantify concentrations and area runoff. An example of this method is the Water Quality Assessment (WQA) procedure developed by EPA as a screening tool for local authorities to assess nonpoint source loadings. The method is based upon the results of previous studies which have found correlations of contaminant loadings with various measurements of land use, precipitation, and other factors. The accuracy of estimates obtained using this procedure varies depending on the amount of detail with which the basin is described.

More sophisticated and potentially more accurate methods utilizing computer models of basin hydrology and runoff quality are also available. These are expensive methods that require considerable input data to specify the configuration of the basin being modeled as well as to characterize the quantity and quality of the runoff. Available models have different limitations and assumptions and must be calibrated prior to model use for predicting future conditions. During calibration, model coefficients are adjusted until the quantity and quality of runoff observed during a previous rainfall event are successfully calculated.

As a test case in Puget Sound the WQA method was used to estimate nonpoint source inputs into two embayments: 1) Elliott Bay, receiving runoff from the highly urbanized Seattle and Duwamish Waterway/Kent Valley areas; and 2) Skagit Bay, receiving runoff from the predominantly rural Skagit River Valley. The loadings calculated with WQA were then compared to loadings computed using flow and concentration data to examine the applicability of the method to quantifying nonpoint source loading to Puget Sound embayments.

In general, the WQA procedure greatly underestimated the quantity of contaminant loading into the two embayments. The reason for the discrepancy lies in the selection of equation coefficients for the WQA model. The contaminant loading estimates obtained using WQA could have been forced to correspond to loadings computed using flow and concentration data by adjusting the coefficient values used (i.e., by calibrating the WQA coefficients to known conditions). However, coefficient adjustment would not be possible for embayments where nonpoint source loading could not be calculated by an independent method; coefficients determined for one embayment would not necessarily apply to another. Furthermore, the need to "calibrate" the WQA coefficients would defeat the purpose of identifying a simple, generalized method for quantifying nonpoint contaminant loading.

This simple evaluation confirmed the difficulty of quantifying, with accuracy, contaminant loading associated with nonpoint sources. The overall usefulness of the WQA model or similar screening methods lies in applications where it is desired to make comparisons among embayments as to the relative significance of nonpoint sources to contaminant loading or to compare the relative importance of specific nonpoint sources to the overall loading within a given embayment. To obtain accurate estimates of nonpoint source contributions to Puget Sound detailed monitoring studies and modelling appear to be required.

Efforts to Increase Data Availability

To minimize ecological and public health risks from the presence of a variety of chemical contaminants in the receiving waters of Puget Sound, a realistic source control, compliance, and enforcement program must be implemented region wide. The initial step towards this goal has already been taken under the Puget Sound Initiative through the development of Action Plans for contaminated embayments such as Commencement Bay, Elliott Bay, and Everett Harbor. In these plans, recommendations are made for short-term and long-term actions. For example, in Elliott Bay suggested interim actions include source control and compliance inspections with additional field data collection requirements to support the long-term action plan design. These recommendations are a good first step; however, the mechanism for their implementation have not been designated yet.

One of the mechanisms that can be immediately utilized to obtain more detailed information on the types and concentrations of contaminants discharged to Puget Sound is the implementation of more stringent monitoring requirements under the NPDES permitting process (i.e., requiring that samples of the discharge effluent be analyzed for all toxicants suspected to be preset in the discharge). The NPDES permitting system is described briefly below.

NPDES permitting is conducted on a case-by-case basis. Seven broad classifications of discharges in Region X are designated. These include: coal mining; ore mining; oil and gas; seafood processing; municipal, pulp and paper; and aluminum. Department of Ecology permitting staff who specialize in these particular discharges determine permissible discharge concentrations and monitoring requirements based upon data for similar discharges, information supplied by the applicant, and the use and quality of the water body receiving the discharge. Evaluation of permit compliance based on regularly submitted discharge monitoring reports and facility inspections is performed by a separate compliance division.

Historically, only discharge flow rate, the conventional pollutants (e.g., nutrients and suspended solids) and metals have been monitored for the majority of Puget Sound dischargers. More recently, some NPDES permits are being written to require analyses for the priority pollutants suspected to be present in the discharge. EPA and Department of Ecology are currently reexamining the overall NPDES permit process with the idea of increasing monitoring requirements as expired permits are reissued.

In December 1986 the Puget Sound Water Quality Authority adopted the first water quality management plan for Puget Sound. For point source pollution the plan emphasizes discharge limits, more stringent permits, compliance inspections, enforcement actions for nonpermitted discharges and increased permit fees. For nonpoint sources the plan emphasizes educational programs, public involvement and legislation (e.g., to require marine pumpout facilities).

It is anticipated that the availability of data required to compute total inputs of priority pollutants to Puget Sound will be increased in the future due to increased permit requirements. Additionally, permit requirements and other strategies are aimed at reducing contaminant inputs to Puget Sound.

Summary

As discussed, data required to compute contaminant loading to Puget Sound are limited. What initially appears to be a simple computation proves to be quite difficult because required information has not been routinely collected in the past.

Available data have been used to compute preliminary contaminant mass loading to Puget Sound; these computations do indicate general trends regarding the relative contribution from different sources in the subregions of Puget Sound. For metals, natural contributions from shoreline erosion and riverine inflow appear to exceed human induced loading. Recall, however, that these natural inputs occur at non-toxic concentrations and would not be considered environmentally damaging. Riverine inflow of organic contaminants also appears to be significant, however, this conclusion is regarded cautiously due to limitations of the available data. Additionally, the overall contribution of human activities to the riverine loads is unknown.

The large loadings associated with natural sources should not be misinterpreted to imply that human induced loadings are insignificant. Unfortunately, the data required to adequately assess the overall contaminant loading associated with human activities is not presently available. The relative importance of urban and agricultural runoff, logging operations, atmospheric deposition, industrial and municipal inputs cannot be quantified at this time. This information regarding human inputs is critical with respect to the protection of Puget Sound.

To improve the accuracy and completeness of contaminant loading estimates better information concerning the chemical concentrations in both point and nonpoint sources are needed. Data are virtually non-existence for many discharge sources. Efforts are currently underway to evaluate source control and compliance programs are well as available means to obtain improved discharge data. It is probable that our ability to determine contaminant loading will be improved in the not too distant future.

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BIOLOGICAL INDICATIONS OF POLLUTION IN PUGET SOUND

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Introduction

Recent studies of pollution in Puget Sound have largely focused upon the identification of the kinds and amounts of certain chemicals. Many of the chemicals that have been found in water, sediments, or marine life are known to be toxic in laboratory studies. However, the toxicity of these chemicals in a marine environment is not always predictable. Many highly complex (and poorly understood) factors influence the toxicity of many chemicals. Therefore, the presence of a chemical or a group of chemicals, or even a relatively high concentration of a single chemical, does not necessarily ensure that the resident marine life are suffering adversity. Some direct evidence of biological impact is needed to answer the biological "So what?" question.

In our attempts to provide answers to this question, marine scientists have developed a wide variety of tests to determine adverse effects. There is no universally accepted single test or methods, so a variety have been used to develop a broad base of evidence for effects. Some involve examining the toxicity of a sample of water or sediment from the Sound to marine organisms. The test is conducted in a laboratory under controlled conditions and is called a bioassay. Some methods involve examining animals living in the study area to determine if the health of individuals or the abundance and composition of communities of organisms is impaired relative to that of residents of non-contaminated areas. The results from both the bioassay tests and the studies of resident biota can be compared with the complementary chemical data and also can be compared between samples from contaminated areas and non-contaminated areas.

Since it is widely known that many toxic chemicals readily attach to suspended particles and eventually sink, the bottom sediments become the final repository for much of the contamination entering the Sound. The animals living in or upon the sediments, then, may become exposed to concentrations of chemicals in the mud far in excess of those in the overlying water. Therefore many of the biological studies have emphasized testing of sediments and examination of bottom-dwelling organisms.

The concentrations of many chemicals have been determined in sediments from many parts of the Sound. For some chemicals the concentrations vary dramatically from place to place. The mixtures of chemicals also vary from place to place, dependent upon local sources.

Since the sediments are a repository for many contaminants, they also can be regarded as a source of contaminant exposure for many biota. Comparing the values in figures 1 and 2, it is apparent that some contaminants (e.g., PCBs) may be passed from environmental media such as the sediments to the biota and become more concentrated from lower to higher trophic (feeding) levels. Other chemicals (e.g., aromatic hydrocarbons) are apparently metabolized successfully and do not accumulate to a significant degree in upper trophic level biota.

Because of these differences in the way toxic chemicals behave, various biological organisms would be expected to be exposed to differing mixtures and concentrations of contaminants. Any single biological test of the effects of contaminants in the Sound may not be indicative of how other tests with other organisms may react. Therefore, a wide variety of tests have been performed by various researchers in the area. Some have shown trends very consistent with trends in contamination; others have not. Some are probably responsive to only some of the chemicals found in the Sound. Others may be responsive to chemicals not detected in routine analytical procedures. The following is a brief summary of some of the more important biological indications of pollution measured in Puget Sound.

Overview of Biological Data

Water bioassays.

Oyster larvae bioassays. Table 1 summarizes the three main biological tests of water quality performed in the Sound. Data also exist for plankton community studies and effluent bioassays.

The microscopic drifting larvae of oysters are very sensitive to pollutants and changes in natural water properties such as temperature. The larvae of the Japanese oyster were used extensively in the 1960s and 1970s in bioassays of water samples collected near and away from the discharges of pulp mills. These discharges proved to be very toxic to the larvae, possibly explaining, in part, the demise of the native Olympic oyster population in Puget Sound. All the mills around Puget Sound now treat their effluents and have significantly decreased the total volume of pollutants discharged. Curiously, the oyster larvae bioassay was also found to be highly sensitive to a naturally occurring organism, *Ceratium*. *Ceratium* is a single-cell drifting plant that, for some reason, seems to kill oyster larvae.

Up to 100% mortality among oyster larvae exposed to some samples of water from the south Sound inlets has been recorded as recently as 1977. Usually less than 5% mortality occurred in tests of samples from the

Central Basin or northern Hood Canal. The toxic samples from Budd Inlet near Olympia, for example, contained a lot of Ceratium. It is possible that the Ceratium "blooms" were enhanced by the abundance of organic material in Budd Inlet water, acting to stimulate proliferation of the microscopic plant. These organic materials occur in high amounts in some south Sound inlets both due to natural sources and man-made discharges.

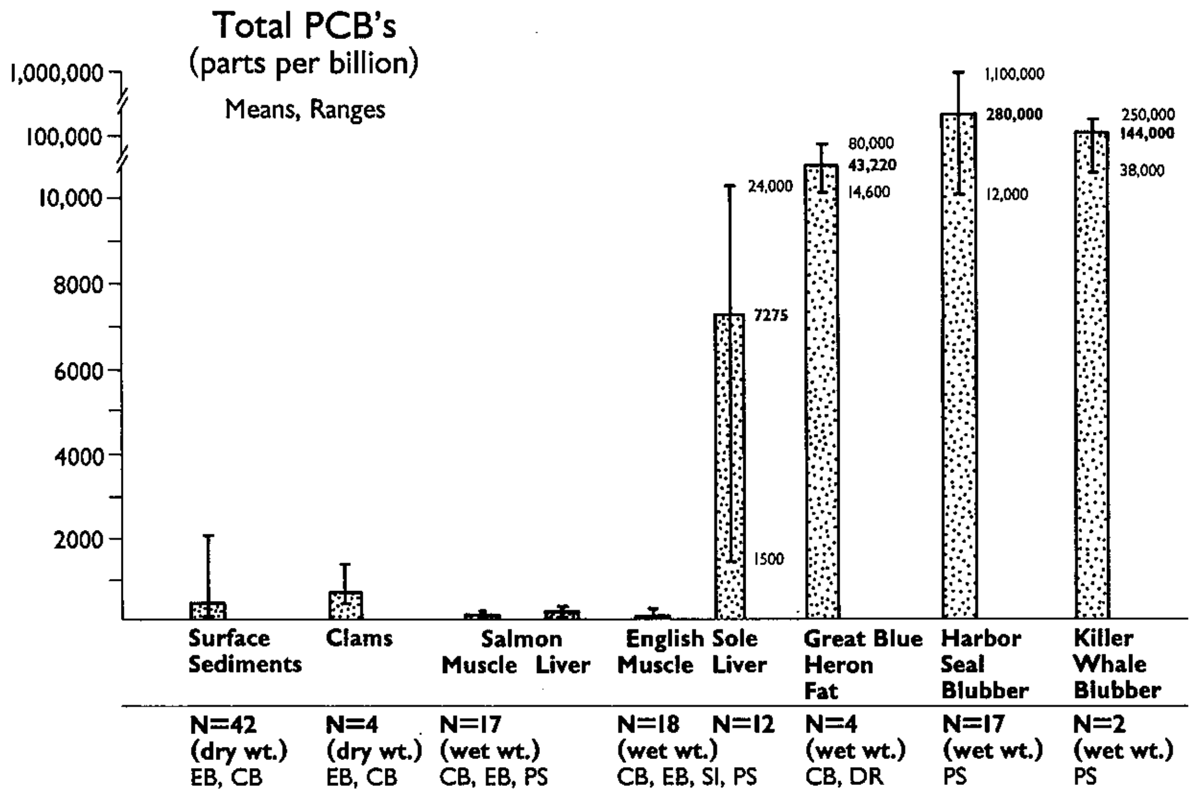

Figure 1. Total PCB concentrations (means and ranges) in surface sediments and selected biological tissues sampled in Elliott Bay (EB), Commencement Bay (CB), Puget Sound Central Basin (PS) for fish, Puget Sound-wide (PS) for seals, Sinclair Inlet (SI), and near the Duwamish River Waterway (DR).

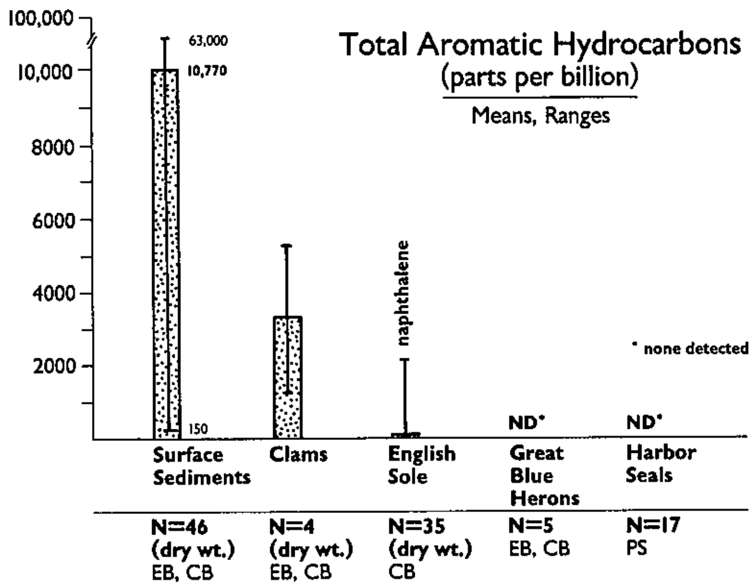

Figure 2. Total aromatic hydrocarbon concentrations (means and ranges) in surface sediments and selected biological tissues sampled in Elliott Bay (EB), Commencement Bay (CB), and Puget Sound (PS). Data for English sole are for livers; those for herons are for breast fat; those for seals are for blubber.

Table 1. Synopsis of water bioassays performed in Puget Sound.

Biological Group	Type of Measurement	Where Observed
Oyster larvae	48-hour acute toxicity bioassay; 50% mortality or 50% abnormal development	Parts of: Port Angeles, Port Gardner, Bellingham Bay Budd Inlet, Totten Inlet, Eld Inlet, Henderson Inlet
Intertidal shellfish beds	Bacterial contamination leading to decertification	Dyes Inlet, Sinclair Inlet, Hammersley Inlet, Budd Inlet, east side of Liberty Bay, part of Port Susan, Burley Lagoon, Minter Bay
	Uncertifiable due to proximity to point sources	East shore of most of central basin, Port Townsend, Eagle Harbor, Port Gamble, Everett Harbor, Bellingham Bay
Flatfish (sole) eggs	Toxicity of sea surface microlayers	Parts of Elliott Bay, Commencement Bay, Port Angeles Harbor

Bacterial contamination. Since shellfish (clams) filter huge volumes of water, tests of these animals can be used to imply water quality conditions. Intertidal shellfish beds are monitored for bacterial contamination. As a result of this monitoring, many parts of the Sound are closed to collection and marketing of clams for commercial sale. However, these areas are not posted as off-limits for recreational clam diggers. This topic is explained more thoroughly in a paper by John Armstrong in this volume.

Microlayer toxicity. Many flatfish such as English sole disperse their eggs into the water to maximize their distribution. The eggs are very buoyant and float to the water's surface where they remain for up to two weeks. Many other species of fish and invertebrates also occur in the upper water column and/or at the surface during part of their development in the Sound. The air-sea boundary at the surface is a film called the microlayer. It is usually about one-half millimeter thick. Toxicants may concentrate there at concentrations several hundreds to two thousand-fold over those of the underlying water.

Laboratory bioassays of microlayer samples from parts of Elliott and Commencement Bays (near Seattle and Tacoma, respectively) showed that some samples were very toxic (lethal) to flatfish eggs. Whereas 74 to 96 percent of the eggs exposed to microlayer samples from a reference area (Sequim Bay) and the Central Basin hatched to live larvae, as few as none hatched following exposure to samples from parts of Elliott and Commencement Bays. Toxicity appears to be highest in samples taken from visible surface slicks contaminated with aromatic hydrocarbons and certain trace metals.

Sediment bioassays.

The five most frequently used sediment bioassays are listed in Table 2. Others involving use of fish larvae, sea urchin larvae, clam larvae, polychaetes, copepods, and shrimp have also been used.

Oyster larvae. Recently the oyster larvae bioassay has been adapted for use in bioassays of sediments. As with the bioassays of water, the tests are performed in a laboratory with samples from the Sound. However, in this case the samples are of the surface sediment. In the oyster larvae bioassays the tests are run with the elutriates of sediment samples. Among the areas tested thus far, samples from parts of Bellingham Bay, inner Everett Harbor, the lower Duwamish Waterway, inner Sinclair Inlet, and the waterways of Commencement Bay have shown significant toxicity. Those from Samish Bay, Port Gardner, outer Elliott Bay, Port Madison and off the west shore of Whidbey Island were much less toxic or were not toxic.

Amphipods. Small shrimp-like animals, called amphipods, have been used in tests of the toxicity of over 600 sediment samples from the Sound. These tests are performed by exposing 20 animals to bulk sediments for 10 days. Figure 3 illustrates the average number of survivors (out of 20) for many

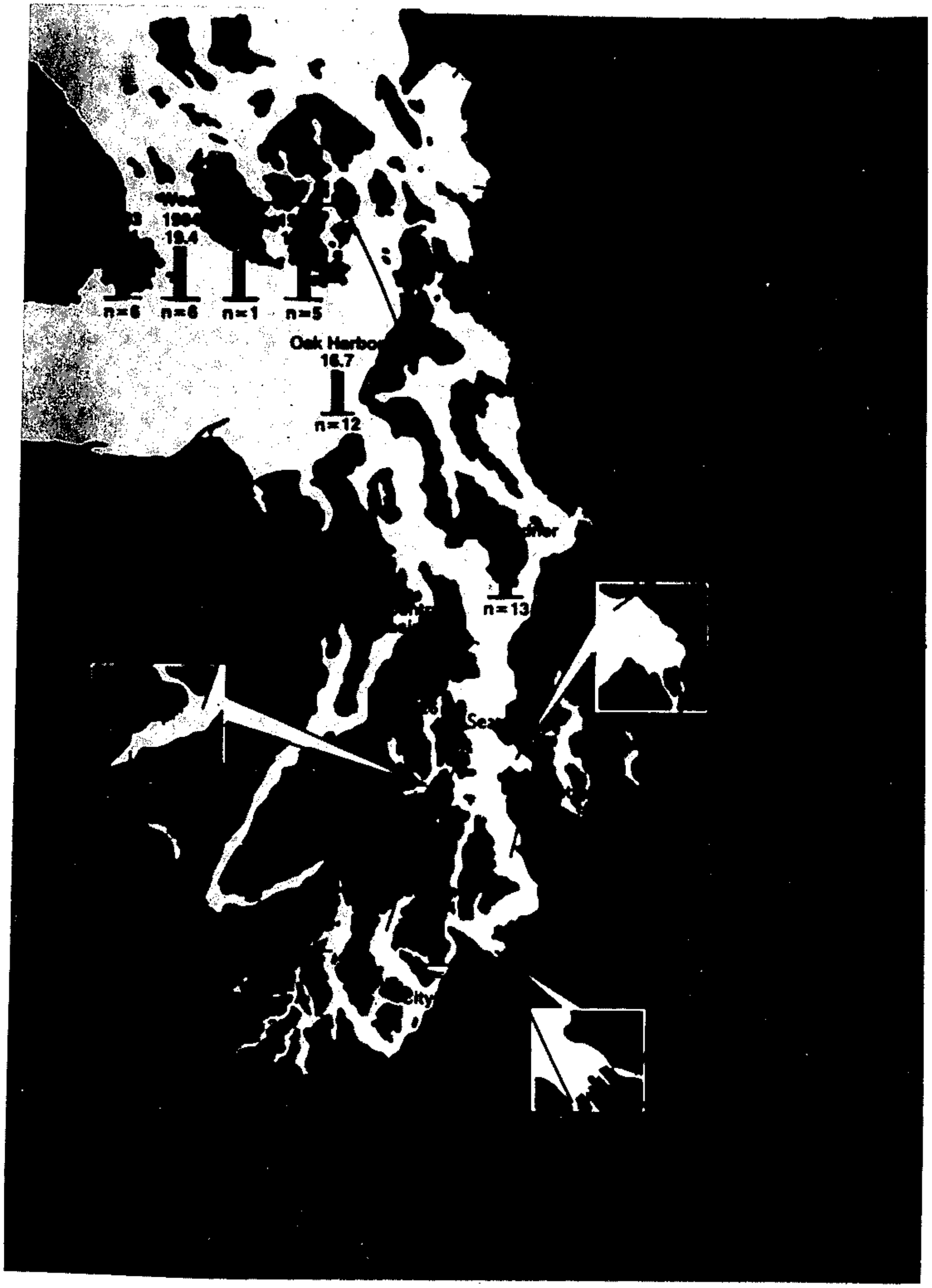

Figure 3. Selected results of sediment bioassays with the amphipod, Rhepoxynius abronius. Average number of survivors (out of 20) after 10 days' exposure to sediment samples from each area.

parts of the Sound. This approach demonstrates the significant differences in the toxicity of sediments from the urban waterways as compared to that of the central basin and rural bays.

Also, samples considered to be toxic are those in which 75% or fewer of 20 amphipods survive after ten days' exposure to the sediments. Areas in which a half or more of the samples were toxic are: off the Denny Way CSO in Elliott Bay, off the mouth of Whatcom Creek Waterway in Bellingham Bay, much of Sinclair Inlet, inner half of Everett Harbor, the lower Duwamish Waterway, Hylebos and City Waterways in Commencement Bay, a part of outer Quilcene Bay, much of Case Inlet, part of Eagle Harbor, off south Bellingham Bay and outer Dabob Bay. Areas in which less than half the samples were toxic include: Sequim Bay, Possession Sound, outer Elliott Bay (including the Four Mile Rock dump site), outer Sinclair Inlet, off the west shore of Whidbey Island, outer Commencement Bay, all of East Passage in the central basin and most of inner Bellingham Bay.

Sediment samples that are toxic to these amphipods are often collected from areas that are most contaminated with toxic chemicals. However, the amphipods used in this bioassay are also apparently sensitive to the amount of organic matter and fine particles in sediments (they normally are found living in sandy habitats). So some of the "toxic" response observed in the bioassays may be due, in part, to these natural properties of sediments that these animals find intolerable.

Table 2. Synopsis of sediment bioassays performed in Puget Sound.

Biological Group/ Media Tested	Type of Measurement	Where Observed
Oyster larvae/ elutriates	96-h mortality and abnormality	Parts of: Tacoma Waterways, Bellingham Bay, Everett Harbor, Duwamish, Sinclair Inlet
Amphipod/bulk sediments	10-d mortality	Parts of: Tacoma Waterways, Elliott Bay, Bellingham Bay, Everett Harbor, Eagle Harbor, Quilcene Bay, Case Inlet
Bacteria (Microtox(R))/ organic extracts	5-min. EC 50 for reduction in bioluminescence	Parts of: Duwamish, Tacoma Waterways, Eagle Harbor
Cultured trout cells/organic extracts	Anaphase aberrations and cytotoxicity	Parts of: Everett Harbor, Bellingham Bay, Elliott Bay, Duwamish, Tacoma Waterways, inner Sinclair Inlet, Birch Bay
Oligochaete/ elutriates	Altered respiration rate	Parts of: Elliott Bay, Tacoma Waterways, Duwamish, off West Point

The results of the sediment bioassays with the bioluminescent bacteria, fish cells and oligochaetes provide subtle end points (as opposed to lethality). They may, in part, be responsive to chemicals that are not acutely toxic. The anaphase aberration test, for example, is known to be responsive to mutagens and promutagens in laboratory tests. These tests have provided results that usually corroborate the results of the acute toxicity bioassays; samples from the same sites were toxic to both. However, as would be expected, there have been differences in the results also.

Biological indicators.

Measures known to be indicative of the exposure of organisms to contaminants have been made with crabs, clams, fish, marine birds, and marine mammals captured or observed in the Sound. Some are listed in Table 3.

Histopathological disorders in fish and crabs. The most widely-used measure has been that of histopathological disorders in bottomfish, especially English sole. Over 300 adult flatfish such as English sole from the bays and harbors of Puget Sound have been studied extensively to determine if they show signs of disorders possibly linked to chemical contaminants. Attention has been specifically focused upon disorders of their livers. A wide variety of disorders have been discovered and identified. Some occur in fish essentially everywhere and probably have nothing to do with pollution. Others, however, seem to only occur in statistically significantly higher frequencies in those portions of the harbors and industrial waterways that are most contaminated.

The highest prevalences of degenerative liver lesions found in areas studied thus far have been in Eagle Harbor, Everett Harbor, the lower Duwamish Waterway, some of the waterways in Commencement Bay, and along the Ruston shore in Commencement Bay. Areas with none or very few fish with these conditions include Budd Inlet, Case Inlet, Carr Inlet, outer Elliott and Commencement Bays and Discovery Bay. Only one fish among about 900 examined from the Central Basin near Des Moines and Pt. Pulley had a tumor-like lesion of the liver. More specific data from these analyses are presented in a paper by Bruce McCain in this volume.

The areas with highest prevalences of lesions are usually those known to be most contaminated with toxic chemicals. However, this co-occurrence does not necessarily mean the liver lesions are caused by the chemicals. They could be caused by or exacerbated by viruses, dietary deficiencies and other stress factors either exclusively or in combination.

Crabs and shrimp from some parts of the Sound have been captured and examined for signs of sublethal disorders. The gills, gut, antennal gland at the base of the antennae, and hepatopancreas (equivalent to our livers) have been studied. About 40% of the crabs caught in the waterways of Commencement Bay had necrosis, or damage, of the hepatopancreas, as compared to 15% to 20% in the Duwamish Waterway and less than 10% in

Table 3. Synopsis of biological indicators of pollution measured in crabs and fish in Puget Sound.

Biological Group	Type of Measurement	Where Observed
Dungeness crab	Necrosis of hepato-pancreas	Parts of: Tacoma Waterways, Duwamish
English sole	High prevalences of liver lesions among adults	Parts of: some Tacoma Waterways, Eagle Harbor, Everett Harbor, Duwamish, Elliott Bay, off the Ruston shore
	High concentrations of PAH metabolites in bile	Parts of: Duwamish, Eagle Harbor, off Clinton, Everett Harbor
	High hepatic aryl hydrocarbon hydroxylase activity	Eagle Harbor, Duwamish
	High prevalences of sister chromatid exchanges in kidney cells	Duwamish
	Lower gonadosomatic index, lower proportion of females completing vitellogenesis, lower fertilization success and lower percent viable hatch	Eagle Harbor, Duwamish

Elliott Bay. However, an opposite trend was observed with midgut necrosis in crabs: about 5% prevalence in the Commencement Bay Waterways, about 10% in the Duwamish and nearly 20% in Elliott Bay. A very small sampling of crabs caught in various rural reference areas had no signs of these disorders.

Fish bile analyses. Analyses of the bile of fish have been performed to determine the concentrations of the metabolites of polynuclear aromatic hydrocarbons that the fish are excreting. These metabolites are not accumulated in the tissues of the fish, and though they may be harmful to the fish, the analytical chemists normally miss them in their routine analyses. Another biochemical test of the exposure of fish to hydrocarbons is that involving the analyses of liver tissue for the activity of detoxifying enzymes. Both of these tests have demonstrated that fish from Eagle Harbor and the Duwamish Waterway had been contaminated significantly with hydrocarbons.

Sister chromatid exchange. A test similar to the anaphase aberration bioassay of sediment extracts has been used in Puget Sound with fish. Sister chromatid exchanges are among the types of chromosome damage that can be caused by mutagens. These mitotic mistakes have been observed in the kidney cells of English sole captured in the Duwamish Waterway at prevalences significantly exceeding those of fish from rural sites.

Impaired reproductive success among fish. Recent studies have provided preliminary evidence that the reproductive success of some English sole in the Sound may be impaired by certain contaminants. This research is continuing.

Health of marine birds. Studies of several species of resident marine birds in 1983 showed that among the many hundreds of chemicals in Puget Sound, only a few (notably PCB, lead, mercury) appeared in the tissues of marine birds. The PCB concentrations in some eggs and adults were very high. Studies completed in 1985 set out to determine if the birds were suffering any major effects. Focus was placed upon tests of reproductive success, histopathological disorders and changes in population size among Glaucous-winged Gulls, Great Blue Herons and Pigeon Guillemots. Clutch size and hatching success were about equal among colonies near the urban bays and in the remote areas. Parasitism was somewhat higher in birds caught near urban bays than in those from remote areas. Gulls from the Duwamish area appeared to have enlarged livers compared to those from elsewhere. The thickness of heron eggshells collected in 1984 had apparently decreased Sound-wide, relative to 1947 values.

So, while some individuals may have shown some subtle signs of stress, the populations, overall, appeared to be doing well. Population sizes of resident Great Blue Herons, Glaucous-winged Gulls and Pigeon Guillemots appeared to be equal to or greater than those recorded historically. However, the possibility exists that some types of effects were occurring that were not measured, since most of the birds that were studied were outwardly apparently healthy.

Health of marine mammals. The Strait of Juan de Fuca/Puget Sound region is home year-round for about 3,000 to 4,000 harbor seals and is visited periodically by other seals, sea lions, porpoises, killer whales, minke whales, and other whales. Since the harbor seals live in the Sound year-round, they have been studied most intensively. As was observed in marine birds, these seals seem to concentrate very few chemicals in their tissues relative to the variety found in the Sound. Concentrations of PCBs in most seals are comparable to those encountered by scientists at many places throughout the world. However, some animals collected in the mid-1970s had relatively high PCB concentrations in their blubber. Studies conducted in 1984 showed that seals from Gertrude Island (south of Tacoma) had equal or higher population growth rates and birth rates, fewer premature births, and roughly equal neonatal deaths of pups as compared to their neighbors on the remote Smith and Protection Islands (reference areas) in the Strait of Juan de Fuca. Ten newly-born pups found dead at Smith Island had discolored or atrophied livers, whereas only two with these conditions were found elsewhere. Some dead pups at Smith Island had symptons of an influenza viral infection. There were no signs of severe degenerative tumors or similar internal disorders among animals examined from South Sound. However, more adult seals had skin lesions near their umbilicus at Gertrude Island than at Smith Island. The significance of these latter findings is not known, but it appears the population is generally doing well.

Table 4. Synopsis of Biological Indicators of pollution measured in marine birds and mammals in Puget Sound.

Biological Group	Type of Measurement	Where Observed
Glaucous-winged gulls	High liver:body weight ratios	Colonies near the Duwamish
Great blue herons	Diminished eggshell thickness relative to 1947	Samish Island, March Point, near the Duwamish, Nisqually Delta
Harbor seals	Premature births, influenza virus, discolored or atrophied livers among pups	Smith Island (reference area)

Population changes.

Changes in the size of populations of various biota have been monitored through surveys in the field, analyses of catches and examination of harvest (landings) records. Populations sizes can be controlled by many powerful nature factors and, in the case of commercially important species, by market conditions and regulations. Nevertheless, the ultimate test of the health of a population of organisms is that of its size. Data for many species, especially those that are harvested, are available. Synopses for one harvested and four non-harvested species are listed in Table 5.

Oysters. The Olympia oyster which was harvested in great numbers (up to 1.6 million pounds in 1914) in the Sound is now grown in only two areas (Little Skookum and Totten Inlets). Less than 100,000 pounds per year are harvested now. The considerable decrease was attributed to the discharges from pulp mills along with severe winter weather in the early 1900s. The population is now making a gradual recovery.

Table 5. Synopsis of selected population changes in Puget Sound biota.

Biological Group	Type of Measurement	Where Observed
Olympia (native) oysters	Harvests reduced from 1.6 million lb./yr. in 1914 to about 100,000 lb./yr in 1984	Historically near pulp mill discharges
Glaucous-winged gulls	Numbers of nesting pairs increased 25x to 600x in past 40 years vs. 4x at Smith Island in past 20 years	Elliott Bay, Commencement Bay colonies
Harbor seals	Population near Tacoma increased from 150 in 1965 to 500 in 1984	Gertrude Island
Harbor porpoise	Population has disappeared	Sound-wide
Killer whale (Orca)	Reduced birth rate, high percent mortality, high percent population change (decrease) relative to other pods	Transient southern pod that frequents Puget Sound

Gulls. The populations of gulls in the Sound have increased dramatically, probably in response to the availability of refuse near the urban areas. Populations of many other marine bird species have fluctuated with varying patterns; none showing signs of any dramatic decreases.

Harbor seals. The size of the harbor seal and sea lion populations have increased rapidly over the past 20 years. Estimates of the harbor seal population at an important haul-out site, Gertrude Island, near Tacoma, reflect this overall trend of increasing numbers of pinnipeds in the Sound (Figure 4). The recent rate of increase at Gertrude Island exceeds the biological reproductive capacity of the population there, indicating that recruitment through emigration has occurred.

Harbor porpoise. The population of harbor porpoise that historically frequented the Sound has disappeared. This species is intolerant of disturbance and probably now avoids the urbanized areas of the Central Basin.

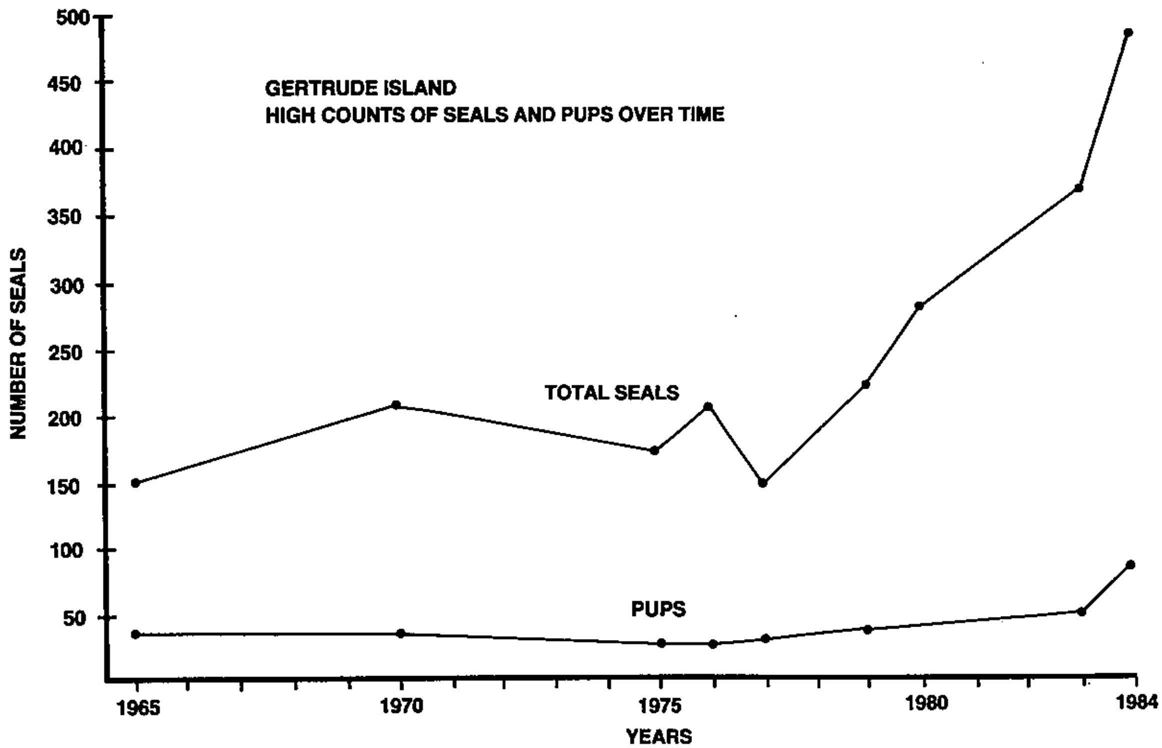

Figure 4. High counts of total harbor seals and pups at Gertrude Island in southern Puget Sound.

Killer whales, gray whales. The size of the pods of killer whales (*Orca*) that visit the Sound most frequently has been increasing over the past 10-15 years, while the membership in the transient pods that visit the region more infrequently has decreased. The size of the gray whale population that passes by the state on its way between Mexico and Alaska has steadily increased since federal protection was implemented. Some dead juvenile whales have been found in the Sound each year for at least the past four years. These deaths are to be expected with an estimated annual rate of calf mortality of 25% among a total population of roughly 17,000 individuals.

Community changes.

Most community-level ecological research in the Sound has been directed to the benthos, those organisms that live in or on the bottom. Three major topical areas have been studied (Table 6).

Soft-bottom benthos. The structure of soft-bottom benthic communities has been assessed in many studies involving several thousand samples. No thorough (statistical) synthesis of all these data has been performed and published thus far. Analyses of some of the data have shown that the benthos in some of the urban bays and waterways are severely impacted. These measures are listed in Table 6. Descriptive and qualitative observations made in the 1950s indicated that many parts of the urban bays such as Everett Harbor and the Tacoma Waterways were abiotic. Abiotic bottom samples are very rarely encountered in the 1980s. The benthos of much of the Central Basin appears to be rich in species, high in biomass and populated with species indicative of a health environment. Spatial and temporal trends in the benthos may be influenced by depth, sediment texture, salinity, and food availability as well as by sources of pollutants.

Table 6. Synopsis of community changes measured in Puget Sound.

Biological Group	Types of Measurements	Where Observed
Soft-bottom benthos	Reduced species diversity and richness, structural changes	Tacoma Waterways, Everett Harbor, Eagle Harbor, Duwamish, inner Elliott Harbor
Epibenthos	Reduced 6-month recruitment on standard-sized artificial surfaces	Tacoma Waterways, lower Duwamish
Selected marine algae	Reduced species richness and growth rates	Near sewage treatment plants

Epibenthic recruitment. Successional patterns and species richness in epibenthic assemblages colonizing artificial substrates indicate that conditions in the Duwamish and Commencement Bay Waterways are significantly different from those of outer Elliott Bay (Seacrest) and relatively rural areas (Port Washington Narrows, Manchester). Figure 5 demonstrates the number of species colonizing these suspended substrates after 6 months exposure in seven areas. Though the salinity was similar at all sites, the freshwater flow in the Duwamish may have been partly responsible for the low number of species observed there. The numbers of species in the Commencement Bay Waterway sites were lower than those found in the other (reference) areas.

Marine algae. Marine algal species comprise a very important component of intertidal and subtidal communities in the Sound. They provide food and shelter directly to certain animals. They provide detritus for many food webs that support important fish and invertebrates. Some of the large kelps are harvested and consumed by people. Some species are very sensitive to changes in wave exposure, water clarity, and concentrations of toxicants in the water. Alterations in the algal components of epibenthic communities thought to not be related to natural factors have been observed near the sewage treatment plants in the Sound.

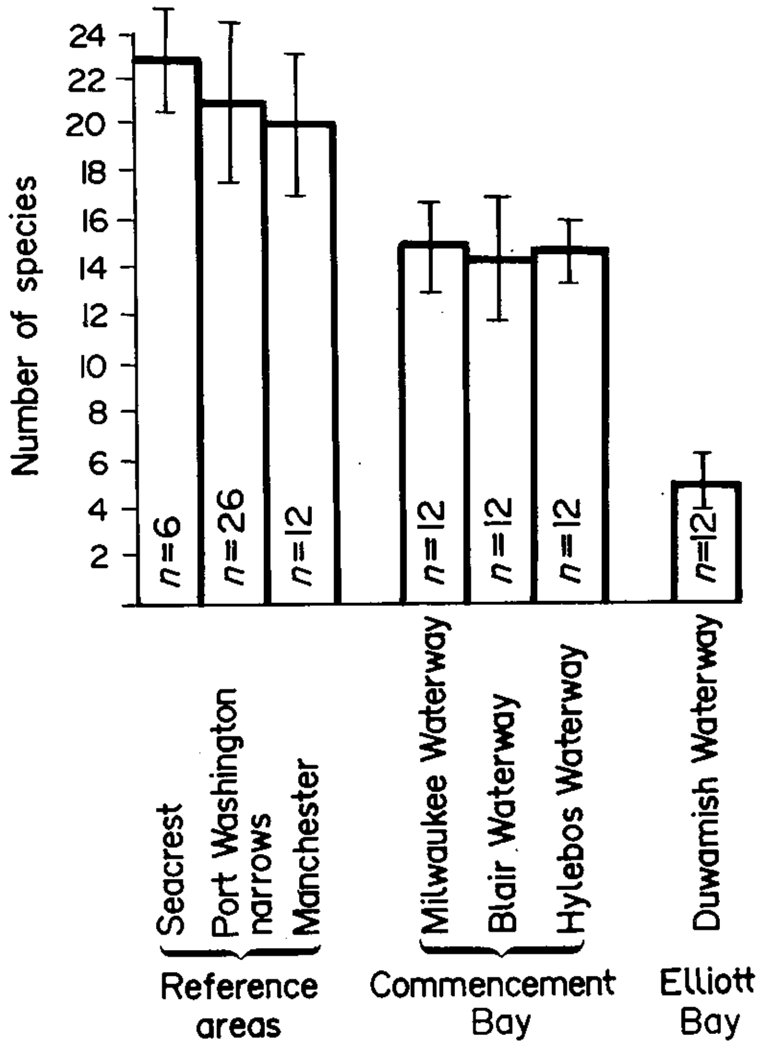

Figure 5. Numbers of species that colonized 20.3 cm x 20.3 cm horizontal substrates over 6-month periods at seven sites in Puget Sound.

Summary

The concentrations of toxic chemicals are clearly most elevated in the sediments of parts of the industrial harbors and waterways near urban centers of the region. Measures of biological stress usually indicate the biota are most affected in these same areas. There are many signs of subtle sublethal effects, e.g., the liver lesions in flatfish, and the enlarged livers among gulls.

There are relatively fewer signs of lethal conditions. Massive fish kills are relatively infrequent as compared to conditions in the 1950s. Few sediment samples from a few small areas have no marine life in them, whereas in the 1950s major parts of some harbors had no life at all. Lethal conditions are mainly observed in bioassays performed with water, sediment and microlayer samples. These tests are often positive (toxic) in samples from the contaminated harbors and waterways and usually not toxic in samples from rural areas or the main basin of the Sound. Finally, the effects observed thus far are mainly restricted to those among invertebrates and fish. Recent studies have shown that no major adverse effects apparently are occurring among the resident marine birds and mammals, though more research should be performed to determine if some subtle changes are occurring.

A very important byproduct of the assessment of the environmental quality of the Sound has been the development and refinement of assessment methods. Many of these methods have involved biological tests performed synoptically with chemical analyses. Some methods initially used in Puget Sound studies are now being performed elsewhere, significantly, in the National Status and Trends Program. Chemical analyses of sediments and bottomfish, histopathological analyses of internal organs of bottomfish and bile metabolite analyses of bottomfish are being performed at over 50 sites along the Pacific, Atlantic, and Gulf coasts.

In addition, the Sediment Quality Triad (Long and Chapman, 1986) was developed in studies performed in Puget Sound. The Triad consists of measures of sediment contamination, toxicity and infaunal community structure. It has been and is being used to develop strong evidence of the relative degrees of pollution of sediments.

While marine scientists have made great gains in our knowledge of the biological effects of pollution in Puget Sound, large gaps in our data still exist. First, the geographic extent of the observed effects is not fully documented. Most of the large bays and harbors that would likely be contaminated, and therefore demonstrate adverse effects, have been studied to some degree. Many other small bays and much of the open waters of Puget Sound basin have yet to be tested fully. Knowledge of the geographic extent of problem areas is needed so remedial actions can be focused upon those portions of the region that most need help. A few studies are either underway or recently completed to fill in some of these gaps. More are being planned.

Second, there is precious little information on how the conditions of the Sound are changing with time. Are environmental conditions getting better or worse? The urgency to take action now in areas that are getting worse exceeds that for areas that are getting better due to existing clean-up efforts. Plans for coordinating and augmenting existing monitoring programs are being formulated.

Finally, we have very little information as to which chemicals or groups of chemicals are causing the observed effects. More and more circumstantial evidence suggests the aromatic hydrocarbons are involved with some types of effects. Without firm knowledge however, the regulatory agencies must make educated guesses concerning which chemicals are the "bad actors" that must be removed from the Sound.

References

Long, E. R. and R. M Chapman. 1986. A sediment quality triad: Measures of sediment contamination, toxicity, and infaunal community composition in Puget Sound. Mar. Pollu. Bull. 16(10):405-415.

BACTERIAL CONTAMINATION OF SHELLFISH IN PUGET SOUND, WASHINGTON - A GROWING CONCERN

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Overview

During the 1940's, the late Seattle restaurateur Ivar Haglund popularized the "Ballad of the Early Settler," a tale of a pioneer who failed to find his fortune in the Alaska gold rush, and returned to the waters of Puget Sound in western Washington to live a happy life surrounded by "acres of clams." Indeed clams, oysters and other shellfish have long been favorite food for the inhabitants of Puget Sound because they were free for the taking. Long before European explorers sailed into the inland waters of Puget Sound, coastal Indian tribes gathered and used its abundant shellfish resources for food and trade. Early western Washington settlers had a maxim about the bounty to be found in the local tidelands-"When the tide is out, the table is set." Shellfish were widespread throughout the Sound, were accessible, and were considered public property. Anyone within reach of the Sound's beaches could dig a bucketful of clams or a bushel of oysters in short order on a low tide and provide fresh seafood at suppertime.

Today, Puget Sound continues to support a rich and varied assemblage of economically important marine shellfish, many of which, such as the Olympia oyster *Ostrea lurida*, are native species. To be able to maintain those aquatic species, and to harvest them without undue restrictions,remain as key elements in the public's perception of the quality of life in our region. Therefore, maintenance of the quality of the Puget Sound environment is closely linked to the social and cultural values which are attached to shellfish resources.

Environmental quality in Puget Sound is, in many respects, much better than in other estuaries in the United States. However, shellfish harvests from a number of the Sound's most productive waters are being banned, restricted, or threatened because of high levels of bacteria (and potentially pathogens), coming from sewage treatment plants, improperly placed or failed septic tank systems, recreational boats and other vessels, hobby farms, and stormwater runoff. Toxic wastes have also been implicated in declines and contamination of shellfish stocks. Paralytic shellfish poisoning (PSP) also remains as a significant water quality factor affecting shellfish in Puget Sound. In the discussion that follows, we will review the extent, impact and treatment of each of these problems in greater detail, but we'll focus on bacterial contamination.

Shellfish-Distribution, Fisheries and Farming

This paper began with a brief look at the past. The present production of bivalve molluscs includes the aquaculture of oysters, clams and mussels, and the capture fishery for clams. Several other shellfish, such as scallops, make up a minor part of the present harvests. In addition, there are many bivalve clams not taken in the commercial or recreational fisheries, such as the tiny but abundant Macoma balthica, which are eaten by valuable fish and bird species. Puget Sound bivalve shellfish are harvested from intertidal to shallow subtidal (i.e., less than 20 meters) depths throughout Puget Sound (Figure 1).

The production and harvest of shellfish in Puget Sound is carried out on both public and private lands. While all subtidal lands and overlying waters are managed and controlled by state or federal agencies, much of the tidelands are under private ownership. This is a result of legislation passed in the late 1800's to encourage the development of an oyster industry. The development of new culture and harvest methods and improved management have opened up additional areas and resources in Puget Sound. For example, in the subtidal areas, geoduck clams (Panope generosa) weighing up to 20 pounds each, are now hand-harvested by divers and subtidal hardshell clams are obtained using mechanical hydraulic harvesting machines. Soft-shelled clams (Mya arenaria) are suffiently abundant in the intertidal areas of some embayments to warrant harvest. In addition, new advancements in artifically seeding oyster and clam beds have allowed an increase and stability in yields beyond what is possible with recruitment from natural setting. Both the capture fishery, or wildstock harvest of shellfish, and aquaculture or aquatic farming, have benefitted from these changes.

The farm production of oysters in Puget Sound has not varied greatly since the 1950's, and now accounts for about 50% of the total state production. The total production of Pacific oysters in Puget Sound is 3 million pounds of oyster meats, or about 6% of the total U.S oyster production. Most oysters are farmed on tidelands in the highly productive small bays and inlets of south Puget Sound.

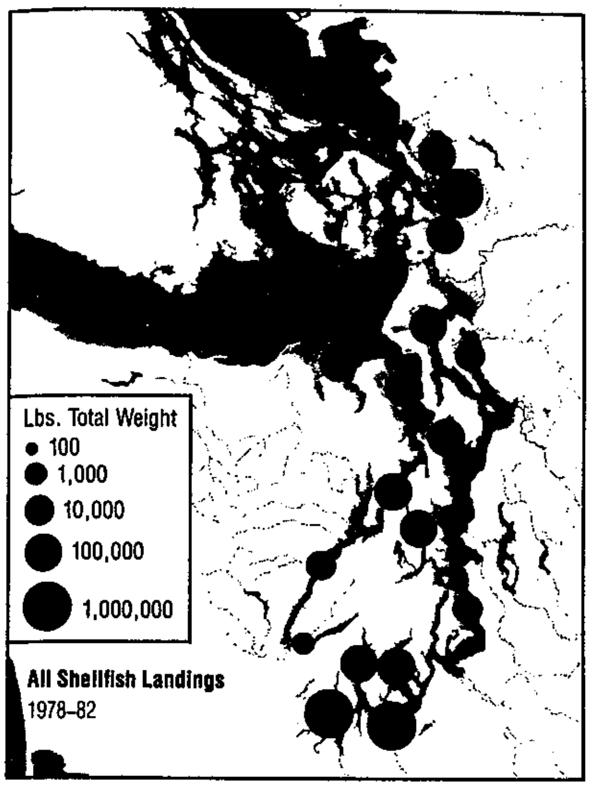

Figure 1. Distribution of shellfish landings in Puget Sound, 1978-82. Each circle depicts average annual landings from the value given up to the next highest value.

The intertidal culture of clams is also carried out by farmers who own the beds or lease tidelands from the state. Most of the farms are small, not exceeding 50,000 pounds per year--with a total annual harvest of 2 to 3 million pounds. Individuals or families with beachfront property may supply commercial farms with clams on a part-time basis, especially in the summer.

Puget Sound supports substantial subtidal clam fisheries. All harvesting operations occur on leased lands managed and controlled by the state. The geoduck clam fishery, which began in the 1970's, accounts for the majority of the present 5 million pound per year harvest.

Finally, within the last 10 years, the raft culture of blue mussels (*Mytilus edulis*) in subtidal and intertidal waters by farmers in central Puget Sound has begun to make a small but growing contribution to the state shellfish production.

Types and Sources of Contamination

Shellfish that strain the seawater for all or a portion of their food, such as clams, oysters, and mussels are very efficient feeders, and can readily remove from the water small particles, such as bacteria (or bacteria-laden silts). When bacteria, or particles containing toxic chemicals, are ingested by the shellfish, the edible shellfish meats become contaminated. Numerous areas throughout Puget Sound have been closed to commercial shellfishing (Table 1 and Figure 2), with the vast majority of these closures being related to bacterial contamination.

Bacteria

Water that has been polluted by human sewage is hazardous because several diseases are transmitted through human wastes, such as typhoid, cholera, dysentary and hepatitus. Usually, disease causing viruses are not measured directly in the water. Instead, the numbers of *indicator* bacteria, i.e., total coliform, fecal coliform, and fecal streptococci, are measured. These bacteria are known as *indicator organisms* because they are supposed to indicate the presence of sewage and ideally are correlated with the number of pathogens in a water sample. All commercial shellfish growning areas are monitored for these indicator organisms by the Washington Department of Social and Health Services (DSHS).

TABLE 1. Areas within Puget Sound where the commercial harvest of shellfish has been closed or restricted due to bacterial contamination.

Date	Location	Cause
Decertified[1]		
1950s	Dyes Inlet-all	Bremerton STP*
1950s	Sinclair Inlet-all	Bremerton STP
1950s**	Oakland Bay/Hammersly Inlet-in the vicinity of Shelton	Shelton STP, Mill
1950s	Budd Inlet	STP, Deschutes River
1960s	Liberty Bay-east side, near Poulsbo	Poulsbo STP, Marina
1968	Port Susan-about 1/3 of the tideflats near the Stillaguamish River	Dairy runoff into the Stillaguamish River, STPs
1981	Burley Lagoon-all	Nonpoint sources
1982	Minter Bay-all	Nonpoint sources
1985	Quilcene Bay around streams at the head of the bay	Nonpoint sources
1985	Henderson Inlet-lower quarter of Inlet	Nonpoint sources

Table I (continued)

Date	Location	Cause
Conditionally Approved		
1982	Eld Inlet-lower quarter of inlet	Nonpoint sources
1983	Penn Cove-portion of north shore	STP, or nonpoint sources
Uncertifiable* **		
Eastern shore of Puget Sound from Tacoma to Edmonds		STPs, industrial outfalls
Hartstene Island, northern tip		STP
Port Townsend		STP
Winslow		STP
Appletree Cove, near Kingston		Sewage outfall
Port Gamble		Sewage outfall
Everett		STP, industry, nonpoint
sources		
Bellingham Bay		STP, mills, nonpoint sources

Table I (continued)

1/ These classifications are described later in this paper under the existing shellfish protection program of the Washington Department of Social and Health Services (DSHS).

*   Sewage Treatment Plant

**   Decertified area reduced in 1980 due to installation of secondary treatment

***   Based on review of geoduck beds for lease suitability by the Washington Department of Fisheries and DSHS.

Sources: Department of Ecology, 1984, "Shellfish Protection Strategy;" and personal communication with DSHS staff.

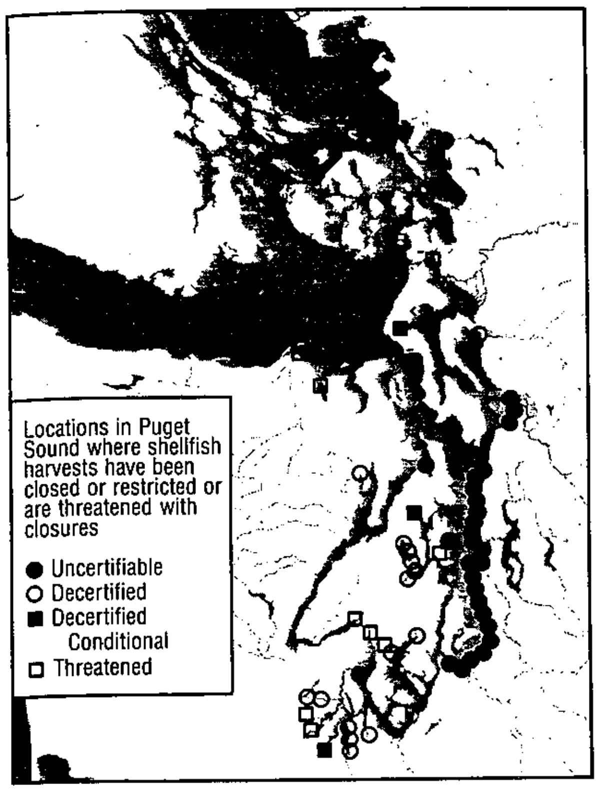

Figure 2. Locations of areas within Puget Sound where commercial shellfish harvest has been closed or restricted due to bacterial contamination. These areas are commonly associated with urban centers, marinas, and sewage outfalls.

Sewage treatment plant (STP) outfalls and the encroachment of large scale development upstream of shellfish beds have, historically, been major factors responsible for the closure of shellfish growing and harvest areas. Any time a STP is constructed with a marine outfall, all waters inside a circle having a radius of one-half mile from the outfall point are closed to commercial harvest of shellfish by the DSHS. The closed area may be larger for particularly large outfalls or vary in shape when water current studies indicate sewage movement along shore.

In addition to point sources (i.e. STPs and combined sewer overflows) of bacterial inputs to Puget Sound, recent water quality surveys indicate that nonpoint source contamination is also an important contributing factor. All storm runoff contains a variety of bacteria and other substances that can be carried to the shellfish via streams and overland flow. Wastes from failing septic systems, dairy farms and "hobby" farms are key sources in more rural areas. In a study that was completed in 1982 on New York's Long Island Sound,the predominant cause for the withholding of certification for about 25% of the shellfish beds was the result of coliform bacteria discharged to the bays by urban stormwater runoff. In some areas, the level of indicator organisms can be high at all times, even when there may be no obvious source of bacteria. Unfortunately, there is no clear answer to the question of health risk of these ubiquitous bacteria in stormwater. Closures of areas due to nonpoint source contamination does not necessarily mean the shellfish are unfit for human assumption; but it does prohibit commercial harvest and sales.

In Puget Sound, urban growth and the resultant discharges from sewage treatment plants have historically had the most significant impact on oyster culture. As was discussed above, shellfish growing areas are carefully monitored to ensure oysters are grown in the highest quality waters. Grounds are usually closed to commercial harvest near marinas, heavily used boat- traffic areas, sewage discharges, and urban areas--and increased development near oyster growing areas places an economic hardship on the oyster growers. Fortunately the most intense urbanization of Puget Sound developed apart from the richest culture areas, thus allowing some of this traditional industry to escape most of the pollution problems. Still, as is shown in Table 1, large areas of valuable intertidal lands are now closed to harvest.

The pattern of the most recent closures strongly suggest that contamination from overland and stormwater runoff in lightly to moderately developed areas is now the most serious threat to the areas used for the culture of oysters and other shellfish. For example, located on the fringes of the cities of Tacoma and Olympia in Central and South Puget Sound, are four important oyster growning areas-Minter Bay, Burley Lagoon, and Henderson and Eld Inlets-that have been decertified or conditionally approved for commercial harvest. These are relatively rural areas that have recently undergone considerable development, induced, in part, by the move to a more charming and less urbanized "rural" lifestyle. This increased human influx has resulted in greater use of onsite waste disposal (i.e. septic tanks, often in poor soils), increased small scale animal keeping (or "hobby farming"), increased development near shorelines and creeks, and more household pets - all potential sources of bacteria which may reach Puget Sound.

The problems of stormwater runoff must not be regarded lightly, because of the potential for wide-scale contamination and the closure of oyster and other shellfish growing areas in Puget Sound. This has been clearly illustrated in a 1984 study conducted by Thurston County in Southern Puget Sound. Particular emphasis in this study was placed on sampling the streams and tributary waters and stormwater drainages to Henderson and Eld Inlets. Samples taken at various locations in a stream draining a large Henderson Inlet storm sewer system exhibited a significant increase in indicator bacteria occurring downstream from the storm sewer outfall. The storm sewer drained land subjected to diverse uses ranging from low density residential to industrial. Smaller culverts, retention ponds, and roadways draining into streams that were tributary to important oyster beds in Henderson Inlet also had very high indicator bacteria levels. Creeks and culverts in the more rural Eld Inlet watershed receive drainage from forested areas, pasture lands, low density residential areas and roadways. Fecal coliform levels in most of the creeks were low to moderate. However,a few of the streams, culverts and drainage ditches in areas with numerous "hobby farms" had bacteria levels as high as those recorded on the more populated areas of Henderson Inlet.

The numerous and diffuse nature of these so-called "nonpoint" sources makes them very difficult to control; therefore, a considerable amount of time and effort must be expended to understand and resolve the problem. It takes the cooperation of landowners and a long-term committment by local, state and federal jurisdictions. There is no easy and set way to reduce the coliform bacteria in runoff. Rather a combination of methods must be employed. These include storage of runoff in ponds, providing areas where the water can infiltrate or seep back into the ground, and various institutional measures such as animal control ordinances, stream corridor preservation and various development ordinances.

The success of these measures in Puget Sound still remains to be assessed. For example, an extensive cleanup of nonpoint sources of contamination was made last year in the drainages surrounding the productive, but closed, oyster beds of Burley Lagoon and Minter Bay. However, a recent water quality and shellfish survey by the DSHS was unable to detect a measurable decline in the coliform levels at any location in the two bays. Because the cleanup effort was intended to be a model for nonpoint source control efforts in Puget Sound, the lack of improvement is of great concern. Additional sampling will be carried out through the winter and summer of 1987.

Closures of commercial shellfish beds prohibit the sale of oysters, clams and others bivalve crops from those areas. However, the producer may be able to "relay" or "depurate" his harvest. Relaying--the transfer of contaminated shellfish to certified waters--is practiced by at least one oyster farmer in Puget Sound. Depuration--the on-site clearance of bacteria in a closed purified sea water system--is presently not allowed in the state; however, it is a common practice in several East Coast states. Relaying is feasible only if the producers have access to certified grounds. It is an expensive process, not entirely acceptable in today's fastidious market where product quality is a foremost consideration. Therefore, resolution of bacterial contamination sources, rather than relying on product treatment, offers the greatest level of product quality, consumer acceptance, and economic return.

Paralytic shellfish poisoning (PSP)

For many years, it was known that humans could suffer poisoning (and in some cases die) when they had eaten clams, mussels and other bivalve shellfish. It was not until the late 1920's that what is now termed "paralytic shellfish poisoning" was determined to be caused by large, seasonal concentrations of a toxic, free-swimming, marine dinoflagellate called Gonyaulax catenella, which when ingested by filter-feeding molluscs, resulted in accumulation of toxins in the body of the shellfish.

Until 1978 PSP contamination was confined largely to sporadic outbreaks in the Strait of Juan de Fuca, and although Gonyaulax catenella was present in Puget Sound, it did not often occur in numbers sufficient to produce toxicity from shellfish consumption. However, in 1978 there was a major outbreak of PSP affecting shellfish as far south as central Puget Sound. Blue mussels and butter clams (Saxidomus giganteus) were the most severely affected, and most intertidal commercial and sport clam digging was banned for several months. Since 1978, annual outbreaks ("blooms") of varying severity of Gonyaulax have resulted in restrictions on the harvest of clams, mussels, and other shellfish at numerous locations in north and central Puget Sound. Although these restrictions have not had a major impact on the commercial harvests, there is concern that PSP could spread to the numerous commercial growing areas of south Puget Sound. The cause of the outbreaks is unknown, and there is no evidence, as yet, to link them to any man-induced factor.

Toxic chemicals

Numerous toxic chemicals occur in the sediments and marine organisms in Puget Sound. These toxic chemicals come from diverse sources such as: point and nonpoint discharges, storm runoff, accidental spills and atmospheric deposition. The results of recent studies indicate that several of these chemicals occur in Puget Sound shellfish, although the available information on bivalves is very limited. Essentially all surveys of toxic chemicals in bivalve shellfish tissues from the Sound indicate that tissue chemical levels are below the few chemical specific action levels established by the Food and Drug Administration. However, most chemicals detected in the tissues have never been assigned action levels. EPA is presently attempting to determine the health risks associated with consuming small quantities of toxic chemicals over long periods of time. These "chemical specific" risk assessments should help put the health concerns associated with these various chemicals in better perspective in the near future.

Existing Shellfish Protection Programs

Several federal and state agencies, as well as local health departments, play major roles in managing and protecting the shellfish resources of Puget Sound. The roles these governmental agencies presently play in managing shellfish are briefly described below.

Washington Department of Social and Health Services (DSHS)

The goal of the DSHS shellfish program is to prevent shellfish-borne disease outbreaks. While discussions here deal mainly with bacterial or viral disease outbreaks, DSHS also has a successful program of guarding the shellfish consumer from health problems associated with paralytic shellfish poisoning (PSP).

DSHS samples commercial shellfish beds to ensure that fecal coliform bacteria levels are at or below established maximum permissible levels. The fecal coliform bacteria, while not harmful themselves, are indicators that are associated with viral and bacterial pathogens that can cause infectious illnesses. The Washington State regulations addressing fecal coliform bacteria reflect, as do those of most other states, the National

Shellfish Sanitation Program Guidelines issued in 1965 and revised in 1986. The maximum permissable fecal coliform bacteria levels are:

1. 230 organisms per 100 g of shellfish tissue, and

2. A median of 14 organisms per 100 ml, with not more than 10 percent of the samples exceeding 43 per 100 ml, in the water.

The DSHS sampling of commercial shellfish beds has been done in accordance with the National Shellfish Sanitation Program Guidelines. This sampling has been fairly infrequent and irregular in its coverage of shellfish growing areas. However, these guidelines have recently been revised and will require at least yearly sampling in "approved" areas (approved for commercial harvest, bacterial standards are met) and monthly sampling in "conditionally approved" areas (areas which are impacted by predictable pollution events such as sewage treatment plant failure or rainfall of a certain magnitude). Additional DSHS classifications for shellfish growing areas include "decertified" (areas that have once been approved for production and subsequently found to be contaminated) and "uncertifiable" (where commercial production has not previously occurred, but where certification would not be feasible due to the existence of numerous sources of pollution). DSHS does no routine monitoring, classifying, or posting of recreational shellfishing areas.

DSHS (with funding from Region 10 of the Environmental Protection Agency) is presently sampling and evaluating bacterial and toxic chemical contamination of clams at 25 recreational beaches throughout Puget Sound. This one-year study will be completed in 1987 and is the most extensive recreational shellfish survey ever initiated in Puget Sound.

The DSHS shellfish program also includes patrolling areas which are closed to commercial shellfishing, conducting marketplace bacterial surveys, and managing a PSP monitoring program. As part of the PSP monitoring program, local health jurisdictions collect samples from recreational beaches, and the commercial shellfish industry is required to submit samples from commercial growing areas. DSHS conducts the PSP tests for all samples which are submitted by the county health departments and the shellfish industry.

Washington Department of Ecology (Ecology)

Ecology, as the state water quality agency, has the responsibility to maintain and/or restore adequate water quality to protect shellfish beds. Adequate water quality may be maintained through the following Ecology programs:

(1) Water Quality Standards - maximum permissible standards for coliform and other variables have been established for all waters,

(2) NPDES permits - effluent standards are established for point discharges, and shellfish resources are considered as proposed discharges are evaluated. In addition, Ecology conducts a number of intensive surveys each year to determine the effect of discharges on the receiving waters and to investigate other priority or emergency water quality problems, and

(3) Shellfish protection grants are available to counties and other local governments to identify and correct water quality problems.

Washington Department of Fisheries (WDF)

WDF has the responsibility for managing shellfish resources in Puget Sound to assure a sustainable resource for future generations. WDF does very little monitoring to determine either the condition or abundance of bivalves on Puget Sound beaches, and does no routine bacterial or toxics monitoring.

Washington Department of Natural Resources (DNR)

DNR leases and manages state-owned land for commercial shellfishing and various types of aquaculture. DNR does no routine bacterial or toxics monitoring of the shellfish.

Local governments

Local governments (generally counties) are responsible for sampling recreational shellfish beaches for bacterial and PSP contamination and closing these beaches if a health hazard is found. To date, the counties appear to be sampling their beaches adequately for PSP contamination, but sampling for bacterial contamination, with a few exceptions, has been very infrequent due to staff/resources limitations.

Local governments also play a key role in controlling nonpoint source pollution. Some of these nonpoint sources of bacterial contamination include onsite septic systems, stormwater, marinas, animal keeping practices, and various other land use activities.

U.S. Food and Drug Administration (FDA)

FDA provides technical shellfish protection assistance to the state. This includes consultation and technical assistance, an annual review of the state's shellfish program, training on shellfish-related issues and occasional help with shellfish sample collection. FDA also publishes monthly a list of all certified shellfish dealers (those whose growing areas and facilities meet bacterial standards and who are authorized to make interstate shipments) in the country. In addition, FDA occasionally samples commercial growing areas for toxic chemicals and/or fecal coliform bacteria.

National Oceanic and Atmospheric Administration (NOAA)

As part of its Status and Trends Program, NOAA has initiated the sampling of toxic chemicals in blue mussels (*Mytilus edulis*) from seven locations in Puget Sound.

U.S. Coast Guard

The Coast Guard is responsible for regulating the discharge of sewage from boats. However, due to limited staff, there are essentially no Coast Guard checks of Puget Sound boaters to ensure that boats are equipped with approved marine sanitations devices.

Proposed Changes in Existing Shellfish Programs

The Puget Sound Water Quality Authority (PSWQA), a recently formed (1985) Washington State agency, adopted a water quality management plan for the Sound in December, 1986, which will change the way several state agencies are carrying out their water quality and shellfish responsibilities. The PSWQA plan, goals, and agency program changes which involve shellfish, are discussed below.

The Puget Sound plan and goals regarding shellfish are very broad. These goals include protecting shellfish consumers from pathogens and other contaminants, including toxicants, maintaining and enhancing shellfish abundance, reopening closed/correctable* commercial shellfish beds and controlling sources of pollution to prevent additional closures of commercial and recreational beds.

The plan affects mainly the DSHS, Ecology and local governments. It calls for greater coordination and planning among these and other agencies regarding shellfish resources and for reducing nonpoint source pollution. Ecology will continue to provide grants to local governmentsfor commercial shellfish protection as part of the nonpoint program, and DSHS will dramatically increase its commercial shellfish bed fecal coliform bacteria sampling program. In addition, DSHS will establish an ongoing program, based on the recent EPA-DSHS one-year study, to test for toxicants at both commercial and recreational beds. Beds which exceed FDA or other regionally accepted toxics action levels will be closed and re-evaluated. Additionally, DSHS, Ecology, and other state and local agencies will jointly develop a program to protect recreational shellfish beds from pollution. This program includes testing the clams and water for fecal coliform bacteria and closing and posting areas which do not meet commercial bed standards. These agencies will also initiate restoration and protection projects in contaminated or threatened areas.

The PSWQA plan's nonpoint program is closely linked to its shellfish program and includes as its goal the reopening of certain commercial shellfish beds. This is to be achieved by local governments, with oversight by Ecology and the PSWQA, developing watershed action plans for controlling nonpoint source pollution. The local governments are responsible for addressing septic systems, animal keeping and pasture management practices as well as stormwater and other locally important nonpoint sources. These plans may seek voluntary or mandatory (depending on the preferences of the local government) compliance with programs to reduce nonpoint pollution to Puget Sound. Ecology and the PSWQA will audit these action plans every two years for the effectiveness of their nonpoint source reduction programs. If some of these programs are not effective in reducing nonpoint pollution, the PSWQA may include

*Closed/correctable beds are those growing areas where Ecology has determined that improvements are possible; the term is applied to areas that are not intensively developed, do not have major or numerous sewage discharges, and where application of Ecology's shellfish protection program could lead to reopening beds.

prescriptive standards to control nonpoint sources in its 1989 Puget Sound Water Quality Management Plan.

Finally, the Puget Sound plan requires the Washington State Department of Parks and Recreation to obtain a Memorandum of Understanding with the U.S. Coast Guard to permit state inspection of recreational vessels and other uninspected vessels under 65 feet in length for approved marine sanitation devices and to develop an inspection program, coordinated with a boaters' education program, focused on protecting shallow bays and other sensitive areas.

Conclusion

The capture fisherman and aquatic farmer are both dependent on clean water, providing economic incentives to preserve and improve water quality. Aquatic farmering is also uniquely dependent on the proper maintenance and enforcement of regional water quality standards. Problems caused by contamination of shellfish beds all too often can be traced to non-enforcement of existing laws, lax or improper application of existing land use codes, little or no inspection of on-site septic system, and a lack of proper disinfection at sewage treatment plants.

Bacterial contamination is severely limiting our use of the bivalve shellfish resource in Puget Sound. Large areas are closed to commercial harvest and an adequate bacterial and toxicant monitoring program would undoubtably close numerous recreational shellfish beds (and perhaps additional commercial beds as well). Some microbiologists believe that viral and bacterial diseases from the waters or shellfish of Puget Sound are rare only because there is relatively little swimming in Puget Sound and because few shellfish species from the Sound are consumed without cooking.

The PSWQA plan calls for major changes in sampling for bacteria and toxicants in shellfish from commercial and recreational harvest areas in the Sound. In addition, local and state governmental agencies have been asked to address and solve the nonpoint pollution problems which bring bacteria and toxics to the shellfish harvest areas. At this time, it's been left to the local governments to seek voluntary or mandatory compliance with issues like: insuring septic tanks are functioning properly, keeping farm animal wastes out of streams, reducing stormwater runoff, and reducing bacterial contamination from boats in marinas.

If the local governments are not progressing satisfactorily in reducing the nonpoint sources of pollution between 1987 and 1989, the

PSWQA has the option of requiring mandatory changes in the land use activities which are affecting Puget Sound shellfish. Will the local governments' propose voluntary or mandatory means to reducing the bacterial and viral pathogen loading to Puget Sound? And will these means work? And finally, will the state legislature provide the money required for the proposed monitoring and grant programs? These and other important issues concerning the future of recreational and commercial shellfish harvesting and Puget Sound water quality will be determined in the next few years, beginning with the level of funding that the 1987 session of Washington State legislature is willing to provide for plan implementation.

Acknowledgements

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PUGET SOUND SEDIMENTS: A SOURCE AND SINK OF CONTAMINANTS

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Introduction

Why be concerned with Puget Sound sediments? In general, they are some of the cleanest sediments found in estuaries of the east and west coasts of the United States. Nevertheless, highly contaminated sediments are found in some parts of Puget Sound, including the most toxic marine sediment ever tested (Swartz et al., in preparation). Concern over the potential biological effects of these sediments has prompted extensive studies by the National Oceanic and Atmospheric Agency (NOAA), U.S. Environmental Protection Agency (EPA), Washington Department of Ecology, the University of Washington (UW), the Municipality of Metropolitan Seattle (Metro), and other agencies. The wide concentration range and diversity in contamination has made Puget Sound especially useful for studying biological effects of sediment contamination.

Puget Sound sediments are a sink for contaminants from three major kinds of sources: direct discharges from human activities, natural discharges, and relocation of contaminated sediments. Much of the contamination derives from people, as either industrial or municipal discharges. Natural contaminants eroded from geologic material within the drainage basin enter Puget Sound through river discharges. These contaminants include organic compounds [e.g., polynuclear aromatic hydrocarbons (PAH)] from coal deposits (Barrick et al. 1984; Furlong and Carpenter 1982) and metals from a variety of source rocks. Dredged material relocated to open-water disposal sites is yet another source of contaminants to Puget Sound. Fourteen active and inactive disposal sites have been located throughout Puget Sound (Figure 1). Three major sites are located next to the cities of Tacoma, Seattle, and Everett.

Contamination and potential biological effects at these disposal sites are not well characterized but will receive additional attention through the Puget Sound Dredged Disposal Analysis (PSDDA) program administered by the U.S. Army Corps of Engineers (COE), U.S. EPA, Washington Department of Ecology, and Washington Department of Natural Resources. The current policy for these sites is to not permit disposal

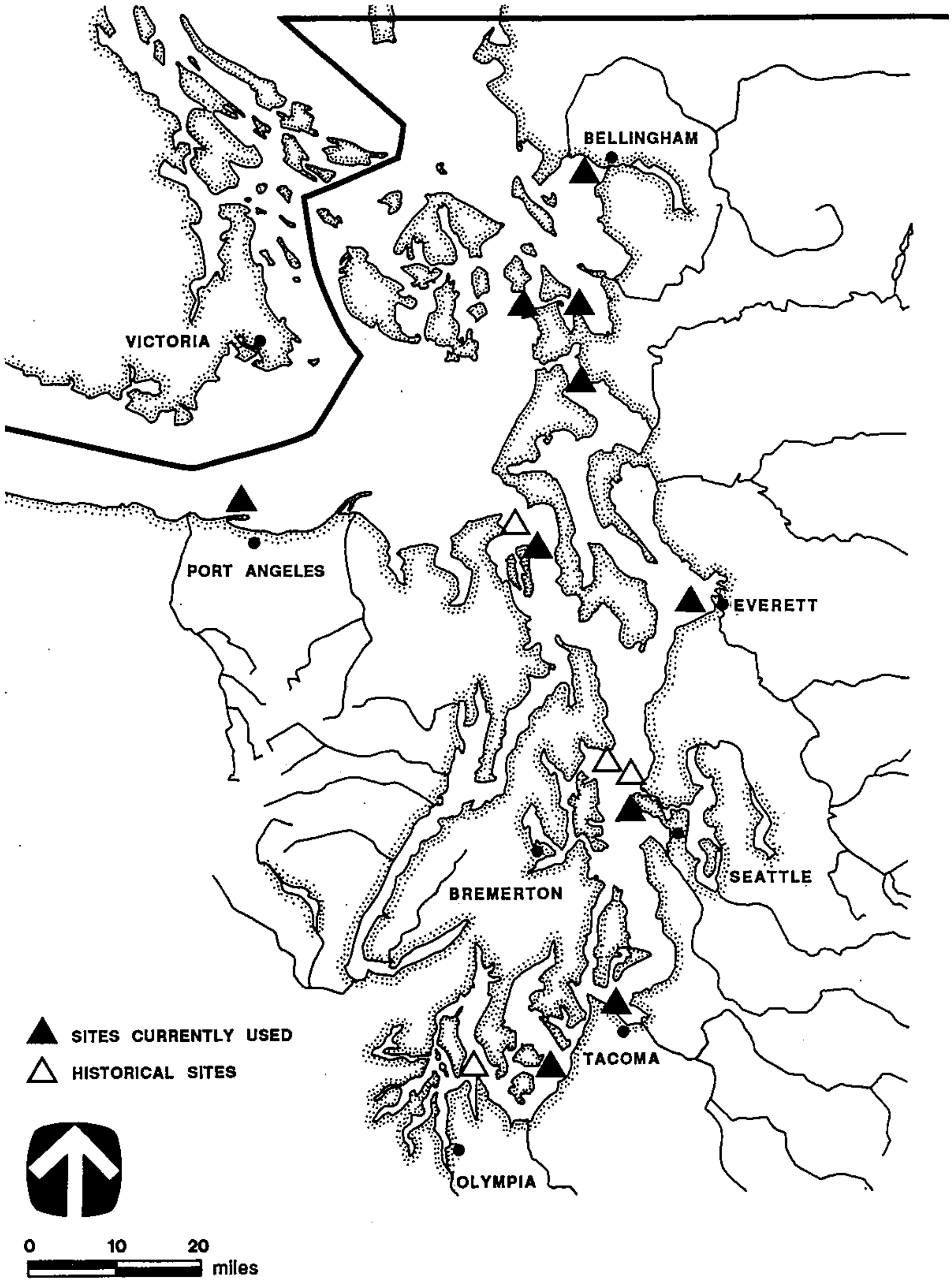

Figure 1. Location of dredged material disposal sites in Puget Sound.

of material more contaminated than that already on site. Proposed guidelines under PSDDA will require disposal decisions to be based on biological as well as chemical test results.

Contaminants of Concern in Puget Sound Sediments

Of the thousands of chemicals known or suspected to exist in the environment, only a small number have been measured routinely in detailed environmental studies. Chemicals that are considered a threat to the environmental health of Puget Sound (and other coastal areas across the country) share some common characteristics:

- A demonstrated or suspected effect on human health or marine life
- An identified past or present source of sufficient magnitude to be of concern
- Potential persistence as a toxic contaminant
- A potential for entering the food web.

Several hundred chemicals have been tentatively identified in selected samples of Puget Sound sediments. Routine analyses have been conducted for only about 150 toxic chemicals and in only some areas of the Sound. Chemicals that have been frequently detected are limited to phenols, PAH, polychlorinated biphenyls (PCBs), other chlorinated hydrocarbons, some pesticides (e.g., DDT), and most metals. Lists of contaminants of concern has been developed by several agencies. A recent summary of contaminants of concern and their general properties has been published by the Puget Sound Estuary Program (Tetra Tech 1986a).

Some of these chemicals are no longer actively produced (e.g., PCBs and DDT), but still enter Puget Sound from dumps, spills, and other waste sources. The sources of many toxic chemicals are difficult to distinguish or are widespread. For example, PAH come from the burning of wood, coal, and oil products; from leaking automobile oils and eroded highway pavement; and from a number of industrial processes including steel production and wood preserving. Other toxic chemicals have both human and natural sources. For example, arsenic comes from copper smelting operations and from ocean water, which contains naturally elevated levels of dissolved arsenic.

Contaminant Accumulation and Burial

Many factors influence contaminant dispersal and accumulation in Puget Sound. The manner in which a pollutant is dispersed from its point of introduction into the marine environment will be largely determined by its chemical properties, particularly its affinity for particles. The mobility, fate, and ecological impact of a chemical contaminant will be determined by 1) the kind of source producing the contaminant, 2) the magnitude of the source discharge over time, 3) chemical phase transformation or alteration near the point of discharge, 4) dispersal mechanisms, and 5) post-depositional changes. Chemical properties of the contaminants and the processes listed above establish a link between pollutant sources and the sediments where pollutants accumulate.

Most contaminants of concern bind to particles that become sediments at the bottom of Puget Sound. This removal process is an important means of immobilizing and eventually burying contaminants under layers of newer deposits. The general process of sedimentation is illustrated in Figure 2. Contaminated material from a source discharge mixes with material from other sources in the water column and is either degraded, transported away, or accumulated in surface sediments.

Two major factors that determine the length of time contaminants will remain in surface sediments include the sedimentation rate (how fast new sediment accumulates) and the thickness of the mixed layer of surface sediments. Contaminants are quickly buried when there is a fast sedimentation rate and a thin surface mixed layer. Alternatively, contaminants can persist for years in surface sediments when there is a slow sedimentation rate and a thick mixed layer. Mixing results from biological activities (e.g., burrowing of benthic organisms and bottom fish) and physical processes (e.g., resuspension of sediments by storms and currents). When freshly deposited material is mixed extensively with older deposits, surface sediment concentrations will not quickly reflect changes in the discharge of contaminants from sources.

Most marine sediments accumulate slowly. Sediment accumulation in Puget Sound (excluding major river deltas and other sites off major discharges of solids) typically ranges from 0.1 to 3 cm/yr in surface sediments (Carpenter et al. 1985). The sedimentation rates are determined using radionuclide techniques and are also expressed as the total mass of sediment accumulation per unit area (0.26 to 1.2 $gm \cdot cm^{-2} \cdot yr^{-1}$). The average mixed layer depth in Puget Sound sediments based on these techniques is approximately 10 cm, but ranges from 0 to 40 cm (Carpenter et al. 1985; Lavelle et al. 1986). Residence time calculations based on radionuclide techniques indicate that contaminants may be retained in the biologically active surface sediments for years or decades.

After a source has been controlled (Figure 2) several years may pass before contaminants from the source are buried below the surface mixed layer. Even so, maintenance or remedial dredging can expose contaminated sediments that have been deeply buried.

Toxic Effects in Sediments

Because sediments are a major sink of contaminants discharged to the environment, they are also a major source of toxic chemicals to organisms exposed to the sediments. Laboratory and field evidence from Puget Sound suggests that adverse biological effects may be associated with high

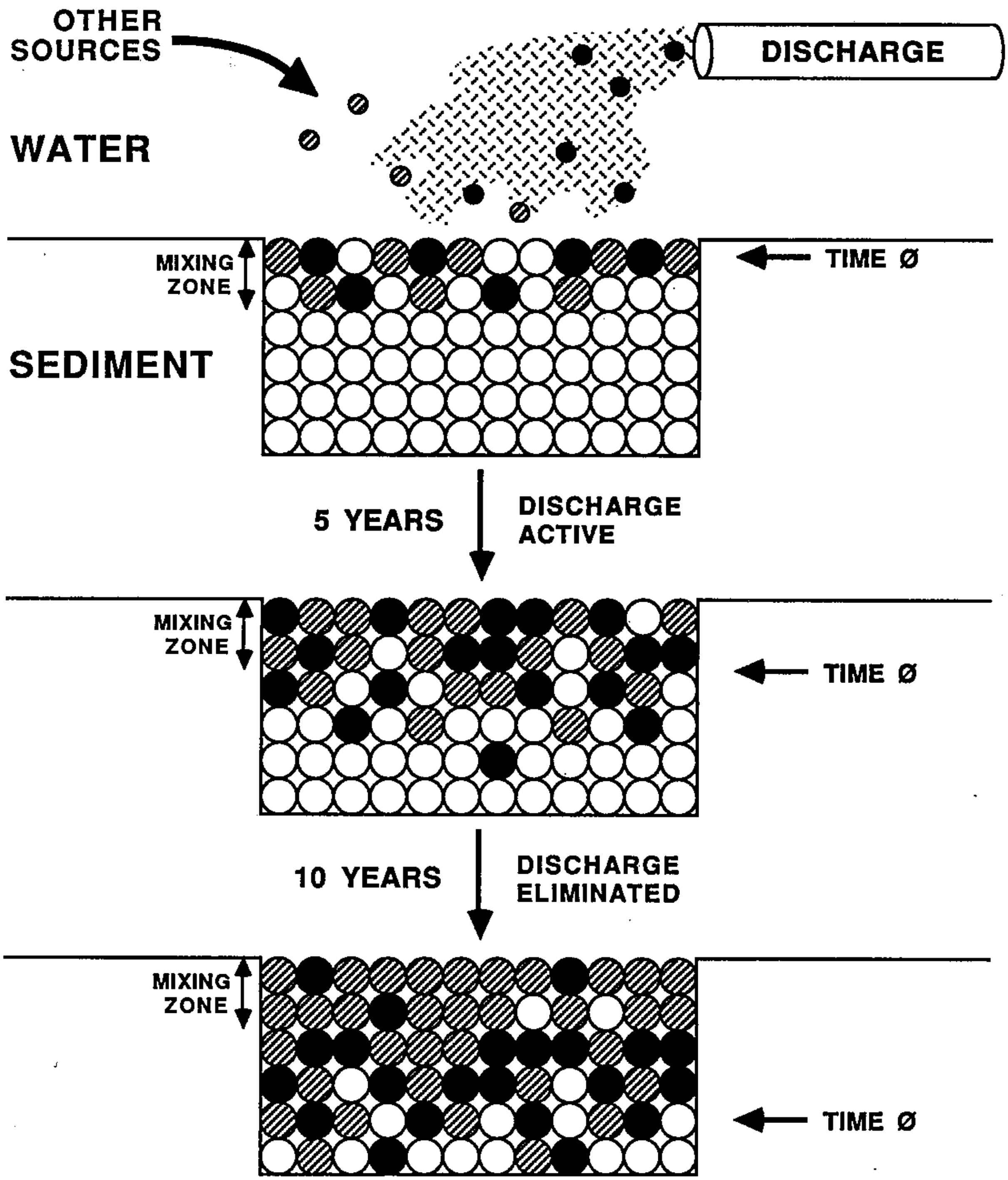

Figure 2. Schematic of sediment accumulation and mixing over time at a site before and after source control of a contaminated discharge.

concentrations of certain contaminants in surface sediments. These biological problems can result from both historical and ongoing sources. Study of the geographic extent of biological problems produced by the present levels of toxic chemicals is still underway.

A number of tests have been used to assess adverse biological effects associated with sediment contamination in Puget Sound (Figure 3). Laboratory tests include acute lethal and sublethal bioassays to measure sediment toxicity (e.g., *Rhepoxinius abronius* amphipod mortality and oyster larvae abnormality). Direct field measurements include the numbers and kinds of organisms living in the sediments (infauna), levels of chemicals in fish and other organisms (bioaccumulation), and the prevalence of abnormalities (lesions) in fish livers.

Definitive cause-effect data relating the individual and collective effects of chemicals to a wide range of biological effects are largely unavailable. As an interim measure, sediment criteria based on empirical associations between sediment chemistry and biological conditions of sediments were developed in Puget Sound for PSDDA, the Puget Sound Estuary Program (PSEP), and the Commencement Bay Nearshore/Tideflats Superfund Investigation (Tetra Tech 1985, 1986b). Matched chemical and biological data collected for the same sediment samples (or strictly comparable samples) are now available for 200 sampling stations in Puget Sound. Although not all biological indicators were measured for every sample, this data set covers 11 different urban and nonurban areas of Puget Sound (Figure 4). Additional theoretical and empirical studies have been conducted for U.S. EPA at the national level (Battelle 1986) and applied to Puget Sound (Tetra Tech 1986b).

In a recent comparison of four independent field and laboratory approaches to relating bulk sediment chemistry to biological effects (Chapman et al. 1987), sediment criteria for three common contaminants yielded comparable values ranging from (dry weight sediment): lead, 50-300 ppm; PAH, 2-12 ppm; PCB 0.06-0.13 ppm. These values include concentrations at or below which biological effects have been shown to be minimal and the lowest concentrations at which biological effects have been shown to occur. Data used in each approach derived either exclusively or in part from Puget Sound.

Identification of contaminated sediments that produce adverse biological effects is only one step in the process of solving environmental problems. Recent efforts in Puget Sound have begun to focus on eliminating problem sediments through a combination of source control and sediment remedial action. A kinetic model is being developed to assess the proper mix of source control and oftentimes expensive sediment remedial action. This model predicts decreases in surface sediment concentrations over time associated with different source control actions. The model also considers sediment mixing and the residence time of contaminants in the biologically active surface sediments. Hence, the model can be used to predict what actions are necessary to obtain

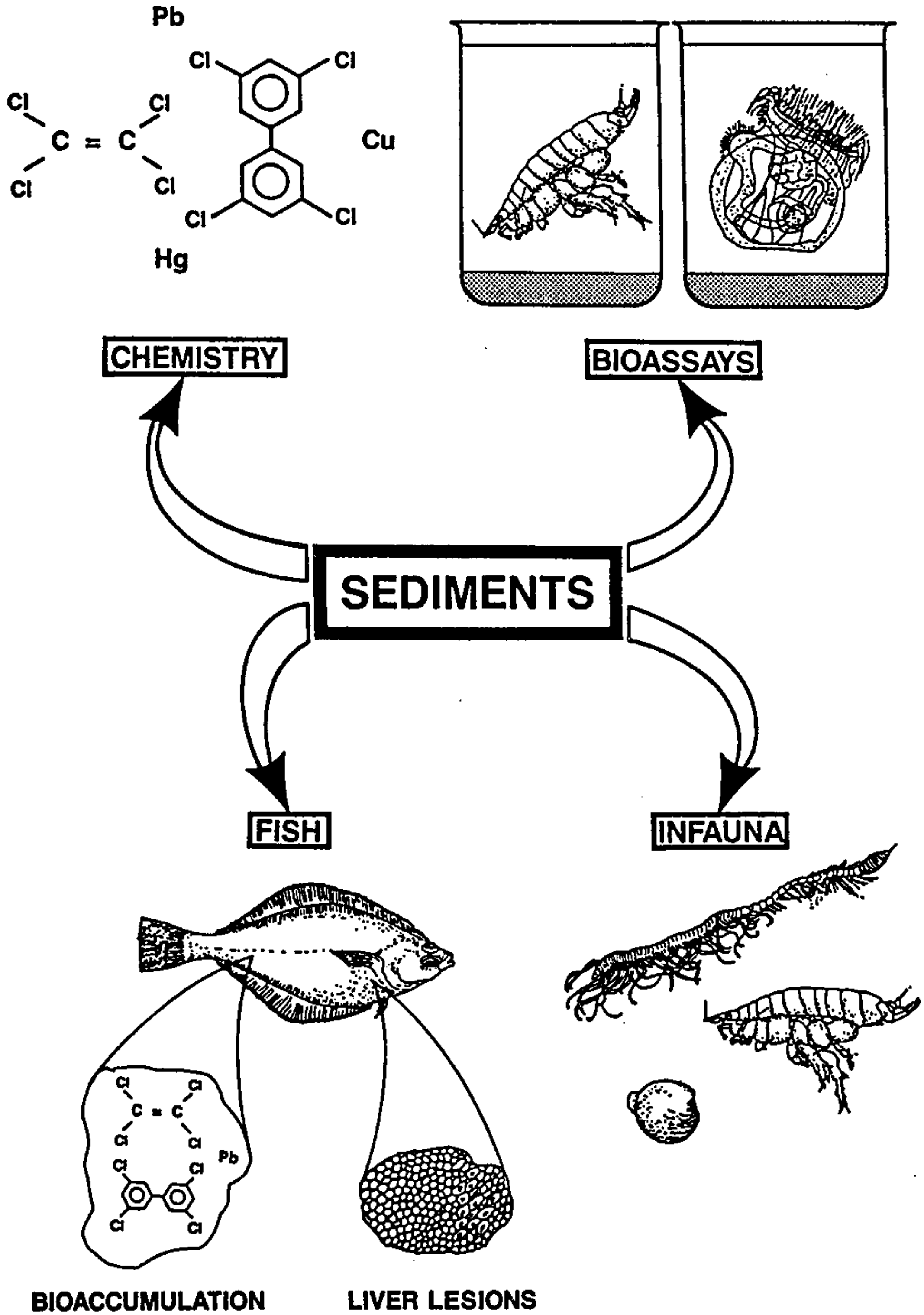

Figure 3. Examples of indicators used to evaluate the extent of problems from toxic chemicals in Puget Sound.

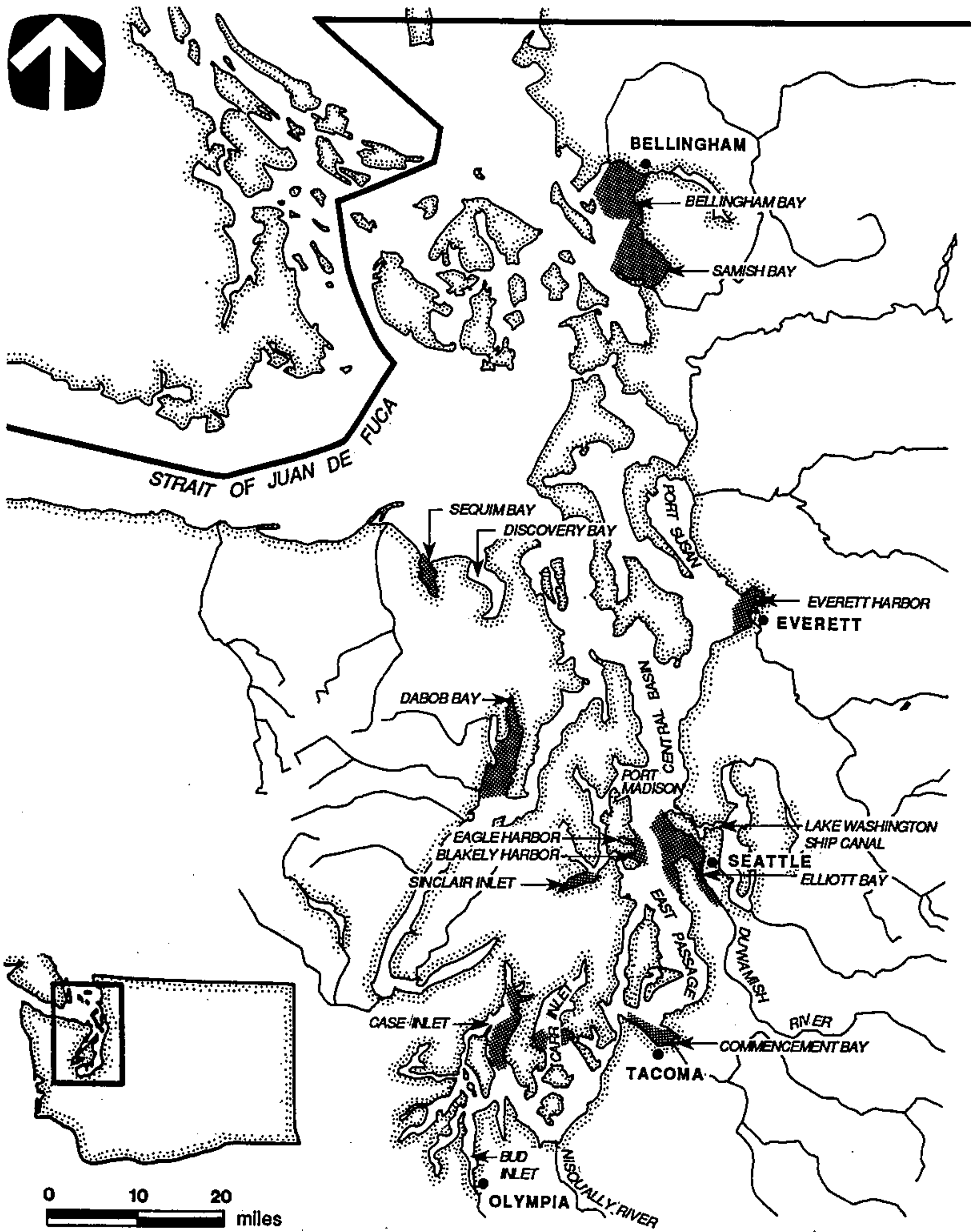

Figure 4. Locations of stations included in the 200-station Puget Sound sediment quality database.

acceptable sediment concentrations (i.e., concentrations that are not expected to produce biological effects) within a reasonable time frame.

Distribution of Chemicals in Puget Sound Sediments

A general overview of the distribution of contaminated areas in Puget Sound is provided in Figure 5. With the exception of metals, hydrocarbons, and PCBs, few other contaminants have been measured in sediments from all regions of Puget Sound. Three general levels of contamination are shown in the figure: 1) areas where high contamination by one or more chemicals appears to be associated with biological effects, 2) "clean" areas where contamination appears to be too low to cause effects (and in fact effects are minimal in the few areas tested), and 3) areas where the potential effects of intermediate levels of contamination are uncertain. As noted, this distribution gives only a rough guide to the potential environmental effects that may accompany the contamination.

Mean and maximum concentrations of some common chemicals of concern are shown in Figure 6 for areas ranging from high to low contamination. Levels of contamination observed in different regions of the Sound correspond strongly with the level of development nearby. For example, the heavily industrialized areas of Seattle (e.g., the West Waterway of the Duwamish River) and Tacoma (e.g., Hylebos Waterway) are among the most contaminated and contain a complex mixture of toxic substances. The Ruston-Pt. Defiance Shoreline near Tacoma contains high levels of certain metals associated with a smelting operation on the shoreline.

Other contaminated areas, such as Eagle Harbor west of Seattle at Winslow, are grossly contaminated in small areas with only a limited number of related substances (i.e., hydrocarbons likely derived from creosote). The harbors at Everett and Bremerton receive wastes from major pulp and paper mill and naval ship repair operations, respectively. These harbors are areas of high contamination, and will be more completely characterized in studies to be completed by PSEP in 1987 and 1988. Some areas of concern in the past are now less contaminated. For example, high mercury contamination observed in Bellingham Bay during the late 1960s has lessened after the source was shut down and contaminated sediments were buried by cleaner material.

The pattern of contamination in Puget Sound demonstrates that, with the exception of spills and intentional dumping at dredged-material disposal sites, distance from source discharges is the major factor in determining the levels of contaminants in Puget Sound sediments. Areas that have intermediate levels of contamination (e.g., Central Puget Sound between Seattle and Tacoma; Figure 6) are predominantly influenced by water currents that transport contaminants from areas with major sources. Areas with low contaminant levels (e.g., bays used as reference areas; Figure 6) are generally far from major development. Even in these areas, natural transport by air and water has introduced contaminants. Probably no area of the Sound is free from some contamination by toxic chemicals.

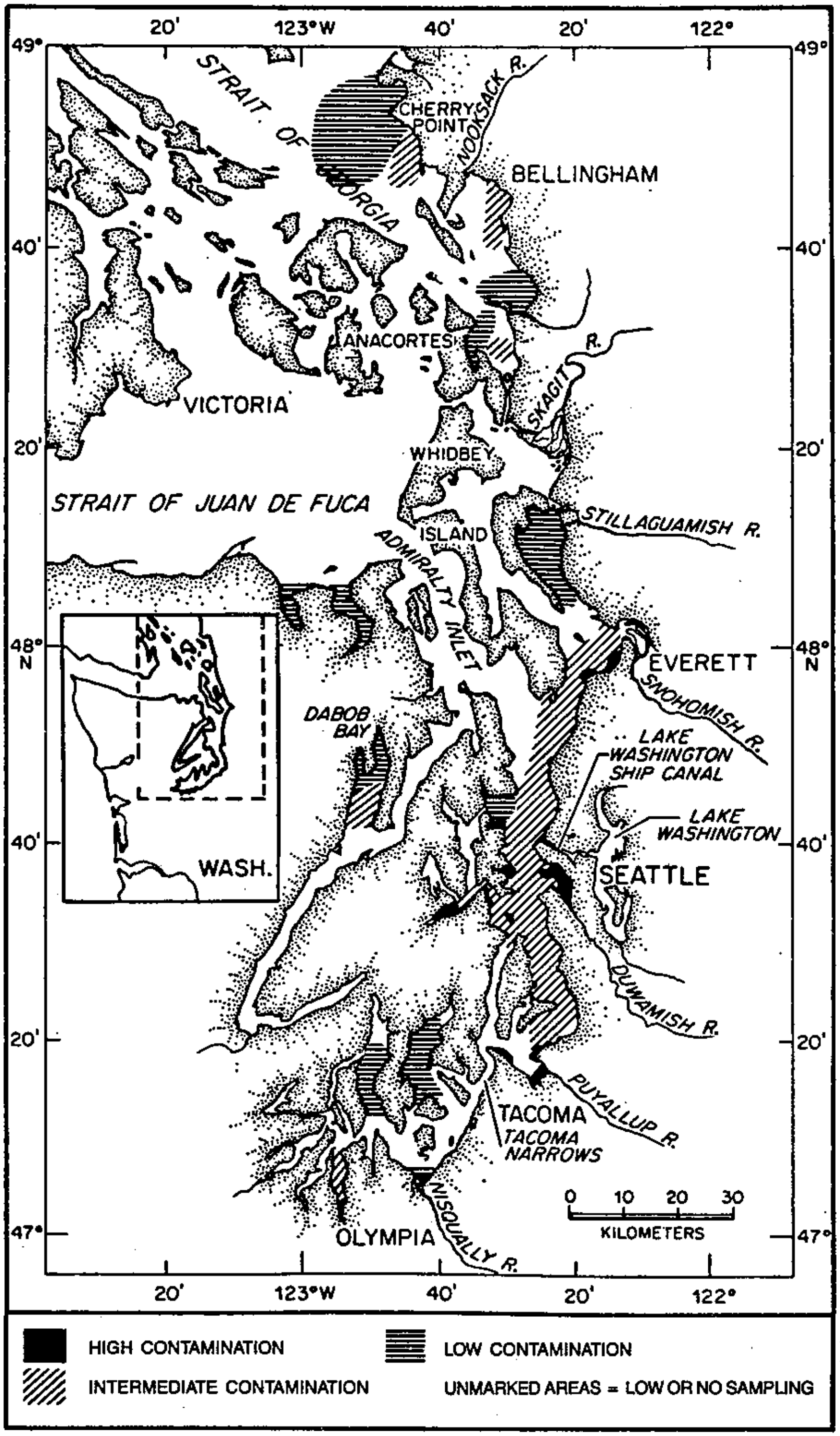

Figure 5. General distribution of toxic chemical contamination in the surface sediments of Puget Sound.

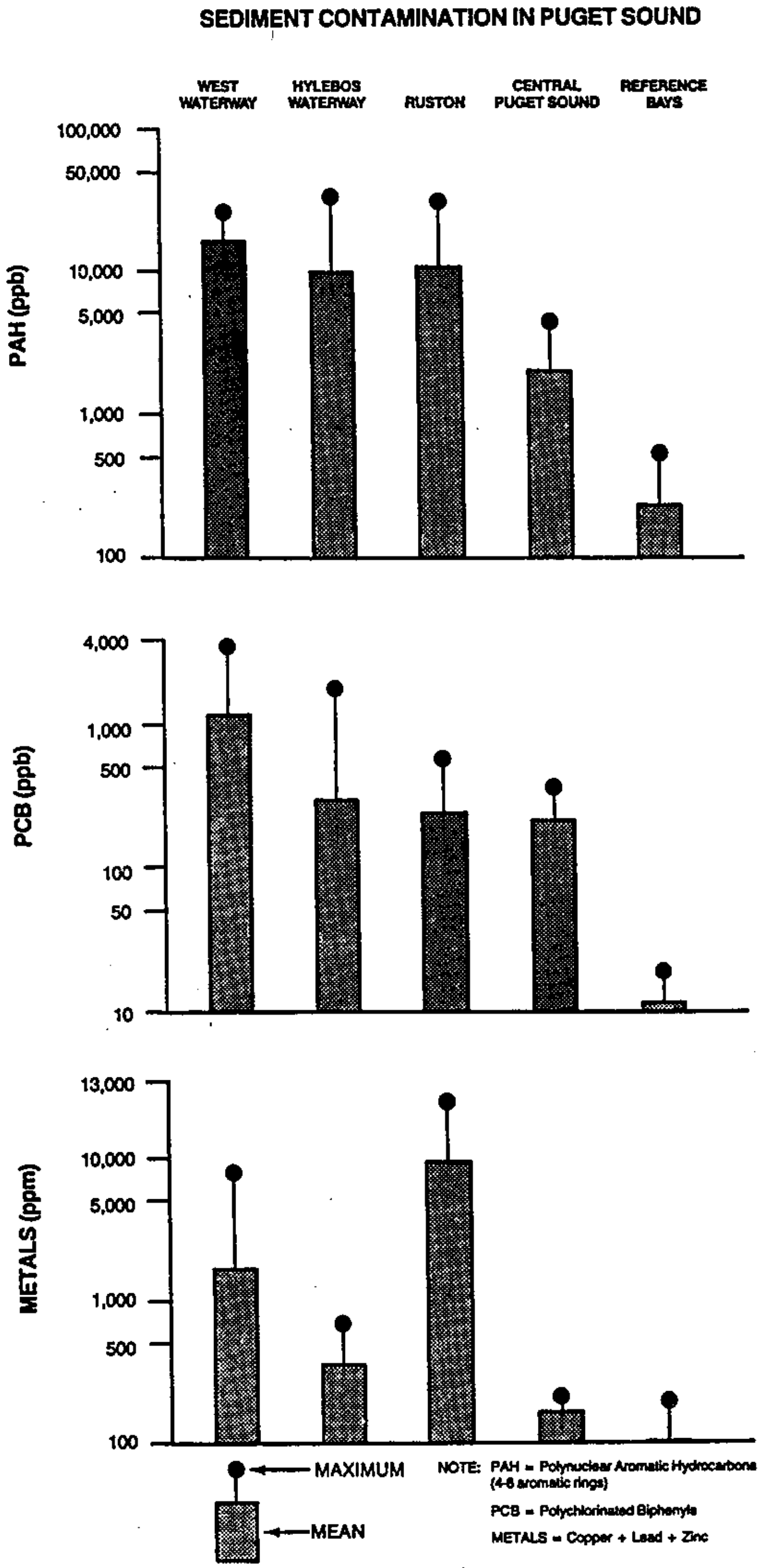

Figure 6. Comparisons of the concentrations of selected toxic chemicals in the surface sediments from representative areas of Puget Sound.

Contaminant problems in industrialized embayments of Puget Sound are diverse both in terms of concentration and chemical composition. This diversity can be revealed in the visual appearance of sediments. For example, sediment cores collected in many urban embayments of Puget Sound are anoxic, greenish black muds with a thin layer of brown oxidized sediment at the surface. In contrast, sediment collected near a major outfall of a now-closed copper smelter on the Ruston-Pt. Defiance Shoreline of Tacoma consists of bands of richly colored sediment that derive from high concentrations (>10,000 ppm) of several metals. A completely different sediment can be collected in Eagle Harbor (Figure 4), where an accidental spill or intentional dumping of creosote has created pitch-black sediments that ooze brown oil. These latter sediments caused 100 percent mortality in a range of laboratory bioassays (Tetra Tech 1986c and references therein) and required dilution to 0.6 percent of the original material in clean sediment before insignificant toxicity was observed (Swartz et al. in preparation). PAH concentrations in subsurface sediment from this area exceeded 2,000 ppm (Tetra Tech 1986c).

In addition to diversity in chemical composition, highly contaminated sediments in Puget Sound industrialized embayments often occur in patches near point sources. For example, contaminated problem areas in Commencement Bay that exhibited biological effects are shown in Figure 7. High concentrations of PAH (>20 ppm) were found close to the head of Hylebos Waterway in Tacoma's Commencement Bay (Figure 7) near a ditch that discharges waste from an aluminum plant. At the mouth of the same waterway near a chemical manufacturing plant, several chlorinated compounds including chlorinated butadienes (industrial by-products) were found at well over 1,000 times reference conditions. Other chemicals measured at over 1,000 times reference conditions were alkylated phenols in sediments adjacent to the main outfall of a major pulp and paper mill in St. Paul Waterway, and four metals (antimony, arsenic, copper, and mercury) in sediments adjacent to the main outfalls of the copper smelter described earlier on the Ruston-Pt. Defiance Shoreline. The most extreme biological effects were found at these same sites in St. Paul Waterway and on the Ruston-Pt. Defiance Shoreline.

A patchy distribution of contamination is characteristic of all of the industrialized embayments, including Elliott Bay off Seattle (Figure 8). In Elliott Bay, patches of high contamination along the Duwamish Waterway contrast with large areas of lower contamination in the outer bay. An area of intermediate contamination is found in the outer bay around the Four-Mile Rock dredged material disposal site (Figure 8).

<u>Historical Trends</u>

By using chemical dating methods and measuring the contaminant concentrations in different sediment layers, the history of contamination can be evaluated. Detailed historical sediment data exist for only some contaminants in Puget Sound, including PAH, PCBs, and most metals. Concentrations of nearly all contaminants measured in this fashion are low in sediments that were deposited in Puget Sound before about 1880. The

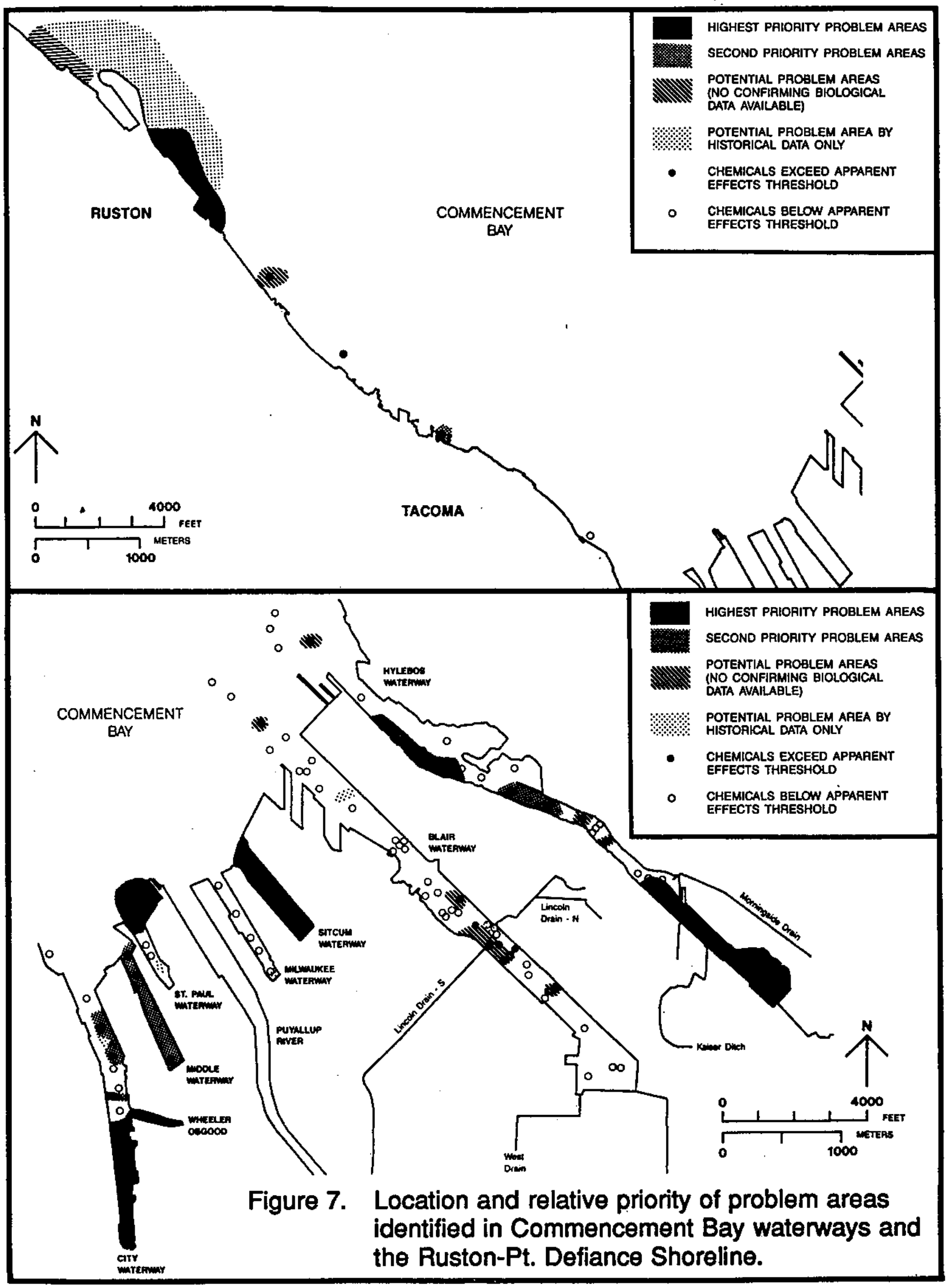

Figure 7. Location and relative priority of problem areas identified in Commencement Bay waterways and the Ruston-Pt. Defiance Shoreline.

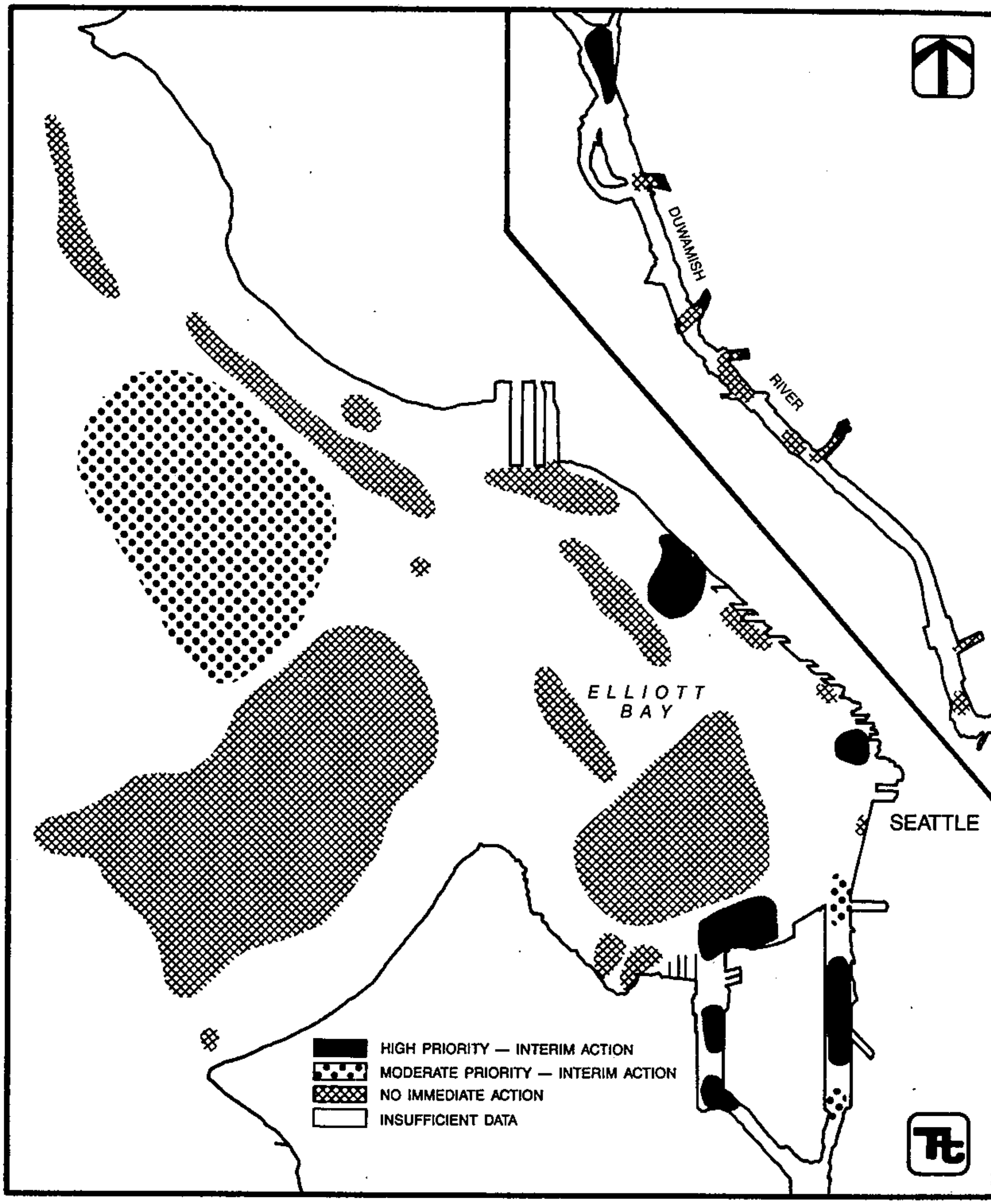

Figure 8. Location and initial relative priority of problem areas identified in Elliott Bay.

late 1800s correspond to the beginning of major urban development of the region. For PAH, which have natural sources (e.g., forest fires and erosion of coal deposits), a significant increase in concentration was observed in sediments dating from the turn of the century. In central Puget Sound, maximum concentrations of PAH appear to have occurred sometime around the 1950s (Figure 9). These PAH concentrations are approximately 2-3 times present day concentrations and over 30 times those of the 1880s. Much greater temporal changes are apparent close to PAH sources in the industrialized embayments and Eagle Harbor. Decreases observed in some areas since the late 1950s probably result from improvements in industrial practices and perhaps from the continued conversion from coal to oil used for home heating (Bates et al. 1984; Barrick and Prahl in press).

PCBs were used commercially only from the 1930s to the 1970s when their use was banned. PCB concentrations in sediments show a corresponding pattern (Figure 9). Several metals (e.g., lead, copper, and zinc) show increased concentrations over the last century, but again have somewhat lower concentrations in recently deposited sediments (Figure 9).

Conclusions

Accurate measurements of many toxic chemicals concentrations in the environment have been made only in the last several years. Consequently, it is difficult to assess the spatial and temporal trends in the concentrations of all but a few toxic chemicals. For some chemicals found frequently in Puget Sound (e.g., PAH, PCBs, and lead), several lines of evidence demonstrate decreasing discharges and sediment concentrations in recent years. Improved pollution controls, changes in product usage, and the closure of some industries are thought to result in similar reductions for other chemicals. Additional data on sources and sediment concentrations are required to support this conclusion. Recent increases in concentrations may result from discharges associated with new industries and more domestic sewage. In general, however, contamination by many chemicals was much worse 10-25 years ago.

Puget Sound as a whole is not highly contaminated in comparison with other coastal areas of the United States. Some small areas of the Sound are contaminated at levels similar to heavily contaminated areas along the East coast and southern California. For particular chemicals, it has been possible to identify sediment concentrations at which biological effects can be observed. This knowledge of the apparent association of chemical contamination and biological effects, although still limited, contributes to a growing body of information useful in addressing environmental problems in all contaminated coastal areas. These problems arise because sediments act not only as a convenient and significant sink for contaminants, but also as a source of toxics to organisms that live in or feed on surface sediments.

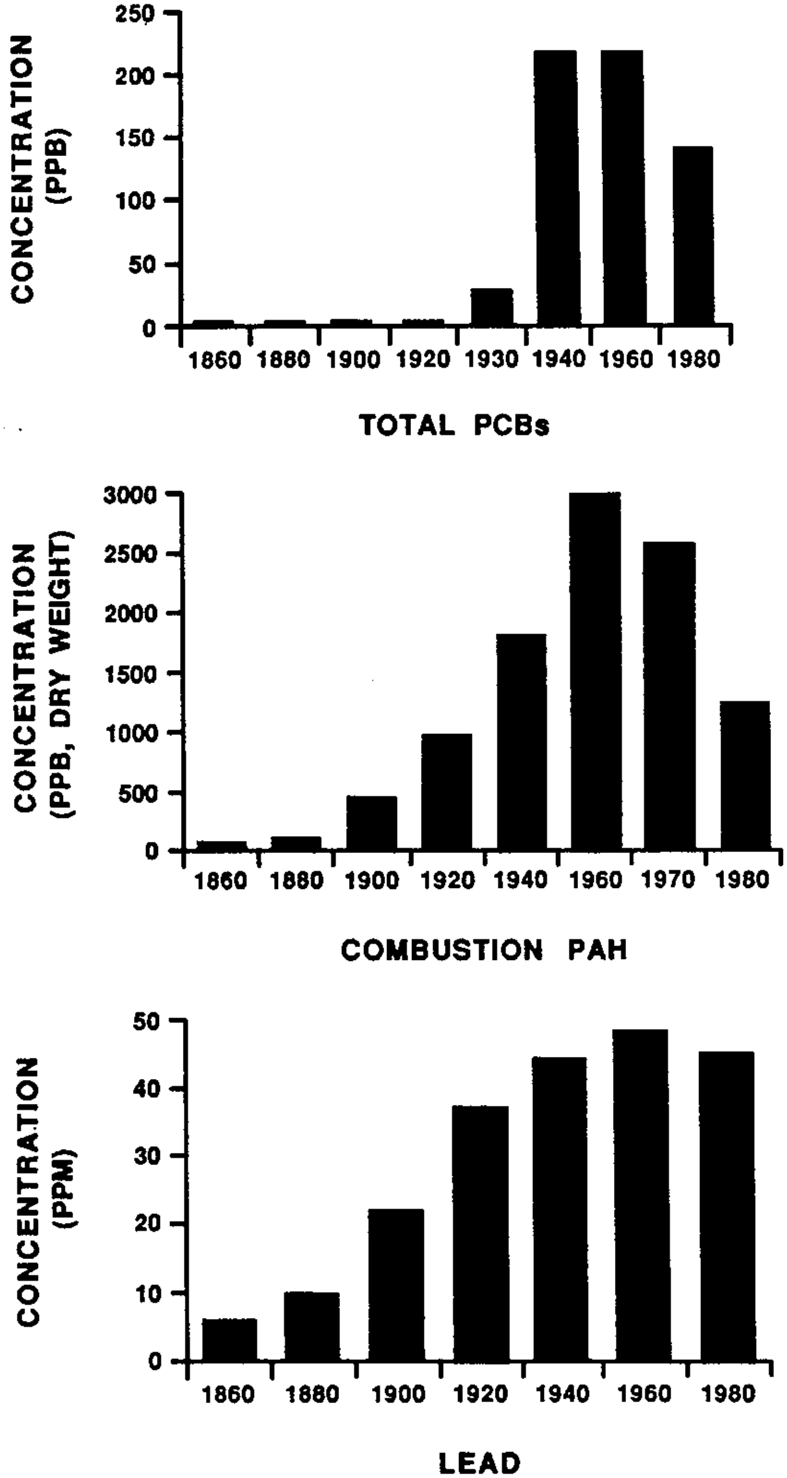

Figure 9. History of sediment contamination by PCBs, PAH, and lead in central Puget Sound from 1860 to 1980.

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TOXIC CHEMICALS IN FISH: EFFECTS ON THEIR HEALTH AND REPRODUCTION

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Introduction

A number of studies conducted during the past decade in Puget Sound have demonstrated the presence of chemically contaminated sediments and bottomfish particularly in certain urban/industrial embayments. A variety of pathological conditions have been found in bottomfish species from several of the most contaminated sites. These findings have served as useful indicators of environmental degradation in several parts of Puget Sound (Malins et al. 1984, Malins et al. 1985a,b).

Certain types of pathological conditions have been most useful in identifying pollution-associated perturbations (Malins et al. 1984, Malins et al. 1985a&b). Many of the lesions have a suspected chemical etiology because they are morphologically similar to lesions observed in laboratory rodents and fish exposed to toxic and/or carcinogenic chemicals.

This paper will briefly outline the distribution of environmental contamination in bottom sediments and fish from Puget Sound (Figure 1) and discuss the possible impacts of these contaminants on the health and reproduction of fish. Most of the information presented in this summary is the result of studies conducted by scientists of the Environmental Conservation Division of the Northwest and Alaska Fisheries Center in Seattle.

Chemical Contamination

A wide variety of anthropogenic chemicals, some in high concentrations, have been found in sediments from a number of sites in Puget Sound. For example, in studies conducted in Commencement Bay, we detected more than 900 individual organic compounds -- including over 500 AHs, hundreds of chlorinated hydrocarbons, as well as various compounds containing nitrogen, oxygen, sulfur and bromine (Malins et al. 1982). There are indications that many other chemicals are present [especially in the Everett Harbor (Malins et al. 1983)]; however, their numbers and identities have not been elucidated because of the limitations of the analytical techniques. We also found mean concentrations of aromatic hydrocarbons (AHs) in sediment

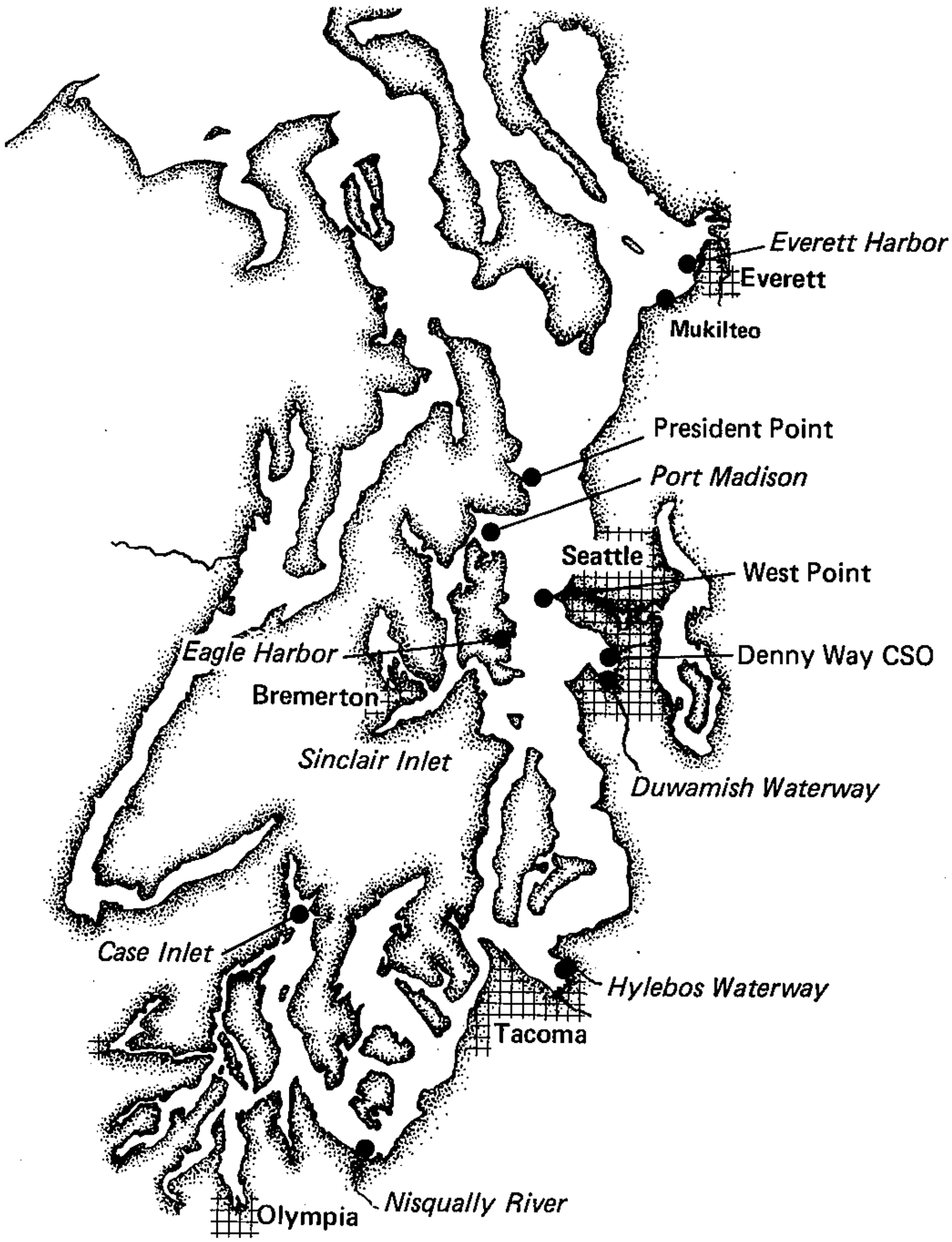

Everett Harbor
Everett
Mukilteo
President Point
Port Madison
Seattle
West Point
Eagle Harbor
Denny Way CSO
Bremerton
Sinclair Inlet
Duwamish Waterway
Case Inlet
Hylebos Waterway
Tacoma
Olympia
Nisqually River

Figure 1

(all sediment concentrations are expressed on a dry weight basis) from urbanized and/or industrialized sites -- Commencement Bay, Elliott Bay, Eagle Harbor, Mukilteo, and Everett Harbor -- to be at least 150 times higher than the mean concentration in sediments from the nonurban embayments -- Case Inlet and Port Madison (Malins et al, 1984). Within these urban areas, the values of AHs varied considerably with respect to individual stations (e.g., 150 to 63,000 ppb in Elliott Bay) (Figure 2). So far, the highest concentrations of summed AHs (120,000 ng/g) were detected in sediments from Eagle Harbor; moreover, over 200 nitrogen containing aromatic compounds were also present in these sediments (Malins et al. 1985a, Krone et al. 1987).

Polychlorinated biphenyls (PCBs) and a variety of chlorinated butadienes (CBDs) were found in virtually every sediment sample from Puget Sound (Malins et al. 1984). Concentrations of PCBs were usually much higher in sediments from most of the sites in Elliott and Commencement Bays compared to those in sediments from sites in non-urban areas (Figure 4). The concentrations of CBDs were substantially higher in Commencement Bay (Figure 3B).

Arsenic concentrations were also consistently higher in the major urban areas (Commencement and Elliott Bays) than in the nonurban areas, whereas the mean concentrations of cadmium were generally similar in all areas.

We also found that food organisms in the stomachs of the English sole (Parophrys vetulus) from selected areas, such as Eagle Harbor (Malins et al. 1985a) and near Mukilteo (Malins et al. 1985b), contained substantially higher concentrations of AHs than comparable organisms from reference sites. For example, the sums of the concentrations of AHs in two composites of food organisms (from five fish each) from Eagle Harbor were 50,000 and 84,000 ng/g, respectively. The concentrations of individual AHs in a composite of benthic food organisms (from six fish) from President Point did not exceed 100 ng/g. These findings suggest that consumption of sediment-dwelling organisms provides an important route of uptake of enviornmental contaminants.

Metabolically resistant organic chemicals, such as PCBs, were found in the muscle tissues of English sole from many Puget Sound sites. In a recently completed study of PCB concentrations in the muscle tissue of English sole, we found that highest concentrations (based on analyses of tissue composites of five fish each) in sole from the Duwamish Waterway (6,900 ng/g) and the Hylebos waterway (2,800 ng/g) (Malins et al., 1986) (Figure 5). English sole from the Case Inlet reference site had muscle concentrations of 400 ng/g. Complimentary laboratory studies suggest that uptake of PCBs from bottom sediments is an important route of bioaccumulation of these chemicals by English sole. English sole held for several weeks in aquaria containing sediment from the Duwamish Waterway bioaccumulated significant levels of PCBs in liver and muscle tissue (Stein et al. 1987).

In contrast to PCBs, concentrations of the more metabolically labile organic

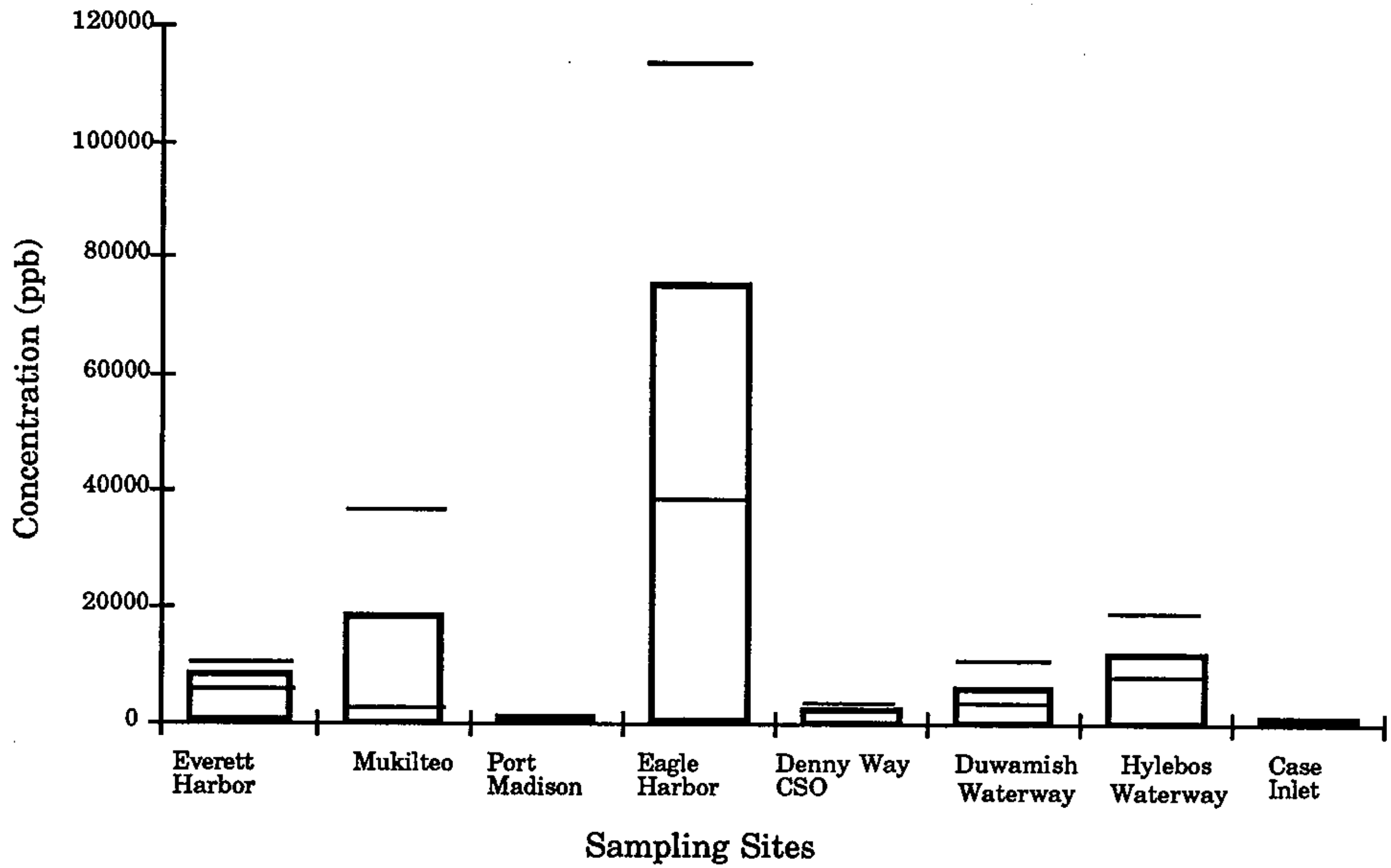
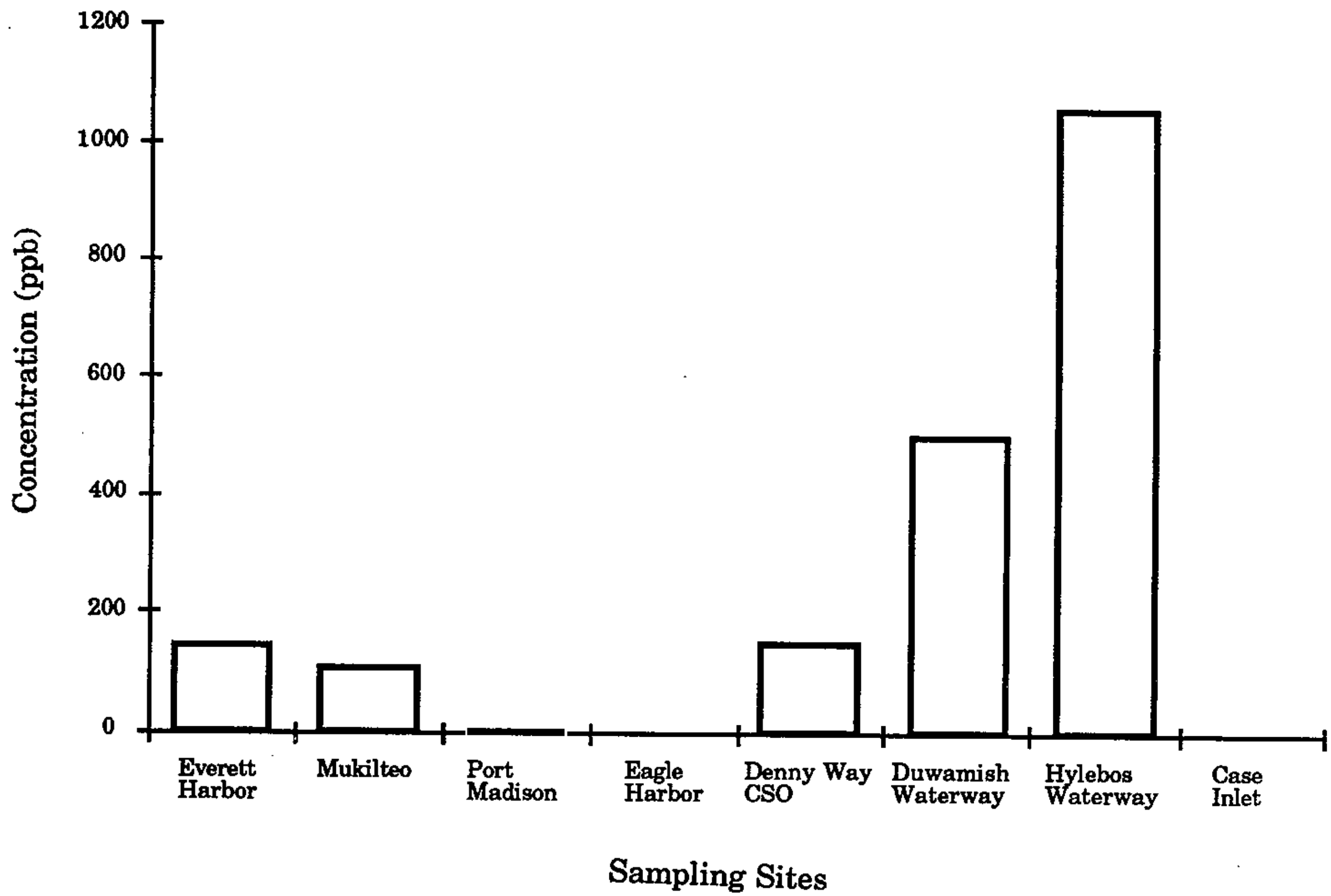

120000
100000
80000
60000
40000
20000
0
Concentration (ppb)
Everett Harbor
Mukilteo
Port Madison
Eagle Harbor
Denny Way CSO
Duwamish Waterway
Hylebos Waterway
Case Inlet
Sampling Sites

Figure 2



Concentration (ppb)
1200
1000
800
600
400
200
0
Everett Harbor
Mukilteo
Port Madison
Eagle Harbor
Denny Way CSO
Duwamish Waterway
Hylebos Waterway
Case Inlet
Sampling Sites

Figure 3

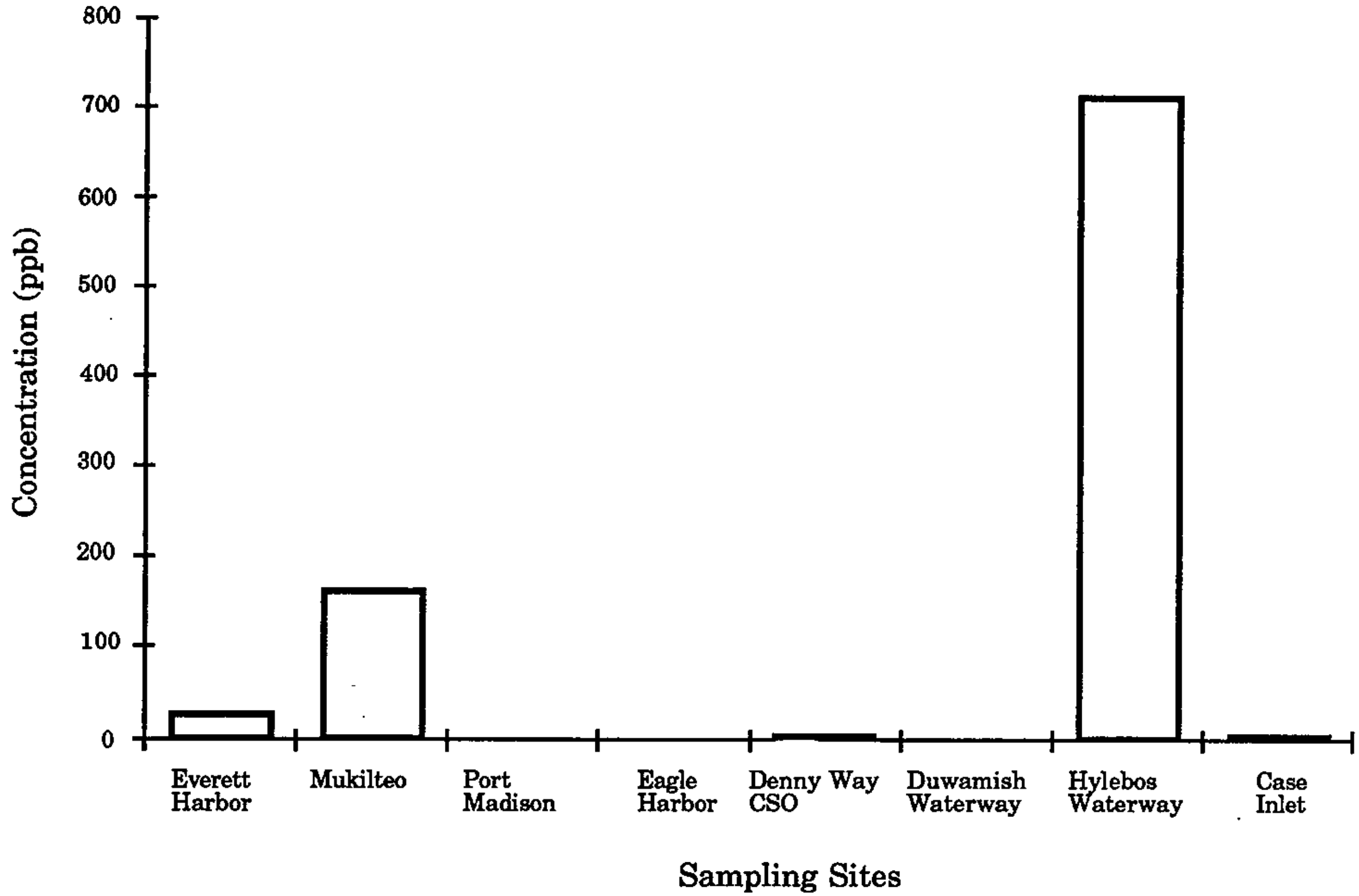

800
700
600
500
400
300
200
100
0
Concentration (ppb)
Everett Harbor
Mukilteo
Port Madison
Eagle Harbor
Denny Way CSO
Duwamish Waterway
Hylebos Waterway
Case Inlet
Sampling Sites

Figure 4

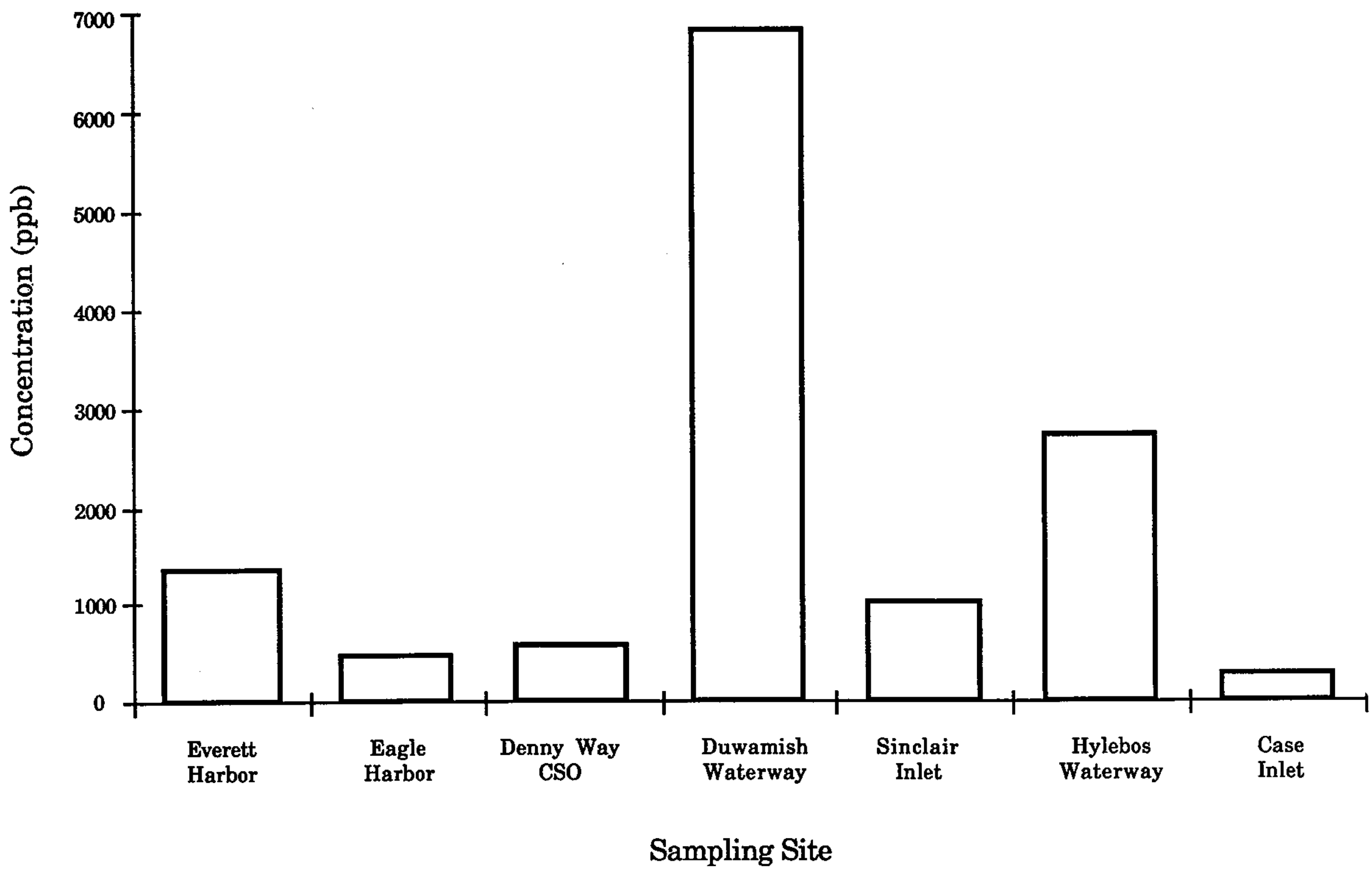

7000
6000
5000
4000
3000
2000
1000
0
Concentration (ppb)
Everett Harbor
Eagle Harbor
Denny Way CSO
Duwamish Waterway
Sinclair Inlet
Hylebos Waterway
Case Inlet
Sampling Site

Figure 5

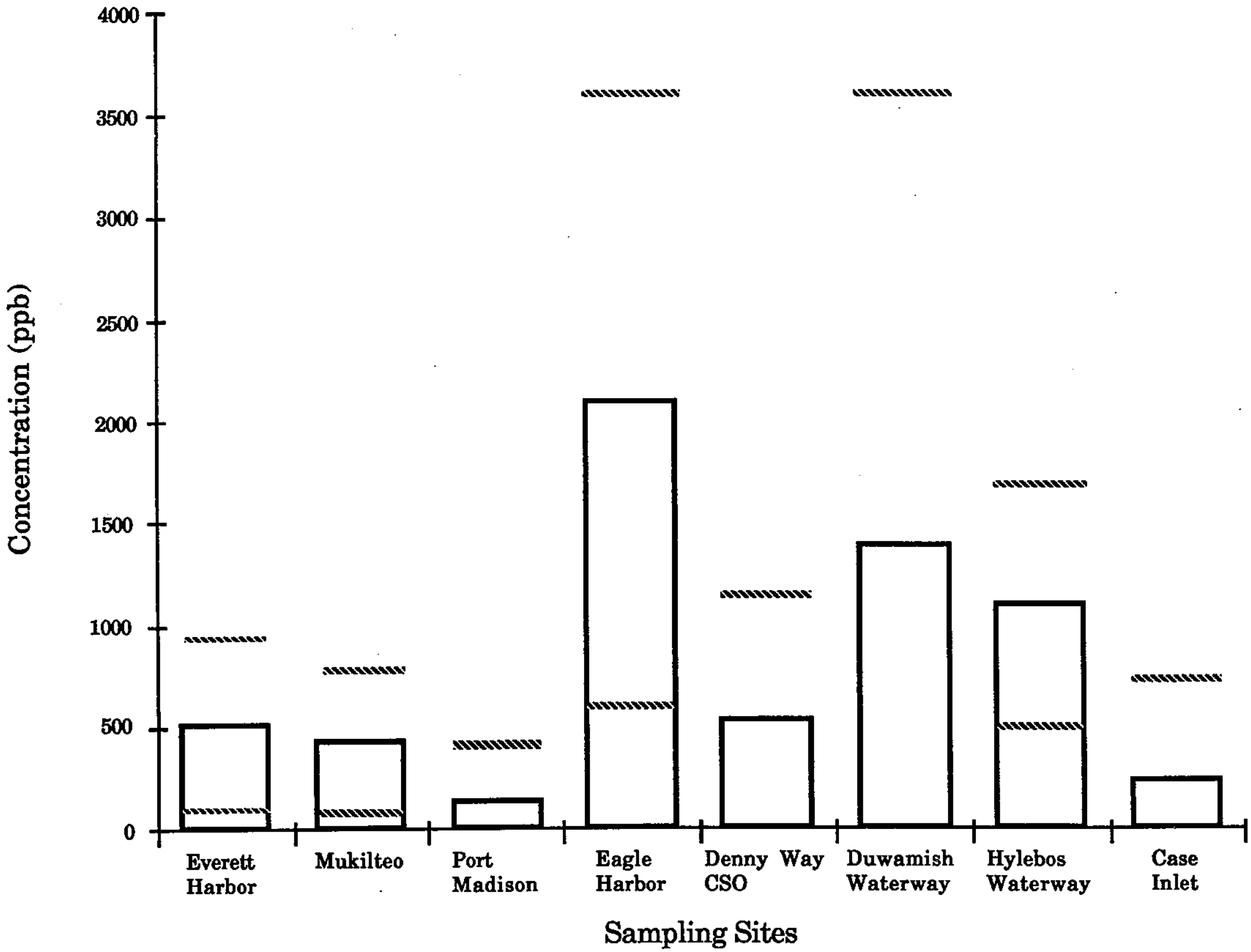
compounds (e.g., AHs) (Varanasi and Gmur 1981) were generally below the limits of detection in the muscle and liver of English sole captured in areas with highly contaminated sediment. In this regard, new HPLC-fluorescence techniques developed in our laboratory by Krahn et al. (1985) allow measurement of concentrations of metabolites of aromatic compounds in the bile. For example, in a study of English sole captured from 11 sites in Puget Sound (Krahn et al. 1986), high concentrations of metabolites which fluoresce at the BaP wavelength pair (380/430 nm) were found in bile of fish from Eagle Harbor (2,100 ± 1,500 ng/g) and the Duwamish Waterway (1,400± 2,200 ng/g), compared to bile of fish from reference sites where concentrations were at least 20 times less (Figure 6). Our laboratory studies have also demonstrated that bottom sediments serve as important sources of aromatic compounds for English sole. When English sole were placed on sediment from the Duwamish River, a significant increase in the fluoroscence at wavelengths appropriate for naphthalene, phenanthrene and BaP in bile was observed over a period of several weeks. Whereas the fish placed on a reference sediment from near the Dosewallips River did not show any increase in bile fluoroscence (Varanasi et al. 1985, Stein et al. 1987). These results indicate a continuous uptake of sediment-associated AHs in fish exposed to contaminated sediment.

In another recently completed study we found that downstream migrant juveniles of certain Pacific salmon species are exposed to chemical contaminants as they pass through polluted urban estuaries (Malins et al. 1987). For example, mean concentrations of PCBs in stomach contents and livers (Figure 1) of Oncorhynchus tshawytscha were three times higher than salmon from the Nisqually River, an estuary in a rural region of southern Puget Sound. The mean concentration of summed AHs in stomach contents of Duwamish Waterway salmon was over 600 times higher than that for reference salmon (Figure 8A). The mean concentration of bile metabolites which fluoresce at the BaP wavelength pair were over 20 times higher in Duwamish Waterway salmon compared to Nisqually River salmon (Figure 8B). We presently do not know if exposure to these toxic chemicals compromises the health of these young salmon.

Pathological Conditions

Hepatic neoplasms and other diseases, have been shown to occur in high prevalences in English sole and certain other bottom-dwelling fish living in waters adjacent to various urban (industrialized) areas in Puget Sound (Wellings et al. 1976; Malins et al. 1984, Malins et al. 1985a,b). A limited number of studies have indicated that certain diseases are closely associated with the presence of elevated levels of such toxic chemicals as AHs and CHs in the sediments. The principal types of urban-associated diseases reported in these fish species have included a variety of hepatic lesions (e.g. neoplasms, "preneoplasms", hepatocellular degeneration/necrosis) and fin erosion.

Several of our investigations have detected hepatic neoplasms in bottomfish species from Puget Sound (Malins et al. 1984, 1985a, 1985b; McCain et al. 1982) The highest prevalences of hepatic neoplasms were found in



Concentration (ppb)
4000
3500
3000
2500
2000
1500
1000
500
0
Everett Harbor
Mukilteo
Port Madison
Eagle Harbor
Denny Way CSO
Duwamish Waterway
Hylebos Waterway
Case Inlet
Sampling Sites

Figure 6

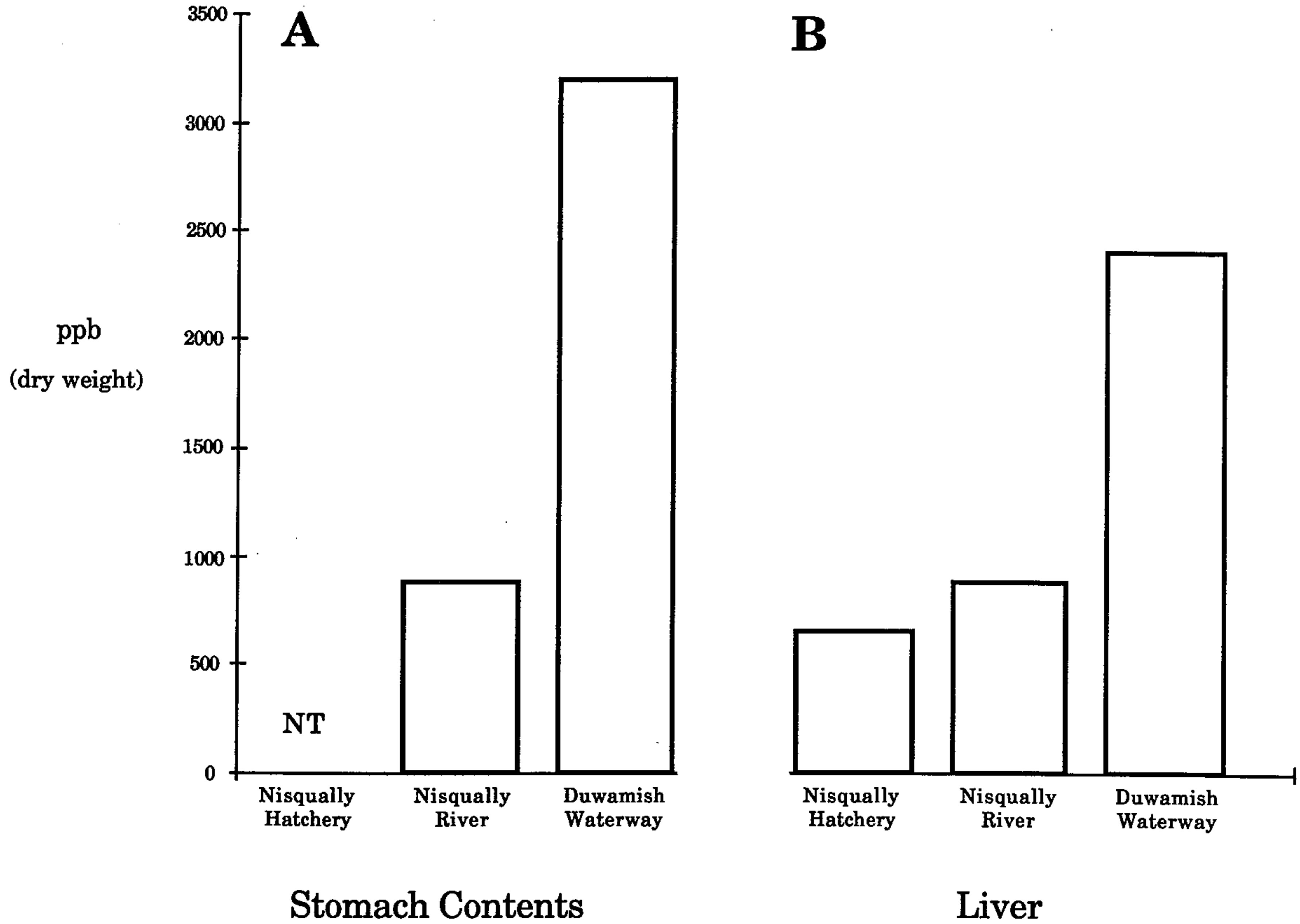

A
B
3500
3000
2500
2000
1500
1000
500
0
ppb
(dry weight)
NT
Nisqually Hatchery
Nisqually River
Duwamish Waterway
Nisqually Hatchery
Nisqually River
Duwamish Waterway
Stomach Contents
Liver

Figure 7

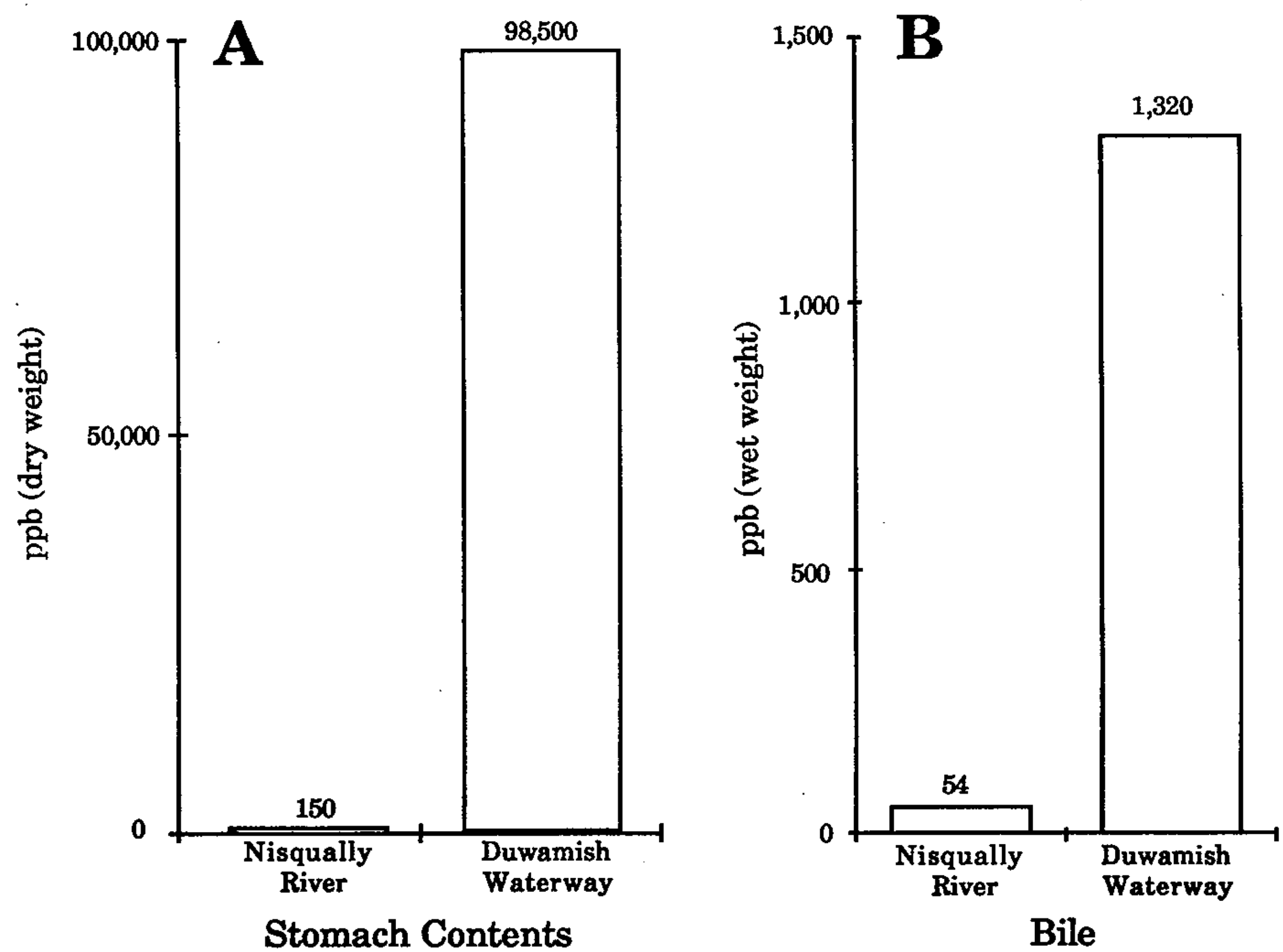

A
B
ppb (dry weight)
100,000
50,000
0
150
98,500
Nisqually River
Duwamish Waterway
Stomach Contents
ppb (wet weight)
1,500
1,000
500
0
54
1,320
Nisqually River
Duwamish Waterway
Bile

Figure 8

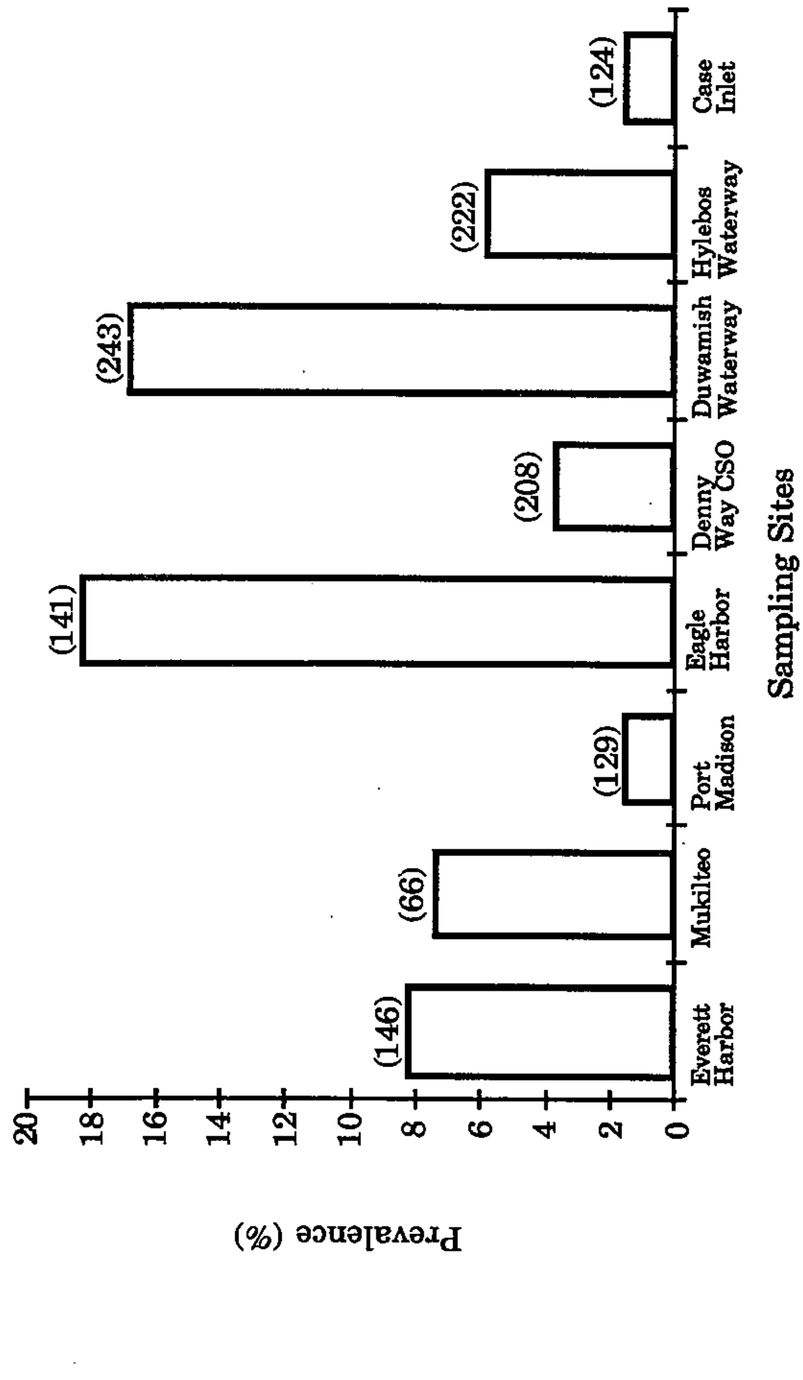
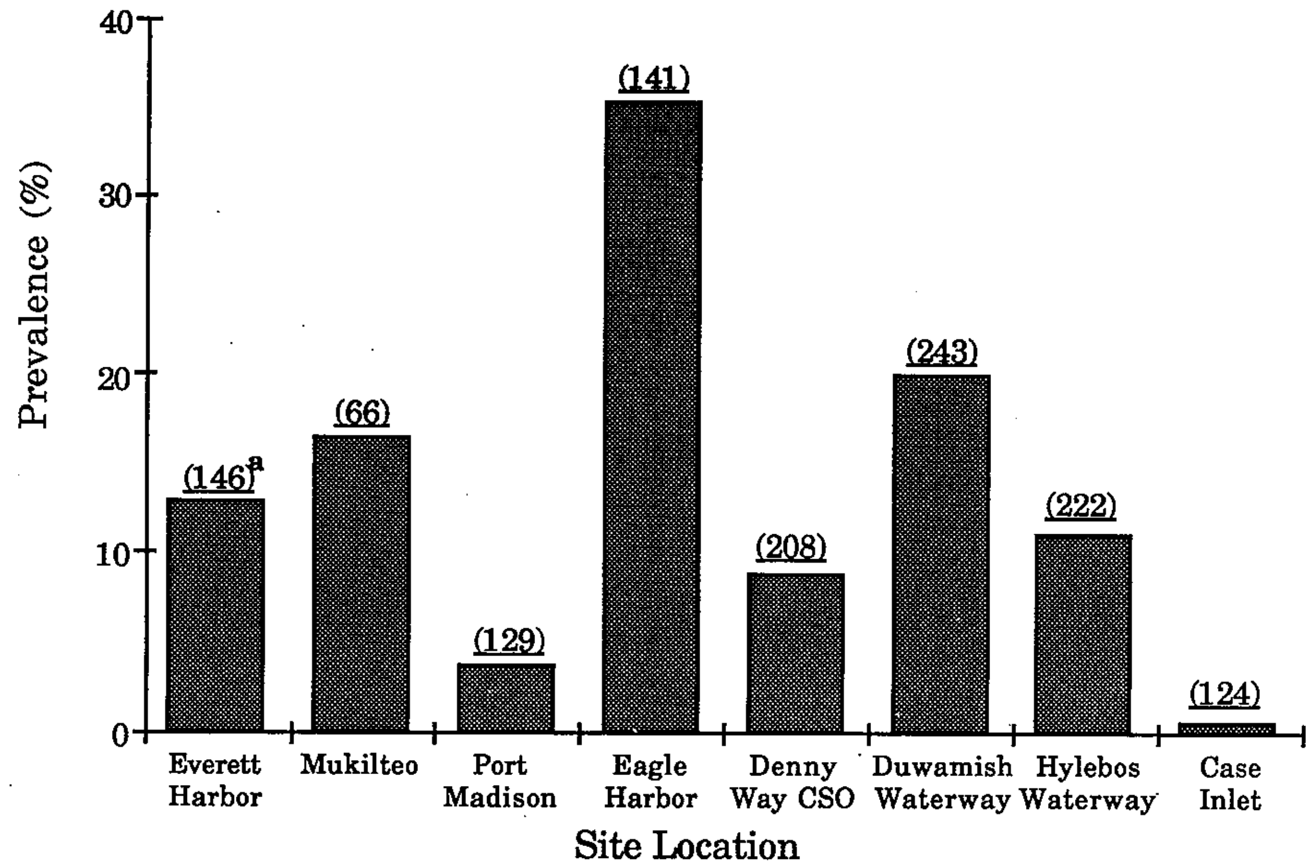
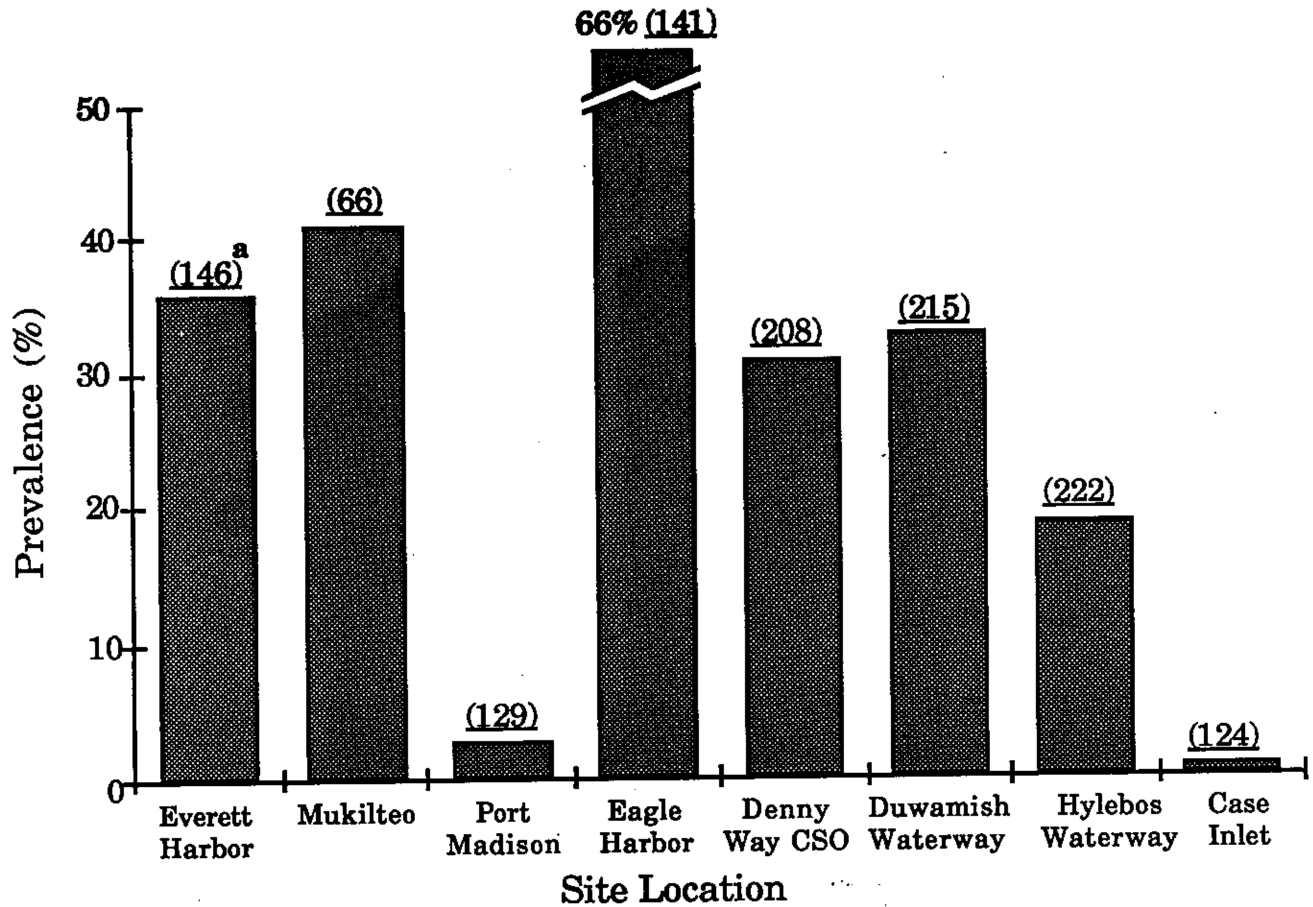

Prevalence (%)
0
2
4
6
8
10
12
14
16
18
20
(146)
(66)
(129)
(141)
(208)
(243)
(222)
(124)
Everett Harbor
Mukilteo
Port Madison
Eagle Harbor
Denny Way CSO
Duwamish Waterway
Hylebos Waterway
Case Inlet
Sampling Sites

Figure 9



[a] (number of fish examined)

Figure 10



66% (141)
(146)a
(66)
(129)
(208)
(215)
(222)
(124)
50
40
30
20
10
0
Prevalence (%)
Everett Harbor
Mukilteo
Port Madison
Eagle Harbor
Denny Way CSO
Duwamish Waterway
Hylebos Waterway
Case Inlet
Site Location

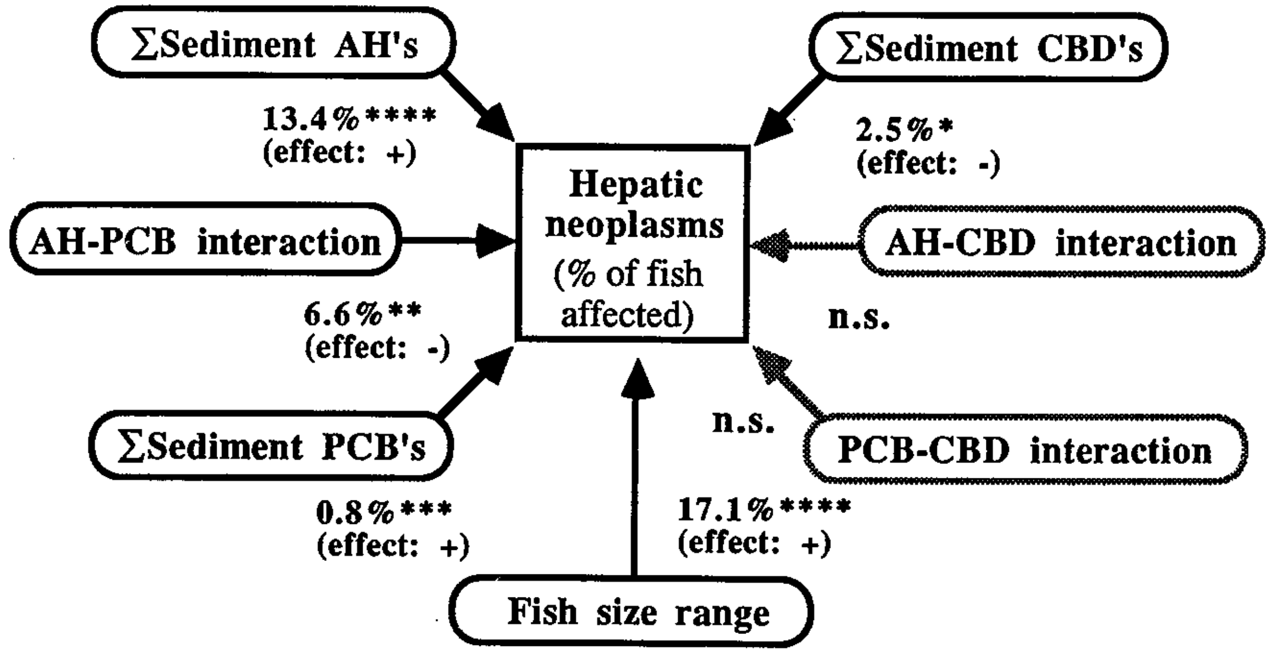
Figure 11

Several of our investigations have detected hepatic neoplasms in bottomfish species from Puget Sound (Malins et al. 1984, 1985a, 1985b; McCain et al. 1982) The highest prevalences of hepatic neoplasms were found in English sole from the lower Duwamish Waterway in Elliott Bay (16.8%, n=215; Malins et al. 1984) and Eagle Harbor (18.4%, n=14; Malins et al. 1985a) (Figure 8). Somewhat lower prevalences of hepatic neoplasms in English sole were found in Everett Harbor, near Mukilteo, and in the Hylebos Waterway in Commencement Bay; they ranged from 5 to 9% (Malins et al. 1984, 1985b). With respect to hepatic neoplasms in rock sole (Lepidopsetta bilineata), the areas having the highest lesion prevalences were the Everett Harbor (4.7%, n=43) and Commencement Bay's Hylebos Waterway (2.5%, n=159) (Malins et al. 1984). Hepatic neoplasms were found in rock sole from all of the urban embayments at prevalences from 0.7 to 4.7%. Pacific staghorn sculpin (Leptocottus armatus) with hepatic neoplasms were found only in Commencement Bay (1.7%, n=116) (Malins et al. 1984). Starry flounder (Platichthys stellatus) with hepatic neoplasms have been detected only in fish from the Duwamish Waterway (1.1%, n=262) (McCain et al. 1982). In early studies (Malins et al. 1984, McCain et al. 1982), hepatic neoplasms were not found in English sole (n=282) from any nonurban areas studied (e.g., Case Inlet, Port Madison, and McAllister Creek). However, in subsequent studies conducted in 1984 and 1985, we detected liver neoplasms in English sole from Case Inlet and Port Madison (Figure 8) (Malins et al. 1986). The tumor-bearing individuals found at the two reference sites tended to be older (≥5 years) fish.

The other types of urban-associated liver lesions were also found in the highest prevalences in sole from areas near Seattle, Tacoma, and Everett, and in other highly contaminated areas, including Eagle Harbor. Prevalences of "preneoplastic" liver lesions in sole from these areas ranged from 10-36% (Figure 10). Low prevalences (0.8 to 3.9%) of this lesion type have been detected in sole from the reference sites (e.g. Case Inlet and Port Madison). The prevalences of specific degeneration necrosis at urban/industrial sites ranged from 19.4% (n=222) in the Hylebos Waterway to 65.9% (n=141) in Eagle Harbor (Figure 11). This lesion type was detected in only 0.8 and 3.1% of the English sole from Case Inlet and Port Madison, respectively.

Studies of the Etiology of Pathological Conditions

Because of the consistent association of liver neoplasms in English sole with chemically contaminated environments in Puget Sound, we investigated the relationships between prevalences of liver neoplasms and concentrations of certain groups of chemicals in bottom sediments and fish tissues (Malins et al. 1984). In order to simplify the complex data set on sediment concentrations of 28 metals and 36 AHs and chlorinated hydrocarbons (CHs) from 40 sampling stations at which both fish and sediment were collected, we performed factor analysis. This mathematical method sorted into groups those chemicals whose concentrations in sediments correlate positively with each other, and yielded four major factors (groups) which accounted for 75% of the variance in the concentrations of chemicals among the stations. Group 1 was dominated by the AHs, Group 2 by the metals, Group 3 by PCBs and selected metals, and Group 4 by CHs.



% = % of variation in neoplasm prevalence explained
n.s. = effect not significant at $p \leq 0.05$
* = effect significant at $p \leq 0.01$
** = effect significant at $p \leq 0.001$
*** = effect significant at $p \leq 0.0001$
**** = effect significant at $p \leq 0.00001$

Figure 12

Using the Spearman rank correlation coefficient procedure, we found a significant ($p=0.003$) positive correlation ($r_s=0.48$) between the prevalence of hepatic neoplasms in English sole and sediment concentrations of AHs (lst group) (Malins et al. 1984). Moreover, in a recently completed summary analysis of the data from the original study of 40 stations combined with data from subsequent studies of 30 stations (e.g., stations in Eagle Harbor and near Mukilteo), a significant ($p=0.0001$) positive correlation between concentrations of sediment-associated AHs and the prevalence of hepatic neoplasms was found using Spearman rank correlation (Table 1).

We also performed a detailed analysis of the results of six field studies using logistic regression (Malins et al. 1987). This method permits the construction of a series of multivariate statistical models relating the prevalences of particular categories of lesions to the combined levels of several different categories of sediment-associated contaminants. Specifically, logistic regression was used to assess the relationships between neoplasm prevalence, fish length, and sediment concentrations of three classes of chemical compounds (AHs, PCBs, and CBDs). The best logistic regression model for neoplasms prevalence accounted for 40.4% of the variation in neoplasm prevalence among the 59 collections of fish at the 46 stations sampled (Malins et al. 1987) (Figure 12). Neoplasm prevalences were positively correlated with sediment concentrations of both AHs ($p \leq 0.00001$) and PCBs ($p \leq 0.0001$), but negatively correlated with sediment concentrations of CBDs ($p \leq 0.05$). Neoplasm prevalences were also negatively correlated with the interaction term for AHs and PCBs ($p \leq 0.0001$). Fish size range exerted an important effect ($p \leq 0.00001$), with observed neoplasm prevalence being greater when only large fish were collected than when the entire size range was employed.

Bile metabolite concentrations measured (at the BaP wavelength pair) in English sole from 11 sites in Puget Sound were also compared statistically (Spearman rank correlation) to the prevalences of certain types of hepatic lesions, including neoplasms in these fish (Table 2) (Krahn et al, 1986). A significant ($p<0.002$) positive correlation ($r_s=0.85$) was found. These results provide supportive evidence for the putative relationship between the aromatic compounds found in the environment and serious liver diseases in bottom-dwelling fish such as the hepatic neoplasm.

Studies conducted by our laboaratory yielded results suggesting that the presence of certain liver lesions in English sole is associated with impaired organ function. Casillas et al. (1985) found an association between certain liver lesions and abnormal values of several serum chemistry parameters characteristic of liver dysfunction and/or damage (Table 3). For example, sole with neoplasms had significantly ($p \leq 0.05$) higher serum concentrations of bilirubin, and significantly lower concentrations of albumin and calcium.

Table 1. Correlations between neoplasm prevalence in English sole and AH concentration in bottom sediments and results of Fisher's combined probability testing (from Malins et al. 1986b).

Sampling Period	No. of stations	No. of tests	Adjusted Signif. level	Neoplasm r_s	Signif- (p) icance
1979-80	31	16	0.0030	0.48	0.003
1982	4	4	0.0125	0.60	0.200
1983	2	4	0.0125	1.00	0.500
1983-84	11	4	0.0125	0.35	0.148
1984	4	4	0.0125	1.00	0.001
1984	9	4	0.0125	0.54	0.066

Results of Fishers Combined Probability Testing

No. of studies in agreement	6
Combined test statistic	39.296
df	12
Significance	0.0001
Adjusted combined signif. level	0.0125

Table 2. Spearman's rank correlation coefficients (r_s) and significance levels for prevalences of hepatic lesions and mean concentrations of bile metabolites measured at benzo[a]pyrene fluorescence wavelengths of English sole from 11 Puget Sound sites (from Krahn et al. 1986).

Lesion type	r_s	Significance level*
Neoplasms	0.853	<0.002
Foci of cellular alteration	0.773	<0.01
Megalocytic hepatosis	0.891	<0.001
Steatosis/hemosiderosis	0.409	<0.5
Total hepatic lesions	0.834	<0.005

* Underlined values indicate results significant at a level chosen to adjust for the number of pair-wise tests performed (0.0125).

Table 3. Significant changes ($p \leq 0.05$) in serum chemistry of English sole (149 fish) with various liver lesions. Values represent percent change relative to normal sole (11 fish).

				Serum Chemistry	
Liver lesion	ALAT	Glucose	Billirubin	Albumin	Calcium
Specific necrosis	+33%	-9%	+31%	-13%	--[a]
Preneoplastic lesions	--	-3%	+31%	-12%	--
Neoplasms	--	--	+31%	-19%	-14%

[a] -- indicates no significant difference.

Effects on Fish Reproduction

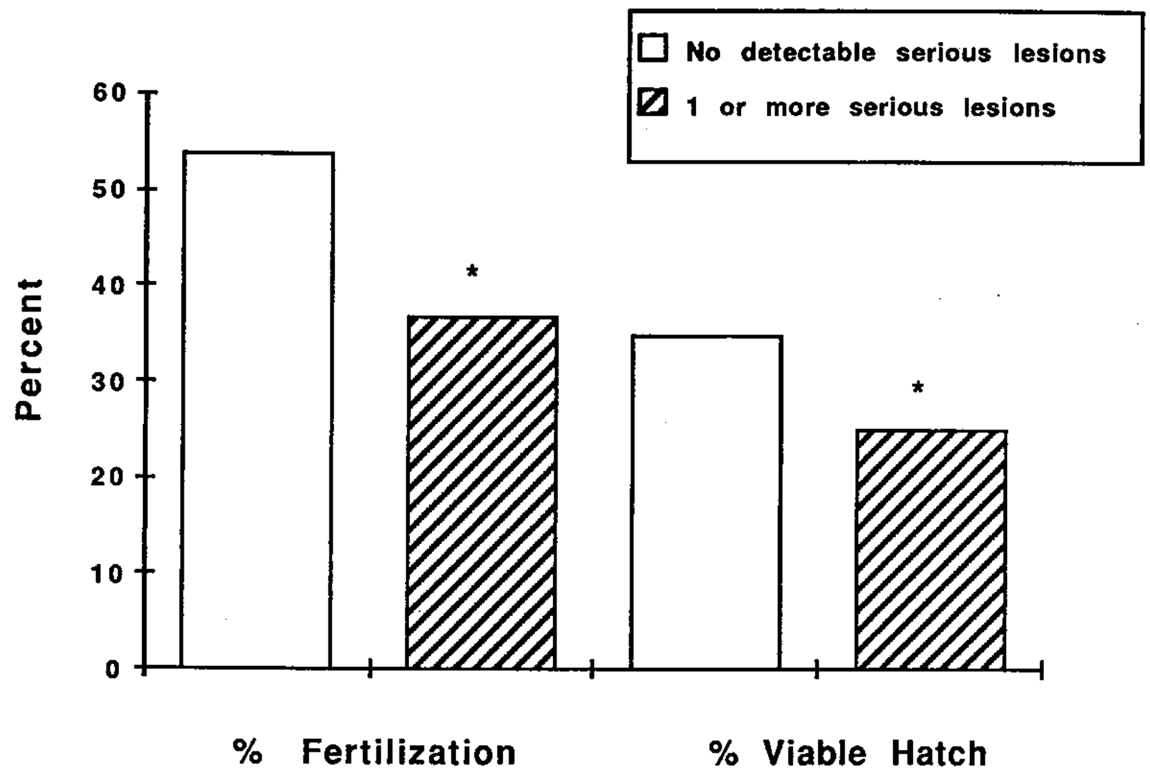
It is clear that prevalences of certain diseases are higher in bottom-dwelling fish from the chemically contaminated areas of Puget Sound, compared to similar species from minimally contaminated areas. Field studies have recently been conducted to evaluate if exposure to contaminated environments affects the reproductive capacity of bottomfish species.

In one series of investigations with English sole, we collected gravid females from contaminated sites and minimally contaminated sites, and induced them to spawn in the laboratory. The eggs were fertilized with pooled suspensions of sperm from several males. The mean percentages of eggs fertilized during this procedure was significantly ($p \leq 0.05$) lower for eggs ($37 \pm 27\%$) from females with one or more serious liver lesions than those for eggs ($52 \pm 30\%$) from females with no detectable liver lesions (Figure 11). Similarly, the mean percentage of viable larvae produced by fertilized eggs was significantly ($p \leq 0.05$) lower for eggs ($24 \pm 22\%$) from females with one or more types of liver lesions compared with those of eggs ($34 \pm 25\%$) from, apparently, "lesion free" sole (Fig. 13).

In an ongoing study, adult (>30cm) female English sole are collected throughout the prespawning period for two consecutive cycles at contaminated sites (the Duwamish Waterway and Eagle Harbor), minimally contaminated sites (near Sinclair Inlet), and at a reference site (Port Susan). Three types of measurements are used to evaluate ovarian development: (1) the presence or absence of signs of vitellegenesis [a stage of oocyte development characterized by the appearance of yolk globules (Wallace and Selman 1981)] in the ovaries, as determined by histological examination; (2) plasma concentrations of estradiol; and (3) gonadosomatic index (GSI), the weight of the ovary divided by the fish's body weight -- results to date show that females from contaminated sites with one or more serious liver lesions had significantly ($p \leq 0.05$) lower GSI values (4.9 ± 4.12) than did females with no detectable lesions (6.5 ± 5.1). Additional biochemical and chemical parameters measured are: activities of hepatic xenobiotic metabolizing enzymes (HXME), concentrations of PCBs in liver and ovary, and concentrations of aromatic compounds in bile. In a complementary laboratory study, sediment extracts are administered to gravid female sole to gauge the subsequent reproductive success of the fish. Both field and laboratory studies use fertilization success (eggs fertilized/eggs spawned) and hatchability (eggs successfully hatched/eggs fertilized) to determine the reproductive viability of the sole's eggs. Evaluation of the results from this two year study should provide in-depth information on whether contaminant exposure impairs reproductive processes in English sole.

Conclusions

We have clearly demonstrated that bottomfish from a few localized areas in Puget Sound near urban centers or other areas receiving heavy inputs



*Significantly lower ($p \leq 0.05$)

Figure 13

of environmental contaminants have high body burdens of toxic chemicals and serious pathological conditions (i.e., liver neoplasms). In addition, very recent studies of juvenile Chinook salmon captured in Seattle's Duwamish Waterway have shown that these fish have substantial body burdens of contaminants. (The potential effects on the health of these juvenile salmon exposed to these toxic chemicals are yet to be assessed.)

To date we have successfully employed a multidisciplinary approach to investigate pollution and its effects in Puget Sound. Following this approach we are further developing sensitive chemical and biological indicators of pollution for use in assessing pollution impact in estuarine and coastal areas. More investigations of cause-and-effect relationships between observed biological effects such as fish diseases and environmental contaminants are also being conducted. At present, evidence linking fish diseases, such as liver tumors, to specific classes of chemicals is based on circumstantial evidence obtained in field studies. These investigations should include additional field studies, as well as controlled laboratory studies. For example, studies in progress in our laboratory involve a series of long-term (1 to 2 year) exposures of English sole and rainbow trout to selected fractions of extracts of sediments from contaminated sites in Puget Sound and to selected individual compounds known to be carcinogenic in laboratory mammals. Fish are periodically sacrificed and examined for histopathological conditions in the liver. Information on cause-and-effect relationships between biological perturbations and individual chemicals or groups of chemicals can help implement source control and/or clean up actions by regulatory agencies.

FIGURES

Figure 1. Map of Puget Sound showing locations of selected sampling sites.

Figure 2. Mean concentrations (ppb, dry weight ± SD) of AHs in sediment samples from selected Puget Sound sites.

Figure 3. Mean concentrations (ppb, dry weight) of PCBs in sediment samples from selected sites in Puget Sound.

Figure 4. Mean concentrations (ppb, dry weight) of chlorinated butadienes (CBDs) in sediment samples from selected sites in Puget Sound.

Figure 5. Mean concentrations (ppb, dry weight) of PCBs in muscle tissues of English sole from seven sites in Puget Sound. Each value represents an analysis of a composite of tissues from five individual fish.

Figure 6. Mean concentrations (ppb, wet weight ± SD) of metabolites of aromatic compounds, measured at BaP wavelengths, in bile of English sole from selected sites in Puget Sound. Each value is the mean of 18 to 37 analyses. (Malins et al. 1986b).

Figure 7. Mean concentrations (ppb, dry weight) of PCBs in stomach content (A) and liver (B) samples from juvenile chinook salmon taken from either the Nisqually River Hatchery, the estuary of the Nisqually River (reference site), or the Duwamish Waterway. Each vaule is the mean of analyses of two composite samples (30 fish per conposite).

Figure 8. (A) Mean concentrations (ppb, dry weight) of summed AHs in stomach content samples from juvenile chinook salmon. (B) Mean concentrations (ppb, wet weight) of metabolites of aromatic compounds, measured at BaP wavelengths (Krahn et al. 1985) in bile of juvenile chinook salmon. For both (A) and (B), fish were captured in either the estuary of the Nisqually River or the Duwamish Waterway. Each value is the mean of analyses of two composite samples (30 fish per composite).

Figure 9. Prevalences (%) of liver neoplasms in English sole from selected sites in Puget Sound. The number of animals examined between 1979 and 1985 at each site is indicated as (n).

Figure 10. Prevalences (%) of foci of cellular alterations ("preneoplastic" lesions) in English sole from selected sites in Puget Sound. Sole were collected and examined histologically between 1979 and 1985). The number of fish examined at each site is indicated as (n).

Figure 11. Prevalences (%) of hepatocellular specific degeneration/necrosis (SDN) in English sole from selected sites in Puget Sound. Sole were collected and examined histologically between 1979 and 1985). The number of fish examined at each site is indicated as (n).

Figure 12. Summary of logistic regression analysis relating sediment concentrations of xenobiotics to prevalences of liver neoplasms among English sole. Results are expressed as percent of variation in neoplasm prevalence. Analysis was based on data from 6 field surveys conducted between 1979 and the present, in which 2697 sole from 46 locations in Puget Sound were examined and 123 cases of hepatic neoplasms were diagnosed. The overall model (AHs + PCBs + size - CBDs - [AH + PCB interaction]) accounts for 40.4% of the observed variation in neoplasm prevalene (n.s. = effect not significant, $p \leq 0.05$;* = effect significant, $p \leq 0.01$;** = effect significant, $p \leq 0.001$;*** = effect significant $p \leq 0.0001$; **** = effect significant, $p \leq 0.00001$.

Figure 13. The reproductive success of gravid English sole from Puget Sound with or without detectable serious liver lesions. The results are based on 65 crosses involving 33 females with serious liver lesions, and 158 crosses involving 79 females with no liver lesions.

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CONTAMINANT LEVELS IN THE EDIBLE PORTION OF RECREATIONALLY CAUGHT FISH FROM PUGET SOUND, WASHINGTON

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Introduction

High concentrations of organic and inorganic contaminants have been found in the sediments of some Puget Sound, Washington embayments, particularly those that are adjacent to urban areas (Malins et al., 1982 a and b). Investigators have also found accumulations of xenobiotic compounds or metabolites in the liver and bile of fish (Malins et al., 1980; Dexter et al., 1981), and in the lipids of marine mammals and birds (Riley et al., 1983; Calambokidis et al., 1984) collected from these areas. Although reports of this contamination have been widely publicized in local news media, the urban embayments of Puget Sound remain a popular fishing site for recreational anglers.

In 1983 a study was initiated to determine the potential for recreational anglers to be exposed to contaminants through consumption of seafood caught near urban areas. The specific objectives of the study were (1) to identify the species most commonly caught by anglers in urban areas of Puget Sound; (2) to demographically characterize the anglers; (3) to characterize the fish consumption patterns of urban anglers (i.e. fishing frequency, amount of fish consumed, tissues eaten, method of preparation); (4) to assess the concentration of principal contaminants in the edible portions of commonly caught species; and (5) to estimate the quantity of selected chemicals consumed by anglers and their families. The major findings of the study will be summarized in this paper. Readers interested in obtaining a more detailed analysis of the study are referred to publications by Landolt et al. (1985 and 1987).

Materials and Methods

Demographic studies. Urban recreational anglers were interviewed over a two year period (November, 1983 to October, 1985). During the first year of the study shoreside anglers (n=4,181) were interviewed at fishing sites located along the waterfronts of four Puget Sound cities (Figure 1). During the second year of the study boating anglers (n=437) were interviewed as they returned to ramps in Seattle and Tacoma.

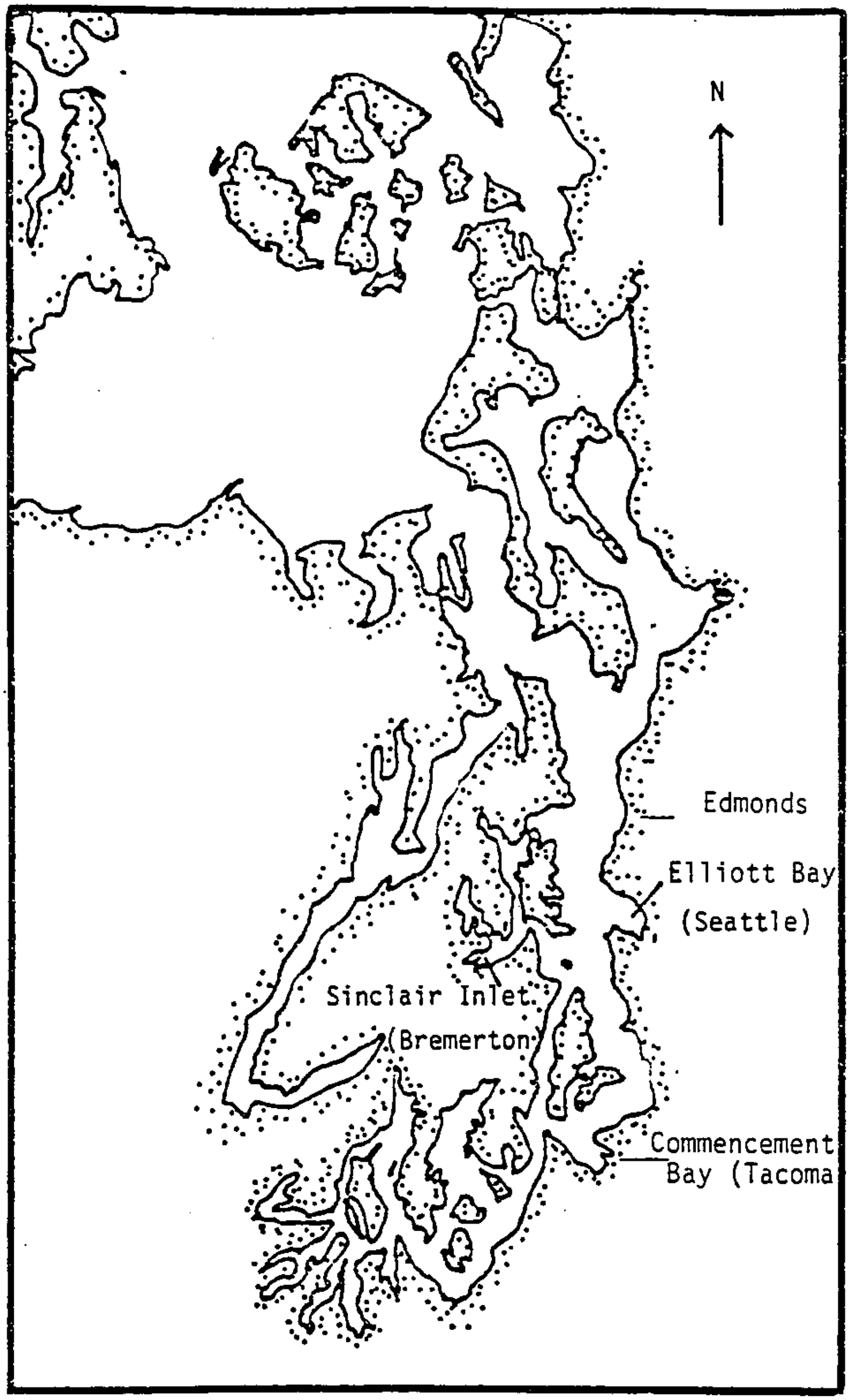

Figure 1. Location of study areas.

Interviews were scheduled so as to provide coverage of different seasons, days of the week, and times of day. A form describing weather and tidal conditions, number of anglers present, type of fishing activity, etc., was completed at the beginning of each survey period.

All interviews were conducted anonymously, that is, names and addresses of anglers were not recorded. Demographic characteristics such as age, sex, race, ethnicity, occupation, and educational background were noted. To estimate fishing frequency, anglers were asked how often they fished in a given area and what type of fish they caught. To estimate consumption, each angler's catch was enumerated, the organisms were taxonomically identified (to species), and their length was measured. The anglers were asked whether they planned to consume their catch. If the answer was positive, they were asked which portions of the body would be eaten, how the tissue would be prepared, and whether other people would partake of it.

Interview data were entered into and analyzed on the PR1ME computer of the Washington State Department of Social and Health Services epidemiology laboratories, using SPSS Version 7.3 (Nie et al., 1975). Statistical tests used a two-tailed significance level of 0.05.

Sample collection for chemical analysis. Based on interview data, several marine species commonly caught by urban anglers were selected for chemical analysis. The organisms were sampled off the piers and at other locations where interviews were conducted. The specimens were either caught with hook and line by the interviewers, were obtained from anglers, or were collected by trawling and beach seining. To prevent contamination of the samples, collectors avoided excess handling and unnecessary contact of the specimens with plastic bags, buckets, rags, docks, fishing piers, etc.

The organisms were placed into glass jars which had been precleaned with detergent, acid rinsed, rinsed with dichloromethane and dried at 200 C. The lids were sealed with a Teflon lining. The specimens were kept cool on ice and transported to the University of Washington. Upon arrival in the laboratory, the jars were drained of excess water and placed in a freezer until dissection and analysis.

Sample preparation for chemical analysis. At the time of analysis, the samples were thawed in their original glass jars and then transferred to solvent-rinsed aluminum foil. After species confirmation, the weight in grams and total length in centimeters were recorded along with any other pertinent information.

The fish skin was cut with a solvent-rinsed scalpel blade and pulled back with forceps to expose the muscle tissue. To avoid contamination, a new scalpel blade and forceps were used to remove approximately 30 g of tissue. Since the specimens varied greatly in size and conformation, specific body sites were chosen to be dissected for each species. Approximately 10-30 g of muscle tissue were used for trace organic analysis, while two subsamples (7 g) were obtained for trace metal analysis and for calculating the wet/dry ratio. All samples and subsamples were stored frozen in solvent-cleaned vials and jars with Teflon-lined lids. In some cases the liver was dissected and stored frozen in solvent-cleaned aluminum foil.

Cooked samples for chemical analysis. In order to obtain a limited evaluation of the effect of cooking on contaminant dose, selected samples were subjected to a "standardized" cooking procedure. Based on interview results, pan-frying was the most common method of fish preparation. In order to minimize variations in cooking, a Teflon-coated electric fryer (wok) was used. This device had thermostatic control and a curved bottom that allowed minimal volumes of oil to be used. Blank analyses were conducted on the cooking oil (Wesson brand), the electric fryer, and the utensils used during cooking (Teflon-coated forceps). Preweighed fish samples (15-24 g) were placed in 50 ml of oil preheated to 200 +/- 10 C. The cooking proceeded for 3-5 minutes, and was halted when the appearance of the fish sample indicated complete cooking. The cooked fish was allowed to drain, and a cooked weight was then determined. Cooked samples were divided between organics analysis and metals assay. Procedures for analysis were identical to those used for raw fish (see succeeding sections).

Trace metals analysis. For trace metal measurement, 0.3-0.5 g dried sample was accurately weighed and transferred into a 50 ml Teflon beaker. The sample was initially digested on a hotplate after adding 10 ml Ultrex HNO_3 and covering the beaker with a Teflon cover. This treatment was enough to decompose most of the organic matter. To assure complete digestion, 2 ml Ultrex HNO_3 and 1 ml $HClO_4$ were added to the sample and the digestion continued to near dryness. If violent reactions were observed, the sample was cooled, an additional portion of HNO_3 was added, and then the digestion was continued carefully.

The final sample was diluted with 0.5 M HNO_3 for instrumental analysis. The lipid content of the sample was not ashed completely and showed as a drop of oil on the surface of the diluted sample. The drop was removed to avoid interference. The instrumental analysis was carried out by flameless atomic absorption spectrophotometry (AA) for Ag, Cd, Cu, and Pb.

For Hg measurement, 1-2 g wet tissue was accurately weighed and placed in glass bottles equipped with glass stoppers. After the bottles were chilled in ice water, 2 ml concentrated H_2SO_4 and 2 ml 6% $KMNO_4$ solution were added sequentially to the samples under continuous stirring (Toffaletti and Savory, 1975). The bottles were then capped and allowed to stand overnight to complete the digestion. Mercury was reduced with $NaBH_4$ and measured as cold vapor.

Neutron activation analysis (NAA) was conducted by standard comparison, in which samples of both known and unknown composition are irradiated together, and the elemental concentrations in the unknowns determined by comparison with the knowns. National Bureau of Standards reference materials were used as standards.

Quality control and quality assurance of the analytical work were approached through a three-tiered program. The first tier included the use of multiple analyses, blanks, standards additions, and primary standards. The second tier included review of laboratory practices and the application of splits, blanks, blinds, and replicates to guarantee performance. The third tier included periodically introducing blinds from outside laboratories and participation in round-robin proficiency testing programs with other laboratories.

Trace organics analysis. Preweighed samples (approximately 10 g) were chopped and slurried with approximately 200 ml methylene chloride. Soxhlet extracted/activated anhydrous granular sodium sulfate (50 g) was added and the mixture ground for approximately 5 minutes using a Brinkman Polytron sonicating tissue homogenizer with PT 35K probe. After initial homogenization, each sample was spiked with 100 ul o,p'-DDE, perdeuterated perylene.The sample was then homogenized further using the PT10 probe. Additional sodium sulfate was added until the sample was efficiently dehydrated as indicated by the persistence of free granular sodium sulfate. When homogenization/dehydration was complete, the slurry was transferred to a fritted glass extraction thimble containing a bed of anhydrous sodium sulfate. The filled thimble was then transferred to a Soxhlet continuous extractor charged with 350-500 ml methylene chloride and extracted for 24 hours. The extract was replaced with fresh solvent and the sample was reground and repacked in the thimble, with fresh sodium sulfate added as necessary, then extracted for an additional 24 hours. Careful Polytron cleaning, inspection and homogenization of blank solvent were used to ensure no cross-contamination between samples. The extracts were combined, concentrated to less than 10 ml, filtered through a 1 um Gelman Acrodisc 0 and diluted to exactly 10 ml, and a 5% aliquot removed for extracted residue weight determination. The remaining extract was concentrated to 1 ml and diluted with 1 ml pentane prior to size exclusion preparative chromatography. Residue weights were determined by air drying to constant weight in a tared aluminum boat.

Size exclusion chromatography (SEC). SEC columns (SX-2 Biobeads, Biorrad, Inc.) were individually calibrated using a standard mixture containing hexachlorobutadiene, hexachlorobenzene, o,p'-DDE, p,p'-DDE, o,p'-DDD, p,p'-DDD, o,p'-DDT, p,p'-DDT, plus several PCB isomerids and several PAHs. They were eluted isocratically with 50% methylene chloride, 50% pentane solvent. Initial elution of the priority compounds (indicated by hexa-chloro-1,3-butadiene) typically began at 90-95 ml, with some non-target compounds (such as pthalates) and considerable biological background eluting in the 70-90 ml fraction. Three fractions were collected: 0-70 ml ("F1", discarded or archived), 70-90 ml ("F2", archived), and 90-350 ml ("F3", for further analysis). The elution behavior of each sample was verified by detection of fluorescent components (perdeuterated perylene plus endogenous PAH) with UV handlight, in a 150-250 ml elution volume range.

Prepared extract concentrate (2 ml) in 50/50 methylene chloride/pentane was loaded on the SX-23 column bed, and the collection of eluate was begun.

Portions of elution solvent (2 ml) were used to transfer the sample quantitatively and to rinse down the walls of the column. The solvent reservoir of the column was then carefully filled without disturbing the chromatographic bed, and the elution continued to completion. Removal and replacement of the top 2 cm of column between samples, if insoluble or non-elution sample components were observed, could be accomplished without affecting the column calibration.

Normal-phase liquid chromatography. Florisil (magnesium silicate, 60/100 mesh, pesticide grade, Sigma Chemical) was cleaned, activated at 1250 C and stored at 100 C until use. The Florisil column (5 g slurry packed in 50/50 methylene chloride/pentane) was direct-coupled to the SEC column and switched into the flow after the "F3" elution cut was reached at 90-95 ml. After elution of the "F3" fraction through the Florisil and collection, the Florisil column was decoupled from the SEC column and further eluted with 50 ml 10% diethylether in petroleum ether. This fraction ("F4") was concentrated and combined with "F3" for GC/ECD. Highly polar components were removed from the Florisil column with methanol and archived ("F5").

Gas chromatography/electron capture detection (GC/ECD). Extracts were solvent exchanged into hexane, spiked with 100 ng/ml decafluorobenzophenone (internal standard 1) and 165 ug/ml octachloronaphthalene (internal standard 2), and subjected to capillary GC/ECD.

Multi-level internal standard-based response curves for each component were established during calibration and verified daily during this analysis. Although these curves are substantially linear, a quadratic response equation was used to fit the calibration data and to quantitate sample components.

Raw chromatographic chart output and integrated response tables were manually inspected to verify proper peak integration, to identify merged components or other indications of interference, and to identify each component of interest, if present. Raw response areas for standard components and analytes were entered in an electronic spreadsheet program (Microsoft Excel run on a 512K MacIntosh personal computer) for quantitation and reporting. Hand calculations were used to verify the accuracy of the final computations.

Level 2 organics analysis. After completing the trace organics screen, some samples were selected for more detailed analysis ("level 2 analysis"). Final extracts (fractions "F3" and "F5" combined) were concentrated to 100 ul and fractionated by high performance liquid chromatography (HPLC). A semi-preparative scale (10 mm i.d. x 250 mm, 5.0 um amine-bonded normal phase, IBM Instruments, Inc.) column was used. Injections were made from a 250 ul partially-filled loop. Detection was accomplished using tandem UV absorbance (254 nm, Waters Model 480) and fluorescence (265 nm excitation and 370 nm emission; Schoeffel Model FS970) spectrometers, each reporting to electronic integrators. Instrument response to target PAH was calibrated prior to and following sample separations. Analytical results from the preparative fractionations were computed using external standard response curves. Two fractions were collected for analysis--an early, low molecular weight PAH (FB) and chlorinated hydrocarbon fraction, and a late high molecular weight PAH fraction (FD). These were concentrated to 10 and 50 ul, respectively, and spiked with perdeuterated phenanthrene internal standard (110 and 150 ng/ul, respectively) for GC/MS analysis.

Analysis by GC/MS was performed using a Finnigan 4023 system, containing a Hewlett Packard 5840B gas chromatograph equipped for capillary analysis with direct transfer of the column through the vacuum manifold into the ionizer of the MS. All quantitation was based on internal standard; 1 ul injection volumes were used.

Samples of chlorinated hydrocarbon fractions (FB) were reanalyzed by GC/ECD. The remaining sample was then diluted to 200 ul in hexane. An expanded standard containing additional pesticides was employed.

Quality control for organics analysis. Quality control for study samples consisted of: internal recovery compounds in each sample, instrumental quality control, and replicate analysis. The recovery compounds used represented the target classes of contaminants (pesticides, chlorinated hydrocarbons, PAH. Mean recoveries (standard error at 95% confidence) were: 2-chloronaphthalene--80.3 (4.3%), o,p'-DDE--80.6 (1.8%). Instrument quality control procedures consisted of daily blanks and reference standards interspersed with study samples.

In addition to exchange of reference materials, interlab quality control included participation in an international PCB interlaboratory comparison sponsored by the International Commission for the Exploration of the Seas (ICES). The laboratory also participated in the National Oceanic and Atmospheric Administration (NOAA) sponsored National Status and Trends Quality Assurance Program to measure PCB congeners in fish oil and in an U.S. Environmental Protection Agency (EPA)/Centers for Disease Control (CDC) project under the Superfund program.

Results

Demographic studies. The average shoreside angler was an employed (57.2%) male (91.6%) with 12 or more years of education (76.6%). Most were Caucasian (68.7%); however, black (8.1%) and Asian (20.9%) fishermen were regularly encountered. The anglers ranged widely in age with a large percentage falling in the 17-34 year (50.1%) and 35-64 year (35.2%) age brackets. Shoreside anglers fished almost as frequently on weekdays (48.8%) as on weekends (51.2%), and were most active between the hours of 6:00 p.m. and midnight (56.2%). Although anglers fished year round, activity peaked in the Autumn (41,8%). More than half the anglers caught nothing (51.7%). Among those who did catch fish, most (70.7%) landed fewer than five per trip. The five most commonly caught species (based on numbers of organisms) were market squid (Loligo opalescens, 39% of catch), Pacific hake (Merluccius productus, 10% of catch), Pacific tomcod (Microgadus proximus, 5% of catch), walleye pollock (Theragra chalcogramma,4.9% of catch), and Pacific cod (Gadus macrocephalus, 3.3% of catch). Overwhelmingly, the fishermen planned to consume only the fillet (93.2%). The most common modes of preparation were frying (53.2%), baking (16.8%), and boiling (11.1%).

The average boating angler was an employed (68.8%) male (95.9%) with 12 or more years of education (91.4%). Most were Caucasian (86.1%); however, black (3.8%) and Asian (8.3%) fishermen were encountered regularly. The anglers ranged widely in age, with a large percentage falling in the 19-39 year (59.9%) and 40-59 year (27.8%) age brackets. Boating anglers fished predominantly on weekends (95.9%) and were most active between the hours of noon to 6:00 p.m. (66.8%). Although fishing activity occured year round, it peaked during the Summer (56.8%). Only 37.1% of the anglers caught no fish. Among those catching fish, most (72%) landed fewer than five per trip. The five most commonly caught species (based on numbers of organisms) were walleye pollock (29.8% of catch), Pacific cod (15.5% of catch), flatfish (mixed species, 12.7% of catch), rockfish (mixed species, 7.5% of catch), and coho salmon (Oncorhynchus kisutch, 7.0% of catch). Use of the term "mixed species" indicates that the fish had already been skinned and filleted at the time the interview was conducted, and that they could not be identified to species. The vast majority of fishermen (98.9%) planned to eat only the fillets. The most common methods of preparation were frying (41.5%), barbecuing (27.3%) and baking (18%).

Trace metals analysis in raw fish. The mean, range and standard deviation of all trace metal measurements are summarized in Table 1. For the purpose of mean calculation, the "less than" values are considered as real values. For example, if the concentration of As was <0.001 mg/g, the value of 0.001 mg/g was used for the mean calculation. Also, the numerical values of non-detectable results were set to equal zero (ND=0) for the mean calcualtion.

The summary results in Table 1 show that the mean concentration of Hg, Cd, Pb, and Se in all of the groups fluctuated within a narrow range, and that the mean values were almost comparable within the standard deviation of the measurements. The Zn and Cu mean values of the different fish species also showed comparable values; however, squid showed clearly higher levels of Cu and Zn than did the fish samples. Rock sole showed almost twice as much As as did starry flounder (3.3 +/- 0.7 mg/g and 1.5 +/- 0.7 mg/g, respectively). Pacific cod and walleye pollock, both migratory species, showed As values (4.4 +/- 2.9 mg/g and 4.6 +/- 4.1 mg/g, respectively) that were comparable to those of the non-migratory rock sole.

Trace metals analysis in cooked fish. The concentrations of trace metals in fried fish (FF) and raw fish (RF) in nine samples are compared in Table 2. The concentrations of trace metals in fried fish were normalized to the weight of raw fish, and then the ratio of metals in fried fish/raw fish were calculated. For the ratio calculations, "less than" or "more than"

Table 1. Mean concentration of trace metals in Puget Sound fish muscle. Values are in ug/g (ppm) of wet tissue.

Species	Length (cm)	Weight (g)	Dry/wet ratio	As	Se	Zn	Ag	Cu	Pb	Cd	Hg
Starry flounder											
Range	28.7-37.7	236.7-680.7	0.14-0.19	0.5-2.6	0-0.3	3.9-6.6	0.0004-0.001	0.22-0.40	0.001-0.002	0.002-0.01	0.002-0.017
n	8	8	8	8	8	8	8	8	8	8	8
$\bar{x}$	33.5	456.5	0.17	1.5	0.13	4.9	0.0006	0.28	0.002	0.005	0.02
σ	3.8	181	0.02	0.7	0.10	1.0	0.0002	0.07	0.0005	0.003	0.05
Rockfish											
Range	13.3-46.0	48.3-2,060	0.19-0.22	0.8-2.9	0-0.2	2.6-5.7	0.0006-0.002	0.17-0.59	0.001-0.01	0.002-0.02	0.002-0.028
n	16	16	16	15	14	16	16	16	16	16	16
$\bar{x}$	24.8	460.3	0.2	1.8	0.11	4.0	0.0008	0.32	0.005	0.009	0.02
σ	9.6	562.5	0.01	0.7	0.07	0.8	0.0005	0.11	0.005	0.006	0.02
Sablefish											
Range	35.0-48.3	428.0-889.0	0.17-0.22	0.8-1.7	0.1-0.1	2.6-3.1	0.0007-0.002	0.26-0.3	0.001-0.002	0.015-0.023	0.003-0.022
n	2	2	2	2	2	2	2	2	2	2	2
$\bar{x}$	41.7	658.5	0.2	1.3	0.1	2.9	0.001	0.28	0.002	0.02	0.013
σ	9.4	326	0.04	0.6	0	0.4	0.0009	0.03	0.0007	0.006	0.013
Rock sole											
Range	21.2-34.8	165.6-509.5	0.21-0.25	2.2-4.3	0-0.2	4.1-6.1	0.0006-0.0007	0.11-0.45	0.002-0.008	0.002-0.02	0.002-0.009
n	8	8	8	8	7	8	8	8	8	8	8
$\bar{x}$	27.2	278.1	0.23	3.3	0.13	5.1	0.0007	0.26	0.004	0.007	0.003
σ	4.8	158.5	0.02	0.7	0.1	0.7	0.0001	0.1	0.003	0.006	0.002
Walleye pollock											
Range	26.3-37.3	146.7-465.3	0.16-0.19	1.1-11.4	0-0.1	3.5-4.8	0.001-0.008	0.25-0.28	0.001-0.012	0.002-0.006	0.001-0.073
n	7	7	7	7	7	7	7	7	7	7	6
$\bar{x}$	30.4	276	0.17	4.6	0.07	3.9	0.003	0.4	0.003	0.004	0.016
σ	3.9	107	0.01	4.1	0.05	0.5	0.003	0.2	0.004	0.001	0.03

Table 1. Continued.

Species	Length (cm)	Weight (g)	Dry/wet ratio	As	Se	Zn	Ag	Cu	Pb	Cd	Hg
Pacific cod											
Range	45.6-61.2	860.0-2,050	0.15-0.17	0.7-9.4	0-0.2	3.0-11.2	0.0005-0.001	0.17-0.59	0.001-0.005	0.001-0.010	0.003-0.090
n	6	6	6	6	4	6	6	6	6	6	6
$\bar{x}$	54.5	1,508	0.16	4.4	0.08	4.9	0.002	0.3	0.002	0.007	0.03
σ	5.1	386	0.01	2.9	0.1	3.1	0.003	0.16	0.002	0.005	0.03
Pacific hake											
Range	18.7-54.5	185.4-1,020	0.17-0.18	0.5-3.5	0.1-0.3	2.1-3.6	0.0005-0.001	0.18-0.31	0.002-0.006	0.003-0.020	0.003-0.009
n	7	7	7	7	7	7	7	7	7	7	7
$\bar{x}$	42.8	663	0.17	2.0	0.2	2.8	0.001	0.25	0.004	0.011	0.005
σ	12.8	354	0.005	1.1	0.07	0.6	0.0009	0.05	0.001	0.007	0.002
Tomcod											
Range	18.7-27.1	60.7-143.4	0.16-0.18	0.5-1.4	0-0.1	3.1-4.2	0.0005-0.0005	0.28-0.42	0.001-0.001	0.002-0.004	0.003-0.008
n	3	3	3	3	3	3	3	3	3	3	3
$\bar{x}$	22.0	97.9	0.17	1.0	0.07	3.8	0.0005	0.34	0.001	0.006	0.005
σ	4.5	42.0	0.01	0.5	0.06	0.6	0	0.07	0	0.005	0.003
Squid											
Range	11.1-16.1	46.2-93.0	0.21-0.22	1.3-15.9	0-0.3	11.5-14.3	0.003-0.091	0.53-5.83	0.002-0.008	0.008-0.120	0.003-0.022
n	7	7	7	4	7	7	7	7	7	7	5
$\bar{x}$	13.7	65.8	0.21	5.7	0.06	13.4	0.04	3.3	0.003	0.04	0.01
σ	1.6	18	0.005	6.9	0.11	1.0	0.03	1.8	0.002	0.04	0.007

Table 2. Comparison of trace metals in fried fish (FF) and raw fish (RF) samples. Values are in ug/g (ppm) of wet tissue. ND=not detected, for mean calculation ND set equal to zero.

Sample Type	Sample No.	Fried Wt. / Wet Wt.	% Water Loss (Wt. %)	As			Se			Zn		
				FF	RF	FF/RF	FF	RF	FF/RF	FF	RF	FF/RF
Rock sole	125	0.34	66.0	1.7	2.4	0.7	0.2	0.2	1.0	16.6	5.3	3.1
Tomcod	275	0.25	75.3	0.75	0.5	1.5	0.1	0.1	1.0	7.4	3.1	2.4
Rockfish	276	0.38	62.5	1.9	2.3	0.8	0.34	0.2	1.7	5.4	4.1	1.3
Pacific cod	260	0.32	67.6	5.6	9.4	0.6	0.22	-	-	5.3	3.0	1.8
Sablefish	263	0.34	65.6	0.9	1.7	0.5	0.31	0.1	3.1	5.2	3.1	1.7
Squid	243	0.41	56.7	1.1	1.3	0.8	0.25	ND	-	13.2	12.8	1.0
Starry flounder	116	0.33	66.6	1.0	1.2	0.8	0.13	0.1	1.3	12.7	3.9	3.5
Walleye pollock	231	0.28	72.0	3.8	9.4	0.4	0.22	ND	-	2.7	3.6	0.8
Pacific hake	202	0.40	60.5	2.4	3.2	0.8	0.4	0.3	1.1	5.3	2.4	2.2
$\overline{X}$	-	0.34	66.0	2.1	3.5	0.8	0.24	0.13	1.5	8.2	4.6	2.0
S.D.	-	0.05	5.6	1.6	3.4	0.3	0.1	0.10	0.8	4.8	3.2	0.9
Wesson oil before frying [b]	500	-	-	0.1	-	-	<0.03	-	-	0.6	-	-
Wesson oil after frying [b]	501	-	-	<0.1	-	-	<0.04	-	-	0.6	-	-

[a] < Values or > values set to = values for the mean calculation.

[b] The values are for unheated oil.

Table 2. Continued.

Ag			Cu			Pb			Cd			Hg		
FF	RF	FF/RF	FF	RF	FF/RF	FF	RF	FF/RF	FF	RF	FF/RF	FF	RF	FF/RF
0.016	<0.0007[a]	≥22.8[a]	0.35	0.32	1.1	0.026	0.002	13.0	0.012	0.002	6.0	<0.002	0.003	≤0.6
0.009	<0.0005	≥18.0	0.65	0.42	1.6	0.085	0.001	85.0	0.011	0.004	2.8	<0.002	0.008	≤0.2
0.008	<0.0006	≥13.3	0.46	0.35	1.3	0.015	<0.002	≥7.5	0.008	0.020	0.4	0.023	0.028	0.82
0.004	<0.0005	≥ 8.0	0.40	0.21	1.9	0.033	0.002	16.5	0.008	0.015	0.5	-	0.033	-
0.004	0.0007	5.7	0.63	0.30	2.1	0.013	<0.002	≥6.5	0.013	0.015	0.9	0.055	0.022	2.5
0.011	0.011	1.0	2.20	2.31	1.0	0.011	0.002	5.5	0.012	0.032	0.4	<0.002	0.005	≤0.4
0.005	0.0005	10.0	0.69	0.22	3.1	0.011	0.002	5.5	0.007	0.007	1.0	-	<0.002	-
0.006	0.001	6.0	0.66	0.80	0.8	0.020	0.012	1.7	0.006	0.005	1.2	0.013	0.006	2.1
0.003	0.0005	6.0	0.88	0.28	3.1	0.030	0.002	15.5	0.008	0.003	2.7	-	0.004	-
0.007	0.0002	10.1	0.77	0.58	1.8	0.030	0.003	17.4	0.009	0.011	1.8	0.016	0.01	1.1
0.004	0.0003	6.8	0.56	0.67	0.86	0.020	0.003	25.8	0.003	0.010	1.8	0.021	0.01	0.95
<0.003	-	-	0.03	-	-	<0.020	-	-	<0.01	-	-	-	-	-
<0.003	-	-	0.02	-	-	<0.020	-	-	<0.01	-	-	-	-	-

values were set to equal values; no ratio was calculated for ND values. The results show that the mean concentrations of Ag, Pb, and Zn in fried fish were substantially higher than the corresponding values in raw fish. The ratios of FF/RF were 10.1 +/- 0.86, 1.8 +/- 1.8, 1.1 +/- 0.95, and 1.5 +/- 0.8, respectively. The FF/RF ratio for As was 0.8 +/- 0.3 which shows a "slight" decrease in the concentration of As as a result of frying. The lower values of some metals, such as As and Hg, in fried fish may have been due to the presence of volatile metal compounds (methylated forms of As and Hg) that were lost from the tissue during frying of the samples. Higher values of some metals, such as Ag and Pb, in fried fish should be interpreted as indicating no substantial change in concentration.

Level 1 trace organics analysis. Spiked recovery of hexachlorobutadiene in eight species averaged 140 +/- 35%. This result along with the higher variability seen in replicate samples, suggests that interference may have been significant in low level samples. The precision of instrumental analysis was 1.9% RSD across the calibrated range, with an R^2 value of 0.9999 (for quadratic response function).

Spiked recovery of hexachlorobenzene in eight species averaged 106 +/- 18%. In the five replicate raw fish analyses where HCB was detected, good agreement between analyses was seen in three instances, while in two cases (0.7 and 0.8 ppb), the replicate level was below the detection limit. In actual fish samples, HCB was found above the detection limit in 21 of 67 samples, with a range and average concentration of 0.5-8.0, and 1.5 ppb, respectively (Table 3). The levels seen are in general agreement with previous results.

Spiked recovery of p,p'-DDE in eight species averaged 93.4 +/- 18%. Replicate analysis of seven fish having detectable DDE showed good agreement in five cases, with two examples having less than detection limit results in one replicate. A closely related compound, o,p'-DDE was used as an intra-assay recovery standard, and showed average overall recovery of 80.6%, with a standard error of 1.8%. DDE was detected in 59 of 67 fish samples (Table 3), with a range and average amount of 0,93-15.6, and 3.6 ppb, respectively. This range of values corresponds reasonably well with that of previous studies.

The compounds o,p'-DDD and o,p'-DDT are not expected to occur to any significant extent in environmental samples, as the commercial DDT used and introduced as pollution was largely the p,p' isomer. The o,p'-DDT isomer co-elutes with the p,p' isomer of DDT under the GC conditions used in this study, so these agents are reported together. However, it is reasonable to infer that all of the detected pesticide is contributed from the p,p'-DDT. The quality control results for the o,p'-DDD were detected in 10 of 67 samples, with a range and average amount of 0.75-5.7, and 1.8 ppb, respectively. None of these low level "hits" were confirmed in the GC/MS analysis. Given the method detection limit of approximately 0.7-1.0 ppb for o,p'-DDD, the few examples of its detection in these samples were probably analytical artifacts.

Table 3. Results of Level 1 trace organics analysis. All results are in ng/g (ppb) wet weight.

SAMPLE ID	LOCATION CAUGHT	GRAM WET WEIGHT	% REC 2-Cl-Naph	%REC o,p-DDE	HEXACHLORO BUTADIENE	HEXACHLORO BENZENE	p,p'-DDE	o,p-DDD	p,p'-DDD/ o,p-DDT	p,p'-DDT	PCBs - SUM OF ISOMERIDS	ESTIMATED TOTAL
STARRY FLOUNDER												
195	CB	8.08	56.59	76.19	<DL	<DL	2.67	<DL	<DL	<DL	113	170
200	CB	8.08	0.00	77.09	<DL	<DL	3.21	<DL	1.78	<DL	69	104
199	CB	8.08	37.18	68.61	<DL	<DL	1.10	<DL	<DL	<DL	23	35
198	CB	8.08	81.12	95.58	0.80	1.02	6.42	1.06	<DL	2.21	175	263
96	SI	8.13	66.66	104.00	<DL	<DL	8.00	<DL	3.76	2.05	108	162
111	SI	8.08	87.67	98.49	<DL	<DL	2.81	0.77	<DL	<DL	345	518
105	SI	8.09	50.66	77.61	<DL	<DL	6.23	<DL	3.53	2.06	227	340
116	SI	7.51	63.39	92.33	<DL	<DL	15.60	1.19	<DL	2.05	196	295
112	BREM	16.00	31.53	18.23	<DL	<DL	2.36	<DL	1.72	<DL	64	96
ROCKFISH												
261	AGT	8.10	89.80	81.81	<DL	0.52	<DL	<DL	<DL	<DL	46	68
217	AGT	8.10	61.04	76.82	<DL	<DL	4.91	<DL	1.85	2.02	54	81
218	AGT	8.08	139.35	85.50	<DL	<DL	3.32	<DL	2.17	<DL	86	129
262	PO	8.08	83.41	54.00	<DL	0.61	3.27	<DL	3.27	<DL	56	83
206	CB	8.08	54.29	68.02	<DL	0.84	2.22	<DL	<DL	<DL	49	73
207	CB	8.08	123.60	81.50	0.82	7.68	<DL	<DL	<DL	1.97	60	91
204	CB	8.08	128.20	84.90	<DL	0.86	2.25	<DL	<DL	<DL	72	108
203	CB	8.08	106.50	86.09	<DL	<DL	1.21	<DL	1.85	<DL	48	73
233	EBDS	6.70	72.68	87.45	<DL	<DL	<DL	<DL	<DL	<DL	39	59
234	EBDS	8.08	87.51	77.30	<DL	<DL	<DL	<DL	<DL	<DL	132	199
32	EB#86	8.08	91.93	72.65	<DL	<DL	2.15	0.79	<DL	<DL	60	90
280	EDM	7.54	89.72	77.09	<DL	<DL	3.49	<DL	<DL	<DL	49	74
276	EDM	8.08	102.80	75.18	<DL	1.09	3.87	<DL	<DL	1.86	95	142
277	EDM	7.23	61.69	50.48	<DL	<DL	2.31	<DL	<DL	<DL	25	38
279	EDM	8.08	85.89	83.36	<DL	<DL	2.50	<DL	<DL	<DL	80	120
278	EDM	8.08	95.24	80.37	<DL	<DL	2.35	<DL	<DL	<DL	36	53
BLACK COD												
264	Pt. Md.	7.60	38.83	61.80	<DL	1.84	8.04	<DL	1.97	3.14	85	127
263	Pt. Md.	8.56	68.06	82.57	<DL	<DL	9.71	0.88	1.87	3.46	120	180
ROCK SOLE												
158	EDM	8.08	110.40	90.64	<DL	0.76	2.40	<DL	<DL	<DL	54	81
159	EDM	8.08	88.34	86.58	<DL	<DL	1.07	<DL	<DL	<DL	30	45
162	EDM	8.08	80.46	77.20	<DL	<DL	2.64	<DL	<DL	<DL	58	88
157	EDM	8.15	36.68	50.00	<DL	<DL	<DL	<DL	3.14	<DL	22	33
125	EB #91	8.08	89.33	76.80	1.14	0.89	5.38	<DL	5.36	<DL	166	249
126	EB #91	8.08	38.48	46.76	<DL	<DL	1.04	<DL	<DL	<DL	[illegible]	49
124	EB #91	6.70	65.91	69.01	<DL	<DL	2.88	<DL	<DL	<DL	138	208
123	EB #91	8.08	80.60	92.51	<DL	<DL	2.99	<DL	<DL	<DL	78	116
WALLEYE POLLOCK												
270	Pt. Md.	8.08	68.39	75.73	<DL	<DL	2.41	<DL	1.91	<DL	[illegible]	49
266	Pt. Md.	8.08	16.81	77.82	<DL	<DL	0.94	<DL	<DL	<DL	16	24
267	Pt. Md.	8.08	75.80	92.06	<DL	<DL	3.32	<DL	1.65	<DL	22	32
269	Pt. Md.	8.08	62.51	87.23	<DL	<DL	1.07	<DL	1.88	<DL	17	25
268	Pt. Md.	8.08	82.78	85.30	<DL	<DL	0.93	<DL	<DL	<DL	18	27
232	CB	8.40	78.81	64.27	<DL	1.95	<DL	<DL	<DL	<DL	13	19
231	CB	8.08	90.78	87.55	<DL	0.86	2.37	<DL	<DL	<DL	30	46
PACIFIC COD												
258	P.O.	6.19	106.70	102.60	<DL	<DL	10.60	<DL	<DL	<DL	209	314
259	P.O.	8.12	99.36	97.90	<DL	<DL	6.03	1.99	1.94	1.83	114	171
260	P.O.	6.00	27.40	55.50	<DL	<DL	4.90	5.70	7.80	<DL	456	684
257	P.O.	5.98	66.58	94.17	<DL	<DL	6.12	<DL	2.52	<DL	75	112
256	AGT	8.11	103.30	89.98	<DL	<DL	8.56	2.43	3.96	3.89	163	245
255	Pt. Jl.	8.09	52.55	93.04	<DL	<DL	8.32	2.39	4.70	4.42	189	283

Table 3. Continued.

SAMPLE ID	LOCATION CAUGHT	GRAM WET WEIGHT	% REC 2-Cl-Naph	%REC o,p-DDE	HEXACHLORO BUTADIENE	HEXACHLORO BENZENE	p,p'-DDE	o,p-DDD	p,p'-DDD/ o,p-DDT	p,p'-DDT	PCBs - SUM OF ISOMERIDS	ESTIMATED TOTAL
HAKE												
202	CB	8.08	63.72	73.38	0.83	1.61	5.06	<D.L	1.83	7.47	95	143
DSHS-15	EB#57	8.11	85.39	81.95	<D.L	<D.L	3.69	0.75	1.99	3.45	120	180
DSHS-16	EB#57	8.08	165.90	80.08	<D.L	1.53	3.54	<D.L	3.40	1.86	90	135
281	Pt. Jf.	8.08	8.13	70.51	<D.L	<D.L	2.31	<D.L	1.78	<D.L	41	62
282	Pt. Jf.	8.08	94.12	91.29	1.79	0.66	1.02	<D.L	1.81	1.91	50	75
283	Pt. Jf.	8.08	50.81	90.22	<D.L	<D.L	1.03	<D.L	1.87	<D.L	45	68
284	Pt. Jf.	8.08	102.70	94.60	<D.L	1.23	2.76	<D.L	<D.L	<D.L	72	108
193	EDM	18.00	140.00	95.89	<D.L	0.68	<D.L	<D.L	2.64	<D.L	74	111
TOMCOD												
274	Pt Md.	8.14	59.07	64.62	<D.L	<D.L	2.54	<D.L	3.52	<D.L	33	49
273	Pt Md.	8.14	84.31	85.54	<D.L	<D.L	1.06	<D.L	<D.L	<D.L	57	86
275	Pt Md.	8.13	101.80	83.16	<D.L	<D.L	3.88	<D.L	4.18	3.17	88	132
16+43	CB	9.00	236.00	79.12	<D.L	2.97	<D.L	<D.L	*	<D.L	36	54
SQUID												
239	BREM	8.08	45.55	89.36	<D.L	<D.L	2.81	<D.L	1.90	<D.L	62	93
240	BREM	8.08	56.55	84.37	<D.L	<D.L	0.94	<D.L	1.91	<D.L	55	82
249	EB#70	8.08	86.51	93.39	<D.L	0.96	1.22	<D.L	1.89	<D.L	48	72
245	EB#86	8.08	89.20	87.92	<D.L	1.50	1.10	<D.L	<D.L	<D.L	41	61
243	EB#86	8.16	71.15	96.29	<D.L	1.64	3.49	<D.L	7.44	<D.L	153	230
24	EDM	8.14	46.34	88.40	<D.L	<D.L	2.31	<D.L	1.77	<D.L	38	57
28	EDM	8.08	114.10	103.20	<D.L	<D.L	1.02	<D.L	1.83	<D.L	50	74

LOCATION CODE KEY:
"CB" = COMMENCEMENT BAY
"BREM" = BREM 1ST ST DOCK
"EB#–" = ELLIOT BAY PIER #
"Pt. Md." = POINT MADISON
"EDM" = EDMONDS FISH PIER
"Pt. Jf." = POINT JEFFERSON
"P.O." = PORT ORCHARD
"AGT" = AGATE PASS BRIDGE
"EB DS" = ELLIOTT BAY DENNY ST. INLET
"SI" = SINCLAIR INLET

*merged with o,p-DDT Spike

Spiked recovery of p,p'-DDD in eight species averaged 79.5% (85.2% with the exclusion of one questionable recovery result). Replicate analysis of seven fish samples having detectable p,p'-DDD showed good agreement in two cases and less than detectable results in replicate samples in five cases (all were within 3 ppb of the method detection limit for this compound). In actual samples, p,p'-DDD was detected in 35 of 67 cases, with a range and average amount of 1.7-7.8 and 2.8 ppb, respectively. These levels are consistent with previous results and with the levels of p,p'-DDE reported.

Spiked recovery of p,p'-DDT in eight species of fish averaged 112%. Of the eight fish samples run in replicate, this compound was detected in only one (non-replicated) instance. In actual samples, p,p'-DDT was found in 17 of 67 examples, with a range and average amount of 1.8-7.5 and 2.9 ppb, respectively. These levels are close to the method detection limit, but are consistent with previous reports and with the levels of p,p'-DDE and p,p'-DDD seen in these samples.

Spiked recovery of PCBs was evaluated using a mixture of seven isomerids (dichloro- through octachlorobiphenyl). This task was complicated by the significant background of environmental PCB compounds in the samples. Correction for unspiked background yielded an average recovery for eight species of fish of 115%. Replicate fish analysis showed agreement that averaged 4.4% RSD. Analysis of actual samples gave detectable PCB compounds in 67 of 67 cases, with a range and average sum of 13-456 and 84.3 ppb, respectively. Estimation of total Aroclor level, based on these results, gave a range and average of 19-684 and 125 ppb, respectively. These results are in agreement with previous reports.

Level 2 trace organics analysis. GC/MS analysis of Level 2 fish confirmed the presence of PCBs and chloronaphthalene (spiked QC compound), but failed to confirm the lower level analytes (e.g. hexachlorobenzene, DDT) seen in Level 1 analysis. No other chlorinated xenobiotic agents were identified from these samples, with an estimated detection threshold of 1-10 ppb. Re-analysis of the Level 2 samples by GC/ECD failed to detedt any of the following pesticides (above an estimated detection limit of 1 ppb wet weight): (alpha, beta, gamma, delta)-BHC, aldrin, heptachlor epoxide, gamma-chlordane, dieldrin, endrin, beta-endosulfan, endrin aldehyde, endosulfan sulfate, methoxychlor, mirex. A chromatographic peak at the correct retention time for heptachlor was observed in several samples in amounts equivalent to 1.6-11.5 ppb. None of these results were confirmable by mass spectrometry, although the highest samples were above the nominal instrument detection limit. It is currently believed that this peak was an interferent. The results of these analyses are shown in Table 4.

Polynuclear aromatic hydrocarbons were detected in two assays: HPLC/UV absorbance/fluorescence and GC/MS. The results for both are presented in Table 4. In the present study, these methods should be viewed more as complementary than comparable, since fluorescence and absorbance methods provided more sensitive detection of the key 5-ring PAH compounds than did

Table 4. Level 2 polyaromatic hydrocarbon analysis results. All results are in ng/g (ppb) wet weight.

SAMPLE:	ROCK SOLE		BLACK COD		STARRY FLOUNDER		HAKE		PACIFIC COD		PACIFIC COD		ROCK FISH		SQUID		TOM COD		POLLOCK	
	GCMS	HPLC	GCMS	HPLC	GCMS	HPLC	GCMS	HPLC	GCMS	HPLC	GCMS	HPLC	GCMS	HPLC	GCMS	HPLC	GCMS	HPLC	GCMS	HPLC
SAMPLE WEIGHT, g	4.84		5.13		3.76		4.84		6.19		1.04		8.08		8.16		8.13		8.08	
SPIKE RECOVERY (%)	93.6	88	117.1	67	25.2	48	79.3	75	45.7	57	30.7	58	*	67	52.1	33	50.6	34	96.4	75
DETECTION LIMIT, ppb	0.5		0.5		0.7		0.5		0.4		2.4		0.3		0.3		0.3		0.3	
QUANTITATION LIMIT, ppb	5.2		4.9		6.6		5.2		4		24		3.1		3.1		3.1		3.1	
NAPHTHALENE	<QL				<QL						<QL		<QL							
2-METHYL NAPHTHALENE	<QL				<QL								<QL						<QL	
1-METHYL NAPHTHALENE							<QL						<QL						<QL	
2,6-DIMETHYL NAPHTHALENE																				
ACENAPHTHENE							<QL													
FLUORENE																				
PHENANTHRENE					8.3		7.5		4.3	3.1	<QL		5.6		6.4		3.1			
ANTHRACENE															<QL					
1-METHYL PHENANTHRENE													<QL		<QL		<QL			
FLUORANTHENE	<QL	18.7	<QL		<QL		<QL		<QL	23.5		31.5	<QL		12.5	0.5	<QL		<QL	
PYRENE	<QL	0.1	<QL		<QL		<QL		<QL	25.1			<QL		10.2	3.8	<QL		<QL	
BENZ[a]ANTHRACENE		3.4	<QL	3		2.7		2.5				4		8.5		2.9		2.3	<QL	1.6
CHRYSENE				0.5		0.2						0.5		0.6		1.3		0.3	<QL	0.1
BENZO[e]PYRENE		0.6				0.6				1				3.3		2.1		0.8		
BENZO[a]PYRENE		*		12.3		1.7		4.1						2.8		*		*		*
PERYLENE		*		*		*		*		*		*		*		*				*
DIBENZ[a,h]ANTHRACENE		*						*						12.9		1.4				

BLANK VALUES ARE <DL
* INDICATES MERGED PEAKS

GC/MS, while the lighter PAH compounds were more sensitively detected by GC/MS. Given the greater specificity of the GC/MS analysis, the GC/MS result should be relied upon in such cases of disagreement. Recovery for PAH compounds was estimated by use of perdeuterated perylene spiked into raw fish samples prior to extraction and quantitated in HPLC-fractionated fish using GC/MS. The average recovery seen was 70.7%. The levels of PAH seen ranged from trace levels (<1 ppb) to 32 ppb; however, few of the levels seen could be confirmed by GC/MS. The very low levels of PAH seen in tissue are consistent with several previous studies of PAH metabolism in fish and with field studies of fish tissue taken in what is currently viewed as the most severe example of PAH contamination in Puget Sound, i.e. Eagle Harbor (Malins, 1985). Based on the results shown in Table 4 and in previous studies, individual PAH carcinogens in edible tissue are clearly expected to fall below 10 ppb, regardless of sampling site.

Trace organics analysis in cooked fish. The raw fish versus cooked fish assay results are shown in Table 5. These results are presented in two ways--as raw levels and as levels corrected for recovery of the spiked o,p'-DDE. The cooked fish samples in several cases would not permit quantitation by the standard Level 1 protocol, due to sample or oil matrix interference with the second chromatography standard (octachloronaphthalene), so external standard response was used for these samples. In general, for all of the compounds considered, reductions in tissue levels of 30% or more were seen after cooking. One consistent exception to this trend was the Pacific tomcod experiment, where apparent increases were seen. These increases were not large (a few ppb) and might be an effect of cooking on the fish matrix, or some analytical artifact. Without further replication, however, this result should be considered anomalous. The other samples display expected reductions as predicted by previous studies, and as would be expected for contaminants associated with lipid components of tissue that are rendered out of the fish as liquid during cooking. The overall conclusion from this experiment is that wet tissue analysis of contaminant loading represents worst-case contamination, which would decrease upon frying.

Estimation of human exposure to contaminants. In order to estimate contaminant exposure in recreational anglers, one trace metal (arsenic) and one class of trace organic (PCBs) were selected for study. Based on the data presented in this report, the 5th, 50th and 95th percentile levels of these compounds were calculated (ignoring species and site). These values represented a global estimate of the concentration of these compounds. For arsenic the concentrations were: 5th percentile--1 ppm; 50th percentile--3 ppm; 95th percentile--20 ppm. For PCBs the levels were: 5th percentile--24 ppb; 50th percentile--81 ppb; 95th percentile--315 ppb. Based on these values and using estimated consumption rates (derived from interview data) dosage rates (ug/person/day) were calculated for four commonly caught species. The results are presented in Tables 6 (arsenic) and 7 (PCBs).

Table 5. Organic toxicant levels in raw versus cooked (fried)fish. All results are in ng/g (ppb) wet weight.

	Sample Number	%RECOVERY 2-CL-NAPH	%RECOVERY o,p-DDE	NG/G WET WEIGHT: hexachloro butadiene	hexachloro benzene	p,p'-DDE	o,p-DDD	p,p-DDD + o,p-DDT	p,p'-DDT	Individual PCB isomerids: Cl-3-Ø2	Cl-4-Ø2	Cl-5-Ø2	Cl-6-Ø2	Cl-7-Ø2	Cl-8-Ø2	Cl-9-Ø2	Cl-10-Ø2
INTERNAL STANDARD QUANTITATION:																	
STARRY FLOUNDER																	
Uncooked	116	83.39	92.33	<DL	<DL	15.60	1.19	<DL	2.06	<DL	6.20	<DL	208.28	14.95	10.97	7.30	<DL
Cooked	116-C	104.40	94.07	<DL	<DL	5.27	<DL	2.39	<DL	<DL	<DL	<DL	41.59	3.64	<DL	3.78	1.53
ROCKFISH																	
Uncooked	276	102.80	75.18	<DL	1.09	3.87	<DL	<DL	1.86	1.05	2.08	<DL	19.42	1.49	<DL	<DL	<DL
Cooked	276-C	62.76	48.56	<DL	<DL	0.94	<DL	<DL	<DL	<DL	0.52	<DL	[illegible]	<DL	<DL	0.46	<DL
PACIFIC COD																	
Uncooked	260	27.40	55.50	<DL	<DL	4.90	5.70	7.60	<DL	<DL	3.10	2.90	15.90	1.62	1.98	<DL	<DL
Cooked	260-C	66.46	77.19	<DL	<DL	1.58	<DL	1.89	<DL	<DL	0.98	<DL	6.42	<DL	<DL	0.96	0.31
WALLEYE POLLOCK																	
Uncooked	231	90.78	87.55	<DL	0.86	2.37	<DL	<DL	<DL	<DL	3.25	<DL	7.30	0.66	0.94	<DL	<DL
Cooked	231-C	83.20	67.96	0.85	<DL	<DL	<DL	<DL	<DL	<DL	0.65	<DL	1.80	<DL	<DL	4.28	1.42
TOMCOD																	
Uncooked	275	101.80	83.18	<DL	<DL	1.07	<DL	1.88	<DL	1.68	3.26	<DL	9.33	0.69	<DL	<DL	<DL
Cooked	275-C	66.25	61.97	<DL	<DL	2.04	<DL	6.79	3.26	0.99	3.71	<DL	11.00	<DL	2.21	<DL	8.55
ROCKSOLE																	
Uncooked	125	89.33	76.80	1.14	0.89	5.38	0.00	5.36	0.00	0.65	4.78	0.00	33.17	2.07	1.47	<DL	25.67
Cooked	125-C	111.96	88 80	<DL	<DL	1.75	<DL	2.05	<DL	<DL	1.52	<DL	8.91	0.73	<DL	<DL	1.36
BLACKCOD																	
Uncooked	263	88.06	82.57	<DL	<DL	9.71	0.88	1.87	3.46	0.55	9.17	<DL	30.64	2.26	1.28	<DL	<DL
Cooked	263-C	102.09	74.43	<DL	<DL	2.82	<DL	1.93	<DL	<DL	1.91	<DL	6.39	<DL	<DL	<DL	0.40
SQUID																	
Uncooked	243	71.15	96.29	<DL	1.64	3.49	<DL	7.44	<DL	1.85	43.06	<DL	26.70	1.95	0.99	<DL	<DL
Cooked	243-C	57.61	69.17	<DL	<DL	1.23	<DL	<DL	<DL	<DL	1.34	<DL	7.15	<DL	<DL	<DL	<DL
HAKE																	
Uncooked	202	83.72	73.38	0.83	1.61	6.06	<DL	1.83	7.47	2.47	7.14	<DL	18.45	<DL	<DL	<DL	<DL
Cooked	202-C	61.26	43.42	25.05	0.30	1.26	<DL	<DL	<DL	<DL	0.95	<DL	3.01	<DL	<DL	<DL	1.10
CORRECTION TO 100% RECOVERY:																	
STARRY FLOUNDER																	
Uncooked	116			<DL	<DL	16.90	1.29	<DL	2.22	<DL	6.66	<DL	225.56	16.19	11.89	7.91	<DL
Cooked	116-C			<DL	<DL	5.60	<DL	2.54	<DL	<DL	<DL	<DL	44.21	3.87	<DL	4.02	1.63
ROCKFISH																	
Uncooked	276			<DL	1.06	5.15	<DL	<DL	2.47	1.40	2.77	<DL	25.83	1.98	<DL	<DL	<DL
Cooked	276-C			<DL	<DL	1.94	<DL	<DL	<DL	<DL	1.07	<DL	5.34	<DL	<DL	0.94	<DL
PACIFIC COD																	
Uncooked	260			<DL	<DL	8.83	10.27	14.05	<DL	<DL	5.59	5.23	28.65	2.92	3.57	<DL	<DL
Cooked	260-C			<DL	<DL	2.02	<DL	2.45	<DL	<DL	1.28	<DL	8.32	<DL	<DL	1.24	0.41
WALLEYE POLLOCK																	
Uncooked	231			<DL	0.95	2.71	<DL	<DL	<DL	<DL	3.71	<DL	8.34	0.75	1.07	<DL	<DL
Cooked	231-C			1.02	<DL	<DL	<DL	<DL	<DL	<DL	0.96	<DL	2.65	<DL	<DL	6.30	2.09
TOMCOD																	
Uncooked	275			<DL	<DL	1.29	<DL	2.26	<DL	2.02	3.92	<DL	11.22	0.83	<DL	<DL	<DL
Cooked	275-C			<DL	<DL	3.29	<DL	10.96	5.26	1.60	5.99	<DL	17.75	<DL	3.56	<DL	13.79
ROCKSOLE																	
Uncooked	125			1.28	1.00	7.01	0.00	6.98	0.00	0.85	6.22	0.00	43.19	2.70	1.91	<DL	33.42
Cooked	125-C			<DL	<DL	1.98	<DL	2.31	<DL	<DL	1.72	<DL	10.04	0.82	<DL	<DL	1.53
BLACKCOD																	
Uncooked	263			<DL	<DL	11.76	1.07	2.26	4.19	0.67	11.11	<DL	37.11	2.74	1.55	<DL	<DL
Cooked	263-C			<DL	<DL	3.78	<DL	2.60	<DL	<DL	2.56	<DL	8.58	<DL	<DL	<DL	0.54
SQUID																	
Uncooked	243			<DL	2.30	3.62	<DL	7.73	<DL	1.92	44.72	<DL	27.73	2.03	1.03	<DL	<DL
Cooked	243-C			<DL	<DL	1.36	<DL	<DL	<DL	<DL	1.51	<DL	8.02	<DL	<DL	<DL	<DL
HAKE																	
Uncooked	202			1.30	2.53	6.90	<DL	2.49	10.18	3.37	9.73	<DL	25.14	<DL	<DL	<DL	<DL
Cooked	202-C			40.89	0.48	2.90	<DL	<DL	<DL	<DL	2.19	<DL	6.92	<DL	<DL	<DL	2.53

Table 6. Estimated range of arsenic doses (ug) per person per day of consumption. Values are based on observed mean catch and upon arsenic values from tissue analysis. Differences among species are due to different rates of consumption of fish. Fish consumption rates are from Table 63 in Landolt et al. (1985).

Species	Assumed Consumption rate gms/person/day	Estimated aresenic dose (ug) Percentile bound		
		5th	Median	95th
Sable fish	30	30	90	600
Pacific cod	27	27	81	540
Squid	39	39	117	780
English sole	11	11	33	220
Overall	11	11	33	220

Table 7. Estimated range of PCB doses (ug) per person per day. Values are based on observed mean catch and upon PCB values from tissue analysis. Differences among species are due to different rates of consumption of fish. Fish consumption rates are from Table 63 in Landolt et al. (1985).

Species	Assumed Consumption rate: gms/person/day	Estimated PCB Dose (ug) Percentile Bound		
		5th	Median	95th
Sable fish	30	.7	2.4	9.4
Pacific cod	27	.6	2.2	8.5
Squid	39	.9	3.2	12.0
English sole	11	.3	.9	3.5
Overall	11	.3	.9	3.5

Discussion

The purpose of this two year study was to gain insight into the fishing habits and demographic characteristics of urban anglers with the ultimate goal of estimating their potential for exposure to contaminants as a consequence of consuming recreationally caught fish from Puget Sound. The study did not attempt to assess risk, but rather to estimate catch and consumption.

Catch patterns for shoreside and boating anglers were similar, but not identical. The species most commonly taken by pier fishermen (squid) was not caught at all by boaters. Other species, however, were frequently caught by both groups. Both groups primarily caught pelagic fish rather than sediment-associated species such as flatfish which have been a source of concern because they often bear idiopathic lesions that may result from contaminant exposure. The catch rate was higher for boaters.

Consumption patterns were similar for the two groups in terms of the portions of the fish that were consumed and their mode of preparation. Daily consumption rates differed between groups, with shoreside anglers appearing to have higher consumption rates for most species.

Demographically, the two groups were similar in many respects, but they differed in others. Boaters were much less racially and ethnically diverse, and were predominated by Caucasians. On the whole, boaters had higher levels of education and were more affluent.

In general, the concentrations of trace metals detected in this study closely resembled levels measured in previous Puget Sound studies (Gahler et al., 1982; Stober and Pierson, 1984; Romberg et al., 1984; Tetra Tech Inc., 1985). No major differences were noted between trace organics levels measured in this study and those of previous Puget Sound studies (Malins et al., 1980; Malins et al., 1982; Gahler et al., 1982; Galvin et al., 1984). Results of the cooking experiment were consistent with expected findings.

Contaminant exposure estimates, intended to represent exposures conservatively (i.e. to overestimate exposures within the uncertainty in the estimation method) were lower than similar estimates conducted nationally or in other regions. The U.S. Food and Drug Administration total diet study estimated mean daily intake of total dietary arsenic to be 63 ug/day (compared to a 50th percentile overall dose of 33 ug/day in the present study). FDA estimates of PCB mean daily intake range from 19 ug/day (nationally) up to 39-313 ug/day (Great Lakes region). Thiese values compare to the worst-case estimate of 12 ug/day in the present study.

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THE PUGET SOUND ESTUARY PROGRAM: MANAGING FOR ENVIRONMENTAL RESULTS

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Introduction

Puget Sound, located in the northwestern part of the State of Washington, is one of the most biologically productive and recreationally important estuarine systems in the United States. The 2,200 square miles of bays and inlets, and over 2,000 miles of shoreline, support a rich and diverse commercial and sport fishery for fish and shellfish. Economically, the Puget Sound basin is a focus for industrial and commercial activity, shipping and international commerce. It is a major recreational attraction and contributes significantly to growing tourism in the area. Puget Sound is more, however, it's blue waters, beautiful beaches, and marine life are a symbol of the quality of life so important to the people of the Pacific Northwest.

The quality of Puget Sound is a gauge of our success in environmental protection. Programs to control and prevent water pollution, protect living resources, and minimize risks to public health have long been in place in the Puget Sound region. Over the past 20-30 years, significant environmental improvements have resulted from the control of many conventional pollutants, and today, much of the Sound remains relatively healthy and capable of supporting a broad range of beneficial uses. However, continuing growth and development of the region are imposing ever increasing demands upon the estuary. There is growing evidence that serious water quality problems remain.

In 1985, a number of agencies and organizations joined forces to develop a coordinated strategy for investigating and correcting current Puget Sound environmental problems. The multi-agency effort was initially known as the Puget Sound Initiative, and later as the Puget Sound Estuary Program (PSEP).

The Puget Sound Estuary Program is different than any other estuary program currently sponsored by EPA. The primary difference is the three-pronged approach being used in Washington State. Other estuary programs emphasize characterization of estuarine conditions and long-term planning, while deferring problem resolution until extensive study has been completed. The PSEP program, on the other hand, places equal, if not greater, emphasis on taking early action to control currently recognized environmental problems. The approach encourages enhanced regulatory and enforcement activity throughout the life of the program.

The focus of PSEP resources on issues related to chemical contamination is also unique among similar estuary programs across the nation. The decision to emphasize chemical concerns was based on: (1) consensus among the Puget Sound scientific community that the unchecked spread of chemical contamination is the most serious problem threatening the Sound today, and (2) that limited resources spread thinly over multiple issues could purchase only minimal environmental improvement.

Finally, PSEP is unique because the technically oriented federal program is being conducted in concert with a comprehensive planning effort initiated at the state level. The Puget Sound Water Quality Authority (PSWQA), created by the Washington State Legislature in 1985, has been tasked with the mission of developing a long-term management plan for the Sound. In addition, PSWQA has the responsibility of working with state and local agencies to ensure that plan recommendations are implemented. This state commitment is significant because it frees the federal program to focus resources on technical issues, rather than dividing limited funds between both research and planning. Moreover, the partnership of PSWQA and PSEP provides a vehicle for ensuring that the regulatory and research needs identified by PSEP are addressed expeditiously at the state and local level.

This paper describes the Puget Sound Estuary Program; the environmental concerns that lead to its creation and the strategies that are being developed for addressing them. The three main components of PSEP are highlighted: development of toxics control programs for the most heavily contaminated parts of the Sound; characterization of the Sound's water quality problems and resources; and development of management tools and a management framework for addressing current pollution problems and preserving the future quality of Puget Sound.

Environmental Concerns That Lead to the Creation of PSEP

During the 1980's, studies by the National Atmospheric and Oceanic Administration (NOAA), the U.S. Environmental Protection Agency (EPA), the Washington State Department of Ecology (WDOE), and others, identified significant biological problems involving toxic contaminants at a number of locations in Puget Sound. Significant concentrations of priority pollutants and other chemicals, including highly toxic and very persistent materials, such as polychlorinated biphenyls (PCBs), and heavy metals, such as mercury, arsenic and lead, were identified in the sediments of a number of urban and industrial embayments.

In addition, field surveys identified abnormalities in bottom dwelling communities and increased frequencies of diseases (i.e., liver tumors, skin lesions) in fish caught in areas with high concentrations of chemicals in the sediments. It was suspected that the edible tissue of fish and shellfish harvested in certain parts of the Sound might contain potentially harmful levels of chemical contaminants. Whether or not the consumption of these animals posed a significant threat to human consumers was not known, but data indicated that species in higher trophic levels, which fed on Puget Sound organisms, were accumulating potentially harmful chemicals in their tissues.

In 1985, these and other concerns about the well-being of the estuary prompted the Congress to appropriate funds for use by EPA in initiating the Puget Sound Estuary Program. PSEP combines a near-term search for solutions to current problems, together with longer-term research and monitoring to improve predictive capabilities. The program was created to strengthen and better coordinate the collective regulatory, research, and resource management efforts of the many agencies having responsibilities in the Sound. Currently, a total of sixteen federal, state, and local agencies, and several universities and indian tribes participate in the Estuary Program.

Goals and Objectives of PSEP

The long-term mission of the PSEP is to ensure the maintenance of a healthy marine environment that allows maximum beneficial use of the Sound and its resources. Collectively, the participating agencies seek to achieve a level of environmental quality that provides for the protection of public health and welfare, assures protection and propagation of a balanced, indigenous population of fish, shellfish, and wildlife, and allows recreational activities in and on the waters of the Sound. As a means of achieving this goal, PSEP objectives have been established as follows:

1. Evaluate available information to define the nature and extent of existing and developing water quality-related problems in Puget Sound, particularly those associated with chemical contamination.

2. Identify deficiencies in the data available to support development of pollution abatement and long-range estuary management decisions and develop and implement programs to collect and evaluate the additional needed information.

3. Develop and implement appropriate abatement and remedial action plans to correct priority Puget Sound water quality problems.

4. Establish long-term water quality management policies to ensure protection of public health and the natural resources of the estuary.

5. Improve communication and coordination of water quality management activities among federal, state, and local agencies and interested and effected citizen's groups.

The selection of PSEP goals and objectives and the identification of the program's technical emphases were influenced by several assumptions.

The first assumption guiding PSEP efforts has been that prompt action must be taken to address presently known, acute environmental problems associated with chemical contamination of the Sound. Historically, regulatory agencies with responsibilities in the Sound focused most of their attention on limiting the discharge of conventional pollutants from large facilities. Regulating the discharge of toxic chemicals, and establishing linkages between small facilities and environmental impacts has been more difficult. These difficulties result from the complexity of water quality problems and the uncertainties associated with identifying contaminant sources.

The PSEP program operates on the premise that, in order to protect the Sound, it will not be possible to wait until all cause and effect relationships are established before taking action to resolve pollution problems. Chemical contamination can result from the discharge of large or small facilities, and can be expected wherever industrial or municipal activity is concentrated. Because chemical contamination poses a threat both to human health and marine life, control of contaminants, through whatever means are necessary, has been given high priority by the Estuary Program.

The second assumption which has influenced the design of the PSEP program has been the recognition that a comprehensive approach to estuarine management should incorporate investigation of estuarine processes (e.g., contaminant transport and deposition), assessment of current environmental conditions (e.g., levels of contaminants in fish tissue), and consideration of changes that have occurred in the estuary over time and space. Such analyses attempt to establish linkages between resource use and environmental impact, and improve our ability to predict adverse effects associated with cumulative impacts of pollution. The technical findings resulting from characterization and problem identification studies enable managers to separate perceived from real problems, identify environmental problems that may not be readily apparent, and identify information needed to further assess problems and their causes.

Finally, PSEP efforts have been influenced by the assumption that a coordinated approach and the use of effective management tools are essential to the successful, cost effective and timely resolution of environmental problems. Existing knowledge about the Sound has not always been well communicated, nor have ongoing regulatory or research programs been well coordinated. It is now recognized that joint efforts are required to fully and accurately identify problems, develop new and innovative management tools, and coordinate policies and priorities.

PSEP Accomplishments and Results

Not surprisingly, the studies funded by the Estuary Program can be divided into three main program areas: toxics control in urban bays, estuary characterization, and improved management. In the past two years, substantial progress has been made in each area. The approaches taken and recent accomplishments in each program area are highlighted below.

Urban bay toxics control programs

In addressing chemical contamination in Puget Sound, the first priority of PSEP has been to control sources of contamination to the most seriously polluted areas. Thus, a major thrust of PSEP has been the design and implementation of "action programs" for the urban/industrial bays. This geographic focus enables concentration of limited resources first in the areas which need them most.

By design, the toxics action programs call for early action based on existing information to prevent further chemical contamination and environmental degradation. As part of the strategy, quantitative relationships derived from analysis of existing field data are used to associate contaminant sources and biological effects, and "interim source control action plans" are developed which recommend specific remedial actions (e.g., revised/enhanced/new permits, source monitoring, enforcement action) required to control sources of contamination. The action plan for each bay includes a prioritization of sources, a schedule for action implementation and the identification of the agency or individuals who could most appropriately implement plan components.

To assist in the identification of necessary corrective actions, and to ensure that remedial activities are carried out, special "action teams" of enforcement/compliance investigators are assigned to each bay by the state Department of Ecology. The function of the Action Team is to canvas high priority areas, attempting to identify and control sources of contamination. As interim, or first round, remedial actions are being implemented, supplemental sampling and source analyses are conducted to identify additional problem areas and problem sources. Based on the supplemental data, the interim plan is revised and a new schedule of actions identified.

Toxics Action Programs are currently being implemented in Elliott Bay and Everett Harbor. These programs are possibly the most visible of all PSEP studies. Sampling and source control initiated in Elliott Bay and Everett Harbor over the past two years have generated much media and public attention. Although it is too soon to see dramatic changes in the quality of the study areas, current toxics control efforts are already reducing the loading of chemical contaminants to the Sound. Significant improvements are expected in time.

For Elliott Bay, an interim source control action plan has been developed jointly by EPA and the Washington Department of Ecology, with input from an interagency technical work group and a citizens advisory committee. The three person Elliott Bay Action Team, operating out of Ecology's Northwest Regional Office, has been working in Elliott Bay and the Duwamish River for approximately one year. To date, the team has conducted 156 site investigations of known or suspected sources, initiated 35 enforcement actions, revised 12 discharge permits and issued 5 new permits to previously unpermitted discharges. A revised source control action plan is currently being developed for Elliott Bay, based on the additional site characterization and source data that was generated through a sampling program carried out in the summer of 1985.

The Everett Harbor program was initiated in 1986, approximately one year after work began in Elliott Bay. To date, an Everett Harbor action team has yet to be assigned. However, substantial progress has been made towards characterizing the study area and probable sources of toxic contamination. Based on existing information, a comprehensive problem identification report has been generated and an interim action plan is currently being developed.

Estuary characterization and problem identification

The PSEP approach to improving understanding of the overall estuarine system builds upon previous work undertaken by EPA, NOAA, the Department of Ecology, and the University of Washington. The approach involves synthesis and analysis of spatial and temporal trends using historic and current data on pollutant loads, water and sediment quality, and living resources. In addition, intensive field and literature surveys are used to evaluate current conditions.

An evaluation of past and current estuary characterization efforts revealed several areas in which additional work was needed. In response, PSEP funded characterization and problem identification studies have addressed a broad range of topics, including investigations of chemical uptake in marine organisms, trends in chemical and nutrient loadings and related water quality impacts, routes of contaminant transport and deposition, and evaluation of changes in living resource distribution and abundance. Although many of the PSEP characterization studies have yet to be completed, significant products have already resulted. Two of the most noteworthy are the Puget Sound Environmental Atlas, and a series of pollutant loading reports which detail the current state of knowledge about the loading of various contaminants to the Sound.

The Environmental Atlas, which consists of a series of approximately 500 maps with overlays and accompanying narrative, is expected to provide a common reference for agencies focusing action on preventing and/or solving Puget Sound environmental problems. Based on the consensus of the local scientific community, the information presented in the Atlas includes the most reliable information available about pollution sources, resource distribution, and current environmental conditions.

The Puget Sound Pollutant Loading study focused on identification of historic and recent data about the loading of contaminants, from both point and nonpoint sources, to the estuary. The study provides a basis for using the limited information which now exists, and for determining where additional data collection is needed to quantify specific loadings.

Improved management

In addition to developing an improved technical understanding of the system, an objective of PSEP has been to support the improvement of the overall management of the estuary. Specifically, the program has attempted to develop consistency between agencies, mutual support for common goals and the most efficient use of limited financial resources. In the past two years, PSEP efforts to improve estuary management have focused on a variety of issues. Of particular significance has been progress made in the area of interagency coordination and cooperation.

The majority of funding for PSEP supported studies comes from EPA. However, the U.S. Army Corps of Engineers, the Department of Ecology, Seattle Metro, the City of Seattle, and other agencies have also contributed. Other agencies and individuals are encouraged to participate in PSEP from the planning phase through program implementation. To accommodate this involvement, a formal management structure has been developed. This structure is significant because it represents the first time in recent years that a forum has existed for regular interagency coordination and cooperation on issues concerning Puget Sound.

PSEP is administered on a day to day basis by staff in EPA's Office of Puget Sound. The program receives management direction from an Implementation Committee (IC). The IC, a group of senior-level administrators representing each of the participating agencies, is co-chaired by representatives of EPA, the Department of Ecology, and the Puget Sound Water Quality Authority. The Committee meets bimonthly to discuss water quality problems, to outline and evaluate strategies for dealing with problems, and to identify areas in which interagency coordination can enhance independent efforts.

The IC receives scientific and technical advice from the Technical Advisory Committee (TAC), a committee comprised of members of the scientific community involved in Puget Sound research. The TAC provides recommendations concerning research priorities and assists in the design and oversight of PSEP funded scientific studies. Both the TAC and the Implementation Committee are instrumental in developing and approving annual work plans for the estuary program.

Citizens are involved in PSEP through participation at public meetings and representation on citizens advisory committees (CAC). CACs, composed of representatives of environmental and user groups are currently functioning for each of the PSEP Urban Bay Toxics Action Programs. It is recognized that without citizen support for the program, critical political, legislative and funding support would not be forthcoming.

All participating agencies are considered partners in PSEP. However, the EPA and the Puget Sound Water Quality Authority are developing a special relationship. The Authority, created by the Governor of Washington State in 1985, has been assigned the mission of developing a comprehensive management plan for Puget Sound. This plan provides a framework for the studies being conducted by PSEP. To ensure that resources are not wasted through duplication of effort, and that studies provide information that can benefit both programs, representatives of PSEP and PSWQA have signed a formal memorandum of agreement. The agreement binds both PSEP and PSWQA to coordinating and cooperating on issues involving the management of Puget Sound. As a result of the agreement, PSEP and PSWQA are sponsoring a number of jointly funded studies, including the Puget Sound Environmental Atlas and the Puget Sound Monitoring Program.

In addition to improved interagency coordination, a number of PSEP efforts have resulted in significant progress in the area of improved interagency consistency. The most visible of these efforts have addressed standardization of protocols, development of comprehensive environmental monitoring programs, and techniques for evaluating sediment contamination.

Developed jointly with the U. S. Army Corps of Engineers, the PSEP Protocols Manual is nearing completion. This manual details recommended techniques for sampling and analysis of physical, chemical, and biological variables in Puget Sound. A number of protocols have already been issued, and several are undergoing final technical review. It is anticipated that use of consistent protocols by all agencies will result in the generation of data that is not only of consistently high quality, but is also exchangeable and comparable.

In cooperation with PSWQA, PSEP is developing an integrated monitoring program for Puget Sound. The program, which builds on and augments existing monitoring programs at the federal, state, and local level, represents an attempt to begin evaluating conditions and trends in Puget Sound in a coordinated and consistent manner. The comprehensive monitoring program, which is currently in draft form, will include ambient monitoring of physical, chemical, and biological conditions, monitoring conducted in conjunction with permitted discharges, and intensive surveys.

PSEP efforts to develop tools for evaluating the extent and significance of sediment contamination in the Sound began in

1985. The results of this study are important because they address one of the most complex environmental regulatory problems facing Puget Sound managers today. The first phase of the PSEP sediment quality study is complete, although it is apparent that additional work will be required. PSEP efforts to date have focused on identification and evaluation of techniques that can be used in developing sediment quality values (SQVs). SQVs are chemical specific numerical values which will be used by EPA and other agencies in identifying and managing contaminated sediments in Puget Sound.

In addition to those listed above, other important studies have been sponsored by the Estuary Program. A complete list of these studies is included in Table 1.

Puget Sound Estuary Program Future

By the end of 1987, PSEP efforts will have resulted in substantial progress toward improved management of Puget Sound. A framework will exist to ensure ongoing interagency coordination and cooperation, and the approach developed for the Urban Bay Action Program will provide the basis for future toxics control activity. In addition, the completion of a limited series of characterization studies will enable managers to begin the process of separating real from perceived environmental problems.

Although progress will have been made, it is anticipated that the Estuary Program will receive only two or three more years of federal funding beyond 1987. Much of this support will be needed to complete already initiated studies. Supplemental funding for additional years will be required to address the new environmental questions which are currently emerging.

It would be satisfying for program managers to see all PSEP efforts through to completion. However, the realistic scope of PSEP is limited to developing the basis for additional research and regulatory actions. When federal funds are no longer available, it will be the responsibility of the State to maintain the integrity of the program. To ensure that the transition proceeds smoothly, PSEP will strive to achieve a number of milestones in the coming three years. These milestones include the following:

Urban bay toxics control programs

- Complete final or interim action plans for Elliott Bay, Everett Harbor, Shilshole Bay, Budd Inlet, Sinclair Inlet.

- Work with the Department of Ecology to establish Action Teams in each of the Bays.

- Conduct field surveys as necessary in each bay to collect information for source identification/prioritization.

- Compete several pilot projects demonstrating use of remedial action technologies in addressing in-place sediment contamination.

Characterization and problem identification

- Develop a process for routine updating of Puget Sound Environmental Atlas

- Characterize the nature and extent of chemical contamination in Puget Sound in areas outside of urban and industrial embayments.

- Conduct additional studies to evaluate the significance of emerging environmental problems (e.g., chemical contamination of the sea surface microlayer).

Improved management

- Identify environmentally protective criteria that can be used in identifying, managing, and preventing sediment contamination.

- Develop addition protocols as needed and a process for routine updating of the Puget Sound Protocols Manual.

- Support the implementation of the comprehensive monitoring program for the Sound.

By the end of 1989, the year that EPA funding is expected to expire, a solid basis will have been developed for effective regulation and control of chemical pollution in Puget Sound. It is important to note, however, that the legacy of PSEP will only be a basis for further action, and that this framework will primarily address toxics concerns. Continued commitment on the part of the State will ensure that PSEP recommendations are implemented. Additional funds, from both federal and state sources, will be required to respond to the many non-toxics problems influencing the health of Puget Sound.

Table 1. PSEP Accomplishments to Date

<u>Urban Bay Toxics Control Programs</u>

Elliott Bay
- Data Summaries and Problem Identification Report
- Review of Existing Plans and Activities Report
- Interim Action Plan
- Sampling Program
- Action Team

Everett Harbor
- Data Summaries and Problem Identification Report
- Review of Existing Plans and Activities Report
- Sampling Program

<u>Characterization and Problem Identification</u>

Puget Sound Environmental Atlas

Pollutant Loading Investigation

Contaminant Transport Study

Chemical Contamination of Edible Seaweeds

Symposium Co-Sponsor, Toxic Chemicals in Aquatic Environments and Biological Effects

<u>Improved Management</u>

Implementation Committee and Technical Advisory Committee

Puget Sound Protocols Manual

Human Health Risk Assessment Manual

Evaluation of Techniques for Establishing Sediment Criteria

Puget Sound Data Management Evaluation

Chemicals of Concern Matrix

Development of Standard Reference Material for Puget Sound Sediments

Table 1. PSEP Accomplishments to Date

Public Education
- Seattle Aquarium Puget Sound Exhibit
- Pacific Science Center Puget Sound Exhibit
- Adopt-A-Beach Volunteer Program
- Puget Sound Notes newsletter

Puget Sound Environmental Management Report

Table 2. Currently Funded PSEP Studies

Urban Bay Toxics Control Programs

Elliott Bay Toxics Action Program

Everett Harbor Toxics Action Program

Shilshole Bay/Lake Union Investigation

Characterization and Problem Identification

Changes in Nutrient Loadings and Water Quality Over Time

Distribution and Abundance of Puget Sound Crab

Chemical and Bacterial Contamination in Puget Sound Shellfish

Chemical Contamination in Blackmouth Salmon

Human Health Risks Associated with Consumption of Puget Sound Fish, Shellfish, and Seaweed

Survey of Toxics Related Problems Outside of Urban Bays

Improved Management

Puget Sound Protocol Development

Development and Refinement of Bioassay Techniques

Development of Puget Sound Monitoring Program

Development of Puget Sound Sediment Criteria

Computer Bibliography of Puget Sound Documents

Public Education
- Adopt-A-Beach Volunteer Program
- Puget Sound Notes newsletter

THE PLAN FOR PUGET SOUND'S FUTURE

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Introduction

The story of Puget Sound is similar to that of other bays and estuaries around the United States. It is a unique natural resource that provides an economic and recreational focal point for the residents that inhabit its shores and watershed. The Sound supports significant international shipping activity and is noted for its fish and shellfish resources, its ecological, scientific, and recreational values, and its beauty. Increases in the number of people and their related activities have led to changes in its environment and increasing competition for use of its natural resources. Problems of pollution and loss of valuable resources have led to public outcry and demand for governmental action.

Thus far, this could be the story of many estuaries in the nation. But in Puget Sound, the response on the part of government has been, perhaps, more timely than in other regions of this country. Although the symptoms were alarming, the estuary had not reached the same state of degradation found in other water bodies such as San Francisco or Chesapeake Bay. In Puget Sound, governmental intervention was timely and decisive. Whether the outcome will be different is the part of the story that remains to be written.

Establishment of the Puget Sound Water Quality Authority

Many agencies in the state of Washington are active in addressing water quality issues. These governmental entities include literally hundreds of public bodies: federal and state agencies; county and city governments; tribal nations; port, water, diking, sewer, and other special purpose districts. This fragmentation of responsibility is a challenge to any effort to manage and protect Puget Sound. In 1984 Region 10 of EPA and the state Department of Ecology took the lead by forming the Puget Sound Action Program (subsequently renamed the Puget Sound Estuary Program). Along with the other state and federal agencies that joined this endeavor, EPA and Ecology made progress in defining the problems in Puget Sound and increasing coordination among the various programs attempting to address them.

Following on this progress, the newly-elected governor, many legislators, and environmental groups felt that a more formal and comprehensive governmental response was necessary to address increasingly alarming reports regarding the health of Puget Sound. In May of 1985 the Washington State Legislature transformed the advisory Puget Sound Water Quality Authority into a full-fledged agency charged with the mission of developing and overseeing the implementation of a comprehensive plan for the cleanup and management of Puget Sound. This plan is to be carried out by existing state and local agencies. The Authority is governed by a seven-member board appointed by the governor (including one full-time chair), joined by two non-voting members--the heads of the state Departments of Ecology and Natural Resources.

Planning Process

As a new agency, the Puget Sound Water Quality Authority faced the tasks of establishing itself as a focal point for Puget Sound activities and developing a planning program that could build the consensus needed for a successful plan. The planning effort was two-pronged. The Authority's technical staff focused on compiling and analyzing available information on Puget Sound's problems; the public outreach staff worked on newsletters, mailing lists, brochures, slide shows, media relations, and getting out to the 12 counties surrounding the Sound to listen to people's concerns about water quality. An advisory committee and panel of scientists were formed to assist the Authority in developing the plan.

The conclusions from the technical analyses were that the primary problems in Puget Sound result from (1) contamination of bottom sediments by organic and inorganic chemicals, and (2) bacterial pollution. The sources of these contaminants are many and varied. Major sources include industrial and municipal discharges; runoff from highways, urban, and agricultural areas; dredging and spoils disposal; failing septic systems; forestry practices; spills; combined sewer overflows (CSOs); and recreational boating.

Documented effects include fin erosion and liver tumors in bottom-dwelling fish in urban bays (Malins et al., 1982); closure of several prime commercial shellfish beds due to bacterial pollution (PSWQA, 1986); changes in structure and abundances in benthic communities (Tetra Tech, 1985); and elevated levels of PCBs and some metals in certain species of fish, shellfish, birds, and marine mammals (Dexter et al., 1981). The bottom sediments, particularly in urbanized areas, appear to be highly toxic to some organisms (Long, 1985, PSWQA, 1986). As a result of the presence of highly contaminated bottom sediments, Commencement Bay is a designated Superfund site, and Eagle Harbor is proposed for such designation. More recently, laboratory studies of the sea surface microlayer (an extremely thin layer of mainly organic substances that float on the surface) have shown high toxicity to fish eggs and oyster larvae (Hardy and Kiesser, 1986). In addition to problems of contamination, Puget Sound has lost over half of its wetlands to human activity (PSWQA, 1986).

There also have been improvements in the Sound over the years with changes in land use, improvements in technology, and tightening of regulations. For example, secondary treatment of pulp mill effluents has largely reversed severe degradation and resource losses that had occurred in some parts of the Sound. The deposition of some restricted chemicals--such as DDT and PCBs--has slowed in recent years (Dexter et al., 1985). At the same time, increased population and more intense land uses have tended to be accompanied by additional water pollution (PSWQA, 1986). It is difficult to predict what effect a population increase of 30 percent by the year 2000 will have on the Sound.

One of the major conclusions of the technical analyses was that there are still large gaps in our understanding of the Sound and how it is affected by contamination. Consequently, it is difficult to precisely determine the status of Puget Sound's resources and predict future trends. Although the sources are known, the relative contributions from different sources are not well understood. And, once pollutants have entered the Sound, only limited knowledge exists as to their fates and effects. Many of the existing studies of biological effects show correlations rather than cause-and-effect relationships. Existing monitoring programs are limited in scope and not coordinated, thus making it difficult to obtain sufficient data for a good understanding of environmental conditions and pollutant loadings.

In addition to analyzing the resource problems, PSWQA studied the effectiveness of current programs to control the known sources of contamination. Point sources of pollution are generally regulated at the state and federal levels, with the NPDES permit system being the primary control mechanism. Examination of this program revealed major weaknesses in all aspects of the point source control program, including major gaps in the control of toxicants and weak inspection, enforcement, and monitoring efforts. Programs at the state and local levels addressing nonpoint source pollution are fragmented, and many sources are uncontrolled. Although wetland preservation is an issue that has received much attention in recent years, many Puget Sound wetlands and other habitats are still threatened by development. Almost all government programs are underfunded, which in many cases means that current federal and state legislative mandates for resource protection are not being carried out. Although there are numerous laws, programs, and agencies addressing Puget Sound issues, the programs lack coordination and are not comprehensive. Many important issues are simply not being adequately addressed. Few overlaps in programs were found.

Along with the technical analyses, the Authority conducted a public opinion survey to assess the knowledge and attitudes of Washington State residents about water quality issues. In general, there is high recognition of water quality problems and support for increased resource protection. Six out of ten people surveyed believe that Puget Sound has a water quality problem. However, many residents believe that industry is the major source of pollution; there is less recognition of problems caused by other sources such as farm practices or urban stormwater runoff.

The results of the Authority's technical analyses were published in a series of nine issue papers and a State of the Sound Report. Following public review and comment on the issue papers, the Authority prepared and issued the draft Puget Sound Water Quality Management Plan and Environmental Impact Statement (EIS). Public hearings were held in all twelve Puget Sound counties on the combined draft plan and EIS, and several hundred written comments were received. Based on the results of this public review, the Authority developed a revised plan proposal and issued the final EIS. In December of 1986, the Authority unanimously adopted the final plan.

The 1987 Puget Sound Water Quality Management Plan

The purpose of this plan is to protect and enhance three resources: the Sound's water and sediment quality; its fish and shellfish; and its wetlands. The plan is premised on a long-term goal to prevent any increase in the introduction of pollutants to the Sound and its watersheds, and to reduce and ultimately eliminate harm from the entry of pollutants to the waters, sediments, and shorelines of Puget Sound. This emphasis on prevention recognizes the simple truth that it will cost more to clean up pollution later than to prevent it now. Each of the source control programs in the plan contains specific goals and actions to prevent additional pollution.

Recognizing that water pollution crosses jurisdictional lines, the plan establishes a framework based on a partnership between state and local agencies, each having a defined set of responsibilities in different areas. The plan also recognizes and includes actions by tribes, the private sector, and citizens, and it relies on the federal government to play an important role as well.

An important emphasis of the plan is effective implementation of existing governmental programs, particularly the provision of adequate staff and funding for those programs. The plan prescribes expansion of existing programs and the establishment of new programs to address designated problems. It uses existing agencies rather than calling for the creation of new ones.

This plan is comprehensive: it addresses the major sources of water and sediment quality degradation and wetland loss; it generally applies to all of the Puget Sound basin; and it employs a range of solutions--regulatory, educational, and policy. At the same time, it calls for programs targeted to particular geographic locations.

Special emphasis is given to the control of toxicants discharged into Puget Sound by strengthening existing regulation of industrial and municipal discharges. This is accomplished through controlling toxicants in permits; adopting sediment quality criteria; increasing frequency of inspections (including unannounced inspections); aggressively seeking out unpermitted discharges; requiring more complete discharge monitoring and use of certified laboratories; and implementing pretreatment requirements. Increased discharge permit fees are proposed to fund a significant portion of the improvements in the program.

The generation and spread of contaminated sediments are controlled through the programs for stormwater, dredging and disposal, and by regulation of point sources. The program for contaminated sediments and dredging includes goals for sediment quality and dredging and disposal programs. It requires standards for dredged material disposal and a feasibility study of multi-user disposal sites for contaminated sediments. And building on a major initiative of the state Department of Ecology and EPA, the plan calls for an accelerated program to identify and investigate contaminated sediment sites.

The plan requires stormwater programs in all cities and other urbanized areas in the Puget Sound basin phased in over the next 13 years. Local stormwater programs are to emphasize source controls and best management practices rather than end-of-pipe treatment.

Control of bacterial pollution from septic systems, farm animals, and recreational boating is addressed in the nonpoint program, with special attention given to commercial and recreational shellfish areas. The plan requires locally determined and implemented nonpoint pollution control action plans in priority watersheds. Local efforts are augmented by several state government programs--a boaters task force to tackle pollution problems from boats; and several initiatives relating to on-site sewage treatment, including a proposal to ensure that systems are functioning properly at the time of property sale.

The protection of Puget Sound wetlands is accomplished by a state level program for identification and acquisition of significant wetland habitats. This program is augmented by enhancement of local regulatory programs for wetland protection.

In recognition of the considerable scientific uncertainty that exists about the effects of pollution in Puget Sound, the plan also includes programs for research and monitoring of the health of the Sound. A comprehensive monitoring program is necessary to guide actions over the long term including modification of the plan and development of new programs.

Because the responsibility for protecting Puget Sound involves action by individuals, businesses, and all levels of government, education is a key feature of the plan. The plan contains both education requirements in specific programs and an overall education and public involvement program.

Inherent in the plan is a strong sense of priorities. Decisions on priorities are reflected by the Authority's decision to include some issues and programs in the plan and not others. The scheduling of target dates for completion of certain programs also reflects decisions on priorities.

The price tag for this plan is estimated to be approximately $20 million per year for agency operating costs. Costs associated with public capital improvement programs and private sector compliance with the plan's provisions would be in addition to this amount. One primary funding source for plan implementation will be the state's Water Quality Account, a fund established by the legislature in 1986 by adding an eight cent per pack tax on cigarettes.

State and local agencies will be the primary implementers of the plan. Through 1991, the Authority will provide continuing oversight and technical assistance and will work to ensure compliance. The Authority is required to revise and update the plan by January 1, 1989, and January 1, 1991.

The adoption of the Puget Sound Management Plan is a major milestone for the Sound. The plan represents the first comprehensive effort to address the Sound's water quality problems and develop ways to solve them. The problems were not created overnight, and they won't be solved overnight. The plan establishes a program for managing the Puget Sound over the long term; a program that will ensure that Puget Sound is protected for the enjoyment and benefit of future generations.

Appendix

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POLLUTION MANAGEMENT IN WASHINGTON STATE

Andrea Beatty Riniker
Department of Ecology
State of Washington

The last two years have brought profound changes in Washington State's management approach to fighting water pollution.

In those two short years we have developed a plan to clean up Puget Sound. We passed several landmark pieces of pollution fighting legislation and approved a major new tax plan which will raise $575 million between now and the year 2000 for improving and protecting our water.

Strong leadership from Gov. Booth Gardner and the Legislature, combined with other factors, have created not only a tide for change in the way we fight pollution, but also high expectations for results.

Those expectations are an important element for us to consider in the months ahead as we continue charting our course to clean up Puget Sound. It is important that we develop realistic plans and realistic expectations.

Puget Sound will not be cleaned up in one year or two, and we must make sure members of the public understand that. Otherwise they may become disappointed with our progress, disenchanted with our program and we could risk losing the important momentum we have gained in improving and protecting the resources of Puget Sound and the rest of the state.

We were fortunate to turn our attention to Puget Sound at a relatively early time, certainly before the situation became desperate. There were a number of factors which helped our state leaders make this commitment.

One factor is the strong environmental ethic in the state. The environment is deeply rooted in the economy and lifestyle of the state. One recent public opinion survey suggested that 64 percent of the people favor environmental protection, even, in some cases, over economic development.

In addition to this strong environmental ethic, however, we had other significant developments. Puget Sound cleanup became a major element in our 1984 gubernatorial election. Scientific studies, which you have heard about today, begged for action on the sound. The media joined the chorus for pollution fighting and we even had a few highly publicized cases of whale deaths which some people attributed to pollution.

All this helped set the stage for the 1985 session of the Legislature which produced a number of major management initiatives.

You have already heard about the legislation creating the Puget Sound Water Quality Authority and its mandate to develop a cleanup plan.

But there were three other significant bills passed. One directed Washington communities to achieve the greatest reasonable reduction in combined sewer overflows in the shortest reasonable time.

Another bill allowed local government the authority to raise money to solve pollution problems in waters where shellfish are produced.

And still another bill focused on groundwater. It gave us the authority to begin protecting not only groundwater quality, but also groundwater quantity.

But we weren't through. A year ago the Legislature came back into session and passed a cigarette tax which will raise $575 million between now and the year 2000.

Those tax revenues, combined with federal and local funds, will give us an additional $1.7 billion to fight pollution during the next 13 years.

But while that is a lot of money, we estimate our costs for secondary treatment, CSO reduction and protection of groundwater and lakes will cost about $3 billion. So one of the key management decisions still on the table is how we will allocate our limited resources.

Even before the authority began its work, the department was taking steps to more effectively combat pollution. There was a perception the Department of Ecology just wasn't doing the job on enforcement. Many felt we weren't being rigorous enough in bringing industry and municipalities into compliance with our environmental laws.

We took steps to change that. We increased emphasis upon taking timely and appropriate enforcement action. In addition, we sought, and the Legislature approved, measures to strengthen our enforcement efforts.

More types of violations were made subject to civil penalties and the maximum amount of penalties was increased from $5,000 per violation per day to $10,000.

There has been an 82 percent increase in the total number of enforcement actions taken from fiscal year 1983 to fiscal year 1987 and a 1,305 percent increase in the dollar amount of water quality penalty assessments.

One of the major management challenges within the Department of Ecology has been the demand to move beyond conventional pollution controls to the control of toxics.

Considering we weren't even at the point where we wanted to be in controlling conventional pollutants, this was an enormous shift in management emphasis.

The shift was difficult because so little was known about this field. There were no EPA standards or industrial and chemical standards, so we did not have clear roadmaps to point the way.

Our work on Commencement Bay in Puget Sound started us on the road to a toxic source control program and laid the groundwork for where we go in other urban bays.

The Commencement Bay work was a first step toward development of sediment criteria and a cornerstone for development of analytical techniques for measuring low levels of chemicals in the sediment.

Commencement Bay also was the first area where extensive human health assessment techniques were used and our work there taught us more about linking contaminants in the sediment to sources.

Today we are developing a toxics control strategy which will be based more on biological effects of discharges rather than on standards for each chemical in the discharges. By looking at the effects of the discharge as a whole, we will be able to take into account the cumulative and combined affects of many chemicals.

Another key management thrust will be to beef up our permit and inspection efforts. These programs have been woefully underfunded in the past.

While the Legislature has not yet approved a final plan, the authority's plan sets some goals for the enforcement and permit programs.

We hope to inspect every permitted facility once a year. And we want to have three inspection visits a year to every major discharger.

Currently our inspection efforts are very inadequate. We have 1,100 permitees but are inspecting only 200.

The permit process also is behind. We have an enormous backlog -- 50 percent for NPDES permits and 60 percent for state permits. Our goal is to get current and remain current in five years.

The authority's plan is to pay for the beefed up inspection and permit programs through higher fees for permit holders. The management plan, in other words, is to have the permit holders pay for services rendered.

Another part of the Puget Sound plan, as you heard earlier, includes a campaign to reduce nonpoint pollution. This includes some sensitive management decisions for Ecology, which must approve local nonpoint reduction plans, step in and develop plans where local officials fail to do a priority watershed plan or use our enforcement authority to require locals to prepare and implement a plan.

We will have to work closely with local government so it will not invest in plans we can't approve.

A major component of nonpoint plans involves land use decisions, and this is obviously sensitive ground for the department. The idea of the state stepping in to develop local priority watershed plans is untried and will be an area to watch in the future.

All of our new initiatives will involve new people -- lots of them. A key issue, as we prepare to get legislative approval of the plan, is the speed with which we can implement it.

We have serious questions about how fast we can gear up. How big a talent pool is there to hire from? How long will it take to hire new employees? Can we find enough office space to house them? How quickly can we get the equipment needed to support them? What about training demands?

We have heard that when the Chesapeake Bay plan was approved and Maryland was gearing up to start work, it took two and a half years to hire 43 people.

We are currently looking at a far more aggressive schedule. One plan calls for the addition of 12 new employees a month over a two-year period. That amounts to 288 new employees in an agency which now has about 700.

As I mentioned earlier, one of or key goals must be to develop a workable implementation plan and realistic expectations.

We have been very fortunate in Washington to have a governor, Legislature and general public which is willing to chart an aggressive course of pollution control. But with those bold mandates came some high expectations.

As managers, we not only have to do a good job implementing those plans but also temper their enthusiasm and expectations so we have a realistic plan.

It would be unfortunate to lose our momentum just because we were unable to meet unrealistic public expectations.

LOCAL GOVERNMENTS AND CLEAN WATER: FULFILLING THE AGENDA

Tim Douglas, Mayor
Bellingham, Washington

The Puget Sound Water Quality Authority has set out an ambitious agenda. Never have we had a more thorough outline of water quality issues and potential solutions. True, sewer and water traditionally have been local government services. However, non-point source control, industrial pre-treatment, drainage utilities, and stringent land use regulations are new territory. With a Puget Sound price tag in excess of $2 billion, clean water must be balanced with other economic pressures of the new federalism.

Secondary Treatment

Until the past three years, secondary treatment in Puget Sound was more a question of if than when. Many communities had been encouraged to pursue waivers because they ranked lower in priority than projects elsewhere in the country. That course suddenly shifted with EPA denial of the Seattle Metro waiver.

No one yet knows the actual cost of compliance. What is clear is that the federal-state-local partnership rapidly is eroding. Ironically, communities which were too low in priority to receive federal funding now must go to secondary treament when federal dollars are disappearing. The federal mandate continues, but funding is down and grants are converting to loans. Local political support might have been there at 90% funding, but the climate changes when ratepayers have to shoulder 60% or more of the cost.

In Bellingham's case, a secondary plant will cost $36.5 million--the most massive public works project in the city's hisotry. Rates will triple or quadruple. Our food processing industry may vanish. In other communities such as Anacortes, bond counsels are pessimistic. The city's economic base simply is inadequate to convince investors that such a project is a good risk.

While the State of Washington has levied a tobacco tax to fund secondary treatment, new water quality issues already are straining the $40-45 million avalable each year. As a result, Office of Financial Management's recently issued report recommends financing at only a 20% grant level. That is far short of the 50% of eligible costs which had been expected. Rather than spread resources so thin, a Puget Sound plan for compliance should stagger the deadlines for plant operation over a longer period.

Since secondary treatment is mandated by the federal and state governments, it deserves solid financial assistance from those same governments. We must maintain the partnership which existed when clean water initiatives were launched. If local resources are depleted to achieve secondary treatment, there will be no money left to respond to other water quality problems

Local Responsibility

Puget Sound Water Quality Authority's September 1986 draft plan was highly proscriptive. It required non-point programs to address either agricultural practices or septic systems. It designated counties as lead agencies for non-point programs. Reaction to the draft was quick and clear: local governments wanted more flexibility to define local problems and priorities.

Puget Sound is composed of many subbasins and watersheds. Some are highly urbanized, while others are rural or timbered. Some watersheds fall entirely within a single political jurisdiction. Others encompass several cities and even more than one county. While the Olympia-Tacoma-Seattle-Everett corridor is rapidly urbanizing, communities north of Puget Sound proper show much slower growth.

In light of these factors, the Authority altered the plan. Local governments now must inventory their own watersheds, identify priority issues and develop action plans. These must be approved by the Department of Ecology. The specific structure for completing the process is left up to local jurisdictions. If they fail to establish a process, the Department of Ecology may impose one. Deadlines are clear. This approach places responsibility squarely on the shoulders of local governments. State government cannot be blamed for imposing an inappropriate or duplicative structure.

The process lends itself to public education. That is essential. Some of the most effective water quality measures involve changes in lifestyle. For example, inappropriate disposal of household toxic wastes, oil runoff from driveways, pesticide, fertilizer and herbicide misuse all contribute to pollution. Forest management and agricultural practices do affect stream loading of sediments and fecal coliform. Changes in practice may occur as quickly through education as they will through enforcement.

Alternatives

Local governments need regulator flexibility so that new methods can be employed. While it is our obligation to demonstrate the effectiveness of a particular process, agencies must not be so locked into certain technologies that they cannot entertain alternatives. Options should be authorized where they do not compromise standards in any meaningful way.

There is some evidence now that industrial pre-treatment has reduced pollution loading in Puget Sound by 50% during the past decade. If that is at all accurate, investment in keeping toxins from "entering the pipe" may be far more cost effective than treatment at the end. Today's technology-based standard does not permit considering options. We may heavily invest in the wrong answers to our problem.

Financing alternatives are important, especially in Washington State where the constitution vigorously prohibits the lending of the State's credit. Privatization is being pursued by at least one community. Others would benefit if staggered payments were made over a 20-year period rather than a lump sum payment immediately. However, debate continues about the Legislature's authority to obligate a future body to such a contract.

There is general concensus that financing technical assistance right now is less important than bricks and mortar. Projects to eliminate combined sewer overflows, service homes with dysfunctional on-site systems, and improve treatment are urgent and costly. Money should help us do the things we need to more than tell us how to do it.

Local governments may be faulted for being too pragmatic. However, as multi-purpose governments, we do have broad ranging responsibilities. Ratepayer revolt and land use politics have yet to emerge in Puget Sound water quality issues. Utilities and land use policies traditionally have been the prerogative of local government. Public resistance could stymie some very progressive policies. To gain and retain public support, government must demonstrate that solutions are thoughtful and cost effective. We must not only endorse objectives at all government levels, but commit to sensible methods of achieving them. Local governments need a responsive ear in the Congress and regulating agencies. Then, we can indeed look forward to a cleaner Puget Sound.