NOAA Technical Memorandum NOS OMA 22

DEVELOPMENT OF EFFECTIVE REGIONAL ENVIRONMENTAL MONITORING FOR PUGET SOUND

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December 1985

UNITED STATES DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary /
National Oceanic and Atmospheric Administration
Anthony J. Calio, Deputy Administrator /
National Ocean Service
Paul M. Wolff, Assistant Administrator

SUBMITTED TO:

Pacific Office
Coastal and Estuarine Assessment Branch
Ocean Assessments Division
National Ocean Service
U.S. NOAA

In Partial Fulfillment of
NOAA CONTRACT #NA82RAC00162

NOTICE

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ACKNOWLEDGEMENTS

The authors wish to thank E. Long of NOAA for his assistance, cooperation, detailed editorial comment, and encouragement during the course of this study.

E.V.S. Consultants acknowledges the assistance of the following staff members: Dr. G.A. Vigers, E. Gerencher and M. Mees. Report production was undertaken by S. Irwin.

URS Engineers acknowledges the assistance of P. Korsmo for his assistance during the study. Report production was undertaken by R. Graham, M. Richards, E. McKnight, A. Hume, and M. Bertman.

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CHAPTER 1. INTRODUCTION

Considerable attention has been focused recently upon the environmental quality of Puget Sound due to the discovery of a variety of water-quality problems that threaten many beneficial uses. One difficulty in dealing with many of these problems has been the limited information regarding their spatial and temporal extent. This limitation could be rectified by the implementation of long-term, repeated sampling (monitoring) of important parameters that would track the condition of the Sound. The goal of this study was to recommend an approach to monitoring the environmental conditions of Puget Sound that would effectively determine whether the "health" of the Sound was getting better or worse with time. The three specific objectives were: 1) define the monitoring needs, 2) compare those needs with existing monitoring programs, and, following evaluation of the existing programs, 3) recommend a monitoring approach for the future. The program proposed herein was developed based upon presently available methods and techniques and with the goal of determining long-term trends in the environmental condition of the Sound.

Puget Sound is a valuable and vulnerable resource supporting a wide diversity of beneficial uses. Often, these uses impinge on each other in conflicting ways such that exploitation of one resource reduces the utilization of others. Proper management of the Sound involves policy decisions and regulations which maximize the utilization of separate components while minimizing the negative impacts on the other components. To have any hope of achieving management approaches that in fact reflect the best interests of Puget Sound resource users, an adequate technical data base must be available to ensure that management decisions are based on an informed recognition of the consequences of those decisions. Monitoring provides a key element in that data base.

Monitoring that collects data over a long time period allows two critical assessments:

1. an *a posteriori* evaluation of the temporal changes in resource characteristics in response to natural and anthropogenic variables; and

2. an *a priori* indication of problems developing in a resource before the problems become critical.

The first assessment allows an evaluation of past management practices and assists in the development of appropriate responses for future conditions. The second assessment allows these decisions to be implemented at an effective point in time to minimize disruptions of beneficial uses. This general view of monitoring has been applied in this report to address environmental concerns specific to Puget Sound.

For purposes of this study, monitoring programs were identified as those studies that have or would acquire data for Puget Sound suitable for determining long-term temporal trends in the studied parameters. As such, the program presented herein differs from the monitoring program recently developed by Jones and Stokes and Tetra Tech (1983a and b). The latter program was primarily oriented towards additional research that would address data gaps in the present understanding of the Sound.

CHAPTER 2. METHODS

2.1 GEOGRAPHICAL STUDY AREA

The study area encompassed all of the inland marine waters of northwestern Washington, including Puget Sound, Hood Canal, the Strait of Juan de Fuca, and the southern Strait of Georgia. Puget Sound and the straits connecting it to the Pacific Ocean contain over 2,500 square miles of water and over 2,000 miles of coastline; it is both an inland sea and a series of very diverse habitats (Quinlan et al., 1985).

2.2 APPROACH

This study involved several tasks.

1. Define the needs of the monitoring program based on an analysis of the water-quality-dependent beneficial uses of Puget Sound that should be protected, the present (1985) water-quality problems, and the major physical and socio-economic factors that influence the Sound.

2. Identify the specific parameters that characterize and influence the beneficial uses, the water-quality problems and the major physical and socio-economic factors.

3. Define the data collection needs that would adequately determine the temporal trends in those parameters.

4. Review and evaluate the ability of presently existing monitoring programs to satisfy the programs needs.

5. Provide a final recommended program.

In addition, as the program was developed, the results of the analyses were compared to a series of specific monitoring objectives, described below, that were representative of present informational needs in Puget Sound. These comparisons provided a means of assuring the ability of the monitoring approach to address real concerns.

CHAPTER 3. EVALUATION OF MONITORING PROGRAM NEEDS FOR PUGET SOUND

3.1 OVERVIEW

The monitoring needs for Puget Sound were based on the answers to three separate but related questions:

1. What beneficial uses should be protected?

2. What adverse, pollution-related problems have been identified in the past or at present in Puget Sound that may continue or reoccur?

3. What major physical and anthropogenic factors affect the Puget Sound ecosystem?

The first question, addressed in Section 3.2, follows from the fundamental need for the monitoring program to be based on the potential losses of resources (e.g., see Goldberg, 1984). Only on such a basis can a truly useful and implementable program be developed. The second question, addressed in Section 3.3, recognizes that natural variability may be so great in marine ecosystems that the low-level, negative effects induced by human activities may be difficult to identify. Hence, it is important that all effects that have in fact been observed should be monitored to determine any future changes (Beanlands and Duinker, 1983). The third question, addressed in Section 3.4, accounts for major natural physical factors such as the weather and river discharges, as well as socio-economic factors such as increased demand for harvestable resources and new regulations and other management practices. These factors exert substantial influence on the receiving system, and hence must be considered when interpreting temporal changes in other parameters.

While it was felt that the answers to these three questions would identify a broad range of specific program needs that would provide the foundation for a complete, holistic monitoring program, it was also recognized that such an approach might be too general to clearly establish the pertinence of the program. Therefore, as the program needs were developed, they were considered in terms of current (1985) water quality concerns identified in the Sound that would reflect the spectrum of problems and the level (or lack thereof) of our understanding of the Puget Sound ecosystem. These concerns were used to develop immediate and concrete objectives for the monitoring program. In all, eight specific objectives were defined.

1. Understanding natural oceanographic and climatic events and phenomena, and the relationships among these, that may influence the Puget Sound biota. Any attempt to monitor anthropogenic influences in the Sound must recognize that many important aspects of Puget Sound are largely controlled by natural oceanographic and climatic factors and events. Changes in

these factors, and particularly unusual events such as major storms, periods of extreme cold and El Ninos, may substantially alter the biota of the Sound and also directly influence the measured water quality parameters. Further, monitoring of the oceanographic and weather factors in conjunction with in-Sound monitoring would assist in understanding the relationships among these natural processes, thus improving our ability to predict future conditions.

2. Determining trends and the natural ranges in the abundances of Puget Sound biota, in particular, valued marine resources such as harvestable fish and shellfish. Obtaining data to assist in the protection of the biota of Puget Sound is probably the most important single aspect of any monitoring program. Direct measurements of biological populations is the most accurate way of determining their status. In addition, the normal temporal fluctuations in the abundances of the biota in the Sound, which can often be quite large, must be defined to differentiate anthropogenic impacts from normal variations.

3. Determining trends in factors that may endanger human health. Water quality problems may directly affect humans through the consumption of contaminated fish and shellfish and through contact with contaminated water. At the present time, anthropogenic contamination of the edible biota and the water by toxic chemicals and by disease-causing microorganisms, i.e., pathogenic bacteria and viruses, are of major concern in Puget Sound. In addition, paralytic shellfish poisoning, a naturally occurring contamination caused by the accumulation in shellfish of substances acutely toxic to many mammals, has been increasing in the Sound. These natural and anthropogenic problems must be monitored to identify them as problems before they impact humans and to track the temporal and spatial trends in the contamination incidences to help identify possible sources and causative factors for corrective action.

4. Determining the trends in the inputs and concentrations of anthropogenic factors that may affect Puget Sound biota. Humans have used the Sound for the disposal of their wastes from the first settlements. However, these discharges were not significant to resident biota until the late 1800's when major industrial and commercial development and population increases occurred. Since that time, a variety of inputs have occurred. These have included wood wastes from lumber, pulp and paper mills; human wastes from municipalities and other inputs of organic materials that decay in the water and reduce the oxygen available to support life; chemical residues that were acutely toxic to organisms, such as sulphite waste liquor from the pulp mills; and other toxic chemicals, such as polychlorinated biphenyls, pesticides, and trace metals, that are long-lived in the environment and that can induce chronic problems in exposed

biota. Some limited areas of the Sound have been virtually devoid of normal marine life in the past due to low levels of dissolved oxygen resulting from large discharges of organic materials. Pathological conditions in some bottom fish may be a continuing problem that may be caused by toxic chemicals.

Therefore, the discharge and accumulation of these waste products must be monitored both to ensure that those inputs whose impacts are known, e.g., oxygen- demanding substances, be kept at acceptable levels and to help define problems associated with other substances, e.g., toxic chemicals, so that controls can be justified and implemented.

5. Determining the natural temporal and spatial trends in receiving system properties needed for the development of safe, effective waste disposal practices. As was discussed earlier (see for example, Objective 4, above), waste disposal has created problems in the Sound. Concerns regarding these problems are continuing. For example, as population growth in the South Sound increases the amounts of human wastes that must be disposed of also increases. Many human waste products discharged to the Sound are largely natural materials that only cause problems when their concentrations become excessive. These effects can be avoided if the waste delivery system is properly designed to discharge the wastes at depths and in areas that can provide adequate dilution, and away from areas that already have water quality problems. Monitoring can collect data necessary to identify suitable (and unsuitable) broad areas and regions as well as guide specific design characteristics to ensure the least environmental impacts of the wastes.

   Similarly, other waste disposal practices can benefit from a knowledge of the areas of the Sound that monitoring can provide. For example, the selection of dredged-material disposal sites can be guided by an understanding of the bottom characteristics, the importance and amount of a particular habitat type that might be destroyed, and the probable stability of the material at the sites examined.

6. Determining the effects of changes in waste disposal practices on the receiving system. At the time this report was being written, many municipal sewage dischargers were faced with conversion from primary treatment of their wastes to the more stringent secondary treatment. In addition, the ASARCO copper smelter was closed in the spring of 1985, eliminating one of the major sources of anthropogenic trace metals. At our present level of understanding of the Sound, it is often difficult to accurately predict the affects that these waste load reductions may have on the Sound. As a result, it is

important these changes be measured directly to determine whether in fact the waste load reductions can be observed in improved regional water quality. In addition, increases in future waste load changes may occur due to greater population and the start-up of new industries. Decreases may occur due to further improvements in treatment methods. It is important that the resulting changes in water quality be monitored to ensure that no unexpected adverse water quality impacts occur.

7. Determining the effects of changes in regulatory management decisions on the receiving system. Regulatory controls over human activities in the Sound can have far-reaching effects. For example, many populations of Puget Sound biota, particularly those of economic interest, have been markedly impacted by regulatory decisions such as the size of the allowable catch, restrictions in fishing gear and closure of fishing areas and seasons. Similarly, waste-disposal practices in the last decade have been largely controlled by broad regulatory mandates rather than by case-by-case reviews of water quality requirements. Finally, shoreline land-use practices have been implemented to protect sensitive and critical habitats for Puget Sound biota. As was the case with Objective 6, above, the outcome of the regulations cannot always be accurately predicted, but must be carefully monitored to verify the wisdom (or lack thereof) of the actions and allow for further modifications necessary to achieve the desired affect.

8. Determining trends in the visual appearance and olfactory characteristics of Puget Sound. The appearance of the Sound is probably monitored, informally, more often than any other parameter and is also probably one of the characteristics of the Sound that is valued by most people. In addition, appearance (water color, clarity and the presence/absence of floatable material and slicks) and a related parameter, the odor of the water and the beaches, have not been included in many formal monitoring programs in the past, in part, because problems associated with these parameters are difficult to quantify and are usually transitory. Therefore, because of their overall importance and because they have not often been included in past programs, monitoring of appearance and odor have been placed in this separate objective.

These specific objectives were defined not to limit the monitoring program, but rather to provide specific tests of the adequacy of the program defined herein to provide the necessary information to support decision-making on the immediate critical issues and potential future concerns. As the program elements were developed in the following sections, they were categorized as to the specific objective(s) for which they provided information.

3.2 BENEFICIAL USES OF THE PUGET SOUND MARINE ENVIRONMENT

Several previous studies have identified lists of beneficial uses for Puget Sound (i.e. Burbank, 1983; League of Women Voters of Washington, 1983; Bailey et al., 1985; WDOE, 1984; JRB Associates, 1984b). A summary list of all beneficial uses related to the Puget Sound aquatic environment is presented in Table 1, based on these previous studies. Beneficial uses that are not directly dependent on good water quality (e.g. commercial navigation, water and waste disposal) are also listed in Table 1, and although they are considered further in the context of Puget Sound water quality monitoring, they are not considered as beneficial uses requiring protection.

Natural variables that are critical for the preservation of each beneficial use are identified in Table 2. In some cases the primary or direct measure of the beneficial use is also dependent on secondary parameters. For example, the abundance of mollusk larvae, a primary parameter for shellfish maintenance, is dependent on food, which consists of detritus and phytoplankton (secondary parameters). Plankton abundance and health can be assessed by measuring chlorophyll a and community structure, and are affected by temperature, salinity and the concentration of dissolved oxygen, nutrients and turbidity (Table 2). It is readily apparent that a few parameters -- specifically temperature, salinity, dissolved oxygen, nutrients, chlorophyll a and turbidity -- are associated with most of the water-quality-dependent beneficial uses as a result of this tiered effect. Table 2 effectively produces a listing of the major ecosystem variables that can be used as monitoring tools to assess the trends and relationships among these beneficial uses.

3.3 POLLUTION-RELATED IMPACTS ON RESIDENT ORGANISMS AND THEIR CONSUMERS

There were seven major documented adverse biological effects identified in Puget Sound that may be pollution-related:

1. Reproductive failures have been observed in harbor seals. These failures have been attributed in the past to toxic chemical uptake, specifically of PCBs and pesticides, but due to the limited studies to date, these conclusions are speculative. The incidence of pupping failure in seals appears to be decreasing (Quinlan et al., 1985).

2. Bacteriological contamination due to anthropogenic sources has resulted in the closure of shellfish beds.

3. A variety of histopathological abnormalities have been noted in bottom fish and other species living in or near areas where sediments have high levels of toxic chemicals.

Table 1. Categories and subcategories of beneficial uses of Puget Sound[a]

- VALUED MARINE RESOURCES
  - Algae/Macrophytes
  - Plankton
  - Detritus
  - Benthos
  - Shellfish
    - Mollusk (larvae) (adult)
    - Crustaceans (larvae) (adult)
  - Anadromous Fish
    - Rearing
    - Migrating
  - Other Fish
    - Spawning
    - Rearing
  - Wildlife
    - Marine Birds (nesting/rearing) (migrating)
    - Mammals (rearing/pupping) (migrating)
- WATER SUPPLY
  - Aquaculture
  - Industrial
- FISHING (Commercial and Recreational)
- KELP CULTURE
- SHELLFISHING
- WATER CONTACT RECREATION
  - Swimming
  - Wading
  - SCUBA
- BOATING (Recreational)
- AESTHETICS
  - Viewing
- COMMERCIAL NAVIGATION[b]
  - Shipping
  - Log Rafting
  - Ferries
- WATER AND WASTE DISPOSAL[b]
  - Stormwater Discharge
  - Municipal Sewage Discharges
  - Industrial Wastewater Discharges
  - Combined Sewer and Emergency Overflow
  - Dredged Material Disposal

[a] Adapted from: Burbank, 1983; League of Women Voters of Washington, 1983; Bailey et al., 1985; WDOE, 1984; JRB Associates, 1984b.

[b] Not directly dependent on good water quality (e.g., polluted waters can be used for these purposes).

Table 2. Measures of the status of beneficial uses (1) and natural parameters affecting/controlling water-quality-dependent beneficial uses of Puget Sound (2)

Beneficial use	(1) Measures of status (2) Controlling parameters
VALUED MARINE RESOURCES	
Macrophytes	(1) Abundance (2) TSDN[a] (2) Food (nutrient concentrations) (2) Turbidity (2) Habitat/Substrate
Plankton	(1) Chlorophyll *a* concentration (1) Community structure (2) TSDN (2) Nutrient concentration (2) Turbidity
Detritus	Not easily measured
Benthos	(1) Abundance (1) Community structure (2) TSDN (2) Food (Plankton/Benthos) (2) Substrate Particle Size Total Organic Carbon
Shellfish	
Mollusk (larvae)	(1) Abundance (2) TSDN (2) Turbidity (2) Dinoflagellates (2) Food (Detritus/Plankton) (2) Habitat
Mollusk (adult)	(1) Abundance (2) TSDN (2) Turbidity (2) Food (Detritus/Plankton) (2) Habitat
Crustacea (larvae)	(1) Abundance (2) Habitat/Substrate (2) TSDN (2) Food (Detritus/Plankton)

Table 2 (continued)

Beneficial use	(1) Measures of status (2) Controlling parameters
VALUED MARINE RESOURCES (Continued)	
Shellfish (Continued)	
Crustacea (adult)	(1) Abundance (2) Habitat/Substrate (2) TSDN (2) Food (Detritus/Benthos)
Anadromous Fish	
Rearing	(1) Abundance (2) Physical Habitat (2) TSDN (2) Food (Benthos)
Migrating	(1) Abundance (2) TSDN (2) Food (Plankton/Fish)
Other Fish	
Spawning	(1) Abundance (2) TSDN (2) Physical Habitat
Rearing	(1) Abundance (2) Food (Plankton/Benthos) (2) TSDN (2) Physical Habitat
Wildlife	
Marine Birds (nesting/ rearing	(1) Abundance, Reproductive Success (2) Physical Habitat (2) Food (Plankton/Benthos)
Marine Birds (migrating)	(1) Abundance (2) Physical Habitat (2) Food (Fish/Plankton/Benthos)
Mammals (rearing/pupping)	(1) Abundance, Reproductive Success (2) Physical Habitat (2) Food (Fish/Plankton/Benthos)
Mammals (migrating)	(1) Abundance (2) Food (Fish/Plankton/Benthos)

Table 2 (continued)

Beneficial use	(1) Measures of status (2) Controlling parameters
WATER SUPPLY	
Aquaculture	refer to specific groups (i.e. kelp, shellfish, fish)
Industrial	(2) Temperature (2) Turbidity
FISHING	(1) Abundance
KELP CULTURE	(1) Abundance (2) TSDN (2) Food (nutrient concentrations) (2) Turbidity (2) Habitat/Substrate
SHELLFISHING	(1) Abundance
WATER CONTACT (Recreational)	(2) Physical Habitat (2) Odor (2) Turbidity (2) Floatables/Slicks
BOATING (Recreational)	(2) Odor (2) Floatables/Slicks
AESTHETICS	(2) Water Color (2) Odor (2) Turbidity

[a] TSDP = Temperature, Salinity, Dissolved oxygen, Nutrients

4. The incidence of dinoflagellate blooms and red tides, leading to problems with PSP in Puget Sound appears to be increasing and circumstantial evidence indicates that it may be related to organic matter and nutrient enrichment from anthropogenic sources.

5. Fish kills and other adverse effects on the biota have resulted from low dissolved oxygen levels in some inlets. This problem was probably due to excessive discharges of organic matter and nutrients. The problem has been largely rectified, but could reoccur.

6. Sediment toxicity due to chemical mixtures in the sediments is the possible cause of mortality and avoidance of contaminated areas by sensitive benthic fauna.

7. Harvestable organisms have been contaminated with toxic chemicals, apparently from anthropogenic sources.

Table 3 presents a list of directly related and secondary parameters that could be used to monitor the trends in these problems. The data base is presently insufficient to adequately describe how these seven issues may be affecting higher trophic level consumers, but some general comments can be made. First, changes in benthic species composition in contaminated/toxic areas undoubtedly affect some consumers preying on benthos. For some species such as flatfish (which prey on bivalves and polychaetes common in industrialized embayments) the net result may be increased food, while for other species which are more selective feeders, the net result may be a diminished food supply. Second, documented histopathological abnormalities have not been shown to directly affect the population size of diseased fauna; however the existence of these abnormalities has undoubtedly affected the willingness of anglers to catch and eat fish in areas where histopathological abnormalities occur. Third, the apparent increased incidence of red tides and dinoflagellate blooms affects both the adult, through reduced value due to the risks of PSP, and larval stages (increased mortality) of shellfish. The net result is both fewer shellfish in certain areas and large-scale closures of the resource to commercial and recreational harvesting (Quinlan et al., 1985). Dinoflagellate blooms have also been associated with historical fish kills in small, localized embayments (Quinlan et al., 1985). Fourth, bacteriological contamination also results in closures of shellfish beds. Fifth, high tissue levels of toxic chemicals pose an unknown threat directly to the resident populations and to animal and human consumers, as well as an indirect effect by reducing harvesting.

The issue of reproductive failures in seals is not an issue of human consumption and probably does not significantly impact the few species (i.e. killer whales) which feed on this group. However, because seals and humans consume many of the same marine foods (fish and shellfish), the problems in the seal population may be an indicator of possible similar effects in humans.

Table 3. Presently identified biological effects that should be monitored

Effect	Possible reason	Parameter(s) to monitor: Primary[a]	Secondary[a]
Reproductive Failures in Harbor Seals	Toxic Chemicals in Food	Reproductive Success	Toxicants in Tissue
Closure of Shellfish Beds	Pathogens/Coliforms in Bivalves	Pathogens in Tissue	Probable Pathogen Inputs (Waste Discharges, Land Use Patterns/Population) Pathogens in Water
Histopathological Abnormalities (bottomfish/others)	Toxic Chemicals/Pathogens	Lesion Frequency	Toxicants in Tissue
Dinoflagellate Blooms	BOD and Nutrient Inputs	% Community Composition	Probable Nutrient Inputs (Waste Discharges, Land Use Patterns/Population) Nutrients in Water
Fish Kills	Low Dissolved Oxygen	Fish Kill Incidences Dissolved Oxygen Concentrations	BOD and Nutrient Loading TOC Levels in Sediments
Benthic Community Changes (Sensitive species, i.e., some amphipods, *Rhepoxynius abronius*, eliminated)	Toxic Chemicals in Sediments Organic Enrichment	Sediment Toxicity (bioassays) Benthic Community Structure Substrate Modification	Sediment Chemistry Levels Physical Habitat Organic Content (sediment) Sediment Texture
Chemically Contaminated Tissue (fish, shellfish)	Toxic Chemicals in Water	Toxic Chemicals in Tissue	Possible Toxic Inputs (Waste Disposal, Source Monitoring, Industrial Development)

[a] Primary parameters are defined as those that probably directly result in the associated biological effect; secondary parameters may indirectly result in the effect by influencing the primary parameters.

3.4 PHYSICAL AND ANTHROPOGENIC FACTORS AFFECTING PUGET SOUND

In addition to previously mentioned parameters, there are an additional seven major physical and anthropogenic factors that affect Puget Sound (Table 4). The trends in these parameters can significantly affect the valued marine resources of Puget Sound. River discharge can alter the salinity, contribute to sediment loadings as well as the loadings of other water quality parameters. Climate and weather conditions affect water temperature, insolation and mixing, and thus affect many beneficial uses. For instance, an intense storm can cause salinity fluctuations, can increase sediment loadings and mix phytoplankton below the euphotic zone. A long, hot dry period can increase water temperatures and surface water stability, thus becoming a causative factor in phytoplankton blooms. Shoreline modifications can eliminate prime spawning and rearing grounds. Currents affect the transport and distribution of both dissolved and particulate contaminants. Changes in pollutant inputs from municipal and industrial sources have the potential for direct effects on the biota. Regulatory controls can affect pollutant discharges and such beneficial uses as commercial and recreational fishing. Other socio-economic factors help determine resource use patterns. For instance, a decrease in English sole landings 1974-1975 in Puget Sound was mainly due to declines in demand (cf. Section 5.3).

Table 4. Physical and anthropogenic factors affecting Puget Sound that should be monitored

Factor	Parameter(s)	Comment
River Discharge	Flow, suspended solids, nutrients, bacteria/pathogens, toxic chemicals	WDOE and USGS collect river discharge, and water quality information
Climate/Weather	Air temperature, insolation/cloud cover, precipitation, storm occurrences	National Weather Service monitors daily
Shoreline Changes	Percent of shoreline modified (by region) Suggested shoreline classification: o bulkhead/piers o riprap/rocky o sand o wetland o estuary	The permitting process allows for regulatory control
Pollutant Inputs Municipal/Industrial/ Other	Waste loadings o long-term changes[a] o extraordinary events (strikes, plant closures, etc.) o new sources or processes	Data available from NPDES permits, 301 (h) waiver applications, and/or regulatory monitoring
Currents	Current speed and direction at various depths in the water column	No present monitoring system

Table 4. (Continued)

Factor	Parameter(s)	Comment
Regulatory Controls	Changes in regulations	Fisheries management and toxic chemical controls (i.e. RCRA, TOSCA, FIFRA) are presently in place
Socio-Economic Conditions	Population changes by county, land use changes, economic indicators	Population changes, war, economic depression affect resource development/use

[a] Present examples include change from leaded to unleaded gasoline; change from coal to oil or gas; changes from agriculture land use to urban land use.

CHAPTER 4. DEVELOPMENT OF A PUGET SOUND MONITORING PROGRAM

4.1 SUMMARY OF PARAMETERS TO BE MONITORED IN PUGET SOUND

All major parameters identified in Tables 2, 3, and 4 were reviewed in terms of the eight specific monitoring objectives of Puget Sound. The results are presented in Table 5, with the parameters organized by the objectives to which they would provide information.

Collecting data for the parameters listed in Table 5 would provide a comprehensive program for Puget Sound and meet the informational needs of each objective. (Alternatively, individual or separate programs could be implemented for each objective by including only those parameters directly pertinent to that objective.) Long-term monitoring of these parameters would provide the necessary information for detailed trend analyses. Table 5, therefore, forms the basis for parameter-specific recommendations for monitoring Puget Sound.

In the remainder of this chapter, each of the parameters in Table 5 is discussed individually in terms of the objectives met, the rationale for monitoring and specific monitoring requirements, including frequency of sampling, sites, data to be obtained, data analyses, and archival requirements. Other monitoring data presently or previously collected are also identified.

The focus of the monitoring programs developed in this study was to track regional, broad-scale trends in all areas of Puget Sound. On this scale, one monitoring program was developed for each parameter that would address the needs of all applicable objectives. This approach eliminated redundancies in the data collection requirements for those parameters that satisfied more than one objective. This approach recognizes, however, that the broad-scale programs would provide sufficient sampling to identify major problems in the Sound, and that identification of a problem would probably trigger a much more detailed study to fully characterize its extent and causes. In addition, the programs developed herein are not sufficiently intensive to satisfy all informational needs for very area-specific projects or concerns. Because one program was developed for each, the parameters are arranged in this chapter by matrix type, i.e., water, sediment, biota, etc., rather than by objective.

No methods of measurement are discussed in the following pages. Since this study was not intended to be a review of methodologies, alternate methods of measurement are not generally discussed. The authors recognize that a variety of suitable methods exist for some parameters, and that new methods will be developed. Therefore, the actual methodologies used must be determined by the professional judgement of the parties responsible for making the measurements.

Table 5. Summary of Puget Sound monitoring parameters presented by individual monitoring objective

1. Understanding natural oceanographic and climatic events and phenomena, and the relationships among these, that may influence the Puget Sound biota.	temperature and salinity dissolved oxygen nutrients (NO_3, NO_2, NH_3, PO_4, SiO_4) turbidity river discharge and water quality climate/weather currents
2. Determining trends and the natural ranges in the abundances of Puget Sound biota, in particular, valued marine resources such as harvestable fish and shellfish.	plankton abundance and community structure dinoflagellates chlorophyll a macrophyte abundance and community structure benthos abundance and community structure shellfish abundance (by species) fish abundance marine bird abundance marine mammal abundance (by species)
3. Determining trends in factors that may endanger human health.	pathogens (enterobacteria/ enteroviruses) in the water column and in shellfish dinoflagellates toxic chemicals in water, and in tissues of benthos, shellfish, fish and mammals fish histopathological abnormalities paralytic shellfish poisoning
4. Determining trends in the inputs and concentrations of anthropogenic factors that may affect Puget Sound biota.	nutrients (NO_3, NO_2, NH_3, PO_4, SiO_4) toxic chemical sediments and sediment particle size, TOC, and oil and grease bioassays toxic chemicals in water and in tissues of benthos, shellfish, fish, mammals, and birds pollutant inputs socio-economic conditions river discharge and water quality
5. Determining the natural temporal and spatial trends in receiving system properties needed for the development of safe, effective waste disposal practices.	temperature and salinity dissolved oxygen toxic chemicals in sediments and sediment particle size, TOC, oil and grease bioassays percent of habitat types currents

Table 5. (Continued)

6.	Determining the effects of changes in waste disposal practices on the receiving system.	dissolved oxygen pathogens (enterobacteria/ enteroviruses) in the water column toxic chemicals in sediments and sediment particle size, TOC, oil and grease bioassays benthos abundance and community structure toxic chemicals in water and in tissues of benthos, shellfish, fish, mammals, and birds shellfish abundance fish histopathological abnormalities pollutant inputs socio-economic conditions
7.	Determining the effects of changes in regulatory management decisions on the receiving system.	pathogens (enterobacteria/ enterviruses) in the water column and shellfish toxic chemical in sediments and sediment particle size, TOC, oil and grease percent habitat types toxic chemicals in tissue of benthos, shellfish, fish, mammals and birds shellfish abundance fish abundance pollutant inputs percent of habitat type regulatory control socio-economic conditions
8.	Determining trends in the visual appearance and olfactory characteristics of Puget Sound.	turbidity odor, floatables/slicks, water color

For some parameters, the analyses indicated that they would be of minimal utility, were largely redundant, or could not be effectively monitored with currently available procedures. No detailed monitoring program was developed for these parameters. For other parameters, information was lacking regarding some critical aspect needed to fully develop a monitoring program. In these cases, the program was developed to the extent possible, and additional research to provide the needed information was described.

WATER COLUMN: TEMPERATURE AND SALINITY (T/S)

Objectives (from Chapter 3):

Understanding natural oceanographic and climatic events and phenomena, and the relationships among these, that may influence the Puget Sound biota.

Determining the natural temporal and spatial trends in receiving system properties needed for the development of safe, effective waste disposal practices.

Rationale for Monitoring:

T/S are two environmental parameters defining key habitat characteristics essential to all Puget Sound biota. These parameters change seasonally in response to the varying influxes of northeast Pacific Ocean water and river discharges, and changes in insolation and air temperature. The normal seasonal cycles in these parameters are important in establishing biological growth cycles in the Sound. In addition, unusual changes in T/S in response to abnormal climatic events such as drought or flooding, may cause substantial alteration of many biological communities.

Temperature and salinity measurements can be used to trace water movements and calculate flushing and refluxing in the major basins of Puget Sound and in embayments. These calculations would be made using water and salt balances. Bottom water intrusions of Strait of Juan de Fuca water would, most likely, not be measured by the monitoring plan described below. However, they should be measured quite well by the salinity and temperature sensors on the current meters (as described in a later section).

Human influences on T/S are generally limited and local in extent. Only in restricted embayments and passages where a discharge may constitute a significant fraction of the available water volume will problems occur. Washington State Water Quality Standards limit the extent of human alteration of natural temperatures, but not salinity.

Frequency:

Stations for all areas of the Sound discussed below should be sampled monthly throughout the year. This frequency of measurement should allow for an adequate determination of annual characteristics.

Intensive surveys of the rate of change of T/S have been few in number but they indicate that influxes of open ocean water and storms can change the T/S regime in the Sound in a matter of days. These changes are normally smaller in extent than seasonal variations, but they may nevertheless be an important variable affecting biological communities (e.g., plankton). These short-term changes would be poorly defined by the monthly sampling. However, salinity and temperature will be measured by the current meters at short time intervals (15 to 30 minutes). This information can be used to fill in the gaps between the monthly samples.

Sites: The largest net flows in the major basins of Puget Sound are on the order of 10 cm/sec or less. Accordingly, to obtain approximately synoptic data for the Sound over a 24-hour sampling cycle, sites in the major Basins should be about 8 to 10 km apart and can be spaced in an even, longitudinal grid pattern.

The sites presently monitored by WDOE would satisfy most of these requirements. The WDOE sites include monitoring in many embayments and in all urbanized areas. Continued sampling at all of these sites would provide indications of the major changes in water quality occurring Sound-wide and hence satisfy the criteria for long-term monitoring as defined herein.

However, to adequately calculate flushing, sites should also be sampled on both sides of sills separating basins, in the central portions of the basins and in the embayments of interest. Thus, the sites presently sampled by WDOE should be augmented by the following locations. Stations should be sited on both sides of the major sill zones and passages: Admiralty Inlet, Tacoma Narrows, Colvos Passage, Possession Sound, and Haro and Rosario Straits. In addition, locations should be added that have been sampled historically by the University of Washington at Bush Point, at Pillar Point, near Port Townsend, at Point-No-Point, at Point Jefferson, at Point Pulley, and at Point Robinson.

Because near-shore effects are transient and highly variable, extremely frequent sampling would be required for their characterization. The present long-term program for monitoring water quality parameters generally excludes such areas from consideration. Exceptions, as discussed later in this report, include pathogen monitoring of shellfish which should be monitored directly and which, if problems are detected, would then trigger more intensive water-column work in the affected area. These short-term investigatory studies would not necessarily alter the monitoring program as presently constituted.

T/S must be collected at a variety of depths since both the vertical density structure as well as the absolute values are of importance. For routine synoptic monitoring, bottle casts of 5 to 7 bottles, depending on the water depths, should be sufficient. Recommended depths are (in meters): 0, 5, 20, 50, 100, 150, 200 or bottom. The smaller depth interval near the surface reflects the greater change with depth of T/S in the near-surface layers. The recommended depths reflect continuity with past available data. The upper 0 to 15 m is the normal range of the depths which include the majority of the productivity, the major changes in salinity due to freshwater inputs and the effects of atmospheric exchanges of gas and energy. The 50 m depth is the approximate depth of the zone of no net motion. Below about 50 m, the waters are normally relatively homogeneous compared to the surface layers and the rate of change of the parameters is fairly constant with depth (Collias et al., 1974). Bottle casts are recommended in preference to continuous profiles (e.g., CTD profiles) because the former are more reliable and can provide discrete, limited numerical values of high quality which can thus be readily entered and maintained in a computer data base.

Data to be Reported:

- station location, date and time
- temperature, salinity and depth
- procedures and QA/QC documentation/codes (i.e., alpha-numeric surrogates suitable for inclusion with the data in a computerized data base)

Data Analyses Required:

- temporal variations from plots of daily and monthly values
- variations from long-term average trends
- temporal trends as a function of climatic or other variables
- spatial relationships
- areas of anomalous behavior/standards violation
- average annual flushing and refluxing for major basins

Data/Sample Archival:

- no sample archival
- full data archival

Other Monitoring Data: The present level of on-going T/S monitoring (discussed in Section 5.2) is largely sufficient to satisfy the major data needs. Additional WDOE monitoring sites not currently included in their network would be useful as noted above. These additional sites would serve primarily to develop better circulation/transport models and could probably be disregarded for routine water quality monitoring.

Of more importance is the establishment of the monitoring program on a year-round basis. WDOE uses a float plane to access the stations. Because the hazards of doing float plane work in winter are great, WDOE does not take samples in winter. To reduce the hazards, boats can be used to collect the needed winter data. Winter data are essential to a complete monitoring program. Many significant changes occur during the high flow winter periods, particularly the common December floods.

WATER COLUMN: DISSOLVED OXYGEN (DO)

Objectives (from Chapter 3):

Understanding natural oceanographic and climatic events and phenomena, and the relationships among these, that may influence the Puget Sound biota.

Determining the natural temporal and spatial trends in receiving system properties needed for the development of safe, effective waste disposal practices.

Determining the effects of changes in waste disposal practices on the receiving system.

Rationale for Monitoring:

DO is a critical parameter characterizing Puget Sound marine habitats; an adequate DO concentration is essential for all higher life forms. As with temperature and salinity, the DO levels in the Sound are largely controlled by natural processes and show strong seasonal changes in response to varying concentrations of DO in the incoming ocean water and to in-Sound production and decay processes.

DO levels, however, are more sensitive to human perturbation than are changes in temperature and salinity. Changes in DO have resulted from direct or indirect loadings of nutrients and BOD. Historically only a limited number of harbor areas, particularly those near pulp and paper mills, have been grossly affected by DO depletion (Quinlan et al., 1985). More recently even these areas have been largely cleaned up, such that few critical low DO areas remain.

However, DO remains an essential monitoring parameter because of its critical importance to a healthy ecosystem. In addition, it represents a relatively easily measured surrogate of the overall impact of conventional pollution.

Frequency:

DO concentrations respond to a number of physico-chemical variables, hence the natural range and short term variations in DO concentrations tend to be large. Seasonal changes are sufficiently large (often greater than 5 mg/l even in unpolluted areas) so that annual averages have too large a variance to be useful for discriminating trends. Within-month changes at any one site and depth are generally much smaller and have a standard deviation on the order of ±20 percent of the monthly mean DO concentration (Ebbesmeyer et al., 1982). With this level of variation, eight to ten samples per month per site would be required to discriminate a 20 percent change in monthly average DO concentrations (at the 95 percent confidence level).

The limited available data do not provide sufficient information to establish whether spatially proximate stations reflect the same temporal change. It is known that DO levels decrease from north to south during the high productivity period in the deep water of the Main Basin (Collias, and Barnes, 1964). Therefore, it appears unwise to suppose that large-scale spatial averages alone can be used to obtain the number of samples required to reduce the statistical uncertainty sufficiently to allow for high-precision monitoring of temporal trends.

However, at present, eutrophication and/or other factors that would be reflected in DO changes are not major problems in the Sound. Therefore, it is suggested that the intensive sampling at a single site necessary to define precise DO trends at that site is not necessary at the present time. The lower frequency (monthly and weekly) sampling currently carried out by WDOE, Metro and others, as discussed in Section 5.2, appears to be adequate to detect major shifts towards low DO problems.

If oxygen-depletion problems are indicated at one or more sites, then twice weekly or more frequent sampling in those areas could be performed to provide high precision data. Since annual trends are most easily identified, the intensive sampling could be performed only during one to three months of the period of maximum oxygen utilization (July through October).

Measurements of DO by bottle casts (Winkler or Carpenter techniques) is recommended.

Sites: Until and unless more intensive sampling is required (this determination could follow a review of available data and future trends as previously noted), DO sampling should be restricted to the sites and depths recommended for synoptic sampling for temperature and salinity. This monitoring scheme would ensure detection of gross trends, particularly in the smaller embayments.

For the detailed trend analysis, intensive sampling need not be conducted at all stations in the affected area. There is generally sufficient mixing within areas that, while spatial differences may exist, these variations are temporally consistent. Thus intensive sampling is only required at one or two stations within an area. These particular stations should be selected as representative of the major water masses in the area.

Similarly, not all depths need to be sampled to obtain data sufficient for comparing long-term variations since oxygen depletion is the process of concern. Two depths, at 100 m depth and near the bottom (or mid depth and near the bottom in shallower embayments), are recommended for the intensive sampling. Waters from these depths are within the oxygen utilization zone, are generally in the landward-moving deep water and are in the depth strata where changes as a function of depth are not as great as in the near surface waters.

Data to be Reported:

- station location, date and time
- dissolved oxygen concentrations and depth
- procedures and QA/QC documentation/codes

Data Analyses Required:

- temporal trends of DO concentrations on an annual basis
- variations from long-term average trends
- spatial differences among stations
- areas or regions showing significant DO depletion including standard violations
- multi-year trends by region

Data/Sample Archival:

- no sample archival
- full data archival

Other Monitoring Data: As discussed above and in Section 5.2. Many, if not most, hydrographic and other surveys for research purposes routinely take DO measurements. These data could usefully supplement the data collection recommended herein if the data were available from a central repository.

WATER COLUMN: NUTRIENTS (NO_3 , NO_2 , NH_3 , PO_4 , SiO_4)

Objectives (from Chapter 3): Understanding natural oceanographic and climatic events and phenomena, and the relationships among these, that may influence the Puget Sound biota.

Determining trends in the inputs and concentrations of anthropogenic factors that may affect Puget Sound biota.

Rationale for Monitoring: Nutrients are essential growth factors for attached algae and phytoplankton. Nutrient enrichment can constitute a water quality problem, but only when 1) it stimulates such excessive plant growth that the resulting decay causes DO depletion, or 2) when changes in absolute or relative nutrient availability shift the composition of the plant community to non food or noxious species.

In Puget Sound, nutrient concentrations apparently do not play a major role in controlling plant growth except in a few poorly flushed embayments, such as Budd Inlet (Collias and Lincoln, 1977). Nutrient enrichment may have had some role in the apparent increased incidence of PSP organisms in the Sound (Saunders et al., 1982), but this relationship has not been conclusively established. In any case, present anthropogenic loadings of nutrients to Puget Sound represent only a small fraction of the total natural load.

As a result, while the need for direct nutrient monitoring in the Sound appears to be limited at present, continued monitoring of this parameter is recommended to provide a direct measure of overall anthropogenic nutrient influences. It is of note that orthophosphate measurements by the University of Washington include historical measurements of reasonable accuracy extending from the early 1930s to 1963 at a few stations in the Main Basin, providing one of the largest monitoring records in the area.

Frequency and Sites: Nutrient sampling should be performed in conjunction with the temperature and salinity sampling previously recommended.

Data to be Reported:

- station location, date and time
- nutrient concentrations, depth, salinity, temperature and DO
- procedures and QA/QC documentation/codes

Data Analyses Required:

- o Long-term trend analysis comparing monthly means for sampled months. Due to limited data, only major changes will be statistically resolvable.

Data/Sample Archival:

- o no sample archival
- o full data archival

Other Monitoring Data: As described above and in Section 5.2.

WATER COLUMN: TURBIDITY

Objectives (from Chapter 3):

Understanding natural oceanographic and climatic events and phenomena, and the relationships among these, that may influence the Puget Sound biota.

Determining trends in the visual appearance and olfactory characteristics of Puget Sound.

Rationale for Monitoring:

Most turbidity in the Sound is due to natural causes, particularly river discharges, and is not considered to be a major water quality problem (Baker, 1982; Dexter et al., 1981). Human disturbance can increase turbidity by increasing upland and shoreline erosion, but it is more likely that human activity has reduced turbidity by building dams.

Turbidity (i.e., particulates including plankton) affects the ecosystem directly by decreasing light penetration and hence plant productivity. At extremely high concentrations, turbidity can result in the smothering of benthic and attached fauna. Excess turbidity can also present visual/aesthetic problems.

Recommendations for Sampling:

Turbidity may be monitored by direct measurements of the mass of particulates (filtration of suspended solids), by transmissometer/nephelometer light penetration methods and, in surface layers, by secchi disk measurements. The results of the methods are not exactly comparable. No procedure for measuring turbidity has yielded any indication of a consistent trend toward either increasing or decreasing levels of fine particulate matter in the Sound.

Monitoring of turbidity that interferes with recreational/visual uses of the Sound can be usefully conducted (c.f. odor and floatables). The incidence of "problems" (i.e., unsightly situations) is expected to be spatially and temporally sporadic and not suitable for routine field sampling. Instead, the incidences of visually objectionable situations should be monitored by means of a readily accessible and well publicized telephone reporting service similar to that used for reporting whale sightings. This service could record the time, place and description (type, size and severity) of the incidences as well as refer problems to the agency responsible for managing the problem.

Frequency and Sites: Monitoring of turbidity at the frequency (monthly) and sites currently sampled by WDOE is sufficient for monitoring purposes, with the following additions recommended: 1) winter sampling is recommended to monitor the high particulate fluxes associated with the high winter flows of the rivers, and the common December floods; and 2) recommended additional sampling sites noted for temperature and salinity, if instituted, should also be used to monitor turbidity.

Data to be Reported:

- station location, date and time
- turbidity measure and depth (including secchi depths)
- salinity, temperature and DO
- procedures and QA/QC documentation/codes

Data Analyses Required:

- temporal and spatial trends on a monthly basis
- major deviations from long-term average conditions (because of the limited data collected, statistically resolvable differences will be large)

Data/Sample Archival:

- no sample archival
- full data archival

Other Monitoring Data: Turbidity monitoring is currently being conducted by WDOE as noted above and discussed in Section 5.2.

WATER COLUMN: PATHOGENS (ENTEROBACTERIA/ENTEROVIRUSES)

Objectives (from Chapter 3): Determining trends in factors that may endanger human health.

Determining the effects of changes in waste disposal practices on the receiving system.

Determining the effects of changes in regulatory management decisions on the receiving system.

Rationale for Monitoring: Runoff and sewage-derived pathogens, bacteria and viruses of animal origin, presently constitute one of the major water quality problems in Puget Sound, including a documentable human health threat. Contamination of shellfish has led to closures of recreational and commercial shellfish beds, while water-borne pathogens pose a risk during water-contact recreation.

Recommendations for Sampling: At present, the concentrations of non-pathogenic organisms, fecal coliform (and/or total coliform) bacteria, are measured in water and biota and used as a surrogate for primary pathogens. Fecal coliform bacteria and most specifically *Escherichia coli* result from and indicate the presence of fecal wastes from humans, other mammals and birds. Wastes from these populations are considered to be the dominant source of pathogens in the marine environment. Only limited studies have been performed (none in Puget Sound) to determine whether in fact the surrogate organisms provide a reasonable representation of pathogens in marine systems (i.e., whether die-off rates, dispersion and distribution of other bacteria and viruses are similar). Transport processes, including die-off rates of fecal coliforms themselves are poorly established. In addition, doubt now exists regarding the ability of conventional microbiological techniques to detect coliforms and/or primary pathogens in seawater.

As a result of these uncertainties, research should be initiated regarding pathogen transport and fate in Puget Sound, to guide the development of a final monitoring plan. In the interim, however, because some records are already available (c.f. Section 5.4), and since the methodology is reasonably well established, fecal coliform monitoring is recommended at least as an indicator of the relative levels of fecal matter pollution. Monitoring for *Escherichia coli* is also recommended since certain other coliforms commonly measured in the total fecal coliform test are now known to originate from non-fecal sources.

The recommendations contained herein are liable to change when and if better data become available regarding the whole pathogen question.

Frequency: The limited available data indicate that short-term (monthly) fluctuations in fecal coliform concentrations are substantial, on the order of a factor of 10 or more, with distinct average wet weather increases of about the same order of magnitude. Thus, comparisons of monthly mean values rather than an annual average appear to be most appropriate. Daily monitoring would, however, only allow statistical resolution of changes on the order of a factor of 4 increases through comparisons of monthly means between years. Weekly samples would provide distinction of about 6-fold increases between consecutive years. Such intensive sampling does not appear to be warranted at present. We therefore recommend continued collection of coliform samples at least monthly from all sites currently monitored by WDOE and by Metro.

Data from more than one month should be combined to yield a series of seasonal means as the most effective way of reducing variances. It is expected that this approach will yield nearly as precise a long-term trend analysis as weekly sampling. A necessary addition to the present programs is winter sampling. The available data strongly suggest that fecal coliform concentrations in the ambient water may be greatest during the high runoff periods. Monthly monitoring should be implemented on a year-round basis.

Sites: The sites currently sampled by WDOE and Metro, with the additional sites recommended in the preceding section on temperature and salinity are probably sufficient for the present. It must be noted that nearshore areas may show substantially higher variances than the open water sites. Hence, it may be difficult to assess trends. In addition, the major beneficial use protected by this monitoring, the shellfish beds, can best be monitored directly as recommended later in this report.

Data to be Reported:

- station location, date, depth and time
- salinity, temperature and DO
- fecal coliform most probable number
- *Escherichia coli* most probable number
- procedures and QA/QC documentation/codes

Data Analyses Required:

- temporal trends by region, comparing seasonal average fecal coliform concentrations
- spatial trends in fecal coliform concentrations
- major sites of violation of standards and potential health risks

Data/Sample Archival:

- no sample archival
- full data archival

Other Monitoring Data: As discussed above, and in Section 5.4.

WATER COLUMN: TOXIC CHEMICALS

Objectives (from Chapter 3): Determining trends in factors that may endanger human health.

Determining trends in the inputs and concentrations of anthropogenic factors that may affect Puget Sound biota.

Determining the effects of changes in waste disposal practices on the receiving system.

General Comment: Dissolved and particulate-associated toxic chemicals impact marine organisms as well as provide the transport medium for toxic chemicals accumulated in bottom sediments. Therefore, if reliable measurements could be obtained, data on the levels of toxic substances in the water column would be invaluable both for monitoring temporal and spatial trends and for transport modeling.

However, for organic chemicals, present analytical limitations are such that we can only just detect many of these substances in water samples, even under optimum conditions. These limitations preclude the present implementation of a successful monitoring program for organic toxic chemicals in the water column. In contrast, the concentrations of dissolved and particulate trace metals in water can be measured accurately, but only with great care. At the present time, the available data do not indicate that metals in the water column are causing a significant toxicity problem in Puget Sound (Dexter et al., 1981; Romberg et al., 1984). This observation is due in part to the fact that natural loadings of metals normally exceed the anthropogenic load. In addition, the available data appear to be insufficient to adequately define the normal spatial and temporal variance which can be expected in the concentrations of trace metals in the water column such that adequate spatial and temporal sampling frequencies for a monitoring program can be assessed.

As a result of the above limitations, no general direct monitoring of toxic substances in the water column is recommended. Secondary indicators, however, i.e. measurements of toxic substances in sediments and biological tissue samples, are recommended and are discussed separately.

As an additional comment related to the concerns discussed in this section, it is noteworthy that in April of 1985 the ASARCO Copper Smelter in Ruston curtailed its metals discharges, as its major smelting operations ceased. This one source emits such high concentrations of Cu that they are estimated to constitute as much as one third of the total anthropogenic Cu input to the Main Basin (Quinlan et al., 1985). The expected decrease in Cu inputs to Puget Sound which will result from the curtailing of this source should be detectable in the receiving waters.

Measuring this change over the next two to five years is recommended: 1) to simply document any actual improvement in ambient water quality; and, 2) to provide a clear test of some of the present circulation, transport and distribution models of Puget Sound. Specific design of this recommended research program is beyond the scope of the present study.

It can be further noted that changes in the Cu discharges associated with Metro's West Point Sewage Treatment Plant, another major source of Cu, resulting from implementation of industrial pretreatment programs, reduced potable water corrosiveness, and perhaps, secondary treatment, may be substantial. These changes may also significantly reduce the ambient Cu levels.

SEDIMENT: TOXIC CHEMICALS IN SEDIMENTS

Objectives (from Chapter 3):

Determining trends in the inputs and concentrations of anthropogenic factors that may affect Puget Sound biota.

Determining the natural temporal and spatial trends in receiving system properties needed for the development of safe, effective waste disposal practices.

Determining the effects of changes in waste disposal practices on the receiving system.

Determining the effects of changes in regulatory management decisions on the receiving system.

Rationale for Monitoring:

Most of the toxic chemicals of concern which have been identified in Puget Sound accumulate to relatively high concentrations (on a mass basis) in the sediments as compared to the water column. As a result, measurement of these substances in the sediments has been a much more fruitful endeavor than comparable attempts at measuring the water column. Results to date demonstrate the utility of sediment chemical measurements in providing information in three major areas: 1) assessment of direct toxicity to resident benthic organisms (and in bioassay testing); 2) the identification of areas of the Sound which have been or are receiving substantial inputs of toxic chemicals; and, 3) estimating the temporal changes (via repetitive measurements over time and sediment coring) in toxic chemical inputs.

The perceived impacts of toxic chemical contamination are of great concern to the general public in the Puget Sound region, even though clear relationships between toxic substances and any direct perturbation of the ecosystem have not been established. Impacts of toxic chemicals include closures or restrictions on some fisheries due to high levels of particular chemicals in the edible tissue of resident fish and shellfish. In addition, toxic substances have been implicated in some benthic community effects and fish histopathological disorders (Quinlan et al., 1985).

Because of these perceived and real problems, and because the sediments are a convenient and effective media for monitoring, it is recommended that the concentrations of toxic substances in the sediments of Puget Sound be monitored directly.

Frequency: The use of sediments as a monitoring tool is hampered by variabilities in sedimentation rates in different areas and by variable depths of surface sediment reworking/mixing. Variable sedimentation rates result in the problem that the most reasonable sampling approach, of taking the upper two centimeters of sediment at all stations, may yield anywhere from 1 to 20 years of recent sediment deposition. This problem can be overcome by selecting sites which have rapid and approximately comparable sedimentation rates.

Sediment reworking by infauna, leading to the homogenization of surficial sediments, presents a greater problem. Recent studies indicate that the depth of the sediment mixed layer ranges from a few cm to greater than 20 cm (Carpenter et al., in press). The resulting estimated effect on accumulating sediments is that an average of about 20 years would be the expected "half-life" of changes in the concentrations of chemicals in the surficial sediment concentrations in response to changes in the input concentrations (Carpenter et al., in press). This means that very frequent sediment sampling in most areas will not provide data sufficient to rapidly detect even complete cessation of inputs of a chemical, and would only detect massive increases in the input concentrations.

Based on this analysis, sediment sampling for monitoring purposes is recommended at 5-year intervals in areas away from direct sources (see below). This frequency is well within the anticipated rate-of-change of the sediment concentrations and frequent enough to detect major changes in inputs. In areas proximate to known or potential sources, more frequent (annual) sampling is recommended. This recommendation recognizes that major changes in inputs should be more readily detectable in these areas, particularly for new compounds of toxicological concern.

Sites: Two major types of sites can be distinguished for monitoring purposes. The first type of site is that at some distance from known or potential direct sources of toxic chemicals. These sites would receive contamination from advective transport and sedimentation of contaminated particulates and hence would reflect the integrated inputs of toxic chemicals from many sources to the Sound. These sites would be least sensitive to major changes in inputs since dispersion and dilution would buffer the extent and rate of change. These sites would also be most sensitive to the buffering effect of sediment reworking. Therefore these sites should be sampled at 5 year intervals.

Specific selection of the long-term monitoring sites that fall into the first category (above) is hampered by the paucity of data from most areas of the Sound. Key criteria for selection include fine-grained sediment to provide maximum detection, relatively undisturbed sediments indicating constant long-term sedimentation regimes, minimum bioturbation, and sites that are representative of defined regions (in a reasonably large area with a demonstrably small variance in chemical concentrations within that region). Because these parameters have been measured at relatively few sites in Puget Sound, an initial baseline effort to obtain these data and make final site selections, is recommended before initiating the long-term monitoring. However, preliminary sites which may be suitable based on the data of Carpenter et al. (in press) include Padilla Bay, Central Possession Sound, the Main Basin near West Point, the north end of Vashon Island, the southern reach of East Passage, and Dabob Bay. Additional sites should be selected in the northern Sound, Hood Canal and South Sound. Data from this selection, which requires coring to determine sedimentation rates and mixing depths, can also be interpreted for *a posteriori* estimates of long-term trends in contaminant loadings.

The second type of sediment monitoring sites are located in proximity to known or potential inputs, i.e., near major point sources such as ASARCO and in areas of general urban/industrial development, and are intended to monitor what is generally a much more rapidly changing environment than the long-term monitoring sites. In addition, major increases in chemical inputs, including the introduction of new compounds, should be detectable in near-field sediments soon after their introduction. As a result, these sites should be monitored on an annual basis.

Specific site selection is recommended in the following selected urban embayments: Bellingham Bay, Anacortes Harbor, Port Angeles, Port Gardner (Everett), Sinclair Inlet (Bremerton), Elliott Bay (Seattle), Commencement Bay (Tacoma) and Budd Inlet (Olympia). While these areas generally have at least some baseline studies defining the extent of chemical sediment contamination, it is difficult to select specific sites in these areas because of the high level of small-scale variability, and the major changes caused by dredge-and-fill operations and other direct human manipulations. Further, recent concern with the risks associated with contaminated sediments may result in specific actions to eliminate these contaminated areas (e.g., by dredging). Therefore, it is obviously necessary to ensure adequate records of any such changes which may result from sediment movement. In addition, multiple sampling and compositing may provide the best means of obtaining samples indicative of the average levels at the site suitable for temporal intercomparisons at a reasonable level of sampling and analytical effort.

Consequently, it is recommended that in each of the urban areas specified above and near Ferndale, Bangor, ASARCO, and the Four Mile Rock Disposal Site, uniform sampling grids (of from 10 to 50 stations depending on the size of the embayment) be established. Surface sediment samples should be collected at each of these stations annually and, depending on resources available, composited to form one or more composite samples for chemical analyses. This procedure has the advantage that comparable data can be obtained for temporal trend analyses even if the number of composites varies from year to year. In addition, the relocation or deletion of one or a few stations necessitated by construction, dredging, or other similar activities could be accomplished without necessarily impairing the validity of the data for temporal comparisons. Finally, archival of a portion of sediment from each station is recommended to allow detailed site investigations if the composites indicated that this was warranted.

Data to be Reported: A number of recent reports (Konasewich et al., 1982; Dexter et al., 1981; Jones and Stokes and Tetra Tech, 1983b; Quinlan et al., 1985) have considered the question of which compounds are of primary concern in Puget Sound. These include a wide spectrum of polynuclear aromatic hydrocarbons (PAHs), chlorinated hydrocarbons and pesticides, PCBs, trace metals (particularly Pb and Ag) and other compounds. At the same time it is known that additional compounds of known toxicity (e.g., dioxins), may be present but have never been analyzed for. A clearer picture of a larger spectrum of compounds found in Puget Sound sediments has recently emerged as a result of the analytical efforts by Metro as part of their TPPS study, and through the intensive analytical investigations in Commencement Bay as part of the WDOE/EPA Superfund Project. Based on these studies, we recommend that as a minimum, the compounds that should be measured are the PAHs, PCBs, phenols (chlorinated and otherwise), chlorinated benzenes, phthalates, and the trace elements arsenic, copper, lead, zinc, mercury and silver.

Because of the present uncertainties and because of the potential for the introduction of new compounds, monitoring only for these specific target compounds is not recommended. Fortunately, the broad range of analyses required to measure the variety of "chemicals of concern" listed above would be reasonably inclusive of most chemicals of probable toxicological potential. Additional detailed analyses are recommended on some of the composited samples collected for routine analyses of the above "chemicals of concern". These additional analyses should be aimed particularly at those samples having large numbers of unidentified compounds.

However, it must also be borne in mind that the major limitation with this approach is the lack of adequate quantification/detection of more polar chemicals and the polar metabolite/degradation products of other chemicals for which the analytical technology is not currently well developed. As procedures become available for measuring these compounds, special synoptic surveys should be used to determine which, if any, should be included in the routine monitoring.

Data to be Reported:

For each sediment sample the data to be reported should include:

- station location, date and time
- water depth
- sediment horizon sampled
- sediment particle size distribution, percent solids, organic carbon content, and total oil and grease
- the concentrations of the pre-specified organic compounds and trace metals
- the identity and concentration of non-specified compounds which are present in the samples at significant levels
- procedures and QA/QC documentation/codes

Data Analyses Required:

- o comparisons, by station, of the temporal trends in sediment concentrations. Given the low sample numbers, sample variability and buffering due to sediment reworking, only large changes will be discernible
- o comparisons through time of the spatial differences in concentrations
- o date of appearance of any new toxic chemical
- o comparisons of sediment chemistry, infauna and bioassay data in a Triad Index (Long and Chapman, in press)

Data/Sample Archival:

- o an aliquot of all samples should be stored frozen for possible future analyses
- o full data archival

Other Monitoring Data:

At the present time, there is no formal region-wide monitoring program for sediments and not all areas have been adequately sampled in even preliminary surveys to clearly ascertain the best places for long-term monitoring sites. However, recent and probable future sampling in many areas and undoubtedly in the urban embayments, in association with non-monitoring studies, may well satisfy the recommendations for monitoring in these areas for the foreseeable future. In addition, NOAA's Status and Trends Program began monitoring toxic chemicals in sediments from three areas beginning in 1984: Elliott Bay, Commencement Bay, and the Nisqually estuary (Ed Long, NOAA, pers. comm.).

Additional data required include sediment particle size distribution and total organic carbon, as described below. Data should be gathered for each site.

Sediment Particle Size Distribution

Rationale for Monitoring:

Sediment particle size distribution (texture) is not a primary variable which should be monitored directly to detect human perturbations. Rather, texture is a necessary variable in: 1) explaining the distribution and abundances of sediment-associated organisms; and, 2) because many chemicals tend to be sorbed to higher concentrations on finer-grained material, explaining the distributions of toxic substances.

Frequency and Sites: Sediment grain-size measurements should be made on aliquots of all samples taken for benthic community, bioassay and chemical analyses. No separate sampling is necessary.

Data to be Reported:

- o station location, date, time, water depth
- o depth of sediment analyzed
- o percents of gravel, sand, silt and clay and mean phi should be reported, as a minimum, with other standard analyses (sand/mud ratio, skewness, sorting, etc.) also recommended
- o standard sieve and pipette analyses are recommended with data reported at least at one-half phi intervals in the sand class and one phi intervals in the silt and clay sizes
- o procedures and QA/QC documentation/codes

Data Analysis Required:

- o Particle size distributions are determined principally in conjunction with explaining the distributions of toxic substances and/or benthic fauna, but maps of sediment texture should be composed as this information would be useful in characterizing areas for habitat, predicting chemical accumulation sites and circulation/sedimentation studies.

Data/Sample Archival:

- o no sample archival
- o full data archival

Sediment Total Organic Carbon (TOC) and Oil and Grease (O&G)

Rationale for Monitoring: As with sediment texture, the organic matter in the sediments may affect the distribution of sediment-associated organisms and the concentration of many toxic chemicals which preferentially sorb to organic matter. Therefore sediment organic content should be measured concurrently with sediment grain-size in all samples collected for benthic infaunal analyses and for sediment chemical analyses.

Recommendations for Sampling: The only difficulty with organic content analyses is the selection of the technique to use. Of primary interest in the test is the amount of biologically degradable/sorbed organic matter and organic detritus and the fraction active in chemical interactions. Larger wood chip debris and coal fragments are generally not as biologically important as other forms but are included in most tests. Further study would be beneficial in developing simple and reliable tests to quantitate not only the total amount of organic carbon but also the amounts in different organic types. At the present time, we recommend the measurement of two major types of organic matter, total organic carbon and oil and grease.

Two major approaches have been used to characterize sediment total organic carbon: 1) high temperature combustion, which oxidizes all organic carbon as well as some other constituents, hence the name Total Volatile Solids (TVS); and, 2) instrumental techniques which use either dry (heat) or wet (chemical) oxidation of the organic matter. The latter procedure can usually better define the organic fraction measured and often provides simultaneous measurements of other parameters (e.g., organic nitrogen), which can be helpful in differentiating sediment types. However, the instrumental procedure is inherently more complex, often more costly, and not always readily available. In addition, different instruments measure different organic constituents resulting in data that are sometimes not directly comparable. For these reasons, the more robust and more widely available TVS test is recommended for monitoring purposes.

The TVS procedure probably overestimates the biologically and chemically "active" organic fraction, particularly when wood debris is present. However, limited data indicate the total and "active" fractions usually at least roughly correlate, and any loss of specificity is balanced by the greater assurance that different studies will yield comparable results.

The measurement of oil and grease is based on a straight procedure of hydrocarbon solvent extraction and determines the lipid-soluble fraction of the organic matter. This parameter complements the TVS/TOC measurements in characterizing the type of organic matter in the sediments.

For both procedures, it is important that protocols clearly defining the analytical procedures be specified to ensure comparable data among all monitoring efforts.

Frequency and Sites: TOC and O&G determinations should be made on aliquots of all samples taken for benthic community and chemical analyses. No separate sampling is necessary.

Data to be Reported:

- o station location, date, time, water depth
- o organic content measure(s), depth in sediment
- o sediment texture
- o procedures and QA/QC documentation/codes

Data Analyses Required:

- o Sediment organic carbon is determined principally in relation to the distributions of toxic organic chemicals and/or benthic infauna. However, distribution maps of TOC and O&G should be prepared as this information would be useful in defining areas of anthropogenic influence, high chemical accumulation and/or high biological productivity.

Data/Sample Archival:

- o no sample archival
- o full data archival

SEDIMENT: BIOASSAYS

Objectives (from Chapter 3):

Determining trends in the inputs and concentrations of anthropogenic factors that may affect Puget Sound biota.

Determining the natural temporal and spatial trends in receiving system properties needed for the development of safe, effective waste disposal practices.

Determining the effects of changes in waste disposal practices on the receiving system.

Rationale for Monitoring:

Measurements of toxic chemicals in sediments do not provide information on the availability of these chemicals to aquatic organisms, nor do they provide information on overall sediment toxicity to resident bottom-dwelling/-associated organisms. Information on sediment toxicity is required to assess whether sediment chemical contaminants are affecting the biota. This information is most effectively obtained by conducting bioassays on field-collected sediments to determine the level of toxicity induced in the laboratory (lethal, sublethal, genotoxic)(Chapman and Long, 1983).

Recommendations for Sampling:

Based on experience to date with sediment bioassays in Puget Sound, we recommend that three specific tests be implemented for each sediment sample analyzed, following the recommendations of Chapman and Long (1983). These tests span a wide range of possible toxic responses using a range of species and life-history stages, in a manner designed to partly accommodate the wide variety of responses to chemical contamination. Acute toxicity should be measured using the amphipod test described by Swartz et al. (1982, 1985). Sublethal toxicity should be measured by the oyster larvae test described by Chapman and Morgan (1983). Genotoxicity should be measured by the fish cell test (rainbow trout gonad cells) described by Landolt and Kocan (1984). These three methods, combined, provide the most useful range of information on sediment toxicity (Chapman et al., 1984; Quinlan et al., 1985).

Frequency:

Comments previously made with respect to the effects of deposition and bioturbation on sediments (cf.

section on toxic chemicals in sediments) apply to collections of sediments for bioassay testing. Consequently, we recommend that sediment bioassay testing be conducted at the same stations as those used for measurements of sediment toxic chemicals, vis: a series of stations in areas away from direct sources to be measured every 5 years, and a series of stations in areas proximate to known or potential sources to be measured annually.

Sites: As per direct measurements of toxic chemicals in sediments; because of small-scale patchiness problems, a total of five closely grouped but separate stations are recommended for testing at each site. Five replicates are the generally accepted minimum for detailed statistical analysis. Sediment chemistry could be performed on a homogenate of aliquots from these five stations.

Data to be Reported:

- station location, date and time
- water depth
- sediment horizon sampled
- amphipod acute toxicity
  - survival at 10 d (mean ± S.D.)
  - avoidance to 10 d (mean ± S.D.)
- oyster larvae toxicity
  - mean survival at 48 h
  - mean abnormalities at 48 h
- fish cell genotoxicity
  - proportion of anaphase aberrations
- sediment texture, percent solids and organic carbon content
- procedures and QA/QC documentation/codes

Data Analyses Required

- comparisons, by site, of temporal trends in toxicity
- comparisons through time of the spatial differences in toxicity
- comparisons of sediment chemistry, infauna and bioassay data in a Triad Index

Data/Sample Archival:

- due to problems of toxicity changes during storage, sample archival is not recommended
- full data archival

Other Monitoring Data: At the present time, there is no formal monitoring program for sediment toxicity and not all areas of Puget Sound have been adequately sampled. A review of areas tested to date is provided in Quinlan et al. (1985). However, recent and probable future studies in many areas, and undoubtedly in the urban embayments, in association with non-monitoring studies, may well satisfy the recommendations for monitoring in these areas for the foreseeable future.

Additional data required include sediment particle size distribution and total organic carbon, as previously described. Data should be gathered for each bioassay site.

PHYSICAL HABITAT — PERCENT OF HABITAT TYPES

Objectives (from Chapter 3):

Determining the natural temporal and spatial trends in receiving system properties needed for the development of safe, effective waste disposal practices.

Determining the effects of changes in regulatory management decisions on the receiving system.

Rationale for Monitoring:

The physical structure of the environment surrounding and supporting Puget Sound biota is an essential element in determining the success of different communities. Human modification of habitats may be one of the major factors influencing the Puget Sound ecosystem. Habitat considerations also bear on socio-economic concerns since development often alters (directly and/or indirectly) public access for recreation and aesthetics.

Recommendations for Sampling:

The deeper, offshore areas of the Sound have been and continue to have limited potential for modification by human activities. The major areas of concern are in the shallow nearshore zones where most development takes place and where substantial areas of habitat critical for the existence of one or more species may be threatened.

At the present time, critical habitat protection is provided through the Shoreline Permit System which requires a review and acceptance of the environmental impacts associated with shore modifications. However, a whole-Sound perspective is generally considered only on major projects which may have a direct influence on more than one area. Shoreline permits are not generally monitored with respect to the potential cumulative effects of many small shoreline modifications.

For some planning, map-making and surveillance purposes, high resolution aerial photographs are taken of the shoreline areas. The U.S. Army Corps of Engineers (ACOE) flies the shoreline annually to ensure permit compliance. However, no annual summaries of these overflights are made.

To monitor percent of habitat types, it is recommended that shoreline permits be used in a holistic sense to determine Puget Sound-wide changes. In addition, the overflights presently conducted by ACOE should be continued as they could provide much useful information for this purpose. Present habitat conditions need to be well-documented, and ground-truth measures need to be established for the aerial photos and permits.

A simple approach to future needs would be to solicit the assistance of one or more public service or environmental organizations (e.g. the Audubon Society, Explorer Scouts, etc.), to provide individuals to perform an annual "beach walk" of most Puget Sound intertidal areas. Using beach section maps and aerial photos, the walkers could note beach conditions, beach type and major structures. In addition, observations of odor, water color and the appearance of slicks and floatables could also be recorded (cf. the section on monitoring of these parameters), along with broken or leaking storm drains and appearances or disappearances of kelp beds.

Frequency: Because most developments require a period of years to complete, annual monitoring of shoreline modification should be adequate.

Sites: All of the Puget Sound shoreline should be monitored.

Data to be Reported:

- aerial photographs of shoreline and nearshore upland areas
- completed projects identified through compiled shoreline permits
- maps and checklists obtained from annual beach walks

Data Analyses Required:

- Data on the nearshore habitats should be presented in graphic form as base charts of the Puget Sound shoreline showing areas of different habitat type. For example, coding or graphical representation could be readily done for five major habitat types: 1) bulkheads and piers; 2) rocky and rip-rap; 3) sloping; 4) estuaries; and, 5) wetlands and eelgrass beds. Areas of known critical habitat could also be depicted. An initial base chart could possibly be developed from USGS topographic maps, NOS charts, and the current Coastal Zone Atlas and NOAA's oil spill vulnerability maps.

- Narrative summary of changes in the habitats, noting areas of substantial change as well as cumulative percentages of different habitat types.

Data/Sample Archival:

- full data archival

Other Monitoring Data: As discussed above and in Section 5.8.

BIOTA: PLANKTON ABUNDANCE AND COMMUNITY STRUCTURE

Objective (from Chapter 3): Determining trends and the natural ranges in the abundances of Puget Sound biota, in particular, valued marine resources such as harvestable fish and shellfish.

Rationale for Monitoring: Plankton (both phytoplankton and zooplankton) are essential ecosystem components and vital food sources for upper trophic level organisms.

Recommendations for Sampling: Phytoplankton blooms are highly variable under natural conditions such that only gross human-induced changes can be detected (Beanlands and Duinker, 1983). Intensive phytoplankton monitoring would be needed to detect any but the most major ecosystem changes and would be extremely expensive. Consequently, we recommend that monitoring concentrate on determining any changes in dominance. Changes in the dominance of major plankton species may affect the availability of these organisms to upper food chains, including fish. Specifically, dominant groups (e.g. dinoflagellates) should be identified and their percent community composition determined.

Monitoring of zooplankton holds problems similar to phytoplankton monitoring. We recommend that dominant groups (e.g.. calanoid copepods, euphausiids/mysids, ctenophores, arrow-worms) be identified to major taxon groups, together with their percent community composition.

Frequency: Phytoplankton - as per dinoflagellates (p. 56).

Zooplankton - oblique net tows should be conducted (using nets equipped with flow meters and a vessel speed of 1.5-2 knots) at the same time as phytoplankton collections.

Sites: As per dinoflagellates.

Data to be Reported:

- station location, date and time
- salinity, temperature, DO and turbidity
- phytoplankton
  - dominant groups
  - percent community composition
  - sample depths

- zooplankton
  - dominant groups
  - percent community composition
- procedures and QA/QC documentation/codes

Data Analyses Required:

- temporal and spatial trends on a seasonal and yearly basis
- major deviations from long-term average trends
- comparisons of phytoplankton and zooplankton data; zooplankton are size-selective feeders on phytoplankton and dominance in zooplankton populations is largely dependent on community composition of phytoplankton communities/blooms, which (e.g. dinoflagellate predominance) may be affected by pollution

Data/Sample Archival:

- samples should, after examination, be properly preserved
- full data archival

Other Monitoring Data: Olympic Community College collect zooplankton samples from Sinclair Inlet and have partially analyzed samples from 1978 to the present. Collections of plankton have been made, for non-monitoring purposes, by various investigators in practically all areas of Puget Sound. These data, if gathered, standardized and combined, could form an effective basis for future monitoring.

BIOTA: CHLOROPHYLL *a*

Objective (from Chapter 3): Determining trends and the natural ranges in the abundances of Puget Sound biota, in particular, valued marine resources such as harvestable fish and shellfish.

General Comment: Measurements of the concentrations of chlorophyll *a* can provide a convenient and quantitative measure of phytoplankton standing stock. Given the vital role of the plankton community at the base of the food chain, it would appear worthwhile to make direct measurements to assure the health of these organisms. However, standing stock is a highly variable parameter, as it is a function of numerous physical conditions in the Sound which themselves vary rapidly both temporally and spatially.

As a result, the utility of chlorophyll *a* measurements as a long-term monitoring parameter may be confounded by the large number of samples required to obtain sufficient statistical precision to resolve temporal and spatial differences. Based on limited data from the Main Basin, we estimate that even daily chlorophyll *a* measurements would be insufficient to resolve differences of 20 percent or less in monthly mean values per site.

Chlorophyll *a* data collected in past and on-going research studies in the region's colleges and universities have provided a reasonable level of understanding of the overall phytoplankton dynamics in the major basins. Such continuing studies are also probably sufficient to flag major productivity problems. Studies of phytoplankton communities recommended specifically for dinoflagellates are considered a more effective monitoring tool than monitoring of chlorophyll *a* for detecting changes in plankton production. As a result, chlorophyll *a* monitoring is not recommended in Puget Sound.

BIOTA: DINOFLAGELLATES

Objectives (from Chapter 3): Determining trends and the natural ranges in the abundances of Puget Sound biota, in particular, valued marine resources such as harvestable fish and shellfish.

Determining trends in factors that may endanger human health.

Rationale for Monitoring: One of the major adverse biological effects identified in Puget Sound, which may be related to anthropogenic pollution, is an increased incidence of dinoflagellate blooms. These blooms are responsible for both large-scale mortalities of bivalve larvae, and (depending on the species present) for "red tides" resulting in PSP-related shellfish closures.

The dinoflagellate *Ceratium* is considered to be responsible for oyster larvae mortalities (Cardwell et al., 1979), while reddish discolorations of the water are due to *Peridinium* and PSP is due to *Gonyaulax*. Because PSP outbreaks in Puget Sound are not necessarily related to reddish discolorations of the water, only careful laboratory analysis can successfully test for PSP in shellfish. The issue of PSP in shellfish is addressed later in this report.

The other significance of dinoflagellate blooms is that they have the potential to affect planktivorous fish by changing the basic food chain. Greve and Parsons (1977) have shown that a food chain based on dinoflagellates will terminate with arrow worms and jelly fish, rather than leading to fish. Such a change could have a major effect on Puget Sound fisheries.

Presently recorded increases in dinoflagellate blooms and in PSP occurrences may be due to a variety of causes including pollution, natural cycles, or non-pollution-related changes to the environment. In any case, it is important to monitor dinoflagellate blooms in Puget Sound, both in themselves and separated into the two common toxin-producing genera.

Frequency and Sites: Composite water samples should be collected in three samplings per year, in spring, summer and fall. Winter is excluded because the typical light-limiting conditions at this time result in low abundances of all phytoplankton groups. Samples should be collected at the same time of day and should include composite samples of water from various depths through the euphotic zone. These samples should be collected at the sites recommended for the monitoring of temperature and salinity.

This intensity of sampling, together with the direct monitoring of shellfish beds for PSP toxins, described below, should be sufficient to monitor long-term trends and flag incidences that may require more intensive sampling.

Data to be Reported:

- station location, date and time
- sample depths for composite
- salinity, temperature, DO and turbidity (of composite)
- dominance (percent community composition) of dinoflagellates compared to all phytoplankters
- dominance (percent community composition) of *Gonyaulax* and *Ceratium*
- proportion of PSP-related species
- procedures and QA/QC documentation/codes

Data Analyses Required:

- temporal and spatial trends on a seasonal and yearly basis
- major deviations from long-term average trends
- areas and times of highest proportion of dinoflagellates and PSP species

Data/Sample Archival:

- samples should, after examination, be properly preserved and archived
- full data archival

Other Monitoring Data: At present, there is no specific on-going program for monitoring dinoflagellates that fulfills all the above recommendations, but some useful data are available. The Washington Department of Social and Health Services (DSHS) monitor commercial shellfish beds to ensure that PSP standards are not exceeded (c.f. Section 5.4). In addition, a number of prior studies have evaluated the historical incidence of dinoflagellate blooms in Puget Sound (e.g. Cardwell et al., 1977, 1979; Saunders et al., 1982; L. Nishitani, University of Washington, personal communication). Finally, DSHS maintains a toll fee PSP hotline (1-800-562-5632) for information exchange; this hotline is important and should be continued.

BIOTA: MACROPHYTE ABUNDANCE AND COMMUNITY STRUCTURE

Objective (from Chapter 3): Determining trends and the natural ranges in the abundances of Puget Sound biota, in particular, valued marine resources such as harvestable fish and shellfish.

Rationale for Monitoring: Eelgrass, kelp and other nearshore aquatic plants are extremely important for marine detrital carbon cycles and support unique populations of marine fauna (Quinlan et al., 1985). Some species are also harvested by Asian Americans. The extent and community composition of these beds should be monitored as changes will impact other ecosystem components.

Frequency: Data on abundance and community structure should be collected once a year, in the spring. These data can be partially gathered by onshore observers as part of the annual beach walk recommended for habitat assessment. Additional data can be gathered as part of aerial surveys presently undertaken for monitoring of marine bird populations and/or shoreline modifications using infra-red photography to determine the location of major plant beds and their densities. Slides of the plant beds can be projected and drawn onto charts and the surface area of the beds calculated using either a polar planimeter or a measured grid network.

Sites: All nearshore areas of Puget Sound should be sampled.

Data to be Reported:

- area (km^2) of each identified major bed, and constituent plant types (species)
- total area of all beds surveyed, by plant type
- procedures and QA/QC documentation/codes

Data Analyses Required:

- temporal trends
- areas showing major variations from previous measurements
- multi-year trends by area
- mapping of data to provide visual representation of major beds

Data/Sample Archival:

- o no sample archival
- o aerial photographs should be properly filed with an appropriate indexing system for ease of retrieval
- o full data archival

Other Monitoring Data: There are no known on-going monitoring programs, however Dr. R. Thom (University of Washington) has conducted baseline studies in King County.

BIOTA: BENTHOS ABUNDANCE AND COMMUNITY STRUCTURE

Objectives (from Chapter 3): Determining trends and the natural ranges in the abundances of Puget Sound biota, in particular, valued marine resources such as harvestable fish and shellfish.

Determining the effects of changes in waste disposal practices on the receiving system.

Rationale for Monitoring: Benthic organisms are essential ecosystem components and vital food sources for upper trophic level organisms. They are also useful indicators of pollution effects.

Recommendations for Sampling: Benthos includes both intertidal and subtidal fauna, macrobenthos and meiobenthos. Intertidal benthos (macro- and meio-) tends to be too variable (subject to natural extremes in physical, chemical and biological parameters) to be a suitable monitoring tool for detecting anthropogenic changes. Subtidal benthos comprises a generally sessile group of organisms that is exposed to conditions at a given site, and which integrates effects over time. The macrobenthos provides less taxonomic and sorting problems than the meiobenthos, hence subtidal macrobenthos should provide the focus of benthic infaunal studies (Gray et al., 1980).

Frequency: Gray (1980) and Gray et al. (1980) have noted that subtidal benthic communities are not at equilibrium in summer, and recommend that long-term monitoring occur in mid-winter. We agree and recommend that sampling occur in mid-winter. Sampling should occur at the same frequency as sediment chemistry and bioassays, viz: a series of stations in deep-water areas away from direct anthropogenic influences to be measured every 5 years and a series of stations in areas proximate to known or potential pollution sources to be measured annually. In addition, annual sampling should continue at the sites sampled by Dr. Fred Nichols (Nichols, 1985).

Sites: Sampling should be conducted at the stations presently sampled by Dr. Nichols and at the same sites as those used for measurements of sediment toxic chemicals and for sediment bioassays, thus providing the basis for the "Triad" (chemistry, bioassays, infauna) recommended by Long and Chapman (in press).

At each site, five replicate samples should be collected and analyzed to a minimum sediment depth of 10 cm. The number of replicates may be adjusted based on analysis of site-specific information; however, five replicates is generally considered an acceptable minimum for statistical analyses of differences between stations.

Data to be Reported:

- station location, date and time
- water depth
- major taxa and family groupings
- species lists
- numbers of organisms per m^2 per sample per station
- species richness per sample
- mean species richness per station
- sediment texture, percent solids and organic carbon content
- procedures and QA/QC documentation/codes

Data Analyses Required:

- comparisons, by site, of temporal trends in benthic community structure and dominance
- comparisons through time of spatial differences in benthic community structure and dominance
- identification of problem areas
- comparisons of sediment chemistry, infauna and bioassay data

Data/Sample Archival:

- samples should, after examination, be properly preserved, archived and curated
- a reference collection should be maintained and updated as necessary
- full data archival

Other Monitoring Data: Nichols (1985) has over 20 years of data related to benthic studies at several Main Basin stations. Continuation of these studies with addition of substrate and depth measurements, together with sediment chemistry and bioassays, could provide the necessary data for delineation of trends in the Main Basin.

Two large subtidal benthic data sets are available for Puget Sound. The first consists of data collected by WDOE and NOAA in northern Puget Sound in relation to proposed oil ports, and reviewed by Zeh and Houghton (1981). These authors noted that it was very difficult to detect any changes in communities due to pollution because natural variation was high and there were substantial problems with the various sampling and taxonomic methodologies used in different studies. We agree with this assessment of the problems with benthic community data, used in isolation, for pollution assessment, and hence have recommended a "Triad" of parameters, which includes sediment chemistry and sediment bioassays to better identify the impacted areas through the corroborative evidence from the three independent measures.

A second large set of benthic data is provided by the Metro TPPS study in Elliott Bay and near West Point, and the Baseline Studies in the Main Basin of Puget Sound related to the proposed Seahurst (Word et al., 1984) and Elliott Bay outfall sites (Stober and Chew, 1984).

All of the above data sets provide useful baseline information for the monitoring program.

BIOTA:	BENTHOS--TOXIC CHEMICALS IN TISSUE
Objectives (from Chapter 3):	Determining trends in factors that may endanger human health. Determining trends in the inputs and concentrations of anthropogenic factors that may affect Puget Sound biota. Determining the effects of changes in waste disposal practices on the receiving system. Determining the effects of changes in regulatory management decisions on the receiving system.
Rationale for Monitoring:	Toxic chemicals accumulated in tissues of benthic biota may directly affect these fauna, or may, in the case of a limited number of specific compounds, be bioaccumulated up the food chain. There is a need to determine baseline levels and any changes to these levels both to evaluate these potential biological and ecological problems, and because measurements of tissue toxicant levels provide information on the availability of toxicants to biota.
Recommendations for Sampling:	Although benthic organisms such as deposit-feeding clams, which are in intimate contact with the sediments, might appear to be a preferred species for monitoring toxic chemicals in tissues, there are problems with their use. First, because they are usually of small size, it is difficult to collect enough tissue to allow for adequate chemical analyses. Second, sediments retained in the guts of these animals may bias the measurements of the contaminant levels in the tissue (Chapman, in press). Consequently, we do not recommend that a benthic infaunal organism be used for this monitoring. Rather, we recommend that bioaccumulation be assessed using the mussel, *Mytilus edulis*. This choice would allow assessment of toxic chemicals released from sediments to the water (the route of availability to most biota) as well as toxic chemicals recently discharged. The advantages of using mussels for monitoring have been detailed by various authors (Farrington, 1983; Goldberg, 1984). In addition, through both the U.S. EPA Mussel Watch program (see 5.14.2), and the WDOE's recent monitoring, there is background information available for Puget Sound regarding the levels of toxic chemicals in the tissues of these

organisms. In addition, since *M. edulis* is an integral component of the food chain for many birds and mammals, Ginn and Barrick (1984) also recommend that *M. edulis* be used as a bioaccumulation indicator in Puget Sound.

Resident mussel populations and/or mussels collected from clean areas and held in the test location can be used for monitoring. Whole tissues should be analyzed for the same chemicals recommended for sediment analyses.

Frequency: Previous experience from the U.S. EPA Mussel Watch Program (Goldberg, 1984) suggests that samples collected every 3-5 years are sufficient to monitor trends in tissue toxicant levels. We recommend that toxic chemicals in mussel tissue be analyzed once every 3 years. Sampling should take place after the reproductive period in the spring. Both male and female mussels of moderate size (about 5 cm) should be analyzed. Whole body analyses (including gonads) are recommended.

Sites: The U.S. EPA Mussel Watch Program monitored three areas of Puget Sound from 1976 to 1978: Boundary Bay, Cape Flattery, and the south end of Whidbey Island. In addition, the WDOE has collected mussels from five areas: Hood Canal, Case Inlet, Carr Inlet, Port Susan and Commencement Bay. In the present report, we have recommended eight nearshore areas with rapidly changing environments for monitoring the toxic chemical levels in sediments, the sediment bioassay responses and benthic infauna assessments: Bellingham Bay, Anacortes Harbor, Port Angeles, Port Gardner, Sinclair Inlet, Elliott Bay, Commencement Bay and Budd Inlet. For comparative purposes it is preferable to include these eight areas in the mussel monitoring program while also sampling areas for which there was a previous data base. Because of the proximity between Port Susan and Port Gardner, these sites can be combined. Based on the above considerations, we recommend the following 14 sites for monitoring of bioaccumulation in mussels: the south end of Whidbey Island, Cape Flattery, Boundary Bay, Hood Canal, Case Inlet, Carr Inlet, Bellingham Bay, Anacortes Harbor, Port Angeles, Port Gardner, Sinclair Inlet, Elliott Bay, Commencement Bay and Budd Inlet. Station locations should be as close as possible to the sites of sediment monitoring or, in areas where sediment monitoring is not proposed, monitoring sites will coincide with those previously used.

The NOAA Status and Trends Program sites will (tentatively) be: Dofflemeyer Point, Browns Point, northeast Elliott Bay (Myrtle Edwards Park), White Point, Possession Point, Point Roberts, and Cape Flattery, beginning in 1984 (Ed Long, NOAA, pers. comm.). Many of these sites may be appropriate for the present monitoring program.

Data to be Reported:

- station location, date and time
- water depth
- tissue toxicant levels (wet and dry weight)
- percent lipid content of tissues
- procedures and QA/QC documentation/codes

Data Analyses Required:

- comparisons, by site, of temporal trends
- comparisons through time of spatial differences
- identification of any extremely high levels
- analyses of these data together with those for sediment toxic chemicals to determine relative trends by area

Data/Sample Archival:

- additional tissues should be prepared and archived by freezing
- full data archival

Other Monitoring Data: As discussed above and in Section 5.14.

BIOTA:	SHELLFISH ABUNDANCE
Objectives (from Chapter 3):	Determining trends and the natural ranges in the abundances of Puget Sound biota, in particular, valued marine resources such as harvestable fish and shellfish. Determining the effects of changes in waste disposal practices on the receiving system. Determining the effects of changes in regulatory management decisions on the receiving system.
Rationale for Monitoring:	Shellfish (in particular oysters, clams, crabs, shrimp) represent an important ecological, commercial and recreational resource in Puget Sound. Historical evidence indicates that pulp mill discharges were responsible for a decline in the abundance of the Olympia oyster in the Sound (Chasan, 1981).
Recommendations for Sampling:	Commercial oyster stock assessments are conducted on a regular basis by the WDF. Catch statistics of other shellfish stocks are monitored. However, as discussed in Section 5.3, catch statistics are influenced by socio-economic and other factors and do not provide an accurate representation of the stocks available. Consequently, we recommend that, while monitoring of oyster stocks and catch statistics for other species continue, this effort should be augmented by regular stock assessments of the following major groups: Pacific oysters, Dungeness crabs and shrimp. These three groups are among the most important recreational and commercial species. Crabs and shrimp are found in areas with chemical contamination, while oyster larvae are sensitive to chemical contamination and dinoflagellates in the water column. Specifically, we recommend that every 1 to 3 years, direct stock assessments be conducted. This would involve standardized methods of collection for each group to determine a catch per unit effort (CPUE) and relative abundance by area in areas where these groups are of most commercial and recreational importance.
Frequency:	Catch statistics to be monitored yearly, as currently done by the WDF. Stock assessments of crab, shrimp, clams and oysters to be done every 1 to 3 years.

Sites: Catch statistics - all of Puget Sound, with particular emphasis on major commercial and recreational beds.

Stock assessment - major commercial catch areas as determined by WDF and WDNR.

Data to be Reported:

- o catch statistics
  - numbers landed (by area of Puget Sound)
  - thousands of pounds landed (by area of Puget Sound)
  - CPUE
- o stock assessments
  - numbers per m^2
  - population age distribution
  - relative sizes of organisms
  - CPUE
  - area, date, procedures and QA/QC documentation/codes

Data Analyses Required:

- o temporal and spatial trends on a yearly basis
- o major deviations from long-term average trends
- o areas showing major changes in catches/stocks

Data/Sample Archival:

- o no sample archival
- o full data archival

Other Monitoring Data: Present monitoring of shellfish stocks is undertaken by the WDF. Commercial oyster stocks are assessed on a regular basis, but other shellfish are not subject to regular stock assessment. Recent efforts by WDNR have concentrated on geoducks to identify areas suitable for harvesting. There is no regular assessment of crab and shrimp stocks; only catches are monitored. In addition, oyster and clam beds closed to commercial harvesting by state regulation are not monitored.

Areas of significant shellfish resources (baseline data to 1977) are documented in the Washington Marine Atlas (Wash. State Dept. of Natural Resources, 1977). Additional information is provided by Koons and Cardwell (1981) and WDOE (1984). The WDNR conducts periodic surveys of shellfish resources (in particular geoducks) in specific areas. Collation and organization of all data gathered by WDF and WDNR may well provide most of the elements of the recommended monitoring program.

BIOTA: FISH ABUNDANCE

Objectives (from Chapter 3): Determining trends and the natural ranges in the abundances of Puget Sound biota, in particular, valued marine resources such as harvestable fish and shellfish.

Determining the effects of changes in regulatory management decisions on the receiving system.

Rationale for Monitoring: Fish are an important ecological, commercial and recreational resource in Puget Sound.

Recommendations for Sampling: A large number of fish species are present in Puget Sound, and it would be illogical to suggest that all be monitored. Rather, certain key species of high commercial and recreational importance should be monitored to detect any changes in stocks. The key species recommended for monitoring are: salmon, bottom fish (Pacific cod and English sole), and herring. These fish groups depend for their existence on a variety of other, lower trophic level food species. Hence monitoring of these upper trophic level groups will serve to indicate potential problems not only with these fish but with other ecosystem components. For instance, salmon feed on a variety of organisms ranging from epibenthos and zooplankton in their juvenile stages to sand lance and herring as adults. Pacific cod feed on crustaceans and molluscs which are found in such contaminated areas as the Commencement Bay Waterways. English sole feed on the benthos as adults. In addition, there is substantial evidence for histopathological disorders in English sole residing in areas of chemical contamination (Malins et al., 1980, 1982, 1984).

Present monitoring of fish abundance, undertaken by WDF, is largely based on catch statistics but adequate stock assessments are performed for salmon and herring (e.g. Pedersen and DiDonato, 1982). Stock assessments for Pacific cod and English sole are necessary because catch statistics alone do not necessarily provide information on the population abundances.

Frequency: Catch statistics to be monitored yearly. Stock assessments to be done every 1 to 3 years.

Sites: Catch statistics: all of Puget Sound.

Stock assessment:
- salmon, Pacific cod and English sole: all of Puget Sound
- herring: Northern Puget Sound and additional areas as new spawning areas are observed

Data to be Reported:

- catch statistics:
  - numbers landed (by species and by area)
  - thousands of pounds landed (by species and by area)
  - CPUE
- stock assessments:
  - salmon
    - yearly returns compared to releases
    - wild/hatchery ratio
  - herring
    - population sizes and ages in different areas of Puget Sound
    - spawning success
  - bottom fish
    - population sizes and ages (by area and by species)
  - area, date
- procedures and QA/QC documentation/codes

Data Analyses Required:

- temporal and spatial trends on a yearly basis
- major deviations from long-term average trends
- areas/species showing major changes in catches/stocks

Data/Sample Archival:

- full data archival

Other Monitoring Data: The Washington Dept. of Fisheries monitors catch statistics for salmon, by species, and obtains data for yearly stock assessments of salmon. Herring catch statistics are also monitored and spawning success is measured directly, on a yearly basis. In addition, sonar has been used in recent stock assessments of herring. The WDF monitors catch statistics of bottom fish, and in recent years have begun to differentiate different species in their reporting. There is no assessment of bottom fish in Puget Sound. In addition to the above, Olympic Community College collects fish by beach seine from the Port Washington Narrows (cf. Section 5.3).

BIOTA: BOTTOM FISH HISTOPATHOLOGICAL ABNORMALITIES

Objectives (from Chapter 3): Determining trends in factors that may endanger human health.

Determining the effects of changes in waste disposal practices on the receiving system.

Rationale for Monitoring: Histopathological abnormalities in bottom fish have been identified as a major biological effect in Puget Sound that may be related to anthropogenic pollution. Many of these fish are harvested by humans and other upper-trophic-level consumers and hence the frequencies of abnormalities may be an indicator of a threat to these consumers. In addition, observations of histopathological abnormalities may be indicators of changes in the levels of anthropogenic pollution. NOAA/NMFS have collected and analyzed fish from urban embayments since 1979 (McCain et al., 1982, 1983; Malins et al., 1984), however no definite temporal trends have yet been determined. This work was largely exploratory and involved collections of several species on an opportunistic basis to check for histopathological abnormalities. Additional information, is expected in 1985, following release of the results of the WDOE/EPA Superfund studies in Commencement Bay, for which intensive histopathological studies of bottom fish were made.

Because the histopathological studies are still exploratory, the recommendations herein may be superseded by forthcoming information.

Recommendations for Sampling: To ensure compatibility with previous studies, English sole is the main species recommended for monitoring. Fish larger than 230 mm total body length should be collected for histopathological examinations. Histopathological examinations should concentrate on the liver, and on seven specific lesions which at present are considered most likely due to contaminant exposure (Quinlan et al., 1985): parenchymal coagulation necrosis, hyalin bodies, megalocytic hepatosis, hypertrophic hepatocytes, eosinophilic hypertrophy, hyperplastic regeneration and liver adenoma. All necropsied fish, whether diagnosed histologically or not, should have their age (otolith measurements), sex, and liver weight/body weight ratios reported.

In addition, all fish caught in the trawls should be examined for external abnormalities according to an agreed-upon protocol. This information will provide for monitoring of fin rot and other external lesions. Finally, we recommend that the population abundances be measured by determining the CPUE by standard procedures during the trawl collections.

Frequency: Yearly (at the same time each year)

Sites: We recommend regular monitoring of at least the Elliott Bay/Duwamish River, a Commencement Bay Waterway (to be selected upon examination of forthcoming data) and a reference area (as per bottom fish abundance). The two embayments have been most intensively studied to date and future monitoring should continue. Sites should coincide with those selected for sediment chemistry, bioassay and infauna determinations. Additional monitoring may be desirable in other areas (e.g., Eagle Harbor) if additional studies reveal high numbers of histopathological lesions in bottomfish from those areas.

Data to be Reported:

- Collection area, date, depth
- fish size, age, sex, weight and other characteristics
- population size, sex, and age distribution
- fin rot incidence
- incidence of specified liver lesions per age group
- liver weight/body weight ratios
- procedures and QA/QC documentation/codes

Data Analyses Required:

- temporal and spatial trends on a yearly basis
- analyses of lesion incidence related to age of fish
- major deviations from long-term average

Data/Sample Archival:

- subsamples of livers from all fish analyzed should be archived separately for possible future analyses
- a reference collection of the seven liver lesions of interest should be maintained and all slides comprising positive identifications of these lesions should be catalogued and archived
- full data archival

Other Monitoring Data: As detailed in Section 5.3.

In addition, the NOAA Status and Trends Program began annual monitoring in Elliott Bay, Commencement Bay and at the Nisqually delta in 1984. This program, funded by the Ocean Assessments Division and performed by the National Marine Fisheries Service, may form the basis for this monitoring.

BIOTA: FISH AND SHELLFISH--TOXIC CHEMICALS IN TISSUE

Objectives (from Chapter 3):

Determining trends in factors that may endanger human health.

Determining trends in the inputs and concentrations of anthropogenic factors that may affect Puget Sound biota.

Determining trends in the inputs and concentrations of anthropogenic factors that may affect Puget Sound biota.

Determining the effects of changes in regulatory management decisions on the receiving system.

General Comment:

There is general public concern that high levels of toxicants in tissues of edible fish and shellfish can be bioaccumulated and result in toxicity to humans. To date, the only toxicant clearly documented to have such an effect is the metal mercury, which reached toxic levels in seafood from Minamata Bay, in Japan. However, mercury concentrations in most of Puget Sound are not elevated in water, sediments or biota and levels appear to be decreasing (Quinlan et al., 1985). A detailed investigation of chemical contaminants in edible non-salmonid fish and crabs from Commencement Bay was conducted by Gahler et al. (1982) who found that all tissue contaminant levels were below FDA guidelines. A seafood consumption study was conducted in Commencement Bay by Noviello and Rogers (1981). NOAA is presently sponsoring a study of fin fish consumption patterns related to tissue contaminant levels, to determine if there is any cause for concern.

At this time, when information is not available on the amounts of chemicals consumed by people collecting seafood in Puget Sound, and with on-going studies in place attempting to provide this information, there is no immediate need for a monitoring program for these parameters beyond the measurements of mussels discussed previously (p.63). However, should further information indicate that there is a problem, a monitoring program may be necessary. Such a program would focus on the biota and areas of concern and help protect human and environmental health by guiding the selective closure of affected areas and the clean-up of the toxic chemicals.

BIOTA: MARINE BIRD ABUNDANCE

Objective (from Chapter 3): Determining trends and the natural ranges in the abundances of Puget Sound biota, in particular, valued marine resources such as harvestable fish and shellfish.

Rationale for Monitoring: Birds are an important ecological and aesthetic component of the Puget Sound ecosystem and many are also protected by the Federal Regulatory Bird Act. They are also top predators that may be affected by accumulation of many toxic chemicals through the food web. Most are affected by loss of habitat. As a result, it is important to assess the abundance of marine bird species, both resident and migratory, to determine any significant changes.

Recommendations for Sampling: The major species considered to be at risk are the Pigeon Guillemot, grebes, cormorants, scoter, Great Blue Heron, and Rhinocerous Aucklet (S. Speich, Cascadia Research, pers. comm.; Quinlan et al., 1985; Riley et al., 1984). Monitoring studies should concentrate on these species. However, because of their importance to the food web of Puget Sound, the total bird population should be monitored as well.

Total bird abundances can be determined by means of monthly aerial surveys from late fall to spring. More detailed ground-level studies are required during breeding periods at selected major nesting sites to determine relative reproduction success.

Frequency: Monthly aerial surveys through the winter and spring when marine birds are most abundant in Puget Sound (Quinlan et al., 1985), and land-based surveys monthly in summer at most nesting grounds.

Sites: All of Puget Sound, in particular bays and beaches.

Data to be Reported:

- date, area, time
- species identification
- number of individuals per species
- proportion of young to adults
- number of nesting pairs
- procedures and QA/QC documentation/codes

Data Analyses Required:

- o temporal and spatial trends (by species and by area)
- o major deviations from long-term average trends

Data/Sample Archival:

- o no sample archival
- o full data archival

Other Monitoring Data:

Monitoring is presently being conducted by the U.S. Fish and Wildlife Service, which conducts monthly aerial surveys of all common species found on the east coast of Puget Sound (October-April). In addition, ground level studies of populations in the San Juan Islands are done monthly during the summer. Walla Walla Community College conducts monthly surveys of seabird nesting populations on Protection Island during the summer. The Audubon Society conducts an annual "Christmas Bird Count" in various areas of Puget Sound in December for all species. Together with the addition of aerial surveys of the west coast of Puget Sound, these studies would provide basically all of the information necessary to monitor the abundance of marine bird populations in Puget Sound, even though some of these efforts focus upon different areas and species.

BIOTA: MARINE BIRDS--TOXIC CHEMICALS IN TISSUE AND REPRODUCTIVE SUCCESS

Objectives (from Chapter 3):

Determining trends in the inputs and concentrations of anthropogenic factors that may affect Puget Sound biota.

Determining the effects of changes in waste disposal practices on the receiving system.

Determining the effects of changes in regulatory management decisions on the receiving system.

General Comment:

The levels of DDT and PCBs that have been observed in the tissues of species such as Pigeon Guillemot in Puget Sound may affect the reproductive success of that species (Riley et al., 1984). Data showing elevated levels of DDT and PCBs in other Puget Sound marine birds have also been obtained by Evergreen State College (cf. Section 5.6).

However, studies conducted to date in Puget Sound with regard to reproductive failures and toxicants in tissue have only been preliminary, hence the extent of possible problems is unknown. Additional studies are being funded by NOAA and USFWS to study reproductive failures and the relationship of this effect to toxic chemicals in tissues. However, at present, data are not available to assess adequately this relationship. As with the bird abundances, the major species considered at possible risk are the Pigeon Guillemot, grebes, cormonants, scoter, Great Blue Heron, and the Rhinocerous Auklet (S. Speich, Cascadia Resarch, pers. comm.; Quinlan et al., 1985; Riley et al., 1984).

We recommend that no monitoring occur until the additional NOAA and USFWS studies are completed and the existence and extent of possible problems is further defined. The monitoring program recommended for bird abundance and community structure will provide information on any major changes to the community and age structures of the community. Only if such changes occur would it be appropriate to analyze toxic chemicals in tissue.

BIOTA:	MARINE MAMMAL ABUNDANCE
Objective (from Chapter 3):	Determining trends and the natural ranges in the abundances of Puget Sound biota, in particular, valued marine resources such as harvestable fish and shellfish.
Rationale for Monitoring:	Marine mammals are an important ecological and aesthetic component of the Puget Sound ecosystem which are protected by the Marine Mammal Protection Act of 1972. They are also top consumers and any effects of pollution on this group of animals may serve as an analog for possible effects on humans.
Recommendations for Sampling:	A variety of marine mammals are found in Puget Sound waters. Of these, harbor seals are the only resident mammals that are common, ubiquitous, breed in Puget Sound, are found in industrialized areas and have received the most study. As a result, this species should be closely monitored for any changes in abundance. Monitoring of harbor seal populations could be accomplished by annual land-based harbor seal counts at major breeding areas supported as possible (dependent on the height of overflights) by information from the aerial photos used to monitor bird populations (and ACOE shoreline overflights) previously mentioned. These detailed land-based surveys would provide information on the number of mating pairs, young produced, and would also serve as a means for collecting any stillborn young for possible tissue analysis. Whales (Orca and grey), porpoises (Dahl and Harbor), sea lions and sea otters also frequent Puget Sound. The populations of these mammals are generally small and variable in Puget Sound and are best monitored informally by providing "hot line" phone service, together with advertising for the general public to report sitings. In addition, individual whales in the resident Orca whale population have been identified by their dorsal markings, making surveys of the population possible by small boat.
Frequency:	Harbor seals: - aerial censuses monthly in the winter and spring; - detailed on-site monitoring during birthing in the spring (Strait of Juan de Fuca) and summer (Southern Puget Sound). Other mammals: - phone sitings throughout the year.

Whales:
- phone sightings throughout the year.
- photo identification of whales approximately every 3 years

Sites:

Harbor seals:
- aerial surveys as possible - all of Puget Sound
- detailed surveys - one major breeding area in each of south (Gertrude Island), and north (Smith and Protection Islands) Puget Sound.

Whales and other mammals:
- all of Puget Sound.

Data to be Reported:

o Whales and other mammals
  - date, time, numbers, species, location
o Harbor seals
  - population estimates by area (vertical photographs)
  - number of breeding seals
  - lengths of individuals
  - number of live births, stillbirths, abnormalities
o procedures and QA/QC documentation/codes

Data Analyses Required:

o temporal and spatial trends (by species and by area)
o major deviations from long-term average trends
o harbor seals only - annual trends in birth rate, number of young and percent survival, percent stillborn and percent abnormal

Data/Sample Archival:

o Any dead harbor seals, in particular stillborn young, observed during the intensive survey should be collected and liver and blubber samples archived (after appropriate ancillary information such as general condition, size, sex, etc. are obtained) for possible future chemical analysis.
o full data archival

Other Monitoring Data:

NOAA has conducted periodic censuses of harbor seals in Puget Sound, however the continuance of these censuses, which are effectively a form of monitoring, is in doubt. The Marine Mammal Investigation Group of WDG has conducted some surveys and is looking for funding necessary to continue the studies. In addition, the U.S. Fish and Wildlife Service often takes seal counts as part of their aerial censuses of bird populations, and the Washington Department of Game assesses the population and health of Puget Sound seals.

Information on whales and porpoises in Puget Sound can be obtained from the Whale Museum, which maintains a telephone hot-line for sightings of these mammals. This information source provides sufficient data (together with detailed studies of harbor seals) for general monitoring of the abundance of marine mammals in Puget Sound.

BIOTA: MAMMALS--TOXIC CHEMICALS IN TISSUE AND REPRODUCTIVE SUCCESS

Objectives (from Chapter 3):

Determining trends in factors that may endanger human health.

Determining trends in the inputs and concentrations of anthropogenic factors that may affect Puget Sound biota.

Determining trends in the inputs and concentrations of anthropogenic factors that may affect Puget Sound biota.

Determining the effects of changes in regulatory management decisions on the receiving system.

General Comment:

As discussed for marine birds, accumulation of toxic chemicals in tissues can affect reproductive success of marine mammals. In particular, studies by Calambokidis et al. (1978, 1979, 1984) have suggested that PCB accumulation is responsible for reproductive failures in harbor seals. However, these authors also suggest that because major inputs of PCBs to Puget Sound are no longer occurring, a decrease in the frequency of these failures may be occurring and harbor seal populations in Puget Sound are increasing (although not as rapidly as those on the outer coast). Studies by NOAA are presently underway to determine the existence and extent of the reproductive failures.

Our previous recommendation to monitor harbor seal abundances directly will provide information on possible changes in the population (size or age structure) that may be of concern. Consequently, we recommend that direct monitoring of toxic chemicals in tissue and reproductive success, particularly of harbor seals, not occur until and unless the present NOAA study and/or monitoring of abundances indicate cause for concern. This recommendation follows the same rationale stated for marine birds, with the additional recommendation that opportunistic collections of dead harbor seals be made during the abundance monitoring and selected tissues be archived for possible future chemical analyses. These tissues could then be used at a later date to test hypotheses regarding possible trends in toxic chemical concentrations in the seals and the relationships between the toxic chemicals and any observed physiological/histopathological problem.

BIOTA: SHELLFISH--PARALYTIC SHELLFISH POISONING (PSP)

Objective (from Chapter 3): Determining trends in factors that may endanger human health.

Rationale for Monitoring: PSP is a serious health threat to humans and possibly other consumers of affected organisms. PSP can cause paralysis leading to the death of the consumer.

The incidences of PSP in Puget Sound have been increasing, possibly due to pollutant inputs or climatic events. PSP incidences result in the closure of commercial and recreational shellfish beds and can also result in the poisoning of biota eating affected shellfish (e.g. birds). Monitoring of PSP (i.e., dinoflagellates, p.56) in the plankton has been previously discussed. The present section is concerned with monitoring the levels of the PSP toxin in shellfish, to provide data on both the areal and temporal extent of PSP in this resource.

Recommendations for Sampling: DSHS presently tests shellfish from commercial shellfish beds for the levels of PSP toxin every other week from April through October and when a problem is suspected. Local health authorities also test samples from recreational beaches when problems are suspected. There is a need to standardize this data collection to provide a sound data base for determining long-term trends. Consequently, it is recommended that both commercial and recreational beds be checked every other week from April to October, or more frequently when a problem is suspected.

Frequency: Every two weeks (April to October), or more frequently if a problem is suspected.

Sites: All commercial and recreational shellfish beds in Puget Sound.

Data to be Reported:

- station location, date and time
- salinity, temperature and DO
- PSP levels in shellfish
- procedures and QA/QC documentation/codes

Data Analyses Required:

- temporal and spatial trends in extent of PSP contamination
- areas exceeding PSP criteria
- percent of resource affected by year
- areas most commonly affected

Data/Sample Archival:

- no sample archival
- full data archival

Other Monitoring Data: As discussed above and in Section 5.4.

BIOTA: SHELLFISH PATHOGENS (ENTEROBACTERIA/ENTEROVIRUSES)

Objectives (from Chapter 3): Determining trends in factors that may endanger human health.

Determining the effects of changes in regulatory management decisions on the receiving system.

Rationale for Monitoring: The presence of bacteria and/or viruses in shellfish can, dependent on the type and numbers of bacteria/viruses, result in human health problems if these contaminated shellfish are eaten.

Recommendations for Sampling: As discussed previously (cf. section on bacteria and viruses in the water column, p.33), there is a need for research into the relationship between the characteristics of the commonly measured surrogate for bacteria and viruses, i.e., fecal coliform bacteria, and those of the true pathogens. However, in the interim, for reasons discussed previously (p.33), monitoring is recommended for fecal coliform and E. coli levels in shellfish.

If research studies indicate that a specific pathogen (vibrio, cholera, etc.) is a problem, then the monitoring program should be expanded or modified to include the measurements of the pathogens of concern.

As discussed in Section 5.4, present coliform monitoring in shellfish is done by DSHS, who measure levels at processing plants and, if levels are elevated there, then measurements are made at the commercial beds. As a result, measurements are made on an irregular basis, as problems are suspected. This procedure is not adequate for long-term uniform monitoring as coliform levels are not measured in the beds when they are below criteria levels at processing plants, nor are they measured once the criteria are exceeded and a bed is closed for a long time period.

Collections of samples from public beaches are presently done by local health departments on an irregular basis. There is a need for regularity in this monitoring such that data are available on a uniform basis. We recommend that sampling be done biweekly in conjunction with PSP analyses of shellfish previously recommended, and coliform water column analyses, which are monthly.

Frequency: Biweekly at commercial beds and public beaches (April-October).

Sites: All commercial shellfish beds, and all public beaches near point sources, where shellfish are harvested recreationally.

Data to be Reported:

- station location, date and time
- salinity, temperature and DO
- fecal coliform most probable number
- *E. coli* most probable number
- procedures and QA/QC documentation/codes

Data Analyses Required:

- temporal trends by region, comparing seasonal average fecal coliform concentrations
- spatial trends in fecal coliform concentrations
- major sites of violation of standards and potential health risks
- percent of resource affected (to closure levels) by year

Data/Sample Archival:

- no sample archival
- full data archival

Other Monitoring Data: As discussed above and in Section 5.4.

RECREATION: ODOR, FLOATABLES/SLICKS, WATER COLOR

Objective (from Chapter 3): Determining trends in the visual appearance and olfactory characteristics of Puget Sound.

Rationale for Monitoring: Unsightly water conditions and objectionable odors can develop from the presence of floatable materials, slicks, discolored water and excessive turbidity. These effects can impair the aesthetic qualities of the Sound and the use of the Sound for recreation.

Recommendations for Sampling: Quantitative sampling approaches for the above normally sporadic and transient events are difficult to design and implement. None of these parameters has been regarded as a major problem recently, diminishing the need for a structured monitoring program. However, because these parameters can affect Puget Sound recreational water use, and may also indicate pollution from spilled oil, sewage, etc., we recommend that a public notification system be established, probably within an existing agency, to accept, record and ensure appropriate responses to objectionable events. These reports should be summarized at least annually to note any trends in increasing frequency or severity of events or shifts in regional instances. In addition, an annual overall evaluation could be obtained as part of shore observations made during the annual beach walk suggested as a possibility in the habitat assessment monitoring (p.50).

Frequency: Sporadic, as incidences occur; annual overall evaluations are recommended, as noted above.

Sites: All of Puget Sound.

Data to be Reported:

- location effected
- type of incident (e.g., floatables, slick, malodorous condition, etc.)
- size of area involved
- severity of incident

Data Analyses Required:

- annual compilation of numbers, locations and severity of different types of incidences reported
- evaluation of temporal trends by region
- evaluation of spatial differences

Data/Sample Archival:

- full data archival

Other Monitoring Data: Oil spills/slicks are currently reported to and recorded by the U.S. Coast Guard.

GENERAL:	RIVER DISCHARGE AND WATER QUALITY
Objectives (from Chapter 3):	Understanding natural oceanographic and climatic events and phenomena, and the relationships among these, that may influence the Puget Sound biota. Determining trends in the inputs and concentrations of anthropogenic factors that may affect Puget Sound biota.
Rationale for Monitoring:	Rivers are the dominant source of freshwater to the Sound as well as a substantial, if not the major, source of inorganic particulate matter. River discharge has a major role in determining the seasonal cycles of many biological communities and also exerts some control over water circulation in the Sound. In addition, the natural riverine loadings as well as anthropogenic inputs to the rivers, make the rivers major sources for many substances, e.g., nutrients and trace metals, of interest from a water quality viewpoint. As a result, interpretation of circulation and biological, sedimentological and other events must take into account changes in river discharge.
Recommendations for Sampling:	Fortunately, the water discharges of most major rivers in the Sound are presently monitored daily on an on-going basis both cooperatively and independently by the U.S. Geological Survey and the WDOE. Suspended solids and other quality parameters are measured monthly at many sites. However, some additional delineation of the suspended load characteristics (i.e., relationship to water flow) of most rivers is advisable. Rather than adding an additional parameter to present USGS monitoring, we recommend initiation of a 2 to 3 year research project to establish the water/suspended load relationships (i.e., rating curves), for at least the major rivers. This approach offers the advantage that the project could be designed to measure the discharge maxima which are often missed in a pre-set, regularly-spaced (e.g. monthly) sampling program. Once reasonable relationships are established, the routinely measured water discharge values should be sufficient for monitoring purposes.

In addition, baseline studies should be considered for determining, by river basin, the total freshwater input: gauged riverflow, ungauged streams, direct overland runoff, plus any direct, subsurface groundwater flow. It is hoped that relatively simple relationships can be established between the ungauged flows and other more readily monitored data (e.g., gauged stream flow, precipitation, etc.).

Frequency: Because the major rivers are controlled largely by dams, short-term flow variations are possible and the daily flow records currently maintained should be continued. Similarly, the less frequent (monthly) values collected at smaller streams are adequate for current overall monitoring purposes.

Sites: All substantial streams should be monitored at least monthly. Smaller streams which are not and have not been monitored should receive at least baseline evaluation to establish discharge comparisons to monitored reference streams.

Data to be Reported:

- station location, date and time
- daily and monthly freshwater discharge rates
- major water quality parameters: nutrients, organic carbon, bacteria
- measured and estimated sediment discharge rates
- procedures and QA/QC documentation/codes

Data/Analyses Required:

- monthly total discharges and monthly average discharge rates
- summary of annual trends and major deviations from long-term average discharges (e.g., floods or droughts)
- notice of events causing flow changes (e.g., dam openings, dam construction, volcanic eruptions, rerouting of STP outfalls, etc.).

Data/Sample Archival:

- full data archival

Other Monitoring Data: WDOE/USGS monitor flow, suspended solids, and other water-quality parameters near 12 river mouths (c.f. 5.2).

GENERAL:	CLIMATE/WEATHER
Objective (from Chapter 3):	Understanding natural oceanographic and climatic events and phenomena, and the relationships among these, that may influence the Puget Sound biota.
Rationale for Monitoring:	Climate and weather are an additional class of variables exerting fundamental control over the physical and biological processes of Puget Sound. Wind-induced turbulence and surface flows, sunlight strength and duration, and precipitation for example all directly affect the growth of phytoplankton. Extremes of heat and cold can directly affect intertidal and other organisms. Thus, these data may help explain naturally occurring cycles that may influence the biota more than pollution. In addition, both long- and short-term changes in the weather can have substantial effects on the circulation patterns in the Sound.
Recommendations for Sampling:	These parameters are recommended for inclusion in the monitoring program in part because they are readily available as daily measurements from the U.S. National and Canadian Weather Services. These data should be obtained from the weather services for major (e.g., Sea-Tac Airport) and selected minor weather stations to obtain a widespread picture of the Sound. While routine monitoring of the weather parameters is recommended at only a few sites, a preliminary analysis comparing all available records in the Puget Sound area would be useful. Such an analysis would help identify regional differences and help select weather data representative of major areas that would be useful in the overall monitoring program.
Frequency:	Usually at least daily average, maximum and minimum values are recorded for each parameter of interest. These daily records are sufficient.
Sites:	Data should be collected for between one and three major weather stations at which a large variety of parameters are available, including Sea-Tac Airport; Port Angeles; Bellingham, Vancouver or Victoria; Everett; and, one site (e.g., Olympia) from the Southern Sound. Additional data as available from the smaller regional weather stations should also be collected.

Data to be Reported: (not all parameters are available from all sites)

- o site and date
- o wind speed, direction and variance
- o precipitation
- o hours of daylight
- o air temperature
- o percent cloud cover

Data Analyses Required:

- o annual summaries of temporal trends, by region
- o variances from long-term average conditions
- o major storm events

Data/Sample Archival:

- o full data archival

Other Monitoring Data: As discussed above.

GENERAL:	POLLUTANT INPUTS
Objectives (from Chapter 3):	Determining trends in the inputs and concentrations of anthropogenic factors that may affect Puget Sound biota. Determining the effects of changes in waste disposal practices on the receiving system. Determining the effects of changes in regulatory management decisions on the receiving system.
Rationale for Monitoring:	Monitoring of industrial and pollutant inputs is required to obtain information on trends in pollutant loadings to Puget Sound.
Recommendations for Sampling:	To some extent pollutant inputs are already being monitored through the National Pollutant Discharge Elimination System (NPDES). The NPDES, administered by the WDOE and as detailed in Section 5.2, monitors about 240 municipal and industrial discharges in the Puget Sound by requiring Discharge Monitoring Reports (DMRs). Non-permitted sources should be subjected to legislation rather than monitoring and are not addressed in these recommendations.

NPDES monitoring requirements are specific to the size and type of discharge involved. Measurements of the effluents are made for basic parameters such as temperature, salinity, DO, pH, flow, suspended solids, BOD and COD. In some cases sampling is done monthly, in other cases samples are taken quarterly.

Trace metals and organic chemicals are measured only when a need to do so is determined. Fecal coliforms are measured by all sewage treatment plants, but not generally on a regular basis. As a result the present data base for monitoring these inputs is inadequate. While it is realized that regular (quarterly or yearly) collection and analyses of samples for metals and organic contaminants in all discharges is both impractical and cost-prohibitive, there are rational alternatives.

We recommend that each discharge be evaluated, based on products produced (in the case of industry) and contributing sources (in the case of municipal effluent) in an initial step to determine the significant pollutants emitted by each source. Significant pollutants would include any with a possibility of impacting the biota of the Sound or its aesthetic quality (e.g., BOD, pH, nutrients, suspended solids, trace metals, etc.).

The evaluation should include a one-time broad-scale analysis of most effluents, including effluent bioassays based on, but not limited to 96-h LC50s with fish. The end result would be detailed information on the most probable sources for specific classes of pollutants to Puget Sound. Based on this information, DMRs could be amended to include particular pollutant monitoring (as necessary). This selective monitoring would be less costly than a broad-scale analyses, but the information obtained would be sufficient for a Sound-wide monitoring of pollutant inputs.

Frequency: As discussed above, monthly, quarterly or yearly depending on the discharge.

Sites: All effluent discharges/dischargers to Puget Sound.

Data to be Reported:

- station, date and time
- flow and production (volume)
- effluent toxicity
- concentrations of each parameter measured (conventionals and toxic chemicals)
- changes in raw products and industrial processes
- general observations
- procedures and QA/QC documentation/codes

Data Analyses Required:

- temporal trends by discharge and by water body, comparing average input concentrations
- spatial trends in input concentrations
- discharges violating NPDES standards and potential pollution risks

Data/Sample Archival:

- no sample archival
- full data archival

Other Monitoring Data: As discussed above and in Section 5.2, the NPDES program monitors effluent discharges under the supervision of WDOE. Each discharge is subject to a permit specifying maximum permissible level of pollutants and sampling frequency. The latter are determined by the size and type of industry. The reports are reviewed to determine compliance, and to estimate on a case-by-case basis, pollutant loadings to Puget Sound. Cumulative loadings to Puget Sound are not estimated.

GENERAL: CURRENTS

Objectives (from Chapter 3): Understanding natural oceanographic and climatic events and phenomena, and the relationships among these, that may influence the Puget Sound biota.

Determining the natural temporal and spatial trends in receiving system properties needed in the development of safe, effective waste disposal practices.

Rationale for Monitoring: An understanding of currents is an important factor in understanding how the Puget Sound ecosystem works as a whole. Interpretation of much of the other monitoring data could be dependent on circulation data. Recent work has shown a large interannual variation in the current regime in the Main Basin (URS Engineers et al., in prep.). At the present time, we do not know the cause of these variations nor can we predict the structure of currents from other physical factors (e.g., tide stage or winds). Therefore currents should be monitored to provide data on circulation and flushing necessary to interpret some of the other monitoring data.

Frequency: Current meters should be deployed on a continuous basis. They should be serviced quarterly. The sampling interval should be as short as possible while allowing for data collection over a three month period. Typically the sampling interval would be 15 to 30 minutes.

Sites: To obtain adequate measurements of the dominant flows in the study area, we recommend nine current meter moorings, three each in the Strait of Juan de Fuca and the Main Basin, and one each in Hood Canal, Whidbey Basin, and the Southern Sound. Specific sites are Kydaka Point, Port Angeles, Point Partridge, President Point, Three Tree Point, northern end of Colvos Passage, Hyde Point, Saratoga Passage, and the northern end of Hood Canal. Current meters should be located at depths of 20 m, 50 m, 100 m, 200 m or bottom. Moorings should be placed near channel marker buoys where possible to reduce equipment loss due to vessel traffic.

Data to be Reported:

- station location, current meter depth, bottom depth.
- date, time, speed, direction, salinity, temperature, pressure, density

- record averages including mean speed, net velocity, variance
- equipment problems, data gaps
- procedures and QA/QC documentation

Data Analyses Required:

- temporal variations of mean speed, net velocity, and variance
- temporal variations of salinity, temperature, and density
- current roses and speed histograms

Data/Sample Archival

- full data archival

Other Monitoring Data: There has been no systematic monitoring of currents in Puget Sound. However, Evans-Hamilton has been able to piece together synopses of data over many years from many studies for the Ocean Assessment Division of NOAA (Cox et al., 1984; Coomes et al., 1984; and Ebbesmeyer et al., 1982).

GENERAL: REGULATORY CONTROL

Objective (from Chapter 3): Determining the effects of changes in regulatory management decisions on the receiving system.

Rationale for Monitoring: The major sources of pollution to Puget Sound include industrial and municipal discharges. Other activities impacting the Puget Sound ecosystem include resource utilization such as fishing, and shoreline development. All of these activities are controlled, to some extent, by regulations from various agencies. For instance, WDOE and EPA, through the NPDES permits, regulate effluent discharges; DNR and WDF regulate commercial and recreational fishing; the ACOE regulates shoreline development. But regulations are not static, and are subject to change based on economic, political and environmental considerations. Because changes to regulations can affect the Puget Sound environment, there is a need to monitor these regulations to assist in determining both their effect on Puget Sound and to assist in explaining observed resource changes.

Frequency: Annual reviews should be prepared of major regulatory changes that have occurred in the preceding time period.

Sites: All of Puget Sound and all federal, State, and local regulatory agencies.

Data to be Reported:

- applicable regulations and changes (by date)
- reason for any changes
- expected impact on the resource(s)

Data Analyses Required:

not applicable

Data/Sample Archival:

- full data archival

Other Monitoring Data: There is no known systematic monitoring of all regulations promulgated by all regulating agencies.

GENERAL: SOCIO-ECONOMIC CONDITIONS

Objectives (from Chapter 3):

Determining trends in the inputs and concentrations of anthropogenic factors that may affect Puget Sound biota.

Determining the effects of changes in waste disposal practices on the receiving system.

Determining the effects of changes in regulatory management decisions on the receiving system.

Rationale for Monitoring:

Anthropogenic effects on Puget Sound are mediated in large part by socio-economic conditions. For instance, strikes may close plants such as the pulp mills, which discharge significant amounts of effluent to Puget Sound. A depressed economy may result in increased nearshore fishing for food, but reduced salmon fishing in areas such as the San Juan Islands where a boat and expensive gear are required. Changes in population may affect previously rural areas and development patterns. New product development may result in new industries with new discharges to Puget Sound.

There is a need, therefore, to monitor socio-economic conditions in order to obtain a better understanding of water quality data, and as a management tool for the beneficial uses of the Sound.

Recommendations for Sampling:

The necessary information is presently available and is being collected on a routine basis by a variety of government agencies and industry groups, but is not being used as an overall monitoring tool for interpreting Puget Sound water quality data. Changes in industrial processes, shut-downs and other factors influencing effluent discharges are monitored through the NPDES permits. Economic information is available in the form of a number of economic indicators including unemployment figures, with area-specific data available from local Chambers of Commerce. The Puget Sound Council of Governments publishes regular economic and demographic information including population and employment forecasts by region. Thus all of the information necessary for monitoring of socio-economic conditions is presently being gathered, and only requires collation for use as part of the present Puget Sound monitoring program.

Frequency: Data should be collated and reviewed annually. Pertinent information could be presented graphically, in tabular form and with text discussions.

Sites: All of Puget Sound.

Data to be Reported:

- economic conditions by region, city and county
- industry or other shut-downs (including labor disputes)
- new industries startups
- upgrading of waste treatment facilities
- population and employment changes by year and region
- changes in major exports/imports conveyed by water
- oil spills and other acute events (e.g., volcanic eruptions, earthquakes)
- other economic factors pertinent to one or more industry, e.g., wars, changes in product demand from recessions, etc.

Data Analyses Required:

- major changes (temporal and spatial)

Data/Sample Archival:

- full data archival

Other Monitoring Data: There is no known systematic collation and presentation of all of the monitoring of socio-economic conditions in Puget Sound in a format and context pertinent to water quality concerns.

4.2 ADDITIONAL REQUIREMENTS

4.2.1. Coordination of Information Between and Within Agencies

For a comprehensive monitoring program to be effective in fulfilling its goals, there must be: 1) a flow of information within the divisions of an agency and among agencies; and 2) a group responsible for gathering, compiling, reviewing and publishing the monitoring data and trend analyses on a regular basis. This flow and dissemination of information would be facilitated by establishing a central repository for the data. This central repository would be responsible for: 1) compiling and analyzing the data to determine trends; 2) preparing summary reports and graphical displays; 3) distributing data and reports to agencies and interested groups; 4) archiving data and samples; and, 5) coordinating the promulgation of analytical and QA/QC procedures.

Annual summary reports, quarterly reports and other publications could be prepared through this central repository. Annual reports would be of general interest and would focus on trends related to the overall health of Puget Sound. The data could be presented primarily in graphical form to highlight trends in major components. Quarterly reports would be more detailed and technical, and would rely primarily on lists of the data collected with highlights of events of major interest to the regional scientific community. Annual reports would be distributed on a wide mailing list while quarterly reports would be distributed on request to a much smaller, technically-oriented mailing list.

The central repository would also be responsible for data archival and retrieval. This process would most likely involve two separate systems. The NOAA/NODC data base system is recommended only for final data archival as routine data retrieval is cumbersome. An in-house, personal computer system is recommended for storage of recent data and for data requiring frequent retrieval. This latter system should be able to readily: 1) retrieve and print-out data; and 2) duplicate data and tapes compatible with other systems.

Whether the central repository is a single entity (for instance, within a new group such as the Puget Sound Water Quality Authority or a more established organization such as the WDOE), or whether it represents the cooperative interaction of several agencies/groups (for example, the present cooperative interactions between WDOE and EPA), is a policy decision. As such, a specific recommendation is beyond the scope of this report. However, it is certain that a central repository is essential to the success of the recommended monitoring program.

4.2.2. Quality Assurance/Quality Control (QA/QC) Programs

A defined QA/QC program should be integrated with each phase of the monitoring program. It is beyond the scope of this project to provide a detailed outline for the individual QA/QC procedures, however general comments are provided.

Although QA/QC plans are parameter- and program-specific, they should generally include directives for: 1) sampling techniques/data collection; 2) detection/confirmation limits; 3) analytical techniques; 4) safety plans; 5) statistical analyses; and, 6) data verification procedures. The QA/QC program must be established before the monitoring program is initiated as, otherwise, incompatible techniques and the inability to ensure the accuracy of the data may result in real difficulties in determining possible trends.

Statistical and other data analysis methods should be designed to determine spatial and temporal differences among data sets. Both large-scale and small-scale differences, if detectable, must be included in these analyses. It is beyond the scope of this project to recommend specific techniques for data analysis, although such techniques as computations of anomalies and moving averages may be useful. However, it is recommended that future users of this and other monitoring programs investigate the use of composite indices or composite measures such as the Triad (sediment chemistry, bioassay and infauna) recommended by Chapman and Long (1983). Composite indices have lower variances than individual parameters and are therefore more useful in determining real differences.

In addition, as part of the statistical analyses, it is important to define the degree to which differences in the spatial and temporal trends must be resolved so that adequate sample sizes can be obtained to provide the necessary discriminatory power among data sets. Where possible in the description of specific monitoring parameters, recommendations have been made in this regard. However, in many cases specific recommendations were not possible due to either a lack of data, or the fact that detailed analyses of disparate and lengthy data sets were beyond the scope of this study. Consequently, for the guidance of investigators initiating the proposed monitoring program, a theoretical analysis and description of a means for optimizing sample sizes is presented in Appendix A.

CHAPTER 5. PAST AND ONGOING MONITORING PROGRAMS IN PUGET SOUND

5.1 SCOPE

This task identifies those programs which are or have been monitored:

- o concentrations and distributions of pollution-related/effected substances, e.g. nutrients, toxic chemicals, and dissolved oxygen in environmental media, i.e. water, sediments and biota;
- o concentrations and distributions of pollution-related organisms, e.g., enterobacteria and enteroviruses;
- o distribution and frequency of diseases in resident biological organisms;
- o population and community abundance measurements;
- o incidences of human health problems; and,
- o trends in pollution loadings to the Sound.

The monitoring programs examined in detail included only those that provided data on a multi-year temporal scale. Intensive (but non-monitoring) studies that collected data for periods of less than a year were excluded from detailed consideration. JRB Associates (1984a) identified and provided a brief description of many of such excluded studies.

Past and ongoing monitoring programs which have acquired data suitable for making long-term comparisons of temporal trends in Puget Sound are identified and summarized in Table 6 and are discussed in the following sections. Monitoring programs were organized into several general groups for discussion purposes, including water quality, fisheries, bacteria and PSP, benthos and plankton, birds, mammals, habitat, pollutant inputs, river discharge, and climate. In addition, the use of sediment cores for retroactive monitoring is discussed. Programs that have been discontinued are also presented. The programs were organized in this manner because many of them provide information for more than one monitoring objective and were thus more readily reviewed by broad, matrix-related groupings. The relationship of the programs to the objectives is evaluated at the end of the chapter.

Most columns of information in Table 6 are self-explanatory. The "QA/QC" column in Table 6 indicates whether any type of quality assurance/quality control plan exists for each monitoring program. Depending on the focus of the individual programs, the QA/QC plans may incorporate one or all six of the components discussed in section 4.2.2. A detailed description of the QA/QC plans for the individual programs can be obtained from the contacts listed in Table 7.

The "Probability of Continuance" column in Table 6 indicates whether programs are likely to continue in future years. In many cases, continuance is assumed due to federal or state mandates. In other cases, such as university research, monitoring has been instigated by individual organizations (e.g., faculty members), and the probability of continuance is determined by their willingness or ability to continue the work.

Table 6. Summary of monitoring programs in Puget Sound

Station Locations	Number of Stations or Agency Station No.	Period of record	Frequency of Sampling	Parameters measured[a]	QA/QC	Probability of Continuance
WATER QUALITY						
Metro Seattle (refer to Table 9 for full details)					Yes	Good
(Offshore)						
Alki Point	160-196	1965-present	quarterly			
Carkeek	115-121	1965-present	quarterly	temperature, salinity,		
Elliott Bay	181-184; 188	1965-present	quarterly	DO, transparency,		
Puget Sound	171	1965-present	quarterly	fecal coliforms, total		
Richmond Beach	101-109	1965-present	quarterly	coliforms, tide,		
West Point	130-132; 135-138; 141-144; 147-148	1965-present	every 2 weeks from 1976	suspended solids		
(Shore)						
Alki Point	242, 244, 246	1970-present				
Blue Ridge	217	1970-present	monthly			
Carkeek	212	1970-present	Oct-May			
Elliott Bay	230, 232, 235, 238, 2323, 2355	1965-present		temperature, fecal		
Fauntleroy Cove	251, 252	1972-present		coliforms, total		
Golden Gardens	219	1970-present		coliforms,		
Lincoln Park	250	1970-present		enterobacteria, tide		
Lowman Beach	249	1970-present	weekly			
Piper Creek	211	1970-present	Jun-Sep			
Richmond Beach	202, 205[b], 206	1970-present				
Shilshole Bay	222, 224[b]	1970-present				
West Point	226-228[b]	1970-present				

Table 6. (Continued)

Station Locations	Number of Stations or Agency Station No.	Period of record	Frequency of Sampling	Parameters measured[a]	QA/QC	Probability of Continuance
WDOE					Yes	Good
Admiralty Inlet	ADM 001	1967-present				
Bellingham Bay	BLL 006	1967-present				
	BLL 008	1967-present				
	BLL 009	1967-present				
Budd Inlet	BUD 002	1967-present				
	BUD 005	1967-present				
Commencement Bay	CMB 003	1967-present				
	CMB 006	1967-present				
	CMB 010	1967-present				
Carr Inlet	CRR 001	1968-present		temperature, salinity,		
Case Inlet	CSE 001	1967-present		DO, pH, turbidity,		
Drayton Passage	DRA 001	1967-present	monthly	transparency, monthly		
Dyes Inlet	DYE 003	1967-present	Apr-Nov	fecal coliforms,		
Elliott Bay	ELB 005	1967-present		total coliforms,		
	ELB 010	1967-present		nutrients		
Eld Inlet	ELD 001	1968-present		(NH_3, NO_2, NO_3, total		
Hood Canal	HCB 002	1968-present		and dissolved ortho-		
	HCB 003	1968-present		phosphate), SWL,		
	HCB 004	1968-present		chlorophyll a, TOC		
	HCB 006	1975-present				
Holm Harbor	HLM 001	1967-present				
Haro Strait	HRO 001	1968-present				
Strait of Juan de Fuca	JDF 005	1967-present				
The Narrows	NRR 001	1967-present				
Nisqually Reach	NSQ 001	1967-present				
Oakland Bay	OAK 004	1967-present				
Port Angeles Harbor	PAH 003	1967-present				
	PAH 008	1967-present				
Pickering Pass	PCK 001	1967-present				

Table 6. (Continued)

Station Locations	Number of Stations or Agency Station No.	Period of record	Frequency of Sampling	Parameters measured[a]	QA/QC	Probability of Continuance
WDOE (Continued)						
Penn Cove	PNN 001	1977-present				
Port Orchard	POD 005	1975-present				
	POD 006	1977-present				
Puget Sound Basin	PSB 003	1967-present				
Possession Sound	PSS 008	1967-present				
	PSS 015	1967-present				
	PSS 019	1980-present				
	PSS 020	1973-present				
Port Townsend	PTH 005	1977-present				
Saratoga Passage	SAR 003	1977-present				
Sinclair Inlet	SIN 001	1968-present				
San Juan Islands	SJI 001	1968-present				
Skagit Bay	SKG 001	1967-present				
Port Susan	SUZ 001	1968-present				
Toten Inlet	TOT 001	1968-present				
WDNR						
Wycoff Shoal	1	1981-present	weekly	temperature, salinity, nutrients (NH_3, NO_2, NO_3, total ortho-phosphate)	No	Good
NOAA (NMFS)						
Manchester	1	1968-present	2/day	temperature, salinity, DO, transparency	No	Good

Table 6. (Continued)

Station Locations	Number of Stations or Agency Station No.	Period of record	Frequency of Sampling	Parameters measured[a]	QA/QC	Probability of Continuance
USFWS Marrowstone Island	1	1981-present	3/week April-November	temperature, salinity, DO	No	Good
American Sea Vegetable Co.				temperature, salinity, pH, nutrients (NH_3, NO_2, NO_3)	No	Depends on adequacy for aquaculture
Tramp Harbor	1	1983-1984	daily			
Lummi Bay	1	1983-present	weekly			
Seattle Aquarium Elliott Bay	1	1978-present	daily-weekly	temperature, salinity, DO, pH, turbidity, total coliform	No	Good
Pt. Defiance Aquarium The Narrows	1	1982-present	monthly	temperature, salinity, pH, DO	No	Good
Sundquist Laboratory[c] Rosario Strait	1	1974-present	3/week	temperature, salinity, DO, pH, turbidity	No	Good
U.S. Dept. of Defense[d] Hood Canal at Bangor	1-20	1974-present	semi-annually	temperature, salinity, DO, pH, nutrients (NH_3, NO_2, NO_3, total orthophosphate)	No	Good

Table 6. (Continued)

Station Locations	Number of Stations or Agency Station No.	Period of record	Frequency of Sampling	Parameters measured[a]	QA/QC	Probability of Continuance
Olympic Community College Sinclair Inlet/ Port Orchard	variable	1977-present	monthly (September-May)	temperature, salinity, DO, pH	No	Dependent on facility.
			FISHERIES			
WDF (all Puget Sound)						
Salmon Run size	n/a	1965[e]-present	n/a	returns and escapement	Data entry verified only	Good
Salmon Catch	n/a	1910-present	n/a	sport and commercial catches		
Groundfish Catch	n/a	1921-present	n/a	commercial catches		
Herring Spawning	n/a	1972-present	2/week (April-June)[f]	biomass of spawn		
Herring Catch	n/a	1890-present	n/a	commercial catches		
Shellfish Harvest	n/a	1935-present	n/a	pounds harvested		
NOAA/NMFS		1979-present	variable	liver lesion frequency in bottomfish	Yes	Uncertain
Elliott Bay	4					
Commencement Bay	2					
Port Madison	1					
Sinclair Inlet	1					
Olympic Community College						
Port Orchard	1	1978-present	2/year	fish and invertebrate abundance	No	Dependent on faculty
U.S. Department of Defense						
Hood Canal at Bangor	1	1973-present	1/year	fish and mollusk abundance	No	Good

Table 6. (Continued)

Station Locations	Number of Stations or Agency Station No.	Period of record	Frequency of Sampling	Parameters measured[a]	QA/QC	Probability of Continuance
University of Washington	variable	1950s-present	1/year	English sole spawning areas and egg deposition rates	No	Dependent on faculty
		BACTERIA AND PSP				
DSHS	variable	1978-present	variable	coliforms and PSP in shellfish and water	Yes	Good
METRO (Seattle)		See Metro Seattle above				
WDOE		See WDOE (Water Quality)above				
Port of Port Angeles	1	1979-present	bimonthly	coliforms in shellfish	No	Good
		BENTHOS AND PLANKTON				
USGS	1-4	1964-present	1/year	benthos abundance and diversity	Data entry verified	Dependent on individual
Olympic Community College Sinclair Inlet/ Port Orchard	3	1977-present	1/month (none in summer)	zooplankton abundance and diversity	No	Dependent on faculty

Table 6. (Continued)

Station Locations	Number of Stations or Agency Station No.	Period of record	Frequency of Sampling	Parameters measured[a]	QA/QC	Probability of Continuance
			MARINE BIRDS			
USFWS						
Eastshore Puget Sound	n/a	1978-present	monthly, Oct.-Nov.	aerial surveys of marine bird species and number	No	Good
San Juan Islands	n/a	1978-present	monthly, summer	ground survey of marine bird species and number		
Walla Walla Community College						
Protection Island	n/a	1979-present	1/year (summer)	birds nesting on Protection Island	No	Dependent on faculty
WDG (all Puget Sound)	n/a	1982-present	1/year	marine bird species and numbers		
Audubon Society Olympia Tacoma Seattle Bellingham	n/a	1920-present	1/year	bird species and numbers		
			MARINE MAMMALS			
Whale Museum (all Puget Sound)	n/a	1976-present	n/a	whale population estimates	No	Good
NOAA (all Puget Sound)	n/a	1977-present	variable	seal population size and health	Yes	Uncertain
WDG (all Puget Sound)	n/a	1980-present	1/year	seal population estimates	No	Good

Table 6. (Continued)

Station Locations	Number of Stations or Agency Station No.	Period of record	Frequency of Sampling	Parameters measured[a]	QA/QC	Probability of Continuance
			HABITAT			
WDOE (all Puget Sound)	n/a	1977-present	variable	shoreline development (permits)	NA	Good
U.S. ACOE (all Puget Sound)	n/a	1970-1984	1/year	shoreline development (aerial photos)	NA	Good
			POLLUTANT INPUTS			
WDOE/NPDES	see Table 5					
			RIVER DISCHARGE AND WATER QUALITY			
WDOE/USGS						
Nooksack	01A050	variable-present	monthly	temperature; DO; pH; conductivity; turbidity; fecal coliform; nutrients (NH_3, NO_2, NO_3, total and dissolved PO_4); colors, suspended solids; flow; total and dissolved Cd, Cr, Cu, Pb, Zn; hardness.	Yes	Good
Skagit	03A060					
	03B050					
Stilliguamish	05A070					
Snohomish	07A090					
Green/Duwamish	09A060					
Puyallup	10A070					
Nisqually	11A070					
Chambers Creek	12A070					
Deschutes	13A060					
Skokomish	16A070					
Elwah	18B080					

Table 6. (Continued)

Station Locations	Number of Stations or Agency Station No.	Period of record	Frequency of Sampling	Parameters measured[a]	QA/QC	Probability of Continuance
		CLIMATE				
National Climate Data Center						
Anacortes		1909-Present	hourly to	temperature,	Yes	Good
Arlington		1937-Present	daily,	precipitation,		
Bellingham ZN		1912-Present	depending	wind, sky		
Bellingham FAA		1942-Present	on location	cover		
Blaine		1905-Present	and	(variable		
Bremerton		1951-Present	variables	coverage		
Chimacum		1927-Present		among stations)		
Coupeville		1913-Present				
Mt. Vernon		1954-Present				
Neah Bay		1921-Present				
Olga		1890-Present				
Olympia		1940-Present				
Port Angeles		1902-Present				
Port Townsend		1897-Present				
Puyallup		1914-Present				
Seattle EMSU		1970-Present				
Seattle Jackson Pk		1960-Present				
Seattle SEATAC		1943-Present				
Seattle UofW		1925-Present				
Sedro Woolley		1903-Present				
Sequim		1977-Present				
Tacoma		1980-Present				
Wauna		1941-Present				

Table 6. (Continued)

Station Locations	Number of Stations or Agency Station No.	Period of record	Frequency of Sampling	Parameters measured[a]
		DISCONTINUED PROGRAMS		
University of Washington many stations	variable	1932 - 1972	**	temperature, salinity, DO, turbidity, nutrients
Metro Seattle Main Basin near West Point	5	1966 - 1975	weekly	chlorophyll _a_, primary productivity March-October
WDF	40	1956 - 1959	bi-weekly	temperature, salinity, DO, Pearl-Benson Index
U.S. Geological Survey major river estuaries	8	1978 - 1982	monthly	temperature, salinity, DO
U.S. EPA (mussel watch)				toxicant bioaccumulation in mussels
Cape Flattery	1	1976 - 1978	yearly	
Boundary Bay	1	1976 - 1978	yearly	
Whidbey Island	1	1976 - 1978	yearly	
NOAA/NMFS (NW Alaska Marine Fisheries Center) Freshwater Bay	1	1971 - 1980	**	hydrocarbons in a variety of organisms
WDF-oyster larvae bioassay all Puget Sound	variable	1961 - 1976	monthly	toxicity of water to oyster larvae
WDOE (ECOBAM) Port Gardner	variable	1972 - 1981	monthly	water quality; _in situ_ toxicity

Table 6. (Continued)

Station Locations	Number of Stations or Agency Station No.	Period of record	Frequency of Sampling	Parameters measured[a]
Evergreen State College		1974 - 1980	monthly	Dunlin populations
Nisqually River Delta	1			
Kennedy Creek				
South Sound	variable	1978 - 1982	semi-annual	DDT & PCB tissue burdens in birds
U.S. EPA				
Elliott Bay	1	1972 - 1976	PCB and pesticide residues in fish	
Hood Canal	1	1972 - 1976	PCB and pesticide residues in fish	
Nisqually Reach	1	1972 - 1976	PCB and pesticide residues in fish	
Bellingham Bay	1	1972 - 1976	PCB and pesticide residues in fish	

** Sampling was intermittent
[a] DO is dissolved oxygen, SWL is sulfite waste liquor, TOC is total organic carbon.
[b] Sampled concurrently with Metro West Point Station 30.
[c] Additional parameters monitored: carbonate alkalinity, dissolved CO_2, and total alkalinity and sulfides.
[d] Additional parameters monitored: TOC, Cr, Cu, Fe, Pb, Hg, Ag, Zn, Ni.
[e] Some species may have a shorter time of record.
[f] Frequency dependent on weather conditions.
n/a = not applicable.

Table 7. Availability of specific monitoring data

Data category	Agency/group	Format available	Contact/address
Water Quality	Metro Seattle	Computer tape/printout	Janet Condon, Metro, 411 West Harrison, Seattle, WA
		STORET-Computer printout	Ray Peterson, U.S. EPA 1200 Sixth Avenue, Seattle, WA
		OAD-Computer printout	Alan Mearns, NOAA 7600 Sand Point Way, Seattle, WA
	WDOE	STORET-Computer printout	Bob James, WDOE MS/PV-11, Olympia, WA
			Ray Peterson, U.S. EPA 1200 Sixth Avenue, Seattle, WA
	WDNR	Raw data sheets	Tom Mumford, WDNR, Division of Land Management Olympia, WA
	National Marine Fisheries Service Laboratories	Computer printout	Earl Prentice, NMFS P.O. Box 38, Manchester, WA
	U.S. Fish and Wildlife Service	Raw data sheets	Aldo Palmisano, USFWS Marrowstone Field Station, Nordland, WA
	American Sea Vegetable Co.	Raw data sheets	John Olson, American Sea Vegetable Co. P.O. Box 773, Vashon, WA
	Seattle Aquarium	Raw data sheets	Bill Bruin, Seattle Aquarium Pier 59, Seattle, WA
	Point Defiance Zoo & Aquarium	Raw data sheets	John Rupp, Point Defiance Zoo & Aquarium Tacoma, WA

Table 7. (Continued)

Data category	Agency/group	Format available	Contact/address
Water Quality (Continued)			
	Sundquist Laboratory	Raw data sheets	Paul Cassidy, Sundquist Laboratory 1900 Shannon Pt. Ave., Anacortes, WA
	U.S. Dept. of Defense	Computer printout	Linda Trones, Naval Energy & Env. Support Acitivites, Port Heuneme, CA
	Olympic Community College	Raw data sheets	Don Seavy, Olympic Community College Bremerton, WA
Fisheries	WDF-Salmon Program	Computer printout	Jim Ames, Salmon Program, WDF Olympia, WA
	WDF-Marine Fish Program	Computer printout/ raw data sheets	Greg Bargmann, Marine Fish Program, WDF WH-10, Univ. of Wash., Seattle, WA
	WDF-Baitfish Program	Computer printout/ raw data sheets	Robert Trumble, Marine Fish Program, WDF WH-10, Univ. of Wash., Seattle, WA
	WDF-Shellfish Program	Computer printout	Point Whitney Laboratory Brinon, WA
	Northwest and Alaska Fisheries Center, NOAA	Computer printout	NMFS/NOAA 2725 Montlake Blvd. E, Seattle, WA
	Olympic Community College	Raw data sheets	Don Seavy, Olympic Community College Bremerton, WA

Table 7. (Continued)

Data category	Agency/group	Format available	Contact/address
Fisheries (Continued)	University of Washington	Raw data sheets	Bruce Miller, University of Washington Seattle, WA
	U.S. Dept. of Defense	Computer printout	H.O. Porter, Bio Science Division, Naval Ocean System Center, San Diego, CA
Bacteria and PSP	DSHS	Raw data sheets/ computer printout	Jack Lilja, DSHS, Airindustrial Park, Tumwater, WA
	Metro Seattle	See Metro above	
	WDOE	See WDOE above	
	Port of Port Angeles	Raw data sheets	Ken Sweeney, Port of Port Angeles P.O. Box 1350, Port Angeles, WA
Benthos and Plankton	USGS	Computer printout	Frederick Nichols, USGS 345 Middlefield Road, Menlo Park, CA
	Olympic Community College	See Olympic Community College above	
Marine Birds	U.S. Fish & Wildlife Service	Raw data sheets	Steve Thompson, Nisqually National Wildlife Refuge, 100 Brownfarm Rd., Olympia, WA
	Washington Dept. of Game	Raw data summary report	Non Game Program, WA Dept. of Game, Olympia, WA

Table 7. (Continued)

Data category	Agency/group	Format available	Contact/address
Marine Birds (Continued)	Audubon Society	Annual summary reports	American Birds (July issue)
		Data sheets prior to 1968	Audubon Society Archives, Univ. of WA, Seattle, WA
		Data sheets after 1968	Phil Mattock, Zoology Dept., Univ. of WA, Seattle, WA
	Walla Walla Community College	Raw data sheets	Joseph Galusha, Walla Walla Community College College Place, WA
Marine Mammals	Whale Museum	Data sheets	Rick Osborn, Whale Museum Friday Harbor, WA
	NOAA	Computer printout	John Calambokidis, Cascadia Research Collective Water Street Bldg., 218½ West Fourth Ave., Olympia, WA
	Washington Dept. of Game	Raw data sheets	Ann Geiger, WDG 600 N. Capitol Way, Olympia, WA
Habitat	WDOE	Computer printout of permit requests	Shoreline Management, WDOE MS/PV-11, Olympia, WA
	U.S. Army Corps of Engineers	Photographs	Army Corps, Photogrametry Section 4735 East Marginal Way S, Seattle, WA

Table 7. (Continued)

Data category	Agency/group	Format available	Contact/address
Pollutant Inputs	WDOE (NPDES)	DMR-reports in files at Regional Offices	WDOE, Northwest Region 4350 150th Ave. NE, Redmond, WA
			WDOE, Southwest Region MS/PV-11, Olympia, WA
			WDOE, Industrial Section MS/PV-11, Olympia, WA
		DMR-major facilities computer printout	Florence Carroll, U.S. EPA 1200 Sixth Avenue, Seattle, WA
River Discharge Water Quality	WDOE	Computer printout	Bob James, WDOE MS/PV-11, Olympia, WA
Climate	National Climate Data Center	Monthly and Annual Summary Tables	National Climate Data Center, Asheville, NC
Discontinued Programs	University of Washington	STORET-Computer printout	Ray Peterson, U.S. EPA 1200 Sixth Ave., Seattle, WA
	WDOE	See WDOE above	
	Metro	Computer printout	Janet Condon, Metro, 411 West Harrison, Seattle, WA
	WDF	Raw data sheets	M. Tarr, WDF Point Whitney Lab., Brinnon, WA

Table 7. (Continued)

Data category	Agency/group	Format available	Contact/address
	USGS	Raw data sheets	G. Bortleson, USGS 1201 Pacific Ave., Tacoma, WA
	U.S. EPA (mussel watch)	Computer printout, various reports	John Farrington, Woods Hole Oceanographic Institution, Woods Hole, MA
	NOAA	Raw data sheets	Robert Clark, NOAA 2725 Montlake Blvd. E., Seattle, WA
	WDOE (ECOBAM)	Computer printout	Dick Cunningham, WDOE MS/PV-11, Olympia, WA
	Evergreen State College	Raw data sheets	S. Herman, Evergreen State College Olympia, WA
	METRO Seattle	Computer printout	Tom Hubbard, METRO 821 Second Avenue, Seattle, WA
	U.S. EPA	Raw data	P. Butler, Tech. Services Division U.S. EPA, Guly Breeze, FL

The availability of data from these programs is outlined in Table 7, and a list of individuals contacted with regard to these data is provided in Appendix B.

5.2 WATER QUALITY MONITORING PROGRAMS

There are 11 marine water quality monitoring programs currently collecting data in Puget Sound (Table 6, Fig. 1). Two programs (those by Metro and WDOE) encompass large spatial areas. Eight programs (those by the Washington Department of Natural Resources (WDNR), NMFS Laboratory, Seattle Aquarium, Point Defiance Aquarium, Sundquist Marine Laboratory, American Sea Vegetable Co., U.S. Department of Defense, and Olympic Community College) are each generally directed towards monitoring one limited area. These programs are discussed below.

5.2.1. The Municipality of Metropolitan Seattle (Metro)

Monitoring conducted by Metro is divided into two components: offshore and shore monitoring stations (Fig. 2). The offshore stations are identified by 100 series numbers and the shore stations are identified by 200 series numbers (Tomlinson and Patten, 1982). Specific parameters measured are listed in Table 6.

The goal of the offshore monitoring program is to detect changes in water quality resulting from Metro's sewage treatment plant (STP) outfalls in Puget Sound. Samples are taken at three depths on a monthly basis at stations near the West Point STP (both flood and ebbtide conditions) and on a quarterly basis at stations near Richmond Beach, Carkeek Park and Alki Point STP stations, and in Elliott Bay (Table 6) (Tomlinson and Patten, 1982).

The shore monitoring program assesses water quality conditions in areas where human water contact (e.g., wading, swimming) is high. Four stations (224, 226, 227 and 228) (Fig. 2) are sampled at the same time as the West Point offshore stations so that any relationship between shore and offshore contamination of fecal coliform bacteria can be evaluated (Metro, 1983; Tomlinson and Patten, 1982). The shore stations are sampled monthly October through May and weekly June through September (Table 6).

Data on fecal coliform concentrations (1976-1982) have been examined for temporal trends, and to date have shown only seasonal changes (Fig. 3). The concentrations of fecal coliforms are higher during the wet season (November through March) than in the dry season (June through September) at all stations (Tomlinson and Patten, 1982).

Data for the remaining parameters have not been analyzed by Metro to discern temporal trends. These data have been used by A. Mearns (NOAA) to prepare plots depicting temporal trends for transparency, dissolved oxygen and salinity (R. Tomlinson, Metro, pers. comm.; A. Mearns, NOAA, pers. comm.), and these trend analyses will be reported elsewhere (Dexter et al., in press).

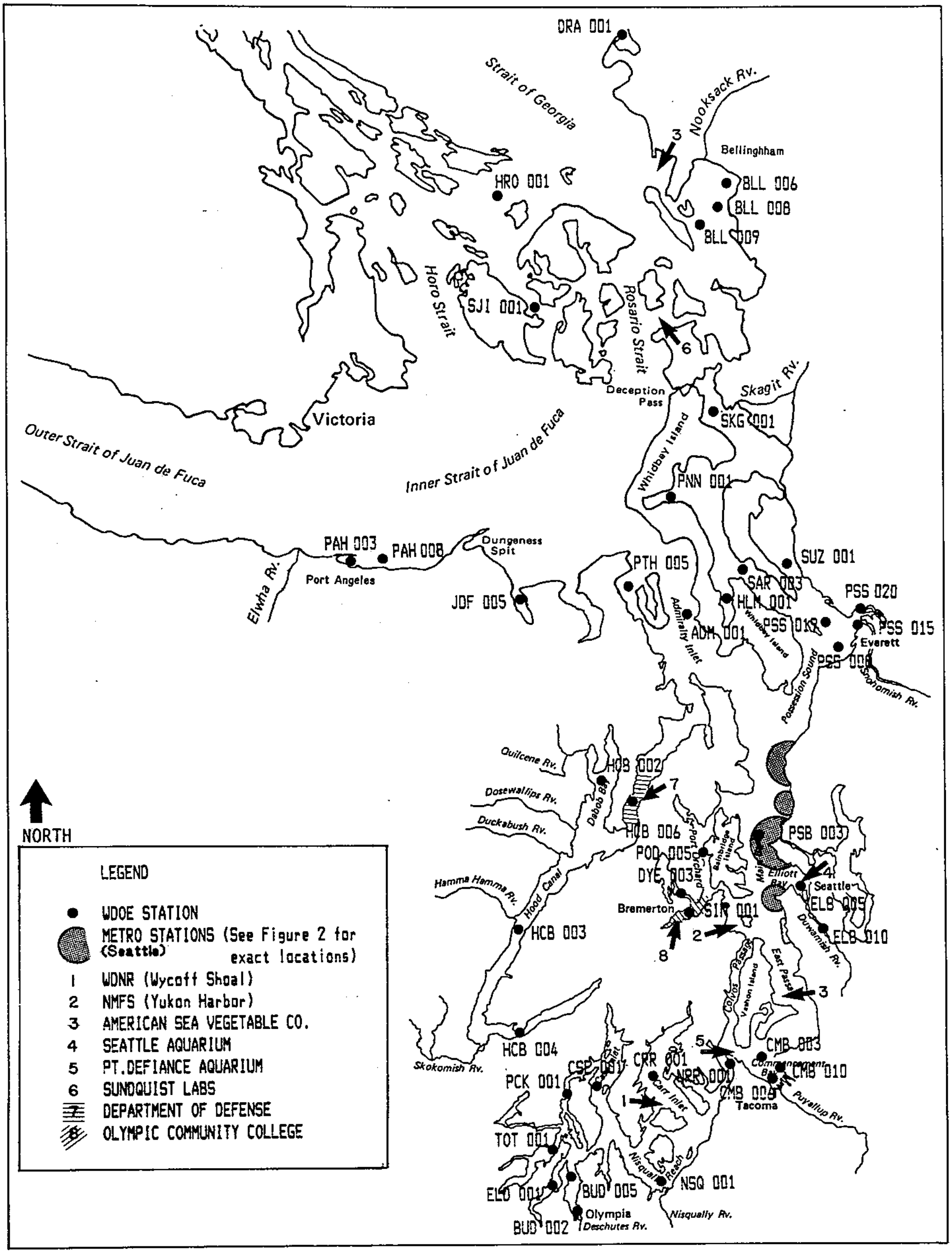

Figure 1. Location of Present Water Quality Monitoring Stations in Puget Sound.

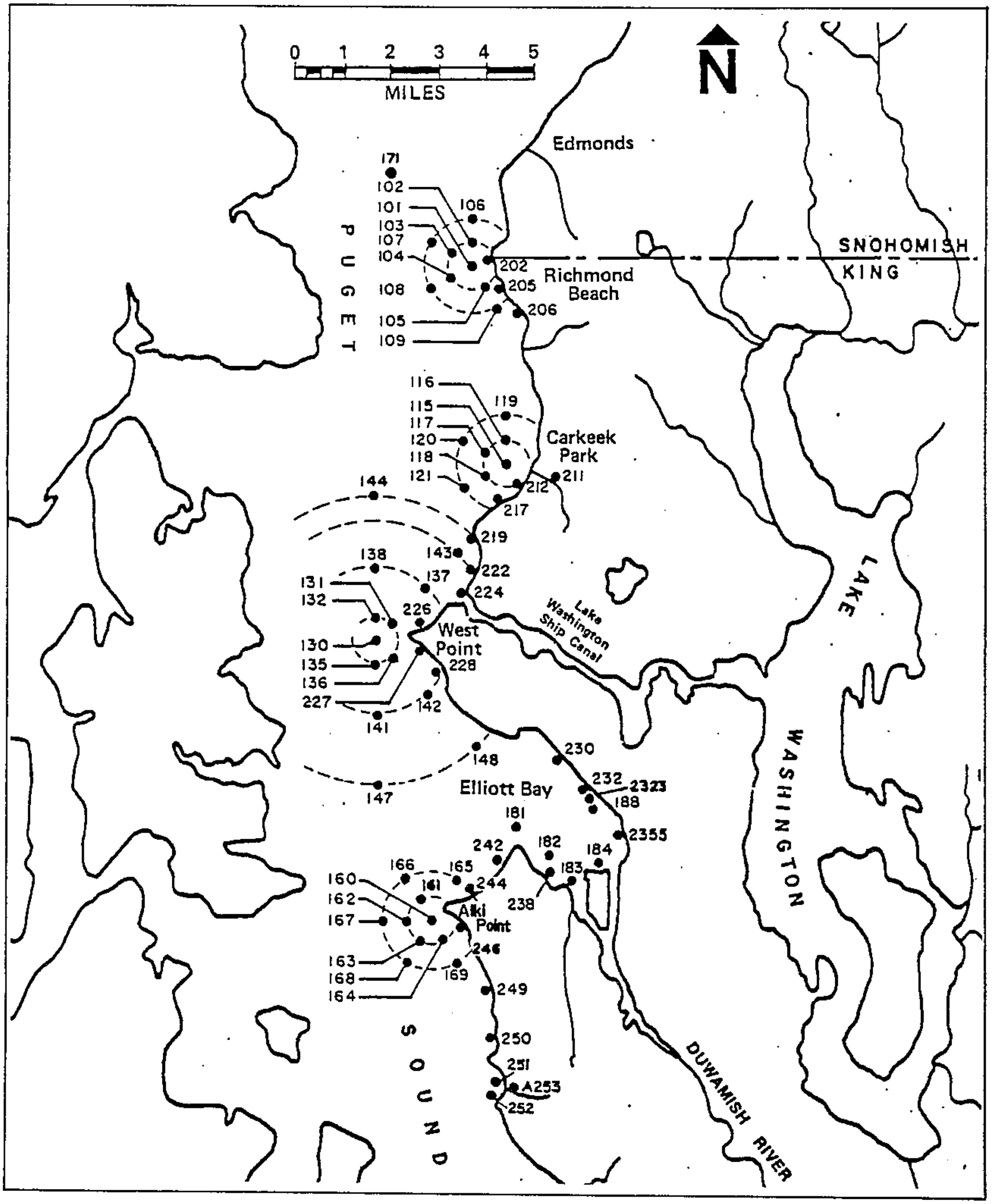

Figure 2. Seattle Metro Water Quality Monitoring Stations.
Source: Tomlinson and Patten, 1982

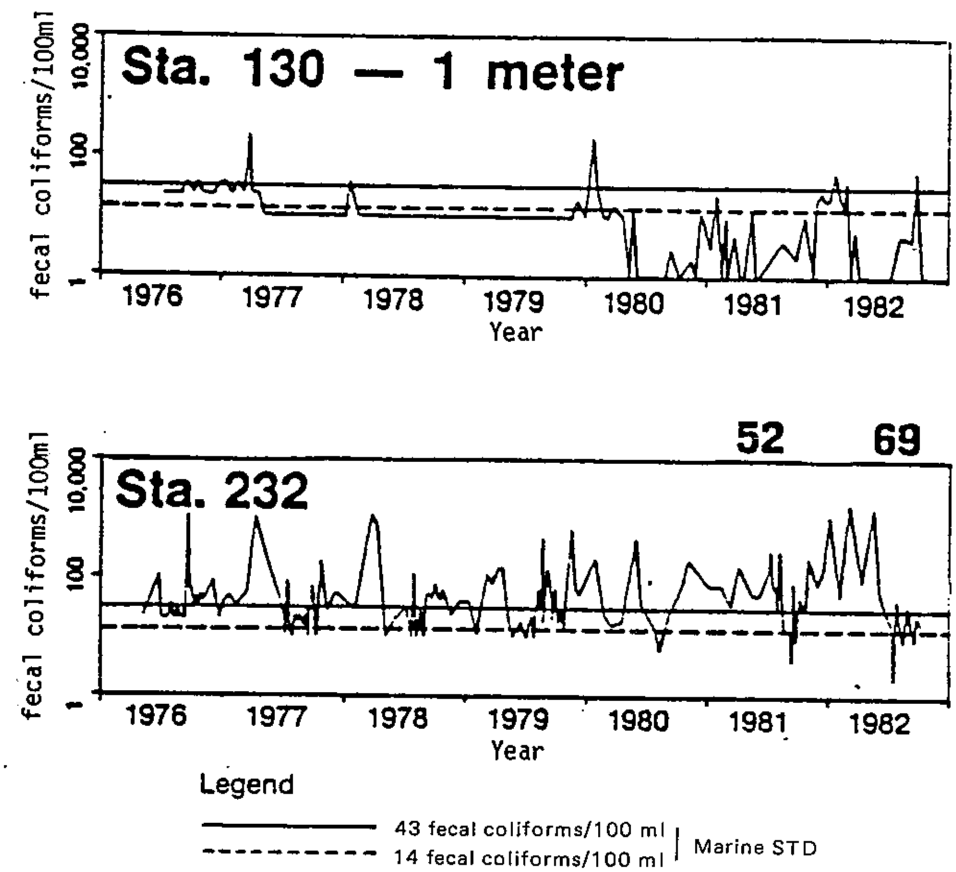

Figure 3. Fecal Coliform Trends Observed at Representative Seattle Metro Stations, based on Monthly Sampling.

Source: Tomlinson and Patten, 1982

The program has been modified over time as new problem areas were identified and as the focus of monitoring concerns has shifted. The changes to date are outlined in Table 8.

5.2.2. Washington Department of Ecology (WDOE)

The WDOE presently maintains a network of 44 stations in Puget Sound that are sampled on a regular basis to assess current water quality conditions (Table 6, Fig. 1). The location and number of stations has changed as the program has been redefined and as new areas of concern were identified (D. Cunningham, WDOE, pers. comm.). These changes, which are not fully documented, include additions and/or deletions of parameters and stations. Section 5.14.1 includes a description of discontinued monitoring stations for the WDOE ambient water quality monitoring program.

Monthly samples are collected at several water column depths from April through November. Since WDOE accesses the stations via float planes, they are limited to collecting samples during relatively calm conditions, precluding sampling during the winter months (WDOE, unpublished data; D. Cunningham, pers. comm.; Jones and Stokes and Tetra Tech, 1983a).

The period of record for most of the 44 stations dates from 1968, with all stations being sampled by the mid to late 1970s (Table 6). Although temperature, salinity, turbidity, transparency, dissolved oxygen, pH, ammonia, nitrate, nitrite, ortho-phosphates, sulfite waste liquor (SWL), and fecal coliforms have been measured during each sampling period, these data have not yet been analyzed to determine long-term trends.

5.2.3. Washington Department of Natural Resources (WDNR)

In conjunction with their aquaculture program, WDNR established a monitoring program to evaluate potential sites for growing seaweed. Initially four stations in the South Sound were sampled on a weekly basis beginning in June 1981 (WDNR, unpublished data; T. Mumford, WDNR, pers. comm.). Temperature, salinity, ammonia, nitrates, nitrites and ortho-phosphates were measured.

By 1983 one station, at Wycoff Shoal, had been chosen as a test site for growing seaweed (Table 6, Fig. 1). Sampling at the other three sites was discontinued, although it continues weekly at the Wycoff Shoal site during the growing season (T. Mumford, pers. comm.).

5.2.4. National Marine Fisheries Laboratories (NMFS)

NMFS takes two daily measurements (morning and evening) of temperature, secchi disk depth, salinity and dissolved oxygen at their Manchester laboratory facility (C. Mahnken, NMFS, pers. comm.; E. Prentice, NMFS, pers. comm.) (Table 6, Fig. 1). The original intent of the monitoring effort was twofold. First, NMFS wanted to determine if there was a relationship between diseases in coho and any of the parameter(s) measured. Second, NMFS wanted to develop a historical data base of the

Table 8. Chronology of Puget Sound monitoring by Seattle Metro (from Tomlinson and Patten, 1982)

Dates	No. of sites	Frequency	Parameters	Rationale
Offshore Stations				
Oct/65-Apr/67	53	West Point-weekly; Richmond Beach, Carkeek Park and Alki Point-monthly; Elliott Bay-intermittent	Temp., transmittance, total coliform, dissolved oxygen, conductivity, salinity, suspended solids and chloride	WDOE requirements for assessing impacts of Metro's discharges on Puget Sound water quality
Apr/67-Mar/68	53	same	Added: fecal coliform in water	Potential change in water quality standard from total coliform to fecal coliform
Apr/68-Mar/76	53	West Point-some weekly, some monthly; Elliott Bay-monthly; Richmond Beach, Carkeek Park and Alki Point-monthly	Dropped: conductivity and chloride	Conductivity-redundant information; chloride-revealed nothing indicative of potential problems
Apr/76-Aug/82	49	West Point-bimonthly; Richmond Beach, Carkeek Park, Alki Point and Elliott Bay-quarterly	Added: pH and tide; Changed: fecal coliform results from MPN-MF; fecal coliform medium from broth to agar; coliform calculations changed	Evaluate influences on effluent plume impacts; MPN to MF-more accurate broth method; broth to agar-more convenient and efficient methods; coliform calculations changed for easier interpretation
Sept/82-present	49	same	Dropped: VanDorn bottle sampling; Added: CTD and bottle rosette sampling	Enhance quality and density of data collected

Table 8. (Continued)

Dates	No. of sites	Frequency	Parameters	Rationale
Shore Stations				
Jan/63-Mar/65	32	June-Sept: weekly Oct-May: monthly (Sta. 224, 226, 227, 228 twice a month)	Temp. and total coliform: Richmond Beach, West Point and Alki Point	WDOE requirements for assessing impacts of Metro's discharges on Puget Sound water quality
Apr/65-Mar/69	32	same	Added: fecal coliform at Elliott Bay	Potential change in water quality standard from total coliform to fecal coliform
Mar/69-Mar/76	21	same	Changed: total coliform and fecal coliform results from MPN to MF; medium changed from broth to agar	More accurate method - a more convenient, efficient method
Apr/76-May/81	21	same	Changed: coliform calculation	Easier interpretation
May/81-Aug/81	21	same	Dropped: Sta. 235; Added: Sta. 2355	Site of Sta. 235 being destroyed
Aug/81-Sept/81	22	same	Added: Sta. 2323	Sampling and examining for contamination problem at broken sewer line under a pier
Sept/81-Jun/82	25	same	Added: Sta. 251, 252, A253	High coliform contamination in area
Jun/82-present	25	same	Added: enterococcus and fecal streptococcus	Better indicator of human health risk

hydrographic conditions at Manchester (E. Prentice, pers. comm.). NMFS has not conducted long-term trend analyses of these data.

Representative data for water temperatures (1968-1983), Secchi disk depth (1977-1983) and dissolved oxygen (1978-1983) were analyzed for trends as part of the present study (Figures 4 and 5). No long-term trends were observed although seasonal trends were observed with temperature (higher temperatures in summer, lower in winter), and secchi disk depth (higher September through March). Figures 4 and 5 represent the range of values observed during the period of record for each parameter.

5.2.5. United States Fish and Wildlife Service (USFWS)

The USFWS Laboratory at Marrowstone Island analyzes their intake water three times a week, from April through November, for temperature, salinity and dissolved oxygen (A. Palmisano, USFWS, pers. comm.). Data date back to 1981, but have not been used for long-term trend analyses.

5.2.6. American Sea Vegetable Co.

In 1983, in the interest of establishing kelp aquaculture sites in Puget Sound, the American Sea Vegetable Company began monitoring two sites: Tramp Harbor (in East Passage) and Lummi Bay (near Bellingham) (Fig. 1). The intent of this monitoring was to obtain data related to possible commercial aquaculture. Daily measurements are taken for temperature, salinity, pH and wind/wave conditions. Nitrogen (nitrates, nitrite and ammonia), phosphate and silicate concentrations are measured on a weekly basis (J. Olson, American Sea Vegetable Co., pers. comm.). Sampling began in February 1983 and continued through May 1984. Sampling will commence again at the Lummi Bay site in August 1984 and will continue through the growing season (August-May). No trend analyses have been conducted on these data.

5.2.7. Seattle Aquarium

Since 1978, the Seattle Aquarium has monitored the quality of water from their intake, located at approximately 13 m below the surface and 4.5 m above the bottom in Elliott Bay (Fig. 1). Total coliforms and dissolved oxygen are measured on a weekly basis while temperature, salinity, pH and turbidity are measured daily (B. Bruin, Seattle Aquarium, pers. comm.; JRB Associates, 1984a). The data are collected to provide information on water quality for the display tanks and have not been used to discern long-term trends.

5.2.8. Point Defiance Zoo and Aquarium

The Point Defiance Zoo and Aquarium began sampling in 1982 from their intake source located off Pt. Defiance at 6 m below the surface (Fig. 1). Temperature, salinity, dissolved oxygen and pH are measured on a monthly basis. The data are collected to provide information on water quality for the display tanks and have not been used to discern long-term trends.

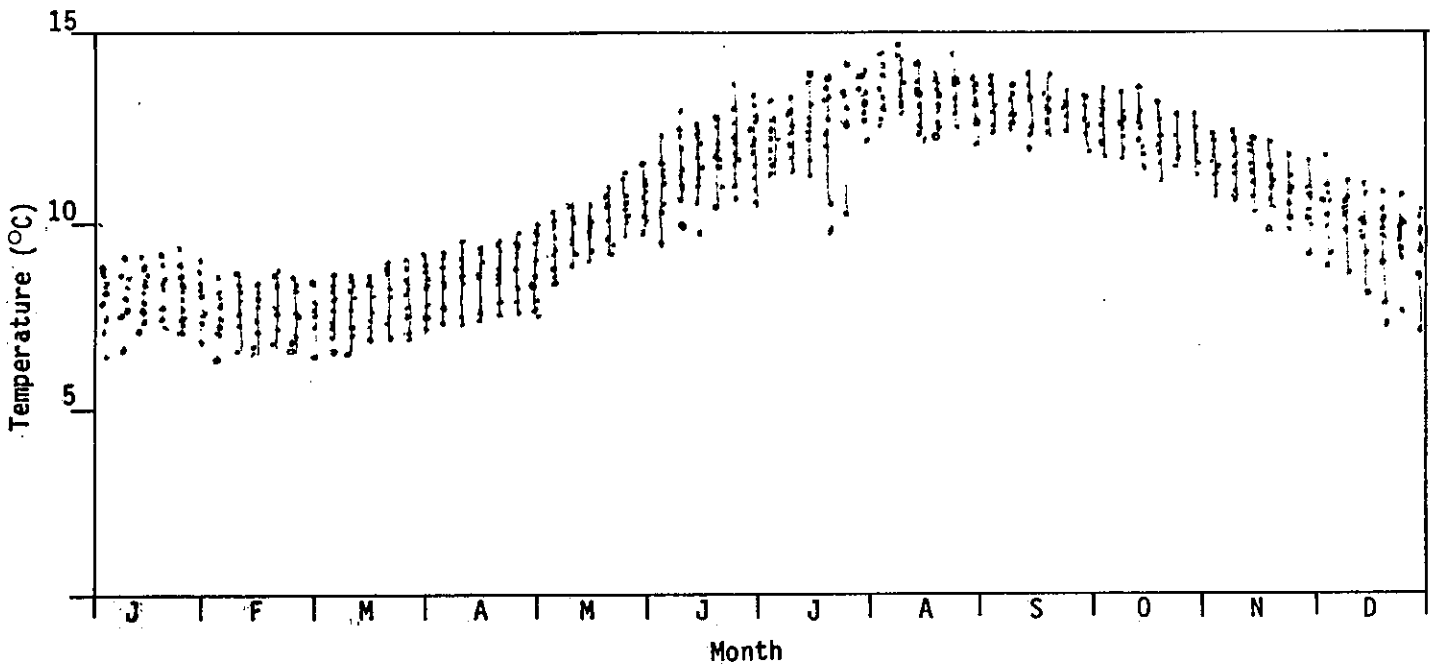

Figure 4. Range of Surface Water Temperature Recorded at Manchester, 1968-1983 (5 day mean).
Source: NMFS, unpublished data

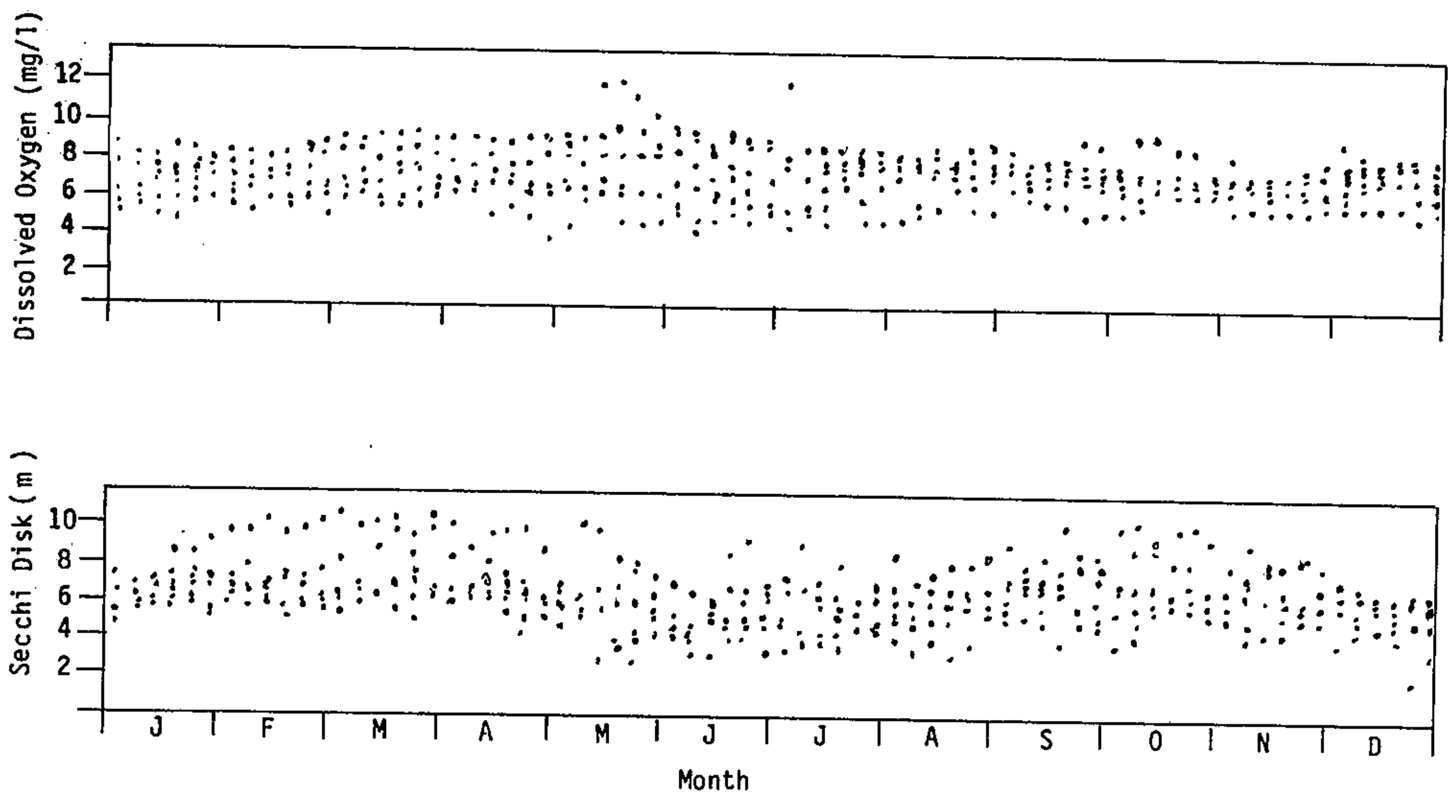

Figure 5. Range of Dissolved Oxygen(surface) and Secchi Disk Readings Recorded at Manchester, 1977-1983(5 day mean).

Source: NMFS, unpublished data

5.2.9. Sundquist Laboratory

From 1974 to the present, water samples have been taken at Shannon Point, near Anacortes (Fig. 1) three times per week for the following measurements: temperature, salinity, pH, turbidity, dissolved oxygen and dissolved carbon dioxide. In 1977, total and carbonate alkalinity were added to the list of parameters sampled. These data are used to monitor laboratory water quality related to specific experiments and have not been used to discern long-term trends.

5.2.10. United States Department of Defense (Navy)

The U.S. Navy collects water samples from 22 sites in Hood Canal including a control station located approximately one-half mile south of the Bangor Naval Yard boundary (Fig. 1). Sampling commenced in 1974 to evaluate the impact of the naval activities on the water quality in Hood Canal (JRB Associates, 1984a). Samples are collected semi-annually (summer and winter) and are analyzed for Cr, Cu, Fe, Pb, Hg, Ag, Zn, Ni, nutrients, TOC, pH, salinity, temperature and dissolved oxygen. The data have not yet been used to discern long-term trends (J. Reeves, U.S. Dept. of Defense, pers. comm.).

5.2.11. Olympic Community College

From 1977 to the present, surface water samples have been collected from several stations in Sinclair Inlet and analyzed for temperature, salinity, pH and dissolved oxygen measurements (Fig. 1). Samples are taken monthly from September through May as part of a class exercise and often include determination of plankton volumes. These data have not been used to discern long-term trends.

5.3 FISHERIES MONITORING PROGRAMS

5.3.1. Washington Department of Fisheries (WDF)

Management of Puget Sound fisheries falls under the domain of the WDF. Three programs have been established to oversee the resource: the Marine Fish Program, the Salmon Program and the Shellfish Program (C. Dalgren, WDF, pers. comm.).

WDF publishes an annual report containing statistics on commercial and sport landings of bottom fish, salmonids and shellfish (D. Gustin, WDF, pers. comm.). Each annual report includes statistics for the current year and available historical data.

The Salmon Program maintains data on run size by species, numbers at the extreme terminal area (i.e., spawning area) and catch by level of effort. WDF is in the process of entering the run size data onto their computer. Data have been collected since the mid-1960s for most of the Puget Sound salmon species (Table 9). Although data have been collected to the present, they were only available to 1980 for the present review.

Table 9. Period of record available for run size of Puget Sound salmon. Data are for all major salmon-bearing streams in Puget Sound.

Species	Period of Record	
coho	from:	1965
chinook		1968
chum		
early		1968
normal		1968
late		1968
sockeye		1967
pink		1959

The Marine Fish Program monitors both commercial and recreational groundfish and baitfish fisheries in Puget Sound. Commercial fisheries data (1920 to the present) are stored on data sheets with recent years stored on an in-house computer and include (by species): date, area, type of fishing gear and number of pounds landed. Recreational fisheries data include catch, by species, and level of effort from the mid-1960s to the present. The quality of the data prior to 1974 is considered poor (G. Bargmann, WDF, pers. comm.). A limited amount of data is collected regarding fisheries habitat. Most of the data are in the form of underwater videotape surveys and SCUBA diving surveys (G. Bargmann, pers. comm.). Biological data on length and age of fish have been collected over 20 years for commercial and 9 years for sport catches and are stored on a new in-house data management system (G. Bargmann, pers. comm.; Kimura and Cross, 1983).

The WDF Shellfish Program has collected a large volume of data concerning the shellfish resources of Puget Sound. However, an inventory of these data has not been made due to the volume of data and to budget cuts which have reduced personnel (R. Westley, WDF, pers. comm.).

Available WDF monitoring data were reviewed and selected data sets were analyzed to determine long-term trends. The results of these analyses are presented in the following pages.

Salmon. Typical data on run size and total catch size are presented in Figure 6 for coho. Run sizes are calculated by incorporating the data from three sources: 1) returns to hatcheries and small enhancement programs, 2) escapement, and 3) catch statistics (commercial and sport fisheries). Escapement is calculated by taking weekly stream survey data and then using a prescribed statistical analysis package to determine escapement based on the average time a spawning salmon survives in each stream.

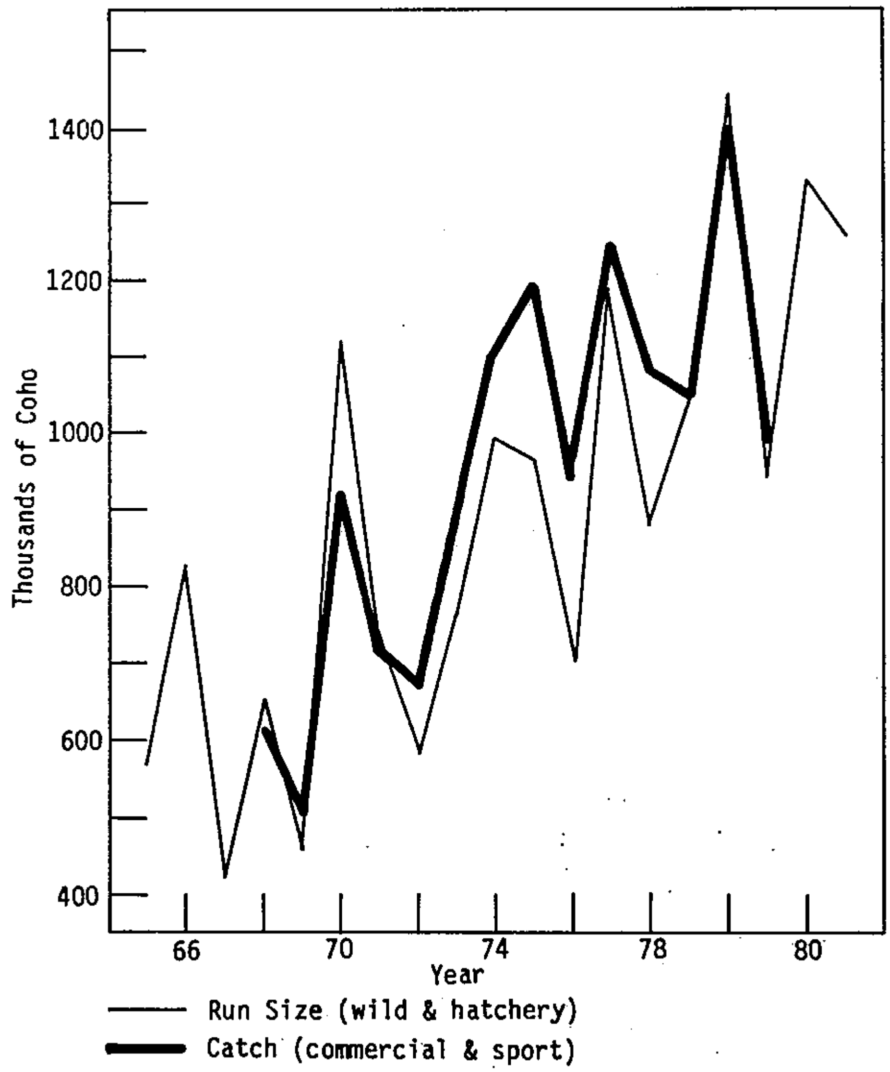

Figure 6. Summary of Coho Run Size (1964-1968) and Catch (1968-1981) in Puget Sound.

Source: WDF, 1982,unpublished data

The salmon resource in Puget Sound has generally increased from the late 1960s to the present (Fig. 6; J. Ames, pers. comm.). Exceptions are the Baker River sockeye run and the Hood Canal and south Puget Sound early chum runs. The sockeye run at the Baker River has declined, possibly due to dams that block fish passage. Decline of the early chum runs may be due to management practices. The early chum return at the same time as coho and are, therefore, harvested along with the coho. The WDF does not require that chum be returned when caught (J. Ames, WDF, pers. comm.).

Sport catches of coho have generally increased since 1946 with a decrease occurring from 1960 through 1978 (Fig. 7). The numbers of coho caught by sport fishermen from 1946-1982 are depicted in Figure 7. Included in Figure 7 is a breakdown of the catch by area (inner Puget Sound, Neah Bay and Strait of Juan de Fuca, and San Juan Islands). The catch of coho in 1960 was poor due to low abundance of both ocean migrants and resident fish; a voluntary closure of the fishery (September 20 - October 23) was initiated by the Washington State Sports Council (WDF, 1960). This cycle was also observed with chinook. Naturally spawning resident coho from lowland streams decreased in the late 1950s and 1960s, possibly due to increased urbanization resulting in decreased sport catches (J. Ames, pers. comm.). During the mid 1960s WDF began releasing "late-release coho" from hatcheries. These coho tend to become resident fish and, as a result of this management policy, the resident population increased. Also, during the later 1970s, personal income increased. More people had access to boats and the specialized fishing equipment needed to catch salmon. Ease of travel to the better fishing grounds in the Strait of Juan de Fuca may also have contributed to the increased number of sport catches in this area since 1972 (Fig. 7; J. Ames, pers. comm.).

Fig. 6 shows that the combined sport and commercial catches of coho often exceeded the run size. This anomaly may be due to the fact that some of the catch is composed of coho caught in the Strait of Juan de Fuca and the San Juan Islands while returning to Canadian waters. (D. Geist, WDF, pers. comm.).

Groundfish. Groundfish stock assessments are not performed by WDF. Commercial landings of sole and flounder have generally increased since 1920 and may now be reaching a plateau, based on catch statistics (Fig. 8). The decrease from 1938 to 1948 may be due to the effects of World War II when men and boats were needed for the war effort (G. Bargmann, pers. comm.). Since 1968 the number of landings has increased only slightly, perhaps indicating that the maximum resource limits have been reached.

The decrease in commercial groundfish (in particular sole) landings in 1974 and 1975 are the result of five factors: 1) harvesting in Hood Canal was closed because of overharvesting in previous years; 2) demand for sole as animal food declined in southern Puget Sound; 3) demand for dogfish increased and fishing effort was accordingly shifted from sole to dogfish; 4) demand for fresh fish decreased due to high inventories of frozen fish; and 5) increased harvesting of rockfish from the Pacific Coast competed with the sole market (M. Pedersen, WDF, pers. comm.).

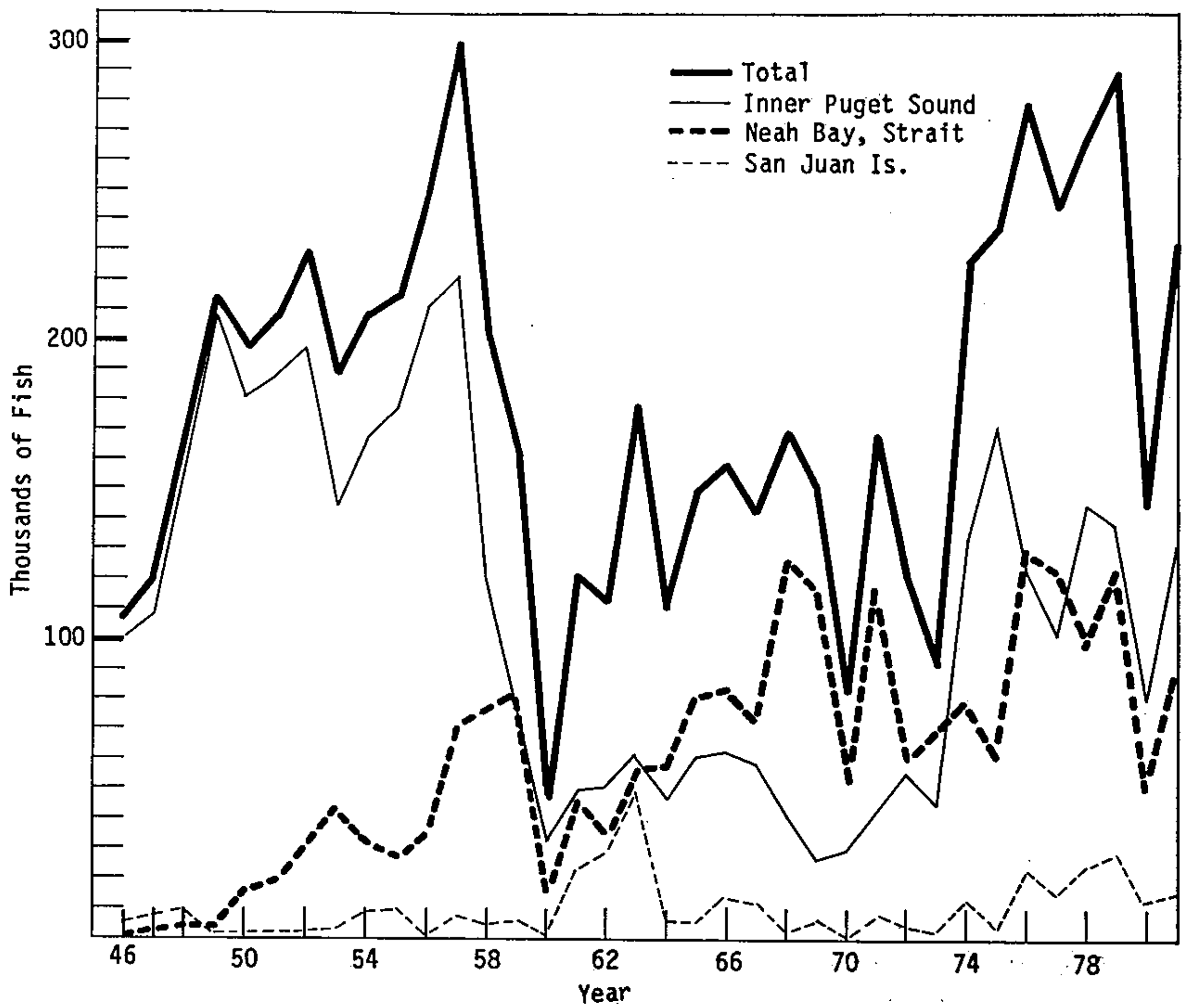

Figure 7. Sport Catches of Coho in Various Areas of Puget Sound (1946-1982).

Source: WDF, 1982

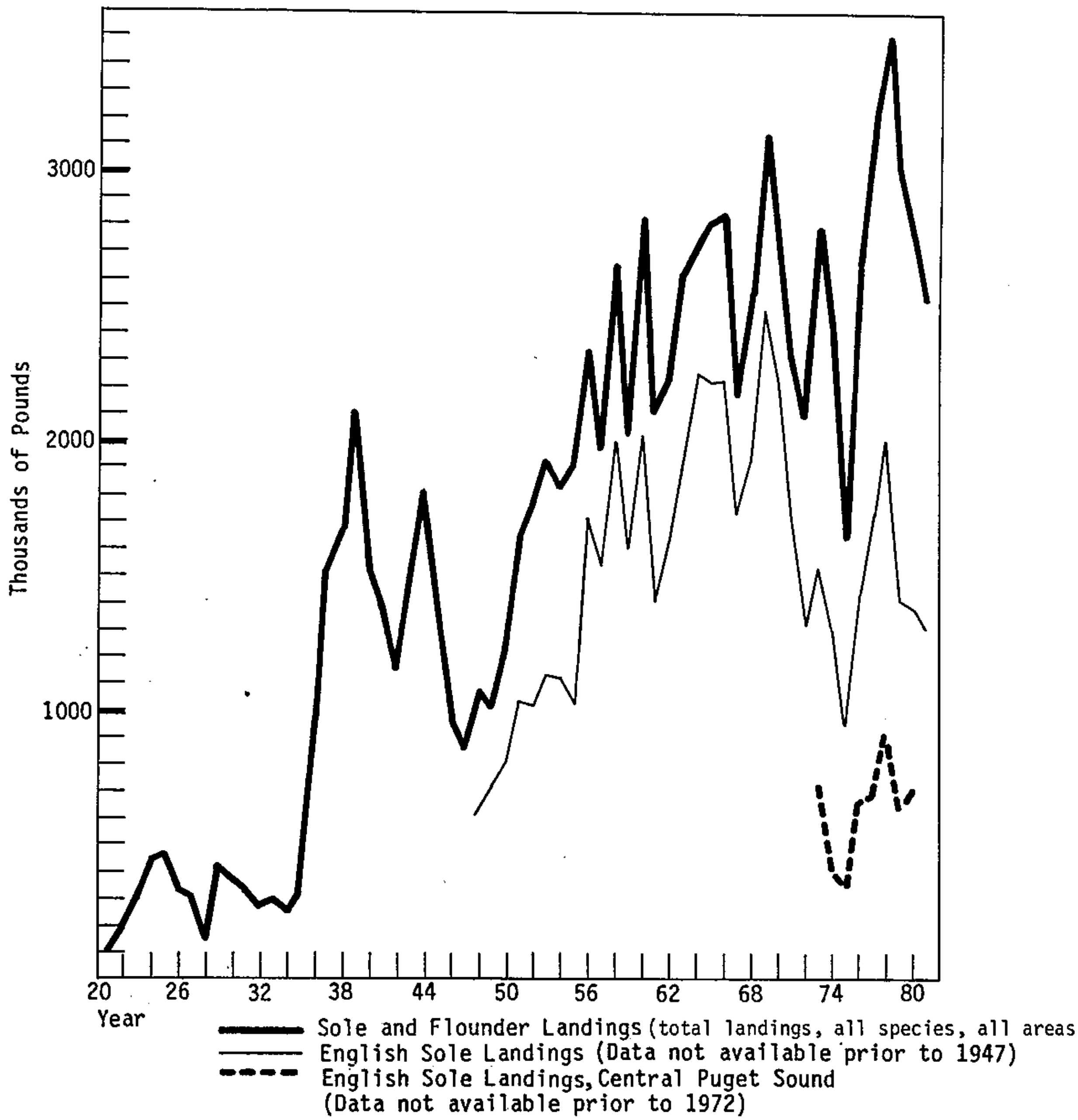

Figure 8. Commercial Landings of Sole and Flounder in Puget Sound (1920-1982).

Source: WDF, unpublished data; Pederson and DiDonato, 1982

Baitfish. The Marine Fish Division of WDF also gathers data on stock abundance of herring in Puget Sound. Population estimates are based on: 1) surveys of spawning grounds (1972-present); 2) hydroacoustic and midwater trawl surveys (1971-present); and, 3) a computerized catch reporting system. These three programs provide data on estimates of escapement, estimates of pre-spawning abundance, and records of landings respectively (Trumble, 1983).

Shellfish. Commercial harvesting of geoducks began in 1970 and increased rapidly until 1977 due to the large market for geoducks in Japan (Fig. 9). In 1977 WDF discovered that geoducks live to be over 100 years old and have low recruitment rates. Consequently, management programs were re-evaluated and WDF determined that the resource could not sustain the previous large harvest of nine million pounds per year. The harvest limits were subsequently reduced to five million pounds per year (L. Goodwin, WDF, pers. comm.). Since 1979 the commercial harvest has fluctuated around five million pounds (Fig. 9).

Stocks of Puget Sound crab are cyclic (6-8 years) with peaks generally corresponding to valleys in the Pacific Coast stocks. The increase in the commercial catch from 1975-1978 (Fig. 9) is due to management changes. In 1975 the WDF instituted regulations which based the harvest season on the molting cycles. Crabs can now only be collected when the shell is hard. This new management practice decreased mortality in the crab traps and therefore increased the catch (Fig. 9). The decrease in commercial crab harvests observed in 1980 and extending to the present may be due to a continuing moratorium on issuing of new commercial licences (D. Bumgartner, WDF, pers. comm.).

The decreased commercial harvest of shrimp in 1975, 1976 and 1977 (Fig. 9) was due to decreased abundance of spot shrimp. In 1976 Hood Canal shrimp harvesting was prohibited and the harvesting season was shortened in 1977. The sport harvest of shrimp generally exceeds the commercial harvest (D. Bumgartner, pers. comm.).

The commercial harvest of oysters and hardshell clams has remained relatively constant over time (Fig. 9), while the total shellfish harvest has fluctuated. Small-scale fluctuations in commercial oyster harvests have occurred due to changes in market conditions (L. Goodwin, pers. comm.). The large total shellfish harvests 1976-1978 may be due to the increase in harvest of geoducks (1975-1977), and to massive landings of sea urchins in 1977 and 1978 (A. Scholz, WDF, pers. comm.).

5.3.2. NOAA/NMFS Northwest and Alaska Fisheries Center

The NMFS has, since 1979, collected and examined bottom fish and other organisms from many areas in Puget Sound. These studies have revealed a number of pathological conditions in various organs of these organisms. Most of these studies have been one time assessments or of short duration.

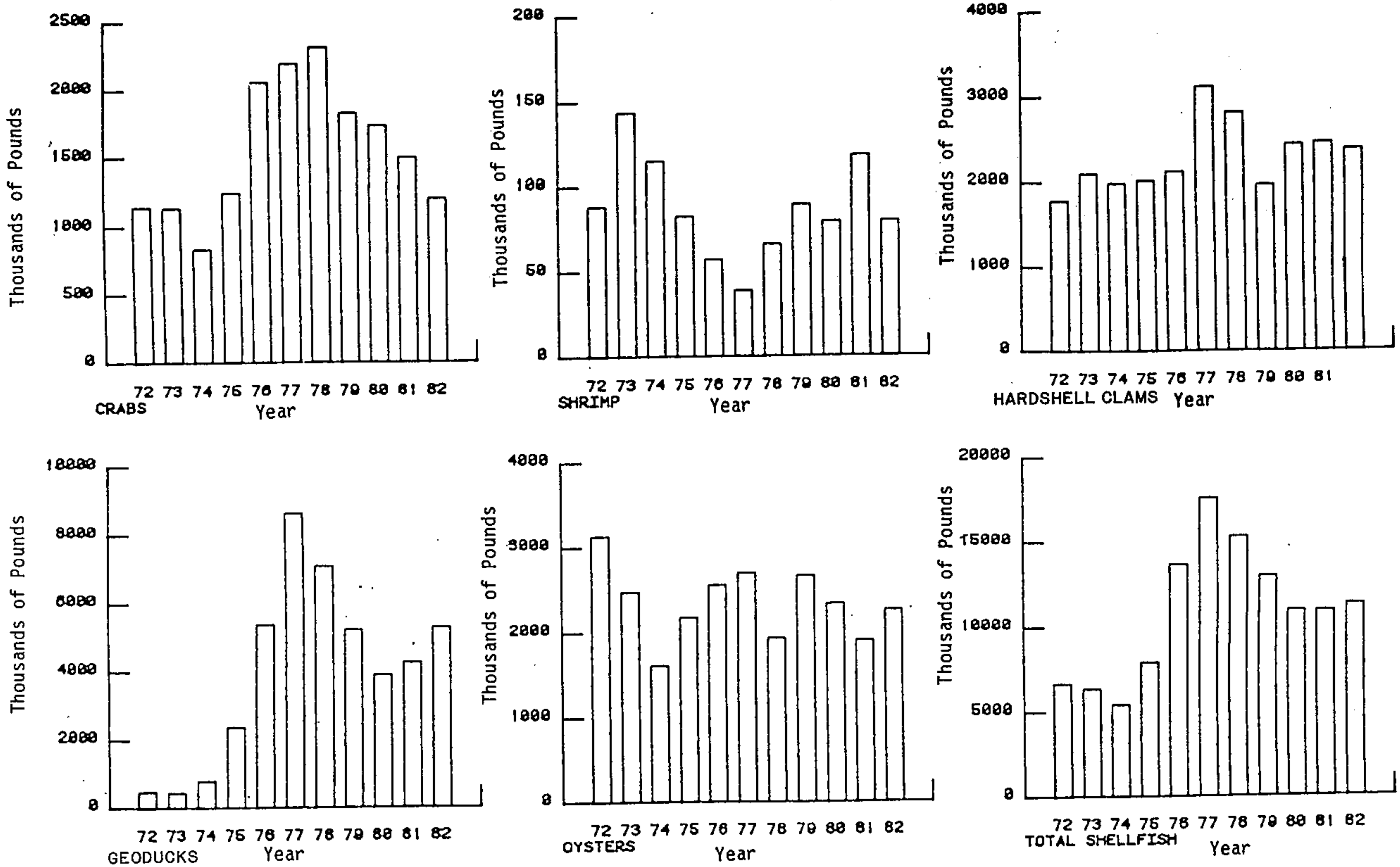

Figure 9. Commercial Shellfish Catch for all of Puget Sound

Source: WDF,1982

However, eight surveys have been made from 1979 to repeat stations in Elliott Bay and Commencement Bay, Sinclair Inlet and Port Madison. Data from individual surveys in 1979 (four surveys), 1980 (two surveys) and 1982 (two surveys) have been compiled and analyzed (McCain et al., 1983). Over the time period covered, a few trends were observed, including some increases and some decreases in lesion frequencies. These trends were not consistent among all stations and no attempt was made to identify causal factors.

5.3.3. Olympic Community College

From 1978 to the present, fish (and invertebrates) have been collected with a 12'x100' beach seine at Port Washington Narrows in the vicinity of a sewage treatment plant (Fig. 10). Samples are collected semi-annually in the late fall and late winter as part of a class exercise. The data have not been subjected to long-term trend analyses.

5.3.4. U.S. Department of Defense (Navy)

The U.S. Navy initiated a fisheries monitoring program in 1973 to evaluate the effect of naval activity on the marine fauna of Hood Canal. Molluscs and fish are collected annually by hand and beach seine, respectively, at six transects (one site) in Hood Canal near the Bangor Base (Fig. 10). The data are then used to calculate abundance and size frequency distributions (JRB Associates, 1984a). In addition, tissue samples are analyzed for trace metals (J. Reeves, U.S. Dept. of Defense, pers. comm.). None of these data have been subjected to long-term trend analyses.

5.3.5. University of Washington

Since the early 1950s, Drs. DeLacy and Miller at the University of Washington have conducted yearly surveys in Elliott Bay to determine egg distribution and spawning areas for English sole. These studies are performed as part of a class exercise and have not been analyzed for long-term trends.

5.4 BACTERIA AND PARALYTIC SHELLFISH POISONING (PSP) MONITORING PROGRAMS

5.4.1. Washington Department of Social and Health Services (DSHS)

DSHS is responsible for monitoring commercial shellfish beds and ensuring that PSP and fecal coliform standards are not exceeded. Samples are collected when problems are suspected rather than at regular intervals, but these data, which are collected at the same sites over a period of many years, provide long-term monitoring information.

Data on bacterial contamination are collected for both the water column and for shellfish tissues (Tables 10 and 11). The water column program has changed since 1982. From 1978 to 1982 the DSHS had a network of stations which were monitored for fecal coliforms about once every two years (Figure 11). Since 1982, DSHS has concentrated more on intensive

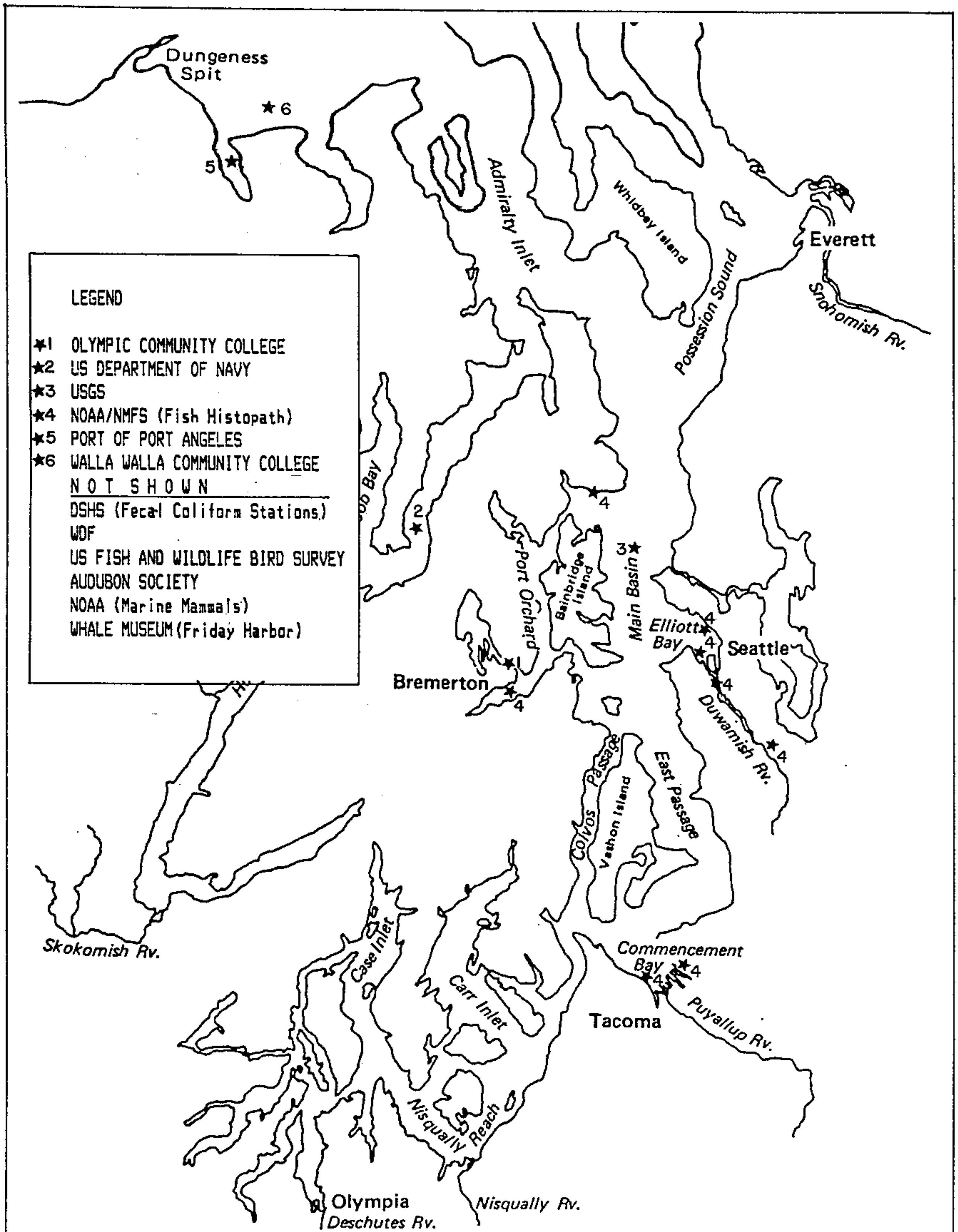

Figure 10. Station Locations for Biological (non-water quality) Monitoring Stations.

Table 10. Data available from DSHS on fecal coliforms in water (by location and date)

*Station	1978 Tide[a]	1979 Tide	1980 Tide	1981 Tide	1982 Tide
1	4/3[b] F	7/16 E		1/19 S	3/8 -
	4/5 E	7/17 F		1/19 F	3/10 -
		7/18 F		1/20 E	3/11 -
		7/19 F		1/20 F	
		7/23 S		1/21 F	
		7/25 E		1/22 E	
		7/26 E		1/22 F	
2	4/3 F	7/16 E		1/19 S	3/8 -
	4/5 E	7/17 F		1/19 F	3/10 -
		7/18 F		1/20 E	
		7/19 F		1/20 E	
		7/23 S		1/21 E	
		7/25 E		1/21 F	
		7/26 E		1/22 E	
				1/22 SE	
3	4/3 F	7/16 E		1/19 F	
		7/17 S		1/19 F	
		7/18 F		1/20 E	
		7/19 F		1/20 F	
		7/23 F		1/21 E	
		7/25 E		1/21 F	
		7/26 E		1/22 E	
				1/22 SE	
4	4/3 F	7/16 E		1/19 F	
		7/17 S		1/19 F	
		7/18 F		1/20 E	
		7/19 F		1/20 F	
		7/23 F		1/21 E	
		7/25 E		1/21 F	
		7/26 E		1/22 E	
				1/22 SE	
5	4/3 F	7/16 F		1/19 E	
	4/5 F	7/17 S		1/19 F	
		7/18 F		1/20 E	
		7/19 F		1/20 F	
		7/23 F		1/21 E	
		7/25 E		1/21 F	
		7/25 E		1/22 E	
				1/22 E	

Table 10. (Continued)

*Station	1978 Tide	1979 Tide	1980 Tide	1981 Tide	1982 Tide
6	4/3 F	7/16 F		1/19 F	
		7/17 S		1/19 F	
		7/18 F		1/20 F	
		7/19 F		1/21 E	
		7/23 F		1/22 E	
		7/25 E		1/22 E	
		7/26 E			
7		7/16 E		1/19 F	
		7/17 S		1/19 F	
		7/18 F		1/20 E	
		7/19 F		1/21 E	
		7/23 F		1/21 F	
		7/25 E		1/22 E	
		7/26 E			
10	4/3 F	7/16 E		1/19 SE	
		7/17 S		1/19 F	
		7/18 F		1/20 E	
		7/19 F		1/20 F	
		7/23 F		1/21 E	
		7/25 E		1/21 F	
		7/26 E		1/22 E	
				1/22 SE	
11	4/3 F	7/16 E		1/19 SE	
	4/5 F	7/17 S		1/19 F	
		7/18 F		1/20 E	
		7/19 F		1/20 F	
		7/23 F		1/21 E	
		7/25 E		1/21 F	
		7/26 E		1/22 E	
				1/22 SE	
33	4/4 F			1/19 E	
				1/20 E	
				1/21 E	
				1/22 E	
34	4/4 F	7/19 F		1/19 E	
	4/6 F	3/5 S		1/20 E	
		3/12 E		1/21 E	
		3/13 F		1/22 E	
		3/14 F			
		3/15 E			

Table 10. (Continued)

*Station	1978 Tide	1979 Tide	1980 Tide	1981 Tide	1982 Tide
35	4/5 E	7/19 F			
	4/6 F	7/20 F			
		3/15 S			
		3/12 E			
		3/13 F			
		3/14 F			
		3/15 E			
36	4/6 F	7/19 F			
		7/20 F			
		3/5 S			
		3/6 E			
		3/7 E			
		3/8 F			
		3/12 E			
		3/13 F			
		3/14 F			
		3/15 E			
37	4/3 F	7/16 F		1/19 E	
		7/17 F		1/19 F	
		7/18 F		1/20 E	
		7/19 F		1/20 F	
		7/23 E		1/21 E	
		7/25 E		1/21 F	
		7/26 E		1/22 E	
				1/22 F	
38		7/16 S		1/19 E	
		7/17 F		1/19 F	
		7/18 F		1/20 E	
		7/19 F		1/20 F	
		7/23 E		1/21 E	
		7/25 E		1/21 F	
		7/26 E		1/22 E	
				1/22 F	
39	4/5 E	7/16 F		1/19 E	
		7/17 F		1/19 F	
		7/18 F		1/20 E	
		7/19 F		1/20 F	
		7/23 E		1/21 E	
		7/25 E		1/21 F	
		7/26 E		1/22 E	
				1/22 F	

Table 10. (Continued)

*Station	1978 Tide	1979 Tide	1980 Tide	1981 Tide	1982 Tide
40	4/3 F	7/16 F		1/19 E	
	4/5 E	7/17 F		1/19 F	
		7/18 F		1/20 E	
		7/19 F		1/20 E	
		7/23 E		1/21 E	
		7/26 E		1/21 F	
				1/22 E	
				1/22 F	
41	4/3 F	7/16 F		1/19 E	
		7/17 F		1/19 F	
		7/18 F		1/20 E	
		7/19 F		1/20 F	
		7/23 E		1/21 E	
		7/25 E		1/21 F	
		7/26 E		1/22 E	
				1/22 F	
43	4/3 -	3/15 E		1/19 E	
				1/20 E	
45	4/4 F			1/21 E	
	4/5 E			1/22 E	
12	4/3 F	7/16 E			
13	4/5 F	10/15 E			
14		10/16 E			
A-1		10/17 E			
A-2		10/18 E			
A-3		10/22 E			
A-5		10/23 E			
		10/24 E			
		10/25 F			
15	4/4 E	7/11 E	8/11 -	1/26 -	
		7/12 F	8/12 -	1/27 -	
		7/13 F	8/13 -	1/28 -	
		7/17 F	8/14 -	1/29 -	
		7/18 E			
		7/19 E			
		7/20 E			
		3/5 S			
		3/5 S			
		3/6 E			
		3/6 E			
		3/15 -			

Table 10. (Continued)

*Station	1978 Tide	1979 Tide	1980 Tide	1981 Tide	1982 Tide
18	4/4 -	7/11 -	8/11 -	1/26 -	
	4/5 -	7/12 -	8/12 -	1/21 -	
		7/13 -	8/13 -	1/28 -	
		7/14 -	8/14 -	1/24 -	
		7/15 -			
		7/16 -			
		7/17 -			
		7/18 -			
		7/19 -			
		7/20 -			

* Station numbers correspond to Fig. 11.

[a] S = slack tide, F = flood tide, E = ebb tide, - = no data

[b] month/day

Table 11. Data available from DSHS on coliform levels in shellfish (by location and date)

Area	1978	1979	1980	1981	1982	1983	1984
Totten Inlet	1/3[a] 1/9 3/6 4/10 5/30 6/12 6/26 7/24 8/21 10/23 11/16 12/18	1/8 2/5 3/26 4/16 4/23 6/4 6/19 7/9 7/16 9/24 10/8 12/17	1/14 1/21 1/28 3/17 3/24 3/21 12/8	2/2 2/17 5/11 7/27 8/24 8/31 9/8 12/7	6/1 8/30	1/3 1/17 4/25 5/9 6/27 10/31 11/14	1/9 2/14 2/21
Skookum Inlet	3/6 4/10	1/15 1/22 9/10 10/1 12/17	3/24 4/21 6/9 7/28 8/11 8/18 9/15 9/22 9/29 11/3	1/5 3/2 3/30 4/6 4/13 4/27 7/20 8/24 9/8 9/14 11/2 11/6 11/30	4/19 6/7 7/12 7/26 7/26 8/2 9/20 9/7	4/25 7/25 6/27 11/14 11/21	2/14
Oakland					8/16	1/31 2/22 7/11 8/15	
Peale Passage					5/23		
Allyn					8/1 11/8	1/10 1/24 2/7 2/28 6/19 8/1 11/7	2/2
Rocky Bay						6/20	

Table 11. (Continued)

Area	1978	1979	1980	1981	1982	1983	1984
Henderson Inlet					7/12 8/1 6/7 8/8 10/14 11/17	1/22 1/31 3/6 3/13 3/14 6/27 7/24 9/25 9/9 10/31 11/4	1/9 1/27 1/30 2/21
Minter Bay					4/26 6/21 8/1 10/4 10/11	5/1 8/2 9/5	
Burley Lagoon					10/31	3/7 3/6 4/18 5/1 5/16 6/20 8/1	
Hogum							2/20
Hood Canal					1/4 6/27 8/29 10/18 10/17	4/3 4/7 5/23 6/5 6/2 10/22	1/13
Quilcene Bay					5/24 7/11	5/22 9/26	
Kilisut Harbor					11/1		
Port Townsend					12/4		
Sequim						4/30	

Table 11. (Continued)

Area	1978	1979	1980	1981	1982	1983	1984
Liberty Bay					5/2 5/17	9/25 10/17	
Port Susan					2/22		2/7
Penn Cove						9/19	1/9
Similk					7/19	10/10	
Samish					7/18 11/29 12/10 12/13		1/21 1/20
Lummi Bay							1/16

[a] month/day

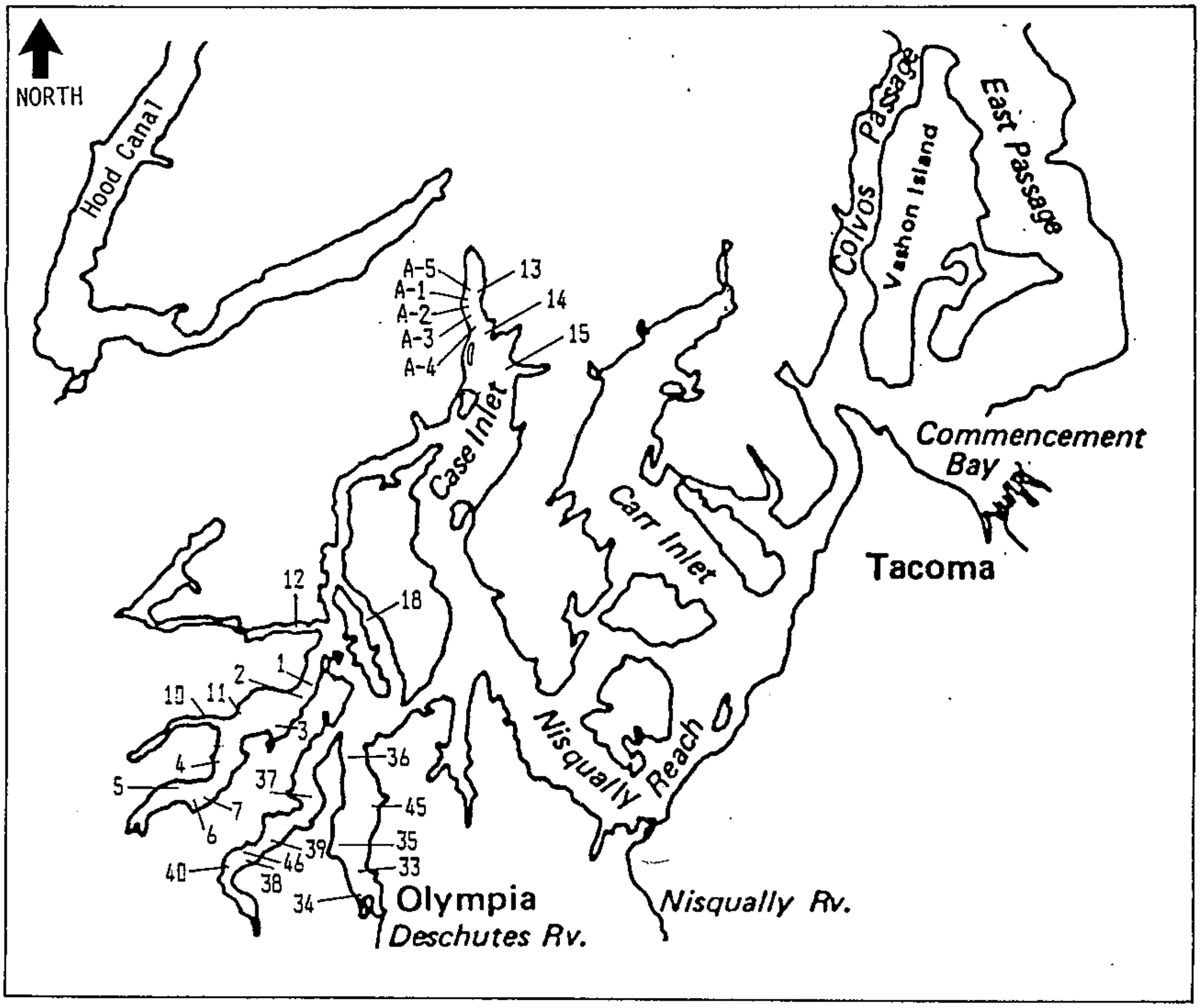

Figure 11. Locations of DSHS Fecal Coliform Water Column Monitoring Stations (1978-1982).

Source: DSHS,unpublished data

surveys generally located in areas of suspected problems. During an intensive survey, samples are taken over approximately 10 consecutive days. A shoreline survey is conducted simultaneously to look for possible sources (J. Lilja, DSHS, pers. comm.). Data from the intensive surveys are in the early stages of being entered onto the DSHS in-house computer system. In addition to the above, tissue samples are also collected every two to three months from the processing plants and are analyzed for both fecal coliform bacteria and PSP.

The PSP data for commercial shellfish beds have been entered onto the DSHS computer system. The data are augmented by samples collected at public beaches by local health departments (J. Lilja, pers. comm.; Saunders et al., 1982; JRB Associates, 1984a). The data are reviewed to determine standards violations but have not been used to determine long-term trends.

5.4.2. Municipality of Metropolitan Seattle (Metro)

Metro analyzes water samples from their shore stations for fecal coliforms and enterobacteria (Table 6). Details of Metro's program are provided in Section 5.2.

5.4.3. Washington Department of Ecology (WDOE)

The WDOE analyzes samples from their quality stations for fecal coliforms. Details of WDOE's program are provided in Section 5.2.

5.4.4. Port of Port Angeles

Since 1979, the Port of Port Angeles has collected data every two months on fecal coliforms in shellfish at the Sequim Bay Marina. The Port was required to take samples prior to construction of the marina and will have samples taken for another 10 years (K. Sweeney, Port of Port Angeles, pers. comm.). These data will be used to track trends in fecal coliform concentrations that may result from the marina.

5.5 BENTHIC ORGANISMS AND PLANKTON MONITORING PROGRAMS

5.5.1. United States Geological Survey (USGS)

The benthic community in the Main Basin of Puget Sound has been monitored for 20 years to determine long-term trends in benthic populations (Nichols, 1985). The main sampling site (at 200 m depth) is located 4 km north of Metro's West Point sewage treatment plant (Fig. 10). Benthic samples have been collected (but not analyzed) at an additional two sites in the Main Basin (F. Nichols, USGS, pers. comm.).

The four major species collected to date from this site are: Macoma carlottensis, Pectinaria californicus, Ampharete acutifrons, and Axinopsida sericata. The dominant species throughout the study was Macoma carlottensis with an average density of $600/m^2$. In 1977 and 1982 the population density of M. carlottensis peaked to over $2000/m^2$ (Nichols, 1985). From 1978 to the present, the combined abundance of the four dominant species has increased. The increase in numbers of A. acutifrons may be due to increased organic enrichment (Nichols, 1985).

5.5.2. Olympic Community College

Zooplankton samples are taken concurrently with surface water samples (cf. Section 5.2). Samples are taken monthly (1977-present), except during the summer recess. Samples have been partially identified but are mainly archived for possible future analyses.

5.6 MARINE BIRD MONITORING PROGRAMS

5.6.1. U.S. Fish and Wildlife Service

Two types of surveys are conducted by the U.S. Fish and Wildlife Service. Since 1978 aerial surveys of waterfowl populations have been conducted on a monthly basis (October-March). Survey flights begin at Budd Inlet and continue north along the eastern shore of Puget Sound. Early surveys included Hood Canal and the western shore of Puget Sound as far as Dungeness. These data have not been analyzed to determine trends.

The second type of survey is a ground survey focused on identifying seabird populations in the San Juan Islands. Surveys are made monthly during the summer. These data have been included in the Catalog of Washington Seabird Colonies (Speich and Wahl, in preparation), which is a compilation of all seabird colonies observed in Washington State. It includes recent surveys along with documented sightings from as early as 1792 (J. Watson, FWS, pers. comm.; S. Spiech, Cascadia Research Collective, pers. comm.). The data have not been used for trend analysis.

5.6.2. Walla Walla Community College

Each summer since 1979 a ground survey has been conducted of seabird nesting populations on Protection Island (Fig. 10). The data have not been used for trend analysis.

5.6.3. Washington State Department of Game

Aerial surveys documenting the presence of marine birds have been conducted in 1982 (summer), 1982-1983 (winter), and 1983-1984 (winter). Each survey was completed in approximately two days. The data are reviewed to ensure that numbers are realistic and verified after they are entered onto the in-house computer system (S. Spiech, Cascadia Research Cooperative, pers. comm.). The period of acquisition of these data is as yet too brief for trend analysis.

5.6.4. Audubon Society

The Audubon Society maintains a telephone hotline for reporting sightings of rare birds. In addition, the Audubon Society conducts annual Christmas Bird Counts during the last week of December and the first week of January. In the State of Washington counts are taken in Olympia, Tacoma, Seattle and Bellingham (P. Mattock, Audubon Society, pers. comm.).

Each study area covers a circle of a 7-1/2 mile radius. The Seattle count extends from Carkeek Park south to Seola Beach and west to Bainbridge Island. The epicenter is located at Pioneer Square in Seattle.

These annual counts began in 1920 with a lapse during World War II. The data have been described as "pretty good" since 1949 (P. Mattock, Audubon Society, pers. comm.).

The major weaknesses with these counts are: 1) they are limited to the urban areas; 2) they are dependent on the ability of the volunteers to correctly identify birds; 3) weather conditions affect visibility; and, 4) counters may not concentrate on all bird species equally. For example, the experienced counter may focus efforts on observing exotic water fowl and not keep track of the common species, while the inexperienced counter may focus their attention only on the common species. However, despite these drawbacks the data, if analyzed, should provide reasonable trend assessments for the common species.

Data sheets are reviewed for verification. During this process unusual sightings may be discarded. Summaries of each Christmas Count held in the United States are included in the July issue of American Birds. The data have not been used for long-term trend analysis.

5.7 MARINE MAMMAL MONITORING PROGRAMS

5.7.1. National Oceanic and Atmospheric Administration (NOAA)

In 1977, 1978, 1979, 1983 and 1984 major studies conducted in Puget Sound focused on harbor seals in three regions (south Puget Sound, Hood Canal and north Puget Sound). Data were collected in five major categories: 1) population size; 2) reproductive success; 3) mortality rate; 4) cause of death; and 5) behavior characteristics. In 1977 and 1984, tissue samples were collected for residue analyses. Chemical analyses were completed for the samples collected in 1977 and it is expected that analyses of 1984 samples will be completed in 1985 (J. Calambokidis, Cascadia Research Cooperative, pers. comm.). These studies will be continued but the frequency has not been established.

Data from the earlier studies are published in a number of reports. Population estimates of harbor seals have also been calculated in conjunction with other intensive studies (Calambokidis et al., 1978, 1979, 1984; Newby, 1971; Johnson and Jeffries, 1983). Seal populations decreased between 1940 and the early 1970s (Calambokidis, et al., 1984). Newby (1971) attributed the decrease to bounty hunting, loss of habitat due to human encroachment and increases in pollutant levels. Since the institution of the Mammal Protection Act in 1972, the harbor seal population in the north Sound and Hood Canal has increased (Calambokidis et al., 1978, 1979). However, populations in the south Sound did not increase until after 1977 (Calambokidis et al., 1984).

5.7.2. U.S. Fish and Wildlife Service

Seal counts are taken by the U.S. Fish and Wildlife Service during their aerial waterfowl population studies (S. Thompson, Fish and Wildlife Service, pers. comm.; cf. Section 5.6). These surveys began in 1978 and cover the east coast of Puget Sound from Budd Inlet to the Canadian border. No trend analyses have been made.

5.7.3. Whale Museum (Friday Harbor)

Since 1976, the Whale Museum at Friday Harbor has maintained a telephone hotline for sightings of whales and porpoises in Puget Sound. The Museum also has a complete photo identification catalog of Orca whales in the inland waters and tracks their migratory patterns. The Museum is in the process of preparing a photo identification catalog for gray whales and Dall's porpoises (R. Osborne, Whale Museum, pers. comm.). During the past few years the number of gray whale sightings has increased in Puget Sound (R. Osborne, pers. comm.). The data collected by the Whale Museum are forwarded to the NOAA National Marine Mammal Laboratory. No quantitative trend analyses have been conducted.

5.7.4. Washington Department of Game

Since 1980, the Marine Mammal Division of the Washington Department of Game has maintained two programs to assess the population and health of Puget Sound seals. The first program focuses on population trends and involves aerial surveys during the pupping season (August). The number of seals observed on haul-outs is recorded and aerial photographs are taken for documentation (A. Geiger, WDG, pers. comm.).

The second program involves monitoring of dead seals found washed up on Puget Sound beaches. The carcasses are measured and the cause of death is determined. The stomach and reproductive tract are removed and analyzed for abnormalities and a tooth is removed to determine the animal's age. Tissue samples are also collected and archived, but have never been analyzed (A. Geiger, WDG, pers. comm.).

These two programs are designed to allow determination of long-term trends. However, to date, no trend analyses of the data have been undertaken.

5.8 HABITAT MONITORING PROGRAMS

5.8.1. Washington Department of Ecology (WDOE)

Through the Shoreline Management Act, WDOE reviews permit applications for all substantial shoreline development. Environmental and recreational impacts are considered in these reviews, on a project-by-project basis. Specific data included in the permit are: legal description of property, local government issuing permit, water body, current environmental condition and proposed environmental condition. This information is entered onto an in-house data management computer system (S. Bailey, WDOE, pers. comm.). No overview of cumulative effects is considered and the data are not reviewed to establish long-term trends in habitat changes.

5.8.2. U.S. Army Corps of Engineers (ACOE)

As part of their regulatory surveillance, the U.S. Army Corps of Engineers takes annual aerial photos of the entire Puget Sound shoreline and examines the pictures in conjunction with their permitting to ensure compliance. Photos from 1970 to 1984 are available. No trend analyses or year-to-year comparisons are made (M. Broliss, ACOE, pers. comm.).

5.9 NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM (NPDES)

As specified in their NPDES permits, all regular dischargers to the Sound must monitor their effluent for a prescribed set of parameters. Approximately 240 NPDES permits have been issued to industrial and municipal dischargers to the Sound or to tributary streams (Jones and Stokes and Tetra Tech, 1983a). The WDOE monitors all NPDES permits. The parameters monitored and frequency of sampling depend on the size and type of dischargers.

Fifty-one of the discharges are classified as major while the remaining discharges are classified as minor (F. Carrol, EPA, pers. comm., Jones and Stokes, and Tetra Tech, 1983a). EPA has entered the specifications for the permits for the major dischargers and the corresponding discharge monitoring reports (DMRs) for 1979 through 1983 onto an in-house computer system (Tait, 1980; F. Carroll, pers. comm.)(Table 12). This system is presently reaching the limit of storage allocations and as a result these data are currently difficult to access (N. Brown, EPA, pers. comm.).

WDOE has disbursed the DMRs for all NPDES permits in Puget Sound from 1974 to the present among three offices: Northwest Office (retains reports for dischargers in King, Snohomish, San Juan, Island, Skagit, Kitsap and Whatcom Counties); Southwest Office (for Pierce, Thurston, Mason, Jefferson, and Clallam Counties); and the Industrial Section (pulp mills, aluminum companies and oil refineries)(B. Sylvester, WDOE, pers. comm.). This information is now being entered onto a personal computer data management system (B. Sylvester, pers. comm.). The data collected have not been used to identify long-term trends in pollutant loadings to Puget Sound.

5.10 RIVER DISCHARGE AND WATER QUALITY MONITORING PROGRAMS

The WDOE and USGS jointly established a network of water quality monitoring staitons located on streams in Washington which are sampled

Table 12. Details of major NPDES permits in Puget Sound (U.S. EPA, Region 10, unpublished data)

Permit holder	Data available[a]:	DO	Productivity	T	pH	Oil & grease	Flow	BOD	COD	As	Cd	Cu	Pb	Zn	Sb	F-	CN-	Ni	Hg	Cr	Sulfide	N	Fecal col.	Residue Cl	Phenols	Susp. solids	Receiving basin
American Smelting & Refining Co.	1979-1981			X	X	X	X			X	X	X	X	X	X												Commencement Bay
Anacortes, City of	1979-1983				X		X	X															X			X	Guemes Channel
Atlantic Richfield Co.	1979-1983		X	X	X	X	X	X	X											X	X		X		X	X	St. of Georgia
Bellingham, City of	1974-1983				X			X															X			X	Bellingham Bay
Boise Cascade	1979-1983			X	X		X	X																		X	Puget Sound
Bremerton, City of	1979-1983				X		X	X															X			X	Pt. Washington Narrows
	1979-1983				X		X	X															X			X	Sinclair Inlet
Crown Zellerbach	1979-1983		X		X		X	X																		X	St. of Juan de Fuca
Dept. of Defense, Manchester	1979-1983				X	X	X																				Puget Sound
Dept. of Defense, Ft. Lewis	1979-1983				X	X	X	X															X	X		X	Puget Sound
Des Moines Sewer Dist.	1979-1983				X		X	X															X			X	Puget Sound
Edmonds, City of	1979-1983				X		X	X															X			X	Puget Sound
Enumclaw, City of	1979-1983				X		X	X															X			X	Boise Creek
Everett, City of	1979-1983				X		X	X				X		X						X			X	X		X	Snohomish River
Georgia Pacific	1979-1983		X				X	X											X							X	Bellingham Bay
Intalco	1979-1983		X	X	X	X	X									X	X						X			X	St. of Georgia
ITT Rayonier Inc.	1979-1983			X	X		X	X																		X	St. of Juan de Fuca
Kaiser Al. & Chemical Co.	1979-1983			X	X	X	X									X	X									X	Hylebos Waterway
Lakehaven Sewer Dist.	1979-1983				X		X	X															X			X	Dumas Bay
	1979-1983				X		X	X															X			X	Poverty Bay
Lynnwood, City of	1979-1983				X		X	X																X		X	Brown's Bay

Table 12. (Continued)

Permit holder	Data available:	DO	Product-ivity	T	pH	Oil & grease	Flow	BOD	COD	As	Cd	Cu	Pb	Zn	Sb	F-	CN-	Ni	Hg	Cr	Sul-fide	N	Fecal col.	Residue Cl	Phenols	Susp. solids	Receiving basin
Metro (Carkeek)	1979-1983				X		X	X															X			X	Puget Sound
(Alki)	1979-1983				X		X	X															X			X	Puget Sound
(Renton)	1982-1983			X	X		X	X			X		X	X	X			X	X	X		X	X	X		X	Green River
(Richmond Beach)	1979-1983				X		X	X															X			X	Puget Sound
(West Point)	1979-1983				X		X	X			X	X	X	X				X	X	X			X			X	Puget Sound
Mobil Oil Co.	1979-1983			X	X	X	X	X	X											X	X	X	X		X	X	St. of Georgia
Mount Vernon, City of	1979-1983				X		X	X															X			X	Skagit River
Occidental Chemical Co.	1981-1983			X	X								X									X		X		X	Hylebos Waterway
Olympia, City of	1979-1983				X		X	X															X	X		X	Budd Inlet
Port Angeles, City of	1979-1981				X		X	X															X			X	St. of Juan de Fuca
Port Townsend Paper Co.	1979-1983			X	X		X	X																X		X	Port Townsend Bay
Puget Sound Navy Shipyard	1979-1983			X	X	X	X																				Sinclair Inlet
Puyallup, City of	1979-1983				X		X	X															X	X		X	Puyallup River
Scott Paper Co.	1979-1983		X	X			X	X																		X	Port Gardner Bay
Shell Oil Co.	1979-1983		X		X	X	X	X	X											X	X	X	X		X	X	Fidalgo Bay
Shelton, City of	1979-1983	X			X		X	X															X	X		X	Oakland Bay
Sonoco Product Co.	1979-1983		X	X	X		X	X																		X	White River
Sound Refining Co.	1979-1983				X	X	X	X													X	X			X	X	Puget Sound
SW Suburban Sewer Dist.	1979-1983				X		X	X															X			X	Puget Sound
	1979-1983				X		X	X															X			X	Central Puget Sound
Sumner, City of	1979-1983				X		X	X															X			X	White River
Tacoma, City of	1979-1983				X		X	X															X			X	Tacoma Narrows
	1979-1983				X		X	X																		X	Puyallup River
	1979-1983				X		X	X															X			X	Commencement Bay
St. Regis Paper Co.	1979-1983		X	X	X		X	X																		X	Commencement Bay
Texaco Inc.	1980-1983		X	X	X	X	X	X	X											X	X	X	X		X		Fidalgo Bay
U.S. Oil & Refining Co.	1981-1983				X	X	X	X												X	X	X			X	X	Puget Sound

Table 12. (Continued)

Permit holder	Data available:[a]	DO	Product-ivity	T	pH	Oil & grease	Flow	BOD	COD	As	Cd	Cu	Pb	Zn	Sb	F-	CN-	Ni	Hg	Cr	Sul-fide	N	Fecal col.	Residue Cl	Phenols	Susp. solids	Receiving basin
Weyerhauser	1979-1983		X	X	X		X	X																		X	Steamboat Slough
	1979-1983				X		X	X																		X	Boise Creek
Pennwalt Chemical Co.	1983			X	X																			X			Hylebos Waterway

[a] DO is dissolved oxygen; T is temperature; BOD is biological oxygen demand; COD is chemical oxygen demand; Fecal col. is fecal coliforms.

monthly. Twelve of the approximately 33 stations on Puget Sound rivers are located near the river mouths (Figure 1). The stations are located at the:

- Nooksack River at Brennan
- Skagit River near Mount Vernon
- Samish River near Burlington
- Stillaguamish River near Silvana
- Snohomish River at Snohomish
- Green/Duwamish River at Allentown Bridge
- Puyallup River at Meridian Street Bridge
- Nisqually River at Nisqually
- Chambers Creek near Steilacoom
- Deschutes River at "E" Street Bridge
- Skokomish River near Potlatch
- Elwha River near Port Angeles

The parameters measured may vary,but generally include flow, temperature, dissolved oxygen, pH, suspended solids, specific conductivity, fecal coliform, turbidity, color, suspended solids, nitrate, nitrite, ammonia, orthophophate and total phosphate. In some cases, trace metals and other parameters are measured. The period of record also varies and in a few cases is not continuous.

5.11 CLIMATE

The National Climate Data Center (NOAA) compiles climatological data from 23 stations in the Puget Sound basin (Table 6). Data recorded at each station vary, with at least precipitation measured at all sites. Data have been recorded for variable lengths of time. Some records date from before the turn of the century. The data are available as monthly and annual summaries (tabular) from the National Climate Data Center (Table 7).

5.12 HUMAN HEALTH MONITORING PROGRAMS

There are no monitoring programs in Puget Sound that collect data on human health effects related to Puget Sound pollution, e.g. from water contact, consumption of pathogen or toxin-contaminated organisms, and the like. However, NOAA is presently funding a 2-year intensive study to determine the concentrations of toxic chemical contaminants in fish caught in urban bays and the consumption habits of urban anglers.

5.13 RETROACTIVE DATA (SEDIMENT CORES)

Sediment core data can be used to retroactively determine temporal trends resulting from past inputs of pollutants, particularly toxic chemicals. This type of analysis generally uses isotopic decay rates to time-date core horizons and then compares chemical concentrations among the identified time periods. This procedure has not been used in any past or ongoing monitoring program, but is included here because a number of recent, short-term studies have collected sediment cores from the Sound with the intent of identifying past trends in pollutant levels (Pavlou et al., 1984; Quinlan et al., 1985; Carpenter et al., in press; R. Matsuda, Metro, pers. comm.; R. Feely, NOAA/PMEL, pers. comm.), and such studies will probably continue in the future. Analyses of available core data indicate that the levels of enrichment of Cu, Zn, As, Pb, Hg and Ag are higher at present than prior to the 1900s. Levels of enrichment of the organic contaminants (PCBs, CBDs and PAHs) are higher than in the 1900s, but may have peaked prior to 1970 and may now be decreasing (Pavlou et al., 1984; Quinlan et al., 1985).

5.14 DISCONTINUED MONITORING PROGRAMS

In addition to the previously identified on-going monitoring programs, there are many monitoring programs that have been discontinued. Selected discontinued studies which play an important role in understanding the dynamics of Puget Sound are reviewed. In many cases these studies have the potential to form a historical baseline, which can then be compared to current data. However, there are problems associated with comparing past and present monitoring. First, parameters of concern differ today from those of concern 20 years ago. Nitrogen concentrations and fecal coliforms are of concern today (1985), but such was not the case 20 years ago. Hence data on these parameters are only available for relatively recent times. Second, measuring techniques have changed with time such that not all data are comparable. These types of problems have generally precluded detailed trend assessment over many data sets.

5.14.1. Hydrographic Monitoring

Research teams from the University of Washington have collected physical and chemical hydrographic data from 1932 (Collias, 1970; Collias and Barnes, 1964) with lapses in coverage during and after World War II (1942-1947). The main parameters measured were temperature, oxygen and salinity. These programs, through 1966, are described in more detail by Collias (1970) and the data through 1972 have been entered onto the Storet data management system at EPA, Region 10 (R. Peterson, EPA, pers. comm.).

The WDOE ambient water quality monitoring program (cf. Section 5.2.2) has changed their network of monitoring stations as new concerns have been identified. In addition to the 44 stations currently monitored, in the past, WDOE has monitored up to 123 stations in Puget Sound (R. James, WDOE, pers. comm.). Data for these additional stations were generally gathered over a two year period in the last 15 years. The parameters measured were the same as those previously monitored; data on the location and period of record for these discontinued stations can be obtained directly from WDOE (R. James, WDOE, pers. comm.).

The Municipality of Metropolitan Seattle has collected and analyzed data on primary productivity and chlorophyll *a* at five stations in the Main Basin of Puget Sound from 1966-1975. Samples were generally taken weekly from March through October; a complete description of this program is provided by Evans-Hamilton (1977). Evaluation of the data did not indicate any significant change over the period of record, but seasonal changes were observed, with peak values in May and July (Evans-Hamilton, 1977).

The WDF collected and analyzed water samples from a total of 40 stations in the south Sound (1956-1957) and the north Sound (1956-1959). Samples were taken approximately every 2 weeks and analyzed for temperature, salinity, dissolved oxygen and the Pearl Benson Index. Twenty-four of these stations were also sampled by the University of Washington which in many cases provided a period of record extending from 1932 to 1963. The specific station locations and sampling dates are depicted and outlined in Collias (1970).

The Puget Sound Earth Application Division of the U.S. Geological Survey measured temperature, salinity and dissolved oxygen in the estuaries of major streams. The project was initiated in 1978 and discontinued in March 1982. The intent of the study was to determine average conditions in each major estuary (B. Foxworthy, USGS, pers. comm.). Samples were taken once per month at high (Nov., Dec., Jan.) and low (Aug., Sept., Oct.) mean discharges in the following rivers: Nooksak, Skagit, Stillaguamish, Snohomish, Duwamish, Puyallup, Nisqually, and Skokomish. These data have never been published but are available from G. Bortleson (USGS, Tacoma, WA) (B. Foxworthy, pers. comm.).

5.14.2. U.S. EPA Mussel Watch Monitoring

The "Mussel Watch" concept was sponsored by the U.S. EPA and was used nationally throughout coastal areas of the continental United States from 1976-1978. During these 3 years mussels (*Mytilus edulis*) were collected from three areas of Puget Sound and environs: Cape Flattery, the south end of Whidbey Island and Boundary Bay. Computer entry of the entire national mussel watch data set will be finished in 1984 (J. Farrington, Woods Hole, pers. comm.); however, published data are available for many parameters (Farrington et al., 1982, 1983; Goldberg et al., 1983). The Mussel Watch program will be continued, under funding from NOAA, in 1985 (E. Long, NOAA, pers. comm.).

Yevich and Barszcz (1983) conducted a histopathological examination of mussels collected in 1976 for the mussel watch. They found that at both the inner Puget Sound and Strait of Georgia stations, mussels were in poor condition, with poor reproductive tract development and evidence of myodegeneration. In addition, the inner Puget Sound mussels showed evidence of calcium secretions while those from Boundary Bay had digestive diverticula in poor condition. The outer Strait of Juan de Fuca mussels had no obvious abnormalities. Yevich and Barszcz (1983) stated that: "We believe that the poor condition of the mussels collected from Puget Sound and Boundary Bay, as determined by parasitism and lack of reproductive development, is of significance. However, we cannot correlate this finding with any known data other than the flushing of multiple pollutants from industrial plants and sewage into the bay". Goldberg et al. (1983) reviewed the 1977-1978 mussel watch data and noted that mussels from Boundary Bay and Cape Flattery had higher concentrations of Zn and Cd than mussels from inner Puget Sound. High values of 229 + 240 Pu were noted in mussels from Cape Flattery, and were attributed to discharges from nuclear facilities. Farrington (1983) and Farrington et al. (1982) noted that the mussel watch concept works for detecting changes of an order of magnitude or greater between stations in different areas.

Mussel Watch monitoring is considered a useful tool by some authors (Farrington, 1983; Goldberg, 1984) and as a less useful tool by others (White, 1984). Despite some criticism of its utility, a global Mussel Watch program is being implemented (UNEP, 1984). WDOE initiated a Mussel Watch monitoring program in the Sound with mussels collected at five sites: Hood Canal (1979, 1980, 1981), Case Inlet (1980, 1981), Carr Inlet (1981), Port Susan (1980, 1981) and Commencement Bay (1981, 1982). The data have not been analyzed to determine possible trends.

5.14.3. Oyster Larvae Bioassays

From 1961 through 1976 the WDF conducted annual oyster larvae bioassays (*Crassostrea gigas*) on water samples collected from a large network of stations located in Puget Sound. Abnormalities in development and number of mortalities were recorded along with ancillary hydrographic information (salinity, NH_4, temperature, Secchi depth, and Pearl Benson Index).

The methods and station locations are described in detail in Cardwell et al. (1977, 1979) and Cardwell and Woelke (1979).

5.14.4. Hydrocarbons at Freshwater Bay

Concentrations of selected hydrocarbons were measured seasonally in the following organisms at Freshwater Bay (Strait of Juan de Fuca) from fall 1976 through summer 1980: false eel grass (*Phyllospadix scouleri*), rockweed (*Fucus* sp.), sea urchins (*Strongylocentratus purpuratus*), starfish (*Hernicia leviscula*), plate limpets (*Notoacmaea scutum*), goose barnacles (*Pollicipes polymerus*), crabs (*Hemigrapsus nudus*), and snails (*Nucella* sp.) (R. Clark, NOAA, pers. comm.; Clark, 1984). These data can be combined with an earlier study where hydrocarbon concentrations in *Mytilus californianus* at Freshwater Bay were measured (R. Clark, pers. comm.; Kwan and Clark, 1981). The available data (1971 through 1980 with a lapse from 1973 to 1976) were combined and are shown in Figure 12.

The concentration of hydrocarbons peaked during the mid 1970s (1976 through 1978) compared to an earlier period (1971 through 1972) and a later period (1979 through 1980). The cause of the increase during 1977 and 1978 is not known; no oil spills were documented at Freshwater Bay during this time period (R. Clark, pers. comm.).

Clark (1984) compared his data for Puget Sound to data collected from the Mussel Watch Program for other areas and observed that the range of hydrocarbon concentrations was generally higher in Freshwater Bay than in other areas (Table 13). The reason for this difference is unknown.

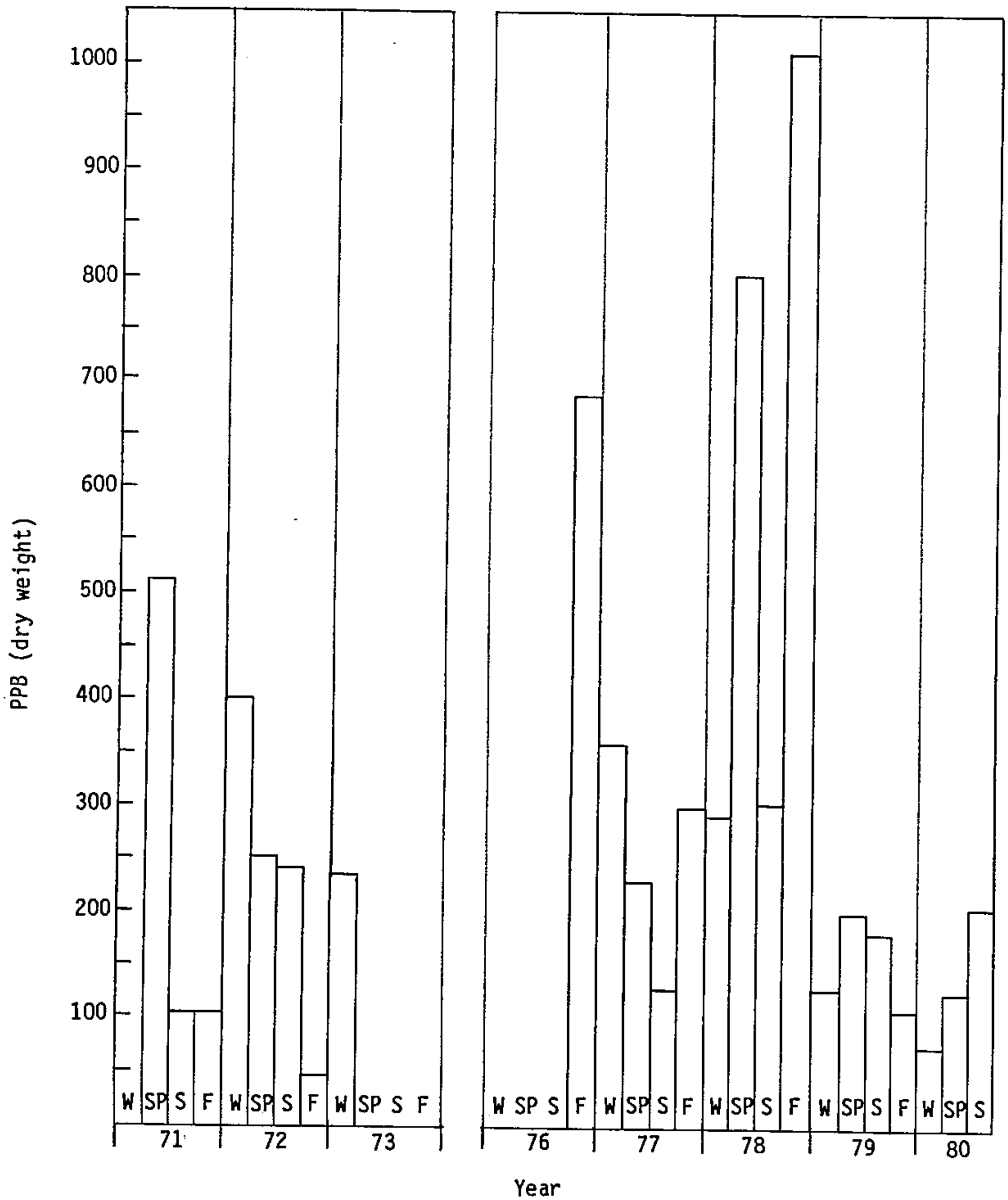

Figure 12. Total Saturated Hydrocarbons in Mussels (Mytilis californianus) from Freshwater Bay (1971-1980).

Source: Clark,1984; Kwan & Clark,1981.

Table 13. Ranges of aromatic hydrocarbons in mussels collected from Freshwater Bay (Clark, 1984) compared with the Mussel Watch Program (Farrington et al., 1982)[a]

Aromatic hydrocarbon	Freshwater Bay	Narragansett Bay	Gulf of Maine	Long Island Sound	Middle Atlantic	San Pedro Harbor
Naphthalene	L1-97[b]	L0.5-9	L0.5-15	L0.5-4	L0.5-8	1
Methylnaphthalenes	L1-1,630	L0.5-18	L0.5-59	L0.5-6	L0.5-6	2
Dimethylnaphthalenes	L1-146	L0.5-6.8	L0.5-204	L0.5-23	L0.5-8	3
Dibenzothiophene	L1-42	L0.5-80	L0.5-90	L0.5	L0.5	L0.5
Phenanthrene	L1-583	3-63	2-310	10-20	13-46	23
Methylphenanthrenes	L1-685	L0.5-185	L0.5-587	6-33	11-55	95
Dimethylphenanthrenes	L1-1,330	L0.5-330	L0.5-1,800	L0.5-84	L0.5-56	107
Fluoranthene	L1-584	10-127	5-336	12-124	20-67	112
Pyrene	8.6-208	11-81	3-329	4-381	12-107	58
Chrysene	L2-267	L0.5-104	L0.5-92	L0.5-79	L0.5-88	219
Benzopyrenes	L1-85	L0.5-112	0.5-50	L0.5	L0.5-51	233

[a] Units: ppb (10^{-9}g/g), dry extracted weight; adapted from Clark, 1984.

[b] L = less than

5.14.5. Ecological Baseline and Monitoring Study for Port Gardner and Adjacent Waters (ECOBAM)

WDOE performed the ECOBAM study from 1972 to 1981 to examine the relationships between reductions in pulp waste discharges and biological changes in Port Gardner. Monthly measurements were taken for dissolved oxygen, salinity, temperature, sulfite waste liquor (SWL), chlorophyll a, nitrate, phosphate and silicate. Benthic recolonization studies, *in situ* live box studies of salmon fry, toxicity tests using Pacific oysters, length, frequency and distribution of fish and shellfish, and benthic infaunal data were collected during this study (WDOE, 1976).

5.14.6. Waterfowl

Two studies have been conducted by Evergreen State College. The first study (1974-1980) involved monthly surveys to determine the population of Dunlin waterfowl at the Nisqually River Delta and at Kennedy Creek. Throughout the study the populations in both areas decreased (JRB Associates, 1984a). The second study (1978-1982) investigated DDT and PCB tissue burdens in birds (and mussels) in the Southern Sound. Shorebirds and falcons (Southern Sound), Pigeon Guillemots (Budd Inlet to Seattle) and mussels (Southern Sound to Bremerton) were collected on a semi-annual basis. Information concerning the data can be obtained from S. Herman (Evergreen State College, Olympia, WA).

5.14.7. Pesticides and PCBs in Fish Tissue

Between 1972 and 1976, the U.S. EPA collected juvenile fish from 144 estuaries nationwide, and analyzed for pesticides and PCBs in their tissues. Four of these estuaries were located in Puget Sound (Duwamish estuary, Big Beef Harbor in Hood Canal, Post Point south of Bellingham, and Nisqually Reach). Three species (English sole, Pacific staghorn sculpin, and starry flounder) and 157 separate fish were sampled. DDT residues were observed in less than 4 percent of the samples; PCB residues were observed only in the fish (27 total) collected from the Duwamish River. The only possible long-term trend observed was a change in PCB isomers from predominately Aroclor 1254 in 1972 and 1973, to Aroclor 1260 in 1974 and 1975, and Aroclors 1260 and 1242 in 1976 (Butler and Schutzmann, 1978).

5.14.8 Fin Erosion

Data on fin erosion in the Duwamish River, collected by various investigators (Miller et al., 1976; Sherwood et al., 1978; McCain et al., 1982) have been summarized by Harper-Owes (1982). From 1966 through 1980, over 6,500 starry flounder collected from the Duwamish River were examined for evidence of fin erosion. Harper-Owes' (1982) analysis indicates that fin erosion prevalence is highly correlated (P=0.01) to PCB tissue levels, and that fin erosion incidences have declined from a mean of 15.6 percent from 1966-1977, to 10.3 percent from 1974-1976, to 2.9 percent from 1979-1980.

5.15 OVERALL EVALUATION OF PRESENT PUGET SOUND MONITORING PROGRAMS

It is difficult to fairly review present Puget Sound monitoring programs as presently constituted in the context of an overall Puget Sound monitoring program as, for the most part, these programs are intended for other purposes. Consequently, critical reviews reveal deficiencies primarily associated with the use of the ongoing Puget Sound monitoring programs as part of a larger, integrated, comprehensive monitoring program. These deficiencies are not reflective of internal problems in individual programs, but rather result from the attempt to use data gathered for internally consistent purposes in a wider context than originally intended. Some of these deficiencies are as follows:

1. The data are often measured only to the level of sensitivity (i.e., detection) required to ensure compliance with standards and hence do not quantitate lower concentrations.

2. Because some programs collect data for compliance monitoring, they are not analyzed to assess long-term trends.

3. There are few established and/or reported QA/QC programs.

4. There is no established process for data exchange among agencies and groups (although in almost all cases data are freely available on request).

This section briefly reviews the adequacy of the present monitoring programs described in detail in previous sections of Chapter 5 to meet informational needs of the specific monitoring objectives, which were developed in Chapter 4 (see Table 5).

Most of these deficiencies appear to be readily correctable through two remedies. First, the implementation of a central repository for compiling and analyzing the data would go a long way toward ensuring evaluation of the information, preparation of regular trend analyses, and exchange of data among all interested parties. Secondly, as noted in Section 4.2, a critical need exists for the development of adequate methodologies for data collection, i.e., QA/QC procedures, and a method for reporting the QA/QC programs backing the monitoring data collections.

5.15.1. Objective 1

The present network of established water quality stations in Puget Sound satisfies most of the requirements of Objective 1 for data on temperature, salinity, DO, nutrients and turbidity. Additional stations should be added in the central areas of some of the major basins, and temporal coverage should be extended to all year sampling at all sites. River discharge measurements and the monitoring of climatic factors are also reasonably well covered at the present time, with the exception that riverine sediment loads should be characterized more thoroughly. No monitoring program presently exists for currents in Puget Sound.

5.15.2. Objective 2

Monitoring of plankton, including dinoflagellates, and macrophytes is virtually non-existent in Puget Sound, and only one true monitoring program exists for the benthos. Considering the importance of these populations to the entire Puget Sound food web, the lack of effective monitoring represents a major shortcoming of the present efforts.

Present fisheries monitoring data for salmonids are based on both catch statistics and salmon run size, and have been used by the WDF to track long-term trends. This data base can be used to discern trends in run size and catch for the species sampled.

Present fisheries monitoring data for groundfish are based on catch statistics. Although the long-term data base (from 1920) is of use, this type of data is not ideal. Catch sizes are closely associated with socioeconomic conditions and management decisions such as area closures, and do not necessarily reflect increases or decreases in the resource.

Until the early 1970s, only catch statistics were collected for baitfish. Although the data base was extensive (dating from 1914), it did not necessarily provide information on the status of the resource. However, over the last 10 years, these data have been augmented by spawn biomass assessments and by hydroacoustic surveys to assess population abundances. These recent additions, coupled with continued monitoring of catch statistics, provide extremely useful long-term monitoring data.

The four on-going marine bird monitoring programs in Puget Sound, combined, provide good coverage of wintering bird populations and of summer nesting populations on Protection Island and the San Juan Islands. However, these studies appear to provide data of relatively low precision such that only major changes in the populations would be discernible. In addition, there is no direct monitoring of reproductive success.

NOAA studies conducted to date provide a good initial data set for monitoring harbor seal populations in Puget Sound, but the continuation of these studies is uncertain. The chemical analyses associated with these studies are among the few that are supported by a QA/QC program that includes inter-laboratory calibration and data verification. Studies by the Washington Department of Game provide a useful, continuing program for monitoring seal populations in the Sound.

Data collected by the Friday Harbor Whale Museum provide good information on whale sightings, but the number of sightings is generally proportional to the amount of advertising for the telephone hot line. The Museum obtains useful data on Orca populations and pod migrations directly, which also constitute good monitoring data.

5.15.3. Objective 3

Programs established by DSHS for compliance monitoring of fecal coliforms and PSP in shellfish tissue and fecal coliforms in the water column, together with monitoring data from WDOE and Metro Seattle of fecal coliforms in the water column, provide fairly good spatial coverage. However, the lack of winter water column sampling by WDOE is a critical omission for monitoring.

DSHS does not regularly sample the water column and shellfish at all commercial beds. Rather, regular analyses are conducted at processing plants, with field samples taken and analyzed when a problem is suspected based on these analyses.

In addition, the status of bacterial monitoring in marine waters is in flux at the present time, with questions being raised as to the best method of evaluating the health risk associated with this problem. Future developments will probably dictate changes in the present programs.

Data are currently being collected on the levels of toxic chemicals in resident organisms, but primarily as part of research studies and one-time surveys. NOAA has initiated a limited program of measurements in mussels, the organism that this study also recommends for monitoring, but the spatial extent of this program is too limited to adequately satisfy the needs of Objective 3.

Similarly, the incidences of histopathological problems in fish have received limited study and have been included in a limited NOAA monitoring program. This effort should be expanded.

5.15.4. Objective 4

Of the parameters recommended for monitoring for Objective 4, nutrients, pollutant inputs and socio-economic conditions are monitored. Of these, pollutant input monitoring should be expanded to include more parameters of interest to the water quality in the Sound, while the others are adequately monitored.

Programs should be established to routinely collect data regarding the levels of toxic chemicals in the sediments and to perform regular evaluations of the sediment toxicity through the use of bioassays.

As was the case with Objective 3, the measurement of the levels of toxic chemicals in mussels in the Sound is included in a spatially limited monitoring program, but additional sampling sites are required to satisfy this objective.

5.15.5. Objective 5

Most of the data needs of Objective 5 would be satisfied if the first four objectives were fulfilled. The hydrographic information discussed in Objective 1 would be sufficient for Objective 5, while the implementation of monitoring of currents is needed for both objectives. Monitoring of the levels of toxic chemicals in sediments and sediment toxicity (bioassays) is not presently being performed. The basic data needed to largely satisfy the needs of Objective 5 regarding habitat types are available through the aerial surveillance programs, but the data are not analyzed for the needed purpose.

5.15.6. Objectives 6 and 7

All of the parameters needed to satisfy Objectives 6 and 7 are discussed under the previous objectives. Most of the data needed for these objectives are not now being adequately met. Regulatory decisions (Objective 7) are not presently compiled and disemminated in one file.

5.15.7. Objective 8

Of the data needs for Objective 8, only slicks caused by spills of oil or other substances are presently monitored (by the Coast Guard). No formal program exists to evaluate the temporal trends in visual appearance or the olfactory characteristics of the Sound.

CHAPTER 6. SUMMARY OF THE RECOMMENDED PUGET SOUND MONITORING PROGRAM

The details of a comprehensive regional monitoring program based on a broad definition of program needs (parameters to be monitored) and adequate to meet a series of specific, current program objectives were presented in Chapter 4. The present status of the monitoring of these parameters in Puget Sound was reviewed in Chapter 5. In this chapter the final recommendations for regional monitoring are summarized in Table 14.

As noted at the beginning of Chapter 4, many parameters are common to more than one of the specific program objectives (see Table 5, p. 19), and one monitoring program was developed for each parameter in that chapter that would adequately meet the informational needs of multiple objectives. Thus, if a single monitoring objective were the only area of interest, objective-specific programs could be implemented as different sets of parameters using Table 5 (page 19) as a guide. However, it was the intent of this effort to develop a comprehensive overall program. Therefore, the summary table (Table 14), presents the program elements arranged by matrix, in roughly the same order as used for discussing the parameters in Chapters 4 and 5.

Table 14 summarizes the basic plan for monitoring each parameter and also summarizes the extent to which the recommended approach is presently being met by current monitoring programs. It is apparent from Table 14, that much of the recommended monitoring is already being performed. The implementation of the entire program recommended herein could be achieved without the allocation of tremendous amounts of additional resources, by taking advantage of existing programs. This overall approach would require improvements, as noted in Chapter 5, in the coordination of sampling within and among agencies and a formalized method of data compilation and analysis.

Table 14. Final summary of recommended Puget Sound monitoring program (Details are explained in Section 4.1)

Parameter(s)	Presently monitored?	Recommended frequency	Recommended sites	Other studies required
WATER COLUMN				
Temperature/ Salinity	partly (not in winter at all locations)	monthly (year-round)	present WDOE stations + additions	intensive daily sampling in selected areas to clarify rate of change and importance of storms and ocean water influxes
Dissolved Oxygen	partly (not in winter at all locations)	monthly (year-round)	as above	intensive sampling at one or two stations in DO depleted areas in the late summer-early fall may be needed in some areas
Nutrients/ Turbidity	partly (not in winter at all locations)	monthly (year-round)	as above	none
Dinoflagellates	no	seasonal (spring, summer, fall)	as above	none
Pathogens (i.e., coliforms)	partly (not in winter at all locations)	monthly (year-round)	as above	intensive studies into the relationship of coliforms to pathogens/viruses
Plankton	partly (near Bremerton)	seasonal (3 times per year; spring, summer, fall)	as above	none
SEDIMENT				
Toxic Chemicals	no			
Particle Size Distribution	no	annual (bays) and 5 yrs (basins)	major basins and specific embayments	final station selection
Total Organic Carbon	no			
Oil and Grease	no			
Sediment Bioassays	no			
PERCENT HABITAT TYPES	yes	annual	all Puget Sound	update base maps
BIOTA-GENERAL				
Macrophytes	no	annual	all Puget Sound	none
Benthic Infauna Abundance	partly	annual (bays); 5 yrs (basin)	at sediment stations and at Dr. Nichol's station	none
Shellfish Abundance	partly	1 to 3 yrs	all Puget Sound	none
Fish Abundance	partly (incomplete stock assessment)	1 to 3 yrs	all Puget Sound	none

Table 14. (Continued)

Parameter(s)	Presently monitored?	Recommended frequency	Recommended sites	Other studies required
BIOTA				
Bottom Fish Histopathology	partly (program continuance uncertain)	annual	3 embayments (2 urban, 1 rural)	methods standardization
Bird Abundance	partly (not all species)	monthly (winter-summer)	all Puget Sound	none
Mammal Abundance				
pinnipeds	partly (insufficient counts)	monthly	all Puget Sound	none
others	partly	record sitings by public when occur	all Puget Sound	none
Shellfish PSP	partly (irregular)	biweekly (April-October)	all Puget Sound	none
Shellfish Pathogens	partly	biweekly (April-October)	all Puget Sound	as per water column pathogens
Mussels--Toxicants in Tissue	no	every 3 yrs	as above (sediment) + additions	as above
GENERAL				
Odor, Floatables/Slicks, Water Color	no	record sitings when occur and annual beach walk	all Puget Sound	none
River Discharge and Water Quality	partly (except suspended solids/load characterics)	monthly (small) and daily (large)	all major rivers	research into water/suspended load relationships
Climate/Weather	yes	daily	all Puget Sound	none
Pollutant Inputs	partly (mainly conventionals)	discharge dependent	all NPDES permitees	one-time detailed analyses of effluents/by-products
Currents	no	continuous	major basins	none
Regulatory Control	no	variable	all Puget Sound	none
Socio-economic Conditions	partly (data collected by various sources)	variable	all Puget Sound	none

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APPENDIX A

OPTIMUM SAMPLE SIZE FOR ESTIMATING POPULATION MEANS AND FOR DETECTING DIFFERENCES BETWEEN MEANS

The following discussion applies to parametrical statistical procedures, which are much more powerful than the alternate non-parametric analog. It is recommended that the design of monitoring studies attempt to meet the assumptions required to allow use of parametric procedures. If data fail to meet these assumptions (e.g., are not normally distributed, have heterogenous variances between samples, etc.), then an attempt should be made to transform the data such that the transformed data can be used in a parametric analysis. If this transformation is unsuccessful in meeting the necessary assumptions, then a non-parametric approach is required.

Intuitively, when attempting to estimate a population parameter such as a mean (u), the higher the sample number (n) the closer, or more precise, the estimate. This, of course, brings up the question of how many samples are required to estimate an actual population parameter (a mean) with a specified level of assurance (probability). Given an idea of the variability (S^2) in observations, it is possible to calculate an optimum sample size. An estimate of sample variance, unless reported from a previous study, can only be obtained from preliminary sampling. Commonly, three replicate samples taken in a preliminary survey (or experiment) will provide an adequate estimate of the population variance (σ^2).

In addition to obtaining an estimate of the variability in the population (S^2), one must also state a desired level of precision (±d) within which μ is to be estimated. The smaller d is the more precise the estimate of μ and consequently the larger the sample size, n, required. The estimated sample size required can be determined iteratively with the following formula:

$$n = \frac{s^2 t^2_{\alpha(2),\ (n-1)} F_{\beta(1),\ (n-1,\nu)}}{d^2}$$

where S^2 is the preliminary sample variance with degrees of freedom, d is the half-width of the desired confidence interval, $1-\alpha$ is the confidence level (e.g. α =0.05, 95%) and $1-\beta$ is the assurance that the confidence interval will be no larger than specified (±d). Two-tailed values of the Student's t (n-1 df) and one-tailed values of the F distribution (n-1, ν df) are also used in this estimation.

Since both the t values and the F values require that n is known (which it is not), an iterative method of solving for an optimum n is used. The iterative process is started with an initial guess at n to determine t and F, with a first approximation of the optimum n derived from solving the above equation. Using this new n, this equation is solved again with a progressively more accurate approximation of the appropriate sample size obtained. Obviously the closer the original estimate, the faster a solution will be obtained.

In many phases of environmental studies, situations arise in which, for example, the mean concentration of a waste (μ) is statistically compared with a level (μ_0) which may be considered the highest acceptable level. To detect a difference between μ and μ_0 as small as δ, with a preliminary sample variance S^2, and at the α significance level with $1-\beta$ power, the minimum sample size is required can be estimated iteratively using:

$$n = \frac{S^2}{\delta^2} (t_{\alpha,\nu} + t_{\beta(1),\nu})^2$$

where α can be either α (1) or α (2), depending on whether a one-tailed or a two-tailed test is employed.

In a manner similar to that outlined for determining the minimum sample size needed to estimate a single population mean, the sample size required from each of two populations in order to estimate the difference between the two population means (t-tests) with specified precision, can be approximated (iteratively) using:

$$n = \frac{s_p^2(t_{\alpha(2),\ 2(n-1)})^2\ F_{\beta(1),\ (n-1),\nu}}{d^2}$$

In this case the preliminary sample variances, taken from each population, are incorporated as a pooled estimate, Sp^2, in the calculation.

In all parametric statistical tests it is always desirable to have equal sample sizes ($n_1 = n_2$). In certain situations this may be impractical, with sample 1, for example, constrained to have a size n_1. Upon estimating the minimum sample size, n_1, for each population using the formula above, the size of sample 2 (n_2) can be adjusted to take into account the size constraint of sample 1 as follows:

$$n_2 = \frac{nn_1}{2n_1 - n}$$

A situation which suggests an unequal sample design may require as much as a 15-20% increase in the total number of samples to achieve the desired test characteristics. Thus, whenever possible, an equal number of samples drawn (or allocated) to each treatment is strongly recommended.

In an Analysis of Variance (ANOVA) Model I (fixed effects) design, the minimum number of samples assigned to each treatment effect is dependent upon the variance, the power of the test ($1-\beta$), as well as on an additional quantity known as the noncentrality parameter, approximated by ϕ. These 3 parameters are best related graphically (charts), a technique developed and prescribed by Pearson and Hartley (1951) and Zar (1984).

If an ANOVA design has k groups, is to be tested at the α significance level, has n data (replication) per group, has an estimate of variability among the populations of S^2 (=error MS), and is to detect a difference of δ between the two most different population means, then we can compute:

$$\phi = \sqrt{\frac{n\delta^2}{2KS^2}}$$

Once ϕ is obtained we can consult the appropriate power-ϕ graph, two examples of which are provided in Figure A1. Each graph is for a different ν_1 (groups df) and each curve in the graph is for a different ν_2 (error df). The point at which the calculated ϕ intersects the curve for the appropriate ν_2 is read horizontally to either the left or the right axis to determine the power $(1-\beta)$ of the test.

Given a desired power for the ANOVA, the minimum sample size, n, can be estimated through an iterative process similar to those described previously. In this case ϕ is calculated using a number of different n's in the equation above. That n which provides a ϕ value corresponding (on the graph) to a power value $(1-\beta)$ equal to or slightly greater than that specified, is regarded as the optimum sample size.

Upon examining the graphs presented in Figure B1 it becomes apparent that greater ϕ values are associated with greater power and that ϕ increases with:

i. increased sample size, n;
ii. increased difference among population means (or by δ);
iii. a fewer number of groups, k; and/or
iv. decreased variability within populations, σ^2, estimated by S^2.

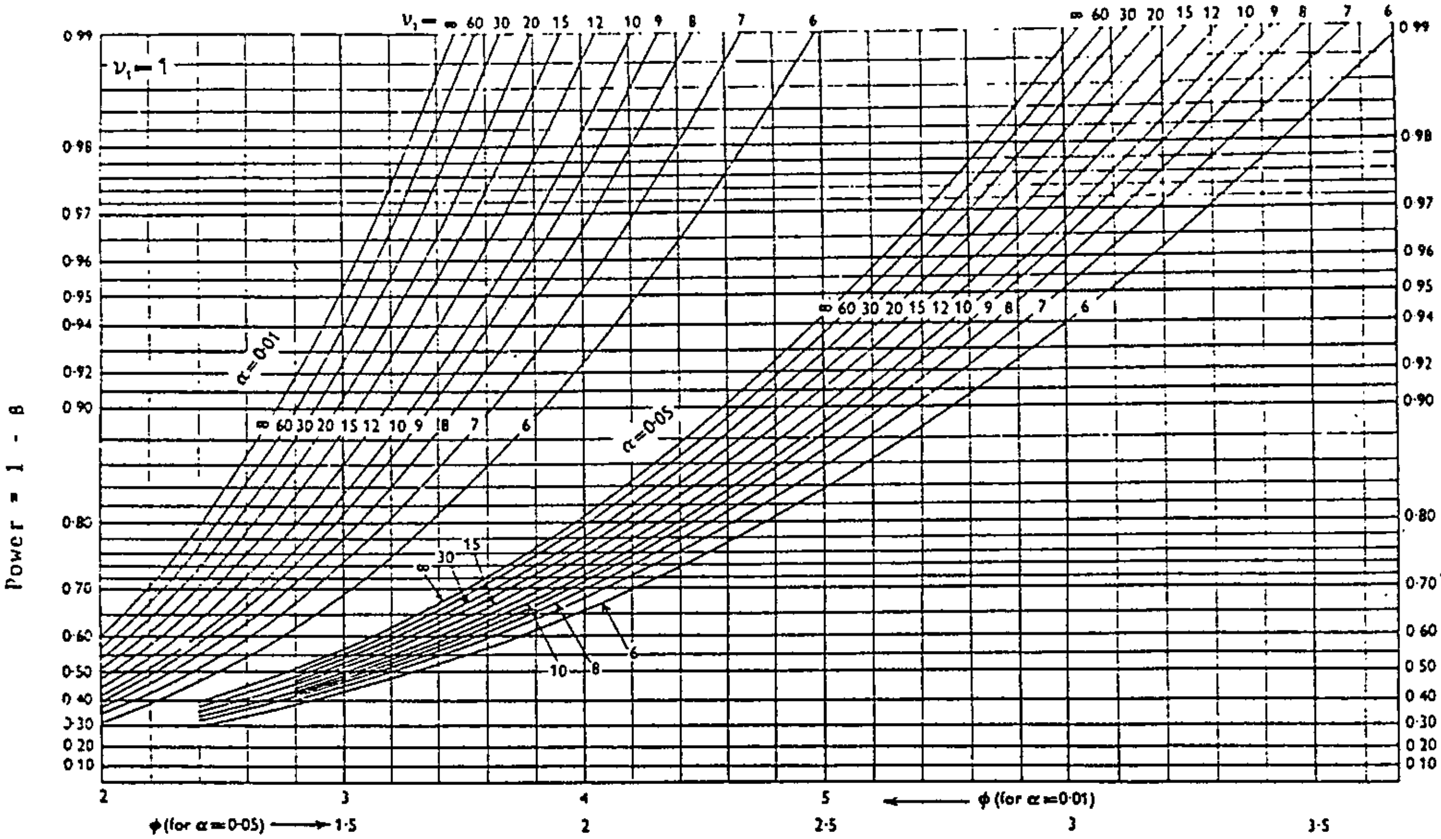
Extension of the above principles can be made to the two factor ANOVA design, but are not discussed here.

Estimating the minimum required sample size, n, using the techniques described above could, in fact, provide a value which may be considered, in view of logistical constraints or budgetary limitations, much too large to be feasible in a proposed study or experiment. In this situation, should the level of replication be arbitrarily set (lower than optimum), we recommend that the power of the statistical test used $(1-\beta)$ be calculated on the basis of the sample size actually employed. A record of $1-\beta$ may be useful in the interpretation of results, particularly in cases which indicate no significant differences, but only marginally so.

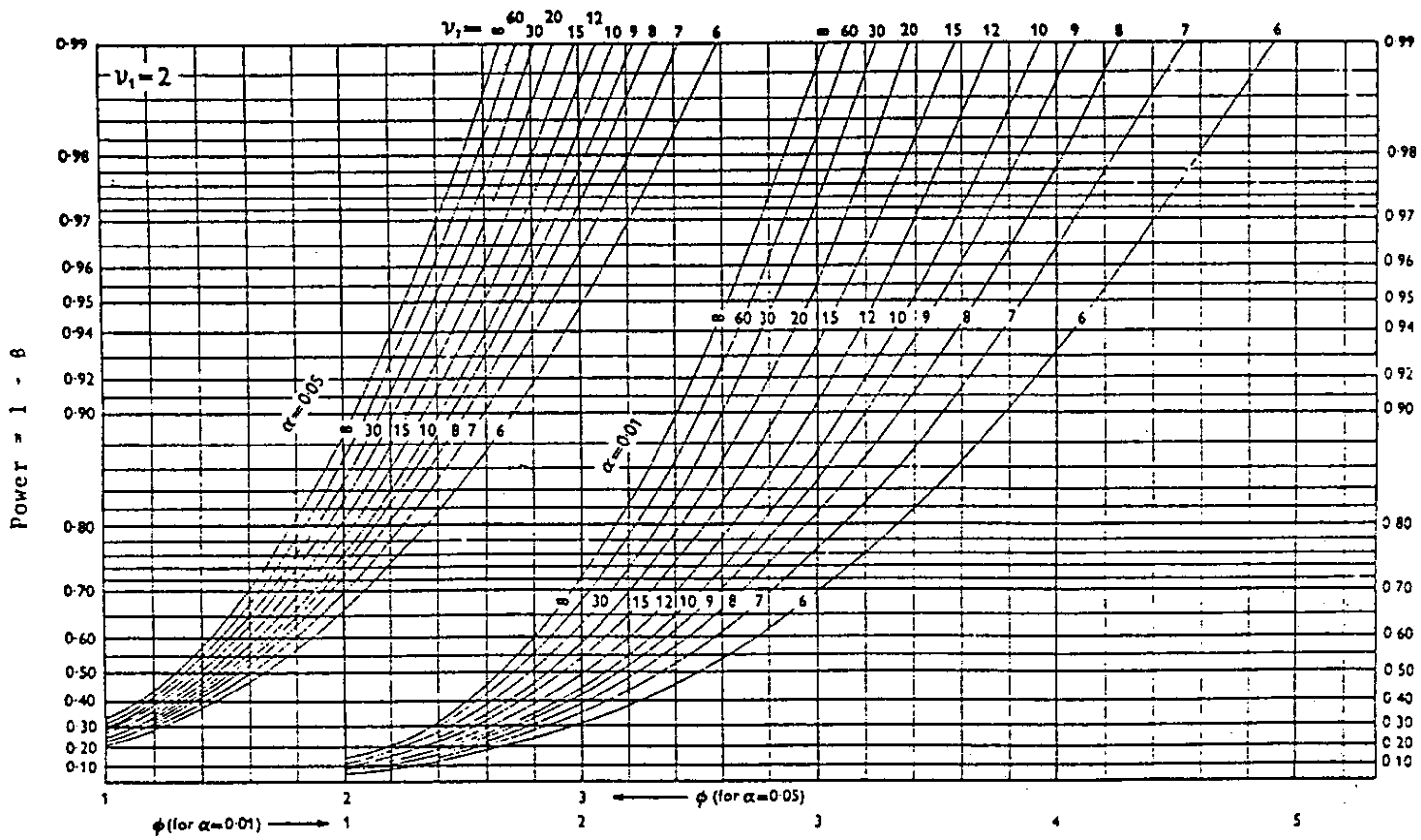
References

Pearson, E.S. and H.O. Hartley. 1951. Charts for the power function for analysis of variance tests, derived from the non-central F-distribution. Biometrika 38:112-130.

Zar, J.H. 1984. Biostatistical Analysis, 2nd Edition. Prentice-Hall, Inc. Englewood Cliffs, New Jersey. 718 pp.



Power and sample size in analysis of variance: $\nu_1 = 1$.



Power and sample size in analysis of variance: $\nu_1 = 2$.

Figure A1. Power ($1-\beta$) and Sample Size in Analysis of Variance (ANOVA) for $\nu_1 = 1$ and $\nu_1 = 2$. Reproduced from Zar Zar (1984), originally from Pearson and Hartley (1951).

APPENDIX B

LIST OF CONTACTS

Name	Affiliation		Telephone # (Area Code 206 unless otherwise noted)
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Brown, Nancy	U.S. EPA		442-1389
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January 3, 1986

E R R A T A

Please substitute the attached version of Figure 36 for that that appeared in NOAA Technical Memorandum NOS OMA 19 "Temporal Trends in Selected Environmental Parameters Monitored in Puget Sound." The data for DDT were mistakenly plotted in the original version.

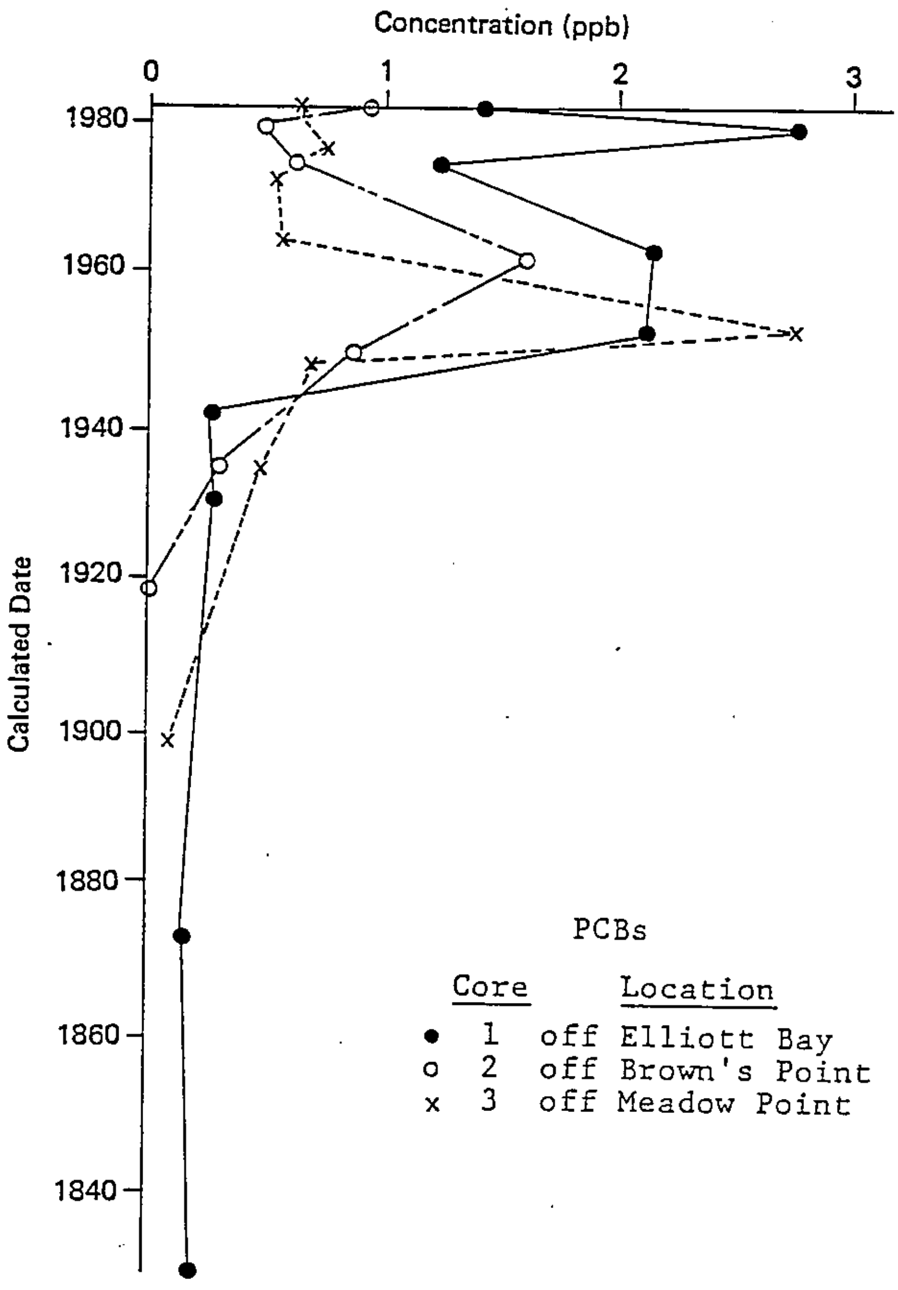

Figure 36. Average concentrations of PCBs in three sediment cores collected in the Main Basin near Seattle as a function of age of the sediments.
Source: Romberg et al., 1984.