NOAA Technical Memorandum NOS OMA 19

TEMPORAL TRENDS IN SELECTED ENVIRONMENTAL PARAMETERS MONITORED IN PUGET SOUND

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TEMPORAL TRENDS IN SELECTED ENVIRONMENTAL PARAMETERS MONITORED IN PUGET SOUND

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NOTICE

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EXECUTIVE SUMMARY

This report focuses on the identification of temporal trends in selected measures of the environmental quality of Puget Sound, based upon a review of historical and recent data. Although extensive research and monitoring have been conducted in Puget Sound, particularly in recent years, no synopsis exists of the temporal trends in the environmental conditions of the region. This report represents a first attempt to compile the available data to produce such a synopsis. The report presents a summary of selected information describing conditions related to Puget Sound from the late 1800s to present. Three objectives were addressed: 1) to place recent studies of the present environmental conditions of the Sound into a long-term perspective; 2) to present historical changes in the basic physical characteristics (temperature, precipitation, etc.) of the region; and 3) to make initial comparisons of trends observable in different long-term data sets.

The population of the Puget Sound region has increased rapidly since the first settlements in the mid-1800s. Commercial and industrial development associated with the growth of municipalities led to increasing volumes of human and industrial wastes. By the mid-1900s, there were reports of incidences of gross pollution near pulp mills resulting in fish kills and other problems with resident organisms and pollution of beaches by human wastes near major cities. Such extreme pollution by conventional pollutants (i.e., oxygen demanding materials and nutrients) has been virtually eliminated in recent years through regulation and treatment of conventional waste inputs.

As these obvious forms of pollution have diminished, attention has turned to more subtle problems associated with the discharge of certain chemicals. These chemicals were known to be toxic to marine life in some circumstances. However, certain types of environmental data have not been collected consistently in the past because accurate methods of measurement have been perfected only recently. Therefore, our ability to depict trends is limited to two methods. The first, semi-quantitative descriptions of waste disposal practices and pollution incidences dating from the 1940s and 1950s, indicates that historical levels were probably not lower than at present. The second, limited data from the analyses of sediment cores and animal tissues, indicates that the levels of polynuclear aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and some other toxic materials have decreased and are lower, at least in some areas, today than they have been in the past. Concentrations of some substances have been stable; and others (e.g., silver) may be increasing in concentration with time.

The populations of harvested resident organisms in Puget Sound appear to have been affected historically more by economic demand, management decisions, and habitat disturbance, than by water quality problems. The Olympia oyster is one species that appears to be an exception: it has decreased in abundance as a result of pulp mill pollution. A number of species, including all salmon, Great Blue Heron, and harbor seals, have increased in numbers in recent years, although their present populations are probably a small fraction of those that existed before the region was settled.

Overall, most of the trends presented here indicate improvement in the overall biological health of Puget Sound in recent years. There are many gaps in information, however, particularly those regarding the inputs, distributions, and effects of pollutants in the Sound.

The impetus for this report and some of the data discussed here resulted from another report titled "Development of Effective Regional Environmental Monitoring for Puget Sound" (Chapman et al., in press). During preparation of that report, it became apparent that an abundance of information was available in monitoring program records, old agency reports, and other historical information that could be compiled to develop an overview of long-term trends in the Puget Sound ecosystem. This report is the result of that compilation and review.

ACKNOWLEDGEMENTS

The authors wish to thank E. Long of NOAA for his assistance during the course of this study and for his review of this document.

We also wish to thank the following URS staff members for their assistance in producing this report: R. Graham, B. Titus, M. Bertman, and J. Ward.

Temporal Trends in Selected Environmental Parameters Monitored in Puget Sound

R.N. Dexter, L.S. Goldstein, P.M. Chapman and E.A. Quinlan

1. INTRODUCTION

This report presents a review of information depicting temporal trends in selected measures of the environmental conditions of the Puget Sound region, compiled from data sets from a number of sources. The data used in this report were compiled, selected and synthesized with the primary intent of illustrating in one report the trends, if any, in a number of key parameters.

There were three major objectives. The first objective was to place the recent measures of these environmental conditions of Puget Sound into a long-term perspective. In many respects present concerns regarding real and apparent water quality problems have been shaped only by very recent studies, many of which had never been performed before in Puget Sound or in the world. While these studies have identified some significant problems, their timeframe is so limited that the results cannot be used to determine whether the Sound is getting "better" or "worse". The historical data were therefore compiled to attempt to provide data to compare the current (1984) water quality conditions with those observed in the past.

Second, the data are presented to determine whether major long-term changes have occurred that might have significantly altered the basic characteristics of the Sound. The Sound as an ecosystem is dependent on a number of basic physical factors, such as water temperature and salinity. Changes in these basic parameters alter both the flow and transport regimes and the biological systems. These physical factors can change greatly over periods of months or years. Natural variations in these parameters can cause changes in biological systems which are more significant than anthropogenic effects. Therefore the data were examined to place historical perspective on the changes that have occurred in the basic physical characteristics of the Sound.

Third, temporal trends in related types of data were examined to determine what correspondences, if any, existed between the data. While it was apparent that many of the data sets had not been adequately examined for long-term trends, it was also apparent that only limited attempts have been made to compare any trends observed in one kind of data with those from any other related data. This type of comparison is particularly important in developing management strategies, including monitoring programs for the Sound. Comparisons among parameters may lead to indications of cause-effect relationships, can guide monitoring programs toward simpler, more cost-effective data collection, and may indicate new parameters that should be monitored.

2. SCOPE AND LIMITATIONS OF THE DATA

With the overall objective in mind, the available data were compiled and parameters and data sets were selected to develop as long a record as possible for those parameters that seemed to best illustrate the temporal trends in:

- the physical system
- water quality
- pollutant inputs, both conventional and toxic chemical
- resident biological communities

The study area addressed in this report includes all of the inland marine waters east of Cape Flattery and south of the Canadian border (Figure 1). Included in Figure 1 are the names of some significant locations referred to in this report as well as the locations of the water quality stations from which data are presented below.

For some parameters, the data presented here are only a small part of the total available while for others all of the data that could be located have been presented. Data were excluded or presented in limited form only if they could not readily be used to determine temporal trends, or if they largely duplicated data already presented. Data sets were sometimes combined to generate the longest temporal record possible. This synthesis of data may have introduced some additional variance in the record due to unknown inconsistencies in the measurements. An effort was made to select data of good quality, but some of the data, particularly from the older sets, do not have adequate documentation to clearly establish their precision and accuracy. In some data sets, obvious errors precluded the use of the data for this report, but in some cases where the data in question were the only ones available for an important parameter, the data have been used, and qualified in the text so that the limitations can be readily recognized.

The report has been organized to present the trends in the factors that effect the ecosystem, i.e., the physical system, pollutant inputs and water quality, followed by the trends in the biological communities. In this way, it was hoped that an ecosystem framework could be maintained with the data presentation following the consecutive dependencies of variables from the major external driving forces to the responding biological communities.

Most of the data have been presented graphically. To facilitate comparisons of the temporal trends among the data sets, most of the graphs are presented on one or both of two time scales: from January 1890 to December 1983; and from January 1950 to December 1983. These temporal ranges were selected to provide adequate visual resolution in the plots of the many records that date from near the turn of the century and for more recent data.

Tabular data sets for the information presented in this report are available from the sources cited with each data set and have been provided to NOAA on IBM-PC compatible diskettes (in Lotus 1-2-3[R] worksheet format).

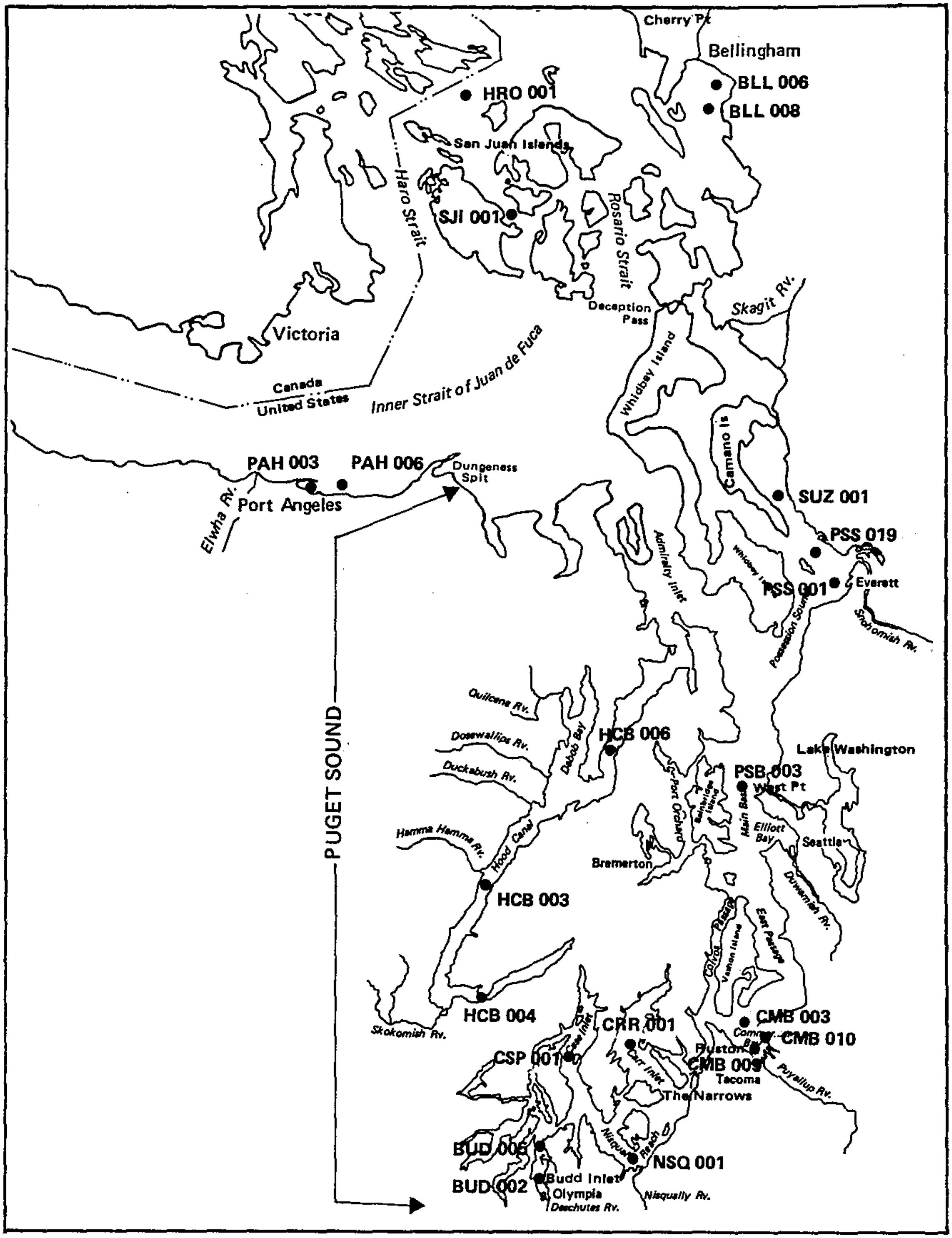


Figure 1. Area map of Puget Sound and Vicinity.

3. DEMOGRAPHIC ASPECTS OF THE REGION

As a foreword to the following chapters, this chapter was prepared to provide a brief overview of the modern development of the Puget Sound region. Certain aspects of this development have led to ecological impacts that are the main concern of this report, but often relationships between ecological changes and anthropogenic influences are difficult to establish. This chapter attempts to catalog some of the larger scale socio-economic changes that provide the backdrop for the remaining chapters. It also provides an opportunity to present a chronology of a variety of one-time events that do not fit into any categories of continuous information, but which individually or in total may have affected Puget Sound.

3.1 POPULATION

The population growth in the Puget Sound region is probably one of the major overall indicators of anthropogenic impacts. Many changes in water quality correspond directly with population. For example, the volume and characteristics of domestic sewage is similar among communities when considered on a per capita basis.

The census figures by themselves provide at least relative measures of:

1. the consumption of resources and the waste products associated with that consumption;

2. the extent of construction and other development that may result in modified habitats and erosion;

3. the demand on the local ecosystem for direct utilization for fishing and recreation; and

4. the extent of commercial and industrial activity that may also generate waste products that find their way to the Sound.

For all of these factors, the ultimate effects on the Sound depend on the extent to which the impacts can be mitigated or controlled. At the same time, population figures alone do provide some measure of the pressure for resource utilization that must be controlled.

Modern (post-settlement) growth of the population in the Puget Sound region is presented in Figure 2a, from 1890 to 1981. These data include the people in the counties surrounding the Puget Sound basin and were compiled in Curl (in preparation).

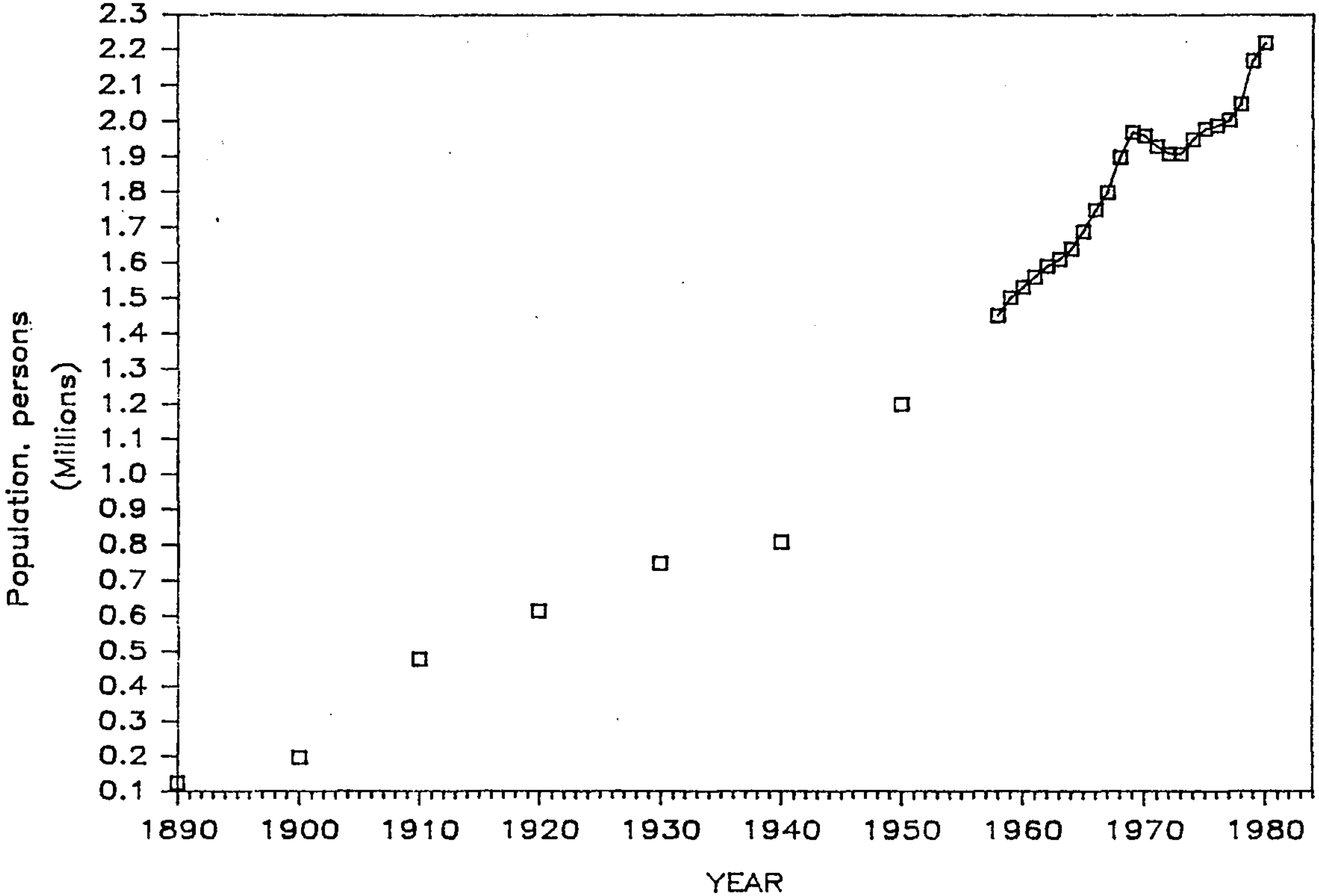


Figure 2a. Population and employment trends in the Puget Sound Region: total population from 1890 to 1985 in the counties of the Puget Sound basin.
Source: Curl, in preparation.

The population growth has been steady since the first white settlers arrived in the mid-1800s. A major growth spurt occurred near the turn of the century, resulting from the arrival of the railroads and the Alaska gold rush. Growth after World War II has been rapid and continuous except for a dramatic emigration during the depression in the aerospace industry in the early 1970s.

3.2 EMPLOYMENT

The employment profile of the Seattle-Everett metropolitan area for the last 45 years, presented in Figures 2b and 2c, indicates the more recent trends in commercial and industrial development in the region. While logging, lumber mills, fishing, and other industries that relied on the local resources were the first developed in the Puget Sound area, current employment is largely in other activities. For example, Figure 2b shows the steady increase in the relative importance of non-manufacturing, service jobs compared to more traditional industrial employment. Figure 2c shows the limited employment in those jobs that were historically dominant and that place a high direct demand on the resources of the Sound compared to such current enterprises as the aerospace industry. In addition, the boom-and-bust employment periods of World War II and the late 1960s can clearly be seen in Figure 2c.

These shifts in the way the residents of the Puget Sound area earn their living are an indicator of the possible types of wastes generated and because of the possible changes in the attitudes they have toward the Sound. Because most residents are now largely divorced from a day-to-day interaction with the Sound, do they, as a whole, care less than their predecessor about its quality? Or have they become less accepting of degradation because they make no direct demands on the Sound's resources and hence can afford to keep it as a "natural" system?

3.3 DEVELOPMENT CHRONOLOGY

Table 1 provides a chronology dating from the last century of selected events that have affected Puget Sound and its surrounding area. These events were selected as historical milestones in the development and use of the Sound. Many of the entries were taken from Chasan (1981) with others from the authors' files. A number of different types of events are recorded:

- Major socioeconomic events such as the coming of the railroads and the introduction of new industries, as well as wars and depressions.

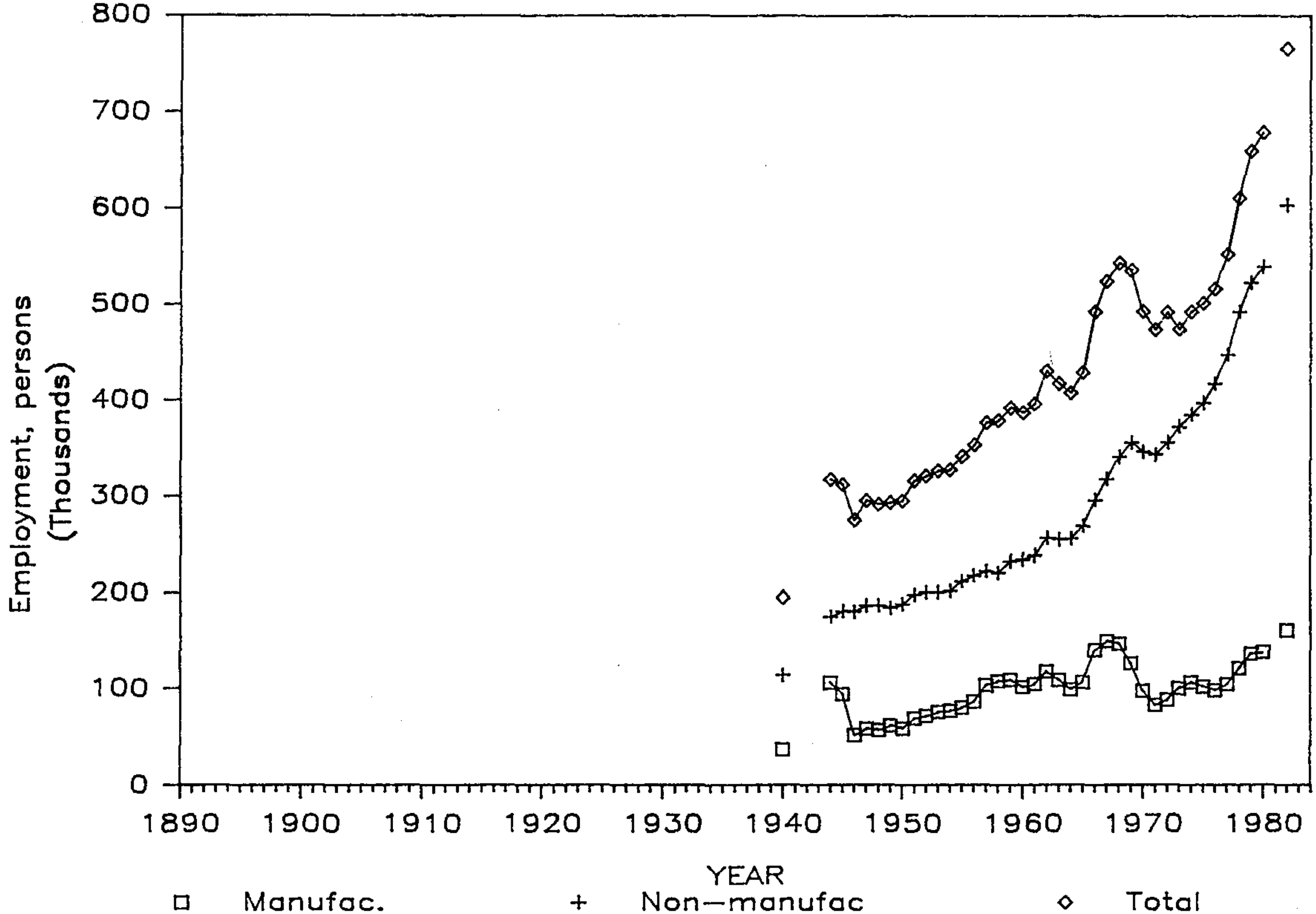


Figure 2b. Population and employment trends in the Puget Sound region: total, manufacturing and non-manufacturing employment in the Seattle-Everett metropolitan area.
Source: Washington Employment Securities Commission, Labor Statistics, 1940-1982.

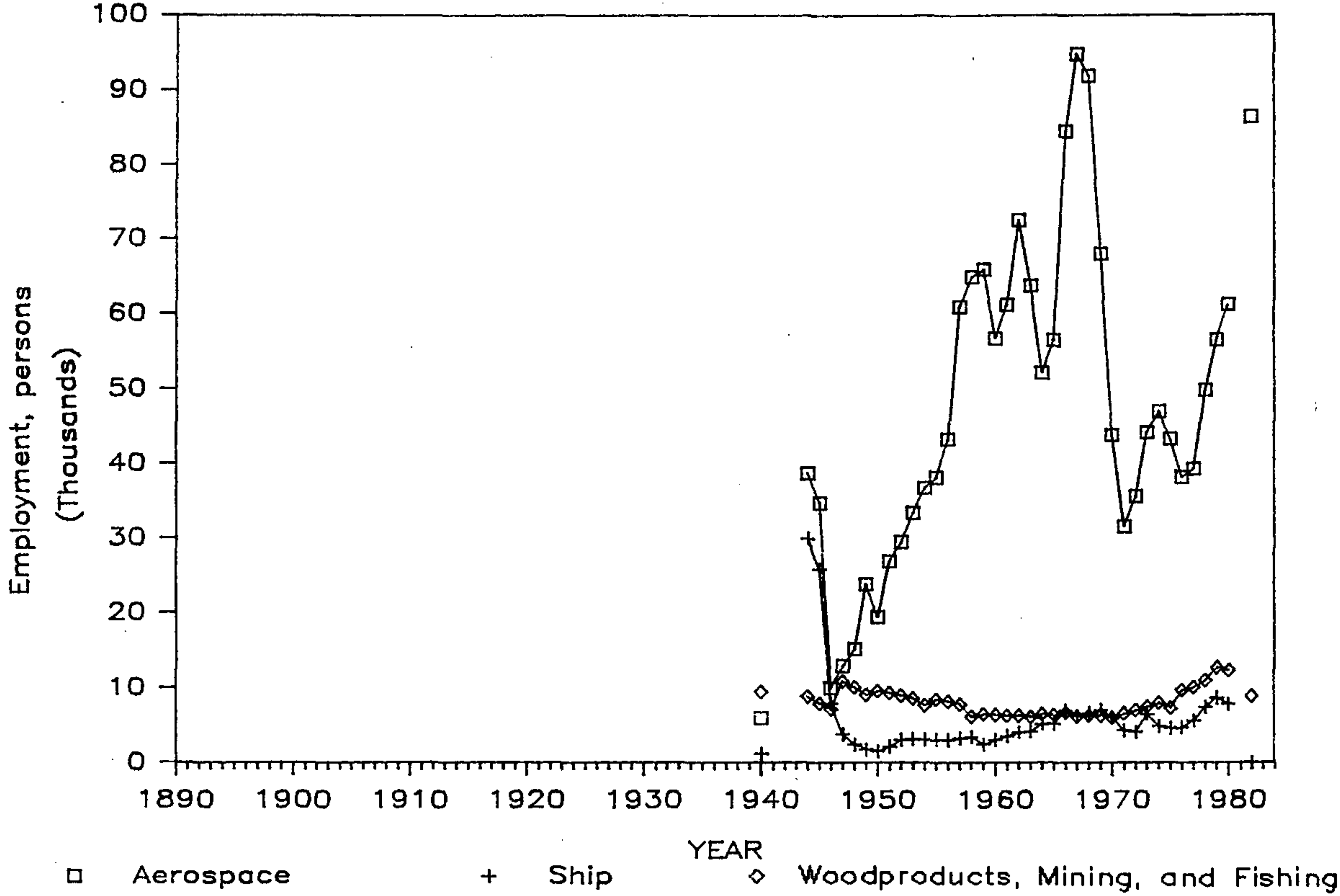


Figure 2c. Population and employment trends in the Puget Sound Region: employment in selected manufacturing industries.
Source: Washington Employment Securities Commission, Labor Statistics, 1940-1982.

- Legislative and legal management decisions such as fishing rights and pollution control laws.
- Human-caused and natural physical events that have altered the Puget Sound ecosystem, for example the diversion of the White River and the Hell's Gate rockslide.

Table 1. Chronology of selected events that affected the development of Puget Sound

1853	Establishment of first sawmills on Puget Sound
1861-1865	U.S. Civil War
1860s	Coal mines started at Bellingham and east of Seattle. First ship yard begins operation (Camano Island).
1877	First fish cannery starts at Mukilteo.
1880s	Northern Pacific Railroad reaches Tacoma. Fish traps introduced.
1883	Timber near the Sound is nearly depleted.
1889	Formation of Washington State Fish Commission. Seattle and Port Blakely fires. Ruston smelter (ASARCO) begins operation.
1893	Great Northern Railroad comes to Seattle.
1893-1897	Nation-wide depression.
1897	First Alaska gold reaches Seattle.
1898	Spanish-American War.
1900	Harbor Island land fill, Seattle. Steam donkeys and steam bandsaws introduced to lumber production.
1903	First use of motorized purse seiners. Wright brothers make first powered flight.
1906	White River diverted from the Green/Duwamish to the Puyallup.
1908	Automobile mass production begins.
1909-1914	Denny Hill regrade, Seattle.
1913	Hell's Gate rockslide in the Fraser River.
1914-1917	World War I.
1914	Panama Canal is completed.
1916	Boeing Aircraft begins operation in Seattle. Most commercial fishing boats are motorized. Lake Washington Ship Canal completed. Cedar River diverted to Lake Washington from the Black/Duwamish Rivers.

Table 1 (Continued)

1917	Most areas of the Sound can be reached by road.
1920s	Pulp mills begin operations.
1930s	National depression.
1934	Fish traps banned by initiative.
1937	First treaty with Canada for joint management of salmon runs.
1938	Major earthquake in Puget Sound region.
1941-1945	World War II
1941	Shellfish harvesting control given to Washington State Department of Fisheries.
1945	Washington State Pollution Control Commission established.
1949	Major earthquake in Puget Sound region.
1950s	Bridges completed at Agate Pass, Hood Canal and the Tacoma Narrows. First oil refinery constructed. First shellfish beds decertified for commercial harvesting.
1951	Nylon fishing nets introduced.
1955	Power block introduced for hauling nets from the water. Permits required for waste disposal into public waters.
1958	METRO created.
1964	Cherry Point selected for aluminum refinery.
1965	West Point Sewage Treatment Plant becomes operational. Major earthquake in Puget Sound region.
1969	Start of aerospace recession. National Environmental Policy Act enacted.
1971	Washington State Environmental Policy Act enacted. Washington State Shoreline Management Act enacted.
1972	National Clean Water Act enacted. Marine Mammal Protection Act enacted.
1973	Arab oil embargo.

Table 1 (Continued)

1974	"Boldt Decision" gives treaty Native Americans 50 percent of fish harvest.
1975	NOAA/MESA Puget Sound project started.
1978	First major PSP outbreak in Puget Sound south of Admiralty Inlet.
1979	Histopathological disorders in bottom fish reported. Hood Canal Bridge sinks.
1983	Northern Tier Pipeline rejected. Commencement Bay declared a Superfund site.
1985	ASARCO smelter closed. Waivers from secondary treatment at municipal sewage treatment plants denied.

4. THE PHYSICAL SYSTEM

This chapter presents trends in some of the the basic water characteristics of Puget Sound and some of the variables that control or are controlled by those characteristics.

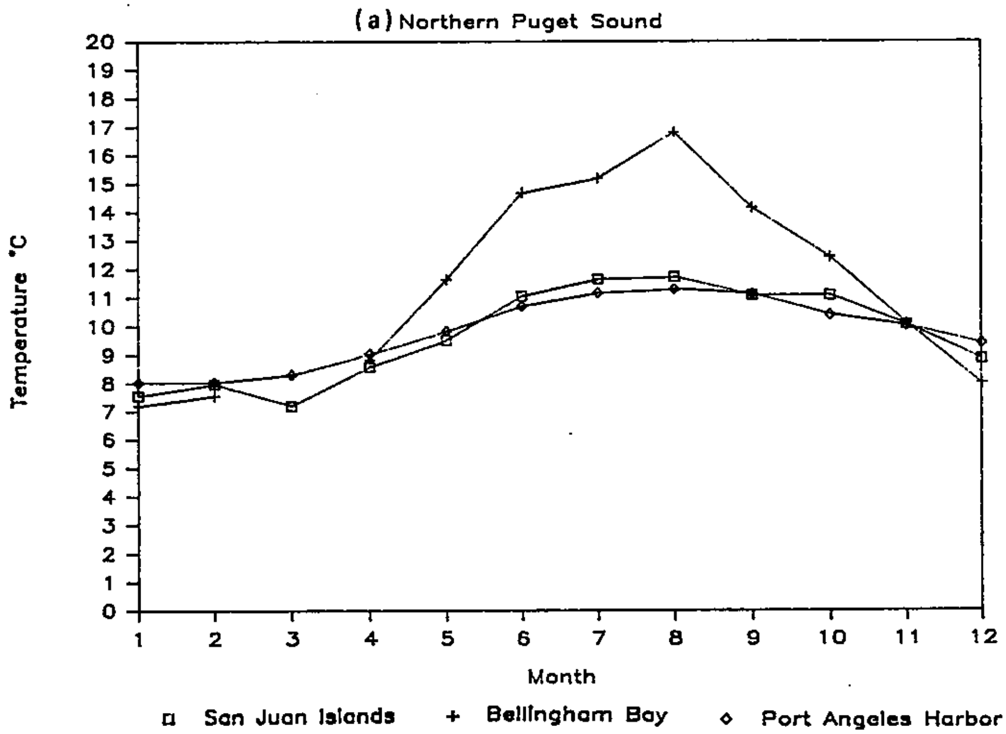
4.1 TEMPERATURE

Water temperature is one of the basic variables that controls the growth of most marine plants and animals. Being cold blooded, increasing water temperature generally increases the metabolic activity of marine animals. However, almost all of the plants and animals have an optimum temperature range and also tend to be sensitive to rapid temperature changes.

Normal seasonal changes in the surface water temperature depicted in Figure 3, are the monthly averages for combined data from the Washington Department of Ecology (WDOE) water quality monitoring program, the Municipality of Metropolitan Seattle (Metro) routine water quality monitoring program (West Point data only), and from various studies by researchers at the University of Washington (UofW). Some of the data sets used extend from 1932 (UofW), but the preponderance of the data is from the late 1960s to 1983. All data were obtained from the EPA Storet data archives.

To make the data more readable, the stations north of Admiralty Inlet were plotted separate (Figure 3a) from those south of Admiralty Inlet (Figure 3b). In each region, selected locations are depicted to illustrate both the open water characteristics and those of major embayments, particularly urbanized ones. In some locations, the values used are the averages of more than one sample station. The embayment values are the averages of the stations shown in Figure 1 for those embayments. The Southern Sound values are averages of the Nisqually, Case Inlet, and Carr Inlet data.

All of the surface water temperatures show similar annual trends, responding to the normal summer/winter cycle. In the Main Basin the open water station at West Point shows the smallest range, while the more enclosed areas of the Southern Sound and Hood Canal show slightly larger ranges (Figure 3b). While similar overall trends are observed in the northern Sound data, it is clear that the waters of the San Juan Islands and at Port Angeles do not undergo the amount of summer warming seen in the more enclosed waters of Bellingham Bay or in any of the more southerly locations (Figure 3a). Winter temperatures are similar throughout the Sound.



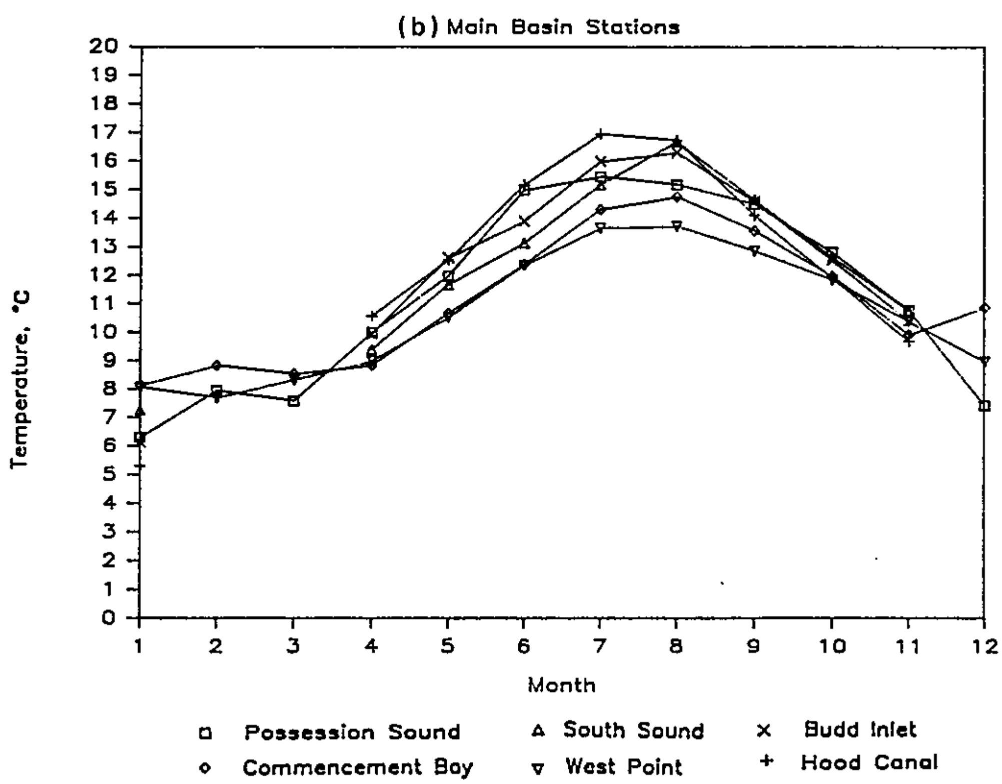


Figure 3. Monthly average temperatures in the surface waters at selected locations in Puget Sound.
(a) locations from the northern Sound, (b) locations from south of Admiralty Inlet.
Source: EPA Storet data files.

The long-term trends in the temperature of the waters of Puget Sound were examined at two locations, at the Seattle tide gauge and at West Point. The tide gauge is located in Elliott Bay. Data from that site were selected because they date from 1922, providing the longest continuous record of water temperatures in Puget Sound. The data have been collected daily in conjunction with the reading of the tide gauge and were available as monthly averages in unpublished Department of Commerce data summaries. West Point was selected because of its relatively central location, away from local influences and representative of the Main Basin, and because it has been one of the most intensely sampled sites in the Sound. Data have been collected there from 1932 to the 1970s by the UofW and from the late 1960s by both WDOE and Metro. Measurements at West Point have been made monthly or less frequently (Chapman et al., in press). When more than one value was available for a single month from the three data sets, the values were averaged to yield a single record of monthly temperatures. The most complete combined data set is from 1950 and is plotted as monthly averages.

In Figures 4 and 5, the data are presented as the mean monthly temperature anomalies, i.e., the difference between the observed monthly average and the long-term temperature average for that month. A positive anomaly value indicates the individual monthly value was warmer than the long-term average. This data presentation was selected to remove from the data the large variations in temperature due to the normal seasonal cycle and thus hopefully better reveal any long-term trends. In addition, to further remove shorter term noise in the data, a 12-month running average of the anomalies was also calculated. The averaging interval was subjectively chosen to smooth most monthly variations but leave annual and longer term trends intact.

The surface water temperature trends observed at the Seattle tide gauge location are presented in Figure 4, while the data from West Point are presented in Figure 5 (5a shows the surface values while 5b shows the values from 80 m to 120 m deep). Both of the data sets showed similar overall trends with slightly higher temperatures in the 1960s, cooler values during the 1970s, and a possible warming trend in the early 1980s. The warmer water associated with the most recent El Nino (1982) is apparent in the West Point data. The tide gauge data indicate a possible cool period during the late fifties. Also, it is interesting to note that the tide gauge maxima and minima seem to lag behind the West Point trends by a few years. This may indicate the effects of local influences on the nearshore data as the tide gauge site probably reflects the properties of Duwamish River water while the West Point site probably is more reflective of open water properties.

Because of the general correspondence between the West Point and tide gauge data, the longer records for the latter site were also examined (Figure 6). Warm periods during the 1920s, early 1940s, and late 1960s are clearly depicted, with a major period of cooler water during the 1950s. Months with extremes of warm or cold temperatures are also clearly noted, for example the cold winter of 1950 and for the El Nino years of 1926 and 1941. No data were collected during the El Nino of 1957.

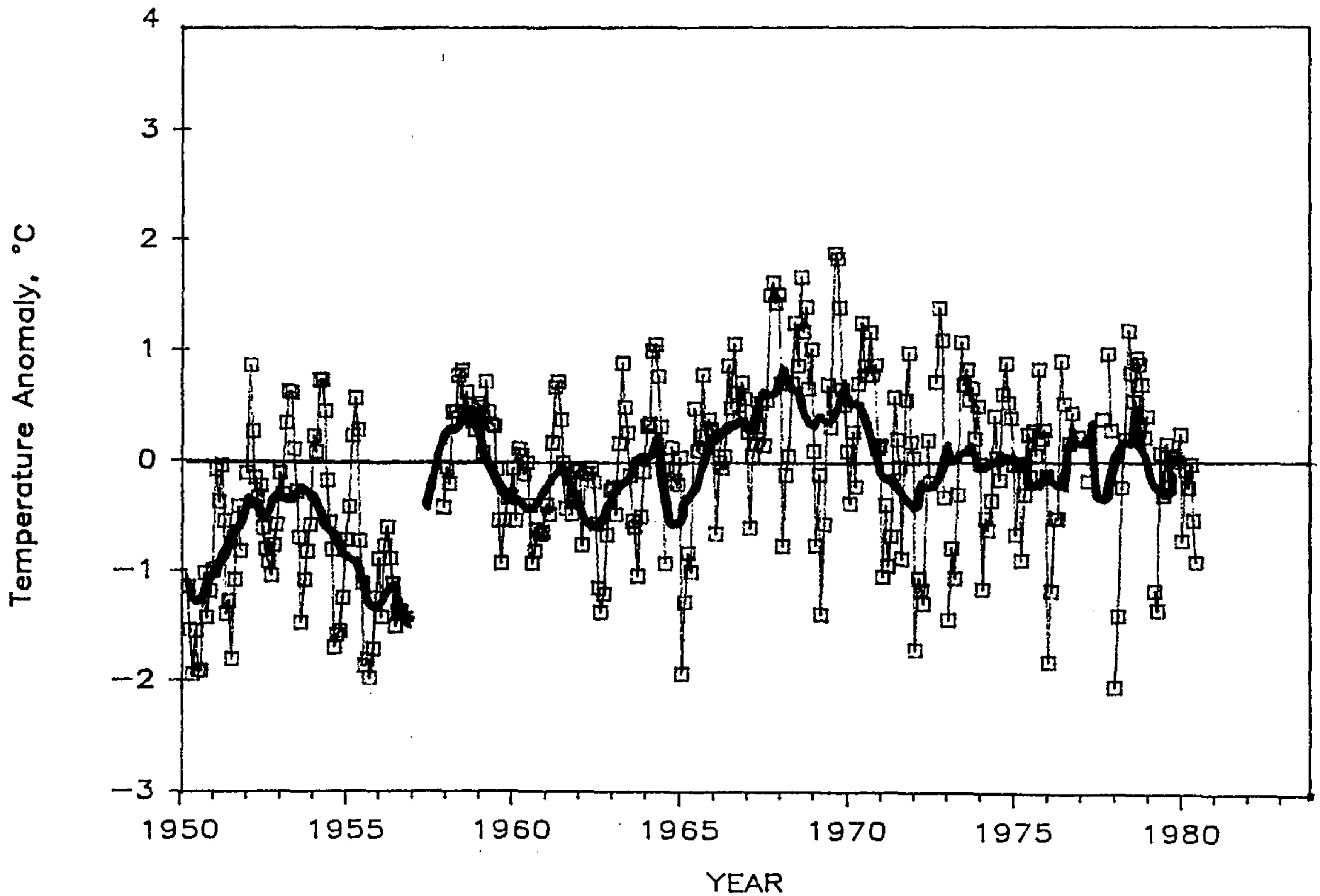


Figure 4. Monthly temperature anomalies in the surface water at the Seattle tide gauge from 1950 to 1983. Background tracing is the 12-month running average of the anomalies.
Source: Unpublished Department of Commerce data.

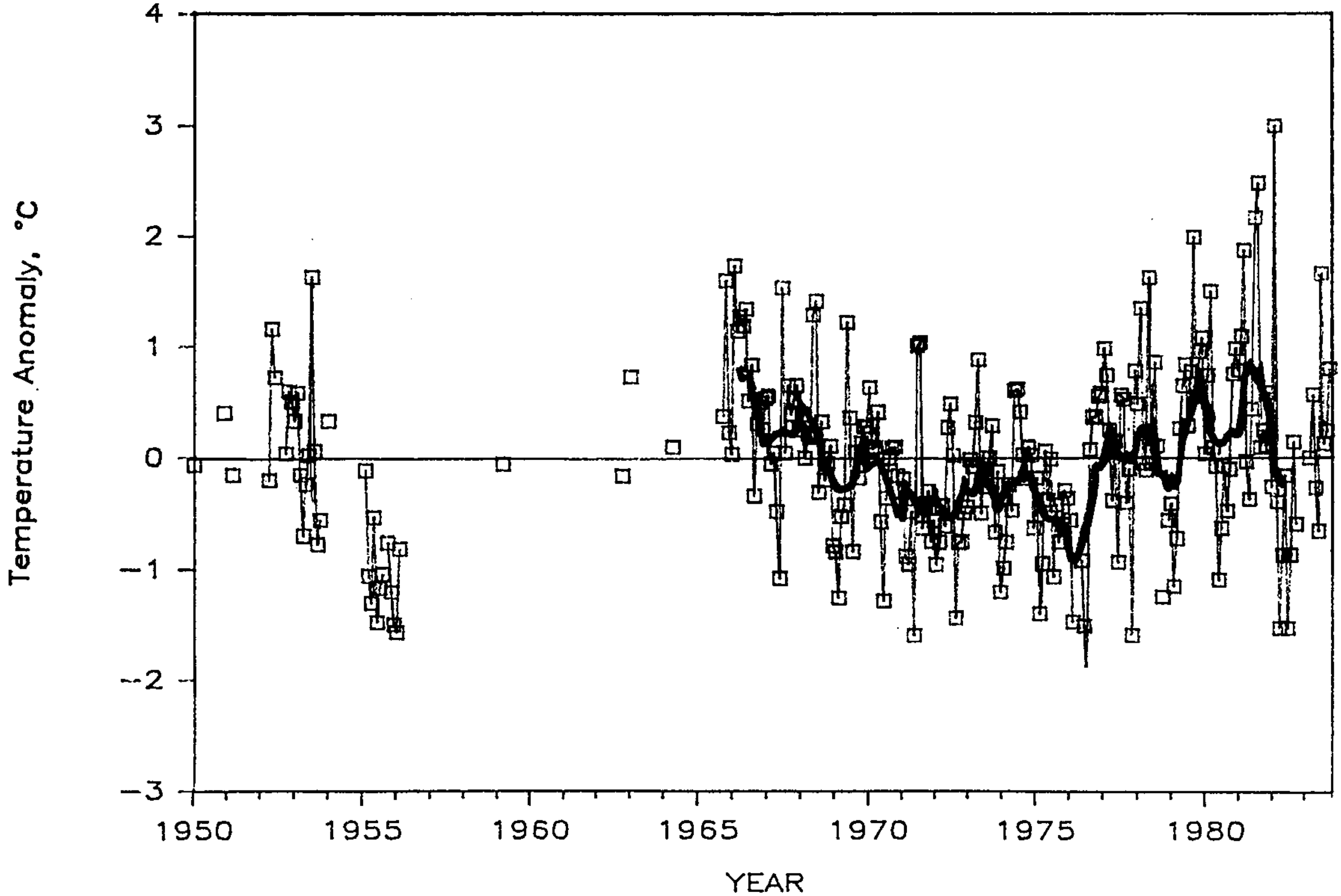


Figure 5a. Monthly temperature anomalies in the water at West Point from 1950 to 1983: surface waters. The background traces are the 12-month running averages of the monthly anomalies.
Source: EPA Storet data files.

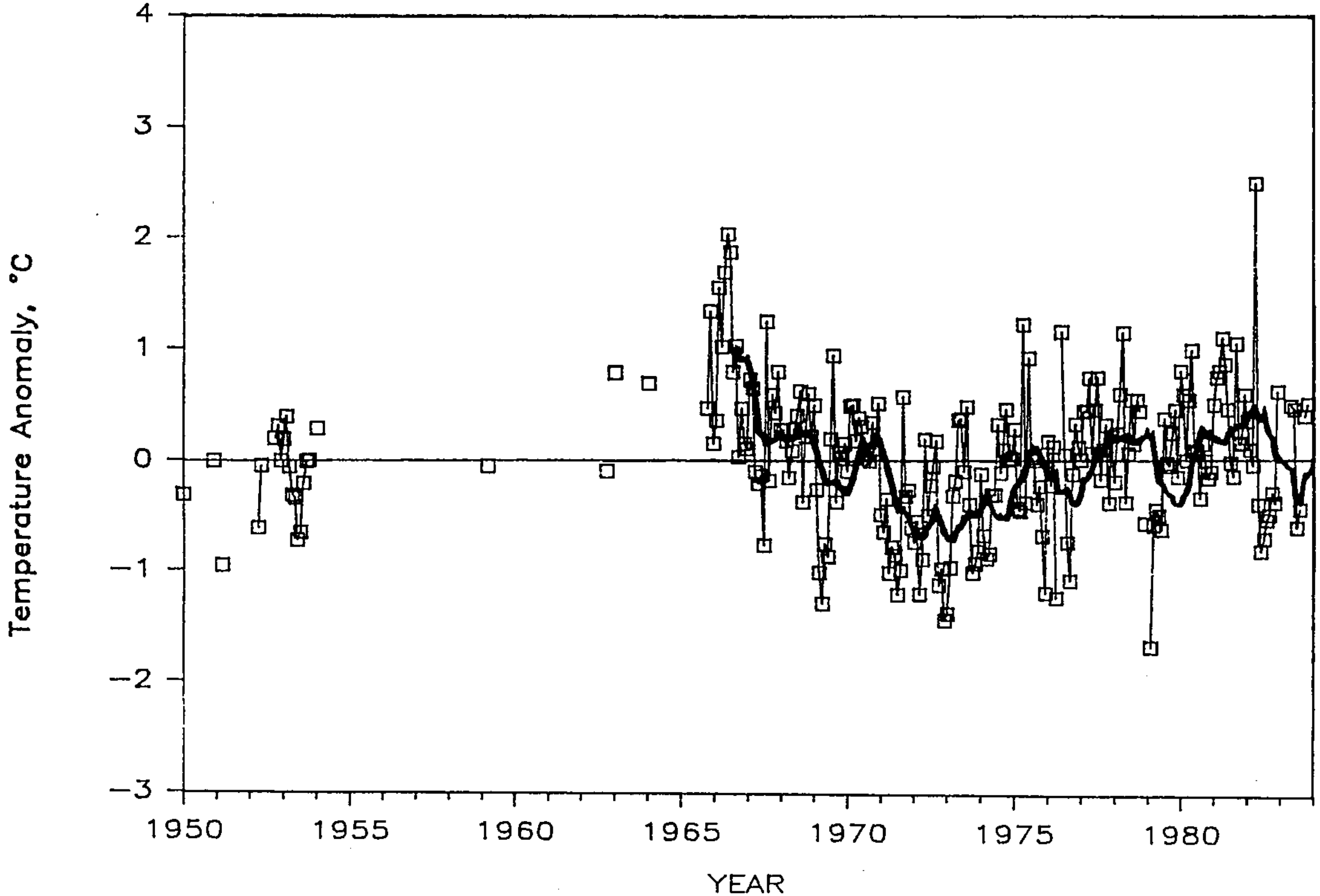


Figure 5b. Monthly temperature anomalies in the water at West Point from 1950 to 1983: waters at depths between 80 and 120 m. The background traces are the 12-month running averages of the monthly anomalies. Source: EPA Storet data files.

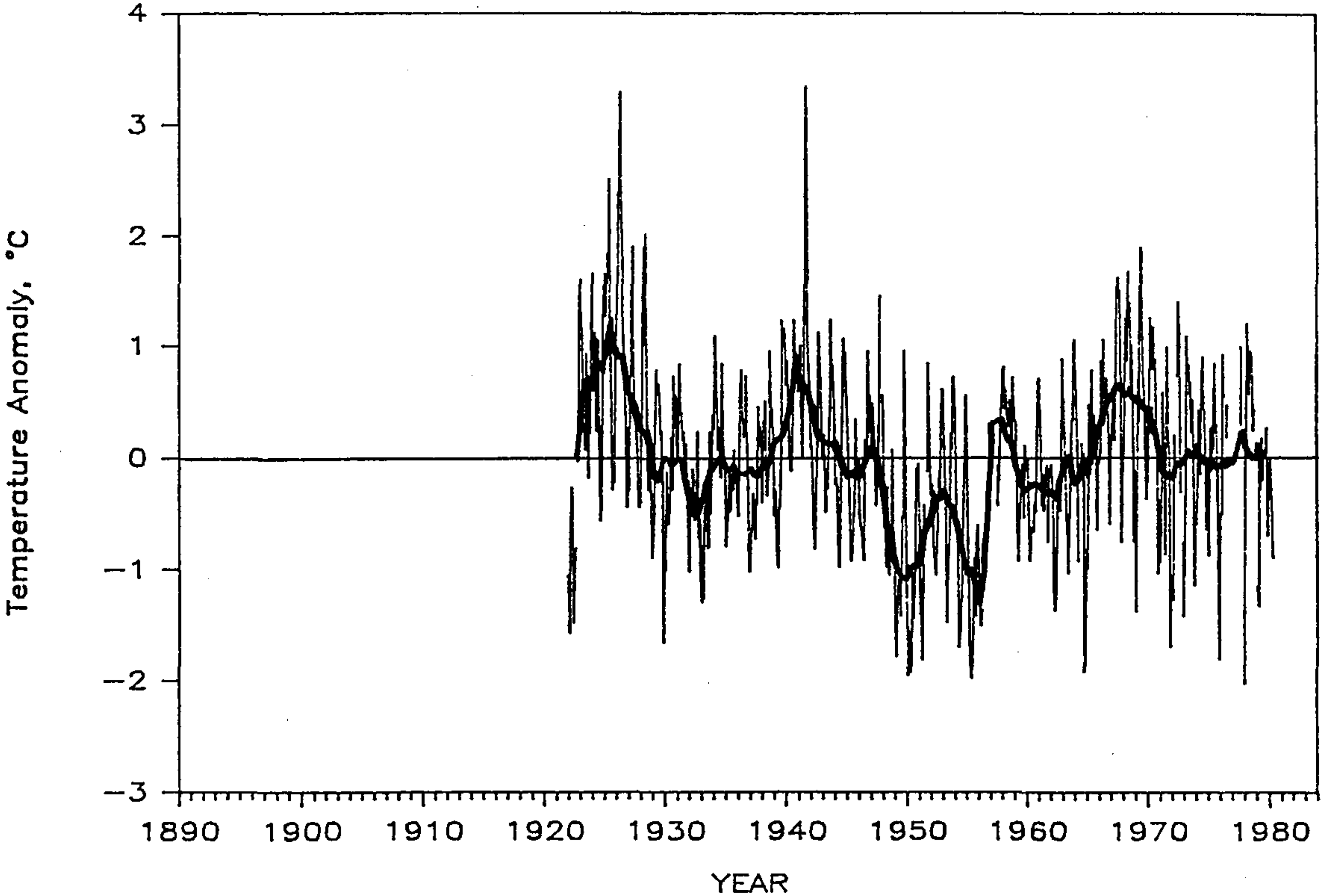


Figure 6. Monthly temperature anomalies in the surface waters at the Seattle tide guage from 1922 to 1980. The background trace is the 24-month running average of the monthly average.
Source: Unpublished Department of Commerce data.

It must be noted, however, that in all cases, the long-term temperature changes that have been observed are on the order of a few degrees, and hence are small compared to the annual temperature cycles. To date, no studies have attempted to determine the possible significance of such small mean temperature changes on any organism or on the major processes such as circulation in Puget Sound.

Because it is reasonable to assume that the sea water temperature is linked to climatic conditions on both the annual and longer cycles, the temporal trends in air temperature were obtained for the Seattle metropolitan weather station (Seattle EMSU, Department of Commerce, 1961 and NOAA 1983). This data set was selected because Seattle is centrally located in the lower Puget Sound Basin and because this weather station has one of the longest continuous records of any in the region, dating from 1888. The data were obtained as the monthly average temperatures, based on nearly continuous temperature measurements. The data are presented in three formats to allow comparisons with the other data plots: 1) the average monthly (seasonal) temperatures (together with precipitation and runoff) (Figure 7), 2) the monthly average temperature anomalies from 1950 to 1983 (Figure 8); and 3) the monthly average temperature anomalies from 1890 to 1983 (Figure 9).

The monthly air temperatures (Figure 7) clearly display the same seasonal change as noted for the waters of the Sound (Figure 3). Comparisons between the long-term air temperature data (Figures 8 and 9) and the surface water records from the Seattle tide gauge (Figures 4 and 6) show a close correspondence between the maxima and minima in the respective records, with the exception that the peaks in the water temperature noted during the El Ninos (1926-27 and 1941-42) (Figure 6) are larger than would be estimated from the air temperature anomalies (Figure 9). This correspondence may be important because the long-term air temperature record clearly shows an increase in the average temperature from the early part of the century, prior to about 1930, to the present. Since the air temperature was collected at an urban site, it is possible that part of this warming trend seen in the data may have been due to local effects, and may not accurately reflect the long-term changes in the regional climate. However, if the air temperature data are representative of the long-term regional trends, then it can be presumed that the water temperature of the Sound was substantially cooler in the early part of the century than at present. No water temperature data are available from prior to 1922.

Interestingly, comparisons between the surface and deep water temperature trends observed at West Point (Figure 5) with the air temperature (Figure 8) indicate that while the same maxima and minima are present in the records, the water temperature maxima and minima precede those in the air temperature record by about 3 years. This observation was not expected. From the close correspondence seen in the annual temperature cycles and between the air temperature and the surface water temperatures at the tide gauge station, a fairly strong temporal correspondence in the

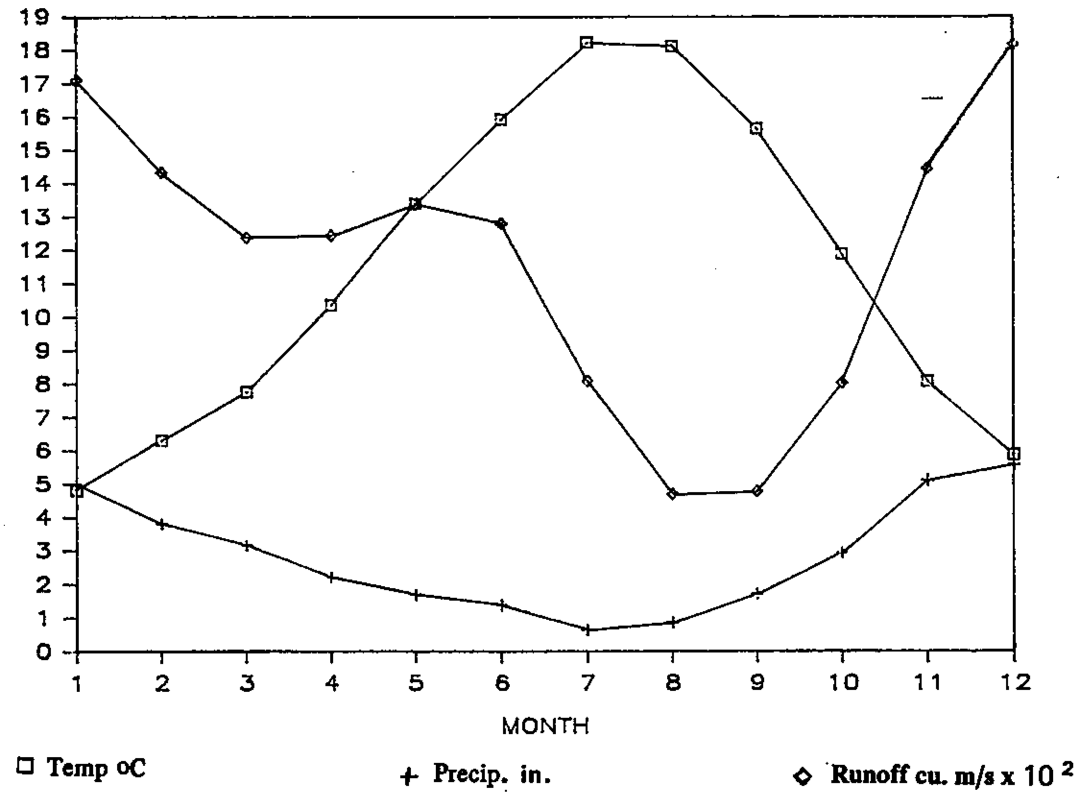


Figure 7. Monthly averages of air temperature and precipitation at Seattle and the total runoff to Puget Sound south of Admiralty Inlet.
Source: Coomes et al., 1984 (runoff); Department of Commerce, 1961; NOAA 1984 (temperature and precipitation).

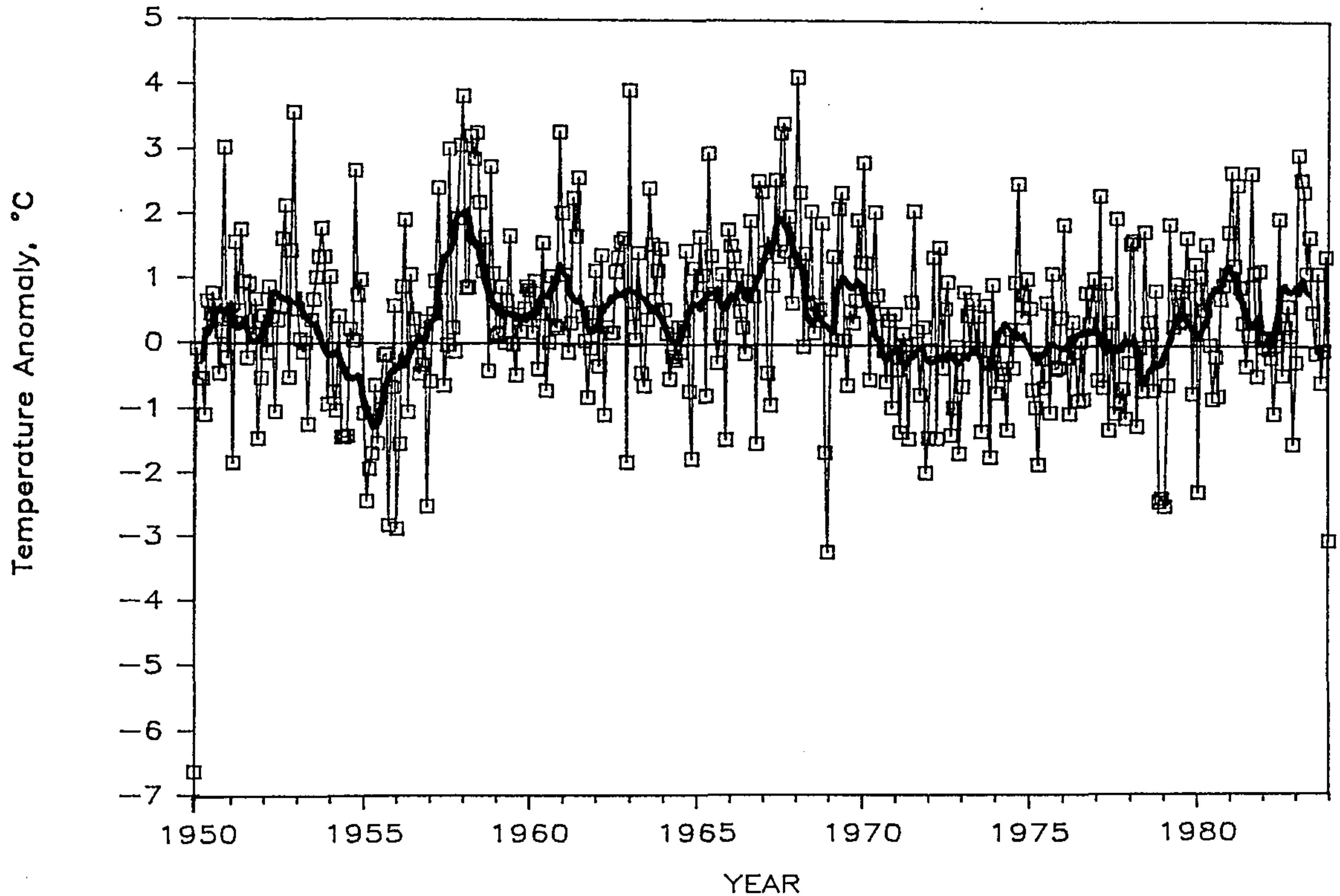


Figure 8. Monthly air temperature anomalies at Seattle from 1950 to 1983. The background trace is the 12-month running average of the monthly air temperature anomalies.
Source: NOAA, 1983.

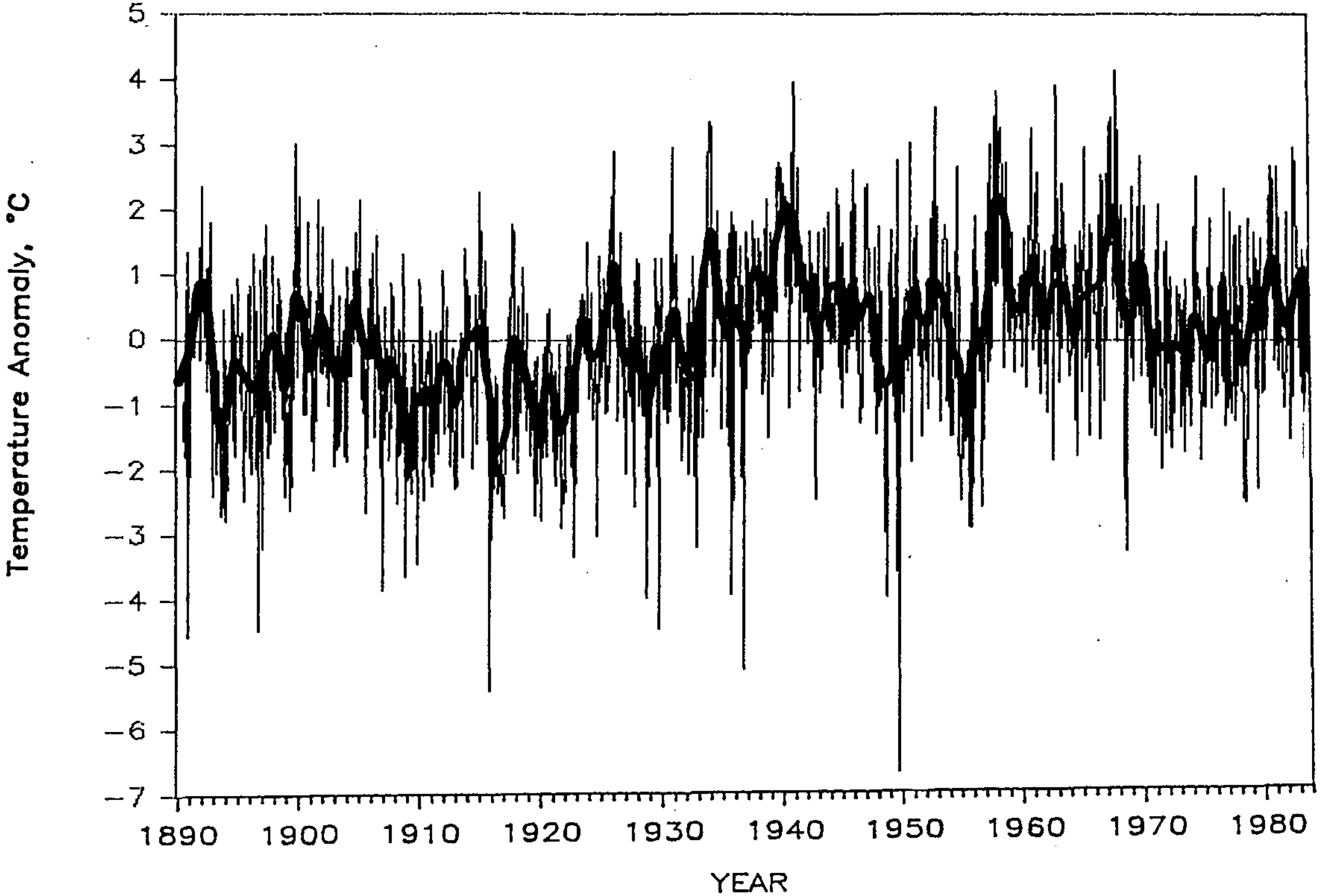


Figure 9. Anomalies in the monthly average air temperature at Seattle from 1890 to 1983. The background trace is the 12-month running average of the monthly average.
Source: Department of Commerce, 1961; NOAA, 1983.

remainder of the basin was expected. It should be pointed out that the sea water temperature records are comparatively short to be establishing firm relationships. However, one conclusion that could be drawn from these comparisons is that the long-term trends in the water temperature in the open-water areas of the Sound are controlled by meso-scale processes, particularly the circulation in the Northeast Pacific Ocean, which may also control, but over a longer time scale, the atmospheric temperatures in the Seattle area. Near surface water temperature in near-shore areas of the Sound may be more strongly influenced by local heating and hence more closely correspond to the air temperature trends.

It must be emphasized again that the temperature differences revealed by plotting the anomalies are small compared to the annual cycles and may reflect at least some sampling imprecision. The fact that the maxima and minima are seen in more than one record indicates that they are probably real, but whether they have any significance to the Puget Sound ecosystem is not known. What can be stated is that long-period temperature changes of varying magnitude have and do occur in the Sound and that the changes over the last century may have been substantially larger than those experienced in the last few decades.

4.2 SALINITY

Together with temperature, salinity is generally considered to be the other major variable characterizing the marine ecosystem. The proper salinity range and freedom from rapid salinity changes are requirements for most of the estuarine organisms of the Sound. Salinity and temperature together determine the density of seawater and hence have a major role in controlling water column stability and circulation. However, density stratification is primarily controlled by salinity differences in the Sound.

Salinity data were obtained from EPA Storet for the same locations (Figure 1), and dates as were selected for temperature. No salinity data were collected at the Seattle tide gauge. The monthly average salinities for the surface water at the selected locations around the Sound are presented in Figure 10 (northern locations, Figure 10a; Main Basin and Southern Sound, Figure 10b). The records date from 1932 in some locations, but are predominately for the period from 1965 to 1983. The seasonal variations in salinity are small in the open-water areas in comparison to the embayments, particularly those receiving direct freshwater inputs, such as Commencement and Bellingham Bays and Possession Sound. Salinities at the northern stations are normally higher than those at comparable stations south of Admiralty Inlet. All locations show at least some seasonal decrease in salinities in the winter through the late spring in response to runoff from rivers in the Sound and also from the Fraser River in Canada.

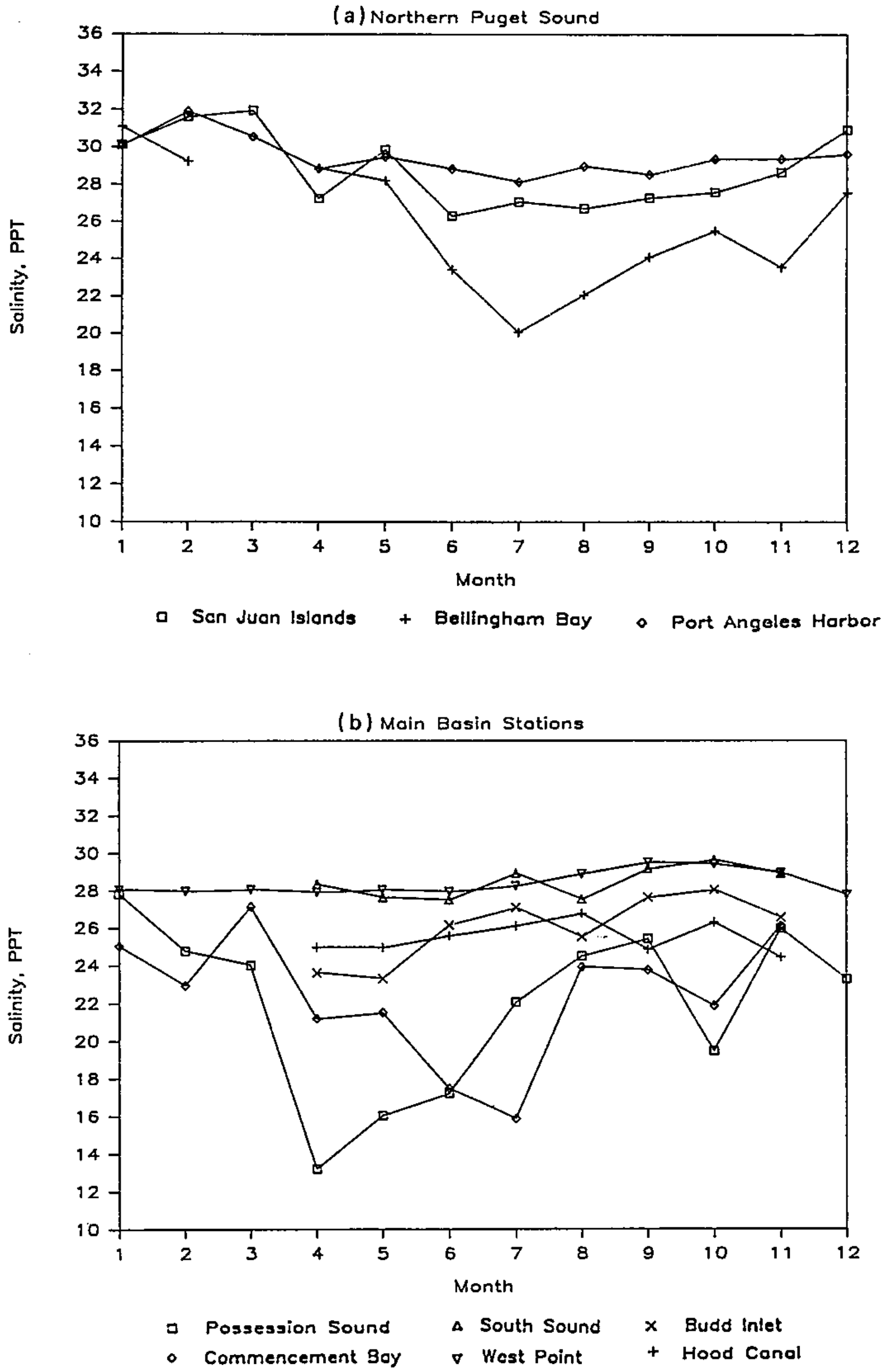


Figure 10. Monthly average salinities in the surface waters at selected locations in Puget Sound.
(a) locations from the northern Sound, (b) locations from south of Admiralty Inlet.
Source: EPA Storet data files.

The long-term temporal trends in salinity were examined using the data from West Point from WDOE, Metro and the UofW that were available from EPA Storet. In months where more than one value was available (measurements generally ranged from one to four values for any month), the values were averaged to yield the average salinity for that month. The data are presented as the monthly salinity anomalies, calculated as the difference between individual monthly average value and the long-term average salinity for that month. Salinities greater than the average yielded positive anomalies. As with temperature, some data are available as far back as 1932, but only the data from 1950 to 1983 are presented here (Figure 11; surface water, 11a; water 80 m to 120 m deep, 11b).

Both the surface and deep-water salinities showed the same temporal changes, but the range of the salinity variations was greater in the surface water, as expected from the greater immediate response to surface freshwater inputs. Over the period of record, no apparent very long-term trends are present, but cycles of a few months to decades in duration involving shifts of a few parts per thousand in the monthly average salinities do appear. These maxima and minima are on the same time scales as those noted for temperature, but in general there does not appear to be any correspondence in the dates at which these peaks occur in the two data sets. The one exception may be the relatively poorly defined low-salinity period in the late sixties which corresponds to an equally poorly established warm period (Figure 5).

Because it has previously been established that the salinity in the Sound responds to the riverine runoff (Ebbesmeyer and Barnes, 1980), runoff data, for which there is a longer record available than for the direct salinity measurement, were plotted to attempt to estimate the possible salinity fluctuations that may have occurred in the past. The runoff values were calculated from the daily discharge measurements made at the major rivers in the Sound. The data were obtained as the monthly average runoff for the Sound south of Admiralty Inlet from Coomes et al. (1984). The values were converted to the monthly runoff anomalies as before. The seasonal cycle of runoff to the Sound was included in Figure 7. Data were available from 1930 to 1978 and are presented on both of the time scales, from 1950 (Figure 12) and from 1930 (Figure 13). In general, comparisons between Figures 11 and 12 indicate a fairly good inverse correspondence between maxima and minima in the salinity and runoff records, particularly for the major "floods." However, there also appear to be additional fluctuations in the salinity data that do not have a runoff analog, e.g., the small peak of higher salinity apparent in the 12-month smoothed data in 1975 and the plateau of lower salinity during the late 1960s. These changes may reflect differences in the salinity of the water from the northeast Pacific Ocean that was influxed into the Sound.

The longer runoff record (Figure 13) indicates low-to-high runoff cycles have occurred at about 5 to 10 year intervals, with a major flood in 1933, followed by nearly a decade of less runoff than the average. No long-term trends of either increasing or decreasing runoff are apparent.

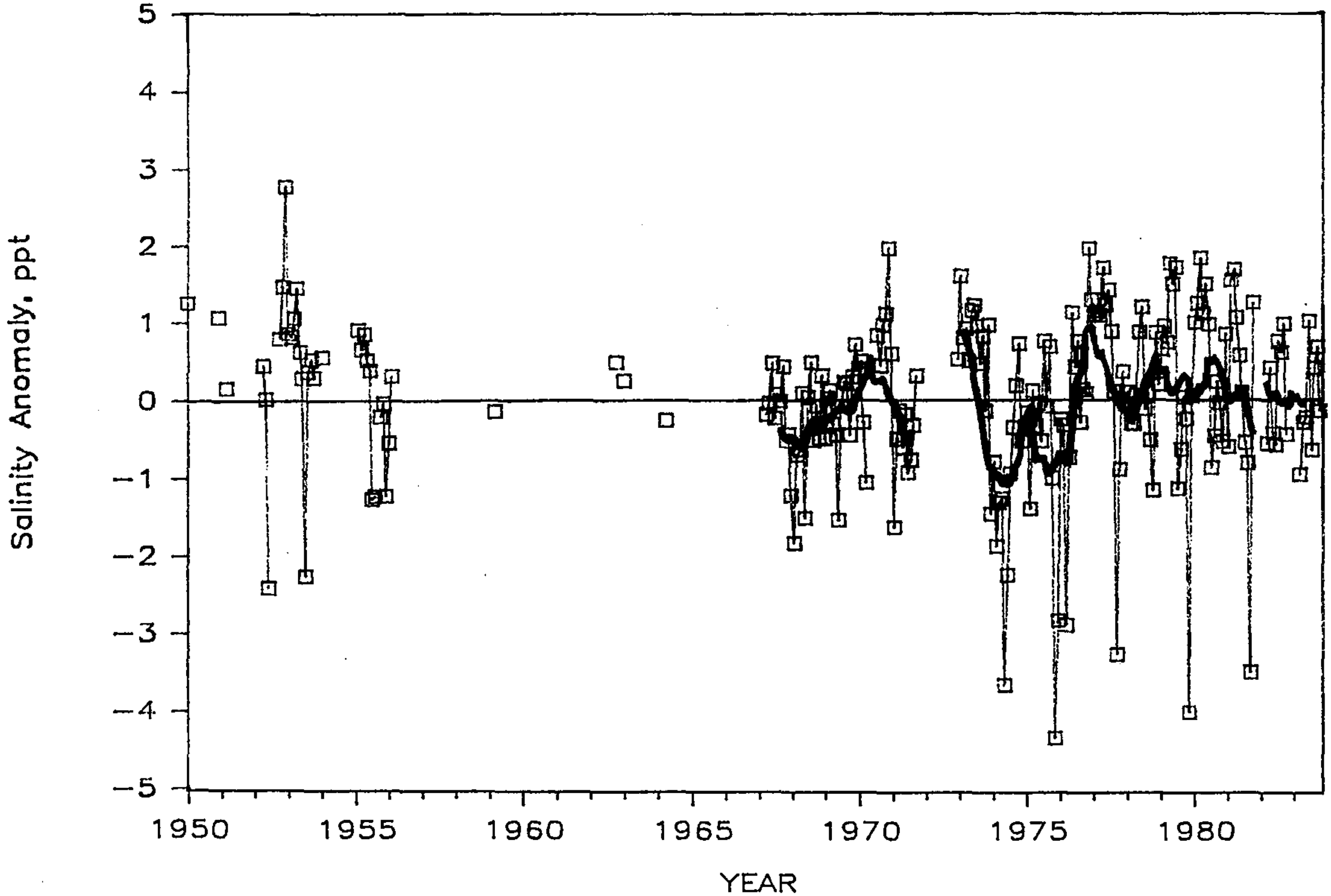


Figure 11a. Monthly salinity anomalies at West Point: in the surface waters. The background trace is the 12-month running average of the monthly salinity anomalies. Source: EPA Storet data files.

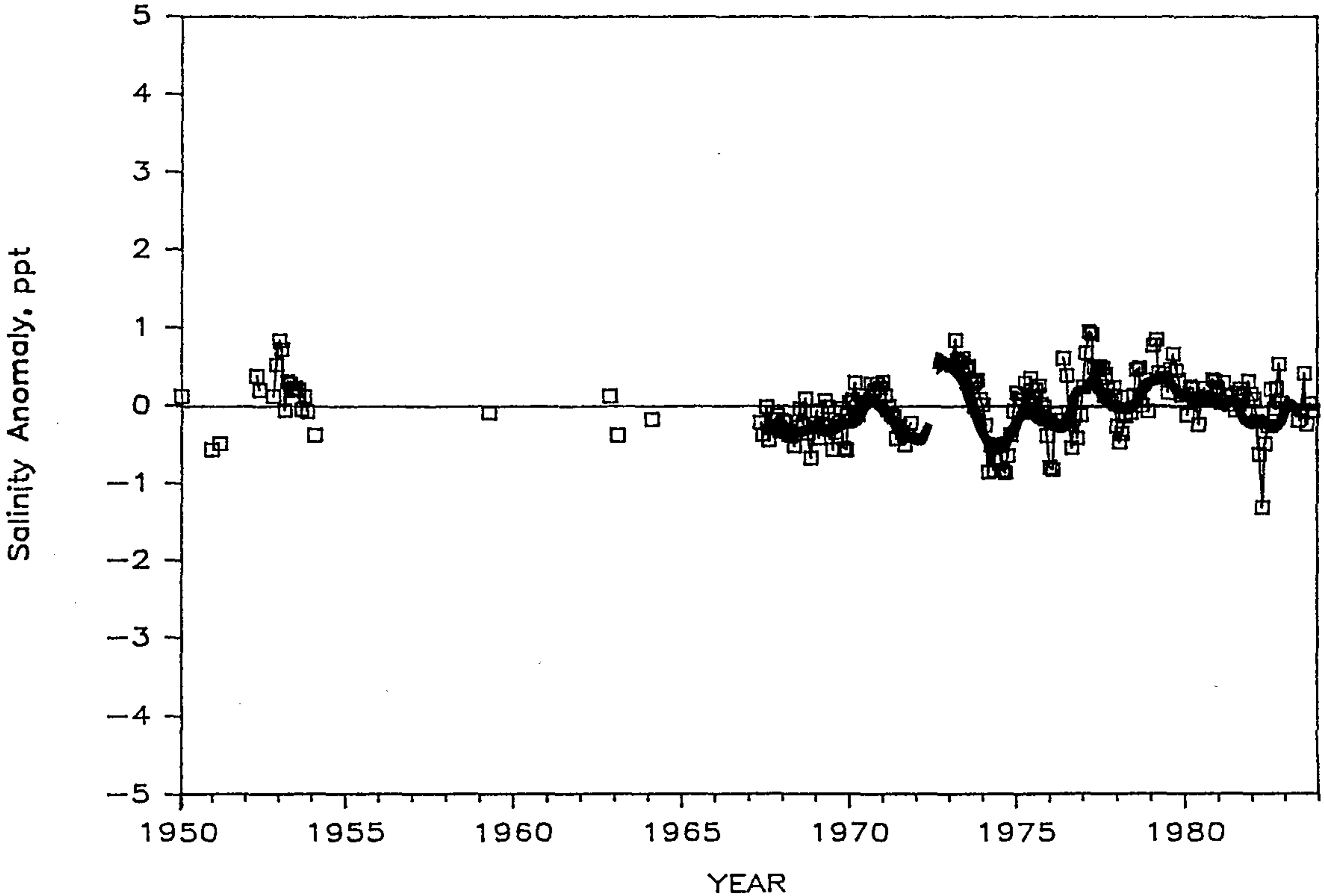


Figure 11b. Monthly salinity anomalies at West Point: in the waters at depths of 80 to 120 m. The background trace is the 12-month running average of the monthly salinity anomalies.
Source: EPA Storet data files.

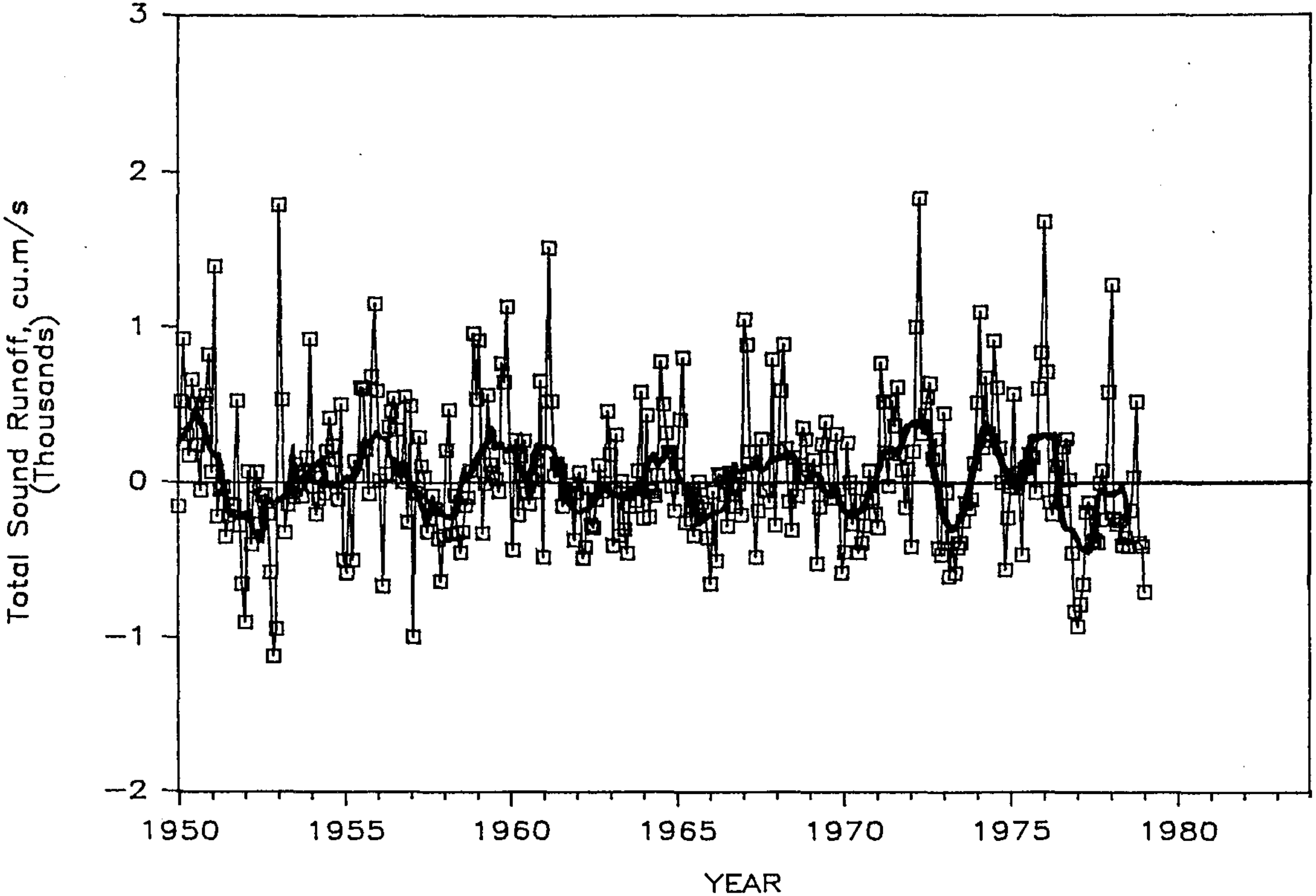


Figure 12. Monthly anomalies of the total runoff to Puget Sound south of Admiralty Inlet from 1950 to 1980. The background trace is the 12-month running average.
Source: Coomes et al., 1984.

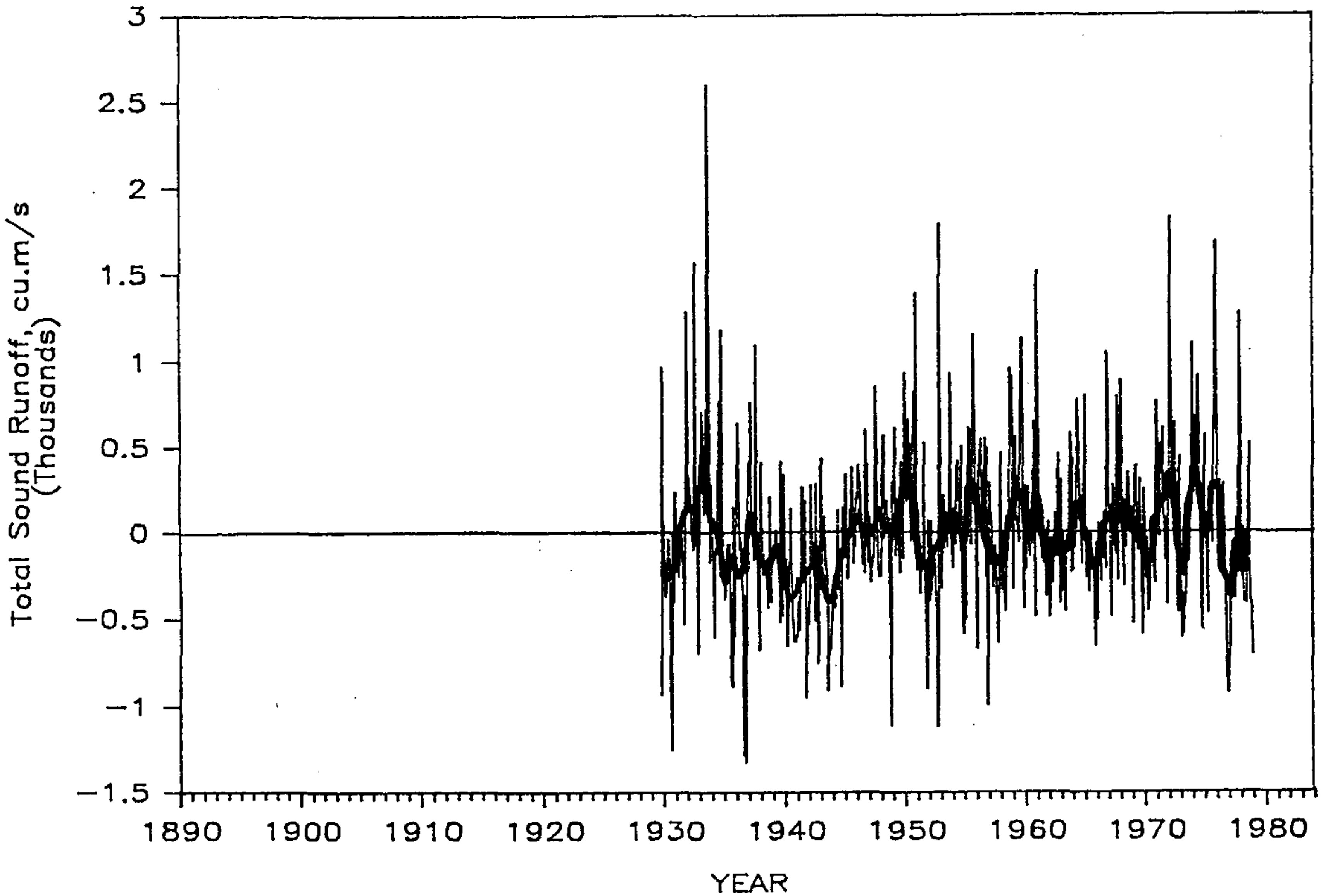


Figure 13. Monthly anomalies of the total runoff to Puget Sound south of Admiralty Inlet from 1930 to 1980. The background trace is the 12-month running average of the monthly anomalies.
Source: Coomes et al., 1984.

In an attempt to extend the record even further, the relationship between precipitation, which has only a minor influence on the freshwater in the Sound as a direct input, and runoff were investigated. The precipitation data were obtained from the Seattle EMSU weather station, the same one from which the air temperature data were obtained. This record extends to 1878, but only the data from 1890 were used. The data are presented as the seasonal cycle in Figure 7 and as the anomalies of the total monthly precipitation from 1950 to 1983 (Figure 14) and from 1890 to 1983 (Figure 15).

Comparisons of the precipitation and runoff records, Figures 12 and 14, and Figures 13 and 15, show the very strong correspondence between rainfall at Seattle and the total runoff to Puget Sound (south of Admiralty Inlet) and demonstrate the validity of using the precipitation data to estimate the trends in past runoff. Important features of the long-term rainfall data (Figure 15) then, are the apparent long period of lower than average rainfall between 1910 and 1930 and the trend toward increasing rain from 1930 to the present. These long-term changes overlie the more regular annual to decade-long variations.

By inference, the changes in the amount of rainfall experienced in the Puget Sound basin resulted in comparable changes in the runoff to the Sound and hence in the salinities. It can be estimated, therefore, that during the 20 years prior to 1930, Puget Sound may have had higher salinities than at present. It must be noted, of course, that since salinity is only partly controlled by runoff, the actual ranges of salinities which occurred during this period cannot be projected. It is possible that if long-term records of the salinities of the northeast Pacific Ocean water were available, they could be used together with the precipitation data to obtain a better picture of the conditions in the Sound during the early part of the century. Locating such data bases was beyond the scope of this study.

As was the case with temperature, the long-term temporal variations in salinity probably have been small compared to the normal annual cycles. The importance of these small variations on the physical or biological processes in the Sound is not known. Recent work has established some clear relationships between short-term increases in the runoff in the Sound and increased currents (Ebbesmeyer et al., 1984). Some long-term changes in the current regimes at time scales similar to those noted in the smoothed salinity and temperature plots have been identified and appear to be related to changes in the water density in the Sound (Ebbesmeyer, personal communication).

Similarly, while the sensitivity of many organisms to short-term salinity fluctuations is well known, the importance of long-term changes of a few parts-per-thousands in the mean salinity has not been investigated directly.

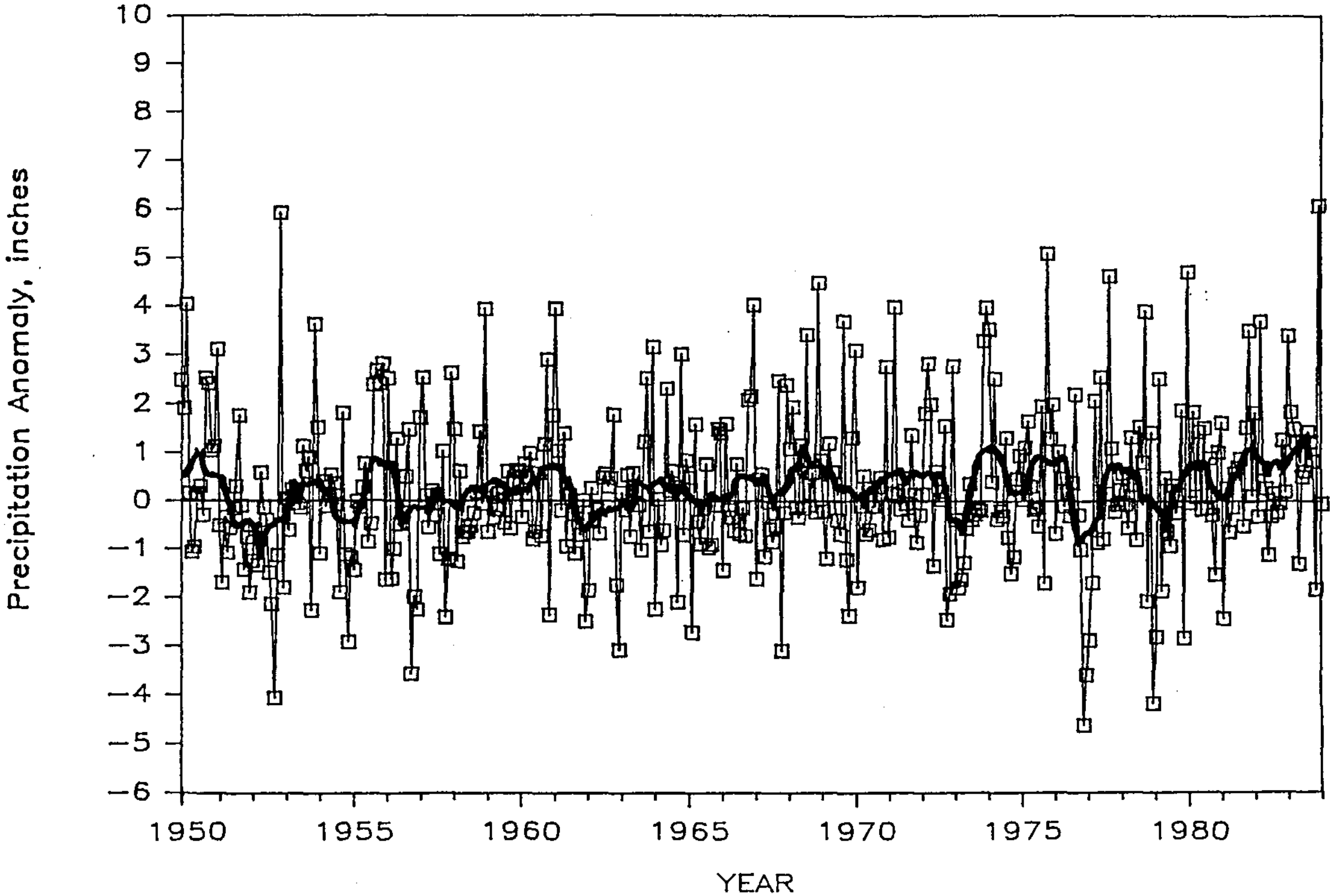


Figure 14. Monthly precipitation anomalies at Seattle from 1950 to 1983. The background trace is the 12-month running average of the monthly anomalies.
Source: NOAA, 1983.

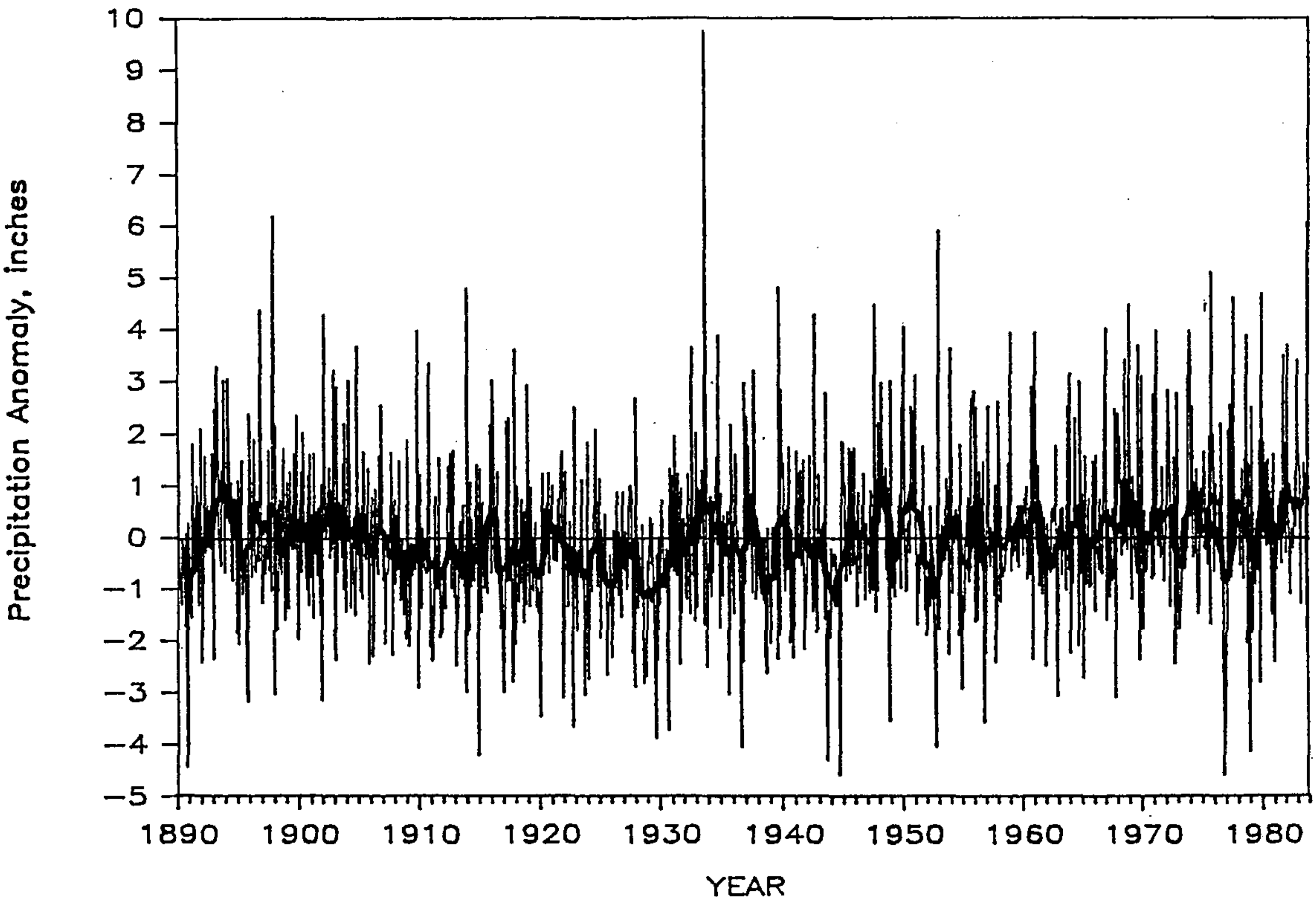


Figure 15. One-year running averages of the monthly precipitation anomalies at Seattle from 1890 to 1983.
Source: Department of Commerce, 1960; NOAA, 1983.

4.3 SEA LEVEL

An additional parameter included in this chapter is the record of sea level that has been maintained at Seattle since 1899 (Hicks et al., 1983). These data are presented in Figure 16 as the monthly average sea level from 1899 to present. The data are included not because sea level itself, which fluctuates daily with the tides, is of critical importance to the Sound, but because of the obvious trend of increasing sea level from at least 1930 and apparently continuing to the present. The timing of the initiation of the sea level rise appears to coincide with the period of air temperature increase (Figure 9), leading to the obvious speculation that the rise is a result of increased water in the oceans resulting from the world-wide melting of accumulated ice. However, this explanation assumes that the temperature rise observed at Seattle is representative of global conditions, and other explanations are possible, including subsidence of the land around the Puget Sound basin or at least near Seattle.

The point to be remembered is that sea level has in recent years risen in the Puget Sound area. While this does not constitute a significant increase in the amount of water in the Sound, an increasing sea level may have major effects on shore structures and shore processes. The higher sea level may have increased the rate of shoreline erosion from wave action as well as changed the extent and characteristics of wetland areas. If the trend continues, it is obvious that many currently low-lying areas will be inundated as the intertidal zone moves upland. As with the previously discussed parameters, no studies have been performed to determine the effect the past changes may have had on sedimentation processes in the Sound, the intertidal organisms, or other shore-related processes.

An additional observation relevant to sedimentation processes is that the temporal variations in precipitation and runoff also have potentially strong effects on the sediment inputs to the Sound. The relative importance of shore erosion and riverine inputs of sediments as well as most other facets of sediment transport and accumulation are poorly understood in the Sound (Dexter et al., 1981; Baker, in press; Lavelle and Mofjeld, 1984; Carpenter et al., in press), but it is interesting to note that both riverine (runoff) and shore (sea level) erosion could be increasing in comparison to earlier in the century.

4.4 WIND SPEED

Wind speed has been included in this chapter (Figure 17) because of recent recognition of the importance of wind stress to the circulation of the Sound (Ebbesmeyer et al., 1984). The data are from the Seattle-Tacoma Airport Meterological Station and were obtained as the monthly average wind speed calculated from nearly continuous measurements (Coomes et al., 1984). The monthly averages are presented to illustrate the large variances at that time interval and to identify major periods of high wind speed or duration.

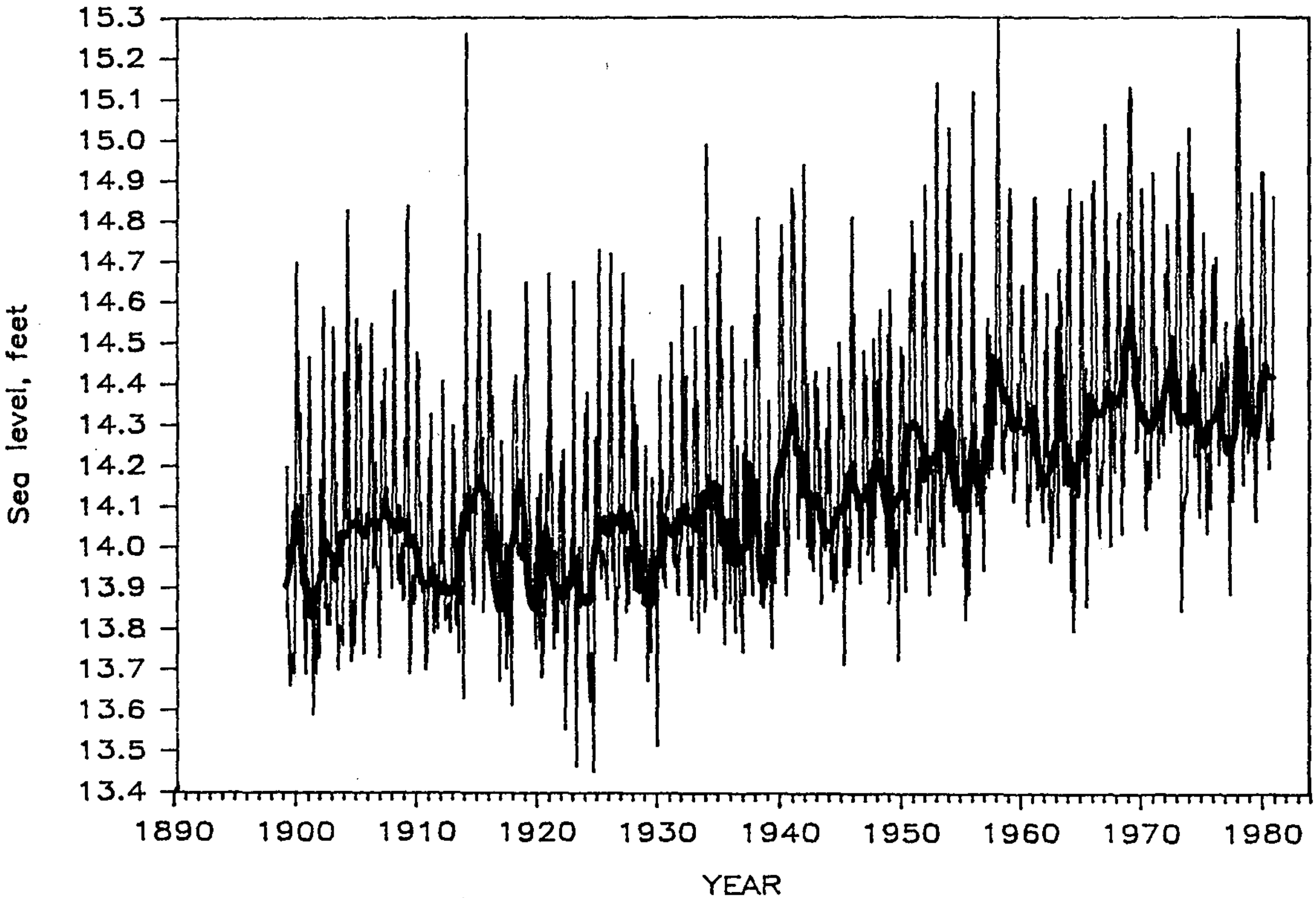


Figure 16. Monthly average sea level at Seattle from 1899 to 1980. The background trace is the 12-month running average of sea level. Source: Hicks et al., 1983.

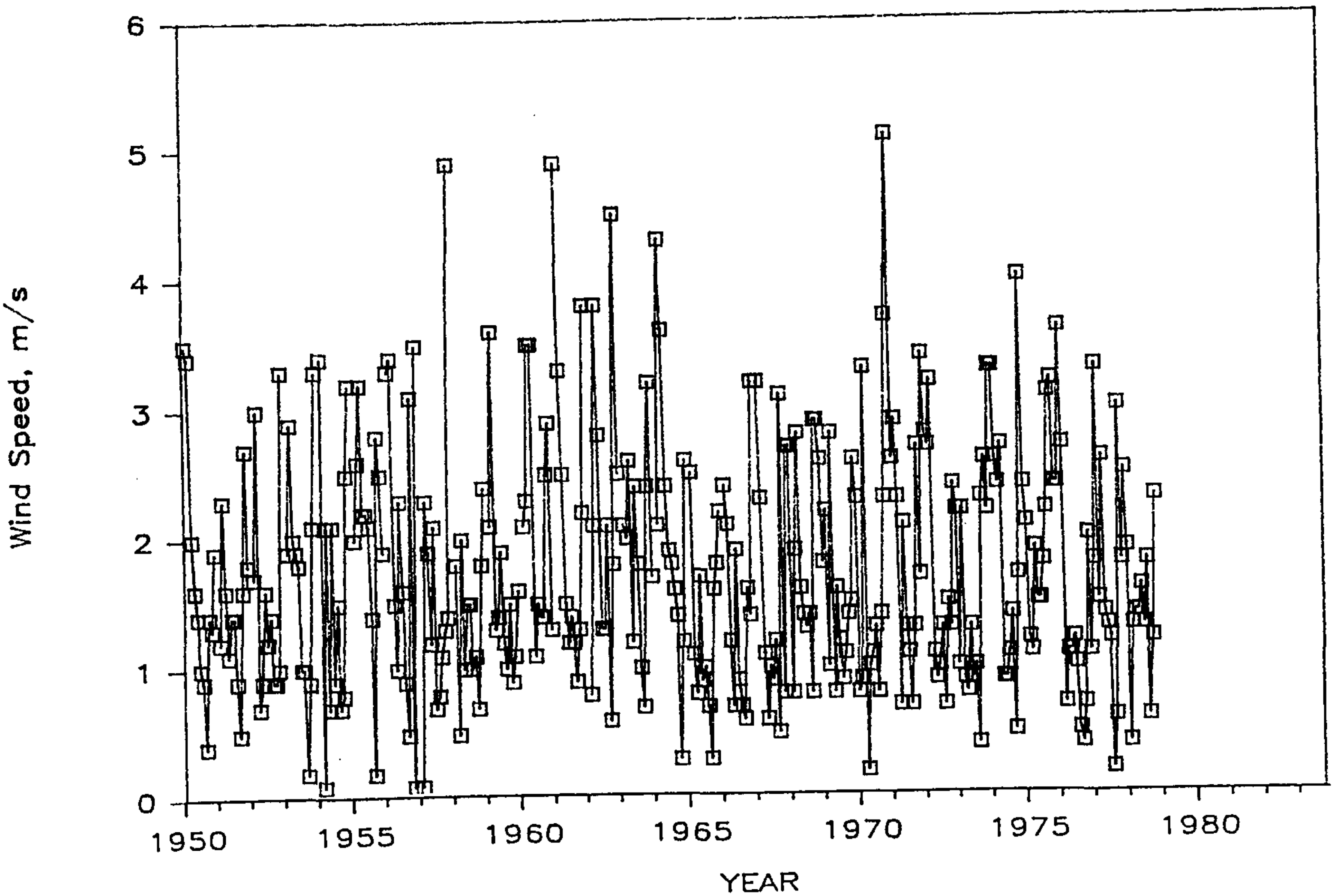


Figure 17. Monthly average wind speed at the Seattle-Tacoma airport from 1950 to 1978.
Source: Coomes et al., 1984.

The normal annual cycle of higher wind speeds during the winter months can be seen in Figure 17, while about five periods of high winds can be identified during the late 1950s and early 1960s and again in 1970. The wind records have been more fully analyzed in Coomes et al. (1984), who presented daily records for wind speed, direction and variance. These authors identified 24 storms of major magnitude, although no effects to the Sound were attributed to any of those storms. As noted earlier, in a companion document, Ebbesmeyer et al. (1984) developed quantitative relationships between wind speed and direction and the circulation of the Main Basin of the Sound. Very briefly, strong winds from the south increase the shallow and deep transport in the Main Basin, while winds from the north tend to retard this transport.

5. CONVENTIONAL POLLUTANTS

"During the past year, an emergency has arisen in regards to pollution of the fresh and salt water areas of the state. The concentration of pollutants in certain areas has reached the danger point... Great damage can be done to the fisheries and recreational assets of the state, as evidenced by the condition of the streams on the Atlantic Seaboard..." The Seattle Times in the fall of 1984? No. This quote is from the Washington State Department of Fisheries Annual Bulletin of 1937 (WDF, 1937a) and demonstrates that human impacts to the Sound are not solely of recent origin, nor have been the efforts to remedy the effects of those impacts.

Anthropogenic pollution of Puget Sound is undocumented but was undoubtedly minimal prior to the settlements in the mid-1880s. However, as is described in Chasan (1981), the change was swift and dramatic resulting from the rapid proliferation of saw mills followed by coal mining, ship building and eventually a large variety of other industries in the Puget Sound basin. The water quality problems associated with this development have been broken down in this report into two major classes: conventional pollutants, which include those waste materials associated with domestic wastes, and toxic chemical wastes. This chapter discusses the temporal trends in the conventional pollutants, while the next chapter presents data on the trends in toxic chemical pollution.

The conventional pollutants include organic matter, plant nutrients such as phosphates and nitrates, and pathogenic microorganisms (bacteria, viruses, etc.). These pollutants can result in two types of water quality problems, low dissolved oxygen levels and high concentrations of disease-causing organisms in the water and in the biota. Excessive discharge of organic matter can result in oxygen depletion as discharged materials are oxidized in the environment. Nutrient enrichment can induce excessive plant growth which, when plants die and decay, also results in oxygen depletion. Pathogenic organisms can remain viable both in the water and after accumulation by filter-feeding organisms such as clams and oysters. Contamination from these pathogens can lead to outbreaks of human disease from water contact or through the ingestion of contaminated food.

In this chapter, data are presented regarding the trends in these principal conventional pollutants, including available data on the inputs and the possible effects the discharges may have caused in the Sound. Consistent with the intent of this report, the data are considered primarily at the scale of the whole Sound. Local effects have rarely been quantitatively documented and are not dealt with extensively in this report.

5.1 ORGANIC CARBON

Consistent, quantitative monitoring of the organic carbon loading to the Sound has only been initiated in the last few decades. However, the historical records clearly document incidences of gross pollution associated with even the earliest industry on the Sound, the lumber mills. These early problems resulted from the disposal in the local waters of the unwanted sawdust, bark and other wood debris from the mills and probably included effects of smothering, oxygen depletion and toxicity. An 1898 Washington State Fish Commission Report (Washington State Fish Commission, 1898) described the problem as:

> "Large beds of clams and the spawning grounds of immense numbers of smelt, herring, and other food fish have been destroyed by the deposits of sawdust and mill refuse...A stringent law should be enacted prohibiting this evil as, not only is it an injury to the fishing industry, but to navigation as well."

The quantities of material and the total impacts to the Sound cannot be assessed this far after the fact, but considering the numbers of both large and small mills and the quantities of lumber handled (Chasan, 1981), both may have been large. Because the mills were most often in protected inlets where the flushing was generally poor, the wood debris could readily form decaying, anoxic bottom deposits. The temporal extent of the problem was poorly documented, but evidently was well developed by the late 1800s, and was still referred to in reports to the middle of this century (Washington State Fish Commission, 1898; WPCC, 1945-1957). The practice of dumping wood debris was made illegal at about the turn of the century, and it appears that a combination of regulatory control, the development of alternative uses, e.g., in hog-fueled boilers, and the eventual closure of many mills as the nearby forests were depleted led to the eventual elimination of the problem.

As the direct discharge of wood debris decreased, two other sources of oxygen-demanding materials were increasing: the pulp mills which were built on the Sound beginning in the early 1920s, and domestic pollution from the growing settlements.

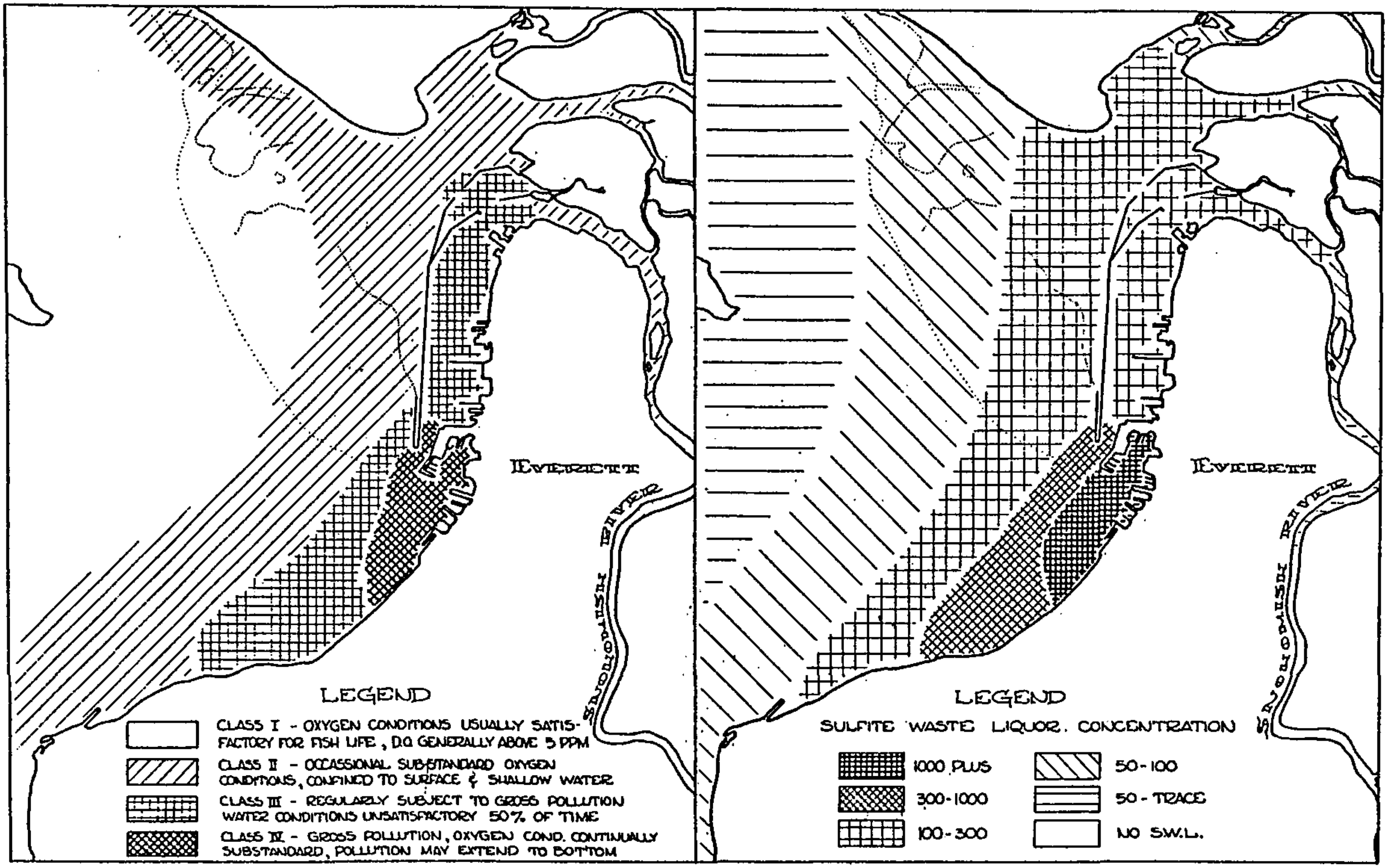
Wood pulp has been made in the Puget Sound region primarily by the sulphite process. This procedure uses chemicals (sulphites and caustic) and heat to separate and recover the cellulose fibers from the raw wood. The waste material, which may represent one-half of the weight of the original wood, is primarily dissolved and has been historically discharged directly to the Sound, together with the residual chemicals left in the process water. This sulphite waste liquor (or spent sulphite liquor), which is toxic at high concentrations and carries a high oxygen demand, was discharged in tremendous quantities by the pulp mills. The resulting toxicity in the discharge zone as well as the longer term decreases in available oxygen, led to declines in nearly all marine organisms in the vicinity of the mills (U.S. EPA, 1967). These impacts, which were apparent from the time the mills first began operations, led to a half-century of arguments among mill owners, fishermen and shellfish growers, and local, state and federal government agencies as to the necessity and extent of waste discharge controls (Chasen, 1981).

Fisheries Department Annual Reports as well as the reports of the Washington State Pollution Control Commission from 1940 to the 1960s clearly document the frequent incidences of fish kills and the limited growth of bottom and piling organisms associated with large areas near some of the mills. The water in these areas was foamy, discolored and had a strong odor of hydrogen sulphide (Townsend et al., 1941). Everett Harbor, which provides a well-studied example of pulp mill effects, received the effluent from two of the largest mills in the Sound and is also a partially enclosed area. Bottom waters are likely poorly flushed relative to open central Sound waters. This site was chronically polluted in the 1930s for miles away from the discharges themselves (Figure 18).

Many mill owners attempted to correct the pollution problems by altering the discharge locations, installing treatment to remove at least some of the toxic materials, and changing the pulping process, but all were eventually required by the state and federal government to employ secondary treatment prior to waste discharge. Conversions by the mills took place during the 1960s and 1970s with the final mill converting to advanced waste treatment in 1980. Table 2 presents a listing of the start-up (and closure) dates of the mills on Puget Sound as well as the locations of their discharges. The quantities of oxygen-demanding material, measured by the 5-day biological oxygen demand (BOD) test, discharged by the mills in 1969, prior to the installation of the final treatment systems, and in 1984 are also presented in Table 2.

To illustrate the effects of advanced waste treatment on the mills' discharges, Figure 19 was prepared showing the temporal trends in the BOD discharges for the major mills. For clarity, the northern Sound discharges are presented separately (Figure 19a) from those discharges located south of Admiralty Inlet (Figure 19b). It is fairly obvious from the data in Figure 19 that the decreases in BOD loadings to the Sound have been substantial, from an approximate total BOD loading for all operating plants of over 2,000,000 lbs/day in 1969 to less than 30,000 lbs/day in 1983 (data from the Discharge Monitoring Reports required and stored by the Washington State Department of Ecology).

Other industries located in the near-shore areas of the Sound have been periodically noted in the Pollution Control Commission reports of the 1940s and 1950s for the discharge of excessive quantities of organic matter. These industries were primarily food processing plants, including particularly fish-, shellfish-and meatpackers. Limited quantitative information is available in these reports but the descriptions that were made indicate that although some problems were significant, most incidences



Dissolved Oxygen Conditions in Port Gardner Bay and the Lower Snohomish River

Occurrence of Sulfite Liquor in Port Gardner Bay and the Lower Snohomish River

Figure 18. The effects of pulp mill discharges in Everett Harbor, 1942.
(a) dissolved oxygen, (b) sulphite waste liquor.
Source: Cheyne and Foster, 1942.

Table 2. Summary of information regarding the pulp mills of Puget Sound

Mill	Dates of Operation	Date Secondary Treatment Started	BOD[c] Loading 1000 lbs/d 1969	1984
Georgia-Pacific[a], Bellingham	1928 to present	1979	280	18
ITT-Rayonier, Port Angeles	1930 to present	1979	470	25
Crown-Zellerbach, Port Angeles	1917 to present	1978	24	4
Fiberboard, Port Angeles	1917 to present	NA[b]	24	4
Scott, Anacortes	1928 to 1977	NA	136	0
Port Townsend Paper Co., Port Townsend	1928 to present	1976	10	1
Scott, Everett	1929 to present	1980	825	12
Weyerhaeuser Sulphite, Everett	1936 to1974	NA	320	0
Weyerhaeuser Thermo-Mechanical, Everett	1974 to 1980	NA	NA	0
Champion International, Tacoma	1928 to present	1977	42	5
Boise-Cascade, Steilacoom	1947 to present	1978	ND[b]	5
ITT-Rayonier, Shelton	1928 to 1957	NA	NA	0

[a] Many, if not most of the mills have undergone one or more name changes as ownership and other changes have altered their corporate structures. An attempt was made to use the current names for each Mill.

[b] NA means not applicable (Mill closed before secondary treatment was initiated); ND means no data.

[c] Data from Discharge Monitoring Reports on file with WDOE.

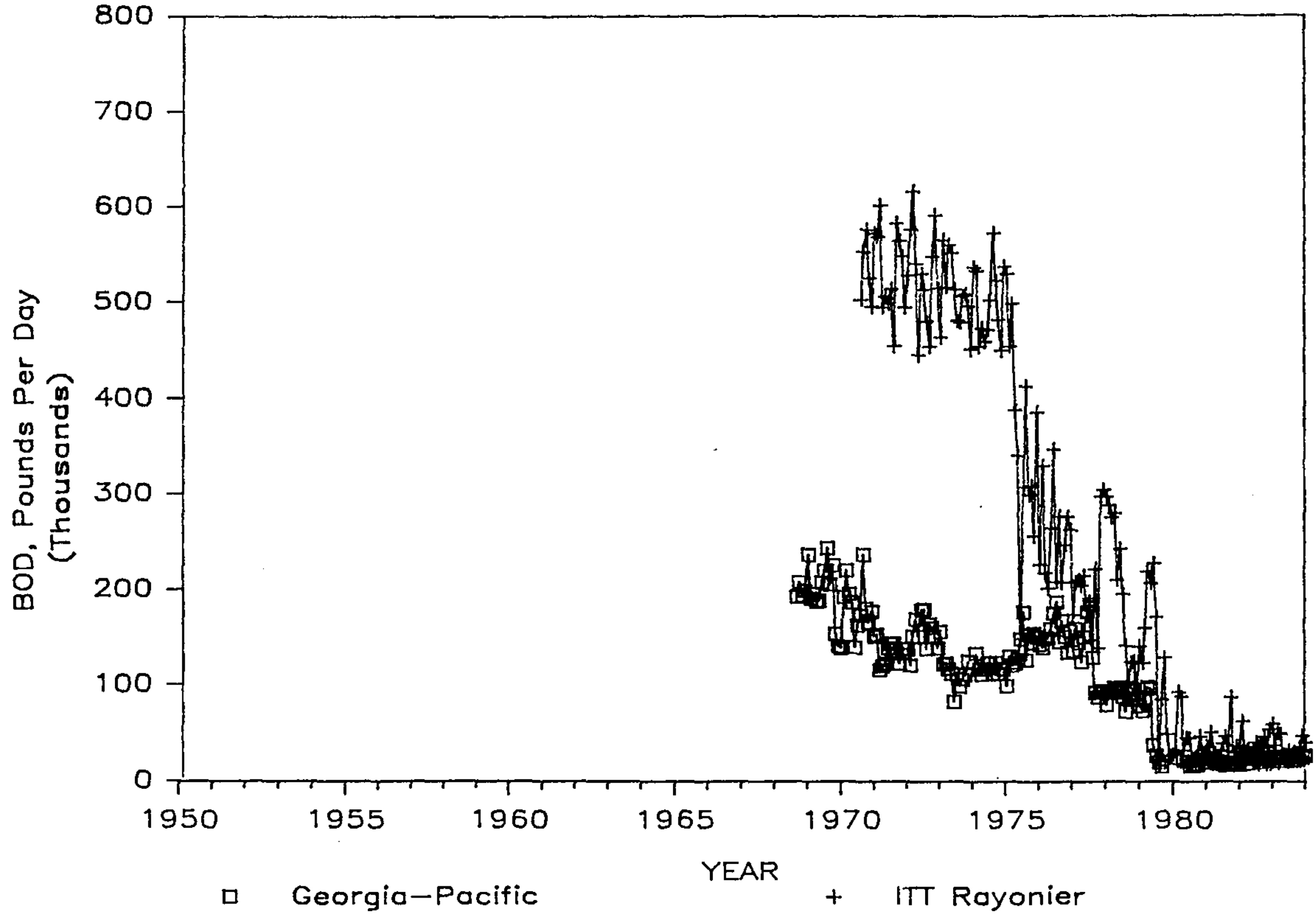


Figure 19a. Biological oxygen demand inputs to Puget Sound from major pulp mills from 1965 to 1983: mills in the northern Sound.
Source: WDOE data files.

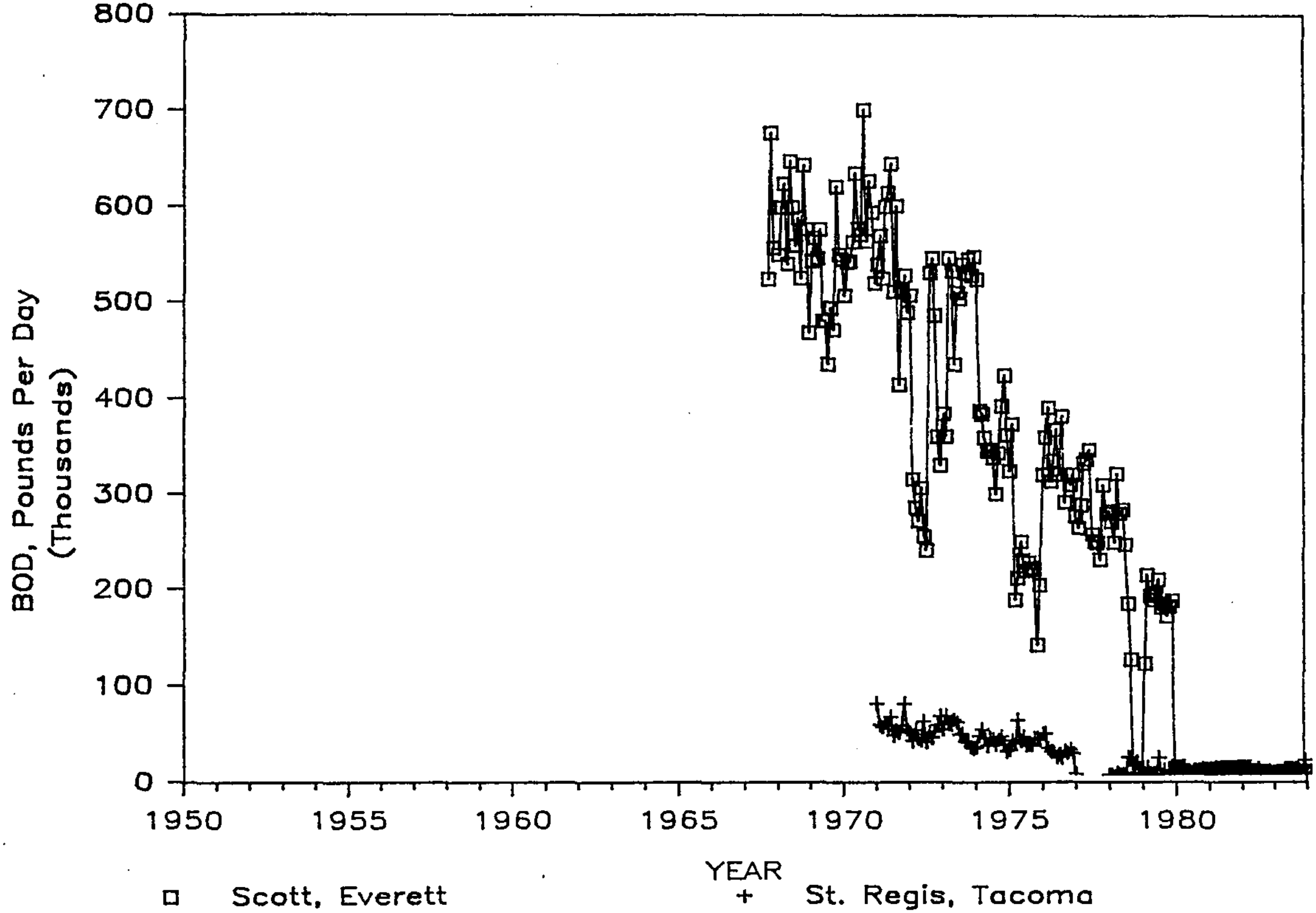


Figure 19b. Biological oxygen demand inputs to Puget Sound from major pulp mills from 1965 to 1983: mills south of Admiralty Inlet.
Source. WDOE data files.

were relatively small, often temporary and of only local influence. Typical citations in the reports include:

> This slaughterhouse and packing plant discharges its wastes into the Wheeler-Osgood Waterway (Tacoma) after treatment with inadequate grease skimmers. Waste waters contain 300 to 350 ppm of grease in addition to other dissolved and suspended solids. There is no blood collection made of hogs blood. This plant presents a particular problem in that its wastes are discharged into a water area where logs are stored and men must work. The estimated population equivalent of this plant is 43,750 persons. (Jones, 1951). (Authors' note: This plant discharged nearly as great a BOD load as the third largest municipal discharger at the time.)

> Inspection of this garbage dump (at Spokane and Alki Streets, Seattle) revealed that...garbage from this dump is swept away by the tide and deposited along the shores of Elliott Bay. (WPCC, 1946a).

> The tidelands near the cannery (at Deer Harbor, Orcas Island) for a distance of at least one-quarter mile were littered with tremendous quantities of wastes ('decomposing fish heads and offal') from the cannery. (WPCC, 1947).

Regulatory control, including hook-up to the local municipal treatment system, increasing use of previously wasted by-products and the closure of many of the plants has virtually eliminated these sources of pollution to Puget Sound.

Discharges of oxygen demanding substances from domestic sources probably grew in direct proportion to the population in the area. Initially these discharges were untreated and were usually discharged at the water's edge. It was not until after after World War II that major steps were initiated to control the domestic waste problem, through the construction of waste treatment plants and offshore discharges (Chasan, 1981; WPCC, 1945-1957). It was not until the late 1960s that raw sewage discharges were virtually eliminated. Essentially all municipal waste discharges now have at least primary treatment and offshore discharges.

Quantitative estimates of the amounts of material discharged by domestic sources was poorly documented prior to the 1960s. No outfalls were monitored in the sense that monitoring is now conducted and very few received any type of quantitative measurement until recently. In 1951, 51 municipalities recorded a total BOD loading equivalent to that of a city of over one million people. Of these, only 18 had treatment plants, 5 of which were secondary (2,800 people were on secondary treatment) (PNDBO, 1951). The major dischargers, including Seattle (500,000 persons), Tacoma (125,000 persons), and Fort Lewis (50,000 persons) had no treatment. Currently there are approximately 76 communities discharging to the Sound, virtually all with at least primary treatment (Jones and Stokes and Tetra Tech, 1983). The current BOD load from all municipal sources to the Sound is about 188,000 lbs per day. Of this loading, approximately 50 percent is from the Metro West Point Sewage Treatment Plant and about 10 percent is from three Tacoma plants (Jones and Stokes and Tetra Tech, 1983).

Because of the relatively good historical documentation available, the West Point discharge was selected for more detailed historical presentation to illustrate the trends in municipal sewage control in the Sound. Primarily because of its size, and hence potential pollution impacts, West Point has been the most closely monitored municipal discharge in the Sound, and data from this monitoring program have provided a significant portion of the information presented in this report (see, for example, the temperature and salinity data from West Point in Chapter 4).

Prior to the creation of Metro and the construction of the West Point Sewage Treatment Plant, the majority of the sewage from the city of Seattle was discharged untreated through a number of discharge pipes. Initially, these wastes were discharged directly onto the beaches, but in the late 1940s, the city extended the outfalls to about 10 m deep. This attempt to relieve the fouling of the beaches was unsuccessful (Sylvester et al., 1950). A partially quantitative evaluation of the conditions in 1957 was summarized in the facilities planning report which led to the construction of the West Point plant (Brown and Caldwell, 1958). The locations of the sewage discharges in 1957 are presented in Figure 20, together with the areas (and acreage) served and estimates of the dry weather BOD loading, when the latter data were available. Based on these limited data, the total BOD input to the Sound from Seattle in 1957 can be estimated to have been about 50,000 lbs per day.

Construction of the West Point plant was intended primarily to clean up Lake Washington, which it did (Edmonson and Lehman, 1981). As a result, raw sewage discharges into Lake Washington (and also into Elliott Bay) were greatly reduced. Discharges of combined storm water and sewage still occur at overflow structures during periods when storm runoff exceeds the capacity of the system, but these discharges are small compared to the total flow. Benefits to the marine environment resulted from the fact that the discharge was not only treated (primary), but the outfall location was moved offshore and to a greater depth, thus providing good dispersion of the effluent. The changes have virtually eliminated incidences of gross fouling of the beaches along West Point and much of Elliott Bay.

Sewage which had been previously discharged into Lake Washington from surrounding communities was now discharged through West Point. The additional sewage offset the load reductions to the Sound achieved by treating the wastes. This effect can be seen in Figure 21a which presents the temporal trends in the BOD discharge from West Point from its construction through 1983. It can be seen that the BOD loading increased to pre-West Point levels (about 50,000 lbs/day) and beyond as the

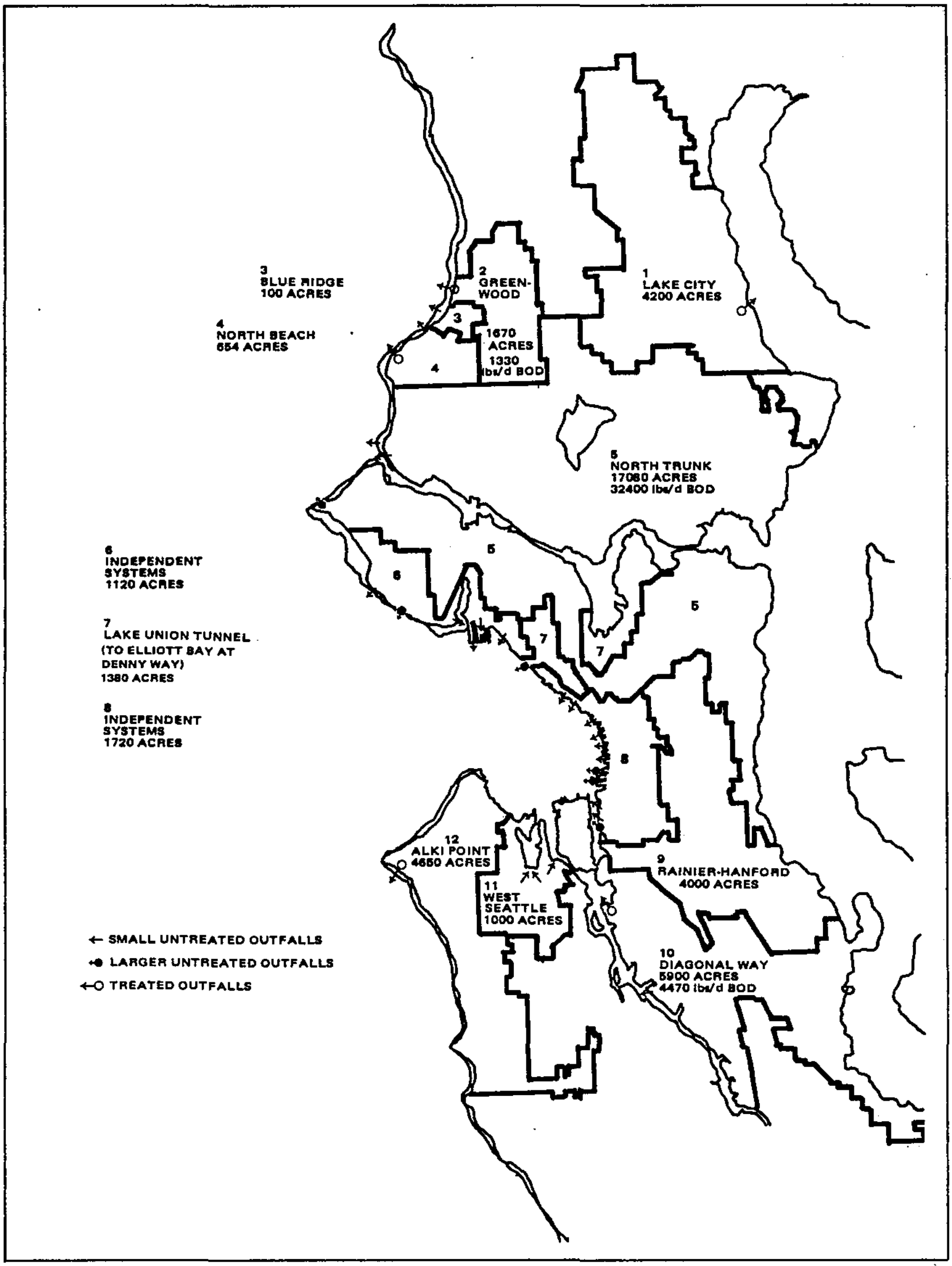


Figure 20. The locations of domestic sewage discharges for the City of Seattle, 1957.
Source: Brown and Caldwell, 1958.

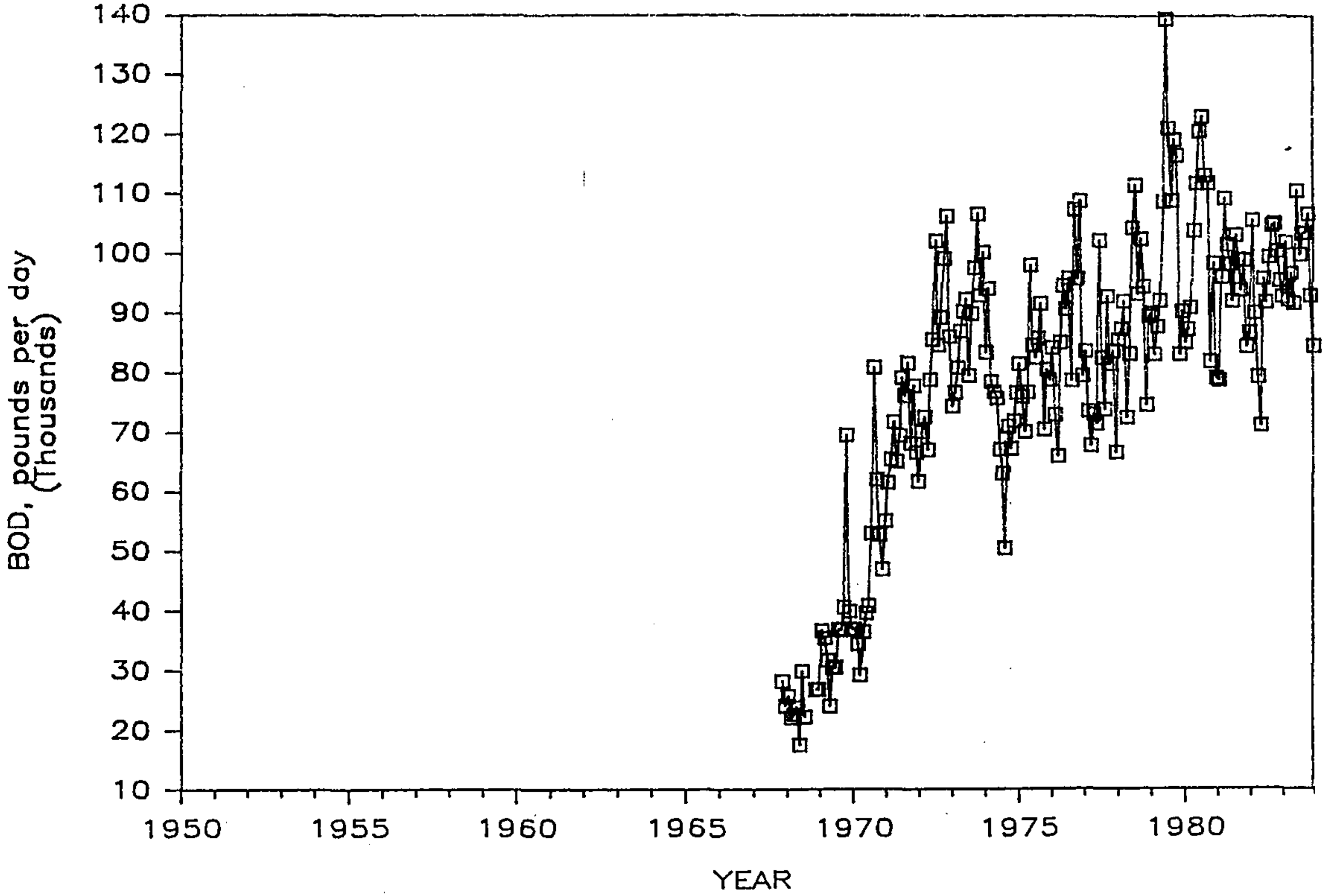


Figure 21a. Biological oxygen demand inputs to Puget Sound from the West Point Sewage Treatment Plant, 1965 to 1983.
Source: West Point Plant discharge monitoring reports.

amounts of sewage treated at the plant increased. However, this discharge is still substantially smaller than the past discharges from the pulp mills. With the load reductions achieved by the pulp mills, West Point is now the largest single source of anthropogenic BOD to Puget Sound (Figure 21b).

As noted earlier, the major impacts of the BOD loadings to the Sound have been localized areas of depressed oxygen and anoxic sediments which have caused fish kills and other problems. For the majority of the Sound, however, the inputs do not appear to have been sufficient to significantly affect the levels of dissolved oxygen (DO). This assumption is illustrated by comparisons of the spatial differences in the DO concentrations observed in the surface water at the same locations as the temperature and salinity data presented in Chapter 2. As before, the DO levels are presented as the monthly average (seasonal) concentrations, with the locations from the northern Sound (Figure 22a) separated from those south of Admiralty Inlet (Figure 22b).

All locations showed similar seasonal trends, with higher DO concentrations in the summer months in response to photosynthetic oxygen production. DO minima occur in the surface waters in the late fall, during the period of algal die-off and decay (Dexter et al., 1981). The largest spatial differences are apparent between the northern locations and those south of Admiralty Inlet. The northern stations may be influenced most strongly by the low-oxygen, deep-ocean water in the Strait of Juan de Fuca.

The DO data were obtained from the WDOE, Metro and UofW data sets available from the EPA Storet files. Most values were collected at frequencies of from one to four values per month and were averaged to yield a single set of monthly values. Anomalies in the DO concentrations were calculated in a manner similar to that used for temperature and salinity. Positive monthly anomalies indicate DO levels higher than the long-term average concentration.

The long-term trends in DO concentrations in the Sound have been analyzed previously for data from the 1930s through 1975 with the conclusion that no long-term changes were evident (Duxbury, 1975). The data from 1950 to 1983 are presented in Figure 23 for the deep water (80-120m) at West Point. This depth range was selected because the lower layers of the Sound show greater seasonal oxygen depletion due to metabolic decay than does the surface (Dexter et al., 1981). As was the case with temperature and salinity, the data are presented as the anomalies of the average monthly data.

Some random interannual variations can be discerned between most years, and small changes of a longer time scale can be identified, particularly in the smoothed running average. The data are too limited to draw clear conclusions, but if any long-term trend is present, it would seem to be a slight increase in the DO concentrations indicated by the most recent data. This trend does in fact correspond inversely to the total BOD loadings, but the changes in the DO anomalies are small in comparison to

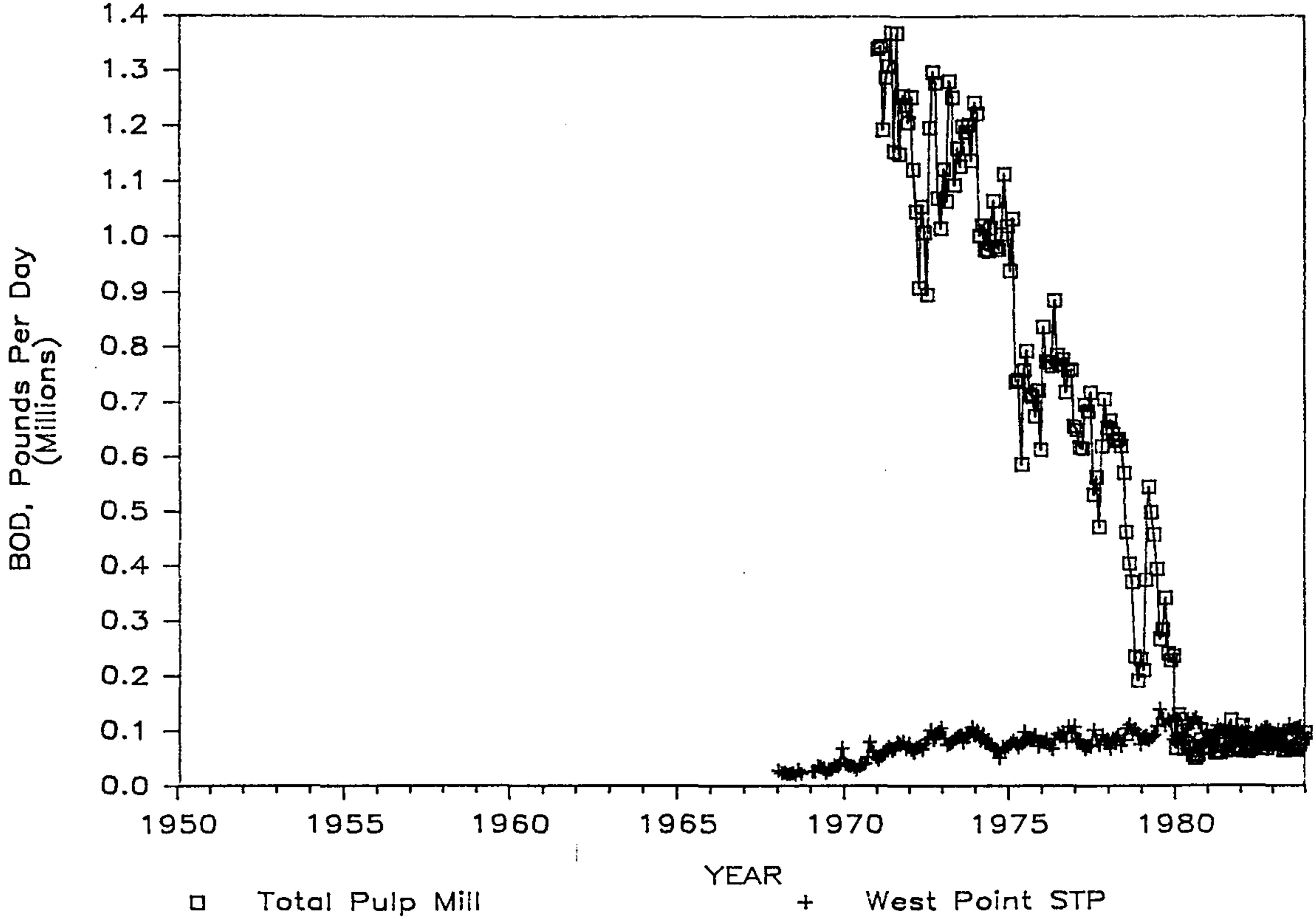


Figure 21b. Comparison of the biological oxygen demand inputs to Puget Sound from the major pulp mills and from the West Point Sewage Treatment Plant, 1965 to 1983. Source: WDOE data files and West Point Treatment Plant discharge monitoring reports.

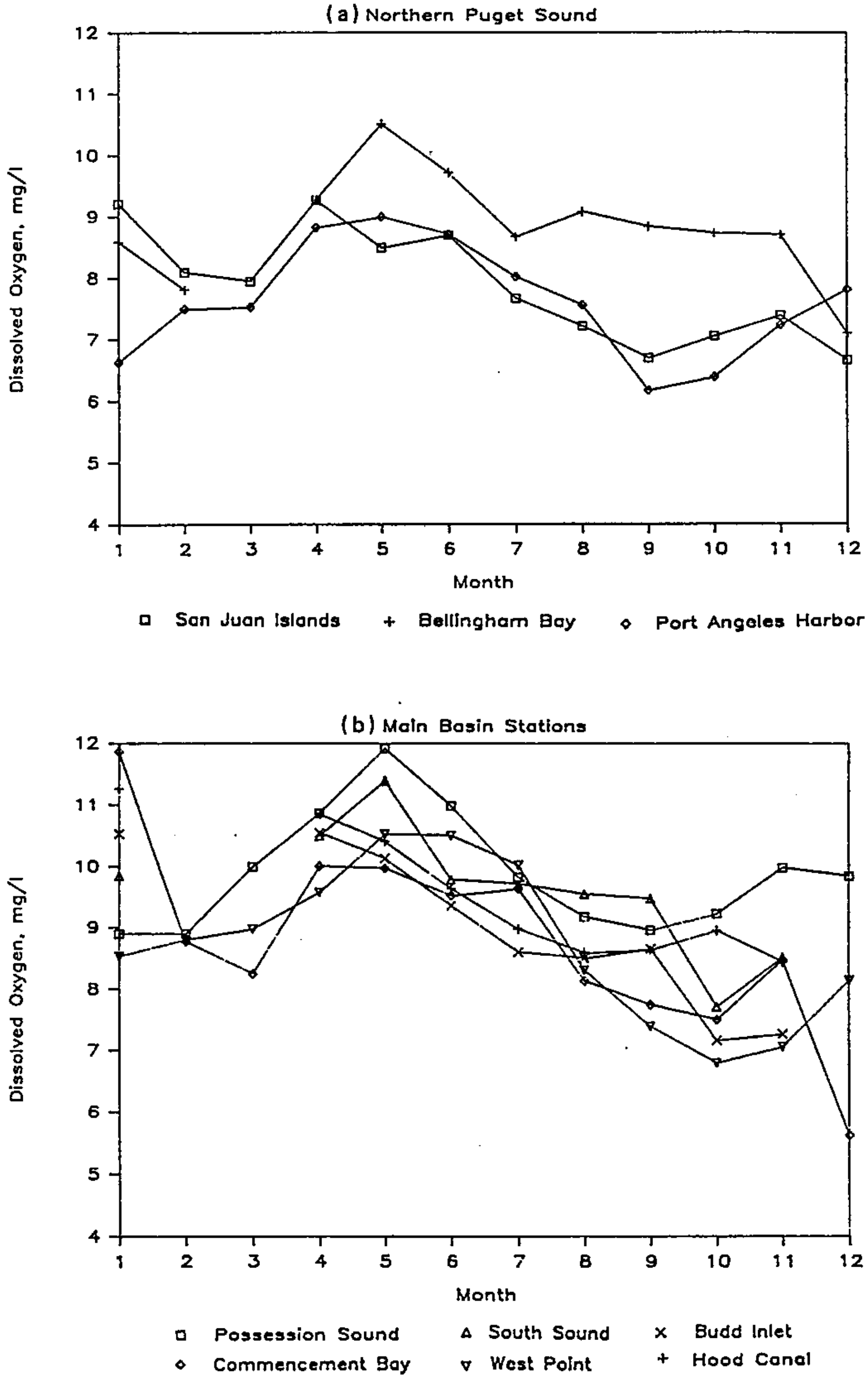


Figure 22. Monthly average concentrations of dissolved oxygen in the surface waters at select locations in Puget Sound. (a) northern Sound locations, (b) locations south of Admiralty Inlet.
Source: EPA Storet data files.

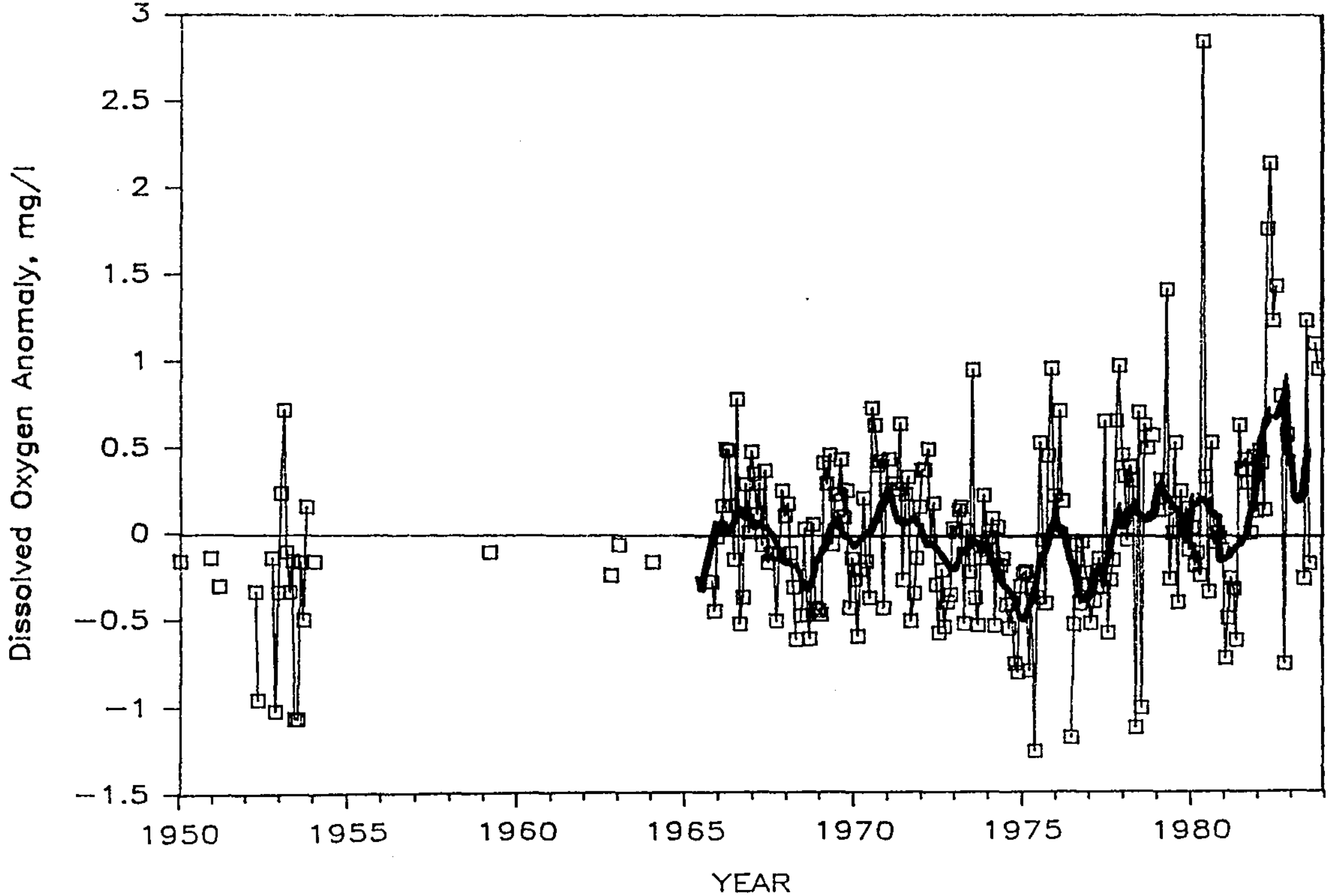


Figure 23. Monthly anomalies in the concentrations of dissolved oxygen in the deep (80 to 120m) water at West Point from 1950 to 1983. The background trace is the 12 month running average of the monthly anomalies. Source: EPA Storet data files.

the normal seasonal changes and, given the difficulties in performing DO measurements accurately (Duxbury, 1975), cannot be taken too seriously. This data analysis indicates that it is important to continue monitoring of DO levels to trace what may prove to be a real effect.

The maxima and minima in the smoothed DO record show some inverse correspondence to the similar features in the temperature plot (Figure 4), indicating the possible influence of water temperature on the metabolic utilization of DO. However, these relationships are speculative considering the quantity and quality of the present data sets.

5.2 ORTHO-PHOSPHATE

Nutrient discharges can lead to virtually the same water quality problems as organic matter if the nutrients enrich the water, inducing excessive growth of plants which eventually die and decay. Because the extent of the data for ortho-phosphate (OP) is considerably greater than that for the other nutrients, and because the relative proportion of one nutrient in the Sound to the other is roughly constant (Duxbury, 1975), the concentration of OP can best be used to assess the temporal trends in the nutrient discharges. Unfortunately, measurements of nutrient levels have been performed less frequently than for many other parameters (e.g., temperature, salinity, and DO) in monitoring programs, and even though OP has the most extensive data record for nutrients, the available data are limited.

Regional differences in the monthly averages of the OP concentrations in the surface waters of the Sound are presented in Figure 24. These data are from the WDOE data set and represent recent (mid-1970s to 1983) data collected monthly at the locations indicated in Figure 1. No winter data were collected and for a number of months no data were taken, so the averages presented in Figure 24 are from a more limited data base than those used to plot temperature and salinity (from 5 to 7 years for each month at each location).

The seasonal trends apparent in Figure 24 indicate an inverse relationship between OP concentrations and the levels of DO (Figure 22). All locations except Port Angeles showed consistent summer depressions of OP, corresponding to the maximum DO concentrations, followed by increases in OP in the fall. These trends are consistent with changes induced by biological productivity as phosphate is first utilized in primary production then released by consumption and decay (Dexter et al., 1981). At Port Angeles, no seasonal trends were apparent.

In the group of locations south of Admiralty Inlet (Figure 24b), the more southerly stations (Budd Inlet, South Sound and Commencement Bay) appear to have higher OP levels than noted in Hood Canal or Possession Sound. West Point appears to be intermediate between these regions both spatially and in OP concentrations. This trend in increasing OP concentrations in bottom water from the north to the south may reflect the

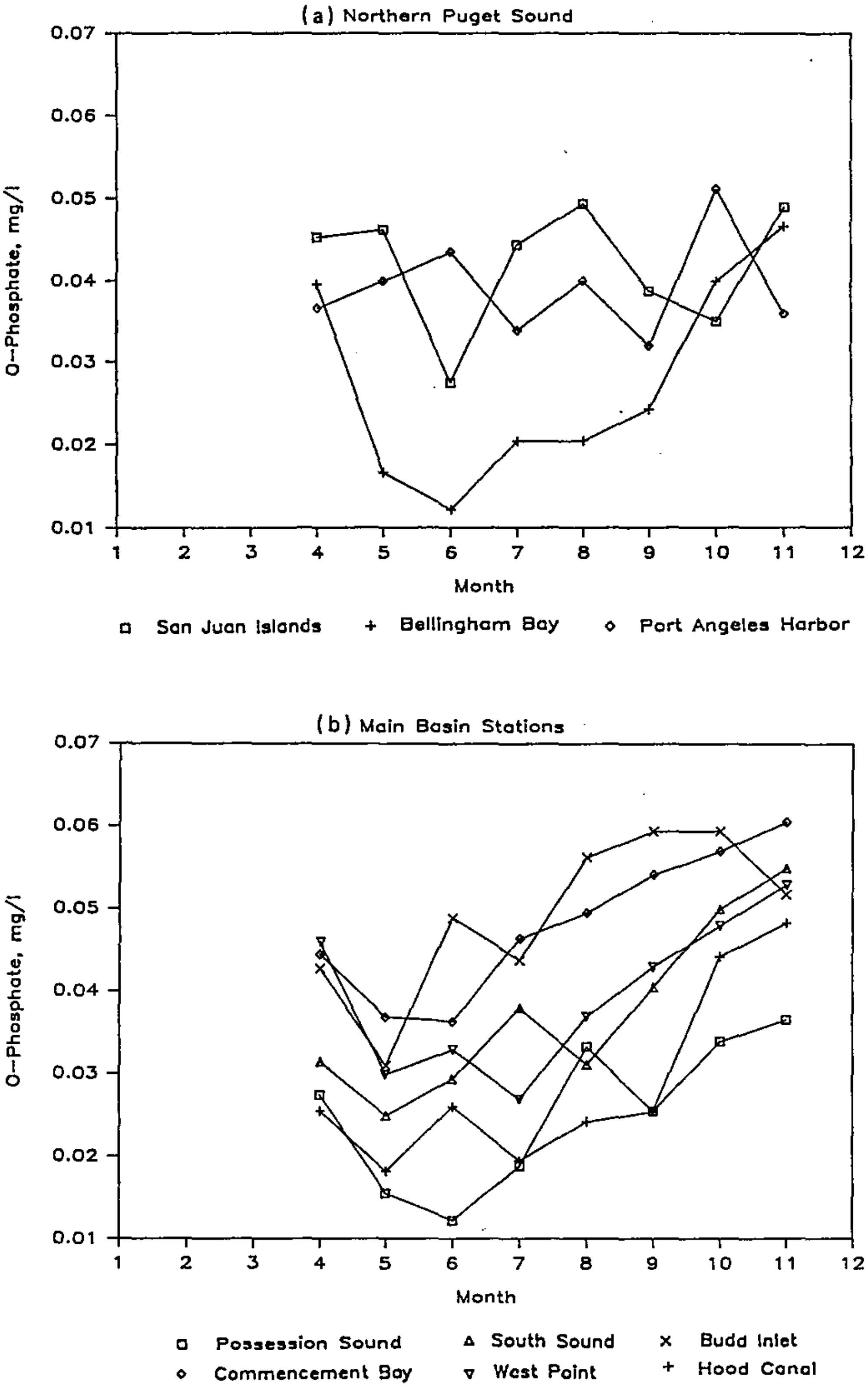


Figure 24. Monthly average concentrations of dissolved ortho-phosphate in the surface waters at selected locations in Puget Sound. (a) northern Sound locations, (b) locations south of Admiralty Inlet.
Source: EPA Storet data files.

influence of metabolic regeneration of OP in the deep water of the Sound during its transit through the basin (Barnes and Ebbesmeyer, 1978) followed by entrainment of the deep waters in the surface layers.

The OP levels in the San Juan Islands and at Port Angeles were approximately the same as those observed at West Point, but they did not show as large or as consistent a seasonal trend. Bellingham Bay showed the largest seasonal OP depression, possibly indicating reduced water exchange during the high productivity period compared to the other locations or significant inputs of low-phosphate river water.

Unfortunately, examination of the data available for analysis of the longer term trends in OP concentrations indicated that the record contained major discrepancies in the concentration values included in the data bases from different sources. These differences have not been resolved. For these reasons, no plots of the long-term trends in OP levels are presented in this report. (Note that the OP data presented in Figure 24 are all from the same data set, which appeared to be internally consistent. Thus, while absolute errors may exist in the data, the seasonal and spatial trends should be correct.) Fortunately, a previous analysis (Duxbury, 1975) has demonstrated that the major sources of OP are natural, dominated by the influx of nutrient-rich open-ocean water. The latter analysis was based on both loading estimates and on the evaluation of the data on the concentrations of OP in the Sound from 1932 to 1975. The analysis could not detect any long-term changes in the OP levels over the period of record.

Besides DO, an additional parameter which could be expected to respond to nutrient enrichment is Secchi depth, a measure of surface-water clarity. Eutrophication, which leads to increased phytoplankton growth, and the discharge of sewage particulates, may reduce clarity and decrease Secchi depths. Natural turbidity from river and shore erosion also affects the Secchi depth. For spatial comparisons, the monthly averaged Secchi depths at the locations shown earlier are presented in Figure 25. These data are primarily from the monthly measurements made by WDOE and date from the late 1960s to 1983. The West Point also includes data from METRO.

The differences between the Secchi depths at the more open-water locations and those in the embayments are obvious. These differences serve to identify riverine and nearshore sediments as a major source of turbidity in the Sound, which may mask any effects of plankton growth. The effect of the river-born turbidity is particularly obvious in Commencement and Bellingham Bays, which both receive the influx from fairly large and turbid rivers.

Seasonal differences within the locations can also be discerned in Figure 25. For example, the West Point data show a bimodal trend with relatively turbid water (shallower Secchi depths) occurring at that location in the early winter and in the early summer. These two Secchi depth minima are consistent with a winter influx of suspended sediment and a summer plankton productivity period (Dexter et al., 1981). The summer minima corresponds with the DO maxima and OP minima at this location (Figures 22 and 24). The South Sound locations show seasonal trends

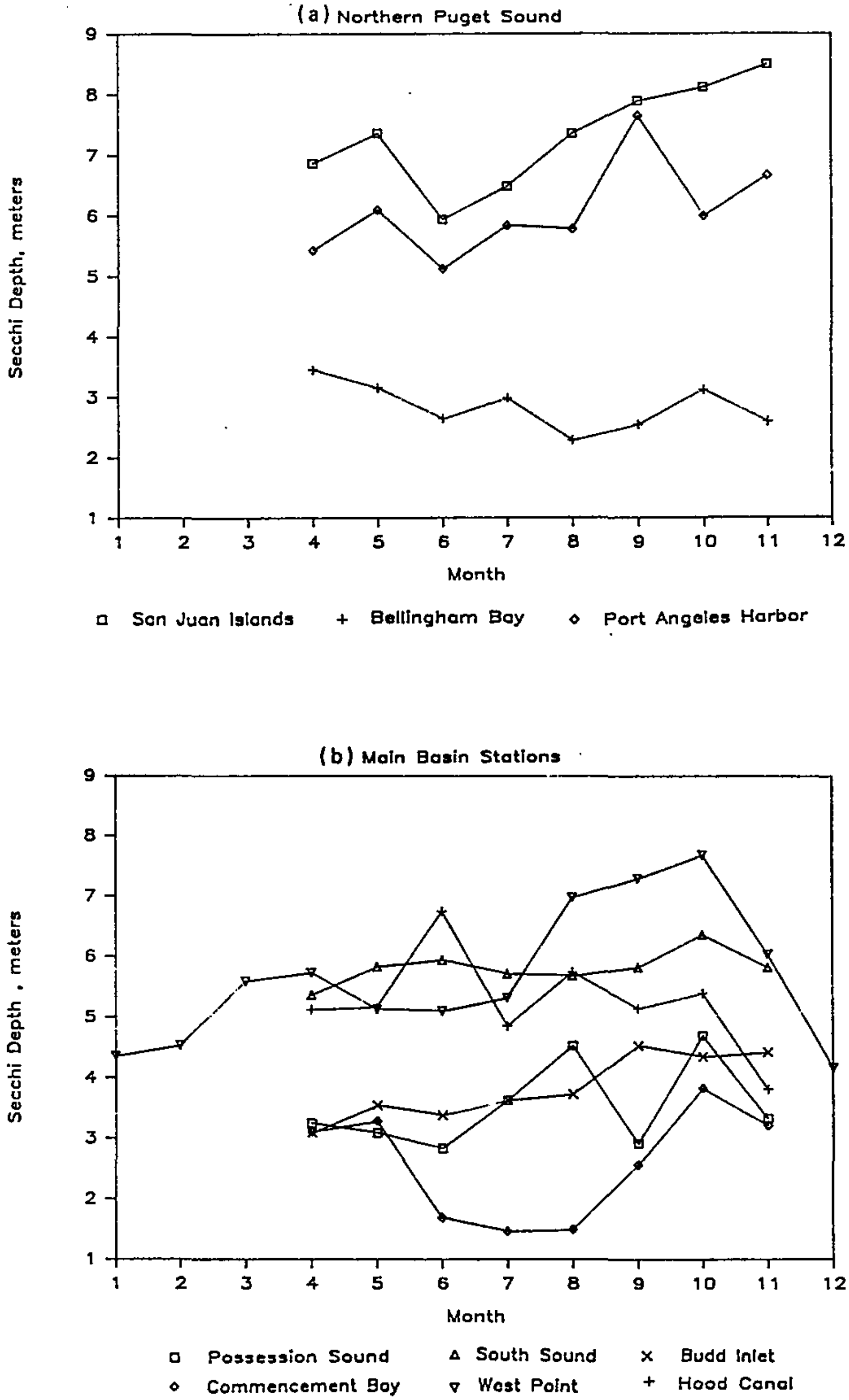


Figure 25. Monthly average Secchi depths at selected locations in Puget Sound. (a) northern Sound locations, (b) locations south of Admiralty Inlet.
Source: EPA Storet data files.

similar to those at West Point, but the winter months have not been monitored and the summer minima appeared in August rather than in June. The northern Sound locations showed seasonal trends similar to those south of Admiralty Inlet, but the open-water locations had clearer water at comparable months. Bellingham Bay is comparable to Commencement Bay, as noted above. Both the San Juan Island and Port Angeles locations showed strong summer minima which are probably due to the influence of the Fraser River but which could also be plankton-associated. However, the winter trends have not been measured and the impact and timing of the Fraser River plume at these locations is not known (Feeley and Lamb, 1979).

The long-term temporal trends in the Secchi depths observed at West Point are presented in Figure 26. The data are from the WDOE and METRO data sets and are presented as anomalies of the monthly averages. The values presented in Figure 26 were calculated to yield positive values for Secchi depths greater than the average (clearer) and negative values for shallower depths (more turbid). The long-term trends revealed in the 12-month running average are small but do show some inverse correspondence to surface salinity and to the total runoff (Figures 11a and 12), indicating the probable importance of suspended sediments rather than plankton to the long-term temporal trends in the turbidity of the Sound. The large, variations over small-time scales in the Secchi depths shown in Figure 26 do not correspond with similar trends in other parameters. The data sets of Secchi depth readings are too short and variable to reliably establish any trends.

5.3 FECAL COLIFORM BACTERIA

The primary concern related to the pre-West Point sewage disposal practices of the City of Seattle and most other municipalities was not eutrophication, but rather the risks of disease from the discharge of potential human pathogens in proximity to areas of human water contact recreation and near shellfish beds (Sylvester et al., 1950; Brown and Caldwell, 1957; WPCC, 1945 to 1957. For example, the WPCC (1947) summarized the situation near Seattle as follows:

> Numerous trips to the salt water beaches around Seattle, coupled with analyses of samples by the State Health Department, indicated a high B. coli [sic] count, indicative of pollution with large amounts of human and domestic sewage. On one of these trips, our investigators were accompanied by members of the various health agencies of the State, King County, and City of Seattle. This trip was during one of the lowest tides of the year. A considerable field of floating solids, resulting from the untreated sewage, was in evidence. All of the salt water beaches were polluted with such solid excreta. Many clam diggers were in evidence. At Alki, a broken sewer main was located discharging untreated sewage directly upon the beach, approximately 100 feet from shore. A representative of the Seattle Engineering Department stated that this condition has been known for approximately 5 years. In view of the conditions, Director Taylor gave releases to the press and radio to the effect that these salt

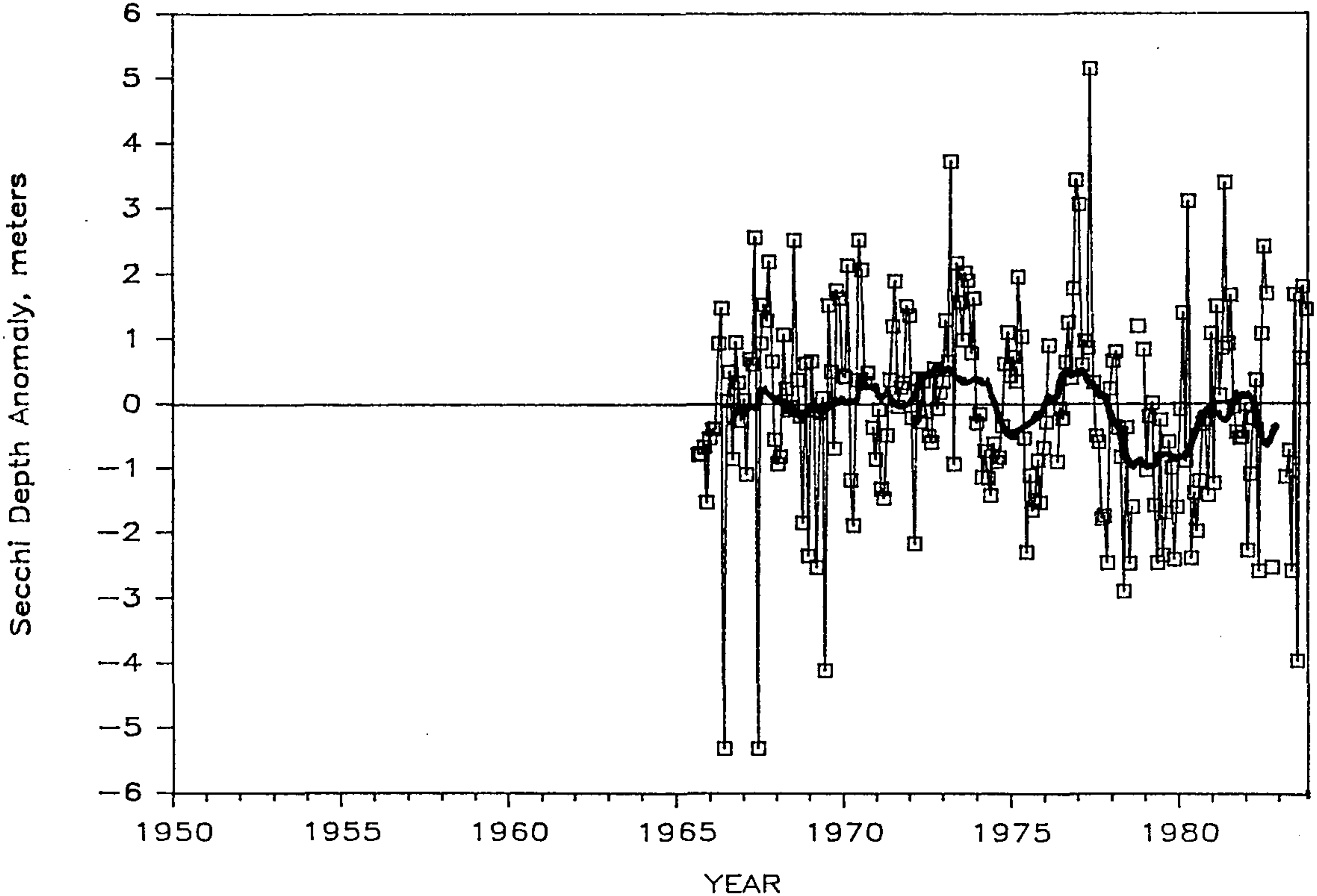


Figure 26. Anomalies in the monthly Secchi depths at West Point from 1965 to 1983. The background trace in the 12-month running average of the monthly anomalies.
Source: EPA Storet data files.

water beaches around Seattle were unsafe for recreational purposes; that the clam beds were in locations of dangerous contamination and the clams should not be used for human consumption.

The parameter that has traditionally been used to indicate the presence of human fecal material and hence at least the possibility of pathogenic contamination, has been the concentration of coliform bacteria. Either total coliform (referred to as "Bacilus coli" in early studies) or fecal coliform levels have been measured. The former is a more generic measure of coliform-type bacteria, while the latter is more specific to bacteria found in the fecal matter of warm-blooded animals. Neither measure may provide a wholly accurate surrogate for the organisms that are truly pathogenic, e.g., Salmonellae, polio virus, etc., but the coliforms probably have provided some relatively quantitative measures of the levels of fecal contamination, the ultimate source of the majority of pathogens (Chapman et al., in press). The use of the two different measures of coliform concentrations, as well as changes in the procedures to measure each, complicates the ability to assess the temporal trends in this parameter.

Using the Seattle experience as the example, data from two studies prior to the construction of the West Point plant have been presented in Figure 27. These figures show the concentrations of total coliform bacteria measured at the locations in marine waters off Seattle noted in the figure. The data indicate high concentrations of bacterial contamination at the sampling sites, most of which were located at or near swimming areas.

Direct measurement of coliform bacteria in the waste discharges has not been routinely performed until recently. Data from the West Point effluent are presented in Figure 28 to show the general levels associated with a major municipal discharge. Because many of the factors affecting the dispersion of the bacteria (and the pathogens) in the environment (e.g., die-off rate and any association with particulates and floatable materials) are not well known (Word and Ebbesmeyer, 1984), it is difficult to predict the bacterial levels that might be encountered in the environment in association with this discharge. The temporal trends in the fecal coliform loadings from West Point indicate possible overall decreases in the loading.

Other data on the environmental levels of coliform bacteria are presented in Figures 29 and 30. The data in these figures are from the Metro monitoring program and show the levels of total and fecal coliform in the waters off West Point and near the Golden Gardens beach. Procedural changes over time in the way the measurements were made account for the apparent steps in the record, as the detection limits were lowered from 20 organisms/100 ml to 10 organisms/100 ml and recently to 1 organism/100 ml. While the data are sparse for making any firm conclusions, it does appear that the degree of bacterial contamination in the waters around Seattle has decreased somewhat over time.

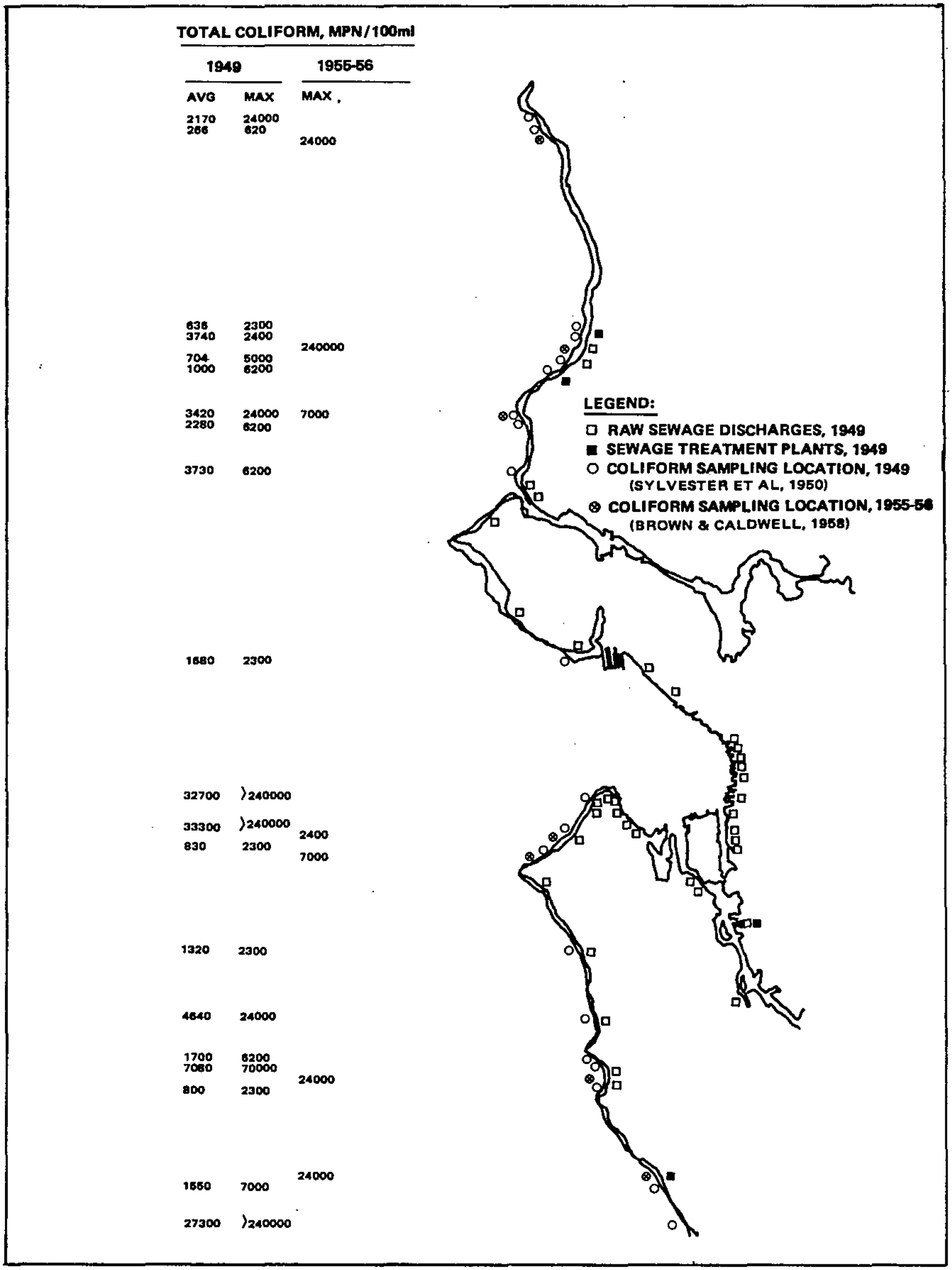


Figure 27. Concentrations of total coliform bacteria observed near Seattle in 1949, and 1955-1956.
Source: Sylvester et al., 1950; Brown and Caldwell, 1958

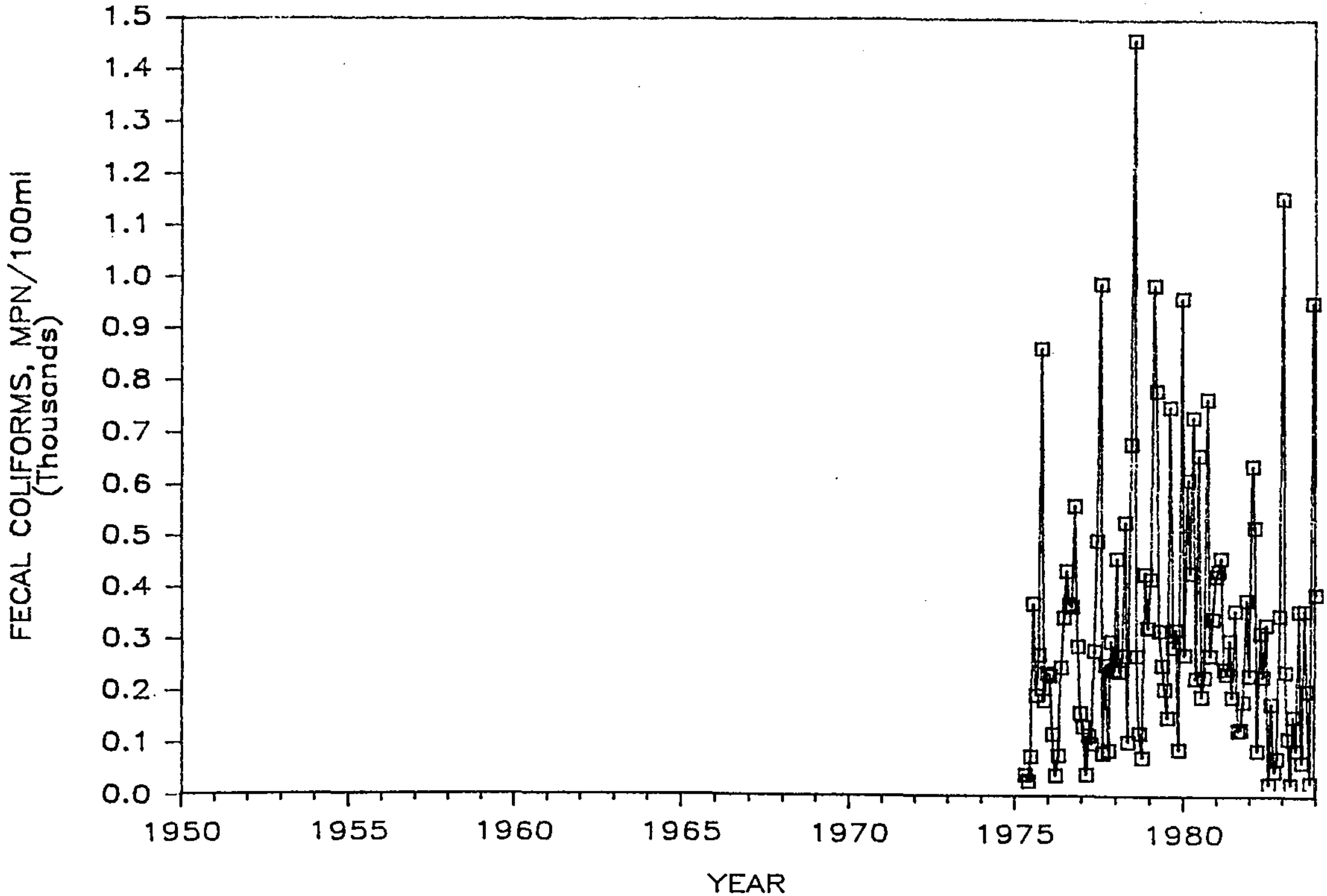


Figure 28. Monthly concentrations of fecal coliform bacteria in the effluent from the West Point sewage treatment plant, 1975 to 1983.
Source: West Point Treatment Plant discharge monitoring reports.

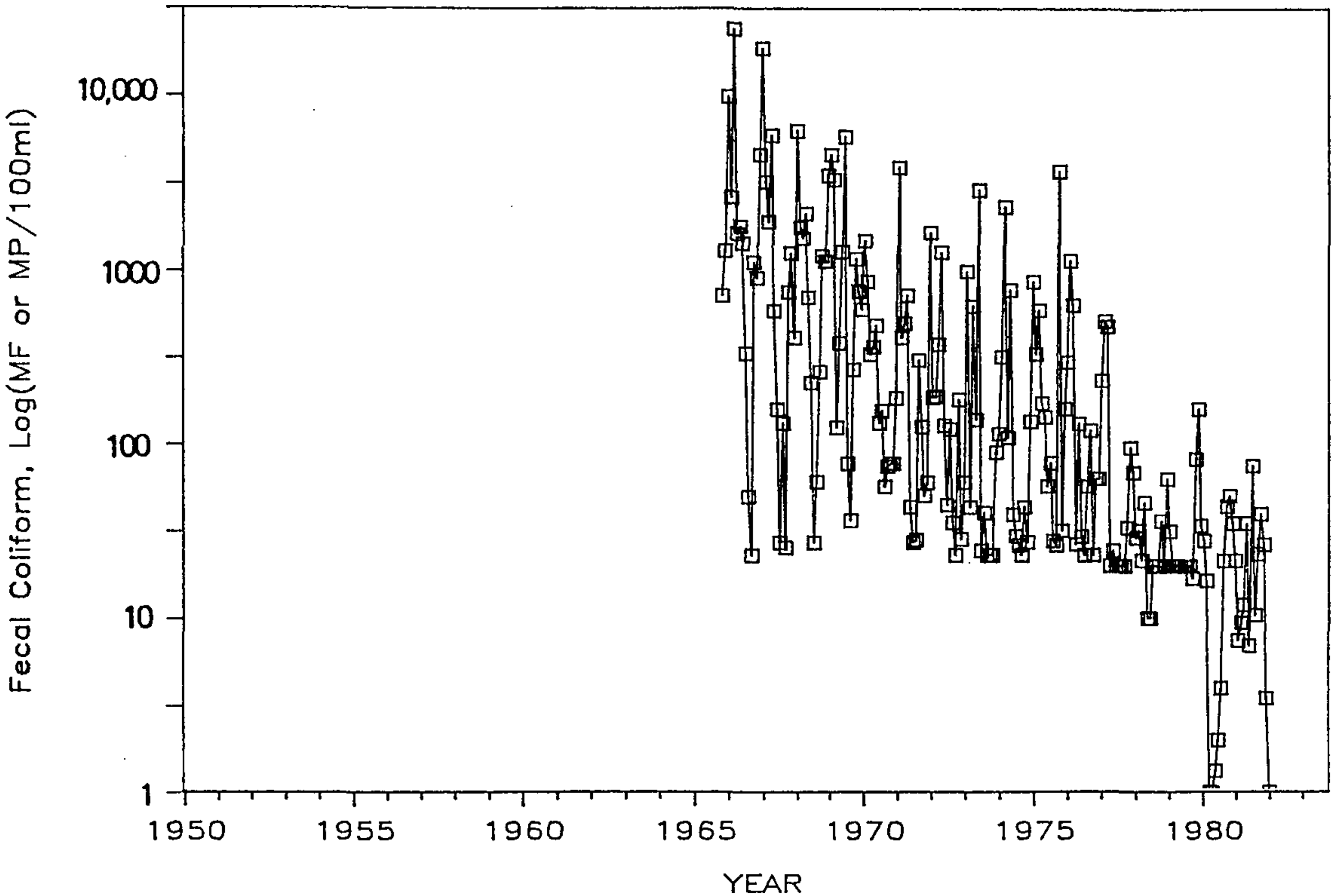


Figure 29a. Monthly concentrations of coliform bacteria in the surface waters at West Point, 1965 to 1983: total coliform.
Source: Metro routine water quality monitoring data files; Tomlinson and Patten, 1982.

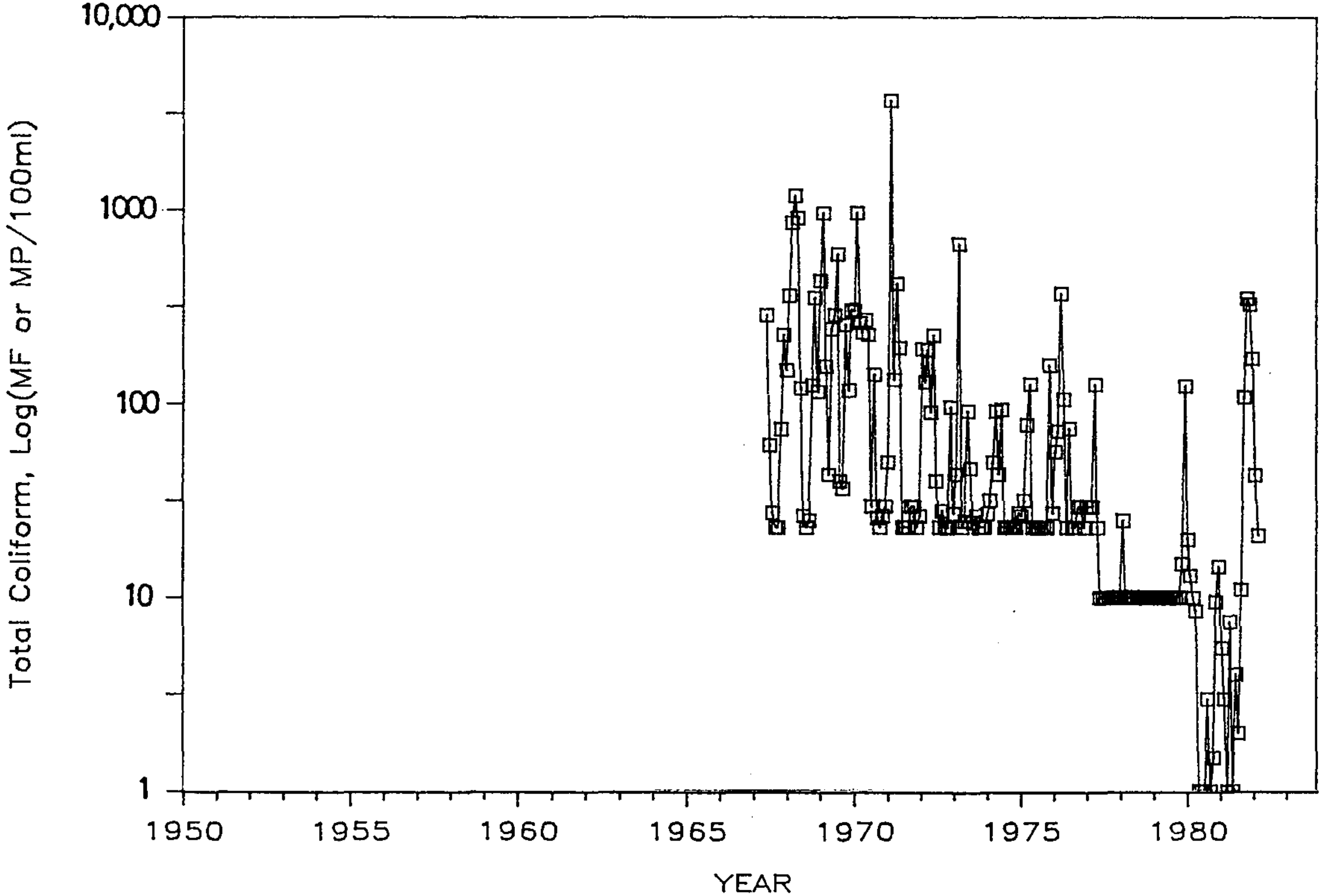


Figure 29b. Monthly concentrations of coliform bacteria in the surface waters at West Point, 1965 to 1983: fecal coliform.
Source: Metro routine water quality monitoring data files; Tomlinson and Patten, 1982.

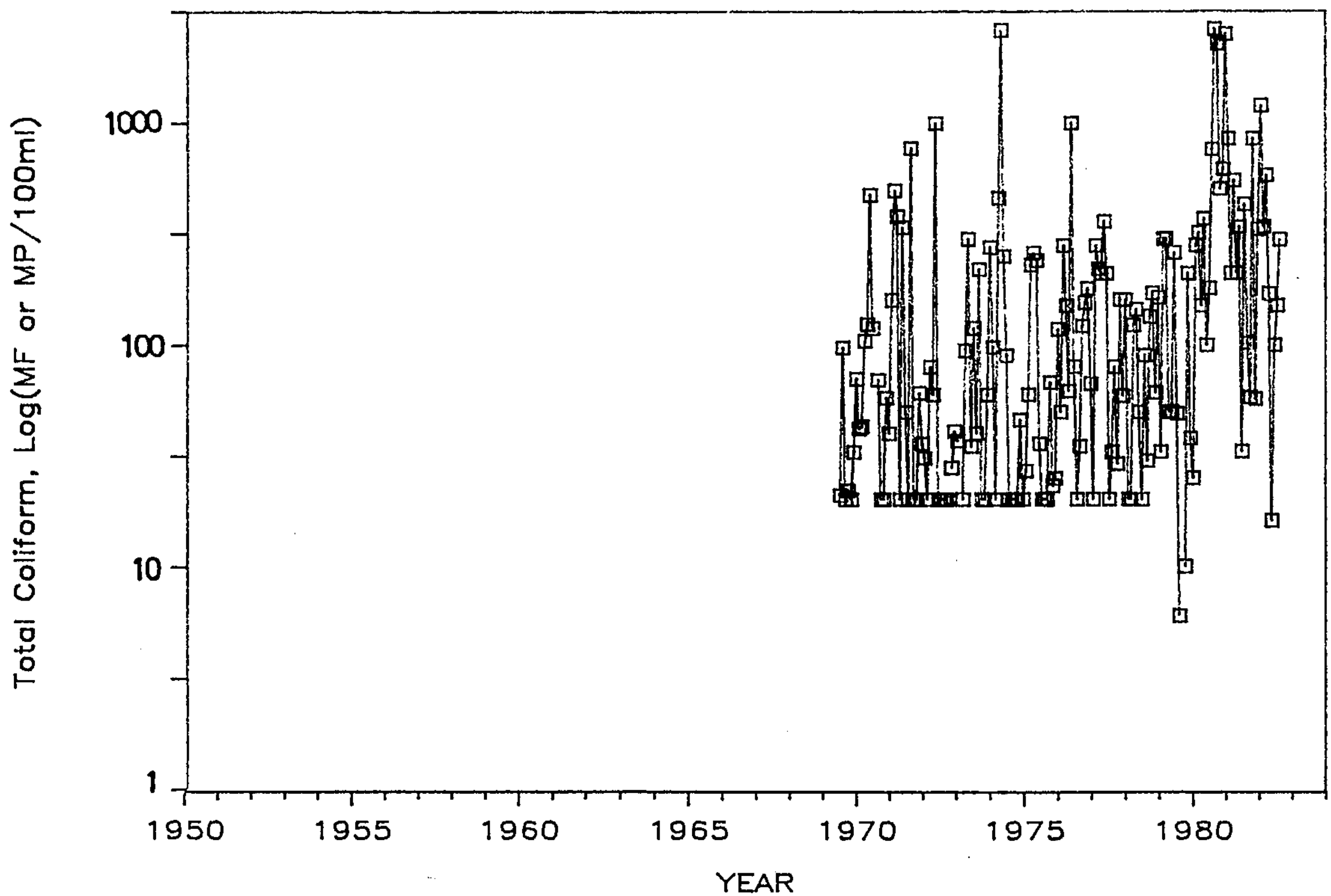


Figure 30a. Monthly concentrations of coliform bacteria in the surface waters at Golden Gardens Beach, 1965 to 1983: total coliform. Source: Metro routine water quality monitoring data files; Tomlinson and Patten, 1982.

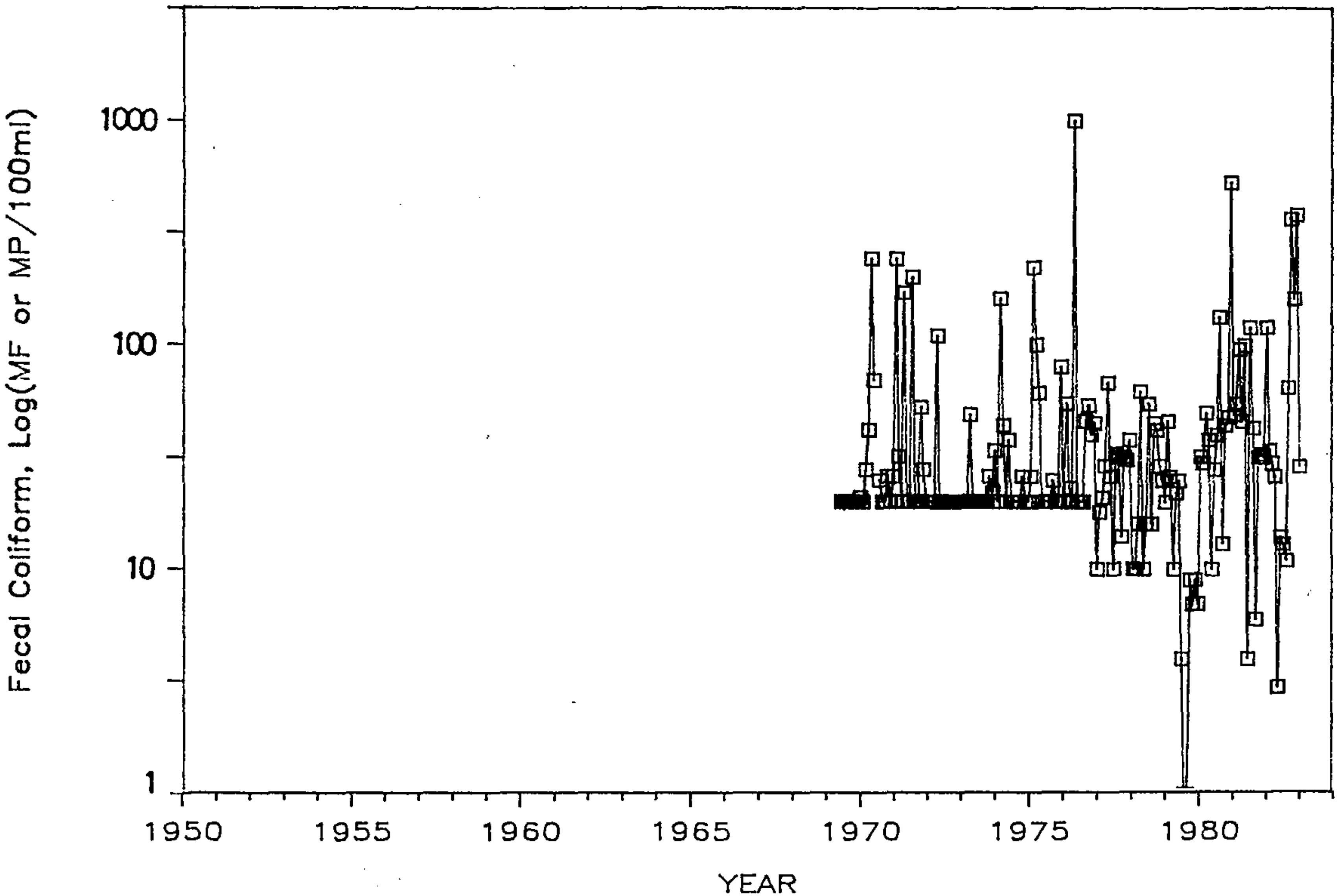


Figure 30b. Monthly concentrations of coliform bacteria in the surface waters at Golden Gardens Beach, 1965 to 1983: fecal coliform. Source: Metro routine water quality monitoring data files; Tomlinson and Patten, 1982.

Many of the measurements made in the more recent data still approach those of earlier periods. This is particularly true during the winter months, and a clear seasonal trend can be observed in most years plotted in Figures 29 and 30. This response indicates that increased surface runoff is a major seasonal contribution to the bacterial contamination of the Sound, both directly from overland runoff, storm drainage and stream flows, and via the sewage disposal systems (see Figure 28 for similar seasonal increases in the loading from the West Point plant). It would be of interest to determine the sources of the coliforms in the storm runoff since it seems unlikely that they are predominantly of human origin.

6. TOXIC CHEMICALS

Toxic chemical inputs to Puget Sound are not of recent origin, despite what appears to be a general public perception otherwise. The recent recognition that toxic chemicals are a problem in the Sound is due to two major factors: 1) the ability to measure trace concentrations of these chemicals in the environment has improved tremendously, and 2) we are now aware that many of these substances pose threats to environmental and human health at concentrations that are very low compared to the levels at which conventional pollutants cause problems. In addition, changes in our view of pollution have accompanied, and probably been furthered by, the progress made in controlling situations of chronic gross pollution in the Sound. When swimming areas were repeatedly closed because of the presence of visible human wastes and major embayments were nearly devoid of life because of low dissolved oxygen, the more subtle forms of pollution from toxic chemicals were of less concern and priority.

Historically, the dominant sources of toxic chemical pollution to Puget Sound were probably industrial discharges. The Washington State Pollution Control Commission reports of the late 1940s and early 1950s provide clear evidence that many industries in Seattle, Tacoma, Bremerton, and Olympia discharged their wastes virtually untreated directly to the Sound. Many of these discharges undoubtedly contained quantities of toxic metals and organic compounds that were a then-unrecognized hazard. The industrial substances of concern at that time were those that were acutely toxic, e.g., acidic and caustic wastes, cyanide, chlorine, etc., and those that left visual evidence, primarily the discharges of oily wastes. Thus, waste discharges that caused no readily apparent acute problem such as fish kills were not of general concern. Many of the discharged wastes were released into areas already grossly affected by raw human sewage and other organic-material loadings. Distinguishing the effects of the toxic chemicals from the effects of conventional pollutants in these wastes would probably have been difficult even if today's sophisticated analytical procedures had been available.

In this chapter an attempt will be made to present an overview of the probable changes over time in the toxic chemical loadings to the Sound. This overview is based on selected historical records, as well as environmental data from the Sound and is probably the least quantitative chapter in this report because of the limitations in the available data. As noted in a number of recent reports (Dexter et al., 1981; Harper-Owes, 1983; Quinlan et al., 1985; Curl, 1982; Romberg et al., 1984), even today, all of the sources of most of the toxic chemicals found in the Sound have not been identified, let alone quantitated. Because of analytical limitations, very few studies prior to the early 1970s even attempted to measure any of these substances either in sources or in the environment. These limitations make it difficult to be particularly quantitative in this presentation.

What has been assembled, however, are data on comparative, semi-quantitative trends in potential sources, data from sediment cores where temporal trends are recorded in the historical deposition profiles, and data from a few other isolated data sets. Three major toxic chemicals for which data are available are discussed: polynuclear aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and trace metals. Observations are also made regarding the possible trends in a few other toxic chemicals.

6.1 POLYNUCLEAR AROMATIC HYDROCARBONS

PAHs are among the most prevalent toxic chemicals in the Sound. Many are known to be carcinogenic, and they are suspected of being involved in at least some of the recently identified histopathological disorders in resident organisms (Dexter et al., 1981; Malins et al., 1980 and 1982). They are probably one of the oldest "pollutants" in the Sound. Because they are formed from nearly any combustion of organic matter and are deposited as atmospheric fallout, some inputs occurred even in prehistorical times from natural forest fires in the Puget Sound watersheds. These inputs were probably small in comparison to the quantities introduced with the development of the Sound in the late 1800s. Beginning with the first saw mills on the Sound, a number of developments dramatically increased the PAH inputs to the Sound.

The first major increases in PAH loadings probably resulted from slash burning and accidental human-caused forest fires. As the near-shore forests were cut back, steam trains and steam-powered "donkeys" were used increasingly to assist in the harvest and transport of the trees. These and other sources of fire resulted, at least in dry years, in situations exemplified by the following:

> ...the whole country seems to be on fire. Several camps have been burned out, and unless rain comes very soon, we fear that there will be very few saved from the flame. We have a good amount of logs on hand here and at the several camps, but if the fire becomes general we may run short, and for that reason you had better be careful about taking foreign orders. We do not wish to frighten you...but if the fire continues we shall be short in the fall. (letter from William Renton, summer of 1883, quoted from Chasan, 1981, p.17).

After the turn of the century, some records of the forest fires in the entire state were kept (Figure 31). These data, compiled and presented in Curl (in preparation) show that immense areas burned during the early part of the century but that the extent of forest fire damage decreased dramatically after 1940. While these data indicate the trends in the quantities of PAHs that may have been generated from this source, they must be interpreted with care. First, the data presented are for the entire state and do not identify fires from only the Puget Sound Basin. Second, trends prior to 1910 are unknown. As noted in the statement presented above, it seems possible that fires in the Puget Sound region may have peaked

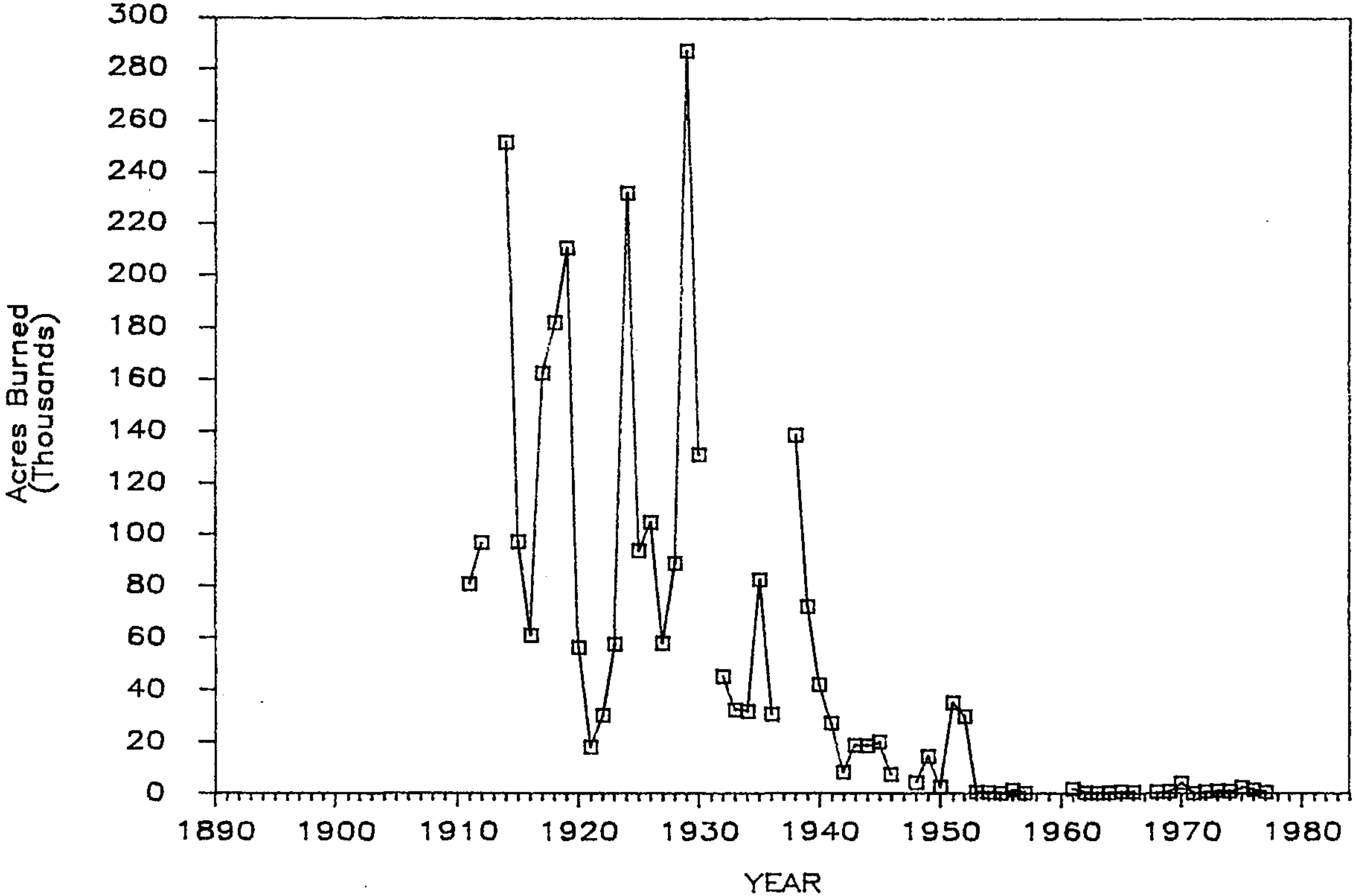


Figure 31. Acres of forest burned in Washington State, 1970 to 1980.
Source: Curl, in preparation.

earlier than the statewide data indicate. Third, innumerable factors, including location, extent, severity and season of occurrence probably all affect the amount of PAH actually transported to the Sound. No information is currently available to allow any quantitative estimates of the PAH inputs from fires. However, the possible importance of this source in the late 1800s and early part of this century is clear as is the decrease in its potential in recent times as control technology improved. (It is also interesting to note that the period of maximum forest fire was during the extended period of low precipitation during the 1920s, Figure 15).

The second major activity that begin in the Puget Sound region in the mid-1800s was coal mining (Chasan, 1981). This activity introduced PAHs to the Sound, both through direct discharges of coal fragments during the mining (via erosion), cleaning and transport of the product, and indirectly through the burning of coal. Coal production for the state is presented in Figure 32. In comparison to the forest fire data, however, most coal production in the state occurred in the Puget Sound basin during the time presented in Figure 32 (Curl, in preparation). Similar to the forest fire trends, coal production in the Puget Sound region peaked in the earlier part of the century and has declined steadily since then. State-wide coal production has increased compared to 1970 levels, but this production is almost all from outside the Puget Sound region (Curl, in preparation). The data, however, also provide no means of obtaining quantitative estimates of the PAH inputs that may have accompanied coal mining and transport, but only indicate the probable relative trends.

Some confirmation of the importance of this source can be seen in a recent study that identified a layer in a sediment core collected off Browns Point, near Tacoma, that contained a large quantity of coal fragments. This layer was at a depth estimated to have been deposited in about 1920 (Barrick et al., 1984).

Similar to coal production, no direct estimates are possible of the quantitative inputs of PAHs to the Sound resulting from the combustion of coal. However, some trends in the possible PAH production from this source can be indicated. Following the analysis of Curl (in preparation), domestic heating is considered to be the greatest producer of PAH from coal combustion, reflecting the relatively poor control of the combustion process in home furnaces. The estimated rate of coal consumption for domestic heating in the Puget Sound region is presented in Figure 33 (Curl, in preparation). The data show an early trend that followed the coal production rate (Figure 31), but peaked during the early 1940s when rationing during World War II limited the use of alternative heating sources (Curl, in preparation).

Other combustion sources of PAHs are either considered to be relatively clean in comparison to coal burning (e.g., fuel oil or wood burning; Curl, 1982), or are poorly documented. Wood heating has probably followed an overall trend very similar to that of domestic coal usage (Curl, 1982) with the exception that wood heating may be increasing since the 1970s and hence could begin again to influence the inputs of PAHs to the Sound. Automotive consumption of gasoline (Figure 34) has increased

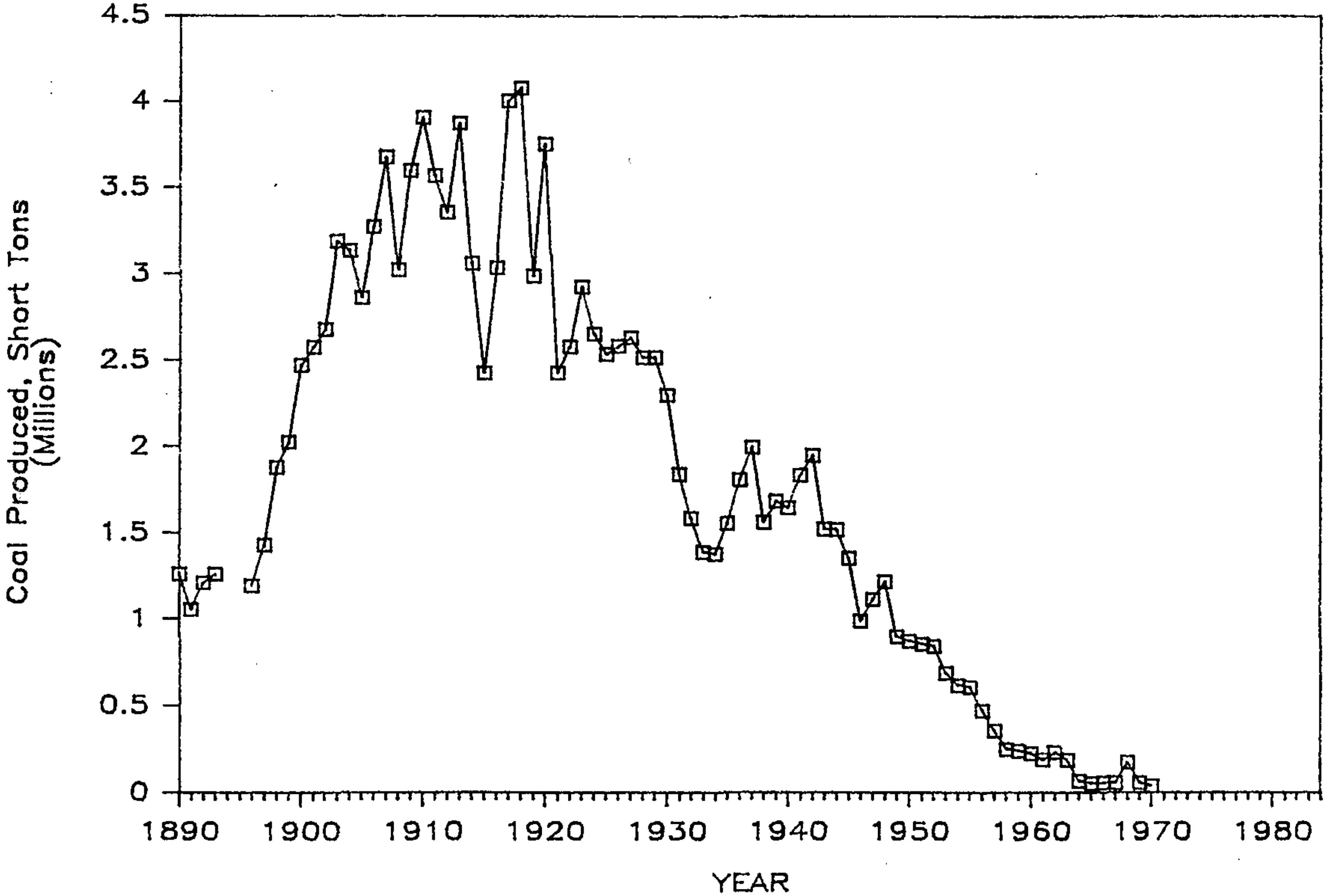


Figure 32. Coal production in Washington State, 1890 to 1970.
Source: Curl, in preparation.

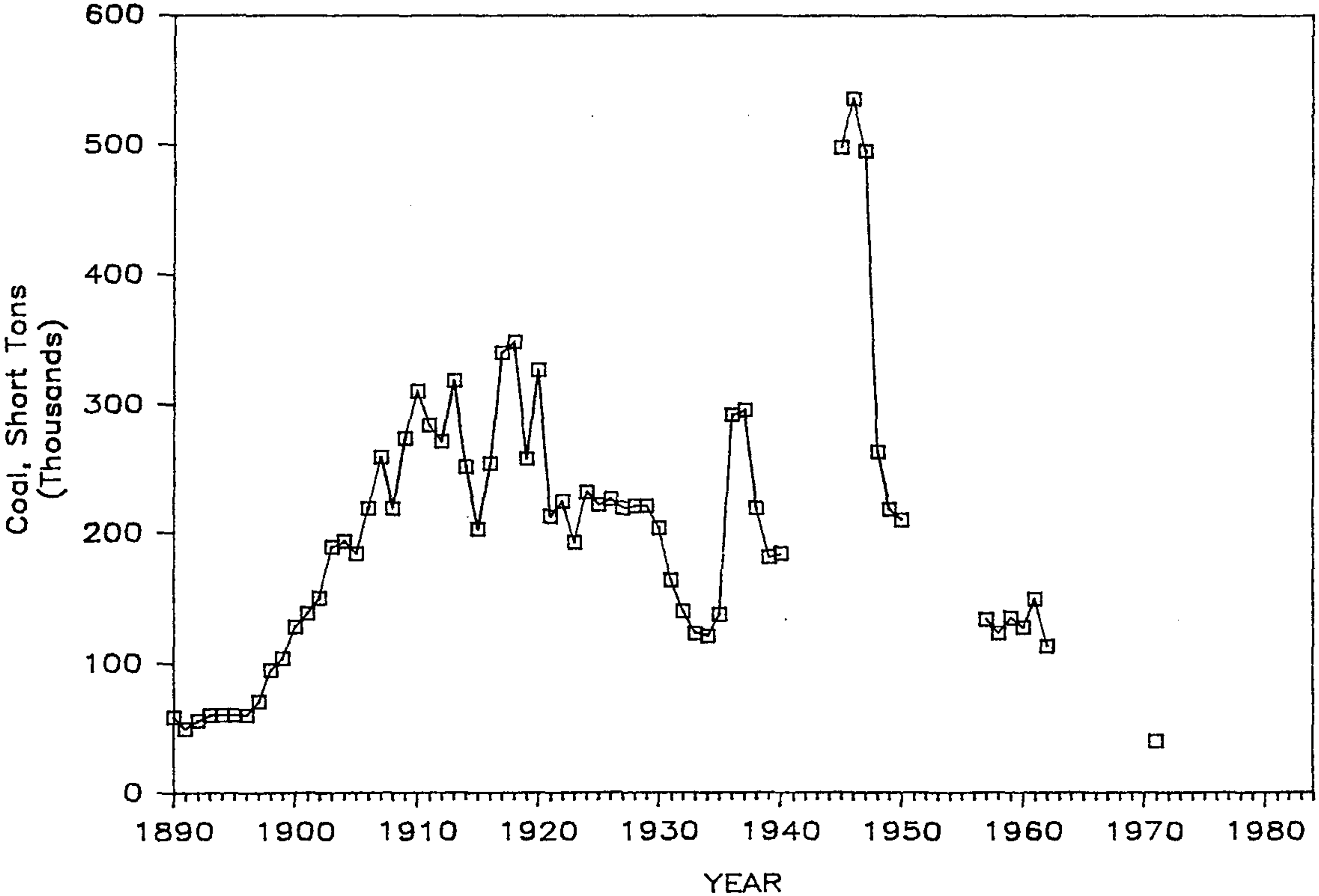


Figure 33. Coal consumption for domestic uses in the Puget Sound Region, 1890 to 1971.
Source: Curl, in preparation.

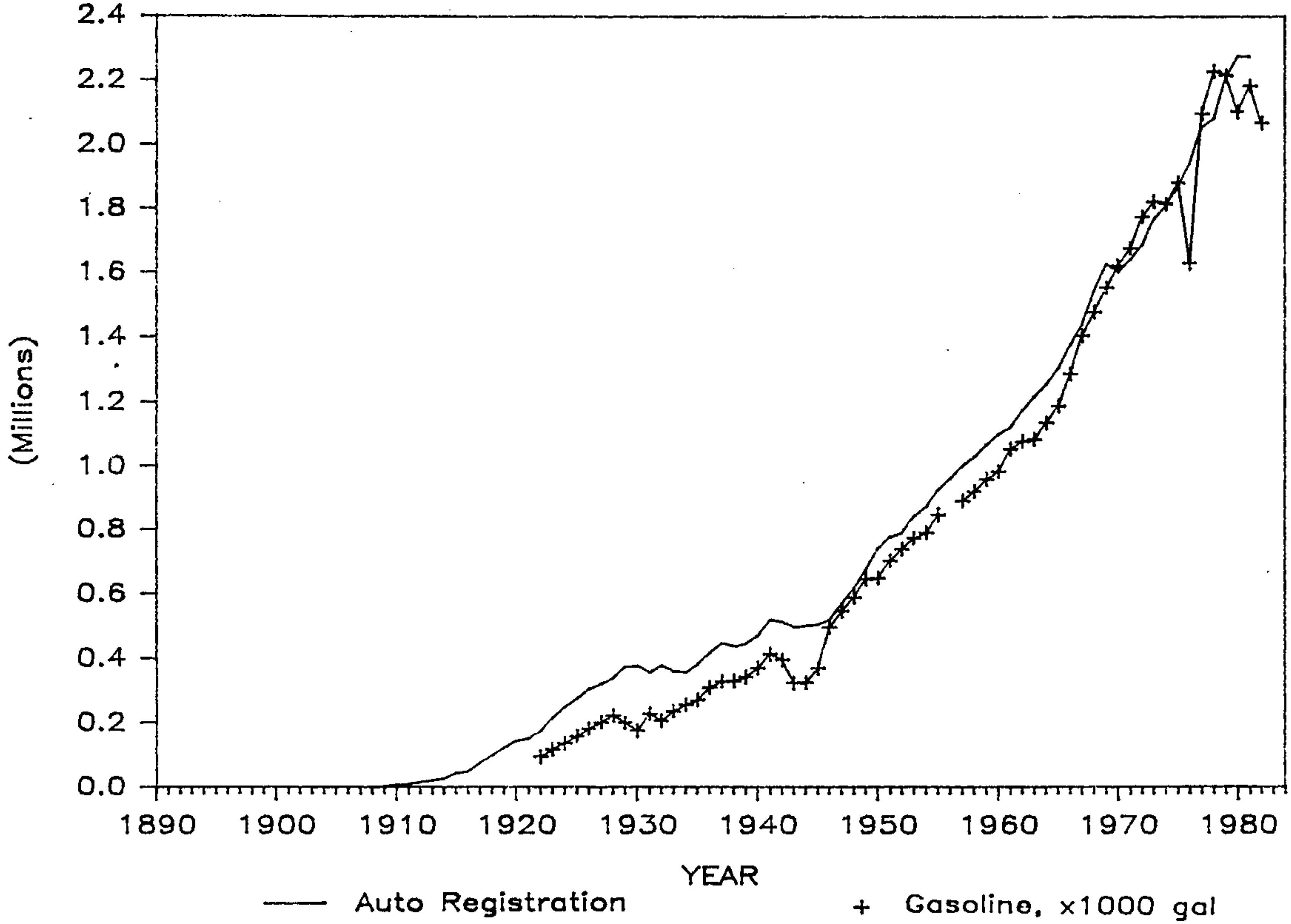


Figure 34. Gasoline consumption by automobiles and automobile registration in Washington State, 1910-1980.
source: Curl, in preparation.

steadily to the 1970s. From the 1970s to the present (1984) economic and political turmoil and the introduction of fuel efficient cars caused the overall rate of increase to drop considerably and to actually decrease in some years.

The final major input source of PAHs to the Sound to be presented is the discharge of oil. Unfortunately, the importance of oil discharges, which may have contributed substantially to the PAH loading to the Sound, is not possible to quantify because of the ubiquitous use and varied sources of oil in the region. Review of the Washington State Pollution Control Commission reports show many instances of visible slicks of varying quantity. The sources of the slicks included oily wastes from industries such as a coal gasification plant, wood treatment companies, asphalt and roofing manufacturers, and shipyards; spills at storage depots; and bilge pumping from ships (WPCC, 1945-1957). Some typical observations entered into the Pollution Control Commission reports are paraphrased in Table 3 to illustrate the extent of the problem.

Oil spills are documented better now. The U.S. Coast Guard initiated a computerized spill monitoring system that became effective in 1982. Since that time about 500 spills per year of varying size have been documented (compared to less than 30 memoranda regarding oil spills in the Pollution Control Commission reports for the year 1946; however, many of the latter citations discuss chronic discharges or the incidence of many spills from a single source). Future trends will thus be more readily traceable, but the past trends in oil pollution to the Sound have not been documented.

The temporal trends in PAH inputs for the Sound indicated in the data presented above can be compared in a general way to the temporal trends obtained from age-dated sediment cores. Because quantitative measurements for PAHs have not been made in the Sound until recently, the record contained in the bottom sediments represents one of the few quantitative routes for estimating the past conditions in the Sound.

This method is based on the assumption that the sediments collect on the bottom in chronological order with the more recent sediments overlying older material. The method also assumes that the concentrations of contaminants that were deposited at any given time were proportional to the ambient levels in the Sound at that time. The dates when different sediments in the cores were deposited on the bottom can be estimated by measuring the changes in radioactivity of a lead isotype (^{210}Pb) with depth in the cores. Unfortunately, the use of this approach for developing temporal trends is complicated and unanimous agreement on many important points in the analysis of the available data from dated cores has not been reached by researchers in this area (Quinlan et al., 1985).

As a result, the information obtained from these cores must be considered as qualitative indicators of the temporal trends. Neither the absolute quantitative changes with time, nor the dates at which changes have occurred, should be considered to be very precisely established.

Table 3. Typical oil pollution citations from the Washington Pollution Control Commission Reports.[a]

<u>Oil Spill on Beach at Manchester</u>

The oil spills discussed in this memorandum along the beaches of Manchester have been due largely to the installations at the Naval Oil Supply Depot. Our investigators checked the situation and found that there had been an accidental spill of between 4 to 6 barrels of oil during the middle of July and this found its way into the Bay. A check of the installations revealed that due to faulty installation, oil spills, which were supposed to be removed by a 12 inch pipe drain, at times made their escape through a 4 inch storm drain and from there entered the Bay. Lt. Commander Paget, in charge of the Oil Supply Depot, promised to correct this and to install proper sumps to handle any accidental spills and thus prevent them from escaping into the waters of Puget Sound. (7)

<u>Oil Spill from Everett Pacific Shipbuilding Company</u>

Complaint alleged that a Navy "flat top" was responsible for the oil pollution through pumping of bilges. Investigation disclosed that most of it was due to oil spillages from the Everett Pacific Shipbuilding Company. The management of this concern was contacted and given a warning notice requesting them to clean up the waste oil and to advise the Commission what action they expect to take to prevent future recurrences of such pollution. (5)

<u>Pollution of Hylebos Creek by A. Benson Service Station</u>

This complaint was sent to the Commission by Senator Barney Jackson of the State Fisheries Department. Upon investigation it was found that Hylebo Creek was being polluted by discharges from a garage and service station owned by Mr. A. Benson. These discharges consisted of large quantities of crank case oil and raw human wastes from two toilets. Mr. Benson was given a copy of the Laws of 1945 pertaining to

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a. Numbers in parentheses at end of citation are the Progress Report Number from which the citation was taken.

pollution, and also a warning notice requesting him to correct the conditions within thirty days. He has assured us that he would take care of this condition immediately. At the expiration of the warning notice, another checkup will be made. (3)

Recheck of Shipyard at Winslow

In a previous memo, recommendations were made to the shipyard at Winslow to improve the method of disposal of waste oil from ships undergoing repairs at the shipyard. A recheck divulged that the company has done a good job of putting in installations to clean up the oil pollution which had been in existence for some time. The old oil burning pit on a gravel bar near the Marine Railway has been cleaned up and is now used only as a fire pit for burning waste wood and some paint. The sides of this pit have been extended upward, so as to prevent extreme high tides from washing any objectionable materials into the bay. All waste oil is now carried to a large pit and burned. Inasmuch as this is about 100 feet back from the beach, there is no possibility of oil spillage into the water.

Oil Pollution Near Ray's Boathouse, Shilshole Bay

Members of the West Seattle Sportsmen's Club recently reported that there was an extensive beach near Ray's Boathouse at Shilshole Bay covered with oil. Inasmuch as this complaint was one of many similar complaints of oil spillages in this vicinity, a thorough search of the neighborhood was made. Our investigators discovered five large tanks on the beach covering an area of approximately ten cubic feet, each containing several hundred gallons of oil. During high tides large amounts of this oil escaped into the water and along the beach. In all probability, this has accounted for the numerous spillages reported from Magnolia Bluff and vicinity during the past several months. THe owners of this property, namely, Dealers Warehouse Inc., of Seattle, were contacted and they revealed that the tanks belonged to the previous landlord, The Tregoning Boat Company of Seattle. A warning notice was given requesting immediate removal of these tanks. Letters are already on file with the Pollution Control Commission to the effect that the tanks have already been sealed to prevent leakage and they will be removed as quickly as possible. (12)

Pollution of Oil from Tanks of E.I. DuPont De Nemours & Company, Tacoma

This complaint was received from the Tacoma Sportsmen's Club. It deals with oil pollution from two oil tanks located at the E. I. DuPont de Nemours and Company plant at Tacoma. Upon investigation, it was found there were two oil tanks surrounded by concrete encasements and instead of cleaning out the overflowing oil, holes were drilled in the bottom of the concrete floors allowing the oil to drain into the slough, a natural duck habitat. The manager of the operations division of the DuPont concern was requested to remedy the situation within the week which he promised to do. (11)

Oil Spill in Swinomish Slough at LaConner

This deals with the complaint of Mrs. Anna Meeks of LaConner regarding an oil spill in the Swinomish Slough. A careful investigation revealed that the oil came from oil trucks unloading onto barges for the supply of army engineers who are in the process of dredging the slough. Mr. Greely, Army Engineer in charge of the project, was contacted and he gave assurance that the utmost care would be taken to prevent any of the oil from spilling during the transfer. (10)

Crude Oil Pollution of Duwamish River by Duwamish Manufacturing Company

This complaint was received from the State Fisheries Department who had received it from the U.S. Coast Guard. Upon investigation, it was found that the oil was coming from the Duwamish Manufacturing Company, a concern producing asphalt roofing products. It appears that during the night some unknown person had opened a valve of one of the 30,000 gallon oil tanks with the result that about 5,000 of crude oil had escaped, most of it finding its way into the Duwamish River. The owner of the concern was requested to clean up the grounds around his plant and instructed him to install a sump or catch basin to prevent a recurrence of similar accidents. (3)

Large Oil Spill in Commencement Bay
Acting on complaints from the Tacoma Sportsmen's Association and the Tacoma Boat Building Company, of a large oil spill in Commencement Bay, a thorough

investigation was made of the condition. This oil spill was traced to the Berkheimer Roofing Company, a Tacoma concern manufacturing roof paper. Here was found a crude oil refining still that was connected to a sump which was overflowing and draining directly into the sewer. The management was given a warning notice, ordering them to correct the situation and install another sump not connected with the sewer whatsoever. The manager gave adequate promises and he was requested to notify the Commission as soon as the installation is made for purposes of rechecking. (6)

Oil Pollution of Elliott Bay at West Coast Wood Preserving Company

This case of oil pollution was called to our attention by a member of the Seattle Poggy Club. Our investigation strongly indicates that the West Coast Wood Preserving Company has been responsible for much of this type of pollution. A sample of the oil floating on the surface of the water was obtained and analysed. This revealed that it consisted mainly of tar oil of the type used for purposes of wood preservation. Another inspection of this plant will be made with a view to pinning responsibility and demanding correction. (3)

Oil Pollution in Washington Narrows by Western Gas Company

After repeated reports of oil pollution in Washington Narrows, the Western Gas Company of Bremerton was rechecked and our investigators became convinced that this concern was chiefly responsible for most of the oil pollution in the area. Moreover, they found that the sump which had been installed about a year ago was not kept clean and therefore did not function properly. Also a secret outfall was installed to carry off the oily effluents from the plant. This outfall was so constructed that it was visible only at extreme low tide. A steady stream of heavy oil was found coming from the outfall and draining onto the beach. The Western Gas Company was supposed to erect an additional sump, but they never did anything about it. Our investigators have recommended that this concern be cited before the Commission in violation of the Pollution Act, Chapter 216, Laws of 1945. (6)

Table 3 (Continued)

Oil Spill in Puget Sound in Vicinity of Magnolia Beach

Here is recorded a heavy oil spill along Magnolia Beach which covered the entire beach to a width of about 15 feet and several blocks in length. It was approximately 2 inches in depth along the high tide mark. An examination showed that the oil was of the same type as that which polluted Shady and Juanita Beaches a number of weeks ago. Although it has been impossible to trace definitely where this oil came from, it is strongly suspected that it came from a Navy Tanker that had been moored in the vicinity. (6)

Oil Pollution from Several Boats Anchored in Holmes Harbor

A number of large ammunition ships have been anchored in Holmes Harbor, Whidbey Island, and have been pumping bilge oil into the waters of the bay. A delegation from Whidbey Island dropped into the office of Chief Biologist Fasten and requested the Commission to investigate the situation. This was done and our investigation revealed five large boats anchored in the Harbor and these were responsible for the oil pollution. The names of these vessels and their owners were obtained. Appropriate letters have been written to the owners with warnings and copies of the Pollution Law. (2)

Oil Pollution from Navy Ships at Blake Island and Sinclair Inlet

Here is described observations of oil pollution from Navy ships. Investigation disclosed approximately 45 ships concentrated in this region and about 6 or 7 large oil slicks on the surface of the waters. Unquestionably these came from various ships of the Navy.

Further Investigation of Pollution from Ammunition Ships Moored in Discovery Bay

Acting on a report from the United States Coast Guard, investigation was made of a large oil slick in the region. Coast Guard Boat No. 83484 had seen a large oil slick on the waters approximately 700 feet long and 200 feet wide that was pumped from the boat Bedford Victory King-231 Anchorage C moored in Discovery Bay. Our investigation disclosed numerous evidences of oil slicks on the surface of the waters and also garbage within the waters dumped overboard from various ships. Previously, officers of the 13th Naval District assured the Commission that no oil or garbage pollution would be dumped within the waters and that barges would collect these items for disposal elsewhere. Investigators found no such provisions made. (4)

Oil Pollution of Beaches Along Port Susan from Russian Steamer "Donbass"

This memo deals with oil pollution of the various beaches along Port Susan caused by oil from the Russian Steamer "Donbass." Contact was made with Commander S.P. Nehlman of the U.S. Coast Guard and after going into the entire matter with him it was decided to leave the Coast Guard to handle the situation. The Russian representatives who have charge of the "Donbass" were given the alternative of either immediately removing the oil or removing the ship. They finally signed a contract with the Foss Tug Company for the immediate removal of all the oil from the broken ship. (5)

Oil Spills at Budd Inlet

In recent months several oil spills have occurred in Budd Inlet. A number of residents have launched complaints that the boats moored in this location under the jurisdiction of the U.S. Maritime Commission were not taking care of oil and garbage in the manner agreed upon between the service and the Commission. Investigation revealed the complaints to be true. Moreover, they learned from employees of the War Shipping Administration that bilge oil is being pumped from these boats daily directly into the Sound. A conference was held with U.S. Coast Guard officials to see what could be done in the matter. (8)

Pollution of Everett Harbor by Oil From Oil Tanks of Great Northern Railroad

Upon investigation of a complaint by the Snohomish Sportsmen's Association, it was found that during the middle of June, over forty thousand gallons of oil had been spilled into the waters of Everett Harbor from the oil tanks of the Great Northern Railroad between

Everett and Mukilteo. Moreover, it was discovered that oil was flowing into the bay constantly through a culvert and the Commission sent a strong letter to the manager of the Great Northern at Seattle with orders to submit plans for the correction of this pollution. The Great Northern has promised to make suitable modifications to absolutely prevent a recurrence of the situation. (1)

Pollution of Oil in Puget Sound, Vicinity of Ray's Boathouse

Acting on complaints from the State Fisheries Department and citizens in the vicinity of Ray's Boathouse, investigator Lobberegt and Chief Biologist Dr. Nathan Fasten made a thorough investigation of this pollution of Puget Sound in the vicinity of Fort Lawton. The pollution was traced to the Great Northern Railroad Roundhouse located near the Salmon Bay locks on Nickerson Avenue, Seattle. This type of pollution has been going on for years and the Great Northern people have been informed of it and requests have been made that they not only correct, but prevent a similar occurrence of the condition. Moreover, they have been requested to submit plans to the Commission which will adequately take care of such wastes in the future. (1)

Dumping of Oil into Duwamish at Foot of Diagonal Avenue, Seattle.

This concerns the report of the dumping of a large amount of oil into the sewer which enters the intersection of East Marginal Way and Diagonal Avenue in Seattle. As yet, it has not been determined who is responsible for this pollution. Further investigation is in progress. (1)

Second Investigation of Dumping of Oil into Duwamish at Foot of Diagonal Avenue, Seattle
(See also Memo 23 in Progress Report No. 1)

This investigation involves the Roundhouse of the Union Pacific R.R. located on Dawson Street and 5th Avenue which was responsible for the oil pollution of the Duwamish at the outfall of the sewer emptying at the foot of Diagonal Avenue. The Union Pacific has assigned two men to watch the water sump into which

Table 3 (Continued)

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the oil is first drained. Daily, two men remove the oil which collects on the surface of the water thereby preventing it from reaching the outfall into the sewer. The Railroad completely assured us that the oil spillages which happened in the past will not be allowed to recur. (2)

<u>Oil Pollution of the Puyallup River by Milwaukee Railroad at Tacoma</u>

This investigation was at the request of the Tacoma Sportsmens Association. It appears there was a bad spill of oil in the waterway known as Dempsey's mill pond, a tidewater estuary of the lower Puyallup River. Some of the Sportsmen have found oil from a sewer outfall that drained the railroad yard of the Chicago Milwaukee Railroad at Tacoma.

A careful check revealed that there had been a bad spill during the middle of January in which a switch engine bumped two 8,000 gallon fuel oil tanks with the result that pump connections were broken and large quantities of oil escaped. In a previous investigation our investigators recommended that adequate sumps be installed and any sewer and valve connections between oil storage tanks and oil separators be completely disconnected. Apparently, this was done but instead of the walls of the oil separator being constructed of concrete, they were constructed of wood. In due course of time the boards, of which the wooden walls were made, shrank, opening seams through which the oil was escaping. When this was pointed out, the officials stated that they would immediately set to work remedying the situation and submit plans to the Commission that would prevent further pollution. (10)

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Figure 35 presents sediment core profiles of the concentrations of the hydrocarbon components most closely associated with combusion, the high molecular weight PAHs (Dexter et al., 1981), from a number of areas of Puget Sound. While details vary among the studies and among the cores, the general trends in most areas appear to be consistent with the input history indicated in the data presented above. Most cores, particularly those collected near the major urban areas, show increasing PAH concentrations in the sediment strata dated about the turn of the century. The combustion PAHs generally reached maximum concentrations in the sediments during the period between 1940 and the late 1950s. This trend is consistent with the data presented above for coal combustion for domestic heating, a relationship that has been observed in other parts of the country. In fact, this maximum is so ubiquitous that it has been suggested as a useful sediment dating tool (Curl, 1982).

In comparison to the combustion PAHs, the n-alkanes and unresolved complex mixture (an analytically defined hydrocarbon component of contaminated sediments), hydrocarbons considered to be more indicative of unburned oil pollution (Curl, 1982; Barrick et al., 1980), reached maximum concentrations in more recent sediments (1955-1970) in the cores from the Main Basin (not depicted here). The trends in these hydrocarbons may reflect the changes in oil usage in the Sound, but it has also been noted that the maxima correspond to the startup of the West Point Sewage Treatment Plant (Curl, 1982).

In summary, both the limited information regarding the inputs of PAHs and the evidence available from the sediment cores indicate substantial reductions in PAHs in most areas of the Sound over the last 30 to 40 years. These data also give some indication that the possible source of the large anthropogenic loadings of the 1940s was inefficient combustion of organic matter (coal), a fact that should be a useful warning for future energy development.

6.2 POLYCHLORINATED BIPHENYLS

PCBs are an interesting group of compounds for studies of temporal trends because they are of wholly anthropogenic origin, are stable chemically, and were not in existence prior to 1929. Because of their toxicity, potential carcinogenicity and ability to accumulate in the tissue of organisms, they were banned from use in the United States in 1972. These dates provide useful start and end dates against which input and distribution data can be compared. At the same time, the temporal data for PCBs in Puget Sound are in a state very similar to those for the PAHs. Most of the major input sources of PCBs to the Sound have still not been identified, nor have all of the uses in the region, thus making even crude estimates of the possible quantities of PCBs reaching the Sound is difficult (Dexter et al., 1981; Harper-Owes, 1983; Quinlan et al., 1985).

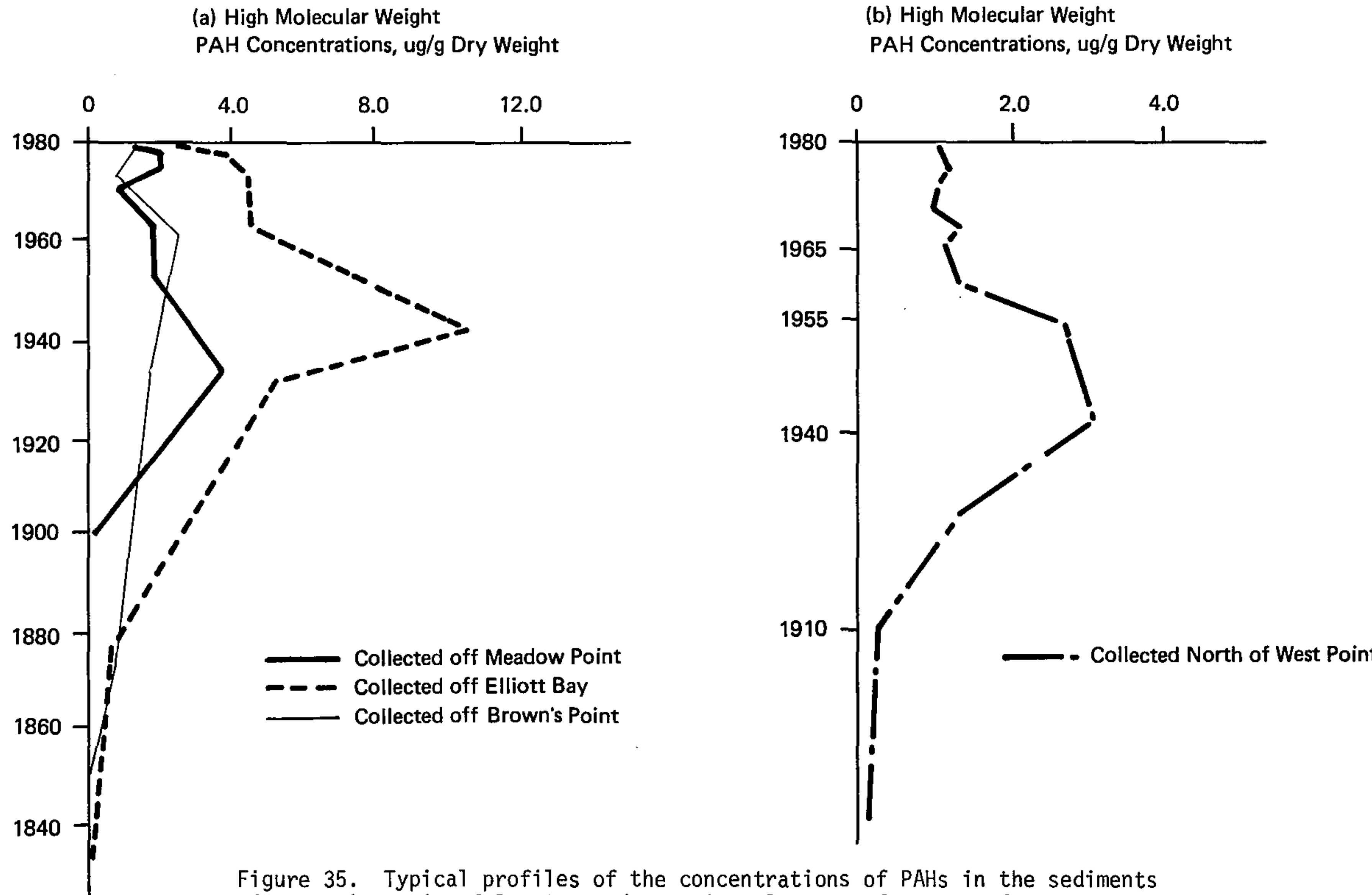


Figure 35. Typical profiles of the concentrations of PAHs in the sediments of the Main Basin of Puget Sound near Seattle, as a function of the age of the sediments. (a) data from Romberg et al., 1984; (b) data from Bates et al., 1984. Different scales are used in (a) and (b). The data depict the sums of Dibenzo(a-h) anthracene, benzo (a) anthracene, benzo (a) pyrene, benzofluoranthenes, chrysene, flouranthene, indeno (1-2-3-c-d) pyrene, pyrene, and benzo (g-h-i) perylene.

PCBs have been measured, however, in various media in the Sound for over a decade and even though 10 year's of data may seem short in comparison with some of the other data sets, it is sufficient to show consistent trends of decreasing PCB levels in recent measurements.

A number of studies of the concentrations of PCBs in the sediments of the Duwamish River were made in the mid-1970s (Dexter et al., 1981). These studies consistently measured concentrations in the range of 1.0 ppm to about 4.0 ppm (dry weight), with a few localized areas of higher levels (Dexter et al., 1981). More recent studies have found values in the same approximate locations in the river to be about 0.5 ppm, one-half, or less, of the former concentrations (Harper-Owes, 1983; Malins et al., 1980 and 1982; unpublished EPA data, 1983).

PCB concentrations have been measured in three cores from the Main Basin near Seattle (Figure 36). Similar trends are shown by each of these cores, that indicate a major increase in the PCB levels beginning about 1940. The presence of PCBs deeper in the cores than the period of their first manufacture (1929; Risebrough and DeLappe, 1972) can be attributed to sediment reworking and mixing by biological organisms (Carpenter et al., in press). In the more recent, shallower sediments, two of the cores showed clear trends toward decreasing concentrations from peak levels in the sediments dated from the 1960s.

The core from closer to Elliott Bay showed a trend similar to the others except that this core also contained a major spike from the period considered to be about the mid to late 1970s. It is interesting to speculate that the date of this maxima, if correct, would correspond fairly well with the date of the major PCB spill in the Duwamish River in the fall of 1974. While this spill was substantially cleaned up in the spring of 1976, it is known that a portion of the spilled PCBs was washed from the site by the major flooding in December 1975 (Blazevich et al., 1977). However, it would seem remarkable that this spill would produce such a pronounced spike in the sediments at the distance (about 5 nautical miles) from the spill that the core was collected. Undated cores from off the mouth of the Duwamish River collected in 1979 and 1980 did not show a similar peak (Dexter et al., 1984), but did indicate that variable concentrations of PCBs in the sediments were common.

Measurements of PCBs have also been made in biological organisms. Harper-Owes (1983) summarized data from a number of studies of the concentrations of PCBs in the tissue of fish caught in the Duwamish from 1970 to the present and observed a decrease similar to that seen in the sediments from that area (Figure 37).

In addition, the concentrations of PCBs in the blubber of harbor seals from the South Sound have been examined from 1975 to 1983 (Figure 38)(Calambokidis et al., 1984). These data depict different age classes of seals and are much too variable and limited to establish clear trends. It may be noted, however, that the extreme values observed in the mid-1970s have not been observed in more recent data.

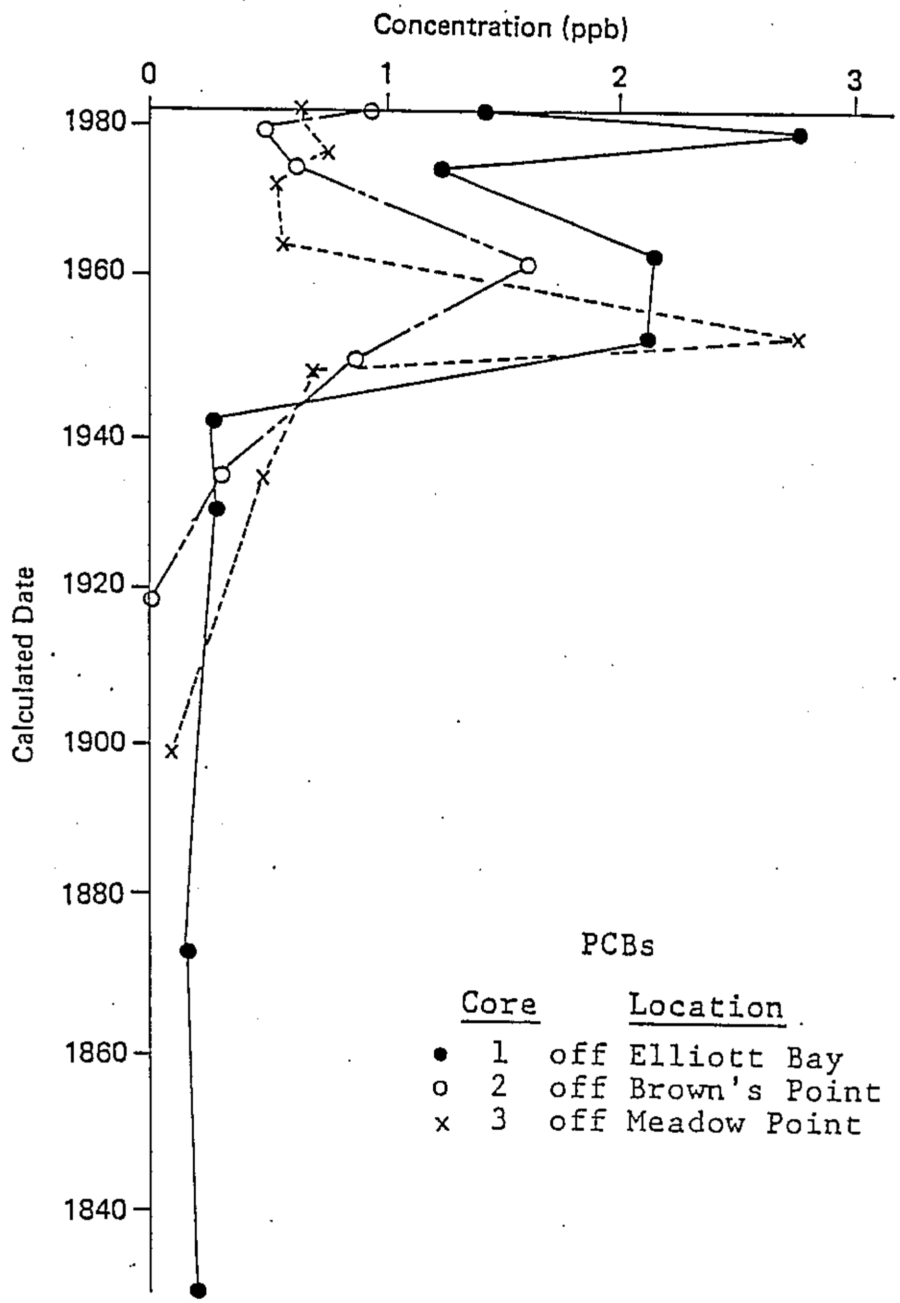


Figure 36. Average concentrations of PCBs in three sediment cores collected in the Main Basin near Seattle as a function of age of the sediments.
Source: Romberg et al., 1984.

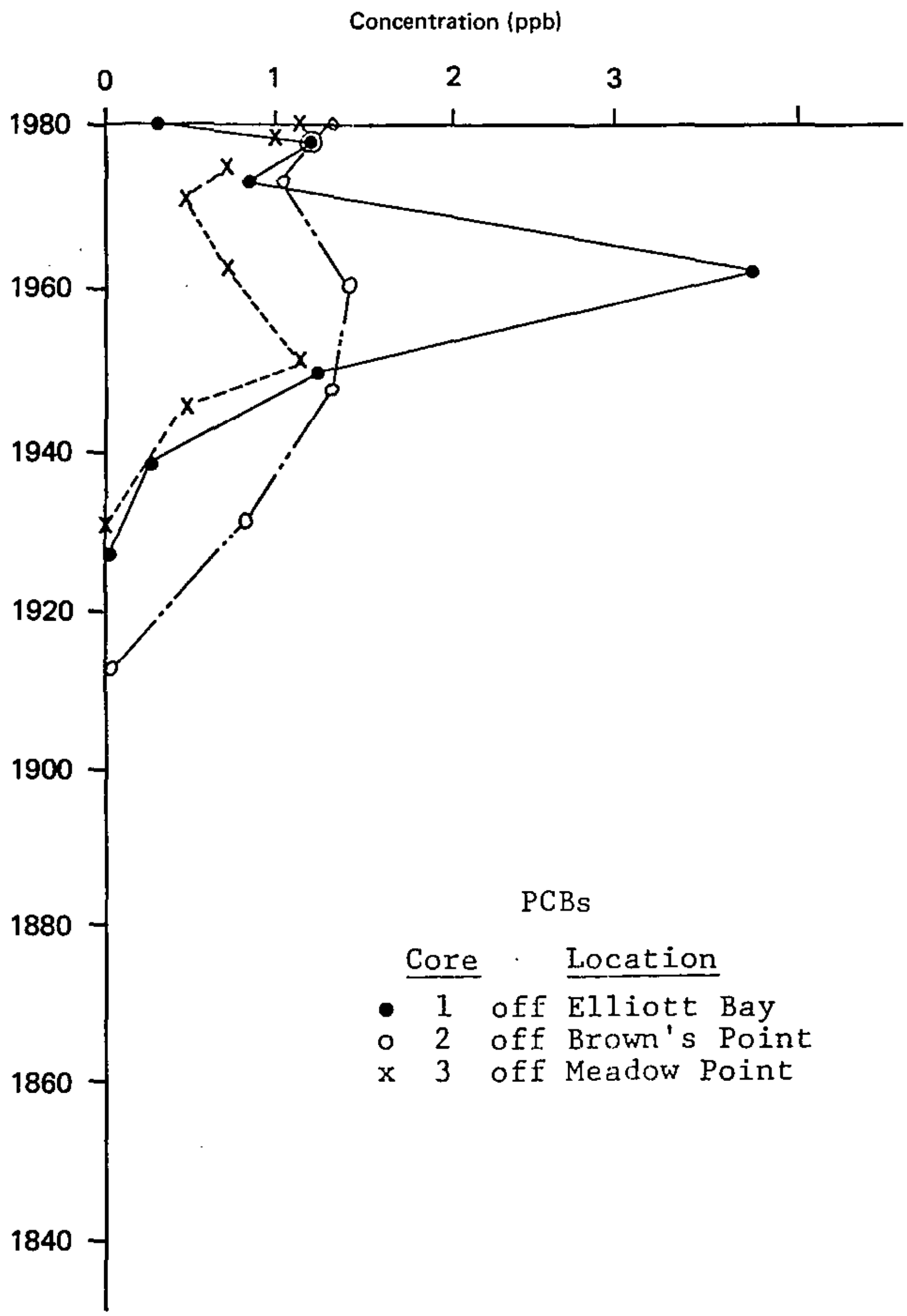


Figure 36. Average concentrations of PCBs in three sediment cores collected in the Main Basin near Seattle as a function of age of the sediments.
Source: Romberg et al., 1984.

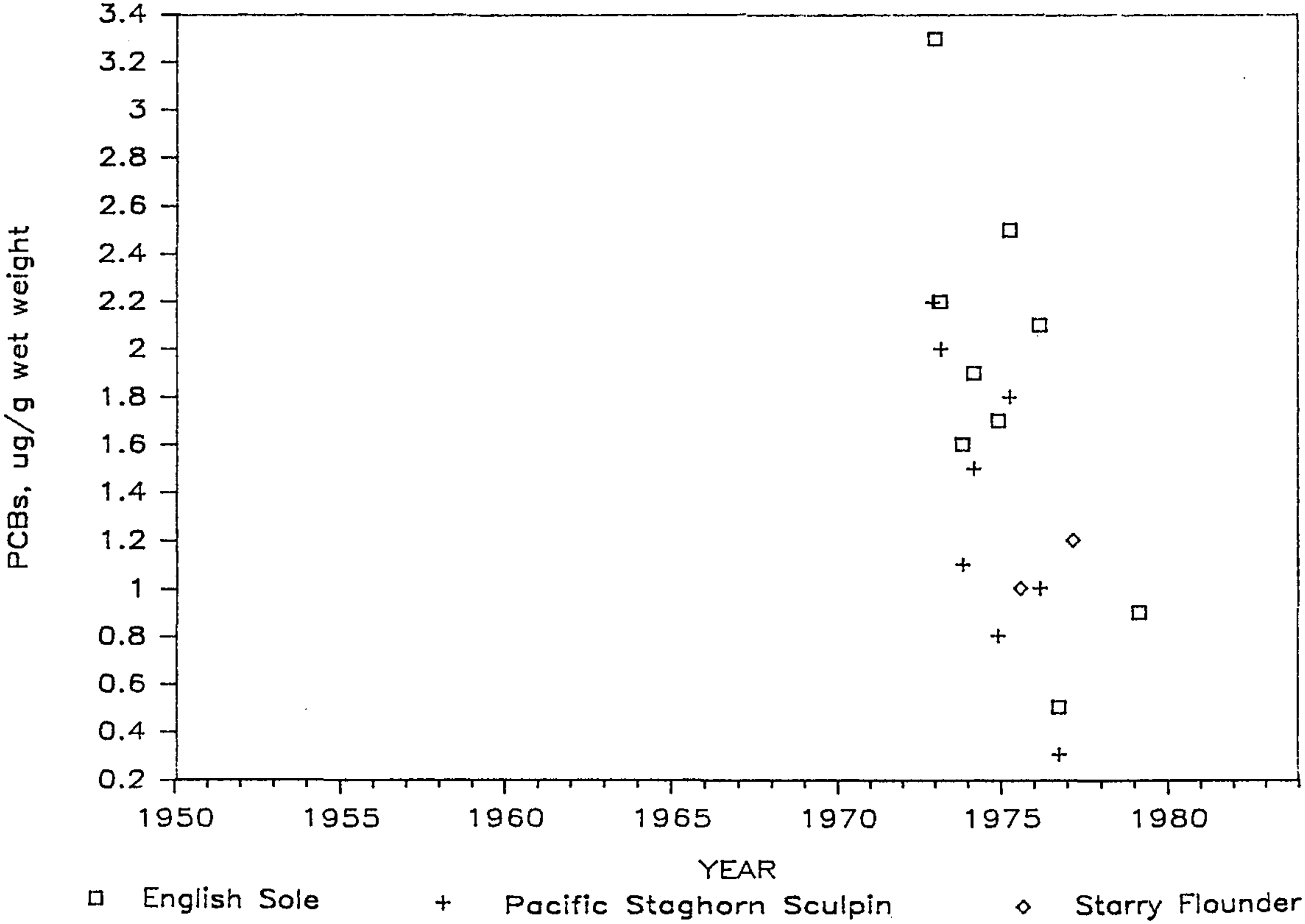


Figure 37. Concentrations of PCBs in fish from the Duwamish River, 1970 to 1980.
Source: Harper-Owes, 1983

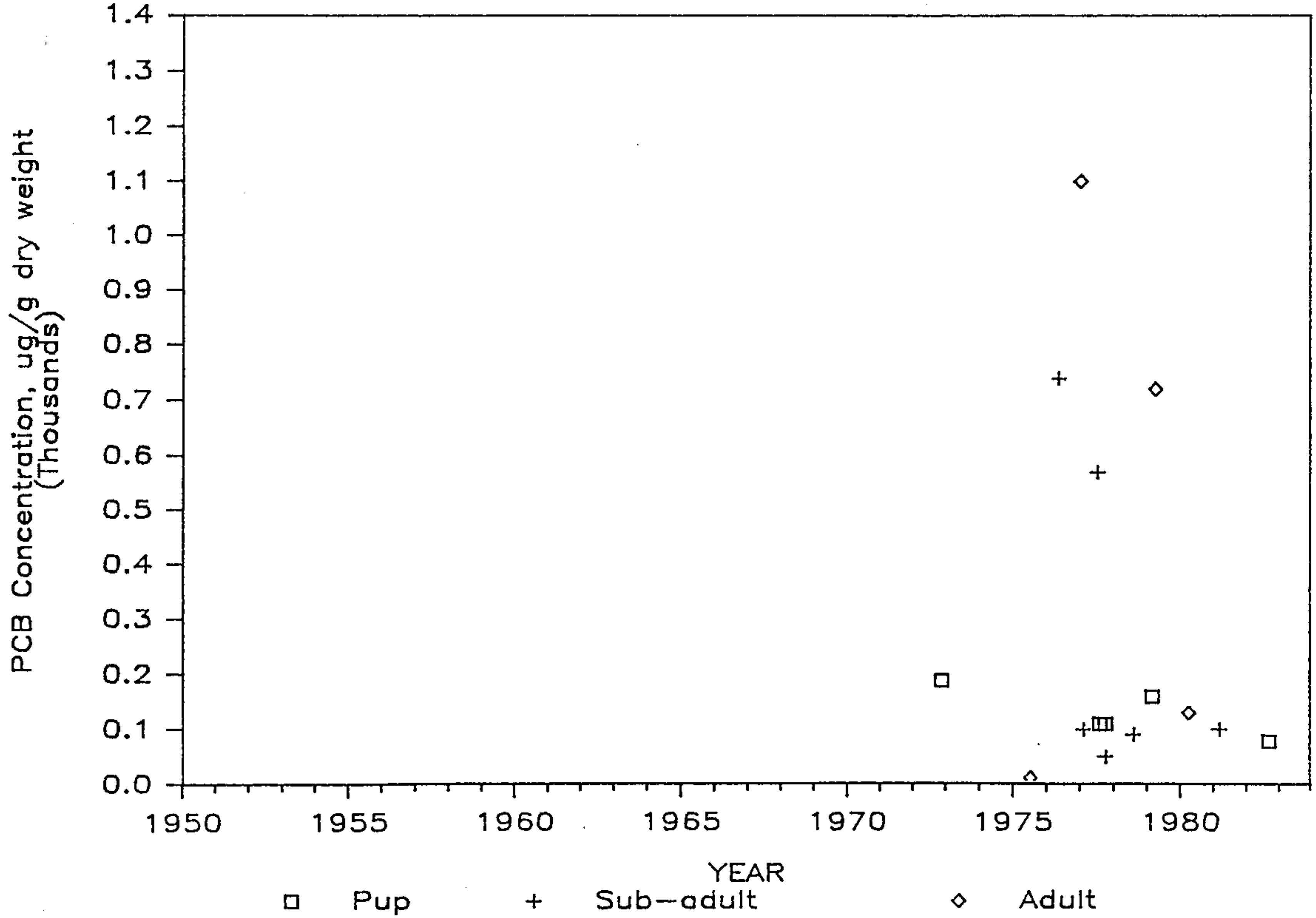


Figure 38. Concentrations of PCBs in the blubber of harbor seals from Southern Puget Sound, 1975 to 1983.
Source: Calambokidis et al., 1984.

Overall, the data provide a limited but consistent indication that the accumulation of PCBs, at least in the Seattle area and probably for the whole Sound, have been decreasing over the last decade, and that the biota are probably beginning to reflect this decrease.

6.3 TRACE METALS

There is more information available for most of the trace metals than for the organic compounds. The trace metals are natural components of all ecosystems and many of the trace metals that are considered to be contaminants in Puget Sound are essential nutrients to many organisms in small quantities. Study of the natural geochemical and biochemical cycles for the metals led to the development of adequate analytical procedures for the analysis of trace metals in environmental samples earlier than they developed for most organic compounds. In addition, the measurement of trace metals has been inexpensive compared to the cost of organic chemical analyses. As a result, generally more data are available from source monitoring and environmental samples from the Sound. Still, data from the years previous to the mid-1970s are limited.

Historically, trace metal inputs to the Sound have been substantial but have been of natural origin. For most of the metals in most areas of the Sound, natural sources, i.e., river runoff, shoreline erosion and the advection of seawater, dominate the inputs (Dexter et al., 1981; Curl, 1982; Romberg et al., 1984). For the purpose of this report, it has been assumed that the natural inputs have been largely constant and that any increases in the concentrations of metals in the Sound have been due to anthropogenic inputs.

Anthropogenic inputs were poorly documented during the early industrial and urban development of the Sound, but a number of specific and generic sources can be identified. Quantitative data for these sources are limited.

A major source of a number of metals, including copper (Cu), lead (Pb) and arsenic (As) has been the ASARCO copper smelter at Ruston (Tacoma). This plant began operation as a lead smelter in 1889 and converted to copper smelting in 1902. Since its start, the smelter has discharged both liquid wastes and atmospheric particulates enriched in metals. Elevation of the Pb and As levels in the soils of Tacoma, south King County, and parts of Vashon Island to even hazardous levels has been attributed to the emissions of the smelter (PSAPCA, 1983). A number of studies have documented the high levels of metals in the surface sediments in the vicinity of the site (Dexter et al., 1981; Barrick, personal communication). Recent monitoring has made quantitative estimates of the current smelter discharges possible (Romberg et al., 1984; Quinlan et al., 1985). While these estimates clearly show the importance of the smelter as a source of metals (e.g., up to one third of the total anthropogenic Cu to the Sound; Quinlan et al., 1985), detailed temporal trends are unknown. It can be surmized, however, that the initial inputs began with the smelter start-up at the turn of the century and have continued at substantial levels. Further, the smelter has been under increasing scrutiny by local, state, and federal agencies since the mid-1970s and the emissions have probably been decreasing since that time. For example, atmospheric emissions of Pb from the main stack have decreased from 23 metric tons per year in 1978 to less than 10 metric tons per year in 1982 (PSAPCA, 1983). Similar decreases have occurred in the liquid effluents (Romberg et al., 1984). Probably the most important fact about the ASARCO smelter now is that it closed in April 1985, thus eliminating one of the major anthropogenic sources of some metals to the Sound.

A variety of other industrial sources, none known to be near the magnitude of the ASARCO smelter, have existed on Puget Sound. The Washington State Pollution Control Commission reports cite numerous instances of metal platers, metal fabricators, welding shops and ship yards in Seattle, Tacoma, Bremerton, and other areas discharging their wastes to the Sound (WPCC, 1945-1957). Interestingly, and illustrative of the past understanding of pollution risks, these discharges were considered problems only when acidic pickling wastes, caustic cleaning solutions or cyanide wastes were discharged in quantities which resulted in fish kills. For example,

> This investigation concerns a complaint that the Camp Plating Company was dumping chemicals into the Hylebos Waterway injurious to fish life. Investigation disclosed that very little cyanide was used and when it becomes necessary to empty this material, suitable means of neutralization are employed. Considerable amounts of mineral acids and certain alkali solutions are used by this concern. After considerable use, these solutions are poured into each other causing neutralization and then emptied. While our technicians believe that this mixing is enough, the manager of the plant, Mr. H. Wiggins, was requested to make additional tests for the purpose of finding out whether complete neutralization of the effluents is accomplished. (WPCC, 1947).

The inference that can be drawn is that neutralized wastes were allowable discharges even though they undoubtedly contained substantial quantities of trace metals.

Other known sources of industrial contamination by trace metals have been identified from a number of sources (Dexter et al., 1981; Konasewich et al., 1982; Curl, 1982; Harper Owes, 1983; Romberg et al., 1984; WPCC, 1945-1950). These include:

- o the use of smelter slag from ASARCO and other smelters for sandblasting of ships, as riprap and roadbed material (a source of many metals, but mainly Cu and As):

- o the gradual dissolution of antifouling paints from the ships (Cu and Sb);
- o the use and discharge of biocides and fungicides for protecting wooden shore structures and wood pulp in the pulp mills (As and Hg);
- o losses from the electrodes in electolytic cells (Hg, mainly in Bellingham Bay);
- o metals from pulping chemicals (at least Zn); and
- o emissions from a lead smelter on Harbor Island, Seattle (Pb);

In all known cases, these industrial discharges are either no longer in existence or are using waste treatment, either on site or through a municipal treatment plant, to achieve substantial waste reductions. For example, the lead smelter on Harbor Island has decreased its emissions by an order of magnitude in the last five years (PSAPCA, 1983). Some illegal discharges from a variety of sources probably still occur, but the regulatory agencies are now better able to enforce discharge limitations. Also, the general attitude of the public and the agencies has shifted from one where the burden of proof was on the agency to show that a discharge was deleterious, to one where the industries must demonstrate the safety of their wastes prior to being allowed to discharge them.

Two other sources of metals can be identified. First, municipal sewage systems (and previous raw discharges) contain measurable quantities of most trace metals. The sources to the sewage systems include the corrosion of pipes in the potable water distribution system, street runoff, and industrial and commercial effluents discharging to the system (Dexter et al., 1981; Romberg et al., 1984; Cooley and Matasci, 1984). The quantities discharged and the recent temporal trends can be illustrated with data from the monitoring of the West Point Sewage Treatment Plant (Figure 39)(only Cu and Pb are displayed in Figure 39, but they are generally representative of the trend in the other metals). The data show sporadic maxima, but a general decrease in the rate of discharge of the metals as pretreatment controls were implemented and the removal of suspended material has become more effective for this plant.

Because the metals in the municipal wastes are predominately associated with the particulate matter in sewage (Cooley and Matasci, 1984), treatment of effluents has increased the retention of the particulate matter and therefore decreased the discharge of trace metals. Thus, historically, there probably was a reduction in the trace metals loadings to most areas of the Sound as a result of the conversion from the discharge of raw sewage to that that has received primary treatment. Secondary treatment would further reduce this loading (Cooley and Matasci, 1984; Quinlan et al., 1985).

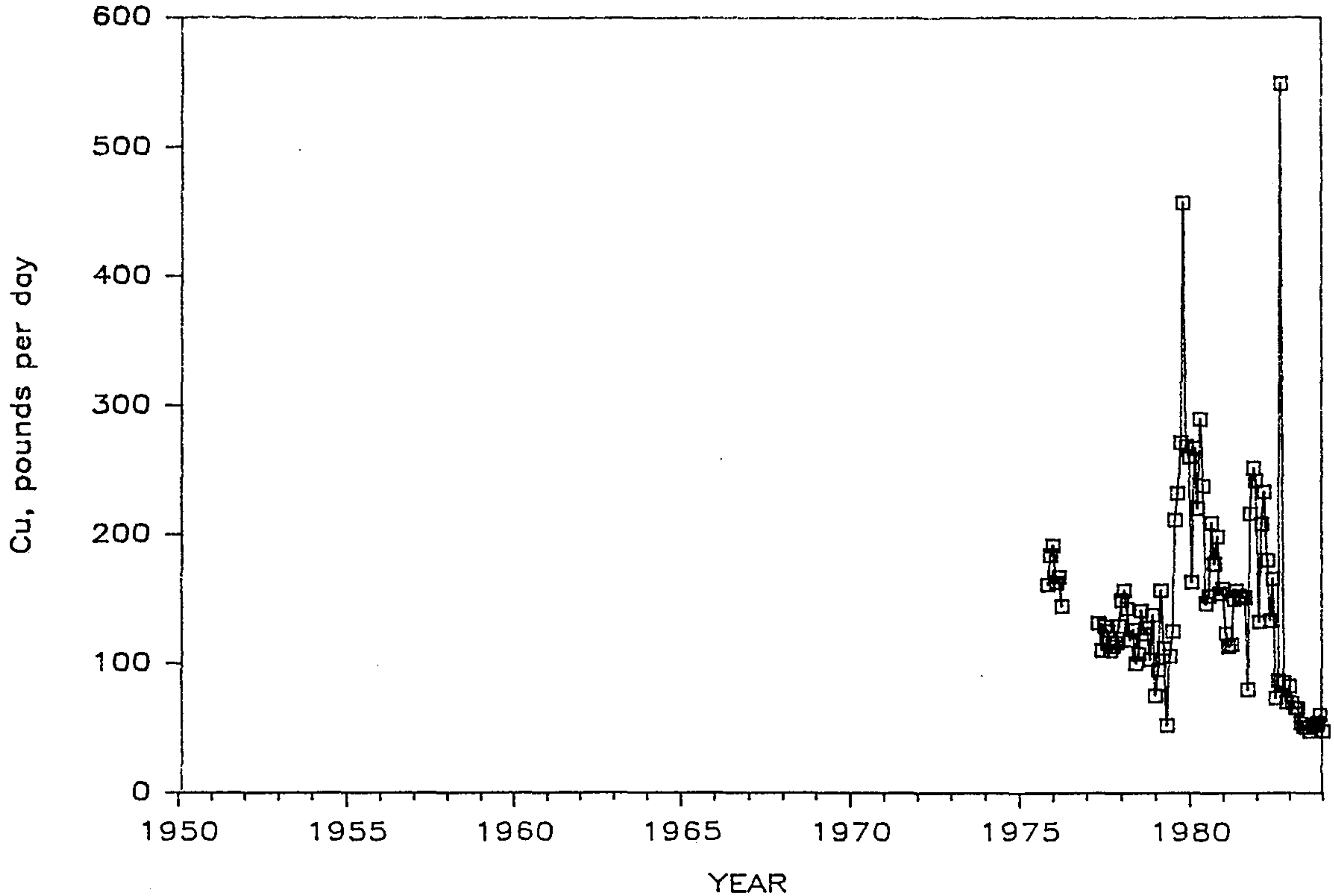


Figure 39a. Discharge rates of copper (Cu) from the West Point sewage treatment plant, 1975 to 1983. Data points are the average value for each month derived from the loading value for each day of the month. Source: West Point treatment plant discharge monitoring reports.

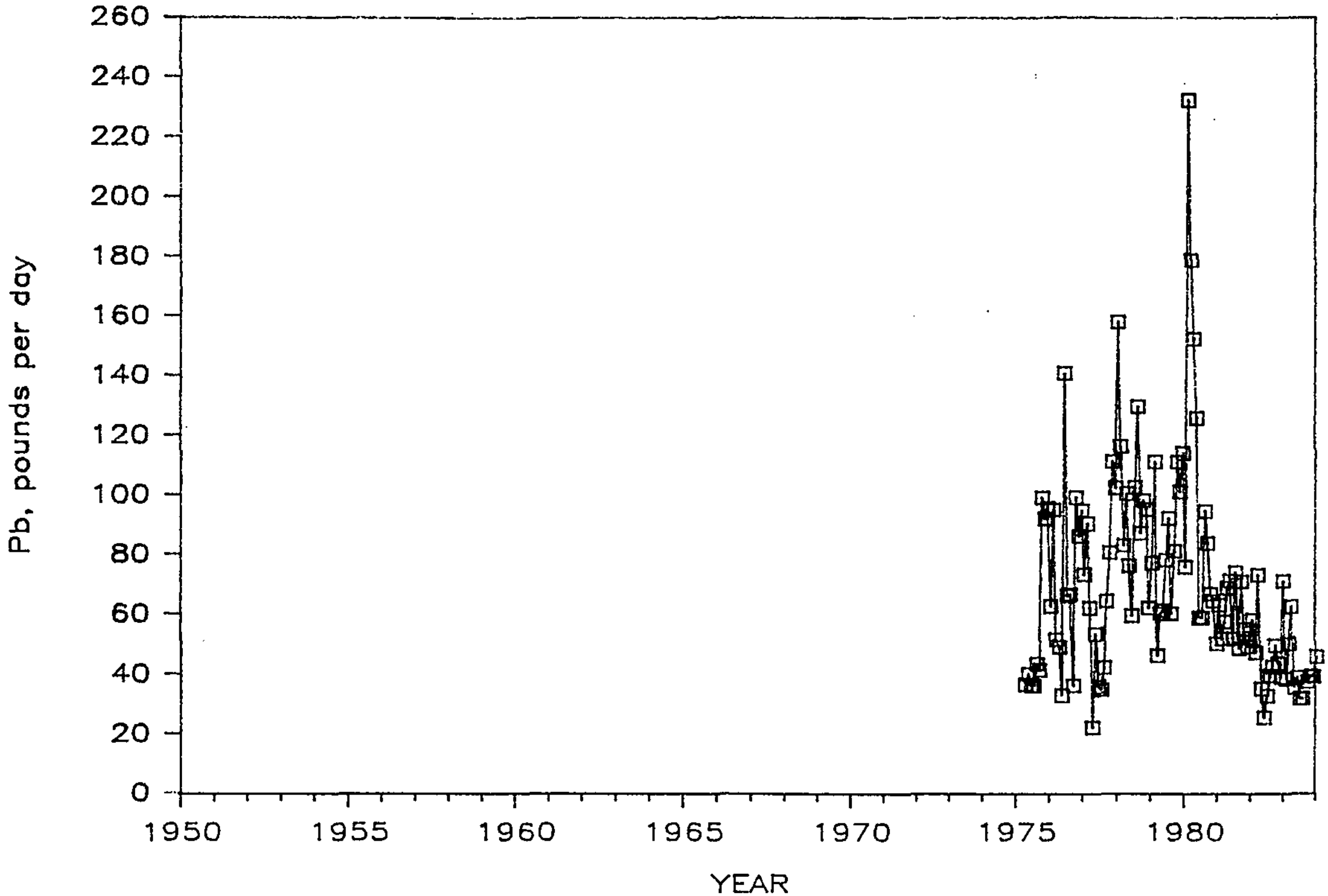


Figure 39b. Discharge rates of lead (Pb) from the West Point sewage treatment plant, 1975 to 1983. Data points are the average value for each month derived from the loading value for each day of the month. Source: West Point treatment plant discharge monitoring reports.

Finally, one of the largest anthropogenic sources of at least one trace metal, Pb, has been the automobile. Lead, in the form of tetraethyl lead, has been added to gasoline since the early 1930s (Curl, in preparation), but other metals including Zn (from tires) and Cu seem to be closely associated with Pb in street dust (Galvin and Moore, 1982). The emissions of the metals from automobile use are predominantly in the form of atmospheric particulates and street dust. These enter the Sound through direct atmospheric fallout and via street runoff either directly through storm drains or indirectly through the municipal treatment system (Galvin and Moore, 1982). Because of the complexity of the transport routes, firm estimates of the amount of Pb and other metals reaching the Sound cannot be made at the present time. Curl (in preparation) has estimated that as much as 5 percent of the automobile-derived Pb could reach the Sound. The probable temporal trends in this input can be estimated by examining the total tetraethyl lead consumption in the Puget Sound basin (Figure 40). As expected, Pb consumption follows that of gasoline very closely until the recent mandated introduction of lead-free gasoline reduced Pb use. Because of the quantities of Pb involved and the fact that nearly all of the material was released to the environment, this source is potentially one of the largest in the Sound from the late 1930s to the present. Recent reductions, however, may continue and may eventually entirely eliminate this input. The long-term trends for other metals associated with automobile use are unknown.

In summary, what data are available regarding the long term trends in the inputs of most trace metals indicate that the levels probably increased in approximate proportion to the population until a number of control measures instituted over the last 10 to 20 years began to reduce the loadings. Some metals, particularly silver, that have been identified to be of concern in recent studies (Quinlan et al., 1985; Romberg et al., 1984), may not have the same trends because their usage in the area is increasing in association with new types of industries, e.g., computer component manufacturing.

The data available from environmental samples from the Sound are generally consistent with the input information. For example, Bellingham Bay is one area in the Sound where temporal trends in the concentrations of a trace metal have been established. Mercury (Hg) levels in the surficial sediments as high as 100 ug/g were observed near the mouth of Whatcom Creek in 1973 (Crecelius et al., 1975), while recent measurements of surficial sediments in the same area detected a maximum concentration of 0.88 ug/g in 1983 (U.S. EPA, unpublished data).

As with the PAHs and PCBs, the concentrations of the metals in the sediment cores from the Sound provide about the best available information on the past levels of contamination. However, the data for metals from age-dated cores must also be considered with care since they suffer from the same problems discussed previously and, in addition, many of the metals can be mobilized in the cores by changes in the oxidation potential and/or the pH as a result of natural biological processes (Dexter et al., 1981).

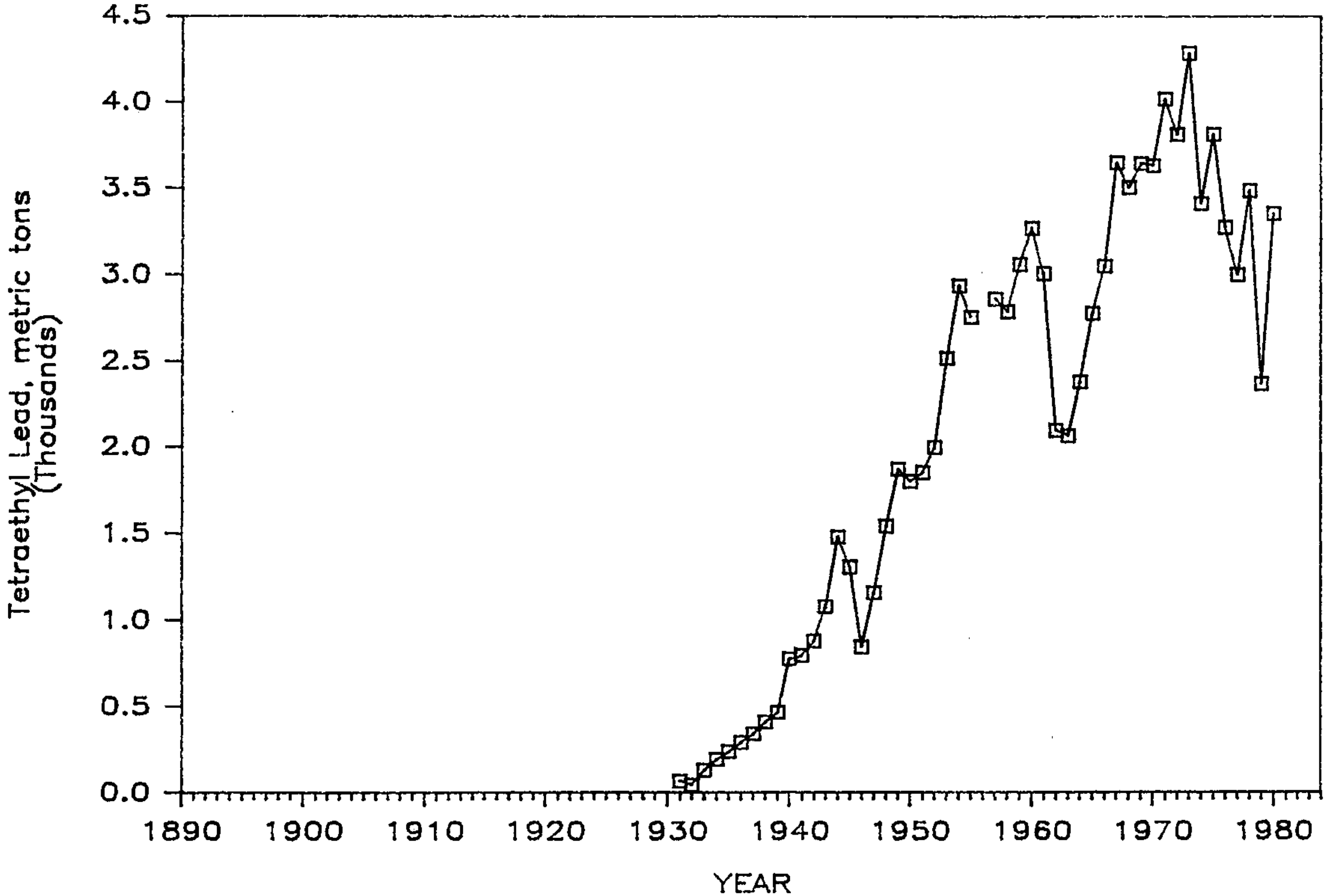


Figure 40. Consumption of tetraethyl lead in automobile gasoline in Washington State, 1930 to 1981.
Source: Curl, in preparation.

Typical core profiles for Cu, Pb, Ag, Hg, and Cd obtained from the averages of nine cores from the Main Basin (Crecelius and Bloom, 1984), are presented in Figures 41 and 42. As illustrated by the figures, most (but not all) of the core profiles showed increases in the concentrations of Cu, Pb, Zn, Ag, and Hg in the sediments deposited since the turn of the century compared to earlier strata. The profiles for other metals were more variable and generally did not show trends with depth in the cores (e.g., Cd) (Romberg et al., 1984). The rapid increase in the concentrations of Pb in the cores is considered by some researchers to be so characteristic of Puget Sound cores, and to have originated from the opening of the ASARCO smelter, that it can be used by itself as a time marker for Puget Sound cores (Romberg et al., 1984). Many, but not all of the cores that have been examined had lower concentrations in the surficial sediments, representing very recent deposits. In some cores, these decreases were statistically significant (Romberg et al., 1984; Crecelius and Bloom, 1984).

The long-term increases and the possible recent decreases in metals concentrations in sediments are in agreement with the general input trends developed above, i.e., anthropogenic inputs increased dramatically from the turn of the century to about mid-centruy when improved pollution controls were instituted. While the more recent data are too limited to offer firm conclusions, it appears that continued monitoring may show that the peak period in metals contamination has passed (assuming progress continues in identifying and controlling inputs).

6.4 OTHER CHEMICALS

A large variety of additional organic compounds in addition to those discussed above has been observed in Puget Sound (Dexter et al., 1981; Konasewich et al., 1982; Malins et al., 1980 and 1982; Romberg et al., 1984). Some sources for a few of the compounds can be found in the historical literature, but by and large, source identification studies for most compounds have only begun. Metro has performed exhaustive analyses of three cores, but these data had not been compiled at the time this report was prepared (Romberg, Metro, personal communication). Hence, no quantitative estimates were available of the temporal trends in the inputs of any of these other compounds. Examples of sources that have been mentioned in historical records (WPCC, 1945-1957) include "oil" slicks from creosote wood treatment facilities in Seattle, Olympia and at Eagle Harbor. These slicks may have included creosote and possibly other wood treatment chemicals. Interestingly, while a wood preserving company is currently under investigation for contamination of parts of Eagle Harbor, in 1947, this company was described thus:

> This wood preserving company has been investigated previously as a source of oil pollution. Corrections had been recommended and a recheck showed no evidence of oil in the waters around the plant and everything on shore was in an exceptionally clean condition. The

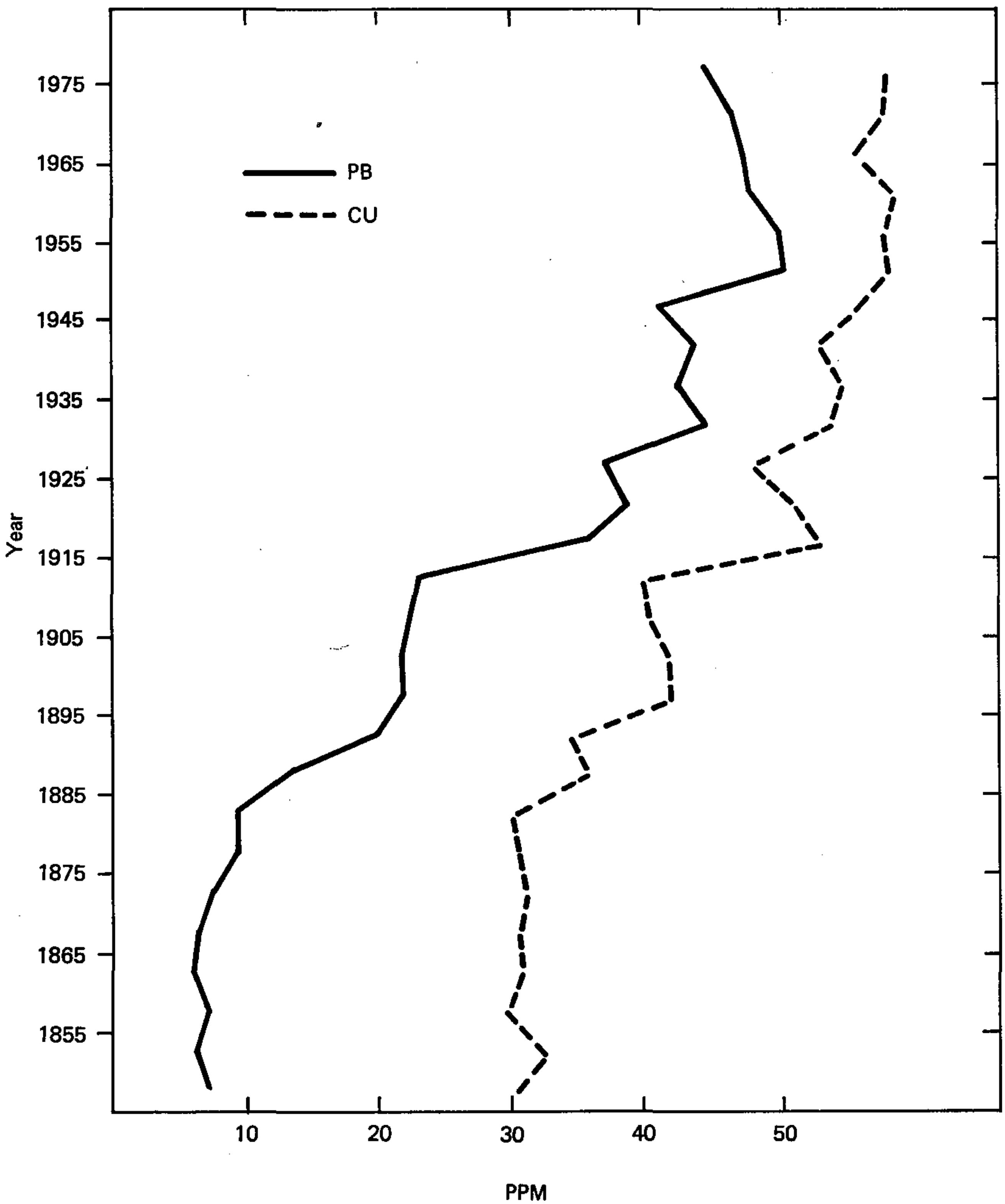


Figure 41. The average concentrations of lead (Pb) and copper (Cu) in 9 sediment cores from the Main Basin of Puget Sound, as a function of age.
Source: Crecelius and Bloom, 1984.

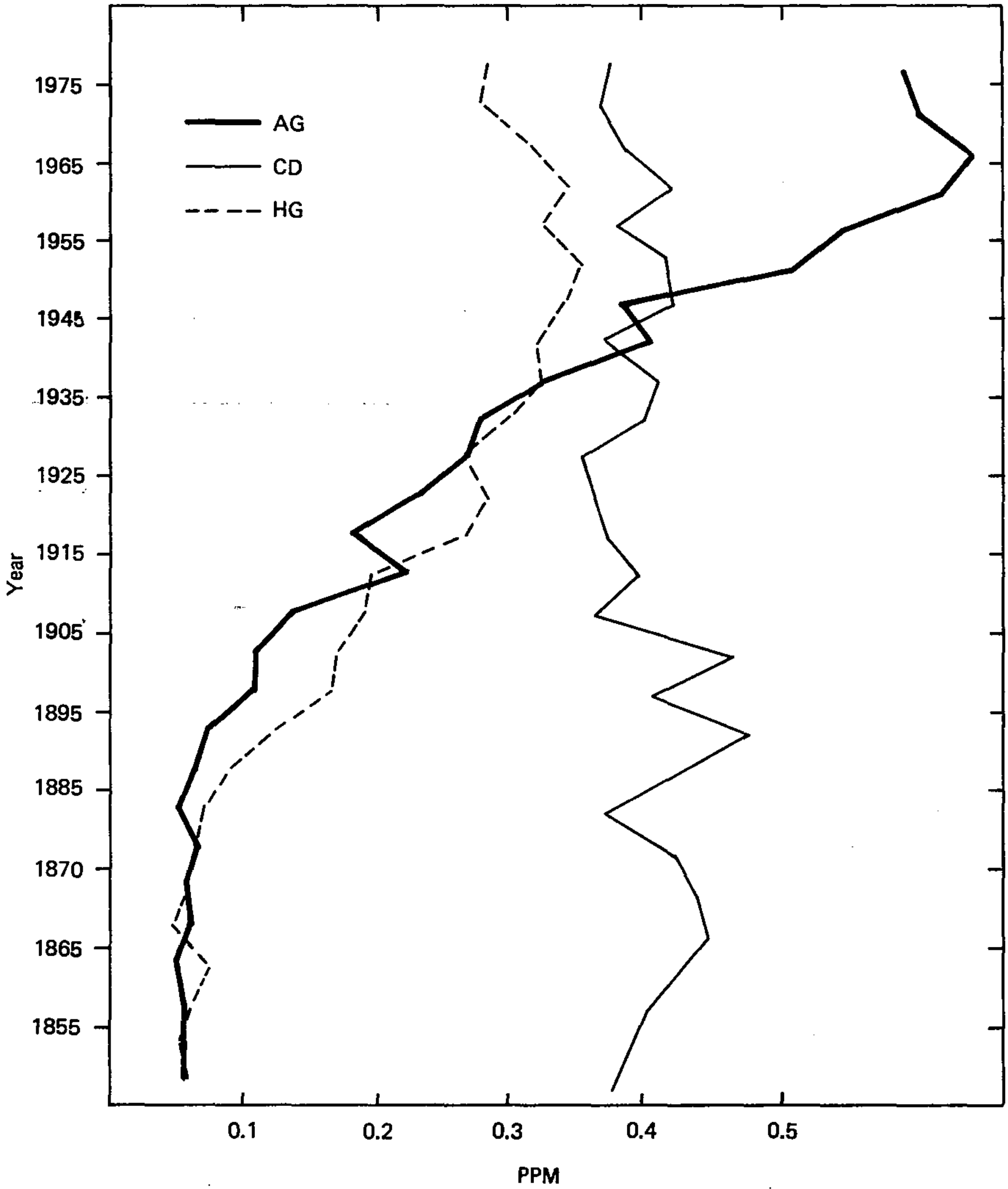


Figure 42. The average concentrations of silver (Ag), Mercury (Hg) and Cadium (Cd) in 9 sediment cores from the Main Basin of Puget Sound, as a function of age of the sediments. Source: Crecelius and Bloom, 1984.

> creosote plant is situated on high ground a considerable distance from the water and every precaution is taken so that no oil spillages can find their way into the harbor. For some time, all of the creosote pilings and timbers have been shipped by barge instead of being dumped in the water and floated. By this method practically no creosote or oil gets into the water. Recommendations of our technicians have been carried out so this plant has ceased to be a source of pollution. (WPCC, 1947).

Other compounds that have been identified in use historically have included organic and organo-metallic fungicides (trichlorophenol, pentachlorophenol and phenyl mercuric acetate) used in large quantities at at least one pulp mill (Wagner et al., 1958). It is unknown how pervasive this use was at other mills, or the possible use of other substances for the same purpose.

Experimental uses of chlorinated benzenes for the protection of shellfish beds from parasites have been discussed, but the use of this technique appears to have been minimal (Loosanoof et al., 1960). Finally, pentachlorophenol spills in Tacoma have been noted in both older and more recent observations (WPCC, 1947; U.S. Coast Guard spill reports, 1981).

Profiles of the concentrations of any of these or other chemicals in sediment cores are very limited. Besides the data developed by Metro, discussed above, Riley et al. (1981) observed subsurface peaks of chlorinated butadienes and other chlorinated organic compounds in the sediments of two Commencement Bay waterways, indicating that after many years of increases, the inputs stopped about 10 to 15 years ago. The source of this material is still not completely documented.

In currently unpublished work, a variety of organic compounds have been measured in cores in the waterways of Commencement Bay, including PAHs, PCBs, many other chlorinated organics and trace metals. For many of the chemicals from all areas of the waterways, the cores showed subsurface peaks in concentration, indicating that past inputs were larger than present inputs (Barrick, personal communication).

6.5 SUMMARY

The temporal trends developed above for both the inputs and the environmental changes in concentrations are tenuous and leave many specific questions unanswered. But they are remarkably consistent in indicating that most toxic chemicals may have reached maximum levels from 5 to 30 years ago and many may now be diminishing. This general conclusion is undoubtedly not true for all chemicals or for all areas of the Sound. In particular, the trends noted appear to represent the results of the major steps in general and site-specific pollution control that occurred in the period from 1960 to 1980. Whether increasing inputs from this point in time from greater population and new and expanding industries will overtake these decreases will have to be monitored closely.

7. POPULATION TRENDS IN RESIDENT ORGANISMS

This section focuses on the assessment of population trends in species which play an important role in Puget Sound. An attempt was made to identify data for as many populations of organisms from as many different trophic levels as possible that have been monitored over long periods of time. At least limited data are presented for plankton, benthic organisms, shellfish, fish, birds and mammals.

7.1 PLANKTON

Long-term studies that have monitored species diversity and/or the abundance of phytoplankton in Puget Sound are lacking (L. Nishitani, University of Washington, personal communication, and R. Strickland, University of Washington, personal communication). A limited study of the phytoplankton community in Friday Harbor was conducted during the 1930s by Lyman Phifer. Dr. Max Taylor at the University of British Columbia has collected data from English Bay (Vancouver, B.C.), and Metro collected phytoplankton data from the Main Basin during the 1960s and 1970s (Ebbesmeyer and Helseth, 1977; L. Nishitani, pers. comm.). These data are too sparse to be used to portray long-term trends.

Phytoplankton can become a water quality concern when present in intense blooms. The exact conditions under which blooms occur are not known, but they may be related to anthropogenic nutrient inputs (Dexter et al., 1981). Many cases of blooms have been noted in historical documents (WPCC, 1945-1957). They were generally considered nuisances which posed little or no threat to human health or to the environment. For example, in 1946 and 1947 the WPCC documented several blooms that resulted in reddish colored water ("red tides")(Table 4). Similar blooms occur today although the frequency and intensity may have diminished.

Paralytic Shellfish Poisoning (PSP), a serious health threat in Puget Sound, is associated with certain "red tide" phytoplankton blooms. PSP is caused by a toxin which is produced by dinoflagellates, generally a species of Gonyaulax. Gonyaulax catenella is the dinoflagellate responsible for producing PSP along the Pacific Northwest coast. The toxin is accumulated in shellfish and other organisms and can cause paralysis leading to death in humans who eat the tainted shellfish (Saunders et al., 1982; and Strickland, 1983). PSP is a recent concern in the Main Basin of Puget Sound and only limited data regarding the temporal trends in PSP occurrences are available.

Table 4. Incidence of red tide observed in Puget Sound

Year/Month	Location	Description	Organism
1946/August[a]	Lower Puget Sound	Water was murky and tinged a deep reddish-brown.	Gymnodinum sp.
1946/UK[b,c]	Budd Inlet	A massive bloom occurred. When these organisms died, they covered mussels, clams, oysters, and fish, resulting in their death. The decomposition of these organisms produced hydrogen sulfide gas which damaged the paint on boat hulls moored in the marina.	Gymnodinum sp.
1947/UK[d]	Seattle and Lower Puget Sound	Red tide observed in these areas.	Noctiluca sp.
1947/UK[d]	Sekiu	Red tide reported in area.	Not known; may have been due to presence of many species of phytoplankton.

[a] Data from WPCC, 1946a.

[b] Data from WPCC, 1946b.

[c] UK = unknown

[d] Data from WPCC, 1947.

Outbreaks of PSP along the west coast of North America have been documented since 1793 when a member of Captain George Vancouver's crew died after eating toxic mussels from the northern British Columbia Coast (Strickland, 1983; Saunders et al., 1982). A major outbreak of PSP occurred along the outer coast of Washington and British Columbia in 1942. Contaminated areas in Washington were observed from Dungeness Spit south to the Columbia River. Three deaths in Washington and eight in British Columbia were attributed to the ingestion of toxic shellfish during this incident (F. Cox, DSHS, personal communication; L. Nishitani, personal communication). As a result of this incident and continuing PSP occurrences, the WDF has restricted the harvest of shellfish (except razor clams) from Dungeness Spit to the Columbia River since 1943. A ban on all harvesting begins each year on April 1 and continues through October 31.

For reasons that are unknown, PSP was not observed east of Dungeness Spit until the late 1960s and early 1970s (F. Cox, personal communication; L. Nishitani, personal communication; Saunders et al., 1982). In the late 1960s, PSP was observed in the San Juan Islands, and in 1974 G. catenella was observed in sufficient numbers near Bellingham to close commercial shellfish grounds in that area. The first major documented bloom south of Admiralty Inlet occurred at Penn Cove on Whidbey Island in 1978. During this bloom, traces of the toxins were observed as far south as Des Moines (Saunders et al., 1982; Lilja, 1981; Strickland, 1983; and L. Nishitani, personal communication).

PSP has now spread into southern Puget Sound, although the concentrations of PSP toxin have not yet (1984) exceeded the level requiring restrictions on the harvesting of shellfish. The toxin was found in shellfish at the Tacoma Narrows in 1979, Nisqually Delta in 1980, Budd and Totten Inlets in 1981, and recently in Skookum Inlet. The toxin was also found in shellfish from Hood Canal north of Bangor in 1979 (L. Nishitani, pers. comm.)

The DSHS is currently in the process of compiling the detailed PSP data collected from 1978 to the present onto a computer data base. Once this data base is complete, data will be available to more clearly track the movement of PSP in Puget Sound and document past and present shellfish bed closures (L. Lilja and F. Cox, pers. comm.).

PSP is of ecological interest as well as being a human health concern. The toxin produced by a related phytoplankter, Gonyaulax excavata, has been observed to accumulate in herbivorous zooplankton which then become a vector of toxicity to higher trophic levels. For example, kills of Atlantic herring have been linked to the ingestion of contaminated zooplankton (White, 1980 and 1981). Deaths of a large number of breeding terns along the Massachusetts coast were associated with the ingestion of sand lance, Ammodytes americanus, tainted with the toxin from G. excavata (Nisbet, 1983).

There were a few cases along the Northwest coast where PSP is presumed to be the cause of fish and bird kills. During the 1942 PSP problem along the Washington and British Columbia coasts, numerous dead sea birds were observed 10 to 20 miles offshore and a massive herring kill occurred along the southeast coast of British Columbia. The suspected cause of death is PSP, although it was not substantiated at the time (L. Nishitani, pers. comm.).

Similar deaths also occurred in Alaska. In 1964, numerous dead fur seals, birds, and foxes that scavenged on the seals and birds were observed. Analyses of the stomach contents of the fur seals and birds revealed that the principal source of food was Ammodytes sp., while the guts of the Ammodytes sp. contained "swimming snails", a known PSP vector (L. Nishitani, personal communication).

The extent to which PSP outbreaks in Puget Sound may affect the resident organisms is unknown, but should be considered in future studies. Continued monitoring and study are also required to track PSP occurrences and develop an understanding of the causes of the PSP blooms.

7.2 BENTHIC ORGANISMS

Although a number of studies have examined the abundances of benthic organisms in the Sound, most of these have been one-time surveys aimed at identifying spatial, not temporal trends (Dexter et al., 1981). Because of sampling and taxonomic differences among these studies, it is not possible to combine them to generate a temporal sequence.

However, one study in Puget Sound that has been continuous since 1964 has the primary purpose of examining the long-term trends in the benthic macroinfauna (Nichols, 1985). Only a portion of the data from one site in the deep (220 m) central Main Basin were available for use in this report (Figures 43 and 44). These data depict changes in the infauna at the sampled site on time scales of a few years to decades. Long-term decreases in the abundance of the brittle star and an increase in the abundances of three molluscs and one polycheate were noted.

The overall trends depicted in these data are of the type often associated with organic enrichment of the sediments, a trend consistent with the increases in organic inputs (e.g., BOD, Figure 21) from the West Point Sewage Treatment Plant outfall (Nichols, 1985). This outfall was located only about 4 km from the sampling location and began discharging in 1965. However, other factors such as long-term changes in water temperature, salinity, and/or currents (see Chapter 4) may also account for at least some of these changes.

7.3 SHELLFISH

The shellfish for which data are presented below include the Olympia oyster, Pacific oyster, shrimp, crab, and hardshell clams. These groups

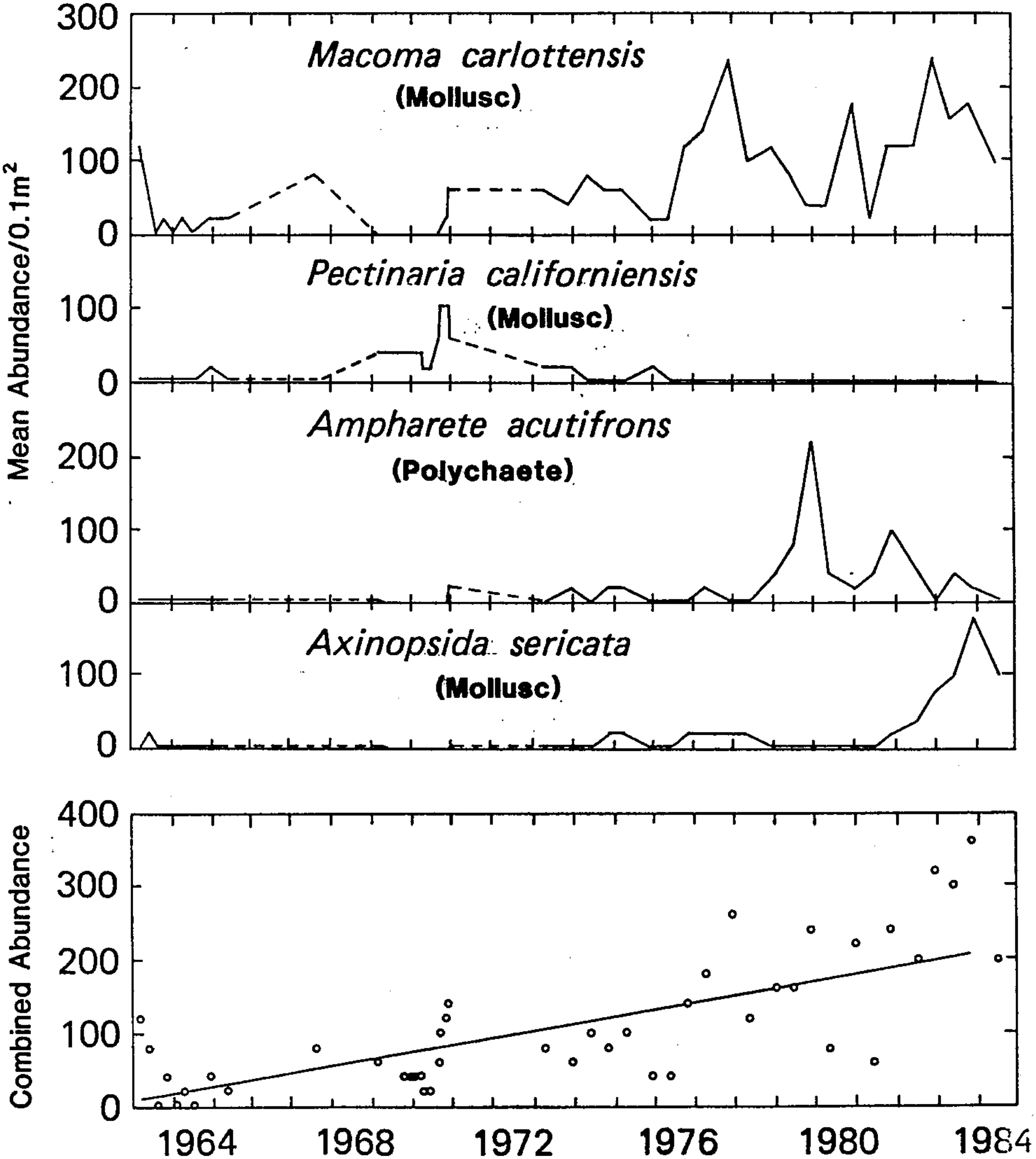
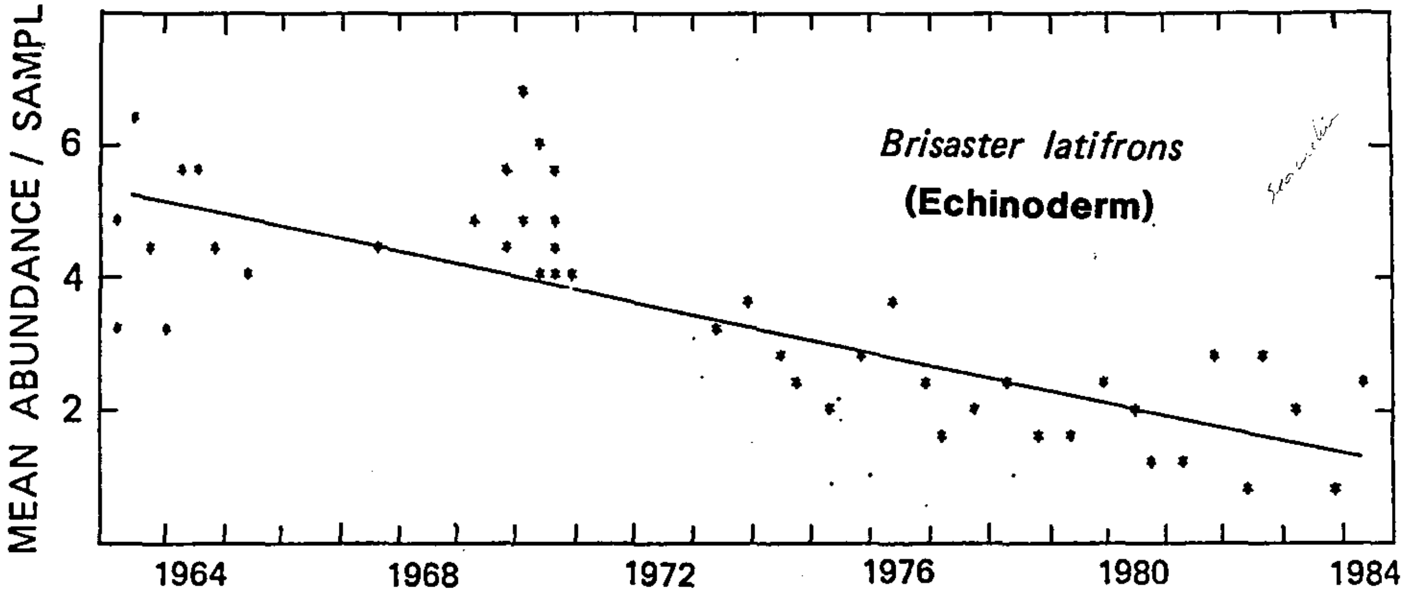


Figure 43. Abundances of selected benthic organisms and all organisms at a site in the Main Basin near West Point, 1964 to 1984.
Source: Nichols, 1985



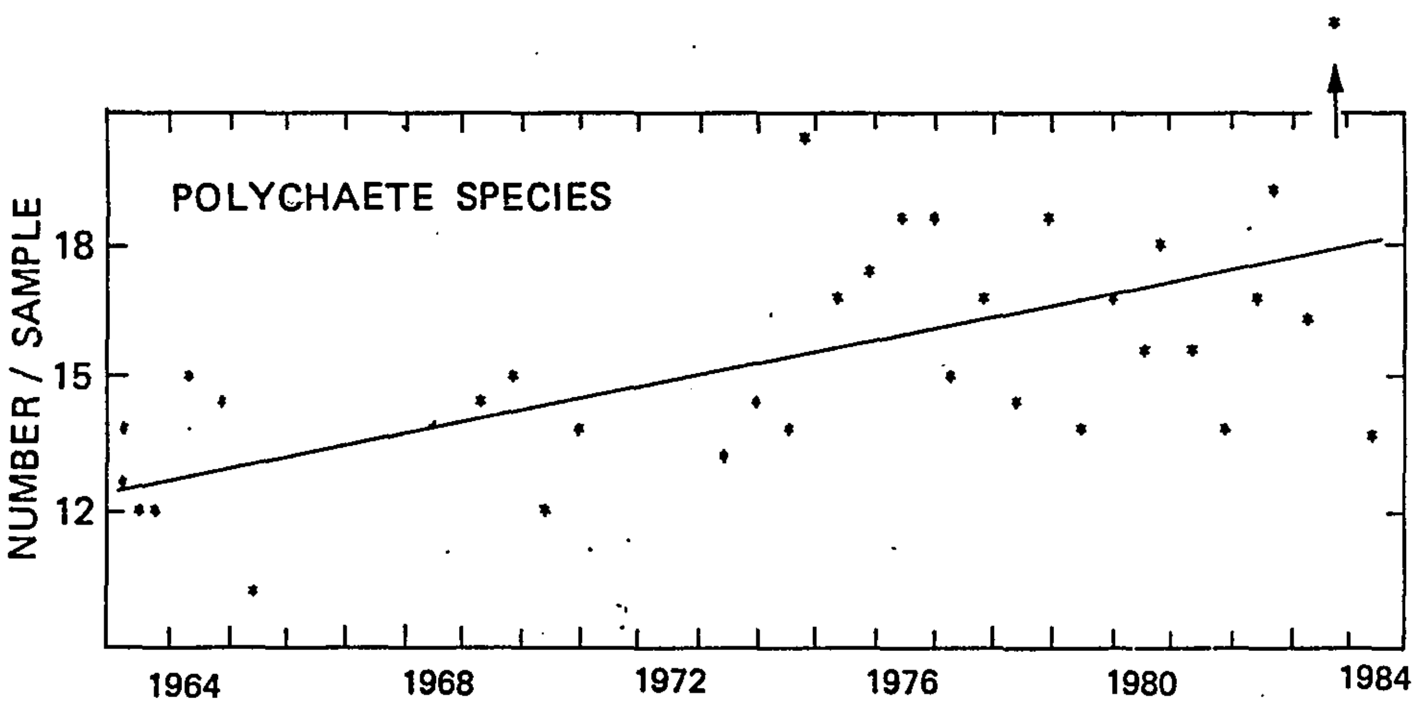


Figure 44. Abundance of one benthic species and polychaetes that appeared to change at a site in the Main Basin near West Point between 1964 to 1984.
Source: Nichols, 1985.

were selected because they have played and in most cases continue to play an important role in the commercial shellfish industry of Puget Sound.

The sources for most of the data are commercial catch and landings statistics from the WDF annual reports. In many cases these statistics were augmented by individual studies conducted by the WDF and the Washington State Water Pollution Control Commission.

Before the data are presented, however, some general cautions regarding their interpretation are in order. The only temporal data available for shellfish (and fish in the following sections) were the commercial catch/landing statistics. These data are not true measures of the population abundance and may not precisely reflect trends that have occurred in the population. They were, however, the only data available and should provide an indication of major changes in the populations over a long period of time.

The catch/landings statistics may not accurately portray the population abundances for three reasons. First, resource management practices implemented by agencies may reduce or limit the harvests independent of the population size. The resulting reduction in the catch statistics may reflect this management practice more than an actual change in the population. In most cases, however, such limitations were implemented when the population stock was facing depletion by overharvesting, and hence such catch reductions often do indicate population decreases.

Second, changing market conditions over time have dramatically altered the demand for specific species harvested in Puget Sound. Both increases and decreases in the catches of specific species have occurred. The resulting changes in the landings statistics therefore may reflect market conditions, not population abundances.

Finally, general economic conditions may have affected the ability of commercial harvesters to purchase equipment, reach the fishing grounds, or sell their catches. The resulting differences in fishing effort may alter the size of the catch, resulting in increases and/or decreases in the catch statistics that were not directly related to the species abundances.

It should be noted that while the WDF makes a technical distinction between catch (fish harvested by fishermen, excluding the fish that are discarded) and landings (tallies of fish brought to the dock), the terms "catch" and "landings" of fish and shellfish are used synonymously in the WDF statistical reports (G. Gargman, WDF, personal communication). Therefore, in the following sections, we have also used the two terms synonymously.

7.3.1 Olympia Oyster

The Olympia oysters (*Ostrea lurida*) were important to commercial oyster growers from the early 1900s. It was during these early days that growers began cultivating the Olympia oyster on specially prepared beds (Gunter and McKee, 1960). Production greatly declined from the early 1920s through at least 1982 (Figure 45). This decline was attributed to pollution from the pulp and paper mills. The Olympia oyster is particularly sensitive to pollution from the mills and many beds were closed following the construction of the mills in the 1920s (Gunter and McKee, 1960).

The Olympia oyster is also sensitive to both extreme cold and extreme hot conditions. During the winter of 1916-1917, a hard freeze hit the area (see Figure 9) and severely decreased production in the Southern Sound. Additional periods of decline have been recorded and attributed to hard freezes (Gunter and McKee, 1960).

Figure 46 shows the historical location of Olympia oyster beds in Puget Sound. These maps were obtained from R. Saunders, WDOE, and E. Hurlburt, WDF, and may have been compiled in the 1960s, but the exact date and source are not known. The total area used for growing Olympia oysters has clearly decreased over time. The Southern Sound, specifically Budd Inlet, Henderson Inlet and the northern tip of Oakland Bay were at one time productive commercial Olympia oyster beds.

Only two areas (Little Skookum Inlet and Totten Inlet) are currently used to grow Olympia oysters for the commercial market. However, pulp mill pollution has been reduced (see Section 5.1), and in the future the area devoted to growing Olympia oyster should expand as a result of redevelopment projects sponsored by the WDF. One project now in progress entails seeding the state shellfish lands in Oakland Bay. Prior to 1927, the Oakland Bay area was used as a source for seed oysters supplied to the regional industry (D. McMillin, Olympia Oyster Company, personal communication).

7.3.2 Pacific Oyster

The Pacific oyster (*Crassostrea gigas*) is not as sensitive to temperature extremes nor to the effluent of the pulp and paper mills as the Olympia oyster and, therefore, was used in Puget Sound to replace the Olympia oyster in commercial beds. Commercial production of the Pacific oyster increased from 1935 to the late 1950s with peak production occurring in 1959 (Figure 47). From 1960 to 1973 production decreased and appears to have stabilized since then.

The decreased production in the 1960s was most likely the result of changing market conditions. During the 1960s oyster meat imported from Japan replaced the Pacific oyster from Puget Sound in prepared food items such as canned oysters, smoked oysters, and oyster stew (R. Saunders, personal communication).

7.3.3 Shrimp

The commercial shrimp industry in Puget Sound has been established since the late 1800s with first catches taken near Oro Bay on Anderson Island (WDF, 1937b; Figure 48). In 1899, approximately 19,000 pounds were

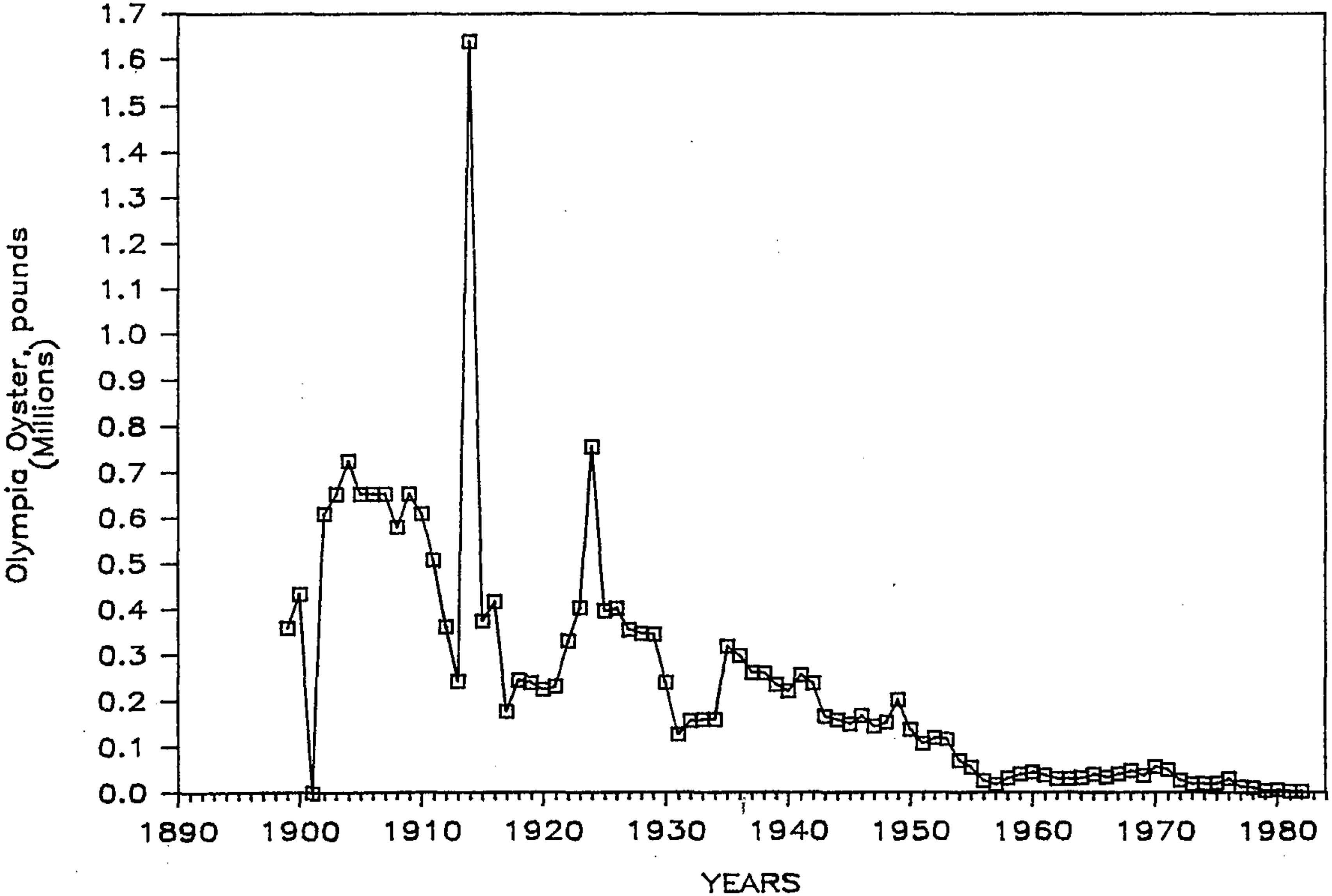


Figure 45. Production of Olympia oysters in Puget Sound (1890-1982)
Source: Gunter and McKee, 1960; Ward et al., 1974; Ward and Hoines, 1982.

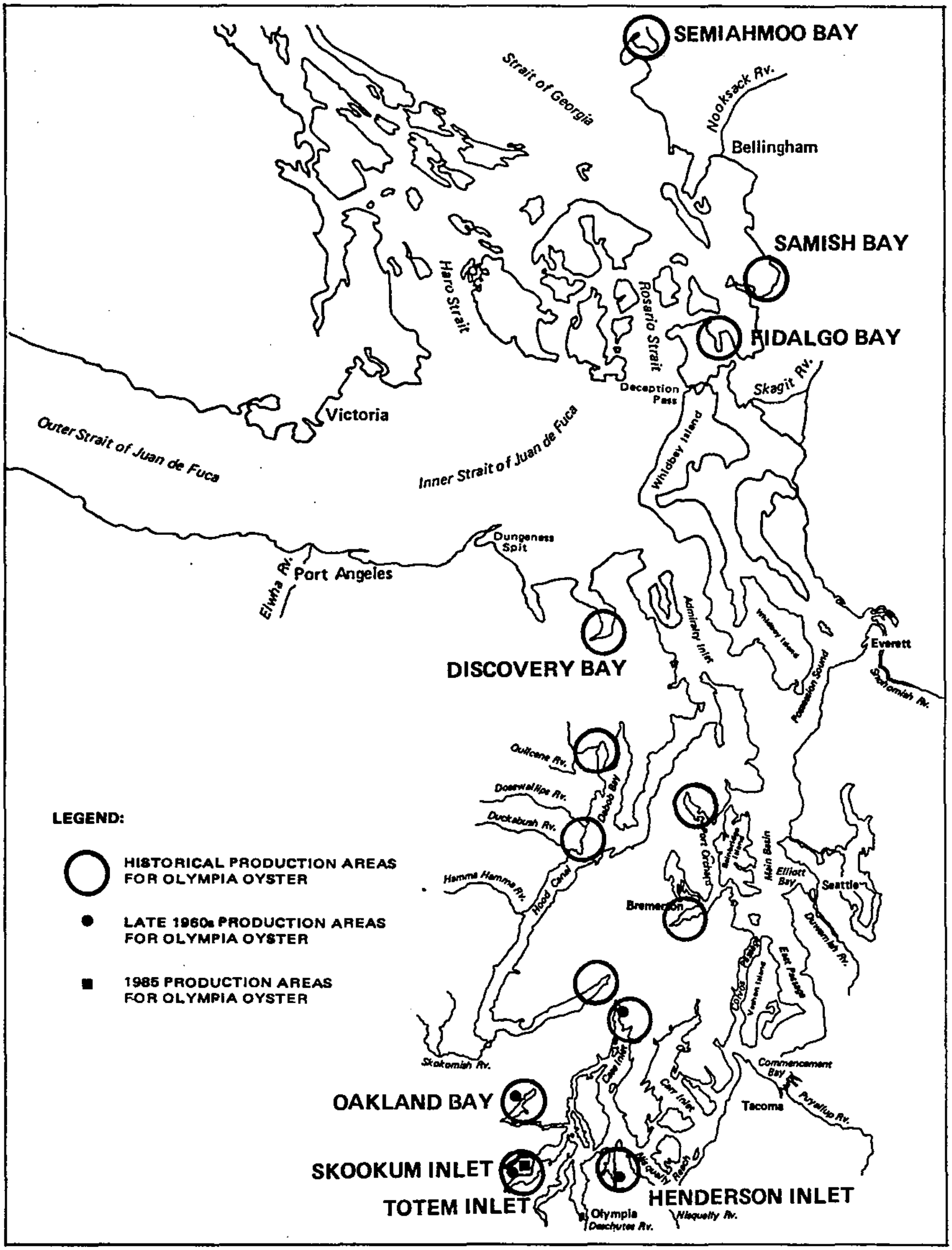


Figure 46. Production areas for the Olympia oyster (historical and late 1960s)
Source: E. Hurburt, WDF; R. Saunders, WDOE; D. McMillian; personal communications.

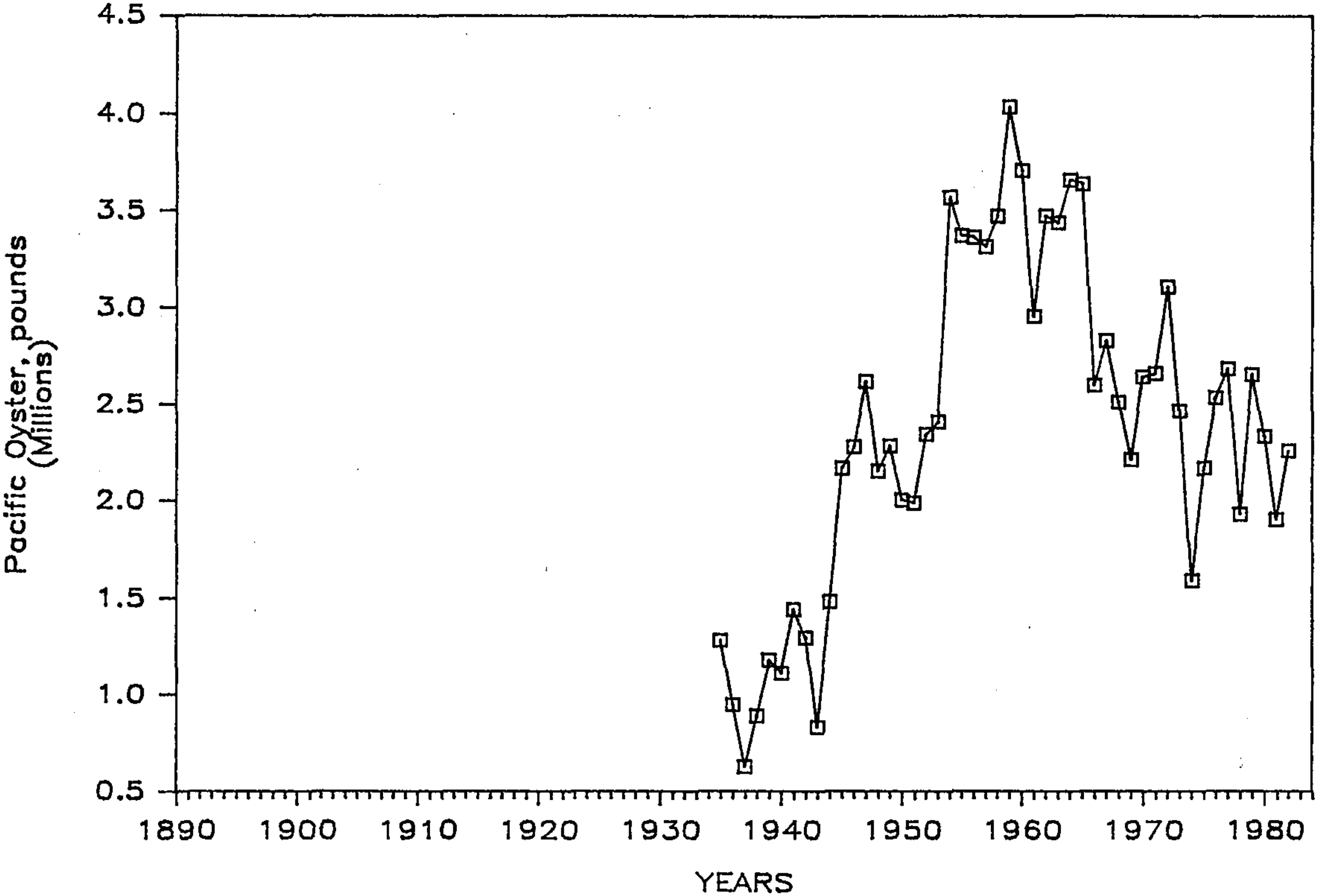


Figure 47. Production of Pacific oysters in Puget Sound (1935-1982).
Source: Ward et al., 1974; and Ward and Hoines, 1982.

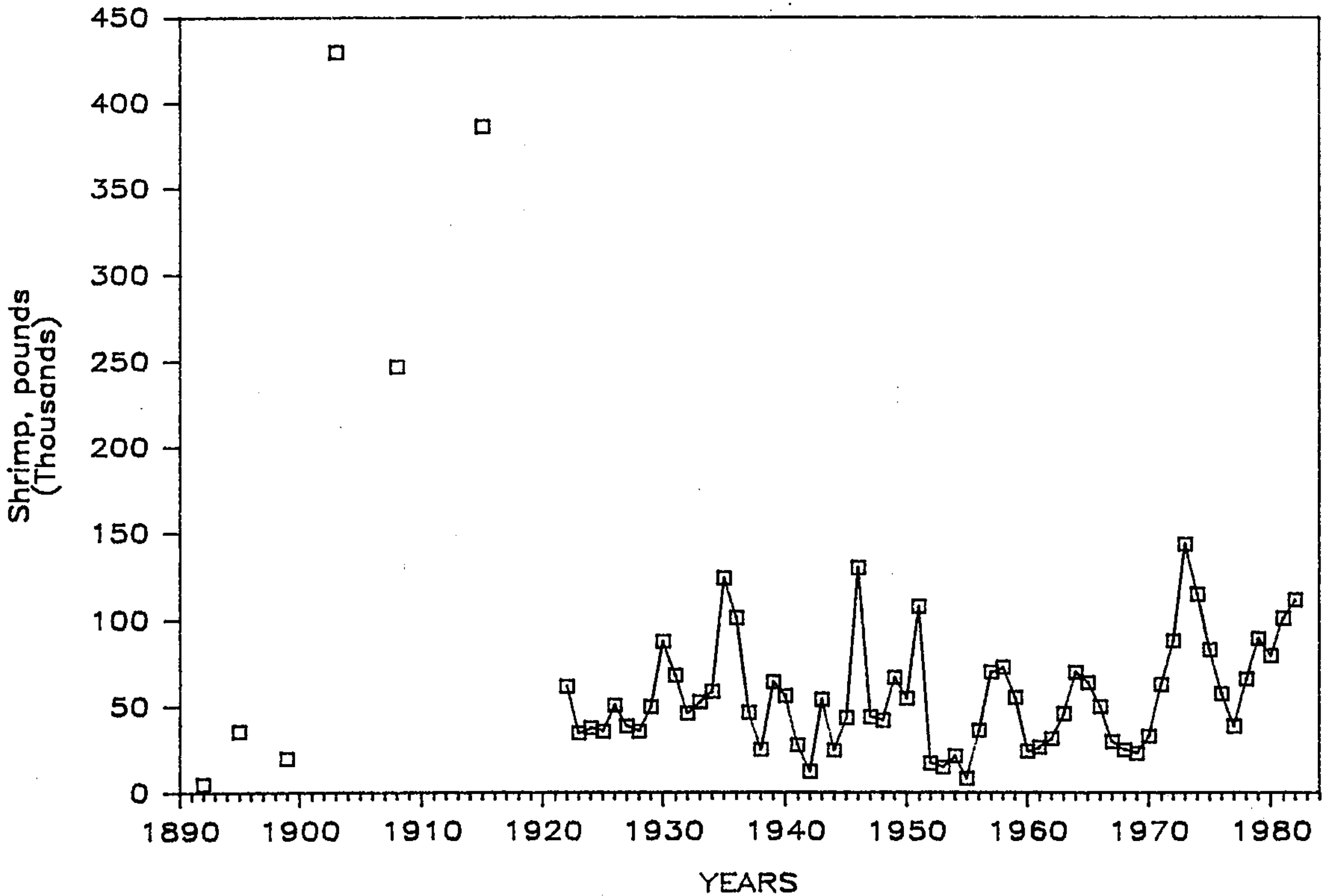


Figure 48. Commercial landings of shrimp in Puget Sound (1898-1982).
Source: WDF, 1937b; Ward et al., 1974; Ward and Hoines, 1982.

harvested from Puget Sound and by 1903 the annual harvest increased to 425,000 pounds. Landings remained high from 1903 through 1915 as new shrimping grounds were exploited in the San Juan Islands and Hood Canal (WDF, 1937b).

By 1906, the effects of overharvesting were being experienced in the shrimping grounds in Pierce County. As these areas showed signs of stock depletion, new areas were exploited and the commercial shrimp industry moved to northern Puget Sound and Hood Canal. Veteran shrimp harvesters said they saw a decline in abundances in all areas as early as 1917. By 1922, the total commercial catch had fallen to approximately 50,000 pounds (WDF, 1937b), and it has fluctuated around that level since then.

Prospecting trips were conducted by the WDF in the early 1930s to assess the abundance of shrimp in Puget Sound. Shrimp were observed in Seattle Harbor, Possession Sound, and Saratoga Passage, but the Southern Sound was almost devoid of shrimp. As an example, in Carr Inlet, five drags produced only 113 pounds of shrimp. No shrimp were observed in Quartermaster Harbor where spot shrimp had formerly been taken (WDF, 1937b).

Shrimping continued on a limited basis in Carr Inlet until 1976, when dwindling stock stopped all shrimping in the Southern Sound. The shrimp have not repopulated the Southern Sound since fishing has stopped. No reasons are known for their dramatic decline and lack of recovery in that area (D. Baumgartner, WDF, personal communication).

Since 1937, the WDF have attempted to increase shrimp stocks by regulating the commercial and sport shrimp fishery. At present, the major sport and commercial fishing areas are in Hood Canal, near Port Angeles, in Holmes Harbor, in Port Susan and in the San Juan Islands. In all areas, restrictions exist on the allowable catch and the length of the fishing season. These controls vary from year to year. In recent years, the sport catch has generally exceeded the commercial harvest (D. Baumgartner, WDF, personal communication).

7.3.4 Crab

The commercial landings of crab (*Cancer magister*) in Puget Sound have been monitored by the WDF from 1935 to the present (Figure 49). In the 1940s, the WDF believed that the crab population in Puget Sound had been severely overfished, particularly in areas used for both commercial and sport harvesting. During this period, the WDF did not have control over the shellfish industry and had to rely on poor market conditions experienced in 1940 to revive the populations (WDF, 1940). It was not until 1941 that the State Legislature gave the WDF the power to regulate the commercial crab industry (WDF, 1941).

In 1942, the commercial landings of crab increased dramatically (Figure 49), due to the elimination of imported canned crab meat from Japan during World War II. Prices rose 300 percent, and fishermen took advantage of the market conditions (WDF, 1942). By 1944 the industry had mushroomed

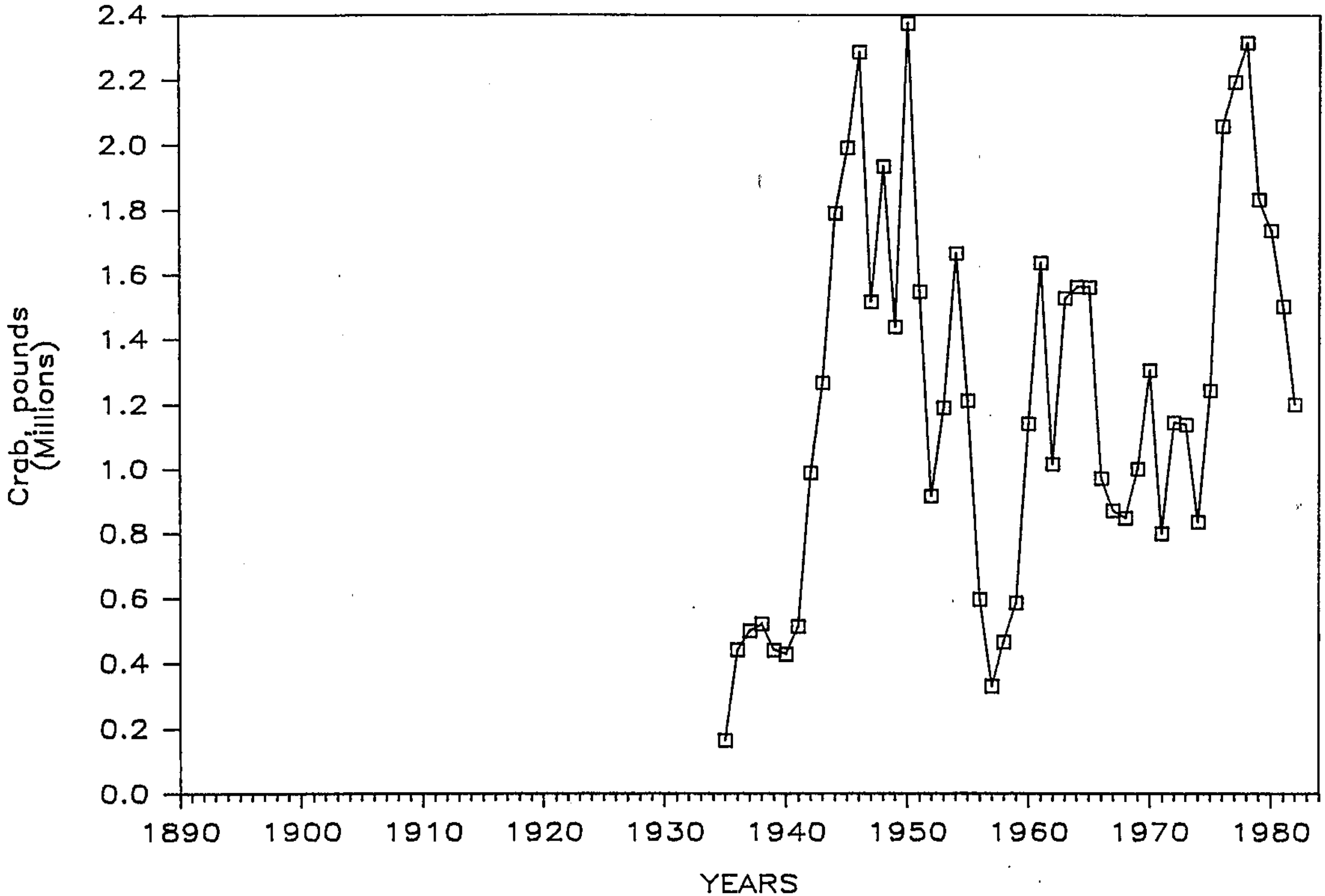


Figure 49. Commercial landings of crabs in Puget Sound (1935-1982).
Source: Ward et al., 1974; Ward and Hoines, 1982.

and overfishing was observed at Dungeness, Anacortes, and Utsaladdy (WDF, 1944). Since 1950, the landings remained relatively stable until the late 1970s when landings increased due to changes in management policy.

In 1975 the WDF instituted regulations that based the harvest season on molting cycles. Since 1975, crab can be harvested in Puget Sound only when the shell is hard. This practice decreased mortality in traps and therefore increased the catch, as noted in the increased harvest in 1978 and 1979 (Figure 49). The decreased commercial landings observed in 1980 and continuing through 1982 may be due to an ongoing moratorium on issuing new commercial crabbing licenses (D. Bumgartner, personal communication).

The commercial landings from 1935 to the present have not shown a consistent long-term increase or decrease, but have fluctuated around 1.3 million pounds. Since the historical data available are landings and not population estimates, it is difficult to assess population changes. However, since the late 1930s and 1940s, the WDF has considered this fishery to be fully utilized, and the trend in the catch probably does indicate that the population has been fairly stable.

7.3.5 Hardshell Clams

World War II had a dramatic affect on the commercial landings of hardshell clams (WDF, 1941, 1942, 1943)(Figure 50). Closures referred to as "War closures" and a decreased labor force curtailed the commercial harvest (WDF, 1942). In addition, gas rationing made it difficult for individuals to get to the beds and harvest clams for personal use. Since 1943, the commercial landings of clams have increased (Figure 50)(Ward et al., 1974; Ward and Hoines, 1982).

7.3.6 Bacterial Contamination of Shellfish

In recent years and continuing to the present, a major factor affecting commercial landings of clams and oysters has been the closure of beds contaminated by fecal bacteria or at risk of being contaminated by fecal bacteria (Table 5). The Washington State Department of Social and Health Services (DSHS) is responsible for certifying and decertifying the beds based on water quality standards. The current (1985) standards are based on the levels of a human/animal fecal waste indicator, fecal coliform bacteria. Maximum permissible fecal coliform concentrations are: 1) in the shellfish, 230 organisms (bacteria)/100 mg of shellfish tissue and 2) in the water column, a geometric mean value of 14 organisms/100 ml of water with not more than 10 percent of the samples exceeding 43 organisms/100 ml (Saunders, 1984). The DSHS considers all areas as closed until the area has been sampled and found to meet the criteria. Areas are examined when a request for commercial harvesting is made and hence the areas that are certified vary over time.

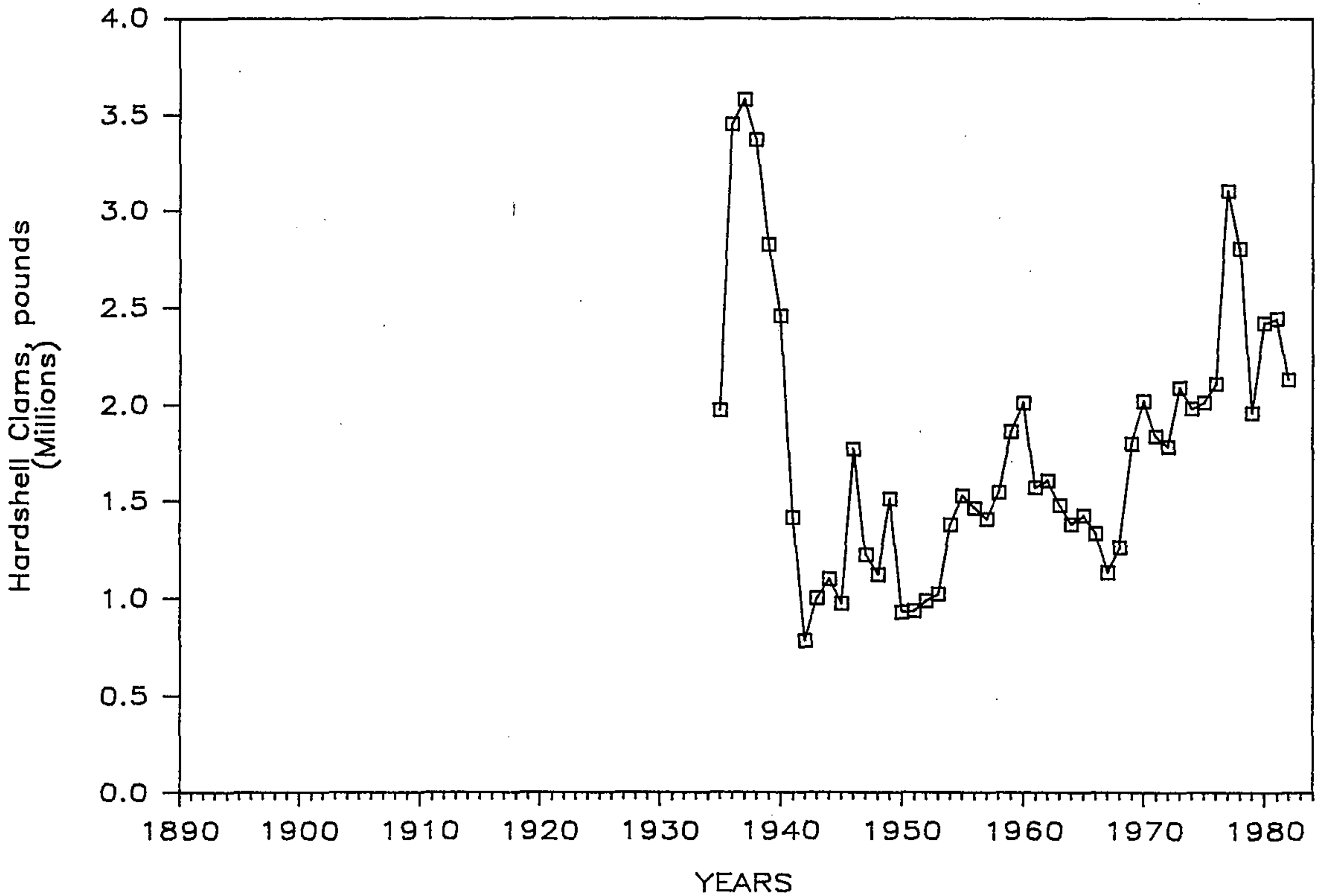


Figure 50. Commercial landings of hardshell clams in Puget Sound (1935-present)
Source: Ward et al., 1974; Ward and Hoines, 1982.

Table 5. Decertified and uncertifiable shellfish culture areas in Puget Sound

Date	Location	Cause
Decertified		
1950s	Dyes Inlet - all	Bremerton STP[a]
1950s	Sinclair Inlet - all	Bremerton STP
1950s[b]	Oakland Bay/Hammersley Inlet - in the vicinity of Shelton	Shelton STP, Mill
1950s	Budd Inlet	STP, Deschutes River
1960s	Liberty Bay - east side, near Poulsbo	Poulsbo, STP, Marina
1968	Port Susan - about 1/3 of the tideflats	Dairy runoff in the Stillaguamish, STPs
10/81	Burley Lagoon - all	Nonpoint
3/82	Minter Bay - all	Nonpoint
Conditionally Approved		
3/83	Henderson Inlet	Nonpoint
2/83	Eld Inlet	Nonpoint
9/83	Penn Cove	STP
Uncertifiable		
Eastshore of Puget Sound from Tacoma to Edmonds		STPs, industrial
Hartstene Island, north end		Private STP
Port Townsend		STP
Kitsap - near Winslow		STP
Appletree Cove - near Kingston		Sewage outfall
Port Gamble		Sewage outfall
Everett		STP, industry, nonpoint
Bellingham Bay		STP, mills, nonpoint

[a] Sewage Treatment Plant
[b] Decertified area reduced in 1980 due to installation of secondary treatment.

In addition, large areas of the Sound are presently classified at levels below complete certifications. Some areas have been decertified that were at one time approved for commercial shellfish production and later found to have fecal coliform counts exceeding the standards (Table 5). The causes for decertification have generally been attributed to the proximity of sewage outfalls, marinas, high population densities and boat traffic (Saunders, 1984; J. Lilja, DSHS, personal communication). The trend in the Sound has been toward increasing areas of decertified shellfish beds.

Areas classified as conditionally approved (Table 5) have restrictions that control harvesting at certain times. In most of these areas, harvesting is prohibited after rainfall exceeds an upper limit, generally 1-1/2 inches in 24 hours (Saunders, 1984). After periods of high rainfall, the concentrations of fecal coliforms may increase because the increased runoff transports fecal bacteria from nonpoint upland sources to the Sound.

Many areas of the Sound are classified as uncertifiable (Table 5) because they are near sources of pollution. These areas are not tested for the presence of bacteria, but are presumed to be at risk of bacterial contamination. For example, the eastern shore of the Main Basin of Puget Sound from Tacoma to Edmonds is classified as uncertifiable and is closed to the commercial harvesting of clams and oysters because of the many municipal sewage discharges in the area (Saunders, 1984; L. Goodwin personal communication; J. Lilja, personal communication).

7.4 GROUNDFISH/BAIT FISH

7.4.1 Groundfish

The WDF has kept records on commercial landings of groundfish in Puget Sound since 1921. Prior to 1948, the data were tabulated by grouping many species together. For example, the sole/flounder category included English sole, Dover sole, petrale sole, rex sole, rock sole, sand sole, and starry flounder. In 1949, the agency began tabulating the statistics by species and in 1963 began compiling the statistics for large subareas of Puget Sound (northern Puget Sound, southern Puget Sound, Hood Canal, etc.). In 1973, the WDF further divided these subareas into smaller areas.

The catch statistics for sole and flounder were used to provide the longest period of record (Figure 51). In general, the commercial landings of sole and flounder have been influenced greatly by market conditions and probably do not reflect changes in abundance (G. Bargmann, WDF, personal communication).

The decreased catch from 1938 to 1948 may have been due to the effects of World War II, when men and boats were needed to support the war effort (G. Bargmann, WDF, personal communication). In 1949, the market for local bottomfish other than sole and flounder decreased dramatically because

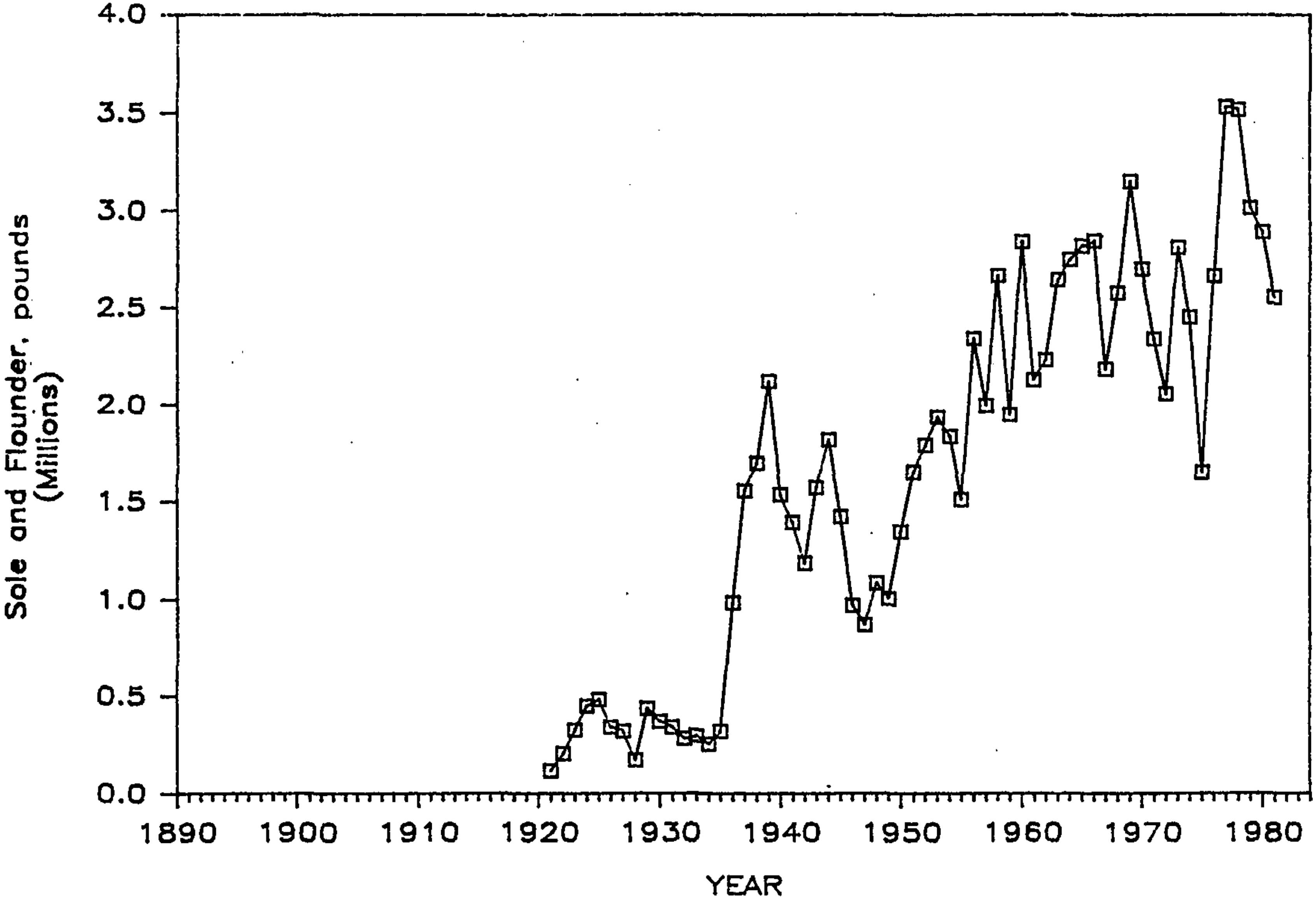


Figure 51. Commercial landings of sole and flounder in Puget Sound (1921-1982).
Source: WDF, unpublished data; Quinnell, 1984.

cheap fish liver oil could be imported from Japan, South America, and South Africa (WDF, 1949). The high demand for sole and flounder and the low demand for the livers from bottom fish other than sole and flounder may have contributed to the increased landings of sole and flounder from 1950 to 1966 as fishermen concentrated on the sole and flounder.

Since 1966, the commercial landings of sole and flounder have fluctuated with no apparent long-term increase or decrease. Quinnell (1984) observed similar fluctuations with English sole. The overall sole and flounder landings have fluctuated around 2,683,000 pounds from 1966 through 1981.

From 1969 to 1981, the WDF has compiled data on the landings per unit effort (LPUE) for the commercial industry. The LPUE displayed fluctuations similar to those observed for the landings, although the magnitudes were different. Central Puget Sound was the only area where a decreasing trend in the LPUE has been observed. The lower LPUE may be due to the increase in effort along with poor class years (Quinnell, 1984). The WDF is currently investigating this further.

7.4.2 Herring

Herring have been and are used extensively as baitfish for both the commercial and sport fisheries. In addition, herring play an important role in the food chain of Puget Sound (Trumble et al., 1977).

The herring catch in Puget Sound fluctuated around 900,000 pounds from 1898 to 1958, then increased to millions of pounds (Figure 52). Present understanding of herring populations indicates that changes in the demand and economic conditions were most responsible for fluctuations in the catch observed in the landings record (WDF, 1969). However, this view was not always taken.

As early as 1898, there were references to the decreasing population of herring in Puget Sound by comparison to the catch during the late 1860s and 1870s. By 1898, what had been thought to be an inexhaustible supply of herring was apparently dwindling. The catch did not compare to "earlier days" (Washington State Fish Commission, 1898).

During the late 1930s and early 1940s, the commercial catch of herring decreased. As a result, the WDF closed most of Puget Sound to the commercial harvesting of herring (WDF, 1940), believing that the decreasing catch was the result of a decreasing population. In 1943, the catch was high which was interpreted by the WDF as an increase in the herring population due to the restrictions (WDF, 1943). Utilizing present-day knowledge of herring, it is believed that the changes in catch observed during the 1930s and 1940s were due in a large part to natural variations in the distribution of herring within the Sound (R. Trumble, personal communication).

In addition to such natural variations, changes in demand and economic conditions play a key factor in the fluctuations observed in the long-term

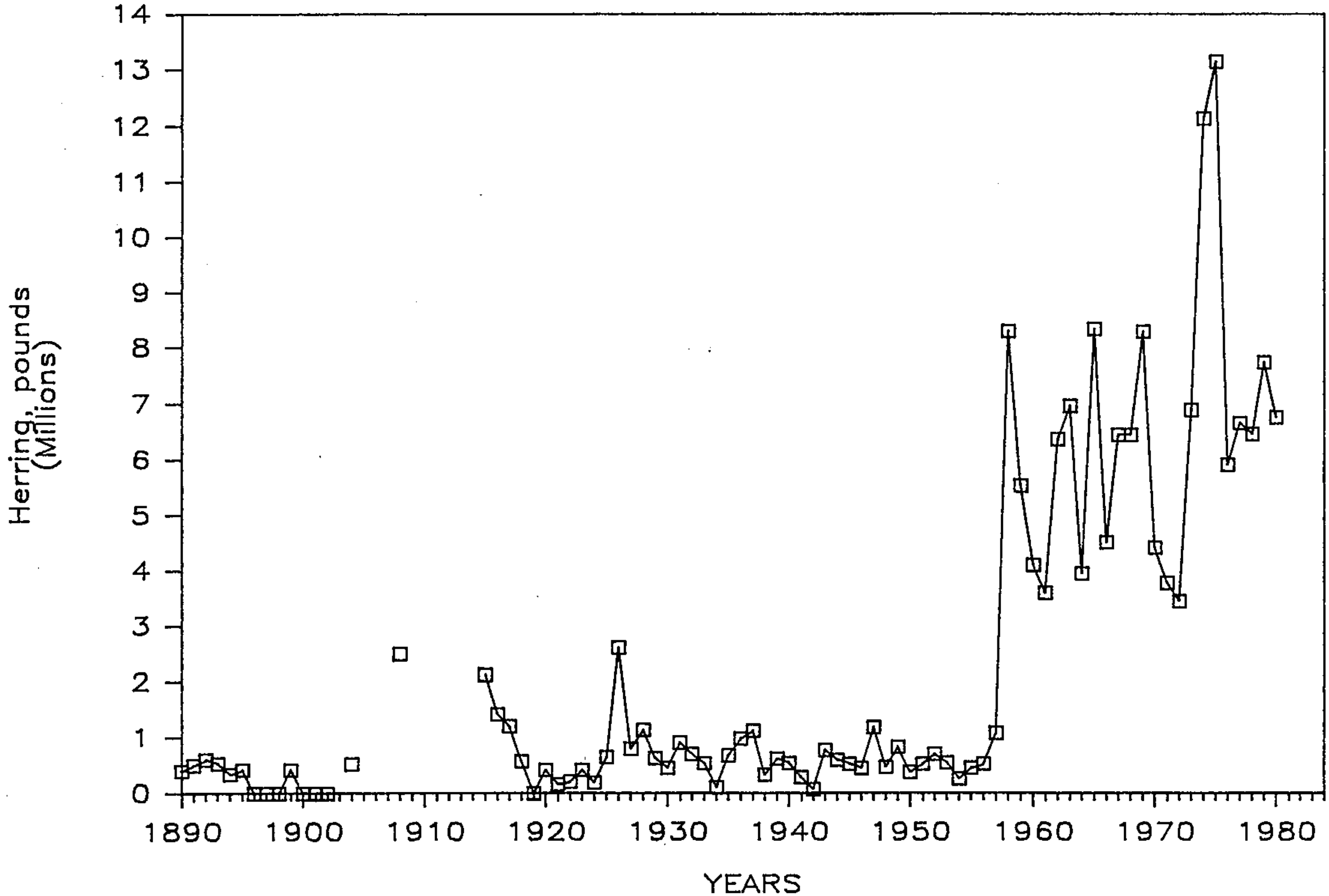


Figure 52. Commercial catch of herring in Puget Sound (1890-1982).
Source: WDF, 1947; Ward et al., 1974; Quinnel, 1984.

record of the herring catch. For example, the exporting of herring to the Phillipines and the Orient collapsed after World War I and was thus probably the major factor in the low catch recorded from 1919 to 1925 (Trumble, 1983). Similarly, the large catch of 1958 has been attributed to a number of factors. First, 1957 was the first year that herring were permitted to be made into fish oil and fish meal. Second, purse seining was allowed over a larger area of northern Puget Sound than previously; and third, harvesting limits were abolished. In central and southern Puget Sound, the allowable length of the lampara net used to catch herring was increased. Since the catch in this area was quite small when compared to the catch from northern Puget Sound, the change in the net length had a minor impact (Trumble, 1983 and Trumble, personal communication).

The harvest of sac-roe herring began in 1973 and placed a high demand on the herring resource. The inception of this industry may have contributed to the jump in the catch recorded in 1973. Because of concerns about the effects of the sport bait and sac-roe herring fishery on the herring stocks, WDF began a research project in 1971 which included spawning ground surveys to estimate annual spawning escapement (Trumble, WDF, personal communication). The data from these surveys are not included in this report.

7.5 SALMON

The population and abundance assessment of salmonids in Puget Sound is based primarily on commercial landings statistics augmented by recent measurements of the run size (1965 to 1982). Most of the data on catch statistics were obtained from two documents: Ward et al., (1974); and Ward and Hoines, (1982). A period of record from 1913 to 1982 was established by combining the data from both reports. These data are portrayed in Figures 53, 54, 55, 56, 57, and 58 for the catches of coho, chinook, chum, sockeye, pink, and total salmon, respectively. Annual reports of the WDF and the State Fish Commissioner were reviewed to provide anecdotal information and explanations of significant and/or unusual changes in the annual catch. The run statistics were taken from unpublished data provided by J. Ames (WDF).

In 1913, the catch in Puget Sound was approximately 39 million fish, most of which were caught in the Strait of Juan de Fuca. The Hell's Gate rockslide on the Fraser River cut the fish off from their major spawning grounds, resulting in a dramatic decrease in the runs, as evidenced by the dramatic drop in the commercial salmon catch of all species after 1913. By 1914 the total commercial catch in Puget Sound decreased to approximately seven million fish (Figure 58). The sockeye was the species impacted the most by the rockslide at Hell's Gate (Figure 56), but in recent years this species has shown signs of increasing abundance (International Pacific Salmon Fisheries Commission, 1983). Both coho and chinook landings decreased from the late 1910s to 1943, but have increased significantly since the late 1950s (Figures 53 and 54).

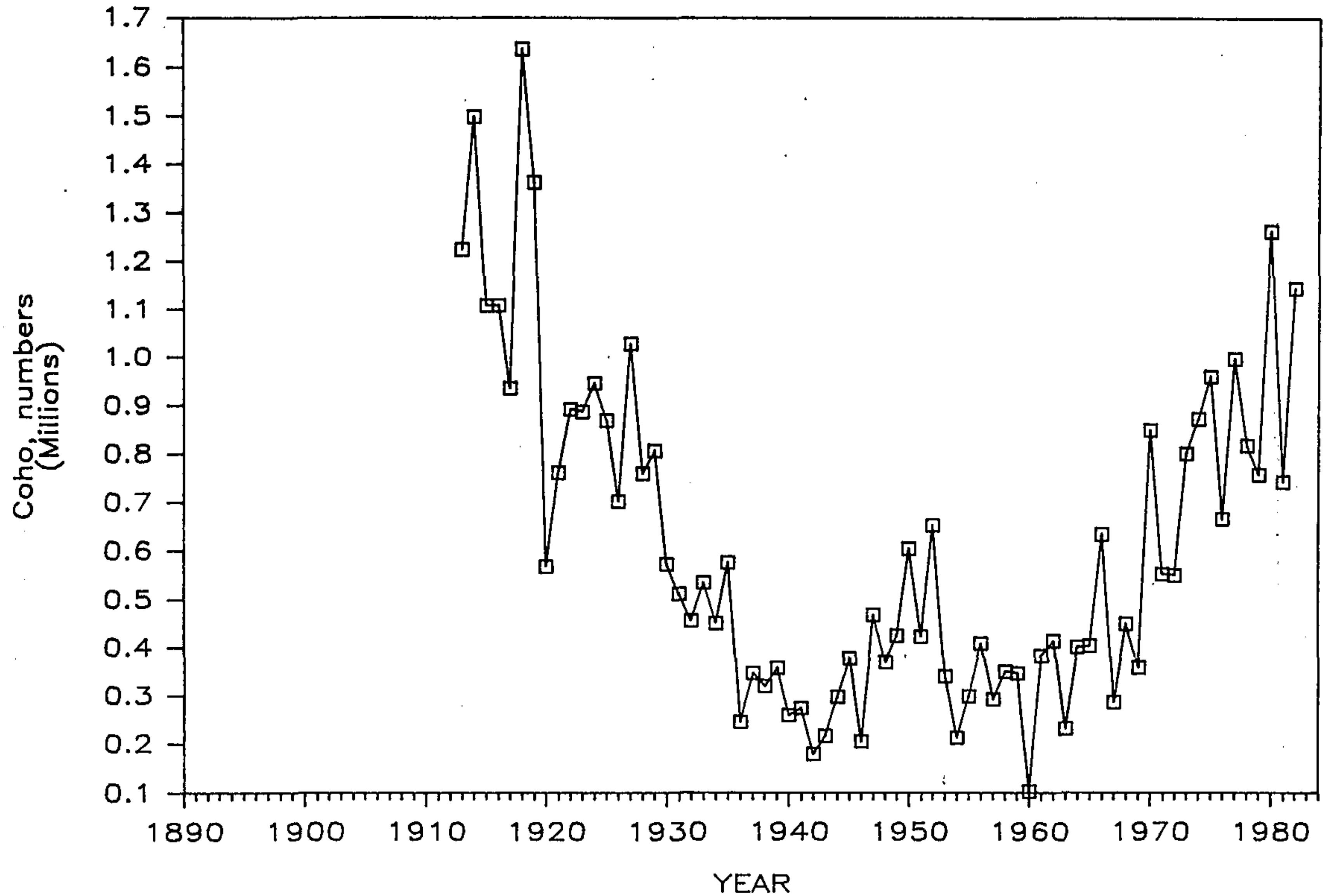


Figure 53. Commercial landings of coho in Puget Sound (1913-1982).
Source: WDF, 1947; Ward et al., 1974; Ward and Hoines, 1982.

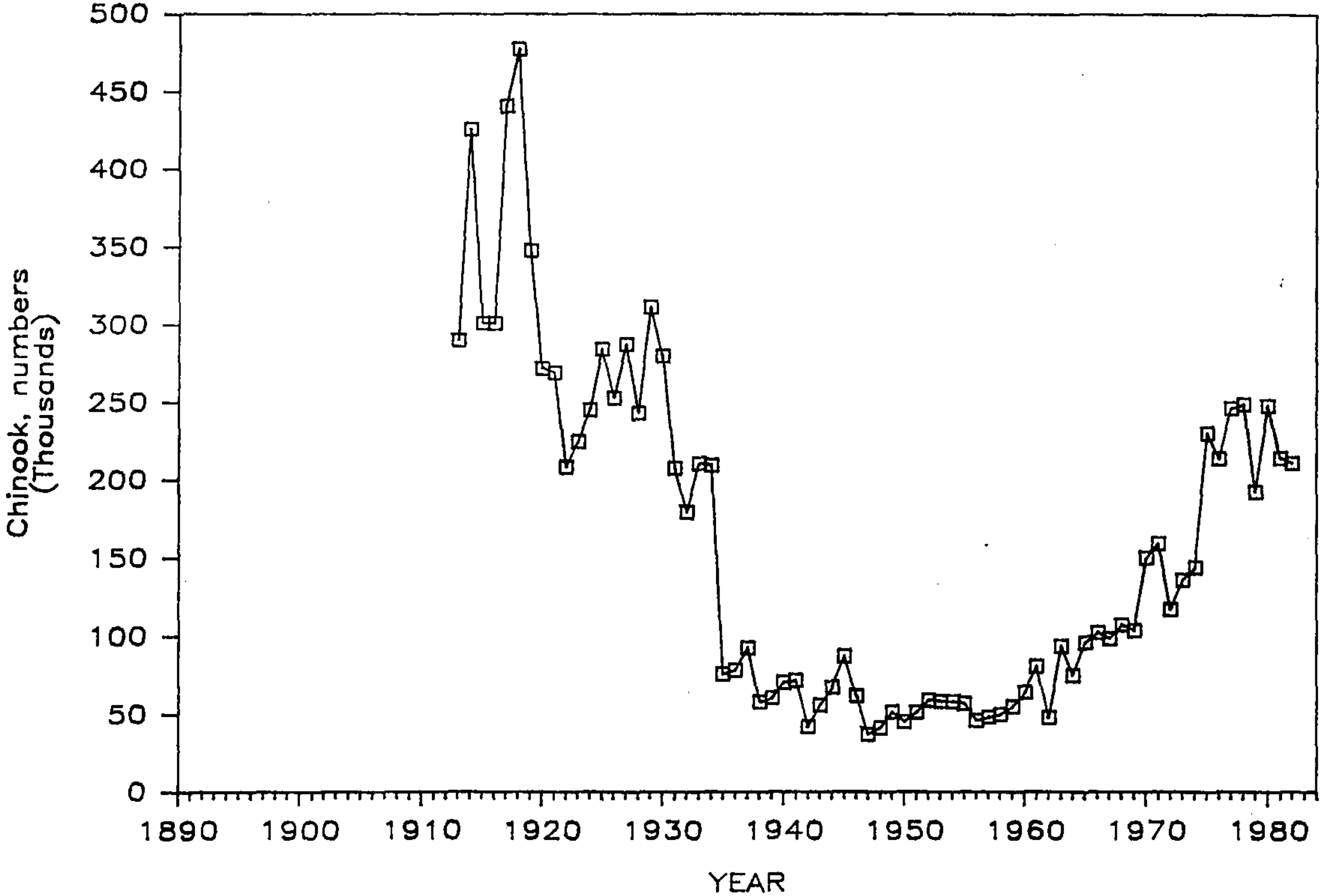


Figure 54. Commercial landings of chinook in Puget Sound (1913-1982). Source: Ward et al., 1974; Ward and Hoines, 1982.

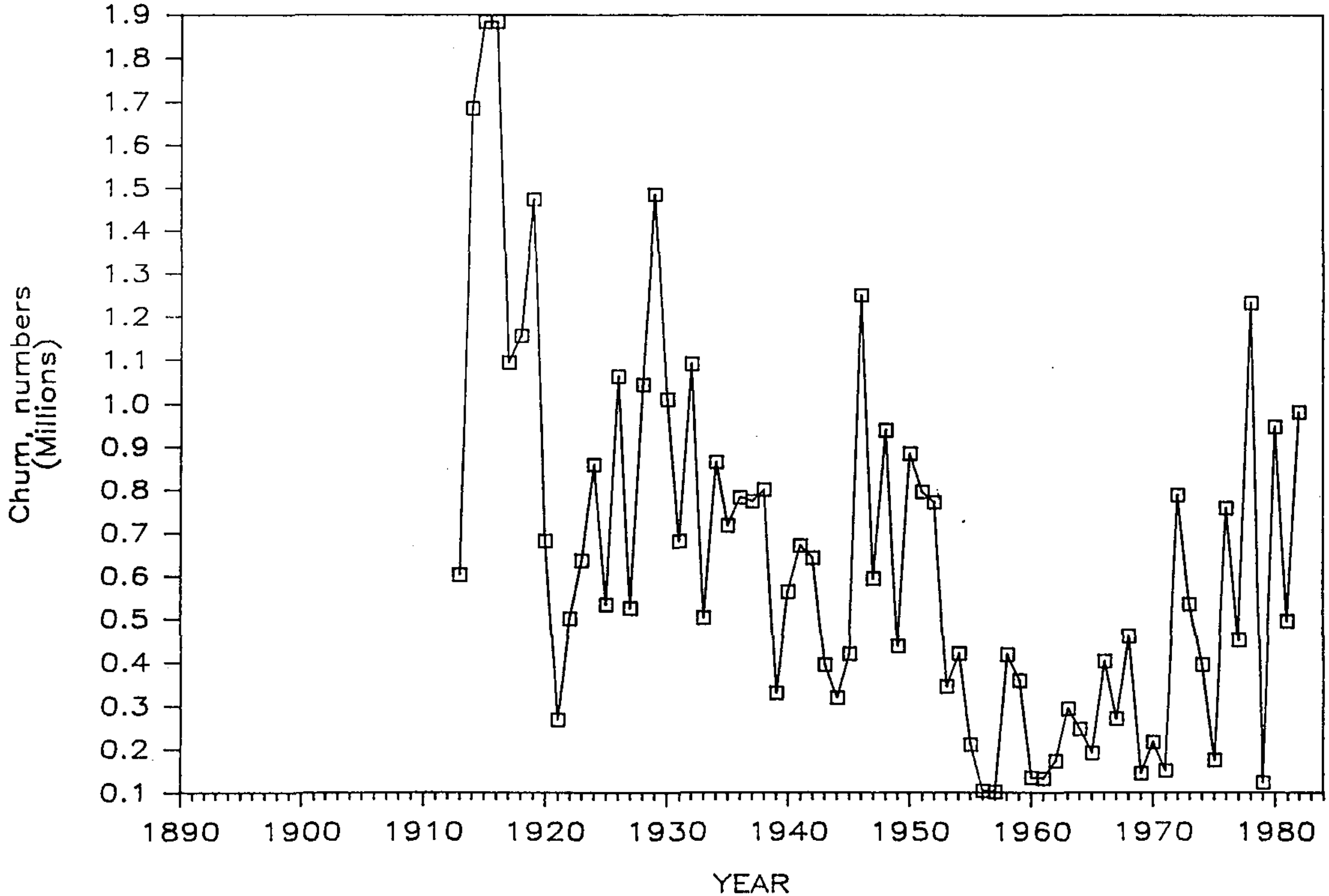


Figure 55. Commercial landings of chum in Puget Sound (1913-1982).
Source: Ward et al., 1974; Ward and Hoines, 1982.

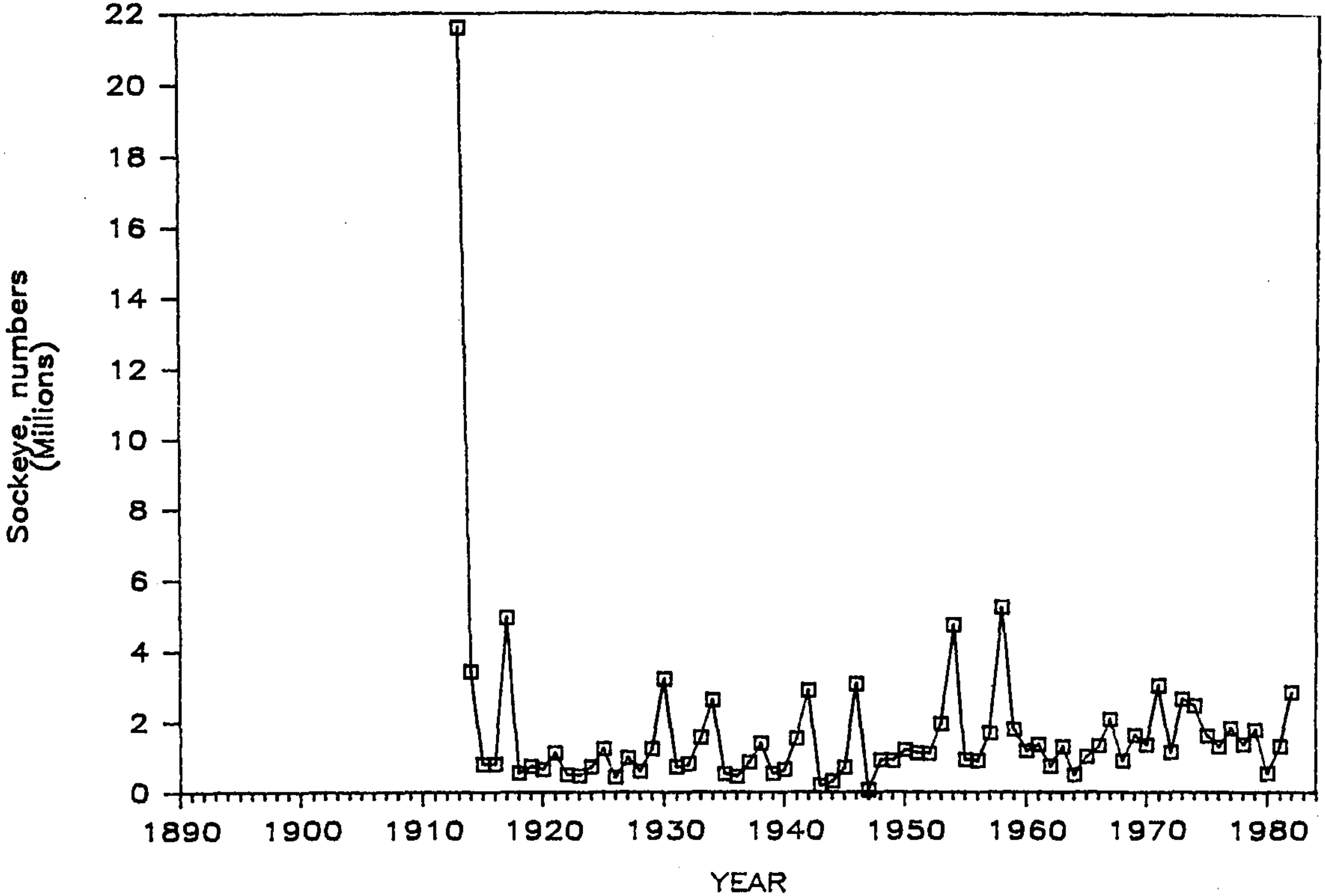


Figure 56. Commercial landings of sockeye in Puget Sound (1913-1982). Source: Ward et al., 1974; Ward and Hoines, 1982.

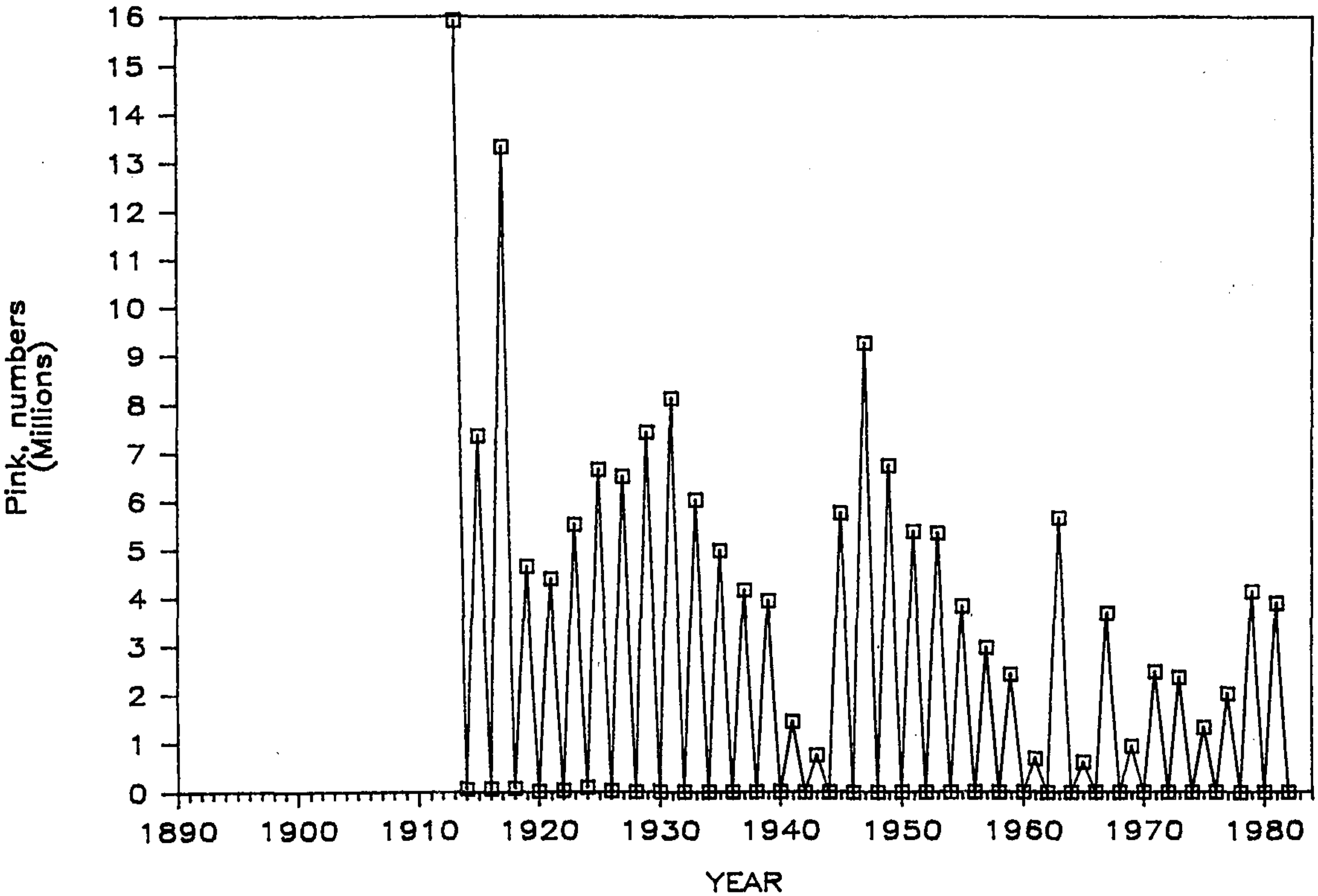


Figure 57. Commercial landings of pink salmon in Puget Sound (1913-1982)
Source: Ward et al., 1974; Ward and Hoines, 1982.

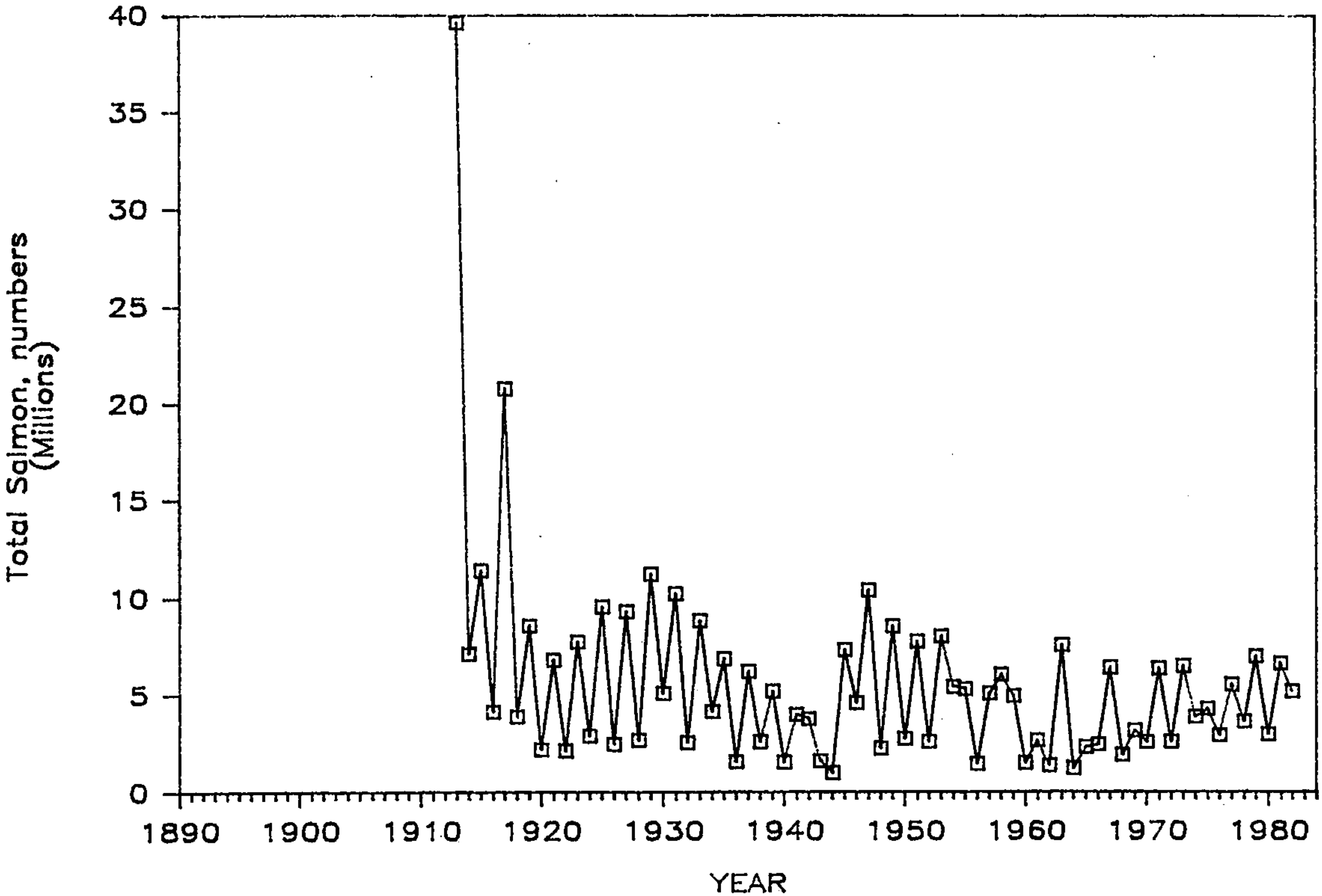


Figure 58. Commercial landings of salmon in Puget Sound (1913-1982).
Source: Ward et al., 1974; Ward and Hoines, 1982.

The commercial landings of chum decreased from 1913 through 1956 and remained at low levels through 1971. Since 1972, the commercial catch of chums has been increasing (Figure 55).

The pinks return during odd-numbered years (Dexter et al., 1981) which explains the substantial catch during odd years and the minimal catch during even years. The commercial landings of pinks have generally decreased since 1913.

The decrease in the catch and run size for all salmon species cannot be attributed solely to the Hell's Gate mudslide. WDF (1939) stated that:

> "the average citizen is quick to blame the decreased salmon runs, compared to former days, entirely on overfishing. Instead, a major factor in nearly every case of depletion has been the destruction of vital spawning grounds by the construction of dams and diversions."

The increase in catch of coho and chinook since the 1960s has been the result of resource management practices. In the mid 1960s, the WDF began releasing "late release fish" which tend to become resident species. This practice increased the salmon population in Puget Sound (J. Ames, personal communication).

Initiative 77 which eliminated the use of fish traps by commercial fisherman became effective in 1935. Prior to 1935 the division of the catch between the United States and Canada was skewed towards the United States (Chasan, 1981). Traps in the Strait of Juan de Fuca were so effective that only a small portion of the Fraser River run reached Canadian fishing grounds and spawning areas. From 1903 through 1931, the United States fishermen landed 58 percent of the sockeye caught in Convention Waters (International Pacific Salmon Fisheries Commission, 1983). In 1935, the first year that Initiative 77 was in effect, the United States share of the Fraser River catch decreased to 13 percent (Chasan, 1981).

The decreased share of the American catch in 1935 provided incentive for the United States to form a treaty with Canada that would guarantee an equal division of the Fraser River catch. A treaty signed in 1937 decreed that there would be an even division of the Fraser River salmon caught in Convention Waters and the Strait of Juan de Fuca.

The International Pacific Salmon Fisheries Commission was formed in 1946 to manage the fishery and oversee the division of the catch (Chasan, 1981; International Pacific Salmon Fishery Commission, 1983). From 1946 through 1983, the share of the landings of Fraser River sockeye were evenly divided, 50.29 percent and 49.71 percent for the United States and Canada, respectively (International Pacific Salmon Fishery Commission, 1983).

7.6 FISH KILLS

The Washington Pollution Control Commission observed and/or investigated numerous fish kills in Puget Sound, as documented in their annual report (WPCC, 1945-1957). A large number of the kills were observed in Everett Harbor, Elliott Bay, and Commencement Bay. Herring seemed to be the dominant fish observed during the fish kills. The number of incidences which reported dead salmon were less, although Orlob et al. (1950) observed a salmon dying during an investigation at inner Everett Harbor. This difference between observed herring and salmon kills may have been due to the fact that herring tend to float when dead, while salmon are a heavier fish and tend to sink.

Since 1969, the WDOE has recorded fish kills reported in Puget Sound. Information recorded includes the date, area, cause, number of fish killed, duration of the event and an estimation of the area affected. This information does not lend itself to graphic presentation and is presented only in tabular form (Table 6). Most of the fish kills appear to be related to accidental chemical spills associated with industries.

7.7 BIRDS

The Seattle Chapter of the Audubon Society, through their annual Christmas Bird count, has compiled data on bird abundance from the 1920s to the present (Chapman et al., in press). The survey area is a 7-1/2 mile radius circle with the epicenter at Pioneer Square, Seattle, Washington (Figure 59). The data recorded include location of the survey, weather conditions, number of individuals participating in the survey, total party hours, and a list of species and number of birds observed. The results of the Seattle count have been included since 1952 in the publication entitled American Birds (P. Mattocks, University of Washington and Audubon Society, personal communication).

As a precautionary note, it should be noted that these bird counts are the results of one-day intensive surveys taken each year between Christmas Day and New Year's Day and are subject to substantial variability from differences in the number and training of observers and weather conditions. Subtle trends are generally not discernible, but major changes occurring over a long period of time should be detectable.

To facilitate analysis of these data, water-oriented birds observed during the counts were classified into seven categories: diving ducks, dabbling ducks, alcids, open water diving birds, herons/bitterns, shorebirds, and gulls (Table 7). These categories were recommended by P. Mattocks (personal communication) and are based on taxonomic order and on general ecological/feeding habits. For example, the American Coot was

Table 6. Fish kills occurring in Puget Sound, 1969 through 1982

Date	Receiving Water	Cause	#Fish	Area Affected	Duration
12/09/69	Puyallup River	Pentachlorophenol	2,500	10 miles	2 days
12/05/69	Quilcene Creek	Siltation	UK	1 mile	1 day
11/17/69	Hylebos W.W.	UK	500	1/2 mile	1 day
11/23/70	Everett Harbor	chemical	+100	extensive	48 hours
12/14/70	Liberty Bay	oil	UK	5 miles	48 hours
6/23/70	Hylebos W.W.	UD	1,000	2 miles	4 days
6/29/71	Puget Sound	oil	1,000	5 miles	30 days
10/13/71	Puget Sound	Upwelling DO	+100	1 mile	4 days
4/26/72	Hood Canal	herbicide	UK	UK	1 day
4/27/72	Oak Bay	Silt	UK	UK	1 day
6/20/72	Dugulla Bay	herbicide	2,000	UK	1 day
9/18/72	Penn Cove	Algae bloom	UK	small	2 days
2/05/73	Padilla Bay	UK	100	3 acres	UK
9/14/73	Budd Inlet	Low DO	UK	UK	1 day
10/18/73	Puget Sound	UK	48,000	rearing tanks @ mariculture	14 days
10/26/73	Unnamed slough	manure	100	1/4 mile	UK
5/9/74	Wapato Creek	UK	3	1/4 mile	1 day
6/17/74	Liberty Bay	waste oil	UK	UK	UK
12/30/76	Bremerton Harbor	drained drydock	UK	small	1 day
11/16/77	Hylebos W.W.	UK	UK	several acres	1 day
8/19/77	Nisqually River	Copper ore	75,000	19 miles	several days
8/09/79	Hood Canal	Anahydrous ammonia	3.2x105	4.6 acres	1 day
7/28/80	Elliott Bay	UK	1,000	UK	1 hour
8/16/80	Hylebos Creek	Thiodan	1,000	1 mile	1 hour
1/6/81	Whatcom Creek	Pentachlorophenol	44,000	Fever Cr. to mouth	1 day
6/2/81	Budd Inlet	Sewage H2S	40,000	Budd Inlet	1 day
8/15/81	Cultus Bay	Low DO	2.5 mil	Sandy Hook Marina	1 day
9/9/81	Budd Inlet	H2S	314,098	No. of Capitol Lake	7 days
8/17/82	Duwamish River	UK	UK	2 miles	2 hours

Source: WDOE, unpublished data
UK = unknown

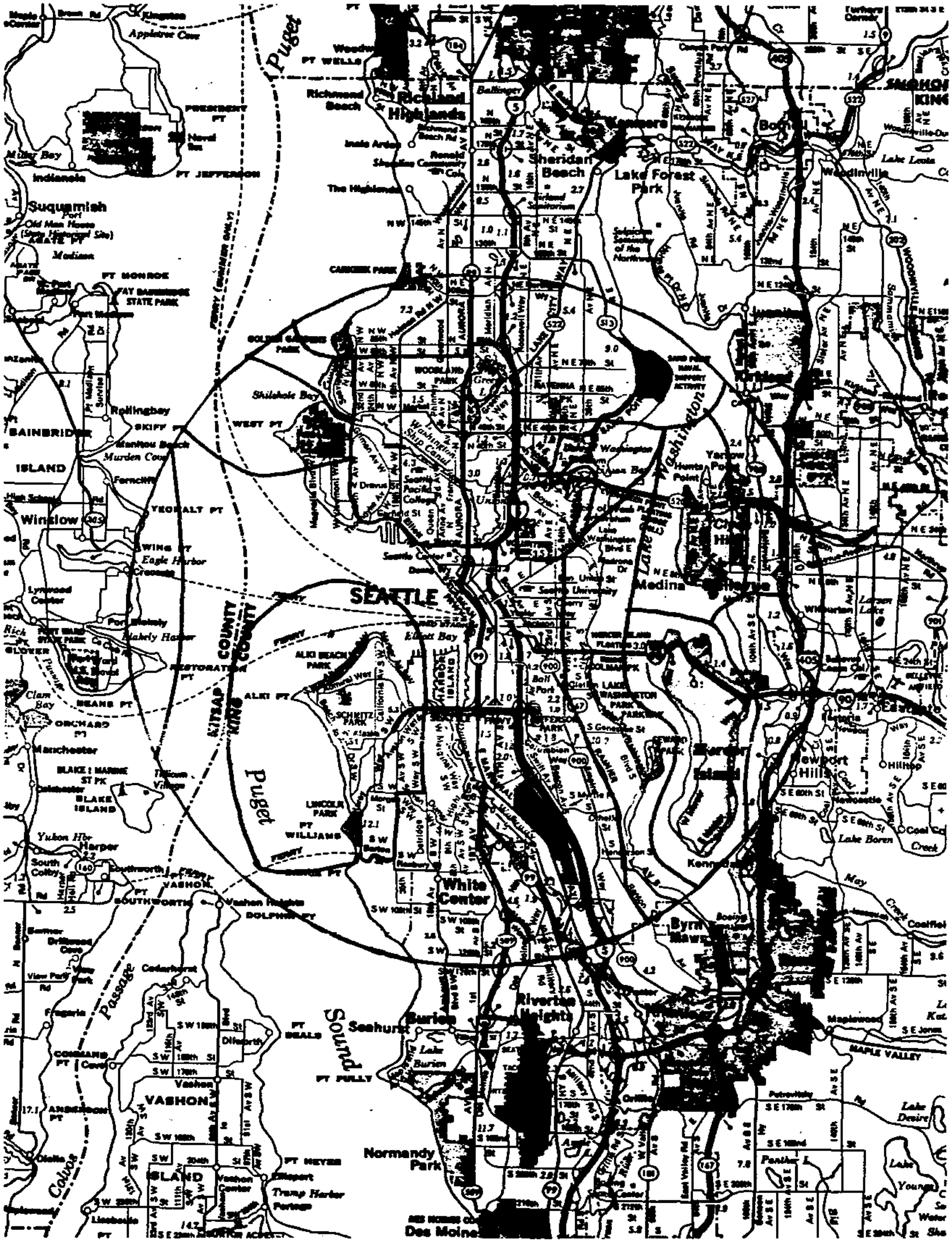


Figure 59. Location of the survey area established for the annual Christmas bird count conducted by the Seattle Chapter of the Audubon Society.
Source: P. Mattocks, Audubon Society, personal communication.

Table 7. Categories used to classify birds observed by the Seattle chapter of the Audubon Society[a]

Category	Order	Scientific Name	Common Name
Open water diving birds	Pygopodes	*Aechmophorus occidentalis*	Western Grebe
		Colymbus auritus	Horned Grebe
		Podilymbus podiceps	Pied-billed Grebe
		Colymbus holboelli	Red-necked Grebe
		Gavia immer	Common Loon
		Gavia arctic	Arctic Loon
	Steganopodes	*Phalacrocorax auritus*	Double-Crested Cormorant
		Phalacrocorax penicullatus	Brandt's Cormorant
		Phalacrocorax pelagicus	Pelagic Cormorant
Alcids	Pygopodes	*Uria aalgae californicus*	Common Murre
		Cepphus columba	Pigeon Guillemot
		Ptychoramphus aleuticus	Cassin's Auklet
		Brachyramphus marmoratus	Marbled Murrelet
		Cerorhinca monocerata	Rhinocerous Auklet
Herons/ Bitterns	Herodiones	*Ardea herodias herodias*	Great Blue Heron
		Butorides virescens virescens	Green Heron
		Bataurus lentiginosus	American Bitterns
Diving ducks	Ansers	*Branta canadensis canadensis*	Canada Goose
		Branta nigericans	Black Brandt
		Anas platyrhynchos	Mallard
		Chaulelasmus streperus	Gadwall
		Dafila acuta	Pintail
		Nettion carolinense	Green-winged Teal
		Mareca americana	American Widgeon
		Spatula clypeata	Shoeveler
	Paludicoleae	*Fulica americana*	American Coot
Dabbling ducks	Ansers	*Marila collaris*	Ring-necked Duck
		Marila valisineria	Canvasback
		Marila marila	Greater Scaup
		Marila affinis	Lesser Scaup
		Clangula clangula americana	Common Goldeneye
		Clangula islandica	Barrow's Goldeneye
		Chariotenetta albeole	Buffelhead
		Oedemia americana	Scoter
		Erismature jamaicensis	Ruddy Duck
		Mergus americanus	Merganser
Shorebirds	Limicolae	*Gallinago delicata*	Common Snipe
		Calidris leucopeae	Sanderling
		Actitus macularia	Spotted Sandpiper
		Calidris alpina	Dunlin
		Arenaria melanocephala	Turnstone

Table 7. Continued

Category	Order	Scientific Name	Common Name
Gulls	Longipennes	<u>Larus glaucescens</u>	Glaucous winged
		<u>Larus occidentalis occidentalis</u>	Western Gull
		<u>Larus argentatus</u>	Herring Gull
		<u>Larus californicus</u>	California Gull
		<u>Larus delawarensis</u>	Ring-billed Gull
		<u>Larus canis</u>	Mew Gull
		<u>Larus philadelphia</u>	Bonaparte Gull

[a] Listing of birds observed in survey, unusual sightings would be placed in appropriate category.

placed in the dabbling duck category because the habitat and feeding habits of the coot are similar to the other dabbling ducks even though they are in different orders. In addition to the seven categories listed above, the counts per observer hour for two species (Great Blue Heron and Pigeon Guillemot) were tallied separately. These two species were selected because they have been the focus of recent studies concerning uptake of contaminants (Riley et al., 1983).

The data were corrected to take into account different numbers of individuals participating in the surveys each year. The number of birds observed in each category was divided by the total party hours, which provided information on the number of birds observed per observer hour. These data were then graphed through time for each bird category (Figures 60 through 66).

Plots of the alcids, open water diving birds, and the Pigeon Guillemot (Figure 60, 61, and 62) generally showed high counts in 1955-1956, 1965-1967, 1973-1975, and 1979-1980.

The plots of diving and dabbling ducks show similar trends with peaks occurring in 1954, 1959, 1968, 1970, 1973, and 1976 (Figures 63 and 64). There are no major long-term increases or decreases apparent for these birds.

Peak abundances of the Great Blue Heron were observed in 1960 and 1980-1983 (Figure 64). The cause of the apparent increases in abundance is not known, but more rookeries have been observed in the Seattle area in the last few years (P. Mattocks, pers. comm.). During a survey conducted in 1981, approximately 80 active nests were observed in King County by Shipe and Scott (1981). The Great Blue Heron was the predominant species in the heron/bittern category. As a result, the graph of heron/bitterns (Figure 66) closely resembles the graph of Great Blue Herons.

From Figure 67, it appears that the range, but not necessarily the overall abundances, of shorebirds recorded per observer hour has increased since the late 1950s. A low of 0.2 shorebirds per observer hour were observed in 1974 with a high of 2.9 shorebirds per observer hour in 1982. The cause of the increased variability is not known.

The number of gulls noted in the records peaked during the period from 1960 through 1965. After 1965, the number of gulls observed per observer hour decreased, but appeared to stabilize in 1967 (Figure 68). The dramatic decrease in gull observations may be due, in part, to the closure of the North Trunk Sewer Outfall. Pictures taken of this outfall (Metro, 1965) show a large number of gulls over the plume north of West Point. In 1965, the North Trunk Outfall was closed as sewage was diverted to the new treatment plant at West Point (see Chapter 4). It should be noted, however, that this decrease does not necessarily indicate that the gull population decreased, but may reflect the fact that the gulls no longer converged in large numbers at one location in the observation area.

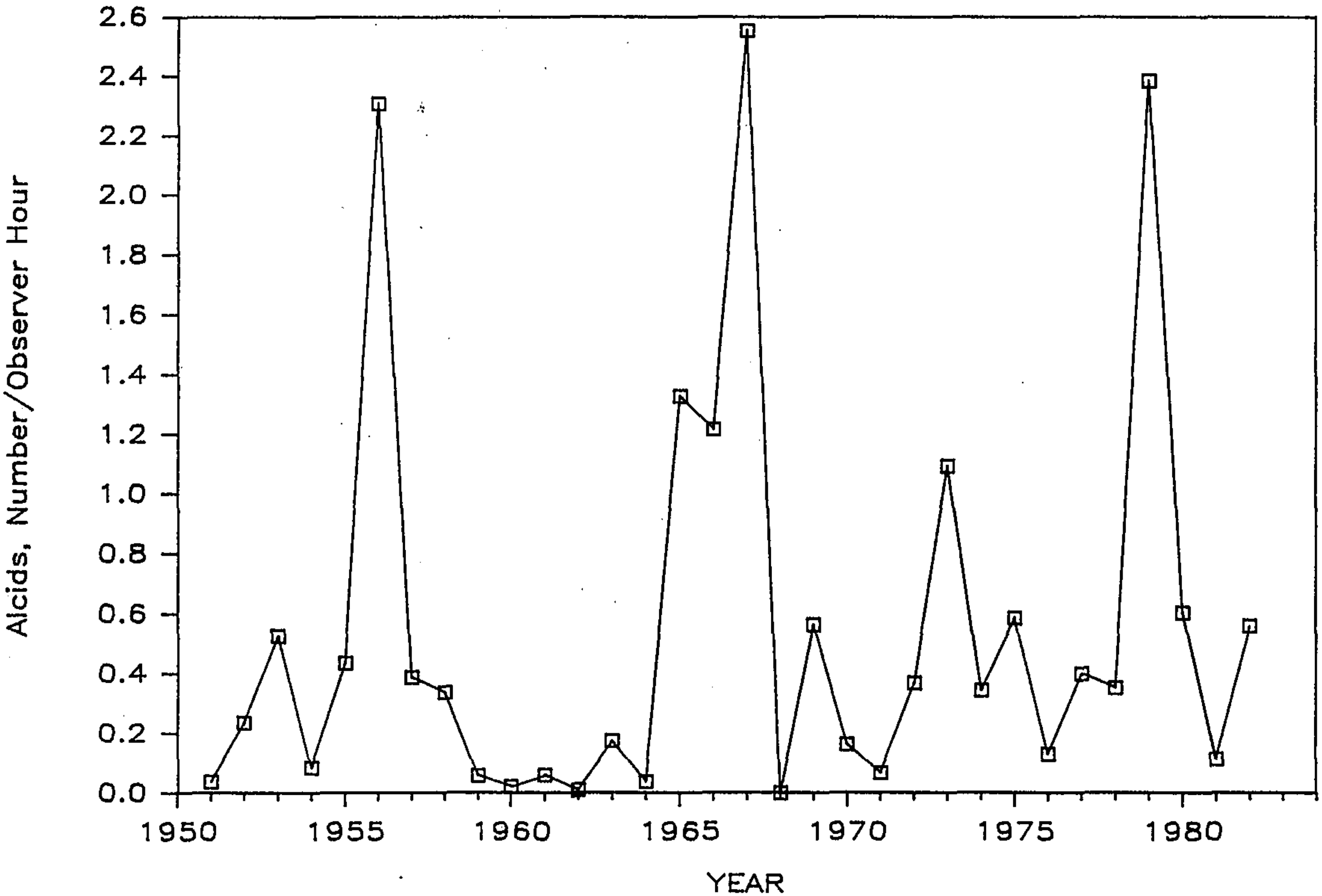


Figure 60. Alcids observed during the Audubon Society's annual Christmas bird counts in Seattle (1951-1982).
Source: American Bird. 1952-1983.

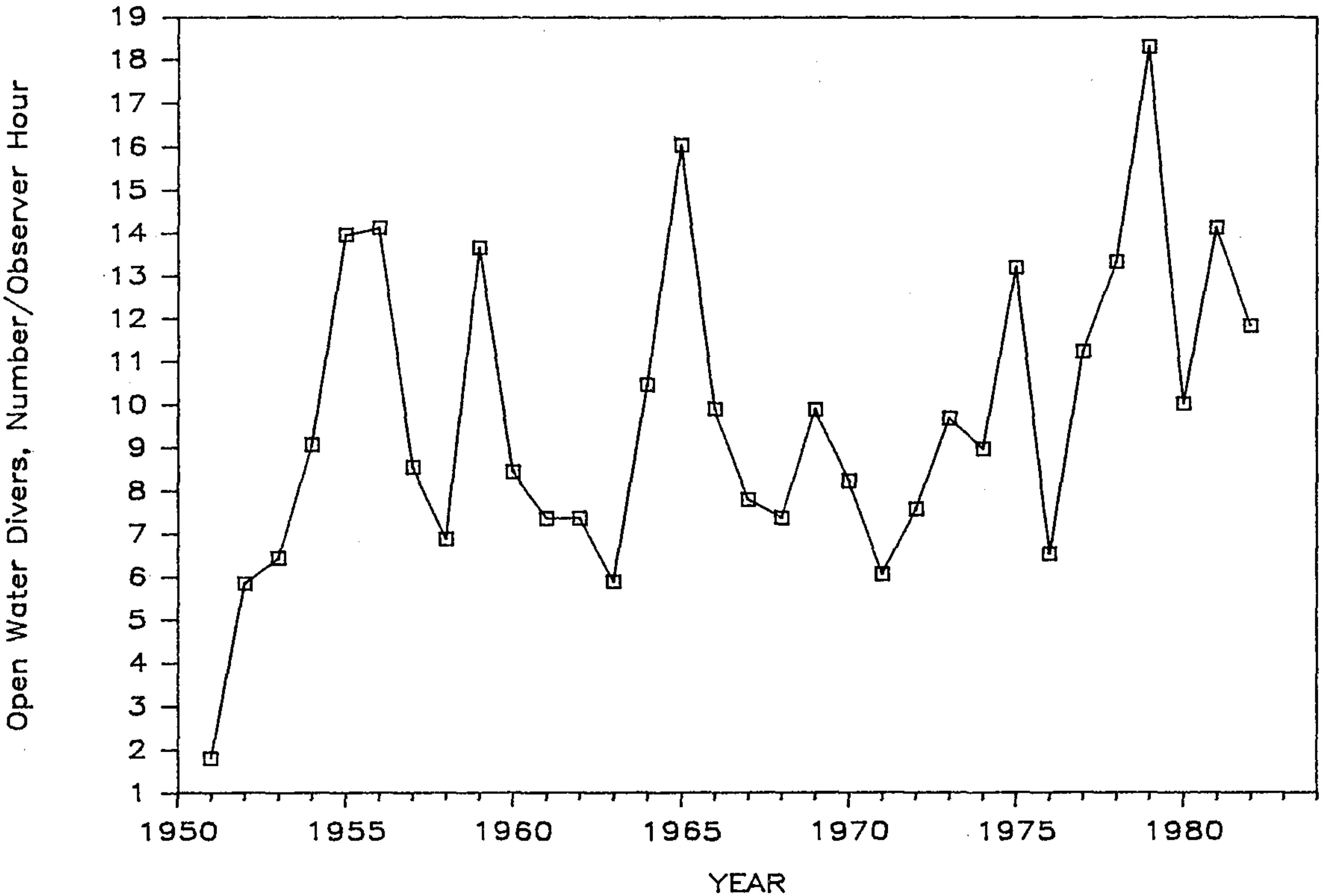


Figure 61. Open water divers observed during the Audubon Society's annual Christmas bird count in Seattle. (1951-1982).
Source: American Bird, 1952-1983).

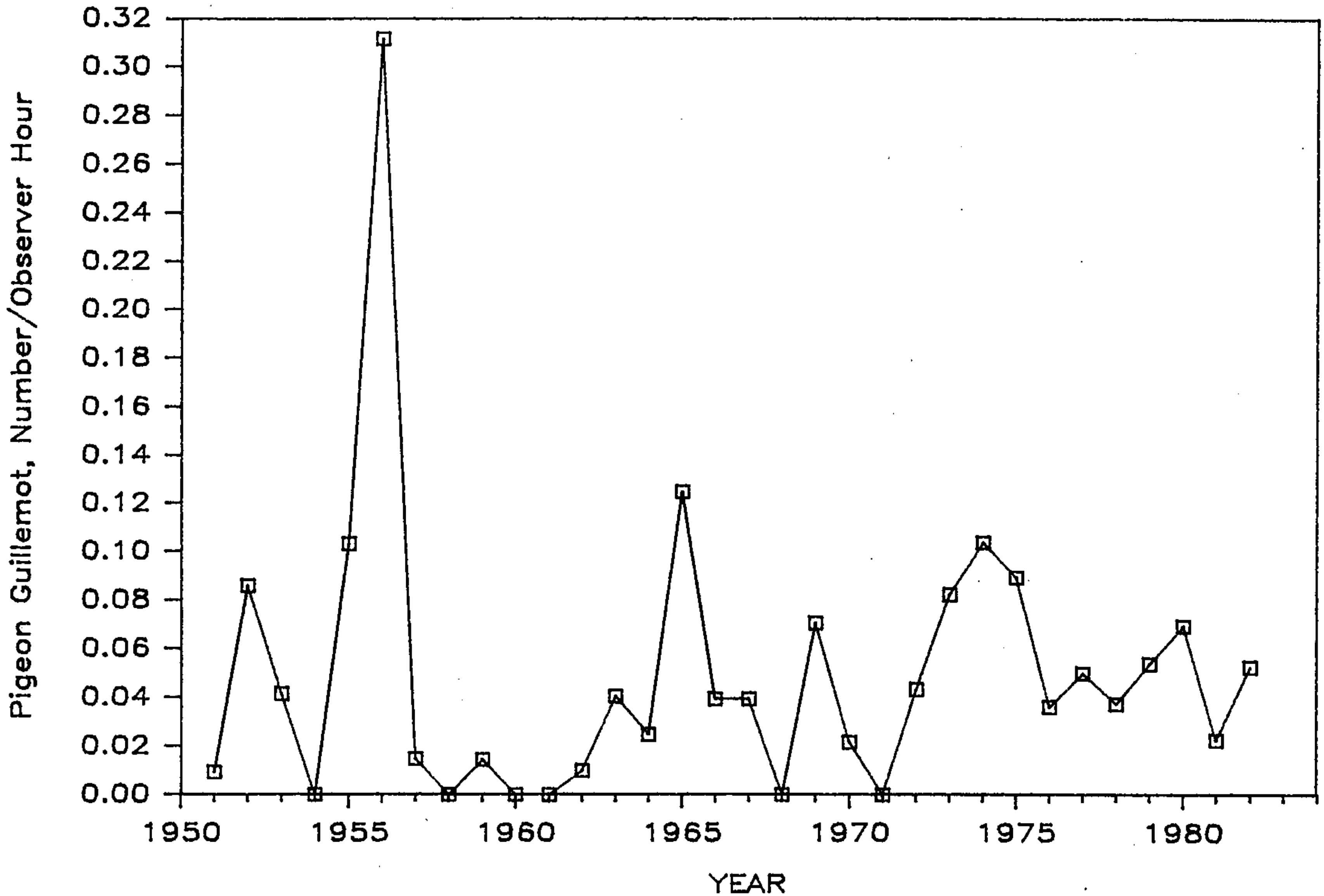


Figure 62. Pigeon Guillemot observed during the Audubon Society's annual Christmas bird count in Seattle (1951-1982).
Source: American Bird, 1952-1983.

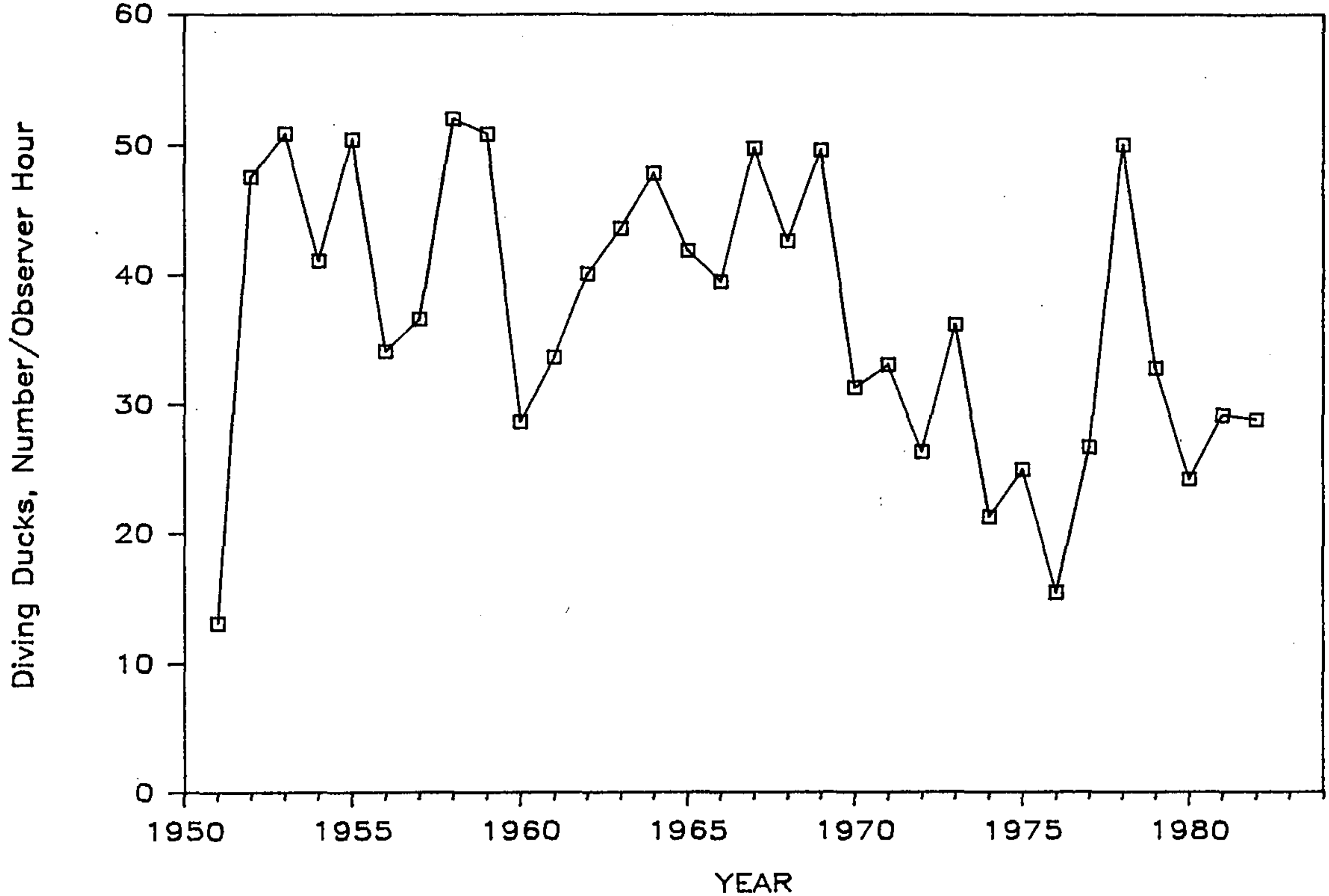


Figure 63. Diving ducks observed during the Audubon Society's annual Christmas bird count in Seattle (1951-1982).
Source: American Bird, 1952-1983.

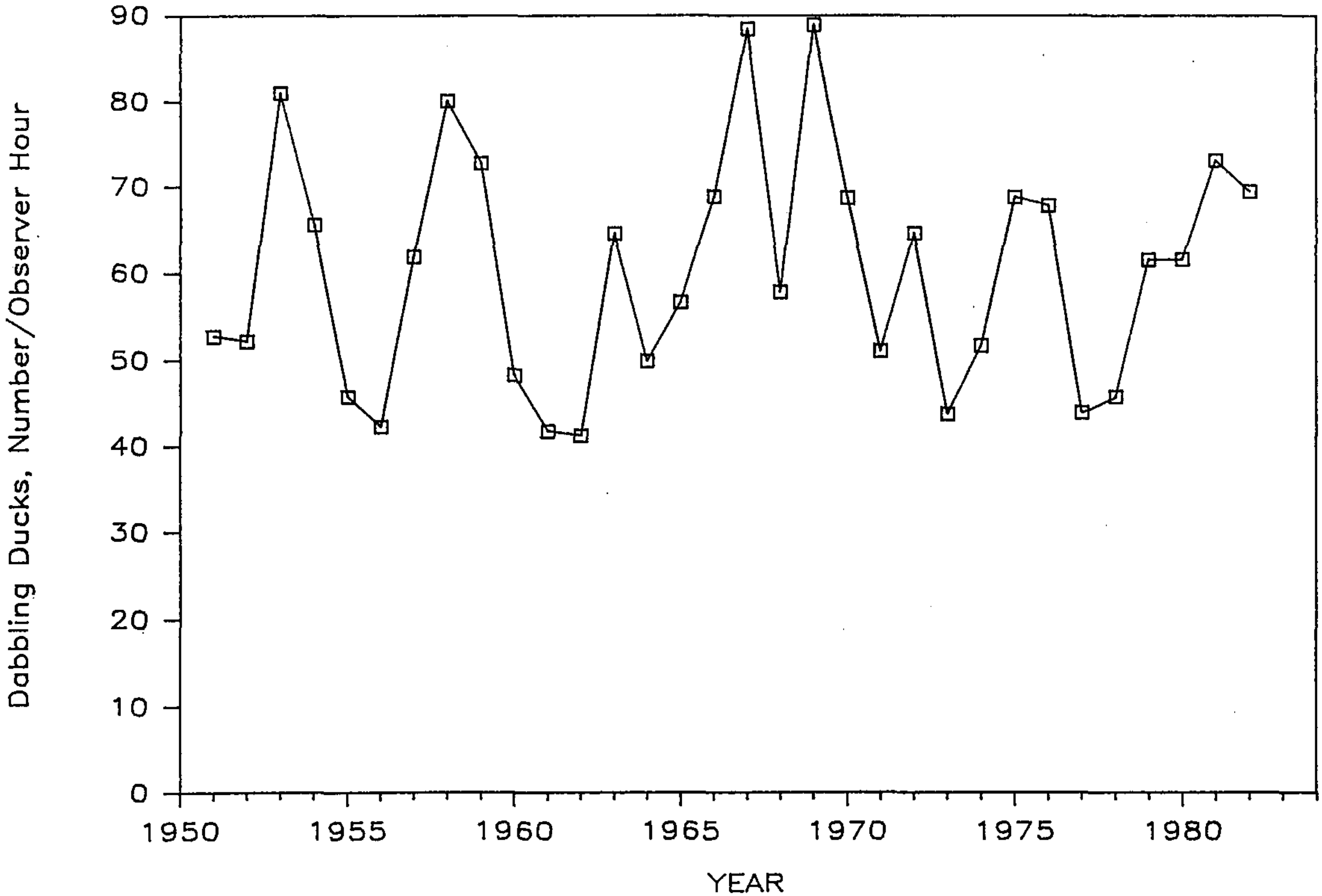


Figure 64. Dabbling ducks observed during the Audubon Society's annual Christmas bird count in Seattle (1951-1982).
Source: American Bird, 1952-1983.

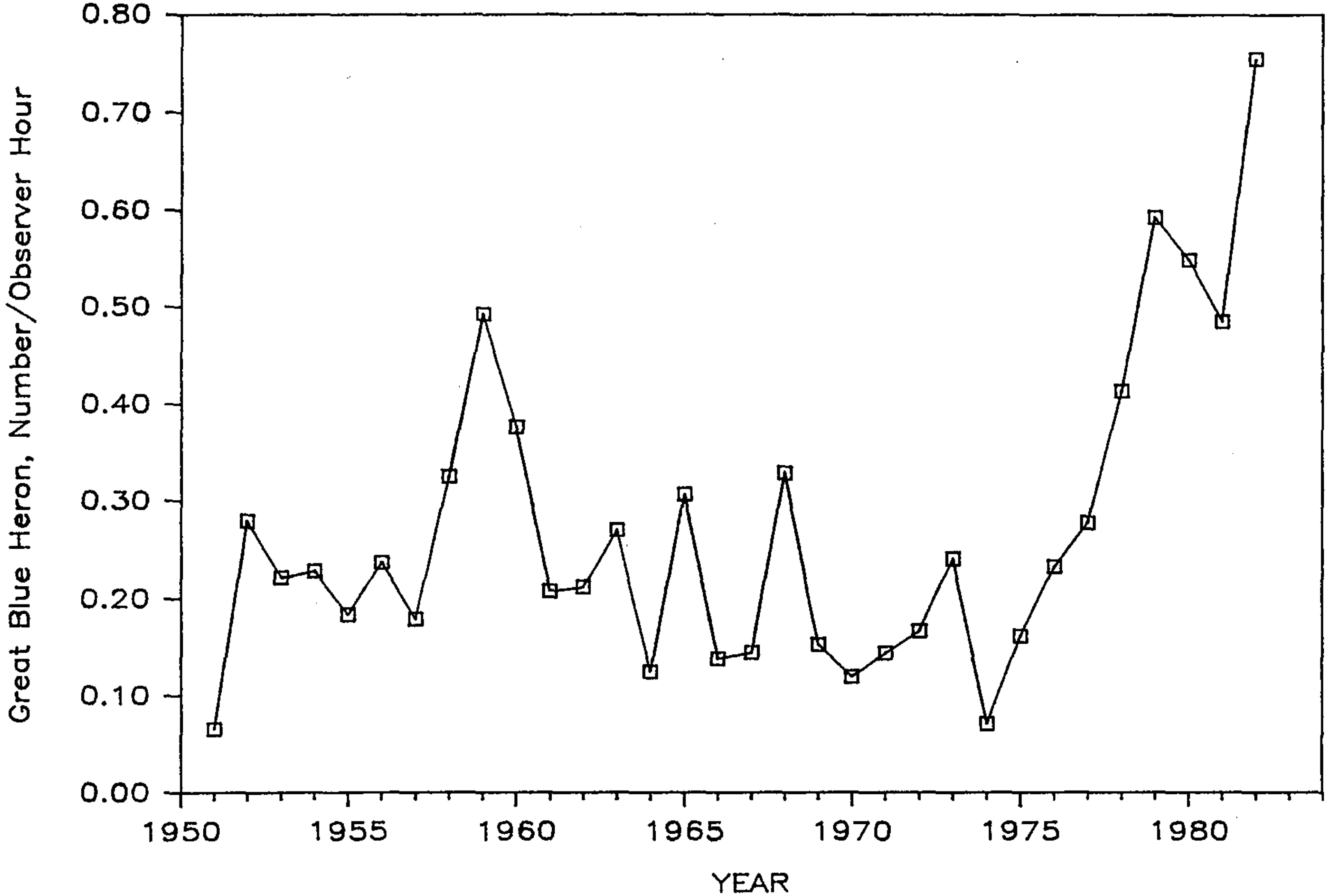


Figure 65. Great Blue Herons observed during the Audubon Society's annual Christmas bird count in Seattle (1951-1982).
Source: American Bird, 1952-1983.

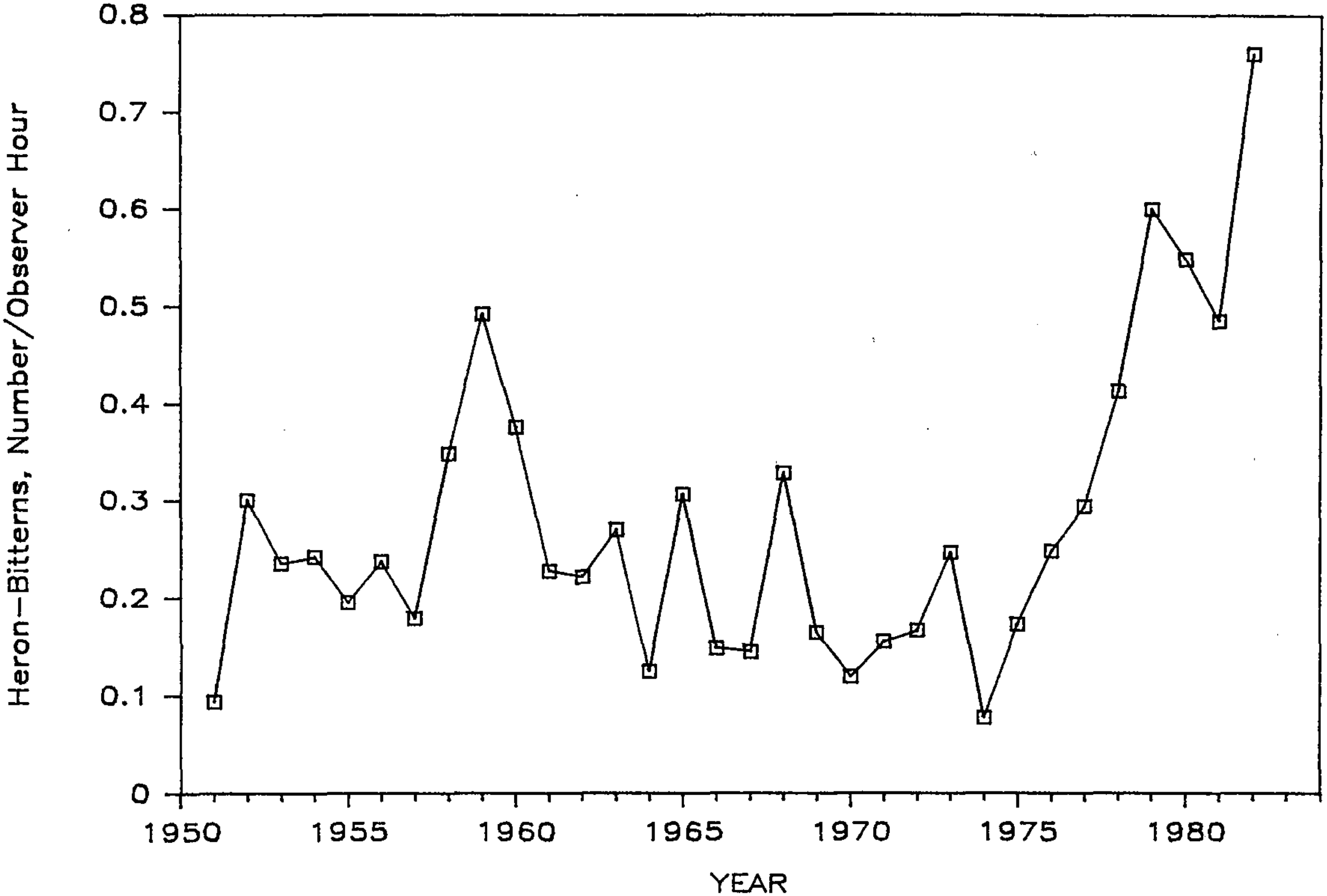


Figure 66. Heron - bitterns observed during the Audubon Society's annual Christmas bird count in Seattle (1951-1982).
Source: American Bird, 1952-1983.

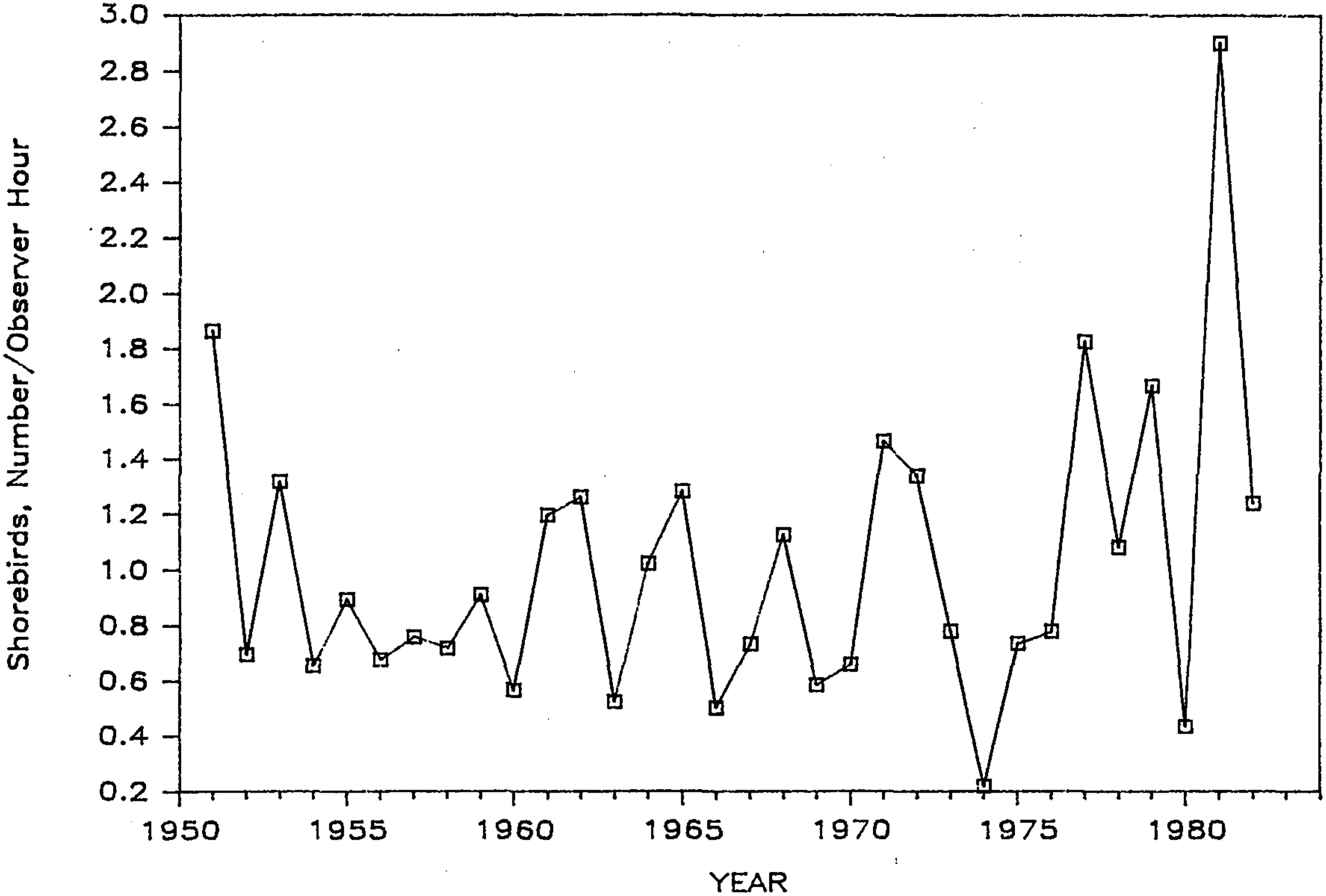


Figure 67. Shorebirds observed during the Audubon Society's annual Christmas bird count in Seattle (1951-1982).
Source: American Bird, 1952-1983.

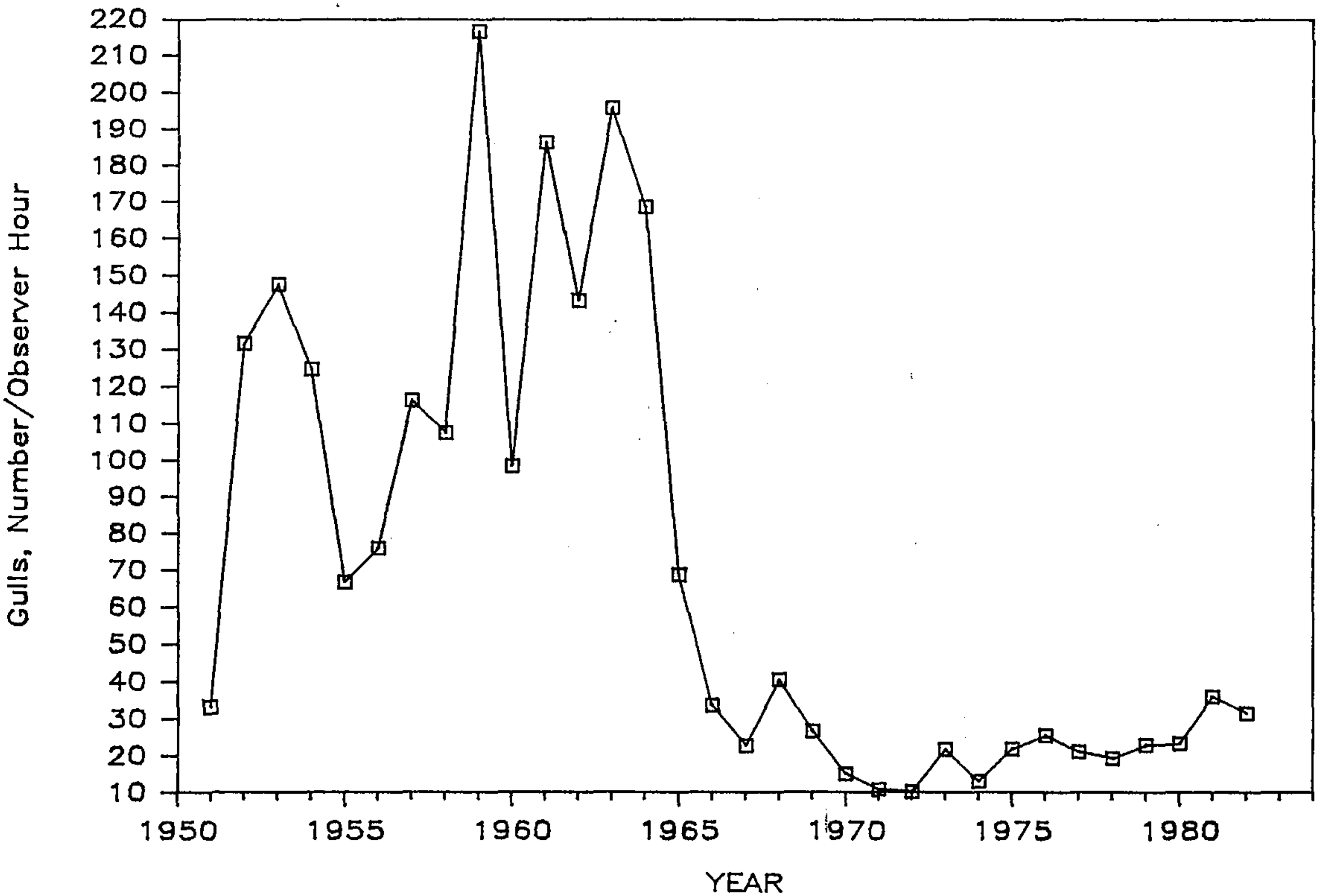


Figure 68. Gulls observed during the Audubon Society's annual Christmas bird count in Seattle (1951-1982).
Source: American Bird, 1952-1983.

With the exception of the gulls and Great Blue Heron, the data do not indicate that the numbers of water-related birds have changed during the period of observation. However, it should be emphasized again that these data are based on a one day per year survey and that the analyses performed in this report are at best rudimentary. As noted earlier, these data can be affected by many factors, including the visibility on the day of the survey, and the overall weather conditions (i.e., a cooler or warmer winter than normal). Poor visibility and inclement weather (i.e., rain, fog, overcast skies, or high winds) may affect the ability of people to see birds and may cause some birds to seek shelter and therefore not be visible to the observers. An exceptionally cool or warm season may affect the birds' migration patterns. For example, during a harsh winter some birds may migrate further south than usual, resulting in different numbers of that species being observed in the area.

The effects of birds being wrongly identified was reduced by grouping the waterfowl into seven categories. For example, the subtle differences between a Common Goldeneye and a Barrow's Goldeneye which may have led to some misidentications, were not important because both species were placed in the same category, dabbling ducks. It should also be noted that the records were not examined to determine whether any individual species except the Great Blue Heron and Pigeon Guillemot may have changed markedly in observed abundance in the last 30 years.

7.8 MAMMALS

Twenty-two species of marine mammals have been observed in southern Puget Sound. Of these, nine are considered common, five rare, and eight accidental (Everitt et al., 1979; Dexter et al., 1981). The harbor seal is the only pinniped known to breed in Puget Sound.

Trend assessments of mammalian populations were limited in this report to the harbor seal since it breeds in Puget Sound, is a year-round resident, and is the one species of mammal for which there are at least some historical population estimates. Measuring the seal populations is difficult because of their avoidance of humans and the record is not extensive (Calambokidis et al., 1978; Dexter et al., 1981). The population of seals at the Nisqually Delta was estimated to be greater than 100 during the late 1920s and again the early 1940s (Scheffer and Sperry, 1931; Scheffer and Slipp, 1944). By 1968 the estimated population had been reduced to three (Newby, 1973), but has since recovered. Total harbor seal and seal pup abundance observations made from 1965 to the present from a nearby area in South Sound, Gertrude Island, have been compiled by Calambokidis et al. (1985) and are presented in Figure 69. The data represent the highest counts recorded at each observation period, thus providing the highest, and hopefully the most comparable, population estimates. The data clearly indicate a large increase in the total seal population at this site, beginning about 1975, and apparently continuing to the present (1985). Pups showed increased abundances only in very recent data.

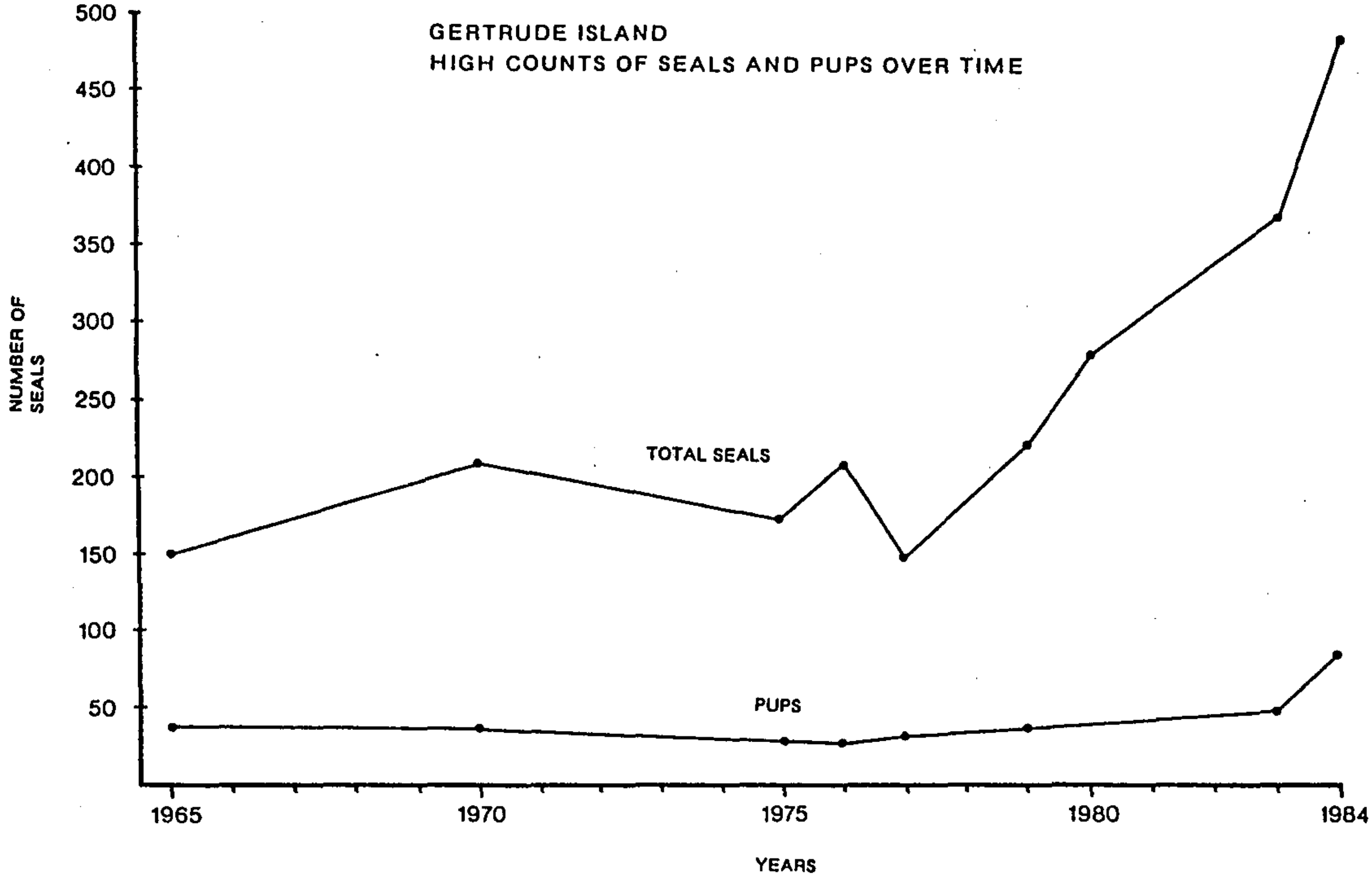


Figure 69. High counts of harbor seals and harbor seal pups at Gertrude Island in southern Puget Sound.
Source: Calambokidis et al. (1985).

A similar trend was observed with the total population of harbor seals in the State of Washington (including coastal waters). From 1944 to the late 1960s, the total population of harbor seals in Washington State was estimated to have declined from 5,000 (Sheffer and Slipp, 1944) to 2,000 (Newby, 1973). By the late 1970s, the population was estimated at over 6,000.

The public's attitude toward marine mammals was quite different in the earlier parts of the century than it is today. During the 1920s through the 1950s, the major thrust was on reducing the harbor seal and sea lion herds because they were considered to be a menace to the salmon fishing industry. The WDF paid a bounty for seal and sea lion scalps from the 1920s to 1960, and some records of the bounty payments are available (Table 8). From 1923 through 1926 the WDF paid a bounty for 3,240 scalps (Scheffer, 1928). Since it has been estimated that 40 percent of the seals killed were not recovered (Scheffer and Slipp, 1944), the actual number of seals killed during this period could have approached 4,500 animals (Table 8).

From 1943 through 1946, approximately 2,500 to 3,500 seal were killed by bounty hunters in the State of Washington (Table 8). To put this into perspective, note that Scheffer and Slipp (1944) estimated the total harbor seal population in the state at that time to be 5,000 animals. During this period, then, approximately one-half to three quarters of the seals in the state were killed. Robert Josephson, Chief of Patrol, WDF, reported that from 1943 through June 30, 1960, 10,832 seals and sea lion scalps were turned in by bounty hunters (letter dated March 6, 1970 cited in Newby, 1973). During this period, approximately 95 percent of the scalps relinquished for bounty were harbor seals. Again, assuming that 40 percent of the carcasses were not retrieved, the number of seals killed could have approached 17,000 (Newby, 1973) over this time period.

The numbers of seals has increased in Puget Sound since the end of the bounty in 1960 and the implementation of the Federal Mammal Protection Act of 1972. Calambokidis et al. (1978, 1979, and 1984) observed increased numbers of harbor seals in Hood Canal and Northern Puget Sound compared to previous years.

7.9 OTHER BIOLOGICAL EFFECTS

Very few concerted efforts have been made to quantitatively document temporal trends in the effects of pollution on biological populations in the Sound. A number of grossly impacted areas of the Sound have been discussed previously where toxic effluents and low dissolved oxygen resulted in periodic fish kills and altered benthic communities in the urban areas and near the pulp and paper mills (see Section 7.2 and 7.6, and Quinlan et al., 1985).

Table 8. Estimated number of seals killed by bounty hunters in the State of Washington (1923-1946)

Year	Number Killed for which a Bounty was Paid	Number Killed for which no Bounty was Paid**	Total
1923	*741	296	1,037
1924	*271	108	379
1925	*1,171	468	1,639
1926	*1,057	422	1,479
1927	-		
1928	-		
1929	-		
1930	-		
1931	-		
1932	-		
1933	-		
1934	-		
1935	-		
1936	-		
1937	-		
1938	-		
1939	-		
1940	-		
1941	-		
1943	! 668	267	935
1944	! 1,266	506	1,772
1945	! 348	139	487
1946	@ 278	111	389

** Based on 40% of seals killed not recovered
* Scheffer, 1928
! WDF, 1945
@ WDF, 1946
- no data available

Similarly, the long-term changes noted recently in the benthic community in the Main Basin near West Point may be due to the effects of the nearby sewage discharge (Nichols, 1985; see Section 7.2, Benthic Organisms).

7.9.1 Water Toxicity

For over a decade, from the early 1960s to the mid-1970s, direct measurements were made of the toxicity of the waters of the Sound to oyster larvae (C. gigas). These data have been presented in detail in Cardwell and Woelke (1979) and are summarized here. The major areas that were tested included those near Port Angeles, Bellingham, Birch Bay/Cherry Point, the Bellingham-Samish-Fidalgo Bay area, Whidbey Basin, Elliott Bay, Commencement Bay, and areas of the Southern Sound. Typical data for areas that exhibited consistent toxic responses are shown in Figure 70. The data are presented graphically as the percentages of the samples per year from an area that had 1) greater than 50 percent abnormal larval development and 2) greater than 50 percent mortality of the larvae during testing. The 50 percent level was subjectively selected to graphically depict the temporal trends in the data and illustrate spatial differences among the tested areas.

Some areas showed relatively little toxicity. Elliott Bay, Birch Bay/Cherry Point, and Fidalgo Bay rarely had abnormalities or mortalities exceeding 50 percent. Greater than 50 percent abnormalities or mortalities in these areas were attributed to salinities lower than the oyster larvae could tolerate (Cardwell et al., 1979). The period of record covers a period of high runoff (Figure 12) and lowered salinities throughout the Sound (Figure 11).

The areas where consistent toxicities were observed (Port Angeles, Bellingham, Port Gardner/Whidbey Basin and Commencement Bay) were areas that all received the effluent from one or more pulp mills. Cardwell and Woelke (1979) concluded that pulp mill effluents were one of the major causes of the observed mortalities. Most of the areas, however, also have river influxes that resulted in some abnormalities and mortalities from low salinities (Cardwell et al., 1979).

The data shown in Figure 70 appear to show a trend in the oyster larvae response only in the Bellingham/Samish Bays system where the frequencies of both high abnormalities and high mortalities decreased during the period of study. The other areas showed more random toxicity, but all areas had lower toxicity in the last years of testing. This latter effect may reflect a change in the way the oyster larvae test was performed during the last two test periods or may constitute multi-year cycles (Cardwell and Woelke, 1979).

It must also be noted that this testing program was terminated prior to the completion of major effluent reductions by the pulp mills in the tested areas (Table 2). Therefore, these data may overestimate the responses that would be observed if the studies were repeated today.

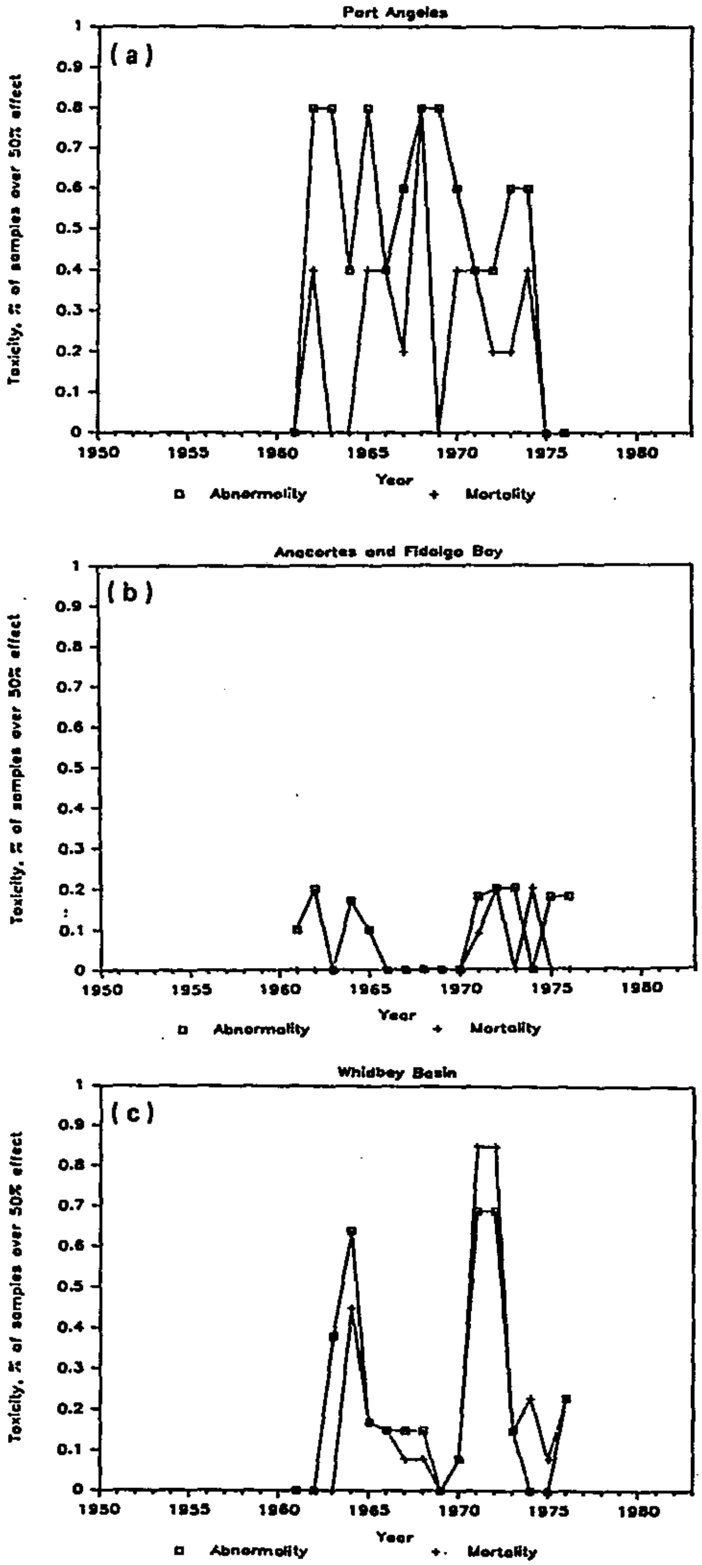
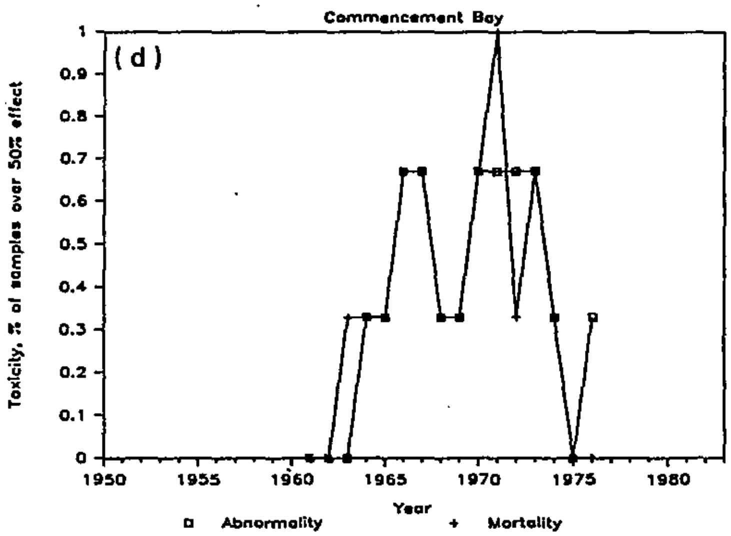


Figure 70. Oyster larvae toxicity in the surface waters at 5 areas of the Sound where greater than 50% toxicity levels were consistently observed between 1960 and 1976. (a) Port Angeles. (b) Anacortes and Fidalgo Bay. (c) Whidbey Basin. Data are the averages of many stations.
Source: Cardwell and Woelke, 1979.



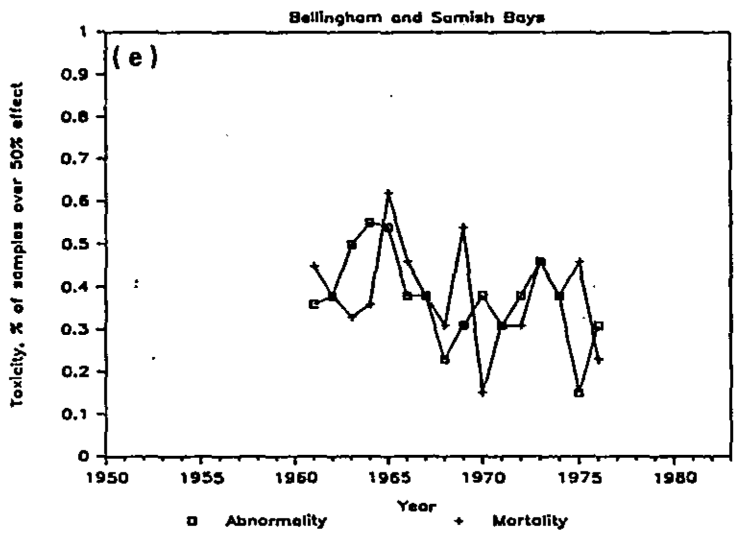


Figure 70. Oyster larvae toxicity in the surface waters at 5 areas of the Sound where greater than 50% toxicity levels were consistently observed between 1960 and 1976.
(d) Commencement Bay. (e) Bellingham and Samish Bays.
Data are the averages of many stations.
Source: Cardwell and Woelke, 1979.

7.9.2 Fish Communities

In a somewhat related effort, the response of the resident fish community in the Port Gardner area to reductions in the mill discharges (see Figure 19b) was followed from 1974 to 1981. These data are presented in Figure 71 as the averages of the number of species of fish and invertebrates (shrimp and crab) caught in monthly beach seines at four stations along the shore south of Everett and as the averages of the numbers of species caught in monthly deep-water trawls at five stations in the inner harbor (East Waterway)(unpublished ECOBAM data from WDOE files). In both areas a strong seasonal variation was observed with the least numbers of species being present in the winter months (December and January). The outer area (beach seines) had greater species diversity than the inner area (deep trawls), which may have resulted from the differences in sampling procedures between the areas.

The outer shoreline did not show any clear temporal trends in the numbers of species caught. This area was dominated by starry flounder, surf smelt, Pacific staghorn sculpin, and crangon shrimp, with frequent occurrences of salmon, English sole, and Pacific herring. The inner harbor samples consisted primarily of surf smelt, Pacific herring and three spined stickleback, but also included salmon, shrimp and a few starry flounder (unpublished ECOBAM data from WDOE data files). The data in Figure 71 indicate that the latter area did show some overall decrease between 1974 and 1981 in the number of species present, even though the effluent loadings from the mills were decreasing (see Section 5.1). The decrease has not been tested for significance and did not appear to reflect a consistent change in a single (or a few) species.

7.9.3 Fish Pathological Disorders

Pathological conditions have been noted in a number of fish and shellfish species in the Sound (Dexter et al., 1981; Harper-Owes, 1983; Quinlan et al., in press; Jones and Stokes and Tetra Tech, 1983; Malins, et al., 1980 and 1982; McCain et al., 1984), with the prevalence being measured most often in non-replicated surveys of different areas of the Sound. As a result, very limited data are available to determine whether these disorders have developed recently or have been present for many years in the effected populations. No changes in population numbers have been attributed to these diseases, but it has been observed that the occurrence of these disorders may be related to the presence of toxic chemicals.

One such disorder, fin erosion, has received limited study in the Duwamish River since 1966. The data for this disease have been summarized in Harper-Owes (1983). They indicate a decline in the incidence of fin erosion in starry flounder in the Duwamish from a high of about 15 percent incidence among fish caught prior to 1971, to about 10 percent incidence in the mid-1970s, to less than 3 percent in the late 1970s. As pointed out in Harper Owes (1983), however, the histological criteria used in identifying fin erosion has varied among studies. Therefore, it is not clear that the apparent decline is an artifact of the developing expertise to identify this disorder or whether the decline reflects biological responses to environmental conditions.

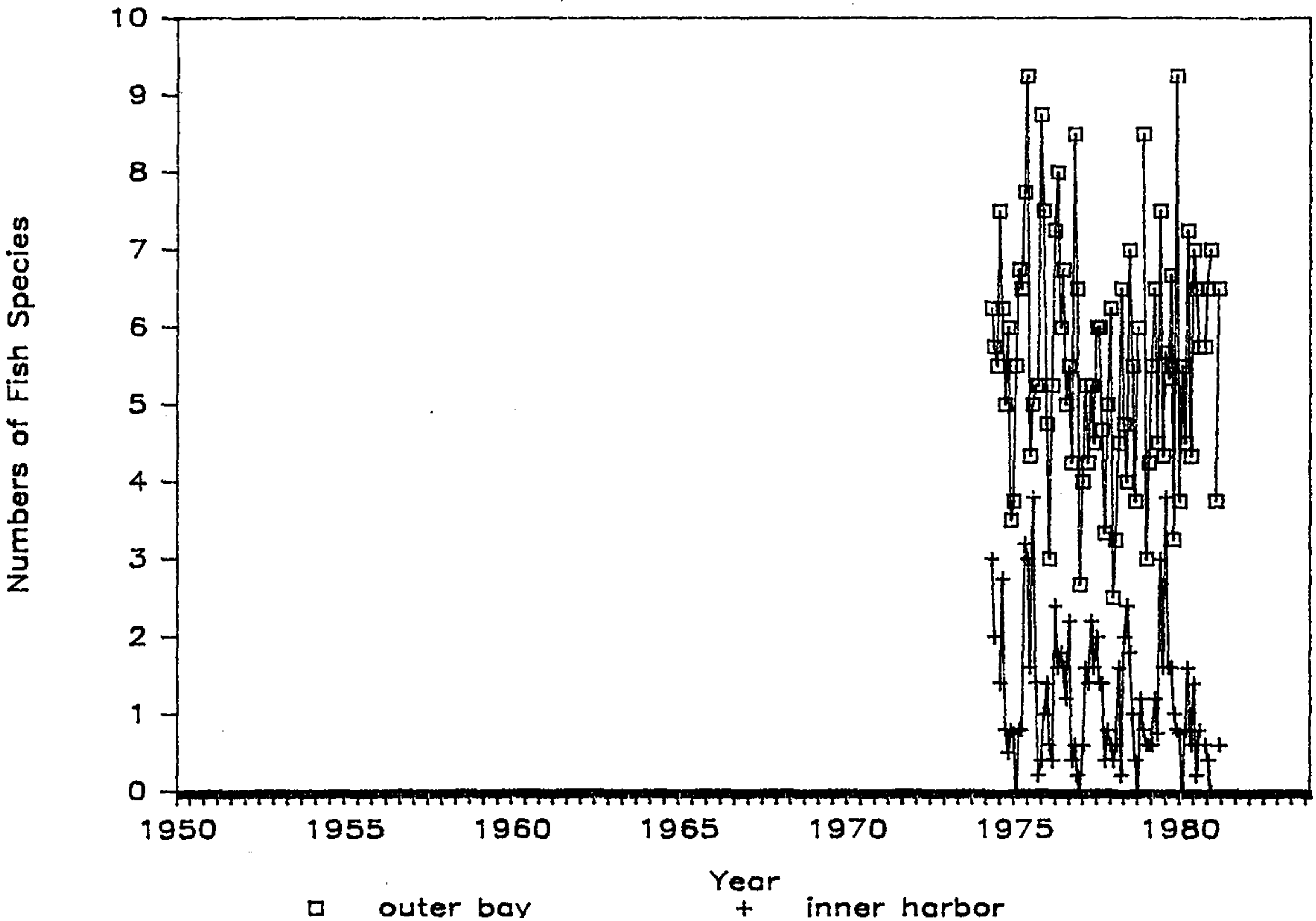


Figure 71. Average numbers of fish and invertebrate species caught in trawls in Everett Harbor, 1973 to 1981. □ = samples from 4 stations between Everett Harbor and Mukilteo, + = samples from 5 stations in the East Waterway (Everett Harbor).
Source: Unpublished ECOBAM data from WDOE data files.

Similarly, abnormalities in the livers of Puget Sound bottom fish have been studied only since the late 1970s. The incidences of pathological liver conditions appear to be greater in the urbanized areas of the Sound than in the remote areas. However, the short time frame (5 years) of the studies and uncertainties in the data due to developing analytical procedures and changing biological criteria make it difficult to develop any temporal trends.

Trend data in the frequencies of liver abnormalities over five years have been collected at eight sites in Puget Sound: Sinclair Inlet; Port Madison; the Hylebos and Sitcum Waterways in Commencement Bay; near Pier 54 and near the Denny Way CSO in Elliott Bay; and at two sites in the lower Duwamish River (McCain et al., 1984). Statistical analyses of the limited data have shown significant increases in neoplasms (tumors), preneoplasms (pretumerous tissue) and degeneration/necrosis in the Duwamish River south of Harbor Island (station 10031). The data for these diseases are presented graphically in Figure 72. Significant increases in specific degeneration/necrosis were also noted in the upper Duwamish River (station 10036) and also near the Denny Way CSO (Station 10041) in outer Elliott Bay. Over the same time period, neoplasms decreased slightly in the Sitcum Waterway (Station 9030). No other major changes in pathological conditions were noted. In addition, because the fish collected in this study were not segregated by age and because the lesion prevalence is greater in older fish (Malins et al., 1980), the temporal and/or spatial difference observed may reflect, in part, age difference among the fish populations sampled. At the present time, the overall implications of these changes and their possible relationship to environmental conditions, including pollutant inputs, are not clearly established.

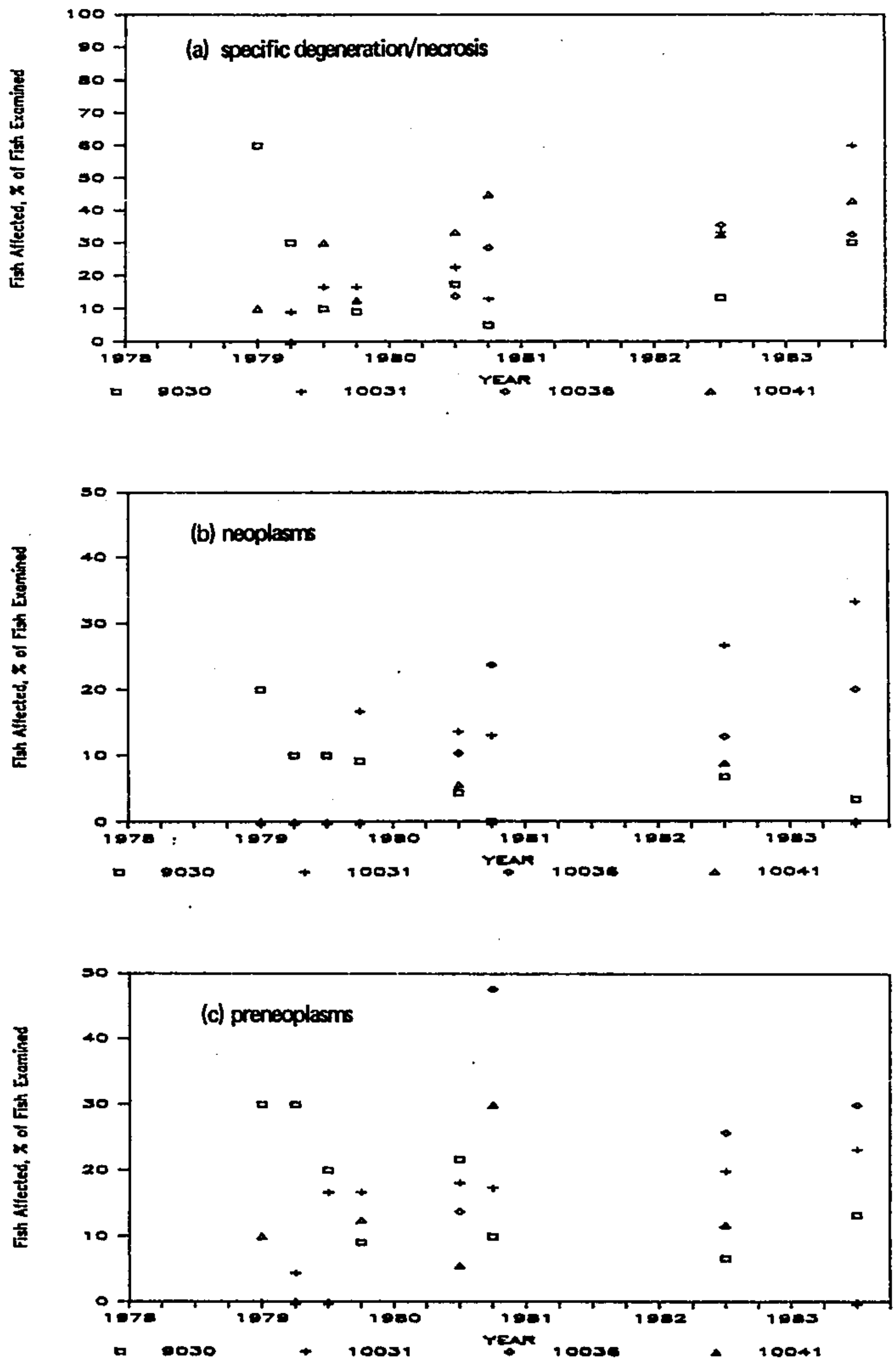


Figure 72. Incidences of selected liver diseases in English Sole from Puget Sound. (a) specific degeneration/necrosis, (b) neoplasms, and (c) preneoplasms. Stations are: 9030, Sitcum Waterway, Commencement Bay; 10031, south of Harbor Island, Duwamish Waterway, Elliott Bay; 10036, near the 14th Ave. S. bridge, Duwamish Waterway, Elliott Bay; 10041, near the Denny Way combined-sewer overflow, Elliott Bay. No data were collected at station 10036 in 1979. Source: McCain et al., 1983.

8. SUMMARY AND RECOMMENDATIONS

8.1 SUMMARY

This report represents the first attempt to combine a variety of long-term data sets reflecting the changing conditions in Puget Sound. Within the constraints of this study, as noted in Chapter 2, some general summary comments can be made.

First, it is apparent that Puget Sound water-quality problems are not of recent origin. It is clear that pollution occurred in many areas before the turn of the century. Most of the early pollution problems were due to BOD loadings from lumber and pulp mills which were recognized early on as a problem. However, some forms of pollution, e.g., some toxic chemicals, were not adequately recognized as hazards by today's standards.

Second, the data reveal that substantial progress has been made in eliminating incidences of gross pollution in the Sound from conventional pollutants. In addition, the levels of some toxic chemicals such as PCBs appear to be decreasing, at least in some areas. However, the data are limited, both spatially and temporally for the toxic chemicals, and continued investigation is necessary to fully identify long-term trends.

Third, the majority of the biological populations for which data are available, i.e., harvested species, have been impacted primarily by economic demands, management decisions and habitat alteration. However, it is clear that some populations, including those of salmon, Great Blue Heron, and harbor seals have been increasing in size in recent years under better protection and control than in the past.

Fourth, with the obvious exceptions of the biologial impacts in grossly polluted areas, only in a few populations can changes be strongly related to water quality conditions, the Olympia oyster being the best example. There are no definite trends apparent yet in such biological impacts as histopathological disorders in bottomfish.

Finally, it appears that recent research in Puget Sound often makes insufficient recognition of the major physical alterations to the Sound that have occurred. For example, such effects as altered sediment supply to the Sound from the diversion and damming of rivers and from changes in sea level are rarely considered in habitat and sediment accumulation studies. Similarly, weather and climate have not been stable over the last century and differences in temperature and precipitation, for example, may have induced substantial changes in the Puget Sound ecosystem. These factors must be explored in more detail than was possible in this report to provide a better perspective on current conditions.

8.2 RECOMMENDATIONS

Many of the parameters discussed in this report should be monitored in the future. A comprehensive analysis of these monitoring needs is presented in a companion report (Chapman et al., in press). Measures of trends observed in the past and reported here can be extended into the future.

A wealth of information regarding pollution incidents, sites of possible pollutant sources, and other aspects of the developmental history of the Sound are contained in agency reports, e.g., from the State Department of Fisheries and the State Pollution Control Commission, and in local histories and other documents. These documents are an invaluable resource to present studies attempting to identify and rectify past and ongoing water quality problems. Copies of these documents should be compiled in a single, accessible location such as the WDOE, PSWQA, NOAA or EPA libraries to ensure their continued existence and accessibility. This effort would require both additional work in identifying useful documents beyond those used in this report and making useable copies available to researchers.

Efforts should be made to document fully the histories of the major industrial and municipal waste discharges in the Puget Sound region based on both analytical data and anecdotal information. This kind of information would be useful in establishing significant dates in the pollution history of the area as well as in identifying potential sources of substances in the system.

Additional effort is needed to make all monitoring data, both past records and new information, accessible. Some data have been collected but never synthesized or catalogued. It would be most helpful if all of these data could be maintained in one location under a single format.

The effort begun in this report should be continued on a regular, e.g., annual, basis. At least a start has been made herein to compile in a single document an overview of trends related to water quality in Puget Sound. Adding the information collected from ongoing monitoring programs would not be difficult, and could provide a readily understandable presentation of trends in the condition of the Puget Sound. Improvements are certainly possible in the geographic scope of the data presentation. Changes, both additions and deletions, in the parameters measured could also improve revised editions of this report.

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