Publication No. 86-e05

WA-17-0050

Analysis of Shellfish and Water Quality from Sequim Bay, Washington

by

Timothy A. Determan
Water Quality Investigations Section

February 1986

Washington State Department of Ecology
Olympia WA 98504-6811

TABLE OF CONTENTS

LIST OF FIGURES

ABSTRACT

Bacteriological data from Sequim Bay collected since 1977 (source, receiving water, and shellfish tissue) were reviewed and analyzed. Based on this review, shellfish tissue data indicated relatively high bacteriological concentrations near the mouth of the bay, with decreasing concentrations to the south and east. To date, contamination has been confined largely to the western shore. No significant change in fecal coliform concentrations in shellfish was detected overall at the most contaminated site (Washington Harbor). Significant trends at the other sites are unlikely. Major sources are apparently located near Sequim Bay entrance. The fecal coliform load from Bell Creek was estimated to be over 500 times higher than that from the Sequim sewage treatment plant. Data are lacking to measure contributions from remaining watershed streams and irrigation return flows. An integrated basin-wide baseline study is suggested.

INTRODUCTION

During the past decade, Sequim Bay residents have debated the effects of changing and intensifying land and water uses. In response to this concern, Dr. Eloise Kailin, president of Protect the Peninsula's Future contacted the Washington Department of Ecology (Ecology) Director Andrea Beatty Riniker. The Water Quality Investigations Section (WQIS) was then instructed to evaluate data from existing monitoring programs. The objectives of this effort were as follows:

1. To locate and integrate historical data from Ecology, Department of Social and Health Services (DSHS), Clallam County, Sequim city officials, and others.

2. To determine whether fecal coliform (FC) concentrations have changed significantly during the course of time.

3. To the extent possible, identify sources which may be influencing FC levels in shellfish.

BACKGROUND

At present, most of Sequim Bay's eastern shore and that south of Sequim Bay State Park are certified by the DSHS Shellfish Sanitation Program for the direct harvest of shellfish (Kennedy, 1984). Commercial harvesting of oysters, clams and geoducks have occurred along the entire eastern shoreline, at Middle Ground (south of the bay entrance) and along the southwest shore at Schoolhouse Point and Blyn (Saunders, 1984).

A debate has emerged within the Sequim community about the relative importance of several potential pollution sources in the Sequim Bay region. One source is the Sequim sewage treatment plant (STP). The plant, a secondary facility, was designed to serve 2,500 people. By 1979, a moratorium on new sewer connections was imposed by Ecology because the plant became hydraulically overloaded at peak flows (D. Anderson, Ecology Southwest Regional Office [SWRO], personal communication). Construction began in 1982 to expand the capacity of the STP. The expansion was completed by December 1983. A chlorination basin (to replace chlorination in a nearby manhole) was completed and began operation on January 3, 1986 (N. Kmet, SWRO, personal communication). The discharge point lies about 2 km north of the Sequim Bay entrance (Elston, et al., 1983) at 5 m depth and about 100 m offshore (Figure 1). Several options for discharge are currently under study. These include relocation of the discharge point and land disposal.

Another issue is the closure of shellfish beds due to boating traffic. There are two major boating destinations in Sequim Bay: the John Wayne Marina near Pitship Point and the Sequim Bay State Park near Schoolhouse Point.

John Wayne Marina opened in the summer of 1984. The present capacity is about 200 boats (K. Sweeny, Port of Port Angeles [PPA], personal communication). The planned and approved final moorage will be 422 slips. The opening was directly responsible for the decertification for commercial shellfish harvest of the shoreline between Sequim Bay entrance and Pitship Point and the Middle

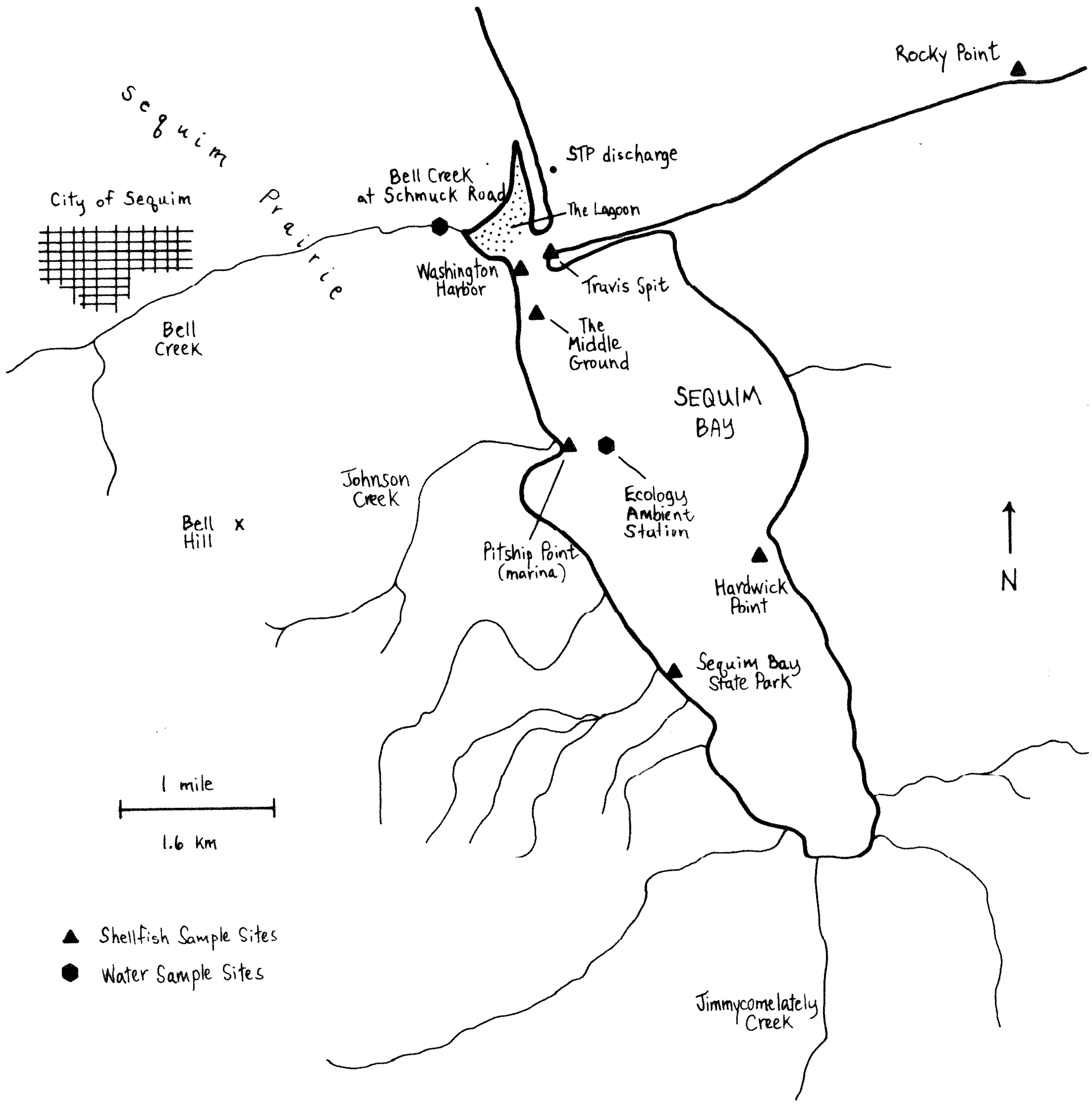


Figure 1. Sequim Bay, Washington, showing sampling sites for shellfish and water from October 1977 to July 1985.

Ground due to risk of waste dumping from passing boats (J. Lilja, Shellfish Protection Program, DSHS, personal communication). Prior to the closure the shoreline was not commercially harvested.

Similarly, a closure is in effect for the shoreline near Sequim Bay State Park. The park maintains 14 overnight boat berths and six mooring buoys (Washington State Parks and Recreation Commission, 1984). There are no pump-out facilities serving watercraft.

Both John Wayne Marina and Sequim Bay State Park treat and discharge domestic wastes on-site. John Wayne Marina operates a septic tank system with a drainfield. The maximum design flow is 6,000 gallons per day. However, the current flow is roughly half this. Sequim Bay State Park operates an aerated sewage lagoon. The chlorinated discharge from the park is intermittent, with a 35,000-gallon-per-day maximum sprayed on forest lands nearby.

Eleven streams flow from the surrounding watershed into Sequim Bay and The Lagoon north of the entrance. Ten of these drain land west and south of the bay. The east shore has the one remaining surface drainage. Most of the streams drain lightly developed subbasins. Some water quality information is available for Bell and Johnson Creeks.

Bell Creek flows through the town of Sequim. It collects irrigation return flows from farms and canals on Sequim Prairie. Flows are highly variable, with seasonal maxima during the summer (D. Carter and W. Bergstrom, SWRO, personal communication). Kennedy (1984) estimated 660 livestock graze near the mouth of Bell Creek.

Johnson Creek enters Sequim Bay at Pitship Point. The creek receives irrigation return flow from the Highland Ditch which passes along the northern side of Bell Hill (D. Carter, Ecology SWRO, personal communication). The area is presently sparsely settled. A residential development has been approved that is predicted to grow from an initial density of 88 five-acre tracts to about 480 lots. The development will be sewered, but residents near Highland Ditch have voiced concern about the effects of the development on water quality (Jimmycomelately Gazette, July 27, 1983).

The role of shoreline residences in contamination of nearshore waters is an issue elsewhere in Washington. A potential problem occurs when waste disposal systems are placed near the shoreline on soils that are only marginally capable of absorbing treated wastewater. In the future, shoreline residences may become a water quality issue in Sequim Bay. Kennedy (1984) conducted a survey of the Sequim Bay shoreline. Soils on Sequim Bay's western shore have highly variable absorption abilities. Southern soils are generally poor. The best soils are found on the east side. Nearly 188 buildings were surveyed. Four (possibly eight) substandard or failed systems were located. Forty-four percent of the surveyed systems were placed in high-risk areas (seasonal or continuously high water tables; flooding during extreme tides; or inadequate distance from bulkhead, stream bank, or waterway).

SOURCES OF INFORMATION

The sources of data or other information available from Sequim Bay are as follows:

1. Samples of littleneck clams, Protothaca staminea, have been taken twice monthly for total and fecal coliform analysis since October 1977 by the PPA (Battelle Pacific Northwest Laboratories 1978, 1979, 1981a, 1981b, 1982; Apts 1983 and 1985; Apts and Crecelius 1985; Apts and Elston 1985). The U.S. Army Corps of Engineers' permit to build John Wayne Marina (issued in July 1983) commits the PPA to continued monitoring through 1997.

   Shellfish samples are taken at six sites within Sequim Bay (Figure 1). An infrequently sampled control site is maintained at Rocky Point 5 km (3 miles) east-northeast of the entrance to Sequim Bay. Samples consist of 15 to 45 clams collected from the lower intertidal zone. The clams are rinsed free of beach sediments with seawater on site, sealed in sterile plastic bags, put on ice, and shipped to Amtest, Inc., Bellevue, WA. for analysis. The analytical method conforms to approved Food and Drug Administration (FDA) and DSHS procedures. Individual quarterly and annual reports (cited above) summarized data and interpreted results through use of arithmetic means and a "categorical" approach to be described later.

2. The PPA also has sampled quarterly for FC in water at four sites in John Wayne Marina since its opening. Three sites are located within the marina. A fourth is located at the mouth of Johnson Creek to the south. The creek mouth is separated from the marina basin by a breakwater made of dredge spoil and large boulders. However, the stream passes through marina property and is subject to the effects of some marina activity. Water samples are analyzed by Amtest, Inc. using methods described above.

3. Ecology has maintained ambient monitoring station JDF005 near Pitship Point since April 1977 (Figure 1). A surface sample is taken for analysis of FC in addition to physical/chemical parameters at the surface and 10 m depth. Samples are taken monthly except during the winter and when inclement weather precludes floatplane operations. Methods of analysis conform to APHA (1985). Data are stored in STORET, a data-analysis system operated by the U.S. Environmental Protection Agency.

4. The DSHS Shellfish Sanitation Program conducted intensive surveys in Sequim Bay in May 1978 and January/February 1980 to assure its acceptability as a shellfish-growing area. During each survey, samples of water and shellfish were taken at numerous sites around Sequim Bay and analyzed by the DSHS laboratory according to APHA (1970) (J. Lilja, Shellfish Sanitation Program, personal communication). Water samples were taken on ebb and flood tides. Hydrographic data (salinity, temperature) also were recorded. The data are available in raw form. On the basis of these surveys, commercial growing beds under production at the time were recertified. Time constraints did not permit the author to evaluate these data; however, they are available if others wish to do so.

5. The DSHS Shellfish Sanitation Program also conducted a shoreline survey during August through December 1984 to locate and evaluate actual and potential sources of pollution. Aspects of this study are found in Kennedy (1984).

6. The city of Sequim has collected water samples from Bell Creek (at Schmuck Road Bridge) twice a week since July 1985. Results are being used to prepare an environmental impact statement (Brown and Caldwell, in prep.) on the city's STP and discharge. Analyses were performed by the Clallam County Division of Environmental Health using APHA (1985) according to Roy Franklin (laboratory director, Clallam County Department of Community Development).

7. The city of Sequim holds a National Pollutant Discharge Elimination System (NPDES) permit for the STP discharge. FC samples of the chlorinated effluent are routinely gathered from the Sequim STP discharge line (Manhole 17A). FC densities are compared to limits imposed by the terms of the permit (200 FC per 100 mL, monthly average). Samples are dechlorinated with sodium thiosulphate (D. Parker, Sequim Department of Public Works, personal communication). Analyses are performed according to Guidelines Establishing Test Procedures for the Analysis of Pollutants (40 CFR 136, Federal Register, December 1, 1976). Data are kept in records maintained at the Ecology SWRO.

8. Sequim Bay State Park holds an Ecology permit for their treatment lagoon. In the past, the park was required to sample its effluent during peak-use periods for FC bacteria. However, this requirement has not been fulfilled. Data are, therefore, lacking. The recently renewed permit will be more rigorously enforced (D. Anderson, Ecology SWRO, personal communication).

METHODS AND RESULTS

The data collected by the PPA from 1977 to the present constitute the most extensive record available from Sequim Bay in terms of sampling consistency, length of record, and station coverage. For this reason, the raw data (Appendix) form the basis for analysis.

Some data collected from October through December 1978 contained values less than 20 FC per 100 gr MPN. However, AmTest, Inc. modified their analytical technique due to the wide range of coliform counts that occurred (Battelle PNW Labs, 1979). This raised the minimum detection limit from 2 to 20 MPN. Many of the samples taken since have had counts below the detection limit and were reported as <20 MPN. Battelle Labs substituted a "worst-case" value of 20 MPN to those samples since exact counts could not be attained. In 1985, counts below a minimum detection of 18 per 100 gr MPN were treated similarly (Appendix). In both cases, the author has done the same.

It may be possible to improve the rigor of statistical analyses by replacing below-limit values with estimators that fall below the minimum detection limit. Gleit (1985) tested several of these methods. The best estimator was derived by an iterative process using a computer. Although beyond the scope of the present work, such a procedure could be used in the future.

Figure 2 shows plots of individual data over the period of record to visualize possible trends at each station. The data are highly variable. Violations of the marketability standards seem sporadic and unpredictable. They are most frequent at Washington Harbor (Figure 2a) and least frequent at Hardwick Point (Figure 2f).

The relative importance of each site was determined by sorting all the data into three categories (Battelle Pacific NW Laboratories, 1978):

a. Results at or below the detection limits of the analysis (20 FC per 100 gr shellfish tissue MPN).

b. Detectable results falling within the limits for marketability set by the FDA and DSHS for shellfish (21 - 230 FC per 100 gr tissue MPN).

c. Results exceeding the marketability standard (230 FC per 100 gr tissue MPN).

The percentage of each category was calculated and bar graphs prepared. This "categorical" approach, used by Battelle Pacific Northwest Laboratories in each of their reports, was applied to the entire record.

Figure 3 shows the distribution of percentages of each category at each site. The sites are ranked (from left to right) according to degree of contamination. Washington Harbor and Travis Spit (on the opposite side of the entrance) are highest. Middle Ground shows evidence of being affected by sources located near the Sequim Bay entrance. Pitship Point is slightly higher than either Sequim Bay State Park or Hardwick Point. The results suggest that major sources are located at the mouth of Sequim Bay. A gradient of high to low exists from the entrance southward to the state park. Hardwick Point, on the east side, may be somewhat isolated from sites on the western shore by north/south tidally induced currents within the bay.

Variation in data collected during a year tends to cloud comparisons among several years. Seasonal factors such as rain-generated runoff from pastures or temperature-regulated filter-feeding rates may affect the concentration of FC in shellfish tissues at different times of the year. Variation caused by seasonal factors at each station was evaluated by sorting data from all years into monthly groups and treating it two ways. First, the percentage of results that exceeded the marketability standard (230 FC per 100 gr tissue MPN) was calculated and plotted. Next, a geometric mean (X) and an estimate of error (one standard deviation above and one below the geometric mean) was calculated for each monthly group. Comparisons were made between months. Generally, FC data are assumed to approximate a "log-normal distribution." This means that the distribution can be made close to normal after the data are converted to logarithms. This normalizing procedure was done for this study in order to increase the rigor of statistical tests. The geometric means and error estimates were calculated from the transformed data.

Figure 4 shows the percentage of samples that exceeded marketability standards at each station in each monthly group. Generally, the warmer months (May through September) seemed to have higher percentages of violation-level samples than at other times, especially at the more contaminated sites. On

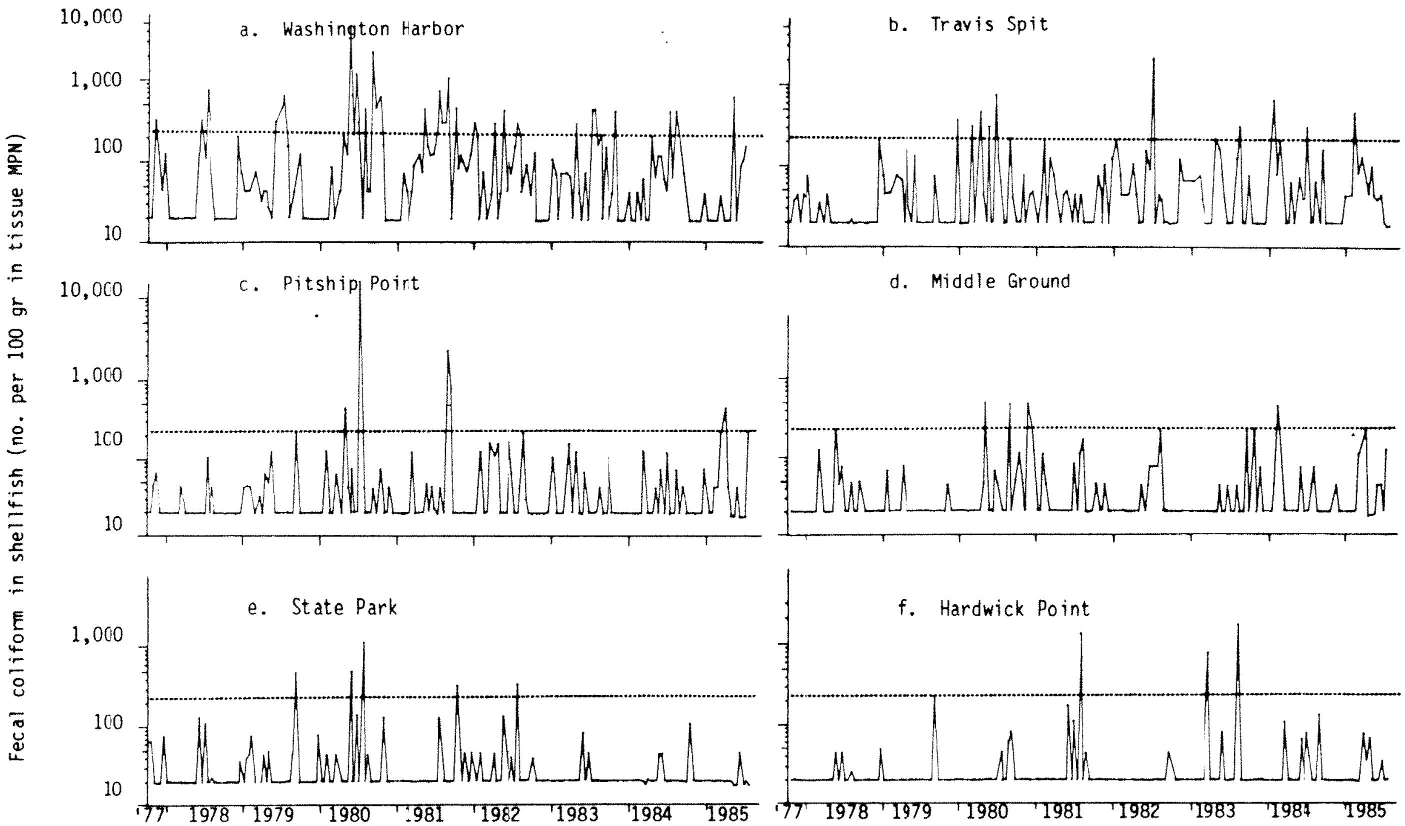


Figure 2. Fecal coliform concentrations in shellfish from October 1977 through July 1985 (horizontal dotted line represents FDA/DSHS shellfish marketability standard).

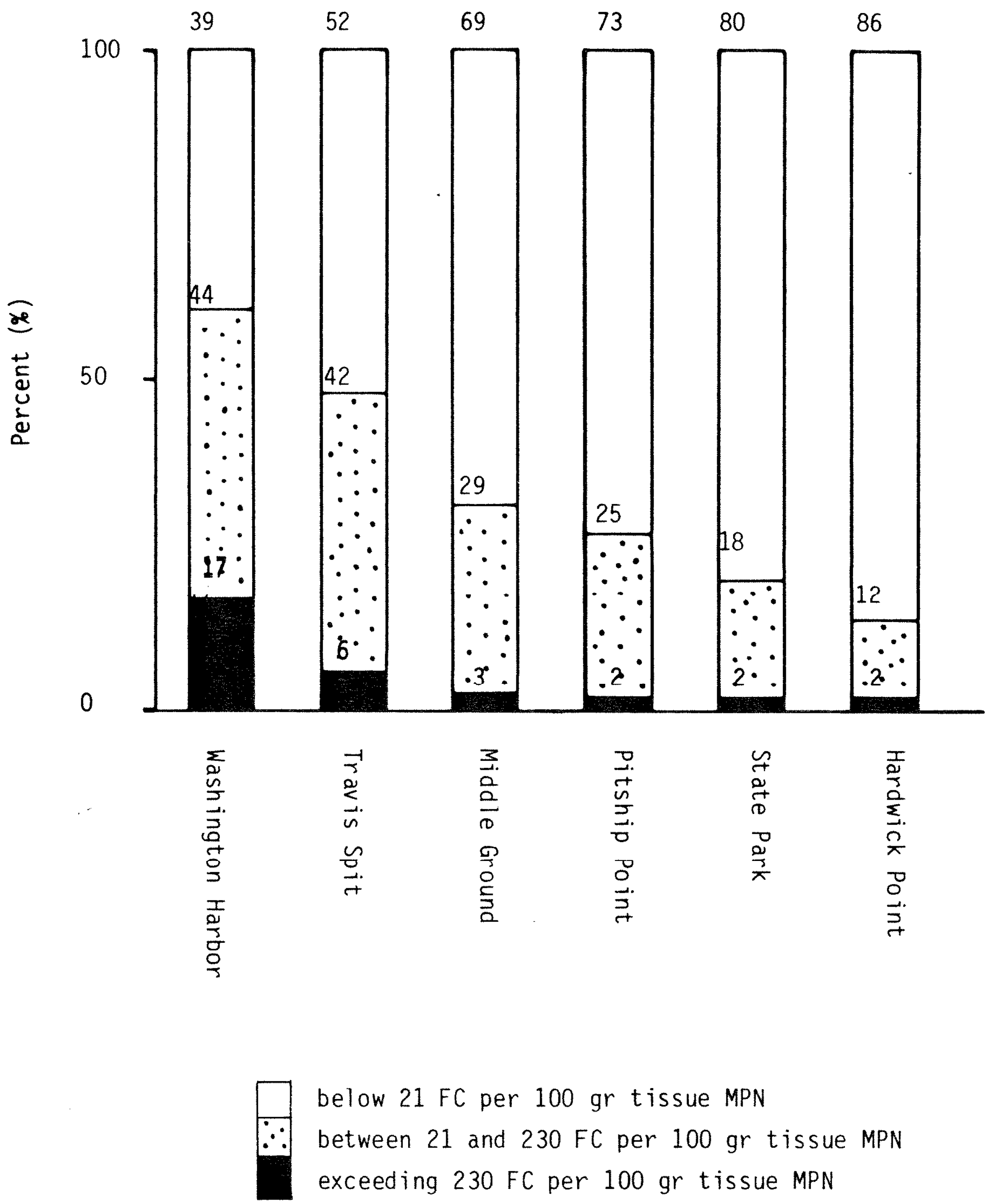
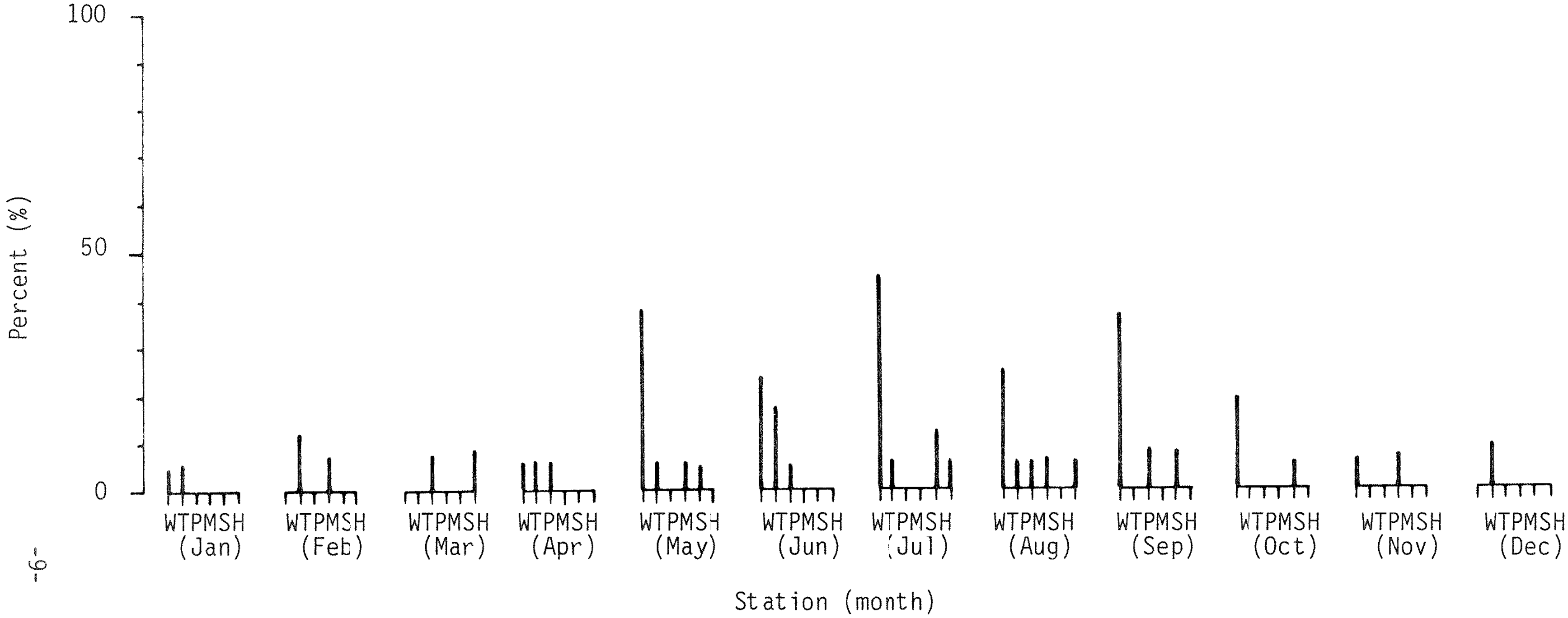


Figure 3. Percentage of shellfish samples in each of three categories of fecal coliform concentrations at Sequim Bay sites from October 1977 through July 1985.



W = Washington Harbor
T = Travis Spit
P = Pitship Point

M = Middle Ground
S = State Park
H = Hardwick Point

Figure 4. Percentage of shellfish samples exceeding the marketability standard (230 FC per 100 gr tissue MPN) at six Sequim Bay sites. The data for the entire study period were grouped by month .

the other hand, the ranks of most sites according to contamination seemed to change from month to month. Only Washington Harbor was consistently highest during the warm months.

Figure 5 shows monthly geometric means at each station for the period of record. Season appeared to be a factor at Washington Harbor. Geometric means tended to be higher in the summer months here than at other times.

The data used to calculate the means shown in Figure 5 contain values set at the minimum detection limit. These values replaced results that were less than the detection limit. Therefore, each monthly mean shown is somewhat higher than would have been true if a lower detection limit was possible and actual FC concentrations known. The difference between calculated and actual means would be related to the proportion of below-limit values in the data. Thus the difference would be least at Washington Harbor which had the least proportion of below-limit values (about 40 percent for the entire record), and greatest at Hardwick Point which had the greatest proportion (about 85 percent). The amount of difference is thus inversely related to the degre of contamination at each site. If the below-limit values were known accurately, seasonal patterns might have been more apparent at those sites with lower concentrations.

An estimate of the presence of a trend (an increase or a decrease over time) in FC levels in shellfish at each site was made by sorting the data into groups of calendar year. The data were treated as follows:

First, FC data from each site during each calendar year were sorted into the three categories of FC levels discussed earlier. Percentages of each category were calculated and plotted. The results are shown in Figure 6. Because of partial records, 1977 and 1985 were eliminated. At five of six sites, the highest number of violations occurred in 1980 (Hardwick Point excepted). Johnson Creek is the likely source of contamination at Pitship Point. The high percentage of violations in 1980-81 predates construction of the John Wayne Marina.

Second, based on Figure 6a, Washington Harbor appeared most likely to show a trend. However, a visual inspection of the graphs of monthly statistics (Figure 5a) suggested a significant seasonal component was present at Washington Harbor. For this reason, the data were deseasonalized. In order to "deseasonalize" the data, each month was assumed to represent a "season." Seasonal (monthly) means were determined as discussed previously. The overall mean for all observations also was calculated (log-transformed data were used in each case). The monthly mean was subtracted from each datum within each month and the difference was added to the overall mean. This produced a theoretical "deseasonalized" data point representing a single observation with the seasonal effects removed (Yake, 1979). The effects of this process are shown in Figure 7 for data from Washington Harbor.

The deseasonalized data from Washington Harbor were then subjected to statistical tests for significant trends of FC densities versus time. Individual sampling dates were converted to numbers of days that had passed since a beginning date arbitrarily set to January 1, 1977 (day number = 0). Two statistical tests were employed. Linear regression, a parametric test which

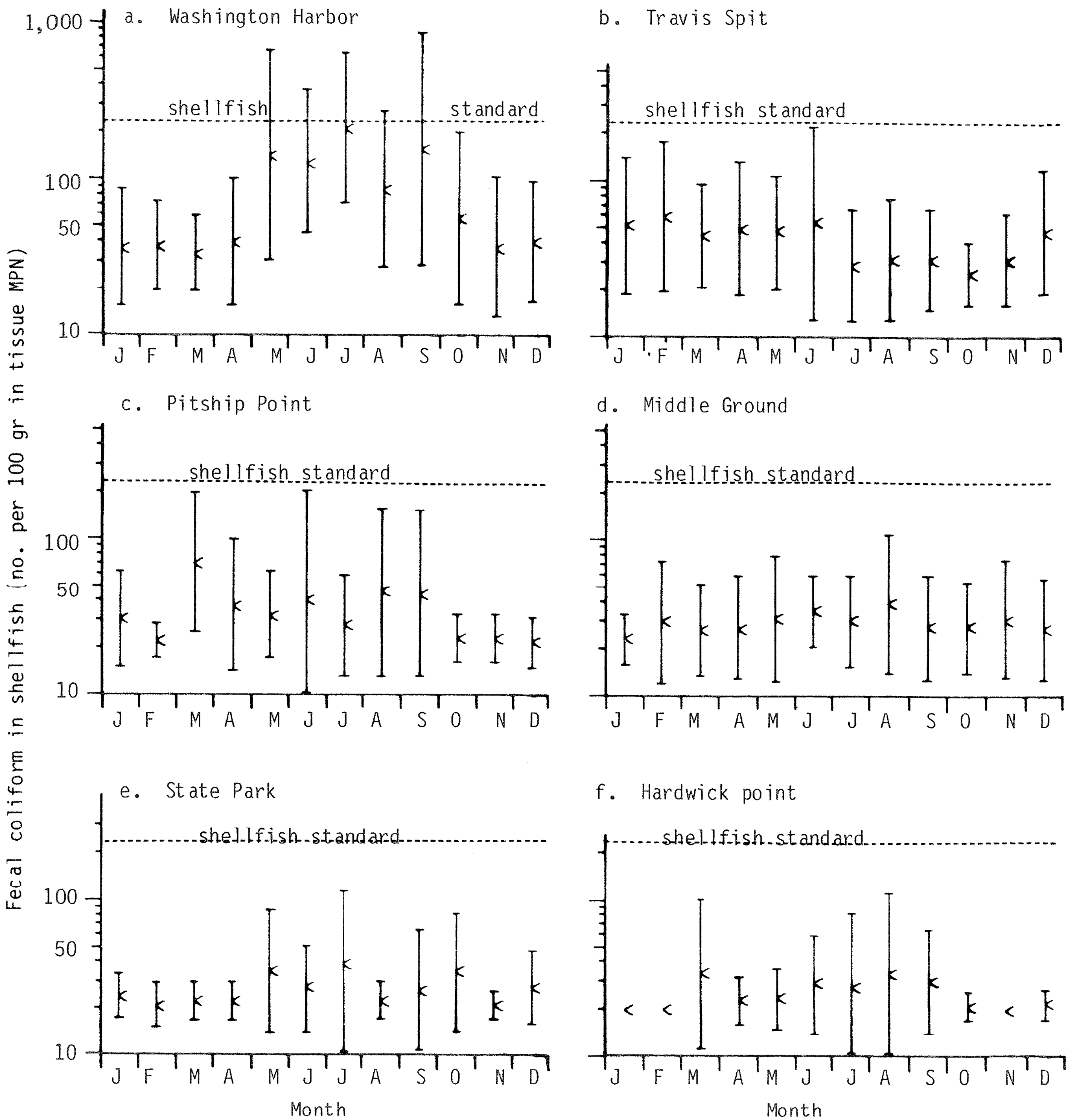


Figure 5. Monthly geometric means of fecal coliform concentrations in shellfish (± 1 standard deviation; log-transformed data) from six sites in Sequim Bay, Washington.

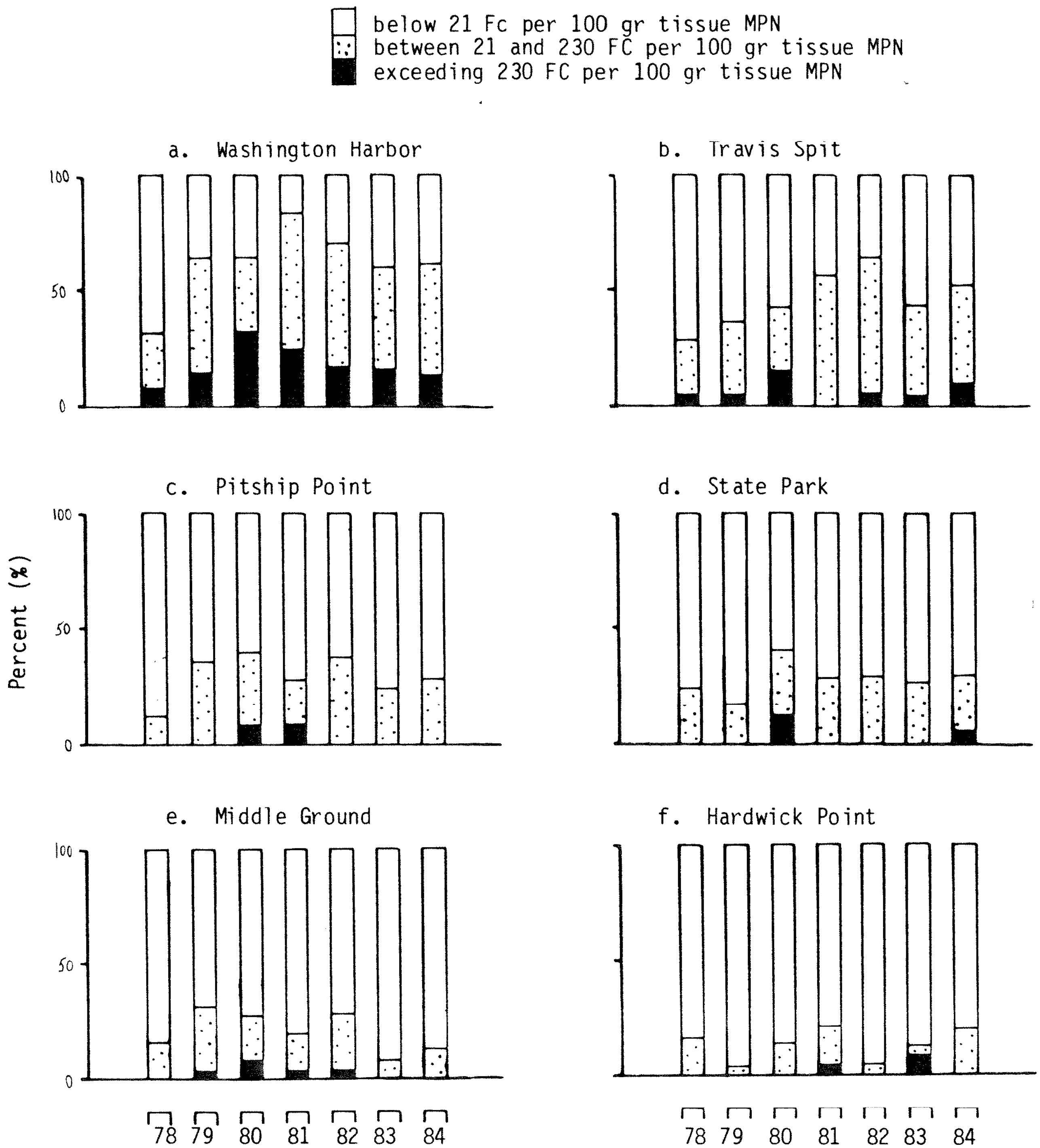


Figure 6. Trends in concentrations of fecal coliform in shellfish tissue at six Sequim Bay sites between January 1978 and December 1984.

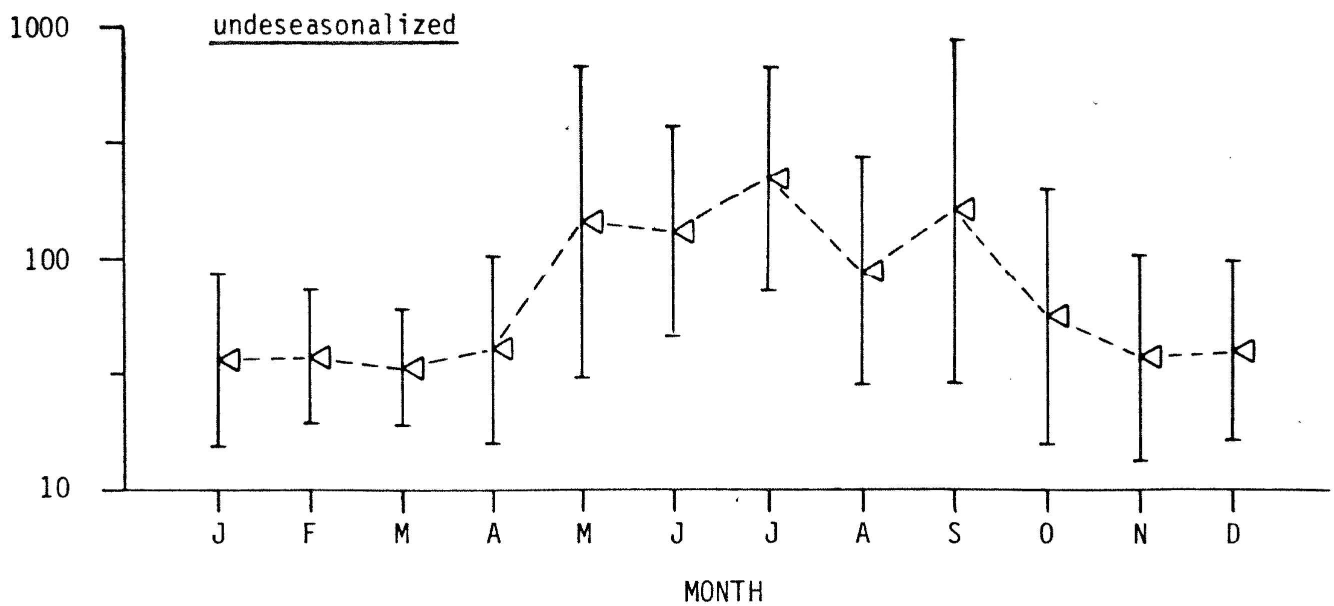


Figure 7. Comparison of monthly mean fecal coliform concentrations from Washington Harbor demonstrating the effects of deseasonalizing the data.

assumes data are normally distributed, and Kendall's Tau, a nonparametric test for correlation, were used (Sokal and Rohlf, 1969). The linear regression was calculated using REG-ANAL, a computer program developed by Dan Kruger, Ecology, in 1978.

Regression (trend) analysis for the entire period of record (1977 - 1985) at Washington Harbor showed the following relationship between the concentration of FC in shellfish (deseasonalized data) and time:

$$\log [FC] = (-2 \times 10^{-5})T + 1.85$$

where [FC] = concentration of FC in shellfish
and T = number of days since January 1, 1977

The quantity (-2×10^{-5}) is the slope of the equation and is very slight. The degree of correlation between FC and time is insignificant (r^2 = 0.001, n = 189).

Kendall's Tau was determined for the entire record (Tau = -0.059) and used to calculate Student's t to test the null hypothesis that there was no significant relationship between FC densities in shellfish and time. The null hypothesis was accepted ($t_s = -1.21$, p = 0.2262; Rohlf and Sokal, 1969). Thus, both regression analysis and Kendall's Tau reach the same conclusion; there is no significant trend in FC in shellfish when the entire period of sampling is considered.

Figure 6a suggests the percentage of Washington Harbor samples exceeding the marketability standard increased until 1980 and then decreased until the present. Regression analysis of the deseasonalized record during those periods was done.

1. From October 1977 through December 1980:

$$\log [FC] = (2.7 \times 10^{-4})T + 1.56; \quad (r^2 = 0.04, n = 78)$$

2. From January 1981 through July 1985:

$$\log [FC] = (-2.7 \times 10^{-4})T + 2.44; \quad (r^2 = 0.09, n = 111)$$

In both cases, the outcome is the same. This method shows no significant trend detectable in the data.

Kendall's Tau was then calculated for both parts of the record. There was no significant trend during the first half of the study (Tau = 0.103, t_s = -3.59, p = 0.0005). However, there proved to be a significant downward trend since January 1981 (Tau = 0.228, t_s = 3.59, p = 0.0005). The lack of provable trend in the first period may be due to relatively fewer data collected (n = 78) compared to the second (n = 111).

DISCUSSION

Sequim Bay is classified as AA marine water (WAC 173-201-085[21]) (Ecology, 1980). Clam, oyster, and mussel rearing, spawning and harvesting are included in the list of beneficial uses to be protected by this classification. Streams and creeks that drain the upland watersheds of these estuaries also are classed as AA because they are "tributaries" to class AA marine waters (WAC 173-201-070[6]-General Classifications). Class AA (Extraordinary) waters are given the highest level of protection in the state.

Numerical criteria for FC in Class AA (extraordinary) waters are as follows:

Part 1: Fecal coliforms are not to exceed a geometric mean of 14 FC per 100 mL (marine) or 50 FC per 100 mL (freshwater);

Part 2: Not more than 10 percent of samples are to exceed 43 FC per 100 mL (marine) or 100 FC per 100 mL (freshwater).

It is clear that shellfish beds in the vicinity of Washington Harbor are contaminated by one or more sources. To date, considerable attention has been directed toward Sequim STP as the most obvious source. Public concern about this issue has led to computer model study of alternative outfall sites (Elston, et al., 1983) and an EIS study (Brown and Caldwell Consulting Engineers, Inc., in prep.). However, the role of Bell Creek as a contamination component has received only recent attention.

Bell Creek FC data (M. Adolfson, Brown and Caldwell, personal communication) from 30 samples collected between July and October 1985 ranged from 133 to 13,700 FC per 100 mL with a geometric mean of 2,188 FC per 100 mL. All of the samples exceeded 100 FC per 100 mL. Thus, Bell Creek violated both parts of the water quality standard.

Bell Creek flow data were recorded at Schmuck Road at approximately monthly intervals from September 1978 through August 1980 (B.W. Drost, USGS, personal communication). The highest flow (11.1 cubic feet per second [cfs] or 7.2 million gallons per day [MGD]) occurred during heavy rains in January 1980. The minimum occurred in August 1979 (3.1 cfs or 2.0 MGD). From the data (four measurements) for July through October 1979, the streamflow averaged 5.4 cfs (3.5 MGD).

A review of NPDES records of Sequim STP during 1983-85 showed that 33 samples of STP effluent collected during the months of July through October had a geometric mean of 38 FC per 100 mL, ranging from 10 to 80 FC per 100 mL. During the same period, STP flows averaged 0.36 MGD. The highest flow during these months, 0.79 MGD, occurred on October 27, 1985.

Fecal coliform loads for each source were calculated using the method of Kittrell (1969):

$$\text{FC load (FC per day)} = [FC] \times Q \times (37.8 \times 10^6)$$

where [FC] = mean fecal coliform concentrations (FC per 100 mL)
and Q = mean flow (MGD)

Substituting the values for both fecal coliform concentrations and flows from each source in the equation, we have fecal coliform loads of 5.2×10^8 and 2.9×10^{11} FC per day for Sequim STP and Bell Creek, respectively. Thus, Bell Creek appears to exceed the STP load by over 500 times. It is not clear how much of the Bell Creek load enters Sequim Bay. During early rising tide, most of the stream flow is probably carried in. Later, marine water entering The Lagoon (north of Sequim Bay entrance) may confine and mix with Bell Creek discharge near its mouth. During the outgoing tide, mixed Bell Creek discharge could drain out of The Lagoon into open water beyond the entrance, undergo further mixing, and afterward enter Sequim Bay as a fraction of the incoming tidal flow.

Loads from the remaining streams discharging into Sequim Bay have not been measured. Thus the relative importance of each as a loading source cannot be assessed. An effort to establish a baseline for the streams is important in view of the potential for development in individual watersheds.

The limited data collected in John Wayne Marina waters and at the mouth of Johnson Creek suggest that the creek may be an important source of FC contaminating clams at Pitship Point. Data collected during the last year show marina waters complied fully with the marine water quality standard (geometric mean = 4 FC per 100 mL; one of 12 samples greater than 43 FC per 100 mL). Johnson Creek, however, violated Part 2 of the freshwater standard (geometric mean = 42 FC per 100 mL; 25 percent of four samples exceeded 200 FC per 100 mL).

Johnson Creek compliance with the water quality standard must be considered tentative for two reasons. First, the data are too limited at present. Second, the water quality standard is interpreted on the basis of the salinity of the sample (WAC 173-201-035):

> (2) In brackish waters of estuaries, where the fresh and marine water quality criteria differ within the same classification, . . . the marine water quality criteria shall apply . . . for fecal coliform organisms when the salinity is ten parts per thousand or greater.

Since Johnson Creek is sampled near its mouth, the sample may contain a fraction of marine water. In order to determine compliance with the standard, either the salinity must be measured on each sample or the sample should be collected upland out of tidal influence.

The choice of shellfish quality as an indicator of trends in pollution appears to be superior to using water quality data alone, despite the high degree of variation. At Pitship Point, localized contamination did not affect water quality at the Ecology ambient station JDF005 just offshore. The 62 samples collected since April 1977 had a geometric mean of 1.28 FC per 100 mL. The highest value, 7 FC per 100 mL, occurred in August 1978 and June 1981. The water quality at the sampling point complied fully with the marine water quality standard and gave no indication of contamination occurring nearby.

Agriculture plays a predominant role in land use in Sequim Bay watershed. Drost (1983) addressed the effects of land use on ground water. Further study is warranted to address the effects of irrigation returns on Johnson and Bell

Creeks. Agricultural activities have been partially related to decertification of several other important shellfish-growing areas (Jackson and Glendening, 1981 and 1982; Determan, et al., 1985). Mitigating measures are beyond the scope of this work, but information is available elsewhere (Jones and Stokes Assoc., Inc., 1984; McKamey, 1983 and 1984; URS Company, Inc., 1977; Ecology, 1979)

Kennedy (1984) estimated 44 percent of shoreline structures are located on high-risk soils. Although most of these systems appear to be working, increasing densities of shoreline residences and aging of existing septic systems may present problems later. Citizens should be encouraged to provide routine maintenance. A review of recent innovations in siting, building, and operating on-site sewage disposal systems might be timely (Jones and Stokes Assoc., Inc., 1984).

CONCLUSIONS

- Six shellfish-sampling sites showed a decreasing gradient of contamination from the entrance of Sequim Bay southward to Sequim Bay State Park. The east shoreline has the least contamination and is likely isolated by Sequim Bay circulation from the west.
- The two sites at the bay entrance (Washington Harbor and Travis Spit) showed the greatest contamination of shellfish, suggesting that the major sources of bacterial contamination are nearby. The sources have likely affected shellfish quality at Middle Ground.
- There was no significant trend in FC levels in shellfish at Washington Harbor when the entire period of sampling is considered. However, examination of the record since January 1981 shows some evidence of improvement. Trends were less likely at the other five sites.
- Seasonality probably plays a role at Washington Beach due to summertime irrigation return flows from Bell Creek. Seasonality seems to be less important at the other sites, but may be masked by the detection limit.
- Of the two major known sources of contamination affecting the northern end of Sequim Bay, Bell Creek load was estimated to be over 500 times greater than that of Sequim STP. However, the complexities of tidal mixing precluded an accurate estimate of Bell Creek's role in Sequim Bay contamination at this time. A more exact estimate should be made.
- To date, John Wayne Marina does not appear to have affected FC counts in shellfish at Pitship Point. Past contamination was likely caused by discharges from Johnson Creek prior to marina construction.
- The sampling of water at John Wayne Marina should be intensified, particularly during periods of heavy use. A sampling site should be placed on Johnson Creek well above both marina and tidal influence to assure complete separation from marina activities.
- Current knowledge in Sequim Bay is the result of concern over specific issues or sources. Considering the importance of the shellfish resource and the degree of watershed development slated for the future, an integrated area-wide baseline study should be considered. The study should address the stream and irrigation contributions during wet and dry weather. The study design should reflect the need for statistical rigor and repetition in the future.

REFERENCES

American Public Health Association, 1970. Recommended Procedures for the Examination of Seawater and Shellfish. 4th Ed., New York, NY.

American Public Health Association, 1985. Standard Methods for the Examination of Water and Wastewater. 16th Ed., Washington, D.C. 1268 pp.

Apts, C.W., 1983. A study of the effects of boat traffic on the levels of coliforms in littleneck clams, *Protothaca staminea*, in Sequim Bay. Port of Port Angeles. Port Angeles, WA.

Apts, C.W., 1985. Letter to D.G. Hendricks (Port of Port Angeles). Battelle PNW Laboratories, Sequim, WA. 1 pp.

Apts, C.W. and E.A. Crecelius, 1985, *ibid*.

Apts, C.W. and R.A. Elston, 1985, *ibid*.

Battelle Pacific Northwest Laboratories, 1978. A study of the effects of boat traffic on the levels of coliforms in Littleneck clams, *Protothaca staminea*, in Sequim Bay. Port of Port Angeles, Port Angeles, WA.

________________, 1979. A study of the effects of boat traffic on the levels of coliforms in Littleneck clams, *Protothaca staminea*, in Sequim Bay. Port of Port Angeles, Port Angeles, WA.

________________, 1981a. A study of the effects of boat traffic on the levels of coliforms in Littleneck clams, *Protothaca staminea*, in Sequim Bay. Port of Port Angeles, Port Angeles, WA.

________________, 1981b. A study of the effects of boat traffic on the levels of coliforms in Littleneck clams, *Protothaca staminea*, in Sequim Bay. Port of Port Angeles, Port Angeles, WA.

________________, 1982. A study of the effects of boat traffic on the levels of coliforms in Littleneck clams, *Protothaca staminea*, in Sequim Bay. Port of Port Angeles, Port Angeles, WA.

Brown and Caldwell, Consulting Engineers, in prep. Draft EIS on Wastewater Disposal Alternatives of the City of Sequim Wastewater Treatment Plant. for Clallam County.

Determan, T.A., B.M. Carey;, W.H. Chamberlain, and D.E. Norton, 1985. Sources Affecting the Sanitary Conditions of Water and Shellfish in Minter Bay and Burley Lagoon. Ecology Report No. 84-10. Wash. State Dept. Ecology, Olympia, WA. 186 pp.

Drost, B.W., 1983. Impact of Changes in Land Use on the Ground-water System in the Sequim-Dungeness Peninsula, Clallam County, Washington. Water Resources Investigations Report 83-4094. U.S. Geological Survey. Dept. of the Interior, Tacoma, WA. 61 pp.

Elston, R.A., E.A. Crecelius, Y. Onishi, and D.S. Trent, 1983. A Study of the Present and Alternative Sewage Outfall Locations for Sequim, Washington. Battelle Pacific Northwest Laboratories, Sequim, WA. 336 pp.

Gleit, A., 1985. Estimation for small normal data sets with detection limits. Environ. Sci. Technol. 19:1201-1206.

Jackson, J.E., Jr. and E.A. Glendening, 1981. Tillamook Bay Bacteria Study: Background Data Review Report. Oregon Dept. Environ. Qual., Portland, OR. 189 pp.

Jackson, J.E., Jr. and E.A. Glendening, 1982. Tillamook Bay Bacteria Study: Fecal Source Summary Report. Oregon Dept. Environ. Qual., Portland, OR. 116 pp.

Jones and Stokes Associates, Inc., 1984. Nonpoint Source Pollution Management: Alternatives Assessment for Burley and Minter Watersheds, Pierce and Kitsap Counties, Washington. Bellevue, WA. 104 pp.

Kennedy, J., 1984. Shoreline Survey of Sequim Bay, Clallam County. DSHS Shellfish Sanitation Program, Olympia, WA. 4 pp.

Kittrell, F.W., 1969. A Practical Guide to Water Quality Studies of Streams. U.S. Dept. of Interior/FWPCA CWR-5. Washington, D.C. 135 pp.

McKamey, B., 1983. Recommended Pollution Control Practices for Homeowners and Small Farm Operators. Kitsap/Pierce Co. Conserv. Dist., Puyallup, WA. 42 pp.

McKamey, B., 1984. Animal Keeping Practices in the Burley, Minter, and Purdy Watersheds of Kitsap and Pierce Counties. Kitsap/Pierce Co. Conserv. Dist., Puyallup, WA. 24 pp.

Rohlf, F.J. and R.R. Sokal, 1969. Statistical Tables. W.H. Freeman and Co., San Francisco, CA. 253 pp.

Saunders, R.S., 1984. Shellfish Protection Strategy. Wash. State Dept. of Ecology. Report No. 84-4. Olympia, WA. 38 pp.

Sokal, R.R. and F.J. Rohlf, 1969. Biometry. W.H. Freeman and Co., San Francisco, CA. 776 pp.

URS Co., Inc., 1977. Farm Water Quality Management Manual. Seattle, WA. 58 pp.

Washington State Department of Ecology, 1979. Management Practices for Irrigated Agriculture. 208 Irrigated Agriculture Water Quality Management Plan. Ecology Publ. No. 79-5B-1. Wash. State Dept. Printing, Olympia, WA.

Washington State Department of Ecology, 1980. Laws and Regulations; water pollution. Wash. St. Dept. Ecol., Olympia, WA.

Washington State Parks and Recreation Commission, 1984. Public Boating Facilities in Washington State. Olympia, WA. 43 pp.

Yake, W.E., 1979. Water Quality Trend Analysis--The Spokane River Basin. Project Report No. DOE-PR-6. Wash. Dept. of Ecology, Olympia, WA. 39 pp.

APPENDIX

Fecal coliform per 100 gms of clam tissue for the period 10-16-77 through 10-17-78 (adapted from Battelle PNW Laboratories, 1978).

Station	10-16-77	10-31-77	11-14-77	11-28-77	12-12-77	12-26-77	1-9-78	1-23-78	2-6-78	2-20-78	3-7-78	3-27-78	4-11-78	4-25-78	5-8-78	5-22-78	6-5-78	6-20-78	7-5-78	7-17-78	8-1-78	8-15-78	8-30-78	9-13-78	10-9-78	10-17-78
Battelle Beach	<20	330	220	45	130	40	<20	<20	20	<20	<20	<20	<20	<20	<20	130	330	110	790	78	33	<20	<20	<20	<20	<20
Travis Spit	20	37	45	<20	45	40	78	20	<20	<20	36	<20	45	<20	20	<20	20	20	330	20	22	<20	<20	<20	<20	<20
Middle Ground	<20	<20	<20	20	*	<20	<20	<20	<20	<20	130	<20	<20	<20	<20	230	45	78	<20	<20	49	<20	<20	49	<20	<20
Pitship Point	<20	45	68	<20	20	<20	<20	20	<20	<20	45	<20	20	<20	20	<20	<20	<20	110	20	46	<20	<20	<20	<20	<20
State Park	68	20	20	20	78	20	<20	<20	<20	<20	<20	<20	20	<20	<20	130	<20	110	<20	<20	22	<20	<20	<20	<20	<20
Nolan's Beach	<20	<20	<20	20	20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	45	<20	45	<20	<20	26	<20	<20	<20	<20	<20
Rocky Point																	20						20			

* Sample not collected due to weather conditions.

Fecal coliform per 100 gms of clam tissue for the period 10/31/78 through 6/26/79.*

	10/31/78	11/14/78	11/28/78	12/5/78	12/17/78	1/3/79	1/15/79	1/29/79	2/12/79
Battelle Beach	<2 [c]	4.5	4	220	79	45	45	45	a
Travis Spit	4	<2	2	70	49	78	20	45	<20
Middle Ground	6.1	6.8	6.8	17	2	<20	68	<20	a
Pitship Point	<2	11	<2	17	2	45	45	45	20
State Park	<2	<2	<2	2	46	20	40	45	78
Nolan's Beach	<2	9.2	<2	4	49	<20	20	20	<20
Rocky Point									

	2/26/79	3/21/79	4/3/79	4/17/79	4/30/79	5/15/79	5/29/79	6/12/79	6/26/79
Battelle Beach	78	33	45	45	27	20	330	b	490
Travis Spit	78	70	<20	170	33	<20	140	20	<20
Middle Ground	<20	<20	78	20	<20	20	<20	<20	20
Pitship Point	20	34	20	68	49	130	<20	<20	<20
State Park	20	<20	45	<20	49	20	<20	20	<20
Nolan's Beach	<20	<20	<20	<20	b	20	20	<20	<20
Rocky Point				45			<20	<20	

Fecal coliform per 100 gms of clam tissue for the period 7/10/79 through 10/22/79. *

	7/10/79	7/24/79	8/7/79	8/21/79	9/5/79	9/26/79	10/9/79	10/22/79
Battelle Beach	700	170	<20	45	a	130	<20	<20
Travis Spit	<20	<20	<20	<20	78	<20	<20	<20
Middle Ground	<20	<20	<20	20	<20	<20	<20	<20
Pitship Point	20	<20	<20	45	230	<20	<20	<20
State Park	20	<20	<20	45	490	20	<20	<20
Nolan's Beach	<20	<20	<20	<20	230	<20	<20	20
Rocky Point	20		<20					

a Samples not collected due to weather conditions.

b Samples not analyzed due to laboratory accidents at AmTest.

c All counts below 20 MPN were given a value of 20 for data analysis.

*Adapted from Battelle PNW Laboratories, 1979.

Fecal coliform per 100 gms of clam tissue (adapted from Battelle PNW Laboratories, 1981a).

SAMPLING DATES	Battelle Beach	Travis Spit	Middle Ground	Pitship Point	State Park	Nolan's Beach	Rocky Point
			STATIONS				
11/5/79	<20[1]	<20	45	<20	20	<20	
11/19/79	<20	<20	<20	<20	<20	20	
12/4/79	<20	<20	<20	<20	<20	<20	
12/17/79	20	490	45	20	78	<20	
1/2/80	<20	<20	<20	<20	<20	<20	
1/14/80	<20	<20	<20	<20	<20	<20	
1/28/80	<20	<20	20	130	45	-[2]	
2/12/80	<20	<20	<20	<20	<20	<20	
2/26/80	93	330	<20	<20	<20	20	
3/11/80	20	20	20	68	45	<20	
4/7/80	45	490	20	20	<20	<20	
4/21/80	230	45	45	460	20	20	
5/6/80	130	<20	490	45	<20	<20	
5/19/80	5,400	330	20	<20	490	20	
5/28/80	790	<20	<20	78	20	<20	
6/3/80	230	<20	<20	<20	20	20	
6/17/80	1,300	790	68	20	140	-[2]	
6/30/80	330	130	45	16,000	<20	20	130
7/24/80	20	<20	20	45	1,100	45	
7/30/80	490	<20	<20	<20	<20	<20	20
8/12/80	45	20	<20	<20	45	<20	
8/26/80	45	230	460	<20	20	61	
9/3/80	2,400	40	<20	45	<20	80	
9/22/80	490	<20	50	<20	20	<20	
10/14/80	630	20	110	78	<20	-[2]	
10/28/80	170	78	45	20	130	<20	

[1] Samples with counts <20 MPN were given a value of 20 for analysis.
[2] **No sample collected.**

Fecal coliform per 100 gms of clam tissue (Battelle PNW Laboratories, 1981b).

SAMPLING DATES	STATIONS Battelle Beach	Travis Spit	Middle Ground	Pitship Point	State Park	Nolan's Beach	Rocky Point
11/10/80	<20[1]	20	<20	<20	<20	<20	
11/20/80	20	45	490	45	<20	-[2]	
12/9/80	<20	50	230	<20	<20	20	
1/5/81	<20	<20	<20	20	20	20	
1/19/81	20	45	20	20	20	-[2]	
2/2/81	78	230	110	<20	<20	<20	
2/16/81	45	<20	45	20	<20	<20	
3/2/81	20	130	20	<20	<20	<20	
3/16/81	45	78	<20	130	<20	<20	
3/30/81	93	45	<20	<20	<20	<20	
4/21/81	130	20	<20	20	20	20	
5/5/81	78	45	<20	20	<20	20	
5/19/81	490	50	20	50	20	<20	
6/2/81	170	40	<20	20	20	170	
6/17/81	130	<20	<20	45	<20	<20	
6/30/81	130	45	83	23	20	110	130
7/15/81	230	20	20	<20	<20	<20	
7/28/81	790	45	110	45	130	1,300	
8/12/81	330	20	170	<20	<20	20	
8/26/81	330	20	20	2,400	<20	45	
9/9/81	1,100	<20	<20	790	<20	20	
9/23/81	20	<20	20	<20	<20	<20	
10/14/81	490	78	45	<20	330	45	
10/28/81	80	50	<20	<20	50	20	

[1] Samples with counts <20 MPN were given a value of 20 for data analysis.

[2] No samples collected.

Fecal coliform per 100 gms of clam tissue (Battelle PNW Laboratories, 1982).

SAMPLING DATES	Battelle Beach	Travis Spit	Middle Ground	Pitship Point	State Park	Nolan's Beach	Rocky Point
	STATIONS						
11/3/81	130	20	20	<20	<20	<20	
11/16/81	110	110	45	20	45	<20	
12/2/81	78	<20[1]	20	<20	20	<20	
12/16/81	130	130	<20	<20	45	<20	
1/11/82	330	220	20	<20	<20	<20	
1/25/82	220	78	–[2]	130	45	<20	
2/8/82	<20	45	20	20	<20	<20	
2/22/82	78	45	<20	<20	<20	<20	
3/8/82	20	45	<20	170	<20	–[3]	
3/30/82	45	110	20	110	45	20	
4/13/82	330	45	<20	170	<20	<20	
4/27/82	<20	20	<20	20	<20	<20	
5/11/82	45	20	45	20	130	<20	
5/25/82	490	170	<20	20	45	<20	
6/8/82	45	92	45	170	<20	20	
6/22/82	110	2,200	78	68	40	20	20
7/6/82	78	<20	78	20	<20	<20	
7/20/82	170	45	78	20	310	20	
8/3/82	330	40	220	45	<20	<20	
8/17/82	230	20	<20	220	<20	20	
8/31/82	45	20	<20	40	<20	20	
9/15/82	110	20	20	20	<20	45	
10/4/82	40	<20	20	<20	40	–[3]	
10/18/82	140	<20	20	<20	<20	<20	

[1]Samples with counts of <20 MPN were given a value of 20 MPN for data analysis.

[2]No sample collected due to weather.

[3]No samples collected due to technical difficulties.

Fecal coliform per 100 gms of clam tissue (Apts, 1983).

SAMPLING DATES	STATIONS Battelle Beach	Travis Spit	Middle Ground	Pitship Point	State Park	Nolan's Beach	Rocky Point
11/1/82	<20[1]	130	<20	20	<20	<20	
11/15/82	<20	68	<20	<20	<20	<20	
11/29/82	20	-[2]	-[2]	<20	<20	-[3]	
12/13/82	<20	-[2]	-[2]	<20	<20	<20	
1/3/83	<20	68	<20	110	<20	<20	
1/17/83	110	-[2]	-[2]	<20	<20	<20	
2/1/83	78	78	<20	20	<20	<20	
2/14/83	20	40	<20	<20	<20	<20	
2/28/83	78	20	<20	20	<20	-[3]	
3/21/83	78	<20	<20	170	<20	790	
4/4/83	70	<20	20	<20	<20	<20	
4/18/83	<20	230	<20	130	<20	<20	
5/3/83	330	170	20	<20	<20	20	
5/17/83	45	80	45	20	80	20	
5/31/83	<20	45	<20	70	<20	80	
6/14/83	80	20	<20	<20	45	20	
6/28/83	<20	<20	45	<20	20	<20	
7/12/83	490	<20	<20	<20	<20	<20	
7/26/83	490	130	<20	<20	<20	<20	
8/9/83	170	330	45	45	<20	1700	20
8/23/83	230	20	<20	<20	<20	<20	
9/6/83	<20	<20	<20	20	<20	20	
9/20/83	170	80	230	110	20	<20	
10/4/83	<20	<20	<20	20	<20	<20	
10/25/83	45	20	230	<20	<20	<20	

[1]Samples with counts of <20 MPN were given a value of 20 MPN for data analysis.

[2]No sample collected due to weather.

[3]No sample collected due to technical problems.

Fecal coliform per 100 gms of clam tissue (Apts and Elston, 1985).

SAMPLING DATES	STATIONS					
	Battelle Beach	Travis Spit	Middle Ground	Pitship Point	State Park	Nolan's Beach
11-7-83	460	20	20	<20[1]	<20	<20
11-21-83	<20	<20	78	<20	-[2]	20
12-5-83	<20	20	<20	<20	<20	<20
12-19-83	<20	-[2]	-[2]	<20	<20	<20
1-16-84	40	700	<20	<20	<20	<20
1-30-84	<20	78	45	<20	<20	<20
2-13-84	20	220	460	<20	<20	<20
2-27-84	45	-[2]	-[2]	<20	<20	<20
3-12-84	20	20	<20	130	18	110
3-21-84	68	<20	<20	<20	20	<20
4-3-84	<20	68	-[2]	<20	<20	<20
4-17-84	20	<20	20	<20	<20	<20
5-1-84	230	-[2]	-[2]	45	<20	<20
5-15-84	68	78	<20	20	45	<20
5-29-84	130	45	78	78	45	68
6-12-84	130	45	<20	20	<20	<20
6-26-84	68	330	<20	130	<20	78
7-10-84	45	18	20	20	<20	40
7-25-84	490	<20	45	<20	<20	<20
8-8-84	68	68	78	78	20	<20
8-22-84	460	<20	20	<20	<20	130
9-5-84	1100	170	<20	45	20	<20
9-25-84	78	<20	<20	<20	<20	<20
10-10-84	-[2]	<20	<20	<20	110	<20
10-24-84	<20	<20	<20	<20	<20	<20

[1]Samples with counts <20 MPN were given a value of 20 MPN for data analysis.

[2]No samples collected due to poor weather conditions or technical problems.

Fecal coliform per 100 gms of clam tissue (Apts, 1985).

SAMPLING DATES	Battelle Beach	Travis Spit	Middle Ground	Pitship Point	State Park	Nolan's Beach
	STATIONS					
11-7-84	20	-[1]	-	20	<20[2]	<20
11-27-84	-	-	45	-	<20	<20
12-5-84	<20	<20	<20	20	<20	<20
12-19-84	<20	45	<20	78	20	<20
1-8-85	45	-	-	<20	<20	<20
1-22-85	<20	45	20	<20	<20	<20

[1] No sample collected due to bad weather or technical problems.

[2] Samples with counts <20 MPN were given a value of 20 MPN for data analysis.

Fecal coliform per 100 gms of clam tissue.*

SAMPLING DATES	Battelle Beach	Travis Spit	Middle Ground	Pitship Point	State Park	Nolan's Beach	Dean's Beach	Johnson's Beach
	STATIONS							
2-5-85	<20[1]	490	20	45	<20	<20		
2-19-85	20	78	<20	45	<20	20		
3-5-85	20	140	110	230	<20	<20		
3-26-85	45	-[2]	-[2]	460	<20	78		
4-9-85	20	45	230	45	20	45	20	<20[3]
4-23-85	20	110	<18	18	20	68	45	

[1]Samples with counts <20 MPN were given a value of 20 MPN for data analysis.

[2]No samples collected due to poor weather conditions.

[3]Samples collected at Johnson's Beach were oysters.

*Taken from letter to D.R. Hendricks (Port of Port Angeles) by C.W. Apts (Battelle PNW Laboratories) mistakenly dated June 10, 1984.

Fecal coliform per 100 gms of clam tissue.**

SAMPLING DATES	Battelle Beach	Travis Spit	Middle Ground	Pitship Point	State Park	Nolan's Beach	Dean's Beach	Johnston's Beach
	STATIONS							
5-7-85	20	45	<18[1]	<18	<18	<18	45	<18[2]
5-21-85	700	40	<18	45	<18	20	<18	
6-4-85	20	45	45	<18	45	<18	45	
6-18-85	93	20	45	<18	18	45	45	<18
7-1-85	110	<18	20	<18	20	18	20	<18
7-15-85	170	18	130	230	<18	<18	<18	

[1]Samples with counts <18 MPN were given a value of 18 MPN for data analysis.

[2]Samples collected at Johnston's Beach were oysters.

**Apts and Crecelius (1985).