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Puget Sound Interim Studies

ECOLOGICAL AND DISEASE STUDIES OF DEMERSAL FISHES IN PUGET SOUND NEAR METRO-OPERATED SEWAGE TREATMENT PLANTS AND IN THE DUWAMISH RIVER

by

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INTRODUCTION

During 1975-76, the Fisheries Research Institute (FRI) conducted ecological and disease studies on the demersal fish in Puget Sound near METRO-operated sewage outfalls and in the Duwamish River. This study was conducted under the auspices of the METRO-funded Puget Sound Interim Studies (PSIS) program.

The ecological studies were divided into two separate programs: (1) An outfall study and (2) a Duwamish River study. The objectives of the outfall study were: (1) To investigate the effects of sewage effluent on demersal fish community structure, (2) to investigate the relationship between sewage outfalls and disease incidence and parasite infestation levels, and (3) to provide baseline data for the analysis of the effects of future sewage treatment procedures on demersal fishes. To satisfy these objectives, a sampling program was designed to collect data on species composition, distribution, and abundance as well as disease and parasite incidences in the vicinity of two METRO sewage outfalls (West Point and Alki Point facilities) and at a control site (Point Pully). This approach will allow comparisons between the outfall and control sites, as well as between-year comparisons at outfall sites where previous data exist (Moulton, et al., 1974; Miller, et al., 1975), and should permit an evaluation of the effects of sewage disposal on demersal fish community structure and "health".

The principal objective of the Duwamish River study was to provide data on the spatial and temporal distribution of tumor-bearing and parasitized flatfishes--in particular starry flounder. Additional data were gathered on the distribution and abundance of all non-flatfish species.

The purpose of the pathological portion of this investigation was to characterize the histopathological, microbiological, and physiological properties of the significant marine fish diseases associated with METRO sewage outfalls. In addition, attempts were made to identify the etiological agent of each disease.

METHODS AND MATERIALS

Ecological Studies

1. Outfall Study

1.1 Sampling Plan

The outfall study sampling program was conducted near METRO-operated sewage outfalls located at West Point and Alki Point, and at Point Pully which served as a control site (Fig. 1). Initiation of monthly sampling was originally scheduled for February 1975 at all three sites. However, because of contractual difficulties, gear problems, and site evaluation, a finalized sampling plan was not in full operation until June. Prior to June, irregular sampling was conducted at each site with all gear types; these data are included in this report.

Beach seine operations were initiated in February 1975 on the south-facing beaches at West Point and Point Pully, and in April at Alki Point. Immediate sampling problems were encountered with the 37-m beach seine which necessitated shifting our sampling to the north beaches at West Point and Alki Point. In the case of West Point, this move seemed justified since studies by the Applied Physics Laboratory (1975) and Evan-Hamilton, Inc. (1974), had shown that effluent from the outfall reached both the north and the south beaches. No difficulties were encountered at Point Pully and all subsequent sampling was conducted on the south beach.

Otter trawl sampling was initiated in March 1975 at West Point and in April at Alki Point and Point Pully. All sampling was originally confined to the south side of each point; however, after changing the West Point beach seine site to the north beach, it was also decided to shift the otter trawling to the north shore. Since the Alki Point outfall is relatively small and the sphere of its influence not clear, it seemed wise to continue otter trawling on the south shore where the outfall was located and where previous sampling had been conducted (Moulton, et al., 1974).

The finalized sampling plan for the outfall study involved beach seining (37-m and 9-m nets) and otter trawling at all sites once each month. At West Point all sampling was confined to the north shore and beach (Fig. 2) except for 9-m beach seine samples which were also taken on the south beach. At Alki Point, all otter trawling was conducted on the south shore, and all beach seine operations were confined to the north beach (Fig. 3). At Point Pully, all sampling was exclusively confined to the south shore and beach (Fig. 4).

1.2 Sampling Gear and Methods

1.2.1 Beach Seine

Three different types of beach seine were used for sampling shoreline fishes in the sand and sand/eelgrass habitats which characterized the beaches at all three sampling sites. All beach seine operations were conducted during the lowest tidal series each month and included sampling with all three types of gear. A 9-m beach seine was used for sampling in shallow water less than one meter deep. This net has 9-mm mesh in the wings, a 6-mm mesh bag, and is fished with a 6.5-m check cord which serves to maintain a constant mouth opening. The 9-m net was set perpendicular to the beach and was pulled parallel to shore for a distance of 30 m. Generally, three to five replicates were made if time permitted. Although this small net sampled only a narrow strip of beach near the water line, it was extremely effective at capturing newly metamorphosed and juvenile flatfishes as well as small eelgrass-associated species.

Two 37-m beach seines were used for sampling the bottom and surface waters of the shoreline zone out to a distance of 30 m. Both 37-m nets have 18-m wings of 29-mm mesh and a 0.6m x 2.4m x 2.3m bag lined with 6-mm mesh. One net was equipped with seven floats and thus served as a floating net which sampled the surface water layer of the shoreline zone. The other 37-m net was a sinking net which sampled the bottom of the same region fished by the floating net. The nets were set in an identical manner and replicates were taken if time permitted and catches were not too large. The 37-m nets were set parallel to shore at a distance of 30 m using a small skiff, and were retrieved at a rate of about 10 m/min. Lines attached to poles at the end of each wing were initially retrieved from a distance of 40 m apart. After 20 m of line had been retrieved, the net opening was closed to approximately 12 m and final retrieval of the net was completed. The 37-m nets sampled a more extensive area than the 9-m net; and at West Point and Point Pully, they sampled an area that was contiguous with the shallow water (5-m) otter trawl station.

Because of extensive eelgrass beds at Alki Point, the 37-m sinking and floating nets could not be properly used. Experimentation (with diving observations) showed that the net worked satisfactorily when three floats were attached just above the bag; consequently, this method was adopted.

All specimens collected were bagged by haul, held on ice, and returned to the laboratory for further processing.

1.2.2 Otter Trawl

A 5-m (footrope) otter trawl was used to sample demersal fishes at depths of 5, 25, 45, 70, and 95 m, at West Point and Point Pully, and 5, 45, and 70 m at Alki Point. Replicate 5-min tows were made at each depth. In some months, replicate series of four to seven tows were made at a particular depth in order to investigate the reliability of our sampling. Catches were bagged separately by haul, placed on ice, and returned to the laboratory for processing.

1.2.3 Drop Net

An important microhabitat for fishes in the study areas is eelgrass (*Zostera marina*). For the most part, eelgrass-associated fishes have not been carefully studied as a group in Puget Sound. Therefore, a 3m x 3m drop net patterned after one used by Adams (1974) was developed for sampling fishes closely associated with eelgrass beds. This net was used at Alki Point from March 1976 to January 1977.

1.2.4 Twenty-Four Hour Studies

At West Point, seasonal (quarterly) 24-hour studies were conducted (November 1975, and February, May, August, and November 1976). During each 24-hour study period, samples were taken with the 37-m beach seine, 5-m otter trawl, and a 46-m trammel net. A series of beach seine and otter trawl hauls was made every four hours, and two trammel nets were set and retrieved at dusk and dawn. Sampling of this nature enabled us to investigate: (1) Diel changes in the distribution of individual species near the METRO outfall, and (2) the influx of larger predatory fishes (e.g., cod, hake, and dogfish) which were not captured during normal daytime sampling.

1.3 Field Collection Information

For all types of sampling, the location, date, time, weather conditions, tidal height, and other relevant environmental data were recorded in the field. Water samples for dissolved oxygen and salinity were taken during beach seining and trawling operations each month. Water samples taken during beach seining were from shallow water less than 1.5 m deep. During trawling operations, bottom water samples were taken at depths of 5 m, 45 m, and 95 m. In addition, bathythermograph tracings were made at the 45-m and 95-m depths. All salinity and dissolved oxygen determinations were made by the METRO water quality laboratory. All physical-chemical and environmental data were recorded and stored for manipulation by computer.

1.4 Laboratory Processing

Laboratory catch processing included identification; enumeration by species; external sexing whenever possible; and examination for tumors, external nematode parasites, fin erosion, and other abnormalities. Total lengths to the nearest millimeter and total weights to the nearest 0.1 g were taken for all specimens. Individuals from all species, with emphasis on the flatfishes, were preserved for later stomach analysis. Otoliths were removed from English sole, rock sole, and C-O sole in order to study growth rates. In addition, otoliths were removed from several other species in order to gather general life history information. All biological data were stored on magnetic tape for computer data manipulation.

1.5 Analysis

1.5.1 Recurrent Group Analysis

Recurrent group analysis is a technique developed by Fager (1957) which can be useful in identifying groups of species frequently occurring together. The technique has been employed with some success in the analysis of fish assemblages, zooplankton groups, terrestrial invertebrates, and fossil assemblages.

The analysis is performed in the following manner (after Fager, 1963). Given a set of (N) samples consisting of the occurrences of (P) species, an index of affinity is computed for each species pair using the formula:

$$\text{I.A.} = (J/N_a \cdot N_b)^{1/2} - 1/2(N_b)^{1/2}$$

where J = the number of joint occurrences

N_a = the total number of occurrences of species A

N_b = the total number of occurrences of species B

This index of affinity is the geometric mean of the proportion of joint occurrences, corrected for sample size. Once indices of affinity have been computed for each pair of species, recurrent groups are constructed according to the following set of requirements (i.e., rules):

(a) All group members occur with one another at some predetermined level of affinity (generally, I.A. = 0.5).

(b) Each group formed includes the greatest number of possible species.

(c) If several groups with the same number of members are possible, then those groups are selected which will give the greatest number of groups without members in common.

(d) If two or more groups with the same number of species and with members in common are possible, the one which occurs as a unit in the greatest number of samples is chosen.

The requirements are taken in order, such that groups fulfilling requirements (a) and (b) are determined first, and then if several alternatives exist, a choice is made by invoking requirements (c) and (d).

1.5.2 Numerical Classification

Classification (normal and inverse) techniques begin with some form of an inter-entity distance matrix. Entities are the units which are to be classified, whereas attributes are the basis for comparison between entities in the computation of inter-entity distances. The so-called inter-entity distance matrix contains all possible calculated distances between pairs of entities. The inter-entity distances may be interpreted as actual physical distances between entities in a p-dimensional coordinate system, where the attributes represent the axes or coordinates and the entities are located in the p-dimensional hyperspace according to their attribute scores. This convenient geometric model serves both for the non-statistical technique of numerical classification (i.e., cluster analysis) as well as for multivariate procedures such as principal components and discriminant analysis.

The three principal types of distance measures used with meristic data (i.e., quantitative) are the Euclidean, Bray-Curtis, and Canberra-metric indices. In this study, the Bray-Curtis index was employed:

$$D_{ij} = \frac{\sum_{k=1}^{n} |X_{ki} - X_{kj}|}{\sum_{k=1}^{n} (X_{ki} + X_{kj})}$$

where D_{ij} = distance between entities i and j

X_{ki} = values of attribute k in entity i

X_{kj} = values of attribute k in entity j

The multi-dimensional relationships between entities are generally displayed in the form of a two-dimensional dendrogram. The actual process of fusing entities and groups of entities with single entities is termed a clustering or sorting strategy. According to Clifford and Stephenson

(1975), there are eight strategies which may be used with any index of dissimilarity. Lance and Williams (1966) have generalized several of these strategies into a single system. The most commonly used strategies in recent marine ecological literature are the group-averaging and flexible techniques. Group averaging was the strategy employed in this study.

With the group averaging method, the distance (D) between groups of entities and single entities or between two groups of entities is given by:

$$D_{hk} = \frac{n_i}{n_K} D_{hi} + \frac{n_j}{n_K} D_{hj}$$

where D_{hk} = distance between groups h and k; where group k is a newly fused group comprising the original groups i and j.

D_{hi} = distance between groups h and i.

D_{hj} = distance between groups h and j.

n_i, n_j, and n_k = number of entities in groups i, j, and k, respectively.

1.5.3 Diversity and Species Richness

The diversity index used throughout this study was the Shannon-Wiener index (H):

$$H = - \sum_{n=1}^{s} P_i \log_e P_i$$

where $P_i = n_{i/N}$

N = total number of individuals

n_i = number of individuals in species i

s = total number of species

This index increases in magnitude when either the number of species increases or the distribution of individuals among the species becomes more even. In contrast, the index decreases when the number of species decreases or a few species dominate the total number of individuals.

Use of the term species richness throughout this report refers simply to the total number of different species occurring in a sample or sample period.

2. Duwamish River Study

2.1 Study Site, Sampling Gear, and Methods

Sampling conducted in the Duwamish River during 1975 represented the continuation of a study initiated during 1974 (Miller, et al., 1975). Monthly samples of demersal fishes were obtained at each of eight stations located in the lower river (Fig. 5). Single 5-min tows were made at each station using a 5-m (footrope) otter trawl outfitted with 6-mm cod end mesh lining. Each haul was bagged separately, held on ice, and later returned to the laboratory for further processing.

2.2 Laboratory Processing

Laboratory processing involved identification and enumeration of all individuals collected. External determination of sex was made whenever possible. Total lengths were taken to the nearest millimeter for all fishes. Total weights were taken to the nearest 0.1 g for flatfish species only. All fish were carefully examined for tumors, fin erosion, and external nematodes. In addition, otoliths were removed from approximately 50 "normal" starry flounder and all externally diseased (i.e., fish with fin erosion and/or tumors) starry flounder in order to determine growth rates for normal and diseased individuals residing in the river. All data were compiled and stored on magnetic tape for computer retrieval.

Pathology Studies

Specimens from normal and diseased fish were obtained and returned to the laboratory for further analysis. The specimens included live and/or freshly dead fish, fish blood, fish tissue, and microbial isolates.

1. Histopathology

For histopathological examination of a diseased fish, the fish was photographed, autopsied, and all abnormalities recorded. The diseased tissue and major internal organs were preserved in either 10% formalin in phosphate buffered saline, or Bouin's fixative. Paraffin-embedded or frozen tissue was sectioned with a microtome, and the sections were stained by a variety of methods including hemotoxylin and eosin, Oil-Red-O, Gomori's iron reaction, Masson's trichrome method, Armed Forces Institute of Pathology lipofuscin stain, and May-Grunwald-Giemsa.

2. Microbiology

Microbiological procedures were designed to isolate disease-associated bacteria, fungi, and viruses, and to determine total bacterial "loads" of fish from various areas. Bacteria and fungi were isolated from the surface of diseased animals using a sterile cotton swab and storing the used swab in a tube containing sea water with 0.5% peptone kept at 0°C until returned to the laboratory 4 to 8 hours later. The swabs were agitated in the storage medium in order to remove most of the attached microorganisms, an aliquot of this medium was diluted with an appropriate volume of seawater-peptone, and 0.05 ml of the suspension was spread on the surface of agar medium in a petri dish. Types of agar media employed were Trypicase Say Agar (TSA), Ordal's Seawater Cytophaga Agar (OSCA), Brain Heart Infusion Agar, and Potato Dextrose Agar with penicillin and streptomycin (for growth of fungi). When bacterial colonies had formed, representative ones were picked, colony purified, and stored in tubes containing OSCA.

Because preliminary attempts to isolate fungi from marine fish yielded very few fungal cultures, efforts to isolate and characterize fungi were terminated.

Virus isolation procedures involved preparing homogenates of fresh and/or frozen-and-thawed diseased tissue, and inoculating fish cell cultures with filtered or unfiltered homogenates. Cell cultures used included explant cultures of English sole fin tissue, a cell line derived from an epidermal papilloma from an English sole, and a cell line derived from chinook salmon embryonic tissue. Following their inoculation, cultures were periodically examined for cellular changes.

Determinations of total surface-associated bacteria were performed by aseptically excising a 1 cm^2 piece of skin from either a starry flounder or an English sole, and placing the skin into a tube containing 10 ml of seawater-peptone and 1 cm^3 of sterile, acid washed sand. The tube was stored at 0°C until returned to the laboratory 4 to 8 hours later. The tubes were shaken vigorously, an aliquot of the medium was serially diluted, and appropriate dilutions were spread on the surface of the TSA and OSCA-containing petri dishes with a sterile glass "rake". The total number of bacteria per 1 cm^2 of skin was calculated as follows:

$$\text{Bacteria/cm}^2 = (\text{Reciprocal of dilution})(\text{Bacterial colonies/dish})$$

Fish used for these determinations were taken from the otter trawl net as soon as it was brought aboard in order to reduce the amount of surface-to-surface contact between fish.

3. Fin Erosion Induction

Attempts to induce fin erosion were initiated by exposing English sole and starry flounder to Duwamish River bottom sediment. Normal-appearing experimental fish were captured near the Nisqually River and held in four 80-gallon flow-through seawater aquaria at METRO's West Point facilities. Bottom sediment was obtained from the Duwamish River near the 16th Avenue Bridge with a grab. Control bottom sediment was taken from McCalister Creek. Two aquaria received Duwamish River sediment and two had McCalister Creek sediment. Between 10 and 15 flatfish were kept in each aquarium. The fish were fed weekly and examined individually for disease signs once a week.

4. Chemical Analysis

Chemical analyses of normal and diseased fish were performed in cooperation with other individuals, agencies, and private laboratories. Blood serum samples were analyzed for 14 compounds and enzymes by Scientia Laboratories, Seattle, Washington. Fish tissues were analyzed for PCBs, DDTs, and heavy metals by the Southern California Coastal Water Research Project (SCCWRP), El Segundo, California.

5. Liver Abnormalities

In order to characterize liver abnormalities in Duwamish River starry flounder and English sole, it was necessary to estimate the prevalence of this condition in addition to establishing its histopathological properties. Random samples of 10 to 50 fish of both species from the Duwamish River, and West Point and Alki Point, were weighed, and the livers were examined for gross pathology, excised, weighed, and in most cases examined histologically. The liver-somatic index (liver weight/body weight x 100) was calculated for each fish in order to determine if livers with pathology also had a greater mass. Control sampling sites for the liver study were McCalister Creek for starry flounder and Point Pully for English sole.

RESULTS

Ecological Studies

1. Outfall Study

1.1 1975-76 Investigations

1.1.1 Environmental Data

Surface temperature at the beach seining sites was lowest between fall and early spring, increased through late spring and early summer, and then decreased during late summer and early fall (Fig. 6). Surface temperatures were highest in July at Point Pully and Alki Point. A very low July surface value (10.5°C) at West Point was omitted because it was believed to be an instrument or reading error. At 5 m, temperature at all three sites was highest in July and remained relatively high through October before declining late in fall (Fig. 6). Bottom temperature at all three sites followed quite similar patterns at both 45 m and 95 m (Fig. 7). Temperature was highest in June and remained relatively high until late fall.

Salinity patterns at the beach seine sites were similar to those at the 5-m trawl depth (Fig. 6). Salinity was lowest in early summer and late fall because of highest freshwater runoff. At 5 m the salinity at West Point was quite variable compared to the other two sites. Salinity fluctuated less at 45 m and 95 m than at the shallower stations (Fig. 7). At 45 m and 95 m, the salinity was slightly higher in summer and fall and lowest in the winter and spring.

Surface water at the beach seine sites was supersaturated with oxygen from March through September and remained relatively high throughout the year (Fig. 6). The percent saturation of dissolved oxygen was relatively high throughout the year at all bottom sampling sites (Figs. 6 and 7). In general, oxygen content was lowest in late summer and fall and highest in spring.

1.1.2 Fish Populations

Species Composition, Distribution, and Frequency of Occurrence. A combined total of 87 species comprising 62,858 individuals was collected at West Point, Alki Point, and Point Pully during 1975-76 (Tables 1, 2, and 3). The majority of species (60/87) occurred at all sites, yet there were significant differences in the abundance of several species between sites. No species of substantial abundance was confined to or absent from any of the sites. At each site the majority of species and individuals were taken with beach seine (principally the 37-m net) rather than trawling gear. The ten most abundant species taken with beach seine gear generally accounted for well over 90% of the total beach seine catch at each location (Tables 4, 5, and 6). Similarly, the ten most abundant trawl-caught species composed most (70-90%) of the otter trawl catch at each site.

Generally, few of the total number of species taken with either gear type occurred on a frequent ($\geq$ 70% of samples) basis. Only 11 beach seine captured species occurred frequently, with the lowest number at West Point (3) and the highest number at Alki Point (11). The only species to occur frequently at all three study sites were staghorn sculpin, rock sole, and English sole. Even fewer species (8) were frequently captured with otter trawl gear. The lowest number occurred at West Point (3), while six occurred at both Alki Point and Point Pully. Ratfish, rock sole, and

English sole were the only three trawl-caught species to occur frequently at each site. Although many species occurred commonly (30-70% of samples) at all three sites, the majority of species occurred only rarely and in low numbers.

Annual Cycles of Abundance, Species Richness, and Diversity

Beach Seine (37-m Net). The annual cycles of abundance (catch per haul = CPH), species richness (SR), and Shannon-Wiener diversity (H) are presented in Fig. 8. At each site the lowest values for CPH and SR occurred during the late winter and early spring (March and April). At Alki Point and Point Pully, CPH and SR increased during the spring and early summer, declined in late summer, and then increased again through the fall. The annual patterns of CPH and SR at West Point, however, were somewhat different. In contrast to the other two locations, only a single peak for CPH and SR was observed. CPH increased slowly during spring and summer, and then rose abruptly in fall (October-December) to the annual maximum. As at the other two sites, SR increased in spring and peaked in summer. However, thereafter the SR declined through the remainder of the year.

Shannon-Wiener diversity (H) at all three sites exhibited an annual cycle which was just the reverse of that observed for CPH. In general, H was highest in late spring, declined during the summer, and then increased again in fall and early winter.

Otter Trawl. The seasonal and bathymetric patterns of total abundance (CPH), species richness (SR), and Shannon-Wiener diversity (H) for each site are presented in Fig. 9. In general, the seasonal bathymetric patterns for CPH were quite similar at each site, although there were differences in absolute abundance. The most striking feature was that CPH was highest at 45 m during fall and winter and highest at 5 m during the late spring and summer. This bathymetric shift to shallower water in spring and summer was primarily due to an onshore movement of adult English and rock sole.

A similar but less distinct seasonal pattern was observed at each site for SR. As for CPH, the SR increased during spring and summer at 5 m; however, the decline at 45 m during this period was less pronounced. Although several species moved into shallower water in the spring and summer, a substantial portion of the increase in SR, at least at Alki Point and Point Pully, was due to an increase in the number of nearshore species normally associated with eelgrass or kelp.

Generally, Shannon-Wiener diversity (H) reflected the patterns observed for CPH and SR. During the summer and early fall, H was highest at 5 m and during the winter H was highest at 45 m.

Annual Cycles of Abundance of Dominant Species

Beach Seine (37-m Net). The monthly abundance (CPH) for the most abundant and frequently occurring species at each site is shown in Tables 7, 8, and 9. In general, species were either most abundant during the spring and summer or during the fall. The abundance of all species declined markedly during winter (January-March). Surfperch, rock sole, and C-O sole were the species that were most abundant during the spring and summer at all sites. Striped perch were not very abundant at West Point; however, the annual cycles of abundance for this species at Alki Point and Point Pully were quite similar. Shiner perch were abundant at Alki Point and Point Pully during the summer, but not at West Point. During the fall, shiner perch, tomcod, tubesnout, English sole, padded sculpin, and staghorn sculpin were the most abundant species. Padded sculpin and tubesnout were abundant in the fall only at Alki Point.

Otter Trawl. The most abundant and frequently occurring species at each site were ratfish, English sole, and rock sole. The seasonal and bathymetric distributions of abundance (CPH) for these species are presented in Fig. 10. Both English sole and rock sole were most abundant between 5 and 45 m; however, each species exhibited marked onshore-offshore migrations during the year. These movements were characterized by an onshore migration from 45 to 5 m in late spring and summer, followed by an offshore migration back to 45 m in the fall. The same general pattern was observed for each species at all three study sites.

In contrast, ratfish were most abundant at 70 and 95 m. At each site, the abundance (CPH) of ratfish was highest during spring and summer, but declined considerably in fall and winter. At Alki Point and Point Pully there appeared to be a movement of ratfish to shallower water (principally 45 m) during the winter. A similar inshore movement was not evident at West Point.

Species Assemblages

Beach Seine (37-m Net). The nearshore species assemblages determined by recurrent group analysis for each study site are presented in Fig. 11. The assemblages at Alki Point and Point Pully are more complex and more comparable to one another than the assemblage at West Point. If the species composing the primary associations (group I at West Point and Point Pully, and the combined groups I and II at Alki Point) at each site are compared, only four species are found in common--shiner perch, staghorn sculpin, English sole, and rock sole. If Alki Point and Point Pully are compared, however, there are six species in common. These include the above-mentioned four species, as well as C-O sole and striped perch.

Those peripheral species or species pairs with some affiliation to the primary (core) associations generally occurred only at night (usually in fall and winter) or were eelgrass associated. For example, the padded sculpin - sturgeon poacher pair at West Point, the tomcod - sailfin sculpin pair at Point Pully, and the sailfin sculpin - great sculpin - hake and pile perch - tomcod - sturgeon poacher groups at Alki Point generally occurred at night. Eelgrass-associated species included the bay pipefish, speckled sanddab, gunnels, and pile perch at Point Pully, and bay pipefish - crescent gunnel pair at Alki Point.

Otter Trawl. The demersal fish assemblages determined by recurrent group analysis for each study site are shown in Fig. 12. In addition, the seasonal-bathymetric distributions of the species groups from each site are presented in Tables 10, 11, 12. In general, the species groups found at each site can be divided into shallow-water and mid-depth occurring groups (5, 25, and 45 m) and deep-water occurring groups (70 and 95 m). Species groups I at West Point and Point Pully and groups I and III at Alki Point occurred, in most instances, between 5 and 45 m. In contrast, species group II at each site was restricted exclusively to 70 and 95 m.

Eelgrass-Associated Species (Alki Point Study)

A summary of the preliminary results from our comparative study at Alki Point of fishes associated with eelgrass and sand substrates is presented in Table 13. The differences in species richness and abundance between the two habitat types is striking. A total of 41 species was collected in eelgrass compared with only 22 on sand. In addition, the density (i.e., fish per unit area of bottom) of fish was also substantially higher in eelgrass, by a factor of nearly 9:1. The most abundant species on sand included shiner perch, English sole, and tomcod, compared with sandlance, striped perch, and shiner perch on eelgrass. Several species were clearly eelgrass-associated, and no species was more abundant on sand than in eelgrass.

Seasonal variations in abundance (CPH) and species richness (SR) on the sand and eelgrass substrates are shown in Fig. 13. In all months (both at night and in the daytime) CPH and SR were markedly higher in eelgrass. A Wilcoxin's signed rank test based on geometric means indicated that both CPH and SR were significantly higher on eelgrass. The seasonal patterns for CPH on both sand and eelgrass were very similar, and were characterized by early summer and fall peaks. Although the overall patterns were similar on both habitat types, the seasonal fluctuations were much greater on eelgrass. In contrast to the CPH, SR increased in early summer and remained high through the fall.

Diel Studies (West Point)

Results from the quarterly 24-hour trawling studies conducted at West Point are presented in Fig. 14 for fall and winter, and in Fig. 15 for spring and summer. Additional data on diel movements based on trammel net sampling are presented in Table 14.

The distribution of total catch per haul (CPH) for English sole and rock sole, by depth and time of day, exhibited roughly similar patterns in spring, summer, and fall. Typically, both species were most abundant in deeper water (25-45 m) during the day, but moved actively into shallow water (5-15 m) at night. This diel pattern was most pronounced in spring and summer studies. During the spring, both species moved into shallow water between 2000 and 2400 hours, and then moved back offshore again by 0400. In the summer, English sole abundance followed a similar pattern; however, rock sole remained active and abundant in shallow water for a much longer period of time. During the fall study, English sole appeared to remain in shallow water (5 m) for a much longer period. In contrast to the spring, summer, and fall, no strong onshore-offshore diel migration was noted for either English sole or rock sole during winter. CPH for both species was higher at night, but peak abundance was highest at 25-35 m.

The limited trammel net data from the fall, winter, and spring studies (Table 14) reflect the onshore-offshore movements of English sole discussed above. Furthermore, these data indicate that large predators such as dogfish, cod, pollock, hake, and adult tomcod, which are not normally found in shallow water in the daytime, were present at night. The capture of sturgeon poachers, slender sole, and Dover sole, which normally occur in deep water during the day, indicated that these species also are actively moving onshore at night.

1.1.3 Fish Health

Tumor Disease

The incidence of tumor-bearing English sole varied considerably by age and time of year at all three study sites (Tables 15, 16, 17). The seasonal occurrence of diseased fish was similar at each site, and was similar to that reported previously for tumor-bearing flatfishes in Puget Sound.

Tumor-bearing young-of-the-year (age 0) were not observed (except for a single fish in April 1975 at West Point) prior to September. The incidence in age 0 fish was highest between September and December. The incidence of tumor-bearing age I and II+ individuals was usually lower than that observed for age 0, and was also more sporadic during the year. The prevalence declined with increasing size and age, with the fewest tumor-bearing fishes being in age groups I and II+.

Nematode Parasites (Philometra)

Nematode-infested English sole and rock sole were observed throughout 1975-76 at all three study sites (Tables 18, 19, 20). Externally evident parasites were not detected on individuals of either species which were less than 150 mm in total length (TL). At West Point and Alki Point, English sole had the highest level of infestation, whereas at Point Pully the rock sole was most heavily infested. In general, the incidence of infested individuals for both species was highest in winter and fall and lowest in spring and summer.

1.2 Between-Site Comparison, 1975-76

1.2.1 Fish Populations

Abundance and Frequency of Occurrence

Beach Seine (37-m Net). At each of the three study sites, ten species generally accounted for at least 95% of the total beach seine catch during 1975-76. Table 21 indicates that shiner perch were abundant (CPH) at all sites, but especially at Point Pully and Alki Point. Striped perch were also very abundant at Point Pully and Alki Point, but much less abundant at West Point. In contrast, juvenile tomcod were exceptionally abundant at West Point but much less so at the other two sites. Other important differences between sites included the higher CPH of C-O sole, padded sculpin, tubesnout, and pile perch at Point Pully and Alki Point.

English sole, rock sole, and staghorn sculpin were the most frequently occurring species at all three sites (Table 22). The results of a Kendall's Concordance test ($W = 0.736$, $x^2 = 30.94$, $df = 14$, $\alpha = 0.05$) indicate that the rankings of species by frequency of occurrence at the three sites are not significantly different. Even though the rankings are not different, there are several qualitative differences between sites.

In particular, C-O sole, striped perch, penpoint gunnels, saddleback gunnels, and bay pipefish occurred much more frequently at Alki Point and Point Pully than at West Point.

The composition and abundance of beach seine captured species from the three study areas were also compared using numerical classification (Fig. 16). The results from this 80-sample, 40-species analysis indicate that, regardless of season, most samples from West Point clustered together, to the exclusion of samples taken at other sites. In other words, the species composition and relative abundance of species at Alki Point and Point Pully were more similar to one another than to West Point during most seasons.

Otter Trawl. The overall otter trawl catches at each of the three study sites were dominated by ten species. Among these dominant species, English sole, rock sole, and ratfish were the most abundant, although their abundance (CPH) and frequency of occurrence varied considerably with depth. The rankings of species by site on the basis of mean CPH for 5 m, 25 m, 45 m, 70 m, and 95 m are presented in Tables 23, 24, 25, 26, and 27, respectively. Site differences occurred at all except the 25-m depth. At 5 m, the CPH for C-O sole and striped perch was considerably higher at Alki Point than at the other two sites. In addition, the CPH for English sole was much higher at Point Pully than elsewhere. The major difference at 45 m was the higher CPH for English sole at West Point. At both 70 and 95 m, the CPH for ratfish was substantially higher at West Point. Other obvious differences included the higher CPH for slender sole at Alki Point and Point Pully, and the higher CPH of Dover sole at West Point and Alki Point.

The frequencies of occurrence by site for the 15 most frequently caught species are shown in Table 28. A Kendall's Concordance test

(W = 0.849, x^2 = 35.67, df = 14, α = 0.05) based on these rankings indicates that there is no significant difference between sites. English sole, rock sole, and ratfish were consistently the most frequently captured species at each site. The principal between-site differences included the more frequent occurrence of Dover sole and rex sole at West Point and the comparatively low frequency of occurrence for roughback sculpin, slender sole, and C-O sole at West Point. Concordance tests based on the rankings of the most frequently occurring species at 5, 25, 45, 70, and 95 m indicated that there were no significant differences between sites at any depth.

Annual Cycles of Abundance, Species Richness, and Diversity

Beach Seine (37-m Net). The annual cycles of abundance (CPH) and species richness (SR) at each study site (Fig. 17) were generally the same during 1975-76. Both CPH and species richness were lowest at West Point during the winter, spring, and summer. CPH was highest at both Alki Point and Point Pully during the spring and summer, and highest during the fall at Alki Point. Maximum species richness occurred later in the year (fall) at Alki Point and Point Pully and was also higher at those sites.

The annual cycles of diversity (H) at the three study sites (Fig. 17) were similar during 1975-76, with the highest diversity occurring in the late spring and summer and during the fall. During the winter and spring, diversity was highest at Point Pully and Alki Point and lowest at West Point. In late summer, however, diversity was highest at West Point.

Otter Trawl. Between-site comparisons of total catch per haul (CPH) at 5 m, 25 m, and 45 m (Fig. 18) indicate that CPH was comparable at West Point and Point Pully. At Alki Point, however, CPH was much higher in spring at 5 m and lower in fall at 45 m. Annual cycles of species richness (SR) and diversity (H) at each depth (Fig. 18) were similar at each site; however, both SR and H were lower at West Point in spring, summer, and fall at 5 m and 45 m.

If CPH of English sole alone is compared between sites at 5 and 45 m (Fig. 19), it is clear that English sole are more abundant at West Point during most seasons. Similar CPH data for rock sole at these depths (Fig. 19) indicate little difference at 5 m but a much higher CPH at 45 m during the fall and winter at Alki Point and Point Pully.

Comparisons of total CPH at 70 m and 95 m (Fig. 20) between the three sites indicate that CPH was considerably higher at West Point during most seasons. The major reason for this difference was the high CPH for ratfish at West Point (Fig. 21). Comparisons of SR (Fig. 20) at these depths indicate that SR was generally lower at West Point in most seasons. Similarly, diversity (H) was observed to be consistently lower at West Point during all seasons (Fig. 20).

1.2.2 Fish Health

Tumor Disease

The overall incidence (beach seine and otter trawl combined) of tumor-bearing young-of-the-year English sole at West Point (2.13%), Alki Point (2.39%), and Point Pully (4.98%) was found to be significantly different ($x^2 = 20.7$, df - 2, $\alpha = 0.05$) during 1975-76. Further analysis indicated that the incidence at West Point and Alki Point was not significantly different ($x^2 = 0.104$, df = 1, $\alpha = 0.05$), but that the incidence at Point Pully was significantly higher than at Alki Point ($x^2 = 5.57$, df = 1, $\alpha = 0.05$) or West Point ($x^2 = 18.58$, df = 1, $\alpha = 0.05$). Although the incidence of tumorous young-of-the-year was higher at Point

Pully, the seasonal occurrence of diseased individuals was very similar at each site (Fig. 22a). Prior to September or October, age 0 tumor-bearing fish were absent except for a single fish at West Point in April. During late summer and fall, tumorous fish appeared at all sites; however, the incidence fluctuated from month to month. No additional tumor-bearing age 0 fish were captured during the subsequent winter or spring.

The overall incidence of tumor-bearing age I English sole also differed significantly ($x^2 = 18.0$, df = 2, $\alpha = 0.05$) between West Point (4.54%), Alki Point (8.36%), and Point Pully (9.27%) during 1975-76. Additional chi square analysis indicated that the incidence was significantly greater at Point Pully than at West Point ($x^2 = 17.4$, df = 1, $\alpha = 0.05$), but that the incidence at Alki Point was not significantly different from that at Point Pully ($x^2 = 3.54$, df = 1, $\alpha = 0.05$). Tumor-bearing age I fish were encountered throughout the study period at all three sites (Fig. 22b) but the incidence was highly variable. In general, however, the incidence was highest during late winter, spring, and summer, and lowest in fall and early winter. During the spring and summer, the incidence was highest at Point Pully, but during early winter it was higher at Alki Point.

Nematode Parasites (Philometra)

The incidence of nematode-infested English sole and rock sole varied considerably between study sites. For both species the incidence was lowest at West Point and highest at Point Pully. The incidence of parasitized English sole at Point Pully was significantly higher than at Alki Point ($x^2 = 16.3$, df = 1, $\alpha = 0.05$) or West Point ($x^2 = 223.4$, df = 1, $\alpha = 0.05$). Similarly, the incidence of parasitized rock sole was significantly higher at Point Pully than at Alki Point ($x^2 = 378.0$, df = 1, $\alpha = 0.05$). Although the incidence of infested fish was significantly different for all pair-wise combinations of the three sites, the incidence was markedly higher for both species at Point Pully.

The incidence of nematode-infested English sole (Fig. 23a) appeared to exhibit a seasonal pattern at all sites. Incidence levels were generally highest in spring, fall, and winter, and lowest in the summer. Similarly, the incidence of parasitized rock sole (Fig. 23b) exhibited a seasonal pattern with a higher incidence in the spring and fall at West Point and Alki Point. At Point Pully, however, the incidence was consistently high throughout the year except during the winter.

Fin Erosion

Fin-eroded flatfish did not once occur at West Point, Alki Point, or Point Pully.

2. Duwamish River Study

2.1 1975-76 Investigations

2.1.1 Fish Populations

Species Composition and Frequency of Occurrence

A total of 8,802 individuals comprising 29 species were sampled in the Duwamish River during 1975-76 (Table 29). Of these species, English sole and Pacific staghorn sculpin occurred most frequently (> 70% of total samples). Commonly occurring species (30-70%) included: Pacific herring, longfin smelt, Pacific tomcod, shiner perch, snake prickleback, padded sculpin, rock sole, starry flounder, and sand sole. Over the entire sampling period, the ten most abundant species accounted for nearly 98% of the total catch (Table 30), with snake prickleback, English sole, longfin smelt, starry flounder, and Pacific staghorn sculpin the most abundant species (about 85% of total catch).

Annual Cycles of Abundance and Species Richness

Abundance (catch per haul = CPH) and species richness (total number of species = SR) for all stations combined exhibited considerable annual variation during 1975-76 (Fig. 24a,b). Catch per haul was generally lowest during late fall and winter (November-March), increased markedly through spring and summer (May-August) with the exception of a slight decline in July, and then peaked in late summer-early fall (September-October). Species richness underwent similar but less marked seasonal variation.

CPH and SR on a station-by-station basis generally followed seasonal patterns characteristic of the entire river. At all stations, the peak catch occurred in September-October, with the highest catches at the mid-river stations (C-E). Generally, CPH and SR were highest at stations in the middle to upper portion of the river (stations D-G) during all months.

Seasonality of Dominant Species

Overall, five species (snake prickleback, English sole, longfin smelt, starry flounder, and Pacific staghorn sculpin) contributed more than 85% of the total 1975-76 catch; however, the relative monthly abundance of these species fluctuated greatly throughout the year (Fig. 25). Snake prickleback were most abundant during the spring, summer, and fall, but especially dominated catches during the summer. During this period of maximum abundance, prickleback were rarely collected in the lower river (stations A and B) but were consistently abundant at middle and upper river stations (C-G), particularly at stations E-G.

In contrast, starry flounder were most abundant during the fall and winter and least abundant in summer. Starry flounder also rarely occurred in the lower river (stations A-C) during periods of abundance and were generally most abundant at the highest stations sampled (E-G). Smaller individuals (50-149 mm) were usually confined to the uppermost stations (Fig. 26) whereas larger individuals (> 150 mm) were more widely distributed (Fig. 26).

Longfin smelt were also markedly seasonal in occurrence, with peaks of abundance in fall, early winter, and summer. The fall-winter peak consisted of individuals 80-115 mm and may represent part of a spawning run. The peak which occurred during late summer was composed solely of young-of-the-year downstream migrants ranging from 30 to 50 mm TL.

English sole and Pacific staghorn sculpin, in contrast to the above discussed three species, appear to be resident members of the estuarine fish community. English sole constituted a substantial portion of the catch in all seasons (Fig. 25); however, they were particularly abundant in spring. Generally, English sole occurred at all stations, yet they were most abundant at the mid-river stations C-E. Staghorn sculpin were also a consistent segment of the catch throughout 1975-76, but tended to be more numerous and widespread in fall. Sculpin usually occurred at all stations except during the summer when they were confined to the middle and upper river stations E, F, and G.

2.1.2 Fish Health

Diseases

Tumors. During the 1975-76 sampling in the Duwamish River, only starry flounder were observed with epithelial skin tumors. The overall incidence of tumor-bearing individuals was 16.9%; however, the incidence varied considerably with time of year and size of fish (Table 31). All tumor-bearing fishes were less than 180 mm TL (Fig. 27), corresponding to ages 0, I, and II. The incidence of tumor-bearing individuals decreased both with increasing size (Table 31) and age. The greatest incidence (44.7%) occurred in the 50-99 mm TL size class and the lowest in the 150-199 mm TL size class. The decline in tumor incidence between successively larger size classes was significant for the 50-99 mm TL and 100-149 mm TL classes ($x^2 = 10.7$, df = 1, $\alpha = 0.05$) and 100-149 mm TL and 150-199 mm TL classes ($x^2 = 112.6$, df = 1, $\alpha = 0.05$), respectively.

Fishes bearing early developmental stage tumors (AEN or angioepithelial nodules) were found only in October, whereas fishes with later stage tumors (EP or epithelial papillomas) were sampled in all months except August. Prior to October, no tumor-bearing young-of-the-year (50-99 mm TL) were observed, but during the late fall and early winter (October-February) the incidence of EP tumor-bearing individuals in the smallest two size classes (50-99 mm TL and 100-149 mm TL) increased rapidly (Table 31). Larger individuals (100-199 mm TL) with tumors, mostly ages I and II, occurred throughout the year, although the incidence was sporadic during summer when the abundance of starry flounder in the river declined.

In general, tumor-bearing starry flounder were confined exclusively to the upper river stations E-H (Table 32); however, smaller individuals (50-99 mm) were found to be located significantly higher in the river than larger (100-199 mm) individuals ($x^2 = 44.9$, df = 3, $\alpha = 0.05$). The smallest (50-99 mm) tumorous fishes, and the only AEN-bearing individuals, were found almost exclusively at the highest two stations, G and H. Tumor-bearing individuals in the 100-149 mm size class had a significantly different distribution than did "normal" individuals of the same size ($x^2 = 27.1$, df = 5, $\alpha = 0.05$), with "normals" being more widely distributed. Both normal and tumor-bearing smaller fishes (50-99 mm) had similar distributions.

Both AEN and EP stage tumors occurred more frequently on the eyed side of individual starry flounder than on the blind side (Table 33). This relationship was found to be statistically significant (x^2 = 84.6, df = 1, α = 0.05). A substantial portion of the total number of tumors (45.0%) were categorized as occurring on both sides of individual fishes; however, these tumors were usually very large and in an advanced stage of development, or located on the fins.

Fin Erosion. Starry flounder with fin erosion disease were sampled in all months during 1975-76 (Table 34). The incidence of fin erosion was highest during winter and early spring, with the exception of a peak in September, and lowest in the late spring and summer. Rather than indicate any seasonal pattern of occurrence, the decline in incidence during the summer seems to reflect a decrease in the abundance of starry flounder in summer. The disease was generally confined to fish greater than 150 mm TL, although a few smaller individuals were also afflicted (Fig. 27). Generally, diseased fish ranged from 150 to 250 mm TL, or age groups II and III. The incidence of fin erosion increased with both increasing size and age (Table 34). Fin erosion incidence increased significantly between the size classes of 100-149 mm (3.7%) and 150-199 mm (12.2%) (x^2 = 23.3, df = 1, α = 0.05), and between 150-199 mm (12.2%) and 200-249 mm (23.8%) (x^2 = 16.8, df = 1, α = 0.05).

Starry flounder with fin erosion were more widely distributed in the river than were tumor-bearing individuals, but were still confined to the middle and upper river stations C-H (Table 35). Although widely distributed, the incidence of fin-eroded fishes was significantly higher at the mid-river stations C-F than at the highest stations G and H (x^2 = 41.9, df = 1, α = 0.05). For all size classes, except the > 250 mm TL class, the fin-eroded and normal fish exhibited similar distributions in the river.

The most commonly eroded fins of individuals starry flounder were the dorsal, anal, and caudal (Table 36). Overall, the dorsal fin was afflicted significantly more often than the anal fin ($x^2 = 11.4$, df = 1, $\alpha = 0.05$). In addition to the dorsal, anal, and caudal fins, the pectoral and pelvic fins were also diseased. The blind side pectoral fin was diseased significantly more often than the eyed pectoral ($x^2 = 20.2$, df = 1, $\alpha = 0.05$); however, the same relationship did not hold for the paired pelvic fins ($x^2 = 1.0$, df = 1, $\alpha = 0.05$).

Parasitic Nematodes. Both English sole and rock sole from the Duwamish River were infested with the parasitic nematode Philometra americana. For both species, externally evident nematodes were observed only on fishes exceeding 150 mm TL. The incidence of English sole infestation ranged from 4.3% in January to 18.2% in October, but exhibited no obvious seasonal pattern (Table 37). Rock sole infestation was much more sporadic during the year with parasitized fishes occurring only in August, September, and January. Although the incidence of parasitized English sole was highest at stations E and F (Table 38), there did not appear to be any relationship between parasite incidence and location in the river. The incidence of infested rock sole was highest at stations A and B, but low elsewhere. As with English sole, there was no obvious relationship between station location and nematode infestation.

Growth and Condition

During 1975-76, growth rates were determined for "normal", tumor-bearing, and fin-eroded starry flounder from the Duwamish River. By assuming a specific date of birth (in this case, April 1), fish collected in any given month were assigned an age in months rather than years. For example, those fish determined to be 1+ years of age (i.e., in their second year of life) during the month of June were assigned the age of 15 months. In order to compare growth rates (both length and weight) statistically, mean total lengths and weights were determined for 3-month age increments (e.g., 10-12 mo., 13-15 mo., etc.). Fig. 28 shows the seasonal growth patterns for three age groups of normal fish (ages I, II, and III), and two age groups of fin-eroded (ages II and III) and tumor-bearing (ages I and II) fishes. The seasonal nature of growth is clearly shown for both normal and fin-eroded fishes, but is less clear for tumor-bearing fish. These data indicate that growth (weight and length) of tumor-bearing fishes is significantly retarded beyond the age of 8-10 months and at all ages thereafter. Only in the later portion of the first year of life (10-12 months) is growth similar for normal and tumor-bearing individuals. In contrast, growth of younger fin-eroded individuals is not significantly reduced from that of normals for more than a year. Only by the age of 34-36 months does growth become significantly retarded.

2.2 Between-Year Comparisons, 1974 and 1975-76

2.2.1 Fish Populations

Species Composition

During both 1974 and 1975-76, a total of 29 species of fish were collected in the Duwamish River, with 79.3% (23/29) of the species occurring in both years. Overall, the ten most abundant species collected during each year were the same. Although the ranking of these species, based on relative abundance, varied slightly between years (Table 30), they were not significantly different ($\tau = 0.69$, $p = 0.0023$).

Seasonal Patterns of Abundance and Species Richness

Abundance (catch per haul), combined for all stations, exhibited similar seasonal patterns in both 1974 and 1975-76 (Fig. 24a). During both years, abundance was lowest in winter, increased in spring and summer, and then later declined in late fall. Abundance was generally higher in 1975-76, especially during the spring and late summer. Species richness (Fig. 24b) also followed similar seasonal patterns, with the maximum species richness occurring slightly earlier (September-October) in 1975-76.

Seasonality of Dominant Species

During both 1974 and 1975-76, the same five species dominated the annual catch: Snake prickleback, longfin smelt, English sole, Pacific staghorn sculpin, and starry flounder. Longfin smelt and snake prickleback were both seasonal residents, with smelt utilizing the river in late summer (downstream migrants) and fall-winter months (spawning adults), and snake prickleback in late spring and summer. Staghorn sculpin, English sole, and starry flounder were year-round residents although the abundance of the latter two species was strongly seasonal. Starry flounder were especially abundant in the winter and fall, but reduced in abundance in the summer. English sole were abundant throughout the year, but particularly in spring. Abundance of staghorn sculpin fluctuated little during the year, and probably represents the most persistent member of the demersal fish community in the Duwamish River.

During both 1974 and 1975-76, English sole and starry flounder exhibited complementary distributions in the river. English sole were most numerous at lower river stations A-D, whereas starry flounder were most abundant in the upper river stations D-H. No starry flounder were ever collected at stations A and B, while few English sole were sampled at the uppermost stations G and H.

2.2.2 Fish Health

Tumor Disease

The overall incidence of tumor-bearing starry flounder (all size classes and tumor stages combined) in the Duwamish River did not differ significantly between 1974 and 1975-76 ($x^2 = 2.08$, df = 1, $\alpha = 0.05$). During both years, the incidence of tumor-bearing individuals declined significantly with increasing size class. For the size classes 50-99 mm, 100-149 mm, and 150-199 mm, the decrease was 47.9% to 14.4% to 1.8% in 1974, and 44.7% to 24.6% to 1.3% in 1975-76. The incidence of tumor-bearing fishes in the 50-99 mm and 150-199 mm size classes did not differ significantly between years, but was significantly different for the 100-149 mm class ($x^2 = 12.1$, df = 1, $\alpha = 0.05$).

The seasonal occurrence of tumor-bearing starry flounder (size classes combined) was quite similar in 1974 and 1975-76 (Fig. 29). The incidence was highest in the winter, declined through the spring and summer and increased again in fall. The high incidence in winter and early spring was due largely to older and larger fishes (age groups I, II, and III) with more advanced (EP) stage tumors, whereas the large numbers of tumorous fishes in fall were mostly young-of-the-year individuals with early stage (AEN) or small tumors.

The incidence of tumor-bearing fishes (size classes combined) was highest in the upper river stations D-G during both 1974 and 1975-76, and their distribution followed remarkably similar patterns in both years (Fig. 30). The incidence of tumor-bearing fishes at individual stations was significantly different only for fishes in the 100-149 mm size class at stations F ($x^2 = 4.26$, df = 1, $\alpha = 0.05$) and H ($x^2 = 13.1$, df = 1, $\alpha = 0.05$). There were no significant differences between years in the occurrence of tumor-bearing fishes at any station for the 50-99 mm or 150-199 mm size classes.

During both years, there were significantly more tumors observed on the eyed side of individual starry flounder than on the blind side (1974: $x^2 = 92.3$, df = 1, $\alpha = 0.05$; 1975-76: $x^2 = 84.5$, df = 1, $\alpha = 0.05$). The proportion of tumors judged to occur on the eyed, blind, or both sides did not change significantly between years ($x^2 = 0.48$, df = 2, $\alpha = 0.05$).

Fin Erosion

The overall incidence (all size classes) of starry flounder with fin erosion did not significantly differ between 1974 (13.5%) and 1975-76 (12.1%) ($x^2 = 0.02$, df = 1, $\alpha = 0.05$). In both years the incidence of fin erosion increased significantly with increasing size (and presumably age) above a minimum threshold size of 130-140 mm TL. In 1974 the incidence of fin erosion was significantly higher ($x^2 = 16.4$, df = 1, $\alpha = 0.05$) for individuals in the smallest size class (100-149 mm), whereas in 1975-76 it was higher in the 200-249 mm ($x^2 = 5.21$, df = 1, $\alpha = 0.05$) and > 250 mm ($x^2 = 4.6$, df = 1, $\alpha = 0.05$) size classes.

The seasonal cycles of fin erosion incidence were quite similar in both 1974 and 1975-76, except for the exceptionally high incidence in September 1975 (Fig. 29b). Generally, the incidence was highest in winter, declined during spring and summer, and increased again in fall. The decline in incidence in spring and summer may have been related to a seasonal decrease in the abundance of starry flounder in the river. In contrast to tumor-bearing starry flounder, fin erosion prevalence was higher at mid-river stations C-F than at upper river stations G-H in both 1974 and 1975-76 (Fig. 30b).

Pathology Studies

Three pathological conditions of flatfish were investigated: The previously observed fin erosion and epidermal papilloma, and a recently discovered liver disease. The pathological characteristics of each disease will be reported separately below.

1. Fin Erosion

1.1 Gross Pathology

The lesions of fin erosion vary from minor defects to extensive destruction of fins. Sometimes almost entire fins are destroyed (Fig. 31). In the less severe lesions there is partial loss, fusion, or distortion of fin rays, generally accompanied by hemorrhages and granulation tissue on the surface of the fin and extending to the main body surface (Fig. 31). Slight to moderate ulceration may be seen at the free margin of the damaged fin, which is often greatly scarred. There is usually a line of hyperpigmentation along the free edge of the defect (Fig. 32).

In the most severe lesions, parts of the fins have lost the bony fin rays entirely and the remaining soft tissue is greatly scarred, retracted, flaccid, and deformed (Fig. 32). The flat epithelial surfaces of such fins are generally without ulceration, but there may be ulceration at the free margin. Frequently, flaps of unsupported fin tissue are folded over so as to graft themselves by permanent tissue union to the adjacent body wall.

1.2 Histopathology

The lesions we observe in starry flounder and English sole are largely those of a chronic fibrosing disease with epidermal hyperplasia, proliferation of dermal fibroblasts, fibrosis, focal infiltrations of cells interpreted as lymphocytes, mucous cell changes, aggregation of melanophores in the vicinity of resorbing fin rays and around sclerotic blood vessels, patchy loss of melanophores from the dermal-epidermal junction, and an increase and spreading of eosinophilic granular cells in the epidermis. These and some other changes are described in the following paragraphs. The majority of lesions are a composite of most if not all of the features described.

Epidermal hyperplasia is a constant feature of the disease. The normal epidermis of the fins of starry flounder and English sole is 7-10 cells thick. The basal layer consists of small germinal cells with basophilic nuclei. As the progeny of the basal cells progress toward the surface, they differentiate into flattened squamous cells, or mucous cells, or eosinophilic granular cells (EGC). In our specimens there is hyperplasia of the epidermis to 2-3 times the normal complement of cells with a corresponding increase in thickness. The individual epidermal cells are generally of normal morphology, but focal fraying of the epithelium, accompanied by degenerative changes in the individual cells, may be seen. Mild papillary folding of the epidermis and underlying dermis is often present (Fig. 33).

Ulceration of the epidermis with necrosis and exfoliation of small strips of epithelium may be present (Fig. 34). These are often detected only microscopically and in no way represent massive necrosis. Granulation and scar tissue are present in the bases of the ulcerations.

Areas of hyperplasia of mucous cells (Fig. 33) alternating with areas of decrease or absence are observed in the epidermis of affected fins. Under normal conditions mucous cells are evenly distributed throughout the epidermis. The mucous droplets in the cells stain with mucicarmine, and PAS reaction is positive, indicating the presence of mucopolysaccharide.

Inclusion cysts lined by epidermal or mucous cells and solid epidermal inclusions are often observed in severely damaged skin. This change usually occurs in fins where the bony rays are largely resorbed, resulting in loss of tissue support. The distal fin may then fold back on the more proximal portion or on the body wall, resulting in entrapment of epithelial sheets. As the tissue heals in this position, inclusion cysts may form.

Proliferation of fibroblasts and marked fibrosis of the damaged fin is a constant feature of fin erosion. The fibrosis is accompanied by sclerosis of small blood vessels in the central vascular axis of the fin web. There is also perineural fibrosis involving the small peripheral nerves (Fig. 35).

Under normal conditions melanophores are evenly spaced along the inside of the dermal-epidermal junction. In fin erosion there is a change in distribution of the melanophores and possibly also an absolute increase in numbers. At the dermal-epidermal junction melanophores may be focally decreased in numbers or absent, or they may be crowded and focally increased. Melanophores are also regularly distributed through deeper fibrocollagenous tissue where they are rarely found. They are often perivascular and perineural in location. Melanophore concentrations are greatest in the proliferative fibroblastic areas and surrounding foci of absorption of fin rays.

Melanophages (macrophages that have phagocytozed melanin granules or fragments of cytoplasm of melanophores) are sometimes present in the fibrocollagenous scar.

Resorption of fin rays is a constant feature of fin erosion. Often a longitudinal section includes a normal fin ray and a fin ray that has been completely resorbed and replaced by fibroblastic tissue and collagen.

The resorptive process (Fig. 34) involves basophilic cells closely spaced along the surface where resorption is taking place. Most of these cells have one or sometimes two nuclei; there are no large multinucleated cells suggestive of the familiar mammalian osteoclasts. The resorptive process often involves the two spicules of the fin ray unequally.

Infiltrations of mononuclear cells interpreted as histiocytes and small lymphocytes are scattered focally through the scar tissue of the deformed fins. Multiple stains for pathogenic organisms in tissue (see Materials and Methods) are negative.

1.3 Microbiology

Attempts were made to isolate microorganisms from fin lesions and internal organs of fish with fin erosion. In addition, several normal fish of each species were examined in the same manner. A total of 232 bacterial isolates were selected at random from 30 different starry flounder and English sole. The fish were captured from the Duwamish River, Point Pully, Alki Point, and West Point; fish from the latter three areas served as non-fin-erosion controls. Fourteen of the isolates were from internal organs and tissues of fin-eroded fish, including kidney, liver, spleen, and blood. Only two of these isolates could be grown on available bacteriological media after the initial isolation, and both of these were from blood.

The remaining 218 bacterial isolates were taken from the surface of fin lesions and normal fins, characterized by several taxonomic tests, and were divided into 50 subgeneric taxonomic groups. No one group was consistently associated with fin lesions.

Since no individual bacteria or group of bacteria appeared to be routinely associated with fin erosion, it is possible that several different bacteria may cause the disease through an accumulative effect. As a means of evaluating that possibility, quantitative bacterial isolations were performed using 1-cm^2 pieces of skin from fish captured in the Duwamish River, Alki Point, and West Point. Duwamish River starry flounder and English sole had approximately $7x10^4$ bacteria/cm^2. English sole from West Point and Alki Point had about $7x10^3$ and $2x10^4$ bacteria/cm^2, respectively.

Efforts to routinely isolate fungi and virus from fin erosion lesions were unsuccessful. Fewer than five fungal isolates were obtained from several different fish. No virus was cultured from eroded fin tissue.

1.4 Disease Induction

In an attempt to determine if fin erosion in the Duwamish River is caused by environmental contaminants, normal-appearing English sole from the Nisqually River were exposed to bottom sediment from the Duwamish River. The experiment was performed in four flow-through seawater aquaria located at West Point using McCalister Creek sediment in control aquaria. Two aquaria had Duwamish River sediment and two had control sediment; each had 15 fish. By one month after the initiation of the test, two of 30 fish in aquaria with Duwamish River sediment had fin erosion, and none of the control fish had the disease. The induced fin erosion resembled the acute necrotizing form described above to occur in English sole in the Duwamish River.

A similar experiment was performed using starry flounder from the Nisqually River. The experimental conditions were exactly the same, except that each aquarium had 10 fish. No fin erosion was observed.

2. Skin Tumors

2.1 Gross Pathology

Three main types of skin tumors were observed--the angioepithelial nodule (AEN), the epidermal papilloma (EP), and the angioepithelial polyp (AEP). AEN were 1 to 5 mm in diameter, hemispherical, pink to red, smooth surfaced, sessile lesions which were located anywhere on the external surfaces of young-of-the-year fish. EP were circular, 0.5 to 5 cm in greatest dimension, and varied in thickness from about 0.5 to 1.5 cm. EP were brown to black, depending upon the amount of melanin in the stroma. Their outer and cutaneous surfaces were cauliflower-like in appearance. AEP were grossly similar to EP except that they were flatter.

Previous laboratory and field experiments have demonstrated that the AEN, EP, and AEP are different stages of the same disease. AEN progress to EP, and AEP are derived from either the AEN or EP (McArn, et al., 1968).

2.2 Histology

Microscopically, the bulk of the AEN consisted of a central mass of vascular connective tissue which was capped by a thin layer of hyperplastic epidermis. EP consisted of a relatively sparse branching fibrovascular stroma, which supported a thick layer of hyperplastic cells of epidermal origin. A tumor-specific cell, known as the "X cell", was seen in both stromal and epidermal spaces. X-cells had an eosinophilic cytoplasm, and a pale nucleus with a prominent eosinophilic nucleolus. AEP were composed mostly of vascular connective tissue containing a few X-cells. The vascular core of the AEP was covered by a thin layer of epithelium. Descriptions of AEN, EP, and AEP of Puget Sound flounder have been published (Miller and Wellings, 1971; McArn, et al., 1968).

No intracellular bacteria or fungi were observed, although virus-like particles have been previously reported to be observed with the electron microscope in X-cells.

2.3 Microbiology

Several attempts were made to isolate bacteria, fungi, or virus from skin tumors. The only microorganisms isolated were bacteria from the surface of tumors, and these were not considered to be significantly different from normal skin flora.

3. Liver Abnormalities

As part of our investigation of fin erosion in the Duwamish River, we examined the internal organs (heart, kidney, spleen, intestinal tract, liver, and gallbladder) of 138 starry flounder and 80 English sole from the Duwamish River, and also specimens of both species from other sampling areas (39 starry flounder from McCalister Creek, 10 starry flounder and 29 English sole from Point Pully, 3 starry flounder and 32 English sole from West Point, and 10 English sole from Alki Point). Abnormal-appearing livers and gallbladders were found in both species, the frequency of which varied from 0 to over 90%, depending upon the sampled area. Investigation of the liver condition in both species has involved the determination of: (1) Frequency and distribution of the liver condition, (2) histopathological characteristics associated with abnormal appearance, and (3) comparison of somatic-liver indices of sample populations from the various sampling areas.

3.1 Gross Pathology

The most obvious macroscopic sign of pathological change in the livers of both species was unusual liver color. Generally, normal starry flounder livers were brown to red-brown, changing to dark tan during the spawning period, whereas abnormal livers were yellow-tan to yellow or had a greenish cast to any of the above colors.

In English sole, normal livers were red to red-brown, except during the spawning season, when they changed to a salmon color. Abnormal English sole livers had a more variable range of colors than did starry flounder. The predominant abnormal colors were mottled yellow/brown or green, cream, brown, and tan. Less common colors included black, maroon, chocolate, orange-cream, and yellow-tan. Occasionally, black spots 0.2 mm to 1.0 mm in diameter were present. Several livers evidenced areas of hemorrhage or small white patches which subsequently were found to be neoplastic tumors. Hepatomas were also found in most of the mottled yellow/brown or green, black, and maroon livers (Fig. 36).

Abnormal livers of both species appeared to be larger and more fragile than normal livers. In addition, gallbladders associated with abnormally colored livers were greatly distended and contained a clear or yellowish liquid instead of the normal green bile. Gallbladder distention and abnormal bile were also routinely found associated with normal-appearing livers of both species in the Duwamish River.

The frequency of gross liver abnormalities was greatest in the Duwamish River for both species (92% in the starry flounder and 89% in the English sole). The frequency of liver abnormalities was lower in McCalister Creek (13% in starry flounder), Point Pully (10% in English sole), and West Point (33% in starry flounder--1 of 3 fish--and 38% in English sole). At Alki Point, 90% (9 of 10 fish) of the English sole had abnormal livers.

To test if abnormal-appearing livers were larger than normal livers, somatic-liver indices (liver weight/total body weight x 100) for 218 starry flounder and English sole from all the sampling sites were compared. The average somatic-liver indices for starry flounder were 2.42 and 1.07 from the Duwamish River and McCalister Creek (control site), respectively.

The English sole average indices were 2.40, 1.63, 1.31, and 1.12 from the Duwamish River, Alki Point, West Point, and Point Pully (control site), respectively. The indices of English sole and starry flounder populations in the Duwamish River and at Alki Point were significantly higher at the 95% confidence level than the indices of these species at Point Pully and at McCalister Creek (control sites).

3.2 Histopathology

Histologically, the normal liver architecture was very similar in both species. The hepatocytes were arranged in 1-2 cell thick muralia radiating outward from a central vein toward the hepato-portal vein. Sinusoidal spaces located between the muralia provided interstitial blood flow. Melanin-macrophage centers (small, compact cellular masses composed of ultrastructurally complex cells which contain the pigment melanin or a melanin derivative endowing the centers with special staining characteristics) were occasionally found associated with the blood vessels. The liver tissue was hepato-pancreatic with the pancreatic tissue located adjacent to the portal vein. The two species differed in their storage of lipid in the liver. In English sole, small lipid-containing vacuoles were present year-round in the cytoplasm of most hepatocytes, whereas in the starry flounder, lipid-containing cytoplasmic vacuoles were present only during the spawning period. During the non-spawning period, lipid was stored in "fat cells" scattered randomly throughout the hepatic tissue (Fig. 37).

All abnormal-appearing livers from both species evidenced somewhat similar histopathological changes, although the English sole livers had more extensive histopathological changes, including neoplasms. At Alki Point, West Point, Point Pully, and McCalister Creek, histopathological liver changes were generally less severe in both species with increased cytoplasmic vacuolation due to lipid accumulation, congestion of small blood vessels, loss of normal liver architecture, degeneration of hepatocytes, and increased interstitial connective tissue being the most common microscopic lesions observed.

Duwamish River starry flounder and English sole livers evidenced the greatest amount of pathological change in abnormal livers. Microscopical lesions common in both species included loss of normal liver architecture including the disappearance of sinusoidal spaces, congestion of most major blood vessels, severe cytoplasmic vacuolation of the hepatocytes due to lipid accumulation, focal necrosis, increased size and number of melanin-macrophage centers, presence of megalocytotic hepatocytes, variable staining properties of the hepatocytes, increased amounts of interstitial fibrous connective tissue, invasive fibroblasts, and increased interstitial melanin deposition (Fig. 38). Hepatomas (neoplastic tumors) were found in 32% of the Duwamish River English sole livers (including two normal-appearing livers) examined and many other Duwamish River English sole livers appeared to be pre-neoplastic--i.e., cells with bizarre nuclei and/or multiple nucleoli were present. Hepatomas were usually basophilic or eosinophilic nodules which appeared to be primary hepatocellular neoplasms (Fig. 39). Invasive eosinophilic and anaplastic nodules were occasionally found (Pierce, et al., 1977). Although metastases to other organs were not found, most nodules appeared to be invasive and probably should be classed as hepatocellularcarcinomas.

Histological examination of the distended gallbladders revealed an unfolding of the mucosa layer, but pathological changes were not evident within the mucosal cells.

4. Chemical Analysis

Chemical analyses were performed on the skin, muscle, liver, kidney, spleen, intestine, and blood serum of starry flounder. Analyses for pp'-DDE, PCBs, cations, and trace metals were performed in cooperation with SCCWRP (Sherwood and McCain 1976). Blood serum samples were analyzed by Scientia Laboratories for concentrations of calcium, sodium, potassium, phosphorus, glucose, urea nitrogen, uric acid, cholesterol, total protein, albumin, bilirubin, alkaline phosphatase, and lactic dehydrogenase. In addition, bottom sediments from the Duwamish River and McCalister Creek (control site) were analyzed for PCBs by SCCWRP.

PCB levels in the liver and skin of fin-eroded starry flounder from the Duwamish River were about 40 times higher than the control fish (Table 39). The other tissues from both the fin-eroded and non-fin-eroded fish had consistently higher concentrations of PCBs than control fish tissues. Also, Arochlors 1254 and 1260 were always detected at higher levels than Arochlor 1242 in Duwamish River fish.

Concentrations of pp'-DDE and trace metals in the tissues of both control and Duwamish River fish were low and did not differ significantly.

Analyses of bottom sediments collected from McCalister Creek and the Duwamish River revealed concentrations of total PCBs of 14 and 5,130 ppb (dry weight), respectively. The amounts of Arochlors 1242, 1254, and 1260 were McCalister Creek 8.7, 5.0, and 0.2 ppb; and the Duwamish River 551, 3,765, and 814 ppb. The sample of sediment from the Duwamish River was collected near the 16th Avenue bridge.

Blood serum analyses showed no significant differences between the levels of the 14 compounds tested in fin-eroded and normal-appearing fish from the Duwamish River. However, the levels of cholesterol and potassium were each about four times higher in Duwamish River fish than in McCalister Creek fish. Duwamish River starry flounder averaged 553 mg% cholesterol and 1.55 mεq/liter potassium. McCalister Creek fish averaged 144 mg% cholesterol and 0.4 mεq/liter potassium.

DISCUSSION

Ecological Studies

1. Outfall Study

1.1 Fish Populations

1.1.1 Nearshore Fish Populations and Assemblages

Beach seine sampling during 1975-76 demonstrated several important differences between the nearshore fish assemblages at the major outfall site (West Point), the minor outfall site (Alki Point), and the control site (Point Pully). These between-site differences included the species composition, frequency of occurrence of several species, abundance (catch per haul), diversity and species richness. In general, Alki Point and Point Pully were more similar to one another in terms of these characteristics than to West Point. For example, over the entire study period, fewer species were found at West Point (43) than at either Alki Point (50) or Point Pully (48). In addition, the annual pooled Shannon-Wiener diversity was lower at West Point (1.65) than at Alki Point (1.78) or Point Pully (1.69). During most seasons, but especially in summer and fall, total catch per haul (CPH) was higher at Alki Point and Point Pully. Similarly, the nearshore species assemblages determined by means of recurrent group analysis (Fager, 1957, 1963) were more diverse and complex at both Alki Point and Point Pully. We believe, however, that these differences between West Point and the control sites can largely be attributed to differences in habitat complexity between the sites rather than to the discharge of sewage effluent by METRO's West Point facility.

Our field observations indicated that the main difference in habitat complexity between the three sites was the relatively high abundance and widespread distribution of eelgrass at Alki Point and Point Pully. In general, only small and scattered patches of eelgrass occurred on the north shore of West Point. The importance of the eelgrass habitat in determining the species composition, abundance, and diversity of nearshore fish assemblages was demonstrated by our sand/eelgrass study at Alki Point. This investigation clearly showed that several species were both more abundant and frequently occurring in eelgrass than on adjacent sandy bottoms.

Indicator Species (Nearshore). Despite the differences between sites in terms of eelgrass abundance and the abundance of its associated fish fauna, the same three species occurred most frequently at each site. These species included English sole, rock sole, and staghorn sculpin. This consistently high frequency of occurrence indicates that these species are year-round members of the nearshore fish assemblages at each site. For this reason, these species are the most likely candidates for status as indicator species of pollutants in the nearshore environment. The demersal nature of the two flatfish species and the high-level carnivore position of staghorn sculpin should make these species particularly useful in food chain studies of pollutant pathways and biomagnification.

Moreover, the widespread distribution of these three species throughout Puget Sound (Miller and Borton, 1974) should also make them useful for larger scale studies of the distribution of contaminants in the marine environment.

Critical Periods and Susceptible Species at West Point. During late spring and summer (May-August), several species of nearshore and demersal fish were abundant in shallow water on the north shore of West Point. These species included juvenile and adult English sole and rock sole, juvenile and adult shiner perch and striped perch, juvenile salmonids, and several species of sculpin. Based on our findings from the sand/eelgrass study at Alki Point, it is probable that numerous additional species occur on the south shore of West Point where considerable eelgrass is located (Moulton, et al., 1974). Since other investigators in the PSIS (APL, 1976) have demonstrated the entrainment of effluent into shallow beach areas during the summer, the possibility exists that these species may be adversely impacted by exposure to effluent discharged from the METRO facility. During the summer, both juvenile salmonids (Kaczynski, et al., 1973) and juvenile English sole are actively feeding on benthic invertebrates and growing rapidly in shallow water. It is therefore possible that the prey populations upon which these species depend may also be adversely affected and thus indirectly affect the growth and survival of these or other species.

Toxicity studies conducted by Stober, et al. (1977), using West Point effluent demonstrated that juvenile English sole (age 0) and shiner perch were the most sensitive species investigated and that chlorine was the principal toxicant. Similar studies by METRO (1973) indicated that juvenile salmonids were even more susceptible. Because of the 1:150 dilution of effluent at the diffuser ports, it seems unlikely that effluent will be sufficiently concentrated to result in the mortality of nearshore fishes or their prey. However, because of the nearshore eddies which are generated on flood and ebb tides, it is possible that elevated concentrations may at times occur in shallow water (APL, 1976).

Another potential cause of mortality for nearshore fishes is exposure to toxic concentrations of heavy metals. During two 96-hour bioassays, Stober, et al. (1977), observed abnormally high mortalities of English sole and shiner perch, and in both cases the mortalities were correlated with peak discharges of mercury and chromium/copper. Furthermore, they indicated that the concentrations of heavy metals recorded during these bioassays occurred at least ten times during 1975-76. They suggested that some organisms in the vicinity of West Point may have experienced heavy mortality during these periods of discharge.

The input of heavy metals to Puget Sound from the effluent discharged by the METRO treatment plant at West Point was shown to be positively correlated with annual rainfall patterns (Duxbury, 1976). Since rainfall is highest in winter and spring, it seems most likely that "slug" discharges of toxic metals would occur during that period. Species utilizing the nearshore area in winter and spring, and thus most susceptible to exposure, include English sole, rock sole, tomcod, shiner perch, juvenile salmonids, and staghorn sculpin.

1.1.2 Demersal Fish Populations

Otter trawl sampling during 1975-76 revealed several differences between the study sites in terms of the frequency of occurrence of species, total abundance, abundance of the dominant species, recurrent species groups, species richness and diversity. Although some site differences were observed at all sampling depths, the major differences occurred in deeper water (70 and 95 m trawl stations).

At each study site, the same three species occurred most frequently-- English sole, rock sole, and ratfish. Notable differences between sites, however, included the higher frequency of occurrence of Dover sole, rex sole, and quillback rockfish at West Point, and the higher frequency of occurrence of roughback sculpin, slender sole, and C-O sole at Alki Point and Point Pully. In a study of demersal fishes in the Southern California Bight during 1969-1972, SCCWRP (1973) reported that Dover sole and rex sole occurred most frequently in an area of heavy waste discharge (Palos Verdes). Furthermore, SCCWRP found that slender sole and the yellowchin sculpin (a rough ecological equivalent of the roughback sculpin) occurred less frequently in the Palos Verdes area. The low frequency of occurrence for C-O sole at West Point was probably due to the lack of eelgrass microhabitat there.

Our trawl studies indicated that the total abundance at 5, 25, and 45 m was quite similar at each of the three sites. At each site, abundance was highest at 5 m during spring and summer, and highest at 45 m during fall and winter. An analysis of this seasonal shift in the bathymetric distribution of abundance revealed that English sole and rock sole exhibited a very pronounced onshore-offshore migration. Such movements are known for many demersal species (Alverson, et al., 1964; McCracken 1963; SCCWRP 1973), and are presumed to be in response to seasonal variations in temperature and dissolved oxygen (Alverson, et al., 1964).

The fall-winter concentration of English sole and rock sole near the 45-m contour in central Puget Sound, as well as the high diversity of demersal fishes observed there, may be related to the "zero net tidal flow regime" which prevails near the 50-m contour (Harmon, et al., 1976). This type of flow results in a depositional environment, concentrates waterborne materials for deposition and may aid in the recruitment of benthic organisms. Harman, et al. (1976), also reported that the diversity of benthic infauna was highest near the 50-m contour. Because of this zero net flow regime, the possibility exists that effluent discharged into this layer may remain in the area and continue to be cycled back and forth across the bottom for several tidal cycles. Demersal fishes and their prey which occur in this area may, therefore, be chronically exposed to contaminants or toxic materials.

Although the total fish abundance for 5, 25, and 45 m was similar at each site, the abundance of English sole and rock sole varied considerably. In general, English sole were much more abundant at West Point between 5 and 45 m than were rock sole. In contrast, rock sole were much more abundant at Point Pully. At the present time, we have no reason to suspect that these differences are related to sewage discharge from the West Point outfall.

A major difference observed between the three sites was the total fish abundance at 70 and 95 m. In nearly every season, the abundance was much higher at West Point. The principal reason for the differences at both depths was the overwhelming abundance of ratfish at West Point, especially at 70 m. The high abundance of ratfish in deep water is particularly significant since this is the depth range which includes the reported average depth of sewage discharge by the West Point facility (EQA, Inc., 1974). SCCWRP (1973) and others (Turner, et al., 1966; Carlisle, 1969) have observed that certain species of fish may be attracted to sewage outfalls, either to feed directly on the discharged material or on smaller organisms attracted to the effluent. In particular, SCCWRP found such to be the case for Dover sole and white croaker in Southern California. The high abundance of ratfish at West Point in deep water near the METRO outfall may simply be coincidental; however, it should not be discounted that some degree of attraction may be occurring.

The Shannon-Wiener diversity (H) and species richness (SR), at all otter trawl depths, were lower at West Point than at either Alki Point or Point Pully. The greatest difference between sites, however, occurred at 5, 70, and 95 m. At 5 m, the lower H and SR at West Point can be attributed to the lack of eelgrass in shallow water. At 70 and 95 m, however, the reduction in both H and SR cannot be easily explained. Numerous studies have shown that polluted or stressed areas have a reduction in diversity and species richness, and are often dominated by one or a few species (SCCWRP, 1973; Bechtel and Copeland, 1970; Haedrich, 1975). In many instances, however, the relationship is simply correlative and no clear cause and effect relationship has been demonstrated. The use of diversity indices has been widely criticized on this point and others as well (Hedgepeth, 1973; FAO, 1976). In the case of West Point, there is no clear evidence that the diversity of demersal fishes is either directly or indirectly (through the benthic food web) related to sewage discharge.

The results of our recurrent group analysis of otter trawl data emphasize two important points. First, the species composing the deep-water groups differ between sites. In particular, the slender sole is a member of the deep-water group at both Alki Point and Point Pully, but is replaced by rex sole at West Point. At each site, ratfish and Dover sole composed the remainder of the deep-water species groups. Second, the deep-water groups at Alki Point and Point Pully are more closely associated with the shallow-water groups than at West Point.

The significance of the apparent replacement of slender sole by rex sole at West Point lies in the different feeding modes of the two species. Slender sole are moderately large-mouthed flatfish which feed on epibenthic and nektonic crustaceans (Hart, 1973), whereas rex sole possess a relatively small, asymmetric mouth and feed on benthic infauna (e.g., polychaetes, bivalves, etc.) (Kravitz, et al., 1976). The apparent replacement of slender sole by rex sole at West Point may be indicative of a higher standing crop of benthic infauna or other changes in the abundance and species composition of the benthic community. If such differences actually exist, they may simply be natural variation between the sites. The possibility also exists, however, that changes may have been caused by the discharge of sewage at West Point.

Several studies (see SCCWRP, 1976; Smith, et al., 1973) have shown that inorganic enrichment of the benthos caused by sewage and/or sludge discharge usually results in an increased abundance and biomass of the infauna, a lowered species diversity, and a marked alteration in the species composition. In Southern California (SCCWRP, 1976) it has been demonstrated that several groups of infauna (e.g., polychaetes, clams, and echiuroids) are restricted to--or their abundance is enhanced in-- areas subject to wastewater discharge. An increased abundance of these types of organisms would in all likelihood result in the increased abundance of fish species equipped to exploit them as prey (e.g., rex sole and Dover sole). For example, SCCWRP (1973) demonstrated the attraction of Dover sole to--and an increase in their abundance near--an area of wastewater discharge off Orange County in Southern California.

Given the present state of our knowledge regarding the benthic environment near the West Point outfall, much of this discussion is highly speculative. Domenowske and Matsuda (1969) found neither a sludge buildup nor an alteration in the abundance of the benthic organisms they examined near the West Point outfall. Their study, however, was conducted in 1966-68 and substantial differences may have subsequently occurred. Recent observations made by Harmon, et al. (1976), have clearly shown that the benthos in the vicinity of West Point is influenced by the METRO outfall. For example, the spatial distribution of seeds discarded from human food followed the outfall plume both north and south from the diffuser and the concentration was highest near the diffuser. Furthermore, they found that certain avenaceous forams (in particular B. elegantissima) exhibited a spatial distribution similar to the outfall plume. According to these authors, this foram has been found associated with outfalls in Southern California. Elsewhere in Puget Sound, this species is a dominant species in habitats with fine sediments and a high organic content. In spite of these observations, an analysis of these benthic data by Stober, et al. (1976), was not able to provide any conclusive statement regarding the present state of the benthic environment near West Point. At the present, data and observations regarding the influence of METRO sewage effluent on the benthos in the vicinity of West Point are contradictory. In our view, the case is unsettled; thus, we believe further study is warranted.

1.2 Fish Health

1.2.1 Tumor Disease

Our observations of tumor prevalence at West Point and the two control sites in 1975-76 indicate that there is no obvious relationship between tumor prevalence and wastewater discharge by the METRO outfall at West Point. Our data show that the prevalence of tumor-bearing fishes was significantly higher at Point Pully (control) than at either Alki Point or West Point. Tumor-bearing Dover sole have also been reported near sewage outfalls in Southern California (Sherwood and Mearns, 1974); however, because of the widespread geographical distribution of diseased Dover sole, they also concluded that there was no relationship between sewage discharge and tumor prevalence. We found no tumor-bearing Dover sole in our study.

The causal relationship between tumor disease and pollution (e.g., sewage discharge) is not clear. Early studies by Young (1964) and Cooper and Keller (1969), from Southern California and San Francisco Bay, respectively, suggested that such a relationship did exist. However, more recent studies indicate that tumor-bearing fishes also occur in non-polluted areas. For example, Levings (1967) and Miller and Wellings (1971) have found tumor-bearing rock sole and flathead sole, respectively, in apparently unpolluted areas. Similarly, Oishi, et al. (1976), have found tumorous flatfishes near Japan in areas not associated with pollution. The apparent association between pollution and tumor incidence in some cases may simply be a coincidence, since shallow nearshore areas are both nursery grounds for juvenile fishes and areas where sewage and wastewater are discharged. Although the relationship between tumors and pollution is suspect, the possibility remains that various types of pollution might increase the susceptibility of flatfishes to the etiological agent responsible for the disease. In this regard, tumors on flatfishes may serve as a general indicator of unsuspected carcinogens in the environment (Miller and Wellings, 1971). Recently, Stich, et al. (1976), have advocated the use of tumor-bearing fishes (English sole and Pacific cod) for just this purpose.

Sampling of tumor-bearing young-of-the-year English sole has been conducted at West Point since 1973 (Miller, et al., 1974, 1976). These data indicate that there has been essentially no change in incidence for the three years, either on the south beach or the north beach. One relationship that has continued over the three-year period is that the incidence on the south beach is consistently higher than on the north beach. The reason for this is unclear, but one possibility is that tumorous fish prefer the softer sediments of the south beach to those on the north side of the point.

1.2.2 Parasite Incidence (Philometra)

Our data from 1975-76 indicate that the incidence of Philometra-infested English sole and rock sole was much higher at Point Pully than at either Alki Point or West Point. These data strongly suggest that there is no relationship between parasite infestation levels and sewage discharge from METRO outfalls in Puget Sound. In general, parasite infestation seems to increase greatly as one progresses farther into southern Puget Sound. For example, recent studies (Miller, et al., 1974) have shown that nematode infestation exceeds 50% in populations of English sole (50.7%) and rock sole (56.3%) at Stadium in Case Inlet. In addition, Holland (1954) reported nematode infestation levels of 72% in Carr Inlet, 90% in Case Inlet, 46% in Colvos Passage, and 0.6% at Golden Gardens. Amish (1976) has reviewed the distributional range and hosts of Philometra outside Puget Sound.

The causes of geographical variation in parasite infestation remain unclear. It has been suggested that local variations in temperature and dissolved oxygen or patterns of water circulation are important controlling factors (Moulton, et al., 1974). In the case of our study, however, these parameters did not vary significantly between sites. A more likely possibility is that the distribution of the intermediate host (probably a copepod) plays an important role in regulating the geographical distribution of the parasite and its subsequent infestation of the primary host (e.g., a fish). The possible explanations for variations in the geographical distribution of the parasite are discussed more fully by Amish (1976).

2. Duwamish River Study

2.1 Fish Populations

Although some twenty-nine species of fish were collected in the Duwamish River during both 1974 and 1975-76, five principal species dominated the structure and seasonal dynamics of the demersal fish community. Two of the species (snake prickleback and longfin smelt) were largely seasonal in occurrence, whereas the other three (English sole, starry flounder, and staghorn sculpin) were basically residents of the river. Periodic sampling in the Duwamish (Salo, 1969) during 1966-67 revealed a similar pattern of dominance by four of the same five species found in 1974-76--English sole, starry flounder, prickleback, and staghorn sculpin.

The most striking difference between years is that no longfin smelt were found in 1966-67. Our sampling, however, demonstrated that smelt were a dominant portion of the catch during the late summer and fall. The reason for this discrepancy is not clear, although it is possible that a new anadromous run became established in the river between 1967 and 1974, or that a previously established small run increased in size. It is also possible that the sampling gear and design used in 1966-67 missed them altogether. There is no evidence for the first of these possibilities, although the latter is plausible for two reasons. First, the sampling conducted during 1966-67 was confined to the portion of the river represented by our stations A-D where the fewest smelt were captured, and secondly, most of the 1966-67 sampling occurred during the months when smelt were comparatively rare during 1974-76.

The striking similarity of the catch results reported by Salo (1969) and our data suggests that water or environmental quality of the Duwamish

River has not appreciably changed in the intervening years.

Although species richness (number of species) in the Duwamish River is not especially high (a total of 29 species) and only a few (5) species dominate, the pooled annual diversity (Shannon-Wiener), based on numbers, for 1975-76 (2.02) is at the high end of the spectrum based on published studies from other polluted estuaries. Haedrich and Haedrich (1974) reported a pooled annual diversity for the heavily polluted Mystic River in Boston to be 1.19 (based on numbers). In the heavily polluted upper portion of Galveston Bay, Bechtel and Copeland (1970) have found the diversity to be severely reduced, ranging from 0.13 to 0.91. Similarly, the annual range in diversity for the moderately polluted Patuxent River was reported by McErlean, et al. (1973), to be in the range of 0.2-1.2. In contrast to these diversity estimates from polluted estuaries, Dahlberg and Odum (1970) indicated that diversity in a pristine Georgia estuary ranged seasonally from 0.7 to 1.8. These comparative data suggest that the Duwamish River may not suffer from the same degree of environmental stress observed elsewhere (e.g., Galveston Bay); however, there are two major difficulties with such comparisons. First, the use of diversity indices has been heavily criticized (Hedgepeth, 1973) because of their unclear cause and effect relationship to environmental stress, and secondly, it is exceedingly difficult to select appropriate areas for comparative purposes. The general similarity of diversity values from the Atlantic coast estuaries suggests that such levels may be characteristic of that region (Haedrich and Haedrich, 1974). What are sorely needed are comparative data for both polluted and non-polluted locales within the same geographical area. At this point, it seems best to take a cautious approach, and not infer the degree of environmental stress on the basis of diversity indices alone. This is especially true in the Duwamish River where a clearly pollution-related disease (fin erosion of starry flounder) is so prevalent.

Annual pooled diversity in the Duwamish River for 1975-76 (2.02) was very similar to that found in 1974 (1.92). Although Salo (1969) did not compute Shannon-Wiener diversity for the 1966-67 sampling, the raw data were available for such computations. Based on those reported data, the diversity in 1966-67 was 1.85; hence, it appears that diversity has not substantially changed over the past ten years. As suggested before, these data imply that water quality has remained little changed in recent years, in spite of increasingly heavy industrial utilization.

2.2 Fish Health

2.2.1 Tumors

An extremely high incidence of tumors in starry flounder was observed in the Duwamish River (especially in fall) during both 1974 and 1975-76. In general, the incidence of tumors varied by sampling site, time of year, and size of fish; however, similar patterns were observed during each year.

Very few early developmental stage tumors (AENs) were observed on starry flounder. Most tumors were late stage tumors (EP), which suggests either that tumor-bearing individuals migrate into the Duwamish River from elsewhere (presumably Elliott Bay) or that they occur in unsampled portions of the river during the earliest months of life when tumors initially develop. This is an important question since knowledge of the location of young fish when the tumors first develop may help determine the location and nature of the etiological agent responsible for the disease. Also germane to this question is the location and timing of spawning of starry flounder. Recent sampling by NMFS personnel in Elliott Bay failed to collect ripe adults (Misitano, pers. comm.) and none were found during the course of our sampling in the Duwamish River. In addition, no individuals less than 50 mm TL were ever sampled in the river during our study. Since the smallest starry flounder collected in the river were always found at our uppermost stations, it has been proposed that newly metamorphosed individuals and those fish less than 50 mm TL were located even higher in the river. However, past data from West Point (south beach) during 1974 indicate that large numbers of recently metamorphosed young were collected in May. This information suggests that spawning occurs in March-April and that development, settlement, and early growth probably occur outside the river.

Tumor-bearing starry flounder were first reported in the Duwamish by Salo (1969). Periodic sampling during 1966-67 indicated that the overall incidence for the resident population was 10.3% (33/321). If only fish less than 160 mm TL were considered, the incidence was considerably higher at 20.1%. Our sampling in 1975-76 showed the overall incidence to be 16.9%, a level which was not markedly different from that observed in 1974. However, our studies also found the incidence to be substantially higher for small individuals at the uppermost river stations G and H in fall. During both years of sampling, the incidence exceeded 40% among small fishes. Salo (1969) reported a lower incidence probably because of the location of his sampling stations. Even though much of his 1966-67 sampling was conducted in fall, the sampling stations used were not high enough up the river to capture the heavily diseased young-of-the-year.

The exceptionally high incidence of tumor-bearing starry flounder in the Duwamish River does not appear to be an isolated phenomenon in Puget Sound. McArn, et al. (1968), found that 2.4% of the starry flounder collected in

Bellingham Bay had tumors, while 54% of the young-of-the-year sampled from the Nooksack estuary were tumor-bearing. Tumor-bearing fishes have also been collected in the Nisqually River and off Big Beef Creek in Hood Canal (S.F. Borton, pers. comm.); however, thus far, detailed studies have not been conducted which would provide reliable estimates of tumor incidence at those locations. The occurrence of tumorous starry flounder and other flatfishes in presumably unpolluted areas strongly argues that the etiological agent responsible for the disease is widespread and not directly related to pollution. It is possible that pollution stress may increase the susceptibility of flatfishes to the disease-causing agent (Miller and Wellings, 1971), yet the data are not sufficient at present to test this hypothesis.

Our studies during 1974 and 1975-76 have shown that tumors (both AEN and EP) occurred predominantly on the eyed side of individual starry flounder. Salo (1969) also reported the same finding for tumorous starry flounder collected in 1966-67. This pattern has persisted over a 10-year period despite the fact that starry flounder may be either left- or right-handed. Miller and Wellings (1971) also reported AEN-type tumors to occur significantly more often on the eyed side of flathead sole. Furthermore, they suggested that this differential occurrence of tumors on the eyed sides indicates that the tumorigenic events probably occur after metamorphosis. Since starry flounder appear to spawn in March-April and metamorphose on local beaches outside the Duwamish River in May, it is possible that the events responsible for tumor formation occur sometime during this period.

Our work in the Duwamish River during 1974 and 1975-76 also showed that the incidence of tumors on starry flounder declined with both increasing size and age. Other studies of tumor-bearing flatfishes have also observed this decline (Miller and Wellings, 1971; Angell and Miller, 1975; Mearns and Sherwood, 1974). Most workers have attributed the decline in incidence to increased mortality. Miller and Wellings (1971) believe that the apparently high mortality suffered by flathead sole is associated with factors such as an inability to feed, escape predators, and an increased susceptibility to environmental changes. The absence of any large (> 200 mm TL) starry flounder with tumors suggests either that diseased fish experience heavy mortality as they grow older, or that they emigrate from the river into Elliott Bay. Since no tumor-bearing starry flounder have been collected in Elliott Bay or nearby areas (Alki Point or West Point), high mortality is the most probable explanation for the decline in tumor incidence with increased age and size.

2.2.2 Fin Erosion

During 1974 and 1975-76, our studies in the Duwamish River demonstrated an exceptionally high incidence of fin erosion in starry flounder. To date, widespread sampling in Puget Sound has not revealed, other than a stray occurrence, any cases of fin erosion. These observations strongly suggest that the agent responsible for fin erosion is confined to the Duwamish River.

The fin erosion disease of starry flounder was first noted by Salo (1969) in 1966-67; however, only 12 diseased fishes (ranging from 76 to 294 mm TL) were collected. In contrast, our sampling during 1974-76 indicated a substantially higher overall incidence (about 13%). The discrepancy between 1966-67 and 1974-76 may be due to mis-diagnosis of the disease or inadequate sampling at the stations where large numbers of diseased fish were found in the 1974-76 studies. Our sampling showed that the highest incidence of fin erosion occurred in the upper river. Unfortunately, however, the sampling reported on by Salo (1969) was confined to the lower river. It is unfortunate that our respective data are not more directly comparable, since it appears that fin erosion disease may be an especially good indicator of toxic substances in the sediment and of the accumulation of sludge deposits (Mearns and Sherwood, 1974).

Fin erosion diseases have been observed in flatfish populations associated with areas of heavy wastewater discharge (ocean outfalls) in both Southern California (Mearns and Sherwood, 1974) and the New York Bight (Ziskowski and Murchelano, 1975). In Southern California, Dover sole are the most frequently afflicted species, although it has been reported for other species including the white croaker and rex sole. In the New York Bight, the disease affects some 22 species of fish, particularly the summer and winter flounder (Mahoney, et al., 1973).

Our observations on fin-eroded starry flounder indicate that only individuals exceeding 100 mm TL exhibit diagnosable external signs of the disease. We also found that the disease was most prevalent among fishes ranging from 150 to 250 mm TL (ages II and III). Similar observations have been made for Dover sole in California (Sherwood and Bendele, 1974) and winter flounder in New York (Ziskowski and Murchelano, 1975). Fin-eroded Dover sole were typically 100-200 mm TL and winter flounder were even larger (200-250 mm TL). In general, it appears that regardless of species and location, fin erosion disease afflicts larger individuals of a population. It is not immediately evident why this should be the case; however, three possibilities exist. These include:

(1) The disease requires a long developmental period prior to becoming externally apparent.

(2) Extended exposure to the etiological agent is required.

(3) The younger, smaller individuals simply do not come into contact with the etiological agent.

Recent induction experiments with Dover sole (Sherwood, 1976), which indicate that at least 13 months of exposure to contaminated sediments is required before early fin erosion signs appear, lend support to the second possibility.

Mearns and Sherwood (1974) have proposed that fin erosion of Dover sole is a function of sediment and fin interactions. Their data indicate that the fins (dorsal, caudal, and anal) with the highest frequency of erosion were those most intimately associated with the sediment and involved in locomotion. Furthermore, they observed that the blind pectoral fin which is in contact with the sediment was more frequently eroded than the eyed pectoral which is not. Similarly, Ziskowski and Murchelano (1975) found that the anal, caudal, and dorsal fins of winter flounder from the New York Bight were most frequently eroded. These data agree well with our observations of starry flounder from the Duwamish River. In each case, the data strongly support the hypothesis that fin erosion is caused by a sediment-associated etiological agent. Recent evidence (SCCWRP, 1976) suggests that one of these agents may be chlorinated hydrocarbons, either accumulated by feeding or taken up directly from the environment.

2.2.3 Growth

It is apparent from our study of the age and growth of apparently normal and diseased starry flounder that tumor-bearing fishes experience markedly reduced growth in both length and weight. Tumor-bearing fishes suffered significantly reduced growth at all ages beyond 8-10 months when compared with apparently normal fish. Miller and Wellings (1971) investigated the age and growth of normal and tumor-bearing flathead sole from East Sound, Orcas Island, and found that growth was significantly retarded for individuals by their second year of life. No significant difference, however, could be found between normal and AEN-bearing young-of-the-year fishes. Similarly, Angell and Miller (1975) were unable to detect a significant reduction in growth for tumor-bearing young-of-the-year English sole in Puget Sound.

The effects of fin erosion on the growth of starry flounder, however, are much less clear. Our data indicate that growth of fin-eroded individuals is reduced only at ages of 34-42 months, nearly 15 months after the first external signs of the disease become visible. Mearns and Harris (1975) have investigated the growth of normal and fin-eroded populations of Dover sole from Southern California and found that Dover sole from the Palos Verdes shelf, a focal point for wastewater discharge and an area of high fin erosion prevalence (Sherwood and Bendele 1975), had a reduced growth rate (in weight) when compared with fish from other coastal areas (e.g., San Pedro, Santa Monica Bay, and Dana Point - Laguna Beach). It is difficult to interpret these results, however, since Mearns and Harris (1975) did not specifically examine growth of fin-eroded and normal individuals directly; rather they compared populations from different areas which were known to have different incidences of the disease.

In general, our data show that growth of tumorous starry flounder is significantly reduced soon after the initial appearance of the tumors. In contrast, fin-eroded fish do not suffer from diminished growth until nearly 15 months after the development of external signs of the disease. These observations suggest that the effect of fin erosion on growth requires a much longer period to manifest itself. The fin erosion induction experiments conducted by Sherwood (1976) on Dover sole, which suggest that the disease requires a long developmental period, tend to support this idea. Although growth of fin-eroded fish is apparently reduced at older ages, there does not appear to be a significant increase in mortality. Evidently, locomotion relating to predator avoidance and feeding behavior is not, in most instances, impaired to the point of causing death. In contrast, tumor-bearing fish appear to suffer extremely high mortality rates.

Our data clearly show that tumor-bearing starry flounder grow more slowly than normal individuals. However, the growth of apparently normal starry flounder from the Duwamish River is also markedly lower than that for populations of non-diseased (i.e., normal) fish from East Sound, Orcas Island (Miller, 1965) and California (Hart, 1973). Miller (1965) found total lengths at age for female starry flounder in East Sound as follows: 2 yr., 302.5 mm; 3 yr., 369.3 mm; 4 yr., 415.6 mm; 5 yr., 459.6 mm; and 6 yr., 500.4 mm. Although starry flounder from the Duwamish River were aged on a monthly basis, it is very clear that normal individuals grow substantially slower than those from East Sound. The reason for this difference in growth rate is unknown; however, it is probably related to the quality and abundance of food available to juvenile and adult starry flounder in the Duwamish. In order to investigate this question further, comparative data are needed on the growth of starry flounder from other areas in Puget Sound.

Pathology Studies

1. Fin Erosion

Our work generally agrees with previous studies of fin erosion in other species (Levin, et al., 1972; Klontz and Bendele, 1973; Mahoney, et al., 1973; Mearns and Sherwood, 1974; McDermott and Sherwood, 1975; Murchelano, 1975). The dorsal and anal fins are most frequently involved and the histopathology of the tissue lesions is similar. Other descriptions also mention focal zones of ulceration at the distal (free) margin of the affected fins, accompanied by extensive subacute and chronic fibrosing inflammation of the underlying connective tissue. We believe that these changes are fundamental and directly related to the scarring, retraction, and deformation of the affected fin. The resorption of fin rays may be a crucial part of the process, depriving the fin of structural support and accentuating the refraction, shortening, thickening, and loss of functional surfaces.

The etiology of fin erosion is unknown. Davis (1953) believes that in salmonids the disease is most commonly caused by bacteria, but other agents may be involved. Other authors (Snieszko, 1958; Bullock, 1968; Bullock and Snieszko, 1970) implicate myxobacteria as possible etiological agents. In some other diseases, such as bacterial dermatitis, similar pathology may be noted (Sindermann, 1966). Schaperclaus (1950) isolated bacteria of the genera Aeromonas and Pseudomonas from black mollies affected by fin rot. Apparently, a variety of bacteria have been suggested as etiological agents in the instance of salmonids and other fishes. In this regard it is always difficult to distinguish primary etiological agents from secondary (opportunistic) invaders.

In marine fishes Pseudomonas can induce experimental fin rot in the cod Gadus callarius (Oppenheimer, 1958). In the herring Clupea harengus, gram-negative, nonspore-forming pleomorphic rods were isolated from the ulcerated surface lesions, as well as from blood, kidneys, and skeletal muscle of affected fish (Sindermann and Rosenfield, 1954).

The studies of Mahoney, et al. (1973), implicate Aeromonas, Pseudomonas, and Vibrio in pleuronectids. These authors believe that the two conditions of dense pathogenic bacterial populations and environmental stress are prerequisites for the occurrence of the epizootic in the New York Bight. Pollution by domestic, agricultural, and industrial wastes could provide the high bacterial density and the environmental stress in the form of multiple harmful chemical agents. The chemical agents could include heavy metals, polychlorinated biphenyls (PCB), insecticide residues, herbicides, and household detergents.

In this regard McDermott and Sherwood (1975) determined levels of PCB and DDT in Dover sole (M. pacificus) with and without the fin erosion from the Palos Verdes area of the Southern California Bight. They found that Dover sole with fin erosion had slightly higher, but not statistically significant, levels of PCB than did normal Dover sole. DDT was found to be consistently and significantly higher in fish with fin erosion than in those without.

Analyses of PCB levels in English sole of the Duwamish River have been performed biannually since 1972 by the Environmental Protection Agency in cooperation with the Washington State Department of Fisheries. Levels of both Arochlor$^{(R)}$ 1260 and 1254 consistently averaged 1,500 ppb (dry weight) for total body mass (Pattie, 1975). Fish from five other estuaries of Puget Sound and the Washington coast did not have detectable PCB concentrations. PCB analyses of livers from starry flounders captured in the Duwamish River have also detected abnormally high levels of PCB (5.2 ppm, wet liver weight) (Pavlou, et al., 1973).

A probable continuous source of PCB in the Duwamish River is the bottom sediments. In analyses of such sediments performed in 1972 by S.P. Pavlou (pers. comm.), PCB levels averaging about 2,300 ppb (dry weight) were found at the river mouth. The levels decreased gradually as the sediment samples were collected farther upstream. Concentrations of PCB were about 500 ppb in areas where most fin-eroded fish were captured.

Although the presence of elevated PCB levels in the tissues and environment of a population of fish with a significant frequency of fin erosion is not proof of cause, PCB may represent a contributing factor. Additional analyses of PCB, DDT, and heavy metals in starry flounder and English sole from the Duwamish River are currently being performed, and the results will be reported in a later publication.

Mearns and Sherwood (1974) suspect that fin erosion in Dover sole from Southern California coastal waters is the result of contact of fins with toxic bottom sediments. Since no evidence of a bacterial disease is found in eroded fin tissue of Dover sole and since compounds such as sulfides, metallic compounds, chlorinated hydrocarbons, acids, and alkalies are known to be in bottom sediments, the authors suggest that toxins may remove protective mucus from fins and expose the fin tissue to the necrosing action of agents in the sediment. More recently, Dover sole with fin erosion are reported to produce a much smaller amount of external mucus than normal-appearing Dover sole (Sherwood and Bendele, 1975).

As in other disease processes in any species, the observations best fit a multifactorial hypothesis of etiology, i.e., it is logical to assume that multiple environmental variables (such as chemical pollutants, physical factors, mechanical injury, etc.) act in some combination on a susceptible genetic background to produce a particular incidence of disease in the population at risk.

2. Tumors

Skin tumors found on flounder in the Duwamish River and near the West Point sewage outfall resembled skin tumors found in other parts of Puget Sound. All three stages of the tumor were observed, and in general the tumors appeared to be histologically similar to flounder skin tumors from other areas.

The causes of flounder skin tumors are not known. Since virus-like particles have been observed in tumor cells with the electron microscope, there is a possibility that they might be virally caused. However, repeated attempts to isolate virus or to transmit the disease in vitro or in vivo were unsuccessful. In addition, other microorganisms are neither observed in, nor isolated from, tumor tissue.

Chemical contaminants of the marine environment cannot be ruled out as a cause of these tumors. Since skin tumors are found on flounder in relatively pristine waters, some of these chemicals may come from natural sources (e.g., natural oil seeps, products of plant metabolism). Additional man-made pollution may augment this natural tumor induction, although such a possibility has not yet been proven.

3. Abnormal Livers

To date, no biological agent has been implicated as the cause of the liver abnormalities in English sole and starry flounder from the Duwamish River or the nearby Puget Sound sites (Wingert, et al., 1975). Parasitism by a protozoan (*Myxidium* sp.) was observed in a large number of English sole and starry flounder from all sampled areas, but no correlation between parasite infestation and liver damage was found. Nutritional deficiencies in the food supply have not been thoroughly investigated.

Couch (1975) and Walsh and Ribelin (1975) have reviewed changes in fish exposed to chlorinated hydrocarbons and other insecticides. Most chlorinated hydrocarbons caused damage to multiple organs, but the liver appeared to be the organ most consistently damaged. Liver lesions associated with chlorinated hydrocarbon toxicities included: (a) Hepatocytes with abnormal fatty vacuolation, (b) cord structure disarray, (c) congestion, and (d) centrolobular degeneration and necrosis.

Couch (1975), Hansen, et al. (1974), Johansson, et al. (1972), and Eller (1971), studying the toxicity of polychlorinated biphenyls (PCB), reported severe fatty vacuolation, enlargement, increased basophilia, and pleomorphism of the hepatocytes. Also present were variable lipid accumulation, sinusoidal congestion, focal necrosis, abnormal fibrous tissue, and chloangiolar epithelial proliferative foci. The presence of PAS positive, diastase-resistant amorphous inclusions (probably ceroid) was detected in hepatic parenchymal cells.

Contamination by the insecticides DDT, DDD, and DDE, PCBs, copper, and lead of the waters and sediments of the Duwamish River has been reported by Pavlou, et al. (1973), and Wellings, et al. (1976). Although none of these chemicals has been positively identified as the etiological agent for the liver damage in the English sole and starry flounder studied, results of analyses for chlorinated hydrocarbons in Duwamish River English sole by the U.S. Environmental Protection Agency (EPA) have shown significant levels of PCBs in total body tissues (1.5 ppm, wet weight) (Pattie, 1975).

The liver damage found in the Duwamish River English sole and starry flounder is generally in agreement with the previously described liver damage produced by PCB and other chlorinated hydrocarbons. The presence of hepatomas in English sole may or may not be the result of PCB contamination as PCB has not been reported as causing hepatomagenesis on teleosts (Ashley, 1967, 1969). However, PCB is known to be a hepatocarcinogens for some mammals (Fishbein, 1974; Kimbrough, 1976).

The liver damage in English sole found at Alki Point, Point Pully, and West Point, and in starry flounder from McCalister Creek, is still under investigation. A relationship has not yet been established between the liver damage at these sites and that found in the Duwamish River.

Although environmental contaminants are suspected as being the etiological agent for the liver lesions in the Duwamish River English sole and starry flounder, the causal relationship between the histopathological damage and levels of PCB and other chemicals in associated tissues needs to be established. The results of such a study could then be used to initiate laboratory investigations employing English sole exposed to specific chemicals.

SUMMARY

Ecological Studies

Outfall Study

1. Sampling of nearshore fishes with beach seine gear during 1975-76 revealed differences between the major outfall site (West Point), the minor outfall site (Alki Point), and the control site (Point Pully), in terms of species composition, abundance, frequency of occurrence, species richness, and recurrent species groups.

2. In large part, the above-noted differences can be attributed to between-site habitat differences. There is no evidence that wastewater discharged from METRO facilities has adversely affected nearshore, shallow water fishes.

3. During the late spring and summer, the possibility exists that juvenile salmonids and other species which exploit the nearshore environment around West Point may be adversely affected by wastewater entrained into nearshore, shallow waters by inshore eddies.

4. Sampling of demersal fishes by otter trawl during 1975-76 demonstrated differences between the major outfall site and the other sites,

in terms of the relative abundance and frequency of occurrence of dominant species, species associations, diversity, and species richness.

5. At this time, we have no reason to suspect that between-site differences in the relative abundance or frequency of occurrence of demersal fishes between 5 and 45 m are related to sewage discharge from the METRO facilities.

6. Sampling at the deeper water stations (70 and 95 m) has revealed differences between sites which may be associated with wastewater discharged from the West Point facility.

7. The above-noted differences at West Point include the following: The apparent replacement of slender sole by rex sole, a greater total abundance during most seasons, a greater abundance of ratfish, and a reduction in both diversity and species richness.

8. In late spring and early summer, English sole and rock sole migrated from deep (45 m) to shallow (5 m) water. Similar patterns were observed at each of the three study sites.

9. Nighttime otter trawl sampling and beach seining indicated that several species not normally collected, or only collected in deeper water, enter shallow water (5-15 m) at night. The reasons for this movement are not fully understood, although it is most likely related to feeding behavior.

10. We have gathered no evidence which links the occurrence of tumor-bearing flatfishes with the discharge of wastewater by METRO. Tumor-bearing fishes occurred at all sampling sites, including the control.

11. The prevalence of <u>Philometra</u>-infested rock sole and English sole showed no relationship to METRO wastewater discharge.

12. Fin-eroded flatfish did not occur at West Point, Alki Point, or Point Pully.

Duwamish River Study

1. Five species of fish generally dominated (> 90% of total) the catch in the Duwamish River; however, their relative abundance varied markedly with the seasons. Starry flounder, snake prickleback, and longfin smelt were seasonal residents, whereas English sole and staghorn sculpin occurred year-round.

2. The occurrence of tumor-bearing starry flounder in the Duwamish River was related to location of sampling station, time of year, and size of fish. Tumor-bearing individuals were captured exclusively in the upper river, particularly at the higher stations. Tumor incidence levels were highest in winter, spring, and fall, and lowest in summer. Tumor incidences were highest for those individuals less than 150 mm TL.

3. Tumors more frequently occurred on the eyed side than the blind side of starry flounder.

4. Growth of tumor-bearing starry flounder was significantly retarded when compared with apparently normal fish.

5. The occurrence of fin erosion disease of starry flounder was related to location of sampling station and size of fish. Fin-eroded individuals occurred most frequently at the middle river stations, and the disease most often afflicted individuals in the 150-249 mm TL size class.

6. The fins of starry flounder most intimately associated with the sediment and involved with locomotion were the most frequently diseased.

7. Growth of fin-eroded starry flounder was not significantly retarded until some 12-15 months after the onset of the disease.

Pathology Studies

1. Starry flounder and English sole at West Point and Alki Point and in the Duwamish River had one or more of the following diseases: Fin

erosion, skin tumors (epidermal papillomas), and a liver disease which, in the case of Duwamish River English sole, included hepatomas.

2. Fin erosion was found only in the Duwamish River and was of two basic types: Chronic fibrosing fin erosion, found in starry flounder and some English sole; and acute necrotizing fin erosion, found only in English sole.

3. A characteristic common to both types of fin erosion was resorption of fin rays associated with fibrosis, granulosis, and loss of fin tissue structure. The chronic form resulted in retracted and thickened residual fin tissue, often with "flaps" or sheets of tissue extended out onto the body. The acute form often had denuded, exposed fin rays and varying amounts of ulcerated epidermis.

4. No disease-specific bacteria, fungi, or viruses were associated with fin-eroded fish.

5. A form of fin erosion was induced in 2 of 30 English sole experimentally exposed to Duwamish River bottom sediment, while 30 fish from the same lot exposed to control sediment remained normal. A similar experiment using starry flounder did not yield fin-eroded fish.

6. Skin tumors (epidermal papillomas) found on flounder from the Duwamish River and West Point were grossly and histopathologically similar to skin tumors found on flounder from other parts of Puget Sound. The frequency of tumor-bearing fish was no higher at these sites than at the control sites, Point Pully and McCalister Creek.

7. Histological examination of liver tissue revealed liver disease in 92% (127 of 138) of the Duwamish River starry flounder and 13% (5 of 39) of the McCalister Creek (control site) starry flounder.

8. Histological examination of liver tissue showed liver disease in 92% (57 of 62) of the Duwamish River English sole, and in the following proportions in English sole from other areas: 90% (9 of 10) at Alki Point, 60% (15 of 25) at West Point, and 22% (4 of 18) at Point Pully.

9. The gross appearance of the liver disease was characterized by liver discolorations and liver enlargement. Average somatic-liver indices (liver weight x 100/total body weight) were 2.42 and 1.07 for Duwamish River and McCalister Creek starry flounder, respectively. English sole had average indices of 2.40, 1.63, 1.30, and 1.12 for Duwamish River, Alki Point, West Point, and Point Pully, respectively.

10. The histopathological lesions in diseased livers from all areas included one or more of the following: Loss of normal liver architecture, cytoplasmic vacuolation of the hepatocytes, blood vessel congestion, and cellular degeneration. In addition, Duwamish River fish had increased size and number of melanin-macrophage centers, focal necrosis, variable hepatic tissue staining, megalocytic hepatocytes, increased interstitial connective tissue, and increased intercellular melanin deposition.

11. Of the Duwamish River English sole, 32% (20 of 62) had hepatomas. These neoplastic nodules were classified as three basic types (based on the staining properties and the appearance of the cells composing the nodules): Basophilic, eosinophilic, and anaplastic. In some cases the hepatomas were grossly visible as white or tan spots.

12. Chemical analyses of blood serum from Duwamish River starry flounder showed that these fish had concentrations of cholesterol and potassium four times higher than fish from a control area, which also suggests the existence of liver disease in Duwamish River flounder.

13. Analyses for PCB in starry flounder and sediments from the Duwamish River and McCalister Creek (control site) showed that the liver and skin of the Duwamish River fish had about forty times the concentration of PCB than did the control fish. The sediment from the Duwamish River had about 360 times more PCB than that from McCalister Creek.

14. Several types of evidence suggest that fin erosion and liver disease in starry flounder and English sole in the Duwamish River are different signs of a single systemic disease caused by one or more toxic chemical contaminants, possibly PCB.

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Table 1. List of species collected in vicinity of West Point during 1975-76. "F" (frequent) indicates species occurred in > 70% of samples; "C" (common) indicates species occurred in 30-70% of samples; "R" (rare) indicates species occurred in < 30% of samples.

		Beach seine			Otter trawl depths				
Species	Total number	9m net	37m[a] net	37m[b] net	5m	25m	45m	70m	95m
Spiny dogfish	9		R	R					
Ratfish	1,420		R		R	C	C	F	F
Pacific herring	481	R	C	C					
Chum salmon	92	R	R	R					
Coho salmon	168		C	R					
Chinook salmon	24		R	C					
Pink salmon	13		R	R					
Dolly Varden	2		R						
Surf smelt	55		R	R					
Longfin smelt	2		R						
Midshipman	1					R			
Pacific tomcod	4,836	C	C	C	R	R	C	C	R
Walleye pollock	18		R				R	R	R
Pacific cod	1					R			
Pacific hake	1								R
Red brotula	1								R
Blackbelly eelpout	56		R			R	R	R	R
Tube-snout	7		R	R	R				
Threespine stickleback	22	R	R	R					
Bay pipefish	1			R					
Shiner perch	4,419	C	C	C	R	R	C	C	R
Striped seaperch	119	R	C	R	R	R	R		
Pile perch	44		C	R		R	R		
Northern ronquil	58		R	R		R	C	R	
Snake prickleback	79		R	R	R	R	R		
Penpoint gunnel	5	R	R	R		R			

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[a] 37m sinking beach seine.

[b] 37m floating beach seine.

Table 1, cont'd

Species	Total number	Beach seine 9m net	Beach seine 37m[a] net	Beach seine 37m[b] net	Otter trawl depths 5m	Otter trawl depths 25m	Otter trawl depths 45m	Otter trawl depths 70m	Otter trawl depths 95m
Saddleback gunnel	3	R	R						
Pacific sandlance	247	R	R	R					
Brown rockfish	56					C	C		R
Copper rockfish	2					R	R		
Redstripe rockfish	2						R	R	
Quillback rockfish	84					C	C	R	C
Painted greenling	2					R			
Whitespotted greenling	3		R						
Padded sculpin	68	R	C	R		R	R		
Scalyhead sculpin	1					R			
Silverspotted sculpin	9		R	R	R				
Roughback sculpin	61		R		R	C	C	R	R
Sharpnose sculpin	42	R		R					
Buffalo sculpin	96	C	C	C	R				
Pacific staghorn sculpin	296	F	F	C	R	R	R		
Great sculpin	3		R	R					
Manacled sculpin	1					R			
Sailfin sculpin	6		R			R	R		
Tidepool sculpin	27	R	R	R					
Red Irish lord	1					R			
Slim sculpin	13						C	R	R
Tadpole sculpin	1					R			
Grunt sculpin	1					R			
Cabezon	2		R			R			
Northern spearnose poacher	5					R	R		
Sturgeon poacher	92	R	C	R		R	C	R	
Gray starsnout	4						R	R	
Spinycheek starsnout	6					R	R	R	
Pygmy poacher	7					R	R		

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[a] 37m sinking beach seine.

[b] 37m floating beach seine.

Table 1, cont'd

Species	Total number	Beach seine			Otter trawl depths				
		9m net	37m^{a} net	37m^{b} net	5m	25m	45m	70m	95m
Blacktip poacher	7							R	R
Bluespotted poacher	31	R					R	C	R
Tidepool snailfish	1					R			
Pacific sanddab	97		R		R	R	C		
Speckled sanddab	56		C		C	C	R		
Rex sole	60						R	F	C
Butter sole	5		R		R				
Rock sole	1,639	R	F	C	F	F	F	R	R
Slender sole	62	R	C			R	C	C	C
Dover sole	229	R	R			R	C	F	F
English sole	4,114	F	F	F	F	F	F	C	C
Starry flounder	32	R	C	R	R	R			
C-O sole	92		C	R	C	C	R		
Sand sole	26	R	R	R	R	R	R		
Hybrid sole	1		R						
Flathead sole	1						R		
Arrowtooth flounder	1						R		
Total number of individuals	19,537								
Total number of species	72								

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[a] 37m sinking beach seine.

[b] 37m floating beach seine.

Table 2. List of species collected in vicinity of Alki Point during 1975-76. "F" (frequent) indicates species occurred in > 70% of samples; "C" (common) indicates species occurred in 30-70% of samples; "R" (rare) indicates species occurred in < 30% of samples.

Species	Total number	Beach seine net 9m net	 37m* net	Otter trawl depths 5m	 45m	 70m
Spiny dogfish	1		R			
Ratfish	314				C	F
Pacific herring	13	R	R			
Chum salmon	41		R			
Pink salmon	6		R			
Coho salmon	25		R			
Chinook salmon	34	R	R			
Rainbow trout	1		R			
Surf smelt	1		R			
Midshipman	37				C	R
Northern clingfish	2	R	R			
Pacific cod	17		R		R	
Pacific tomcod	687	C	F	R	C	C
Walleye pollock	47		R	R	R	R
Pacific hake	3					R
Blackbelly eelpout	24				R	R
Tube-snout	1,874	C	F	C		
Threespine stickleback	2	R	R			
Bay pipefish	35	C	C			
Shiner perch	6,509	R	F	R	R	R
Striped seaperch	2,164	R	F	C		R
Pile perch	108	R	F	R		R
Northern ronquil	69				C	R
Wolf eel	1		R			
Snake prickleback	10		R			
Penpoint gunnel	127	F	F	R	R	
Crescent gunnel	21	R	R	R		
Saddleback gunnel	26	C	C			
Brown rockfish	31		R	R	C	R
Sharpchin rockfish	1				R	

*37-m floating beach seine (see Materials and Methods).

Table 2, cont'd

Species	Total number	Beach seine net 9m net	Beach seine net 37m* net	Otter trawl depths 5m	Otter trawl depths 45m	Otter trawl depths 70m
Copper rockfish	3		R			
Quillback rockfish	45		R		C	R
Redstripe rockfish	15				R	
Painted greenling	4			R	R	
Whitespotted greenling	3		R			
Padded sculpin	337	C	F	C	R	
Smoothhead sculpin	5	R	R			
Silverspotted sculpin	71	R	C	R		
Roughback sculpin	162		R	R	F	R
Sharpnose sculpin	76	C	R			
Buffalo sculpin	88	C	C	R		
Northern sculpin	9				R	
Red Irish lord	14		R	R		
Spotfin sculpin	77			R	C	R
Pacific staghorn sculpin	172	C	F		R	
Grunt sculpin	1			R		
Great sculpin	19	R	R			
Sailfin sculpin	40		R		R	R
Tidepool sculpin	19	C	C			
Threadfin sculpin	1					R
Slim sculpin	44			R	R	R
Manacled sculpin	1		R			
Roughspine sculpin	1				R	
Ribbed sculpin	1				R	
Cabezon	6		R	R		
Northern spearnose poacher	14				R	
Spinycheek poacher	1				R	
Sturgeon poacher	55		C	R	R	R
Gray starsnout	5			R		R

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*37-m floating beach seine (see Materials and Methods).

Table 2, cont'd

Species	Total number	Beach seine net 9m net	 37m* net	Otter trawl depths 5m	 45m	 70m
Pygmy poacher	64				C	R
Blacktip poacher	30					R
Bluespotted poacher	69				R	C
Pacific sanddab	32				R	
Speckled sanddab	72	R	C	R		
Rex sole	32				R	C
Rock sole	1,381	C	F	F	F	R
Slender sole	83		R		R	C
Dover sole	178		R		R	F
English sole	1,530	F	F	F	F	C
Starry flounder	8		R			
C-O sole	357		F	F	R	
Sand sole	10			R		
Arrowtooth flounder	1					R
Flathead sole	1					R
Total No. Individuals	17,367					
Total No. Species	75					

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*37-m floating beach seine (see Materials and Methods).

Table 3. List of species collected in the vicinity of Point Pully during 1975-76. "F" (frequent) indicates species occurred in > 70% of samples; "C" (common) indicates species occurred in 30-70% of samples; "R" (rare) indicates species occurred in < 30% of samples.

		Beach seine			Otter trawl depths				
Species	Total number	9m net	37m^a net	37m^b net	5m	25m	45m	70m	95m
Spiny dogfish	11		R						
Ratfish	530		R		R	C	C	F	F
Pacific herring	2,286		R	R			R	R	
Chum salmon	35			R					
Coho salmon	21		R	R					
Chinook salmon	16		R						
Cutthroat trout	9		R	R					
Dolly Varden	1			R					
Surf smelt	2		R						
Plainfin midshipman	42			R		R	R	R	R
Pacific cod	5						R	R	
Pacific hake	2							R	
Pacific tomcod	496	C	C	R	R	R	C	R	R
Walleye pollock	73		R				R	R	R
Red brotula	1								R
Blackbelly eelpout	4						R	R	R
Tubesnout	267	R	R	R	R				
Threespine stickleback	5	R	R	R					
Bay pipefish	45	C	R	C	R	R			
Shiner perch	11,183	F	F	C	R	R			
Striped seaperch	1,132	R	F	C	R	R			
Pile perch	279		C		R	R	R		
Northern ronquil	51					R	F	R	R
Snake prickleback	17		R	R					
Penpoint gunnel	43	R	R	R	R				
Crescent gunnel	9		R						
Saddleback gunnel	27	R	R	R					

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a--37m sinking beach seine.
b--37m floating beach seine.

Table 3, cont'd

		Beach seine			Otter trawl depths				
Species	Total number	9m net	37m[a] net	37m[b] net	5m	25m	45m	70m	95m
Pacific sand lance	208	R	R	R					
Brown rockfish	79		R		R	C	C	R	
Copper rockfish	6		R			R	R		
Quillback rockfish	56		R		R	R	C	C	R
Redstripe rockfish	23						R	R	
Sharpchin rockfish	1						R		
Kelp greenling	1					R			
Whitespotted greenling	3	R							
Painted greenling	18					R			
Padded sculpin	221	C	C	C	R	R			
Scalyhead sculpin	2				R				
Silverspotted sculpin	1	R	R	R	R				
Roughback sculpin	308		C		R	F	F	R	R
Sharpnose sculpin	8	R							
Buffalo sculpin	11	R	R	R	R				
Soft sculpin	2								R
Red Irish lord	2		R						
Northern sculpin	6						R		
Spotfin sculpin	36					R	C	R	R
Pacific staghorn sculpin	694	F	F	F	R	R			
Sailfin sculpin	38		R	R			R		
Tidepool sculpin	7	R	R	R					
Tadpole sculpin	1				R				
Slim sculpin	38					R	C	R	
Grunt sculpin	4					R	R		
Cabezon	4		R						
Manacled sculpin	2				R				
Northern spearnose poacher	11		R		R		R		
Sturgeon poacher	22	R	R			R	R		

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a--37m sinking beach seine.
b--37m floating beach seine.

Table 3, cont'd

Species	Total number	Beach seine 9m net	Beach seine 37m[a] net	Beach seine 37m[b] net	Otter trawl depths 5m	Otter trawl depths 25m	Otter trawl depths 45m	Otter trawl depths 70m	Otter trawl depths 95m
Grey starsnout	2							R	
Pygmy poacher	21					R	R	R	
Blacktip poacher	16							R	
Bluespotted poacher	53		R				R	C	R
Showy snailfish	1								R
Pacific sanddab	126		R		R	R	F		
Speckled sanddab	75		C	R	C	C	R		
Petrale sole	1							R	
Rex sole	55						C	C	R
Rock sole	2,865	R	F	C	F	F	F	R	R
Slender sole	126		R				C	F	C
Dover sole	119		R			R	C	C	C
English sole	3,493	F	F	F	F	F	F	C	C
Starry flounder	39	R	C	R	R				
C-O sole	542		F	C	C	R	R		
Sand sole	14	R	R			R	R		
Arrowtooth flounder	2								R
Total No. Individuals	25,954								
Total No. Species	73								

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a--37m sinking beach seine.
b--37m floating beach seine.

Table 4. Ten most abundant species collected by beach seine (37-m net) and otter trawl at West Point during 1975-76.

	Beach seine			Otter trawl		
Rank	Species	Total	% Total	Species	Total	% Total
1	Pacific tomcod	3,036	36.0	English sole	1,459	27.1
2	Shiner perch	2,632	31.2	Ratfish	1,417	26.4
3	English sole	1,496	17.8	Rock sole	1,063	19.8
4	Rock sole	558	6.6	Dover sole	199	3.7
5	Staghorn sculpin	140	1.7	Pacific tomcod	196	3.6
6	Striped seaperch	86	1.2	Shiner perch	185	3.4
7	Chum salmon	49	0.6	Roughback sculpin	124	2.3
8	Sturgeon poacher	45	0.5	Pacific sanddab	95	1.7
9	Padded sculpin	43	0.5	C-O sole	69	1.3
10	Buffalo sculpin	40	0.4	Rex sole	60	1.1
	Total	8,126	96.4		4,867	90.7
			(8126/8426)			(4,867/5,368)

Table 5. Ten most abundant species collected by beach seine (37-m net) and otter trawl at Alki Point during 1975-76.

	Beach seine			Otter trawl		
Rank	Species	Total	% Total	Species	Total	% Total
1	Shiner perch	6,423	48.7	Rock sole	650	20.4
2	Striped perch	1,922	14.6	English sole	586	18.4
3	Tubesnout	1,800	13.6	Ratfish	364	11.4
4	English sole	782	5.9	Striped perch	204	6.4
5	Rock sole	692	5.2	Tomcod	133	4.2
6	Tomcod	411	3.1	Dover sole	140	4.4
7	C-O sole	204	1.5	C-O sole	129	4.1
8	Padded sculpin	145	1.1	Roughback sculpin	121	3.8
9	Staghorn sculpin	145	1.1	Slender sole	64	2.0
10	Pile perch	84	0.6	Bluespotted poacher	63	1.9
	Total	12,608	95.7		2,454	77.1
			(12,608/13,175)			(2454/3183)

Table 6. Ten most abundant species collected by beach seine (37-m net) and otter trawl at Point Pully during 1975-76.

	Beach seine			Otter trawl		
Rank	Species	Total	% Total	Species	Total	% Total
1	Shiner perch	10,942	52.1	Rock sole	1,302	29.8
2	English sole	2,393	11.4	English sole	759	17.3
3	Pacific herring	2,283	10.9	Ratfish	536	12.3
4	Rock sole	1,564	7.5	Roughback sculpin	256	5.8
5	Striped perch	1,075	5.1	Tomcod	125	2.9
6	Tomcod	473	2.3	Pacific sanddab	120	2.7
7	Staghorn sculpin	473	2.3	Slender sole	115	2.6
8	C-O sole	446	2.1	Dover sole	111	2.5
9	Pile perch	242	1.6	Tubesnout	94	2.2
10	Tubesnout	157	0.7	Striped perch	48	1.1
	Total	19,891	94.8		3,466	79.4
			(19,891/20,977)			(3466/4367)

Table 7. Monthly catch per haul (CPH) of the five most abundant and frequently occurring species taken with the 37-m beach seine at West Point during 1975-76. Dash indicates no fish collected.

Rank	Species	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1	Tomcod	7.0	--	--	--	--	0.5	0.5	0.5	1412.0	39.0	14.0	33.0	12.5	--	--	--
2	Shiner perch	11.0	--	--	1.0	0.5	25.5	19.0	28.5	929.5	139.5	74.0	36.0	50.5	0.5	--	--
3	English sole	44.0	--	4.0	26.5	71.5	44.0	59.5	67.0	175.5	22.0	103.0	64.5	29.5	15.5	1.0	21.5
4	Rock sole	0.5	--	--	--	35.0	37.0	34.0	29.5	23.5	25.0	27.5	10.5	19.5	2.0	6.0	29.0
5	Staghorn sculpin	13.5	--	0.5	0.5	2.0	6.5	4.0	5.5	10.5	2.5	1.0	16.5	6.0	0.5	--	0.5

Table 8. Monthly catch per haul (CPH) of the nine most abundant and frequently occurring species taken with the 37-m beach seine at Alki Point during 1975-76. Dash indicates no fish collected.

Rank	Species	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Apr	May	June
1	Shiner perch	0.5	--	130.0	64.0	258.5	189.5	143.0	1542.0	648.0	1307.5	59.0	--	--	26.0
2	Striped perch	1.0	--	83.0	90.0	350.5	301.0	19.0	76.0	99.0	10.5	--	0.5	38.5	24.5
3	Tubesnout	--	--	6.0	5.0	14.5	26.0	90.5	984.0	211.0	136.0	38.0	2.5	9.0	6.5
4	English sole	8.5	--	25.0	79.0	6.0	3.0	20.0	111.0	265.0	41.0	55.0	5.0	15.5	7.0
5	Rock sole	3.0	--	81.5	55.0	41.5	15.5	9.0	24.0	47.0	23.5	11.0	7.0	64.0	33.5
6	Tomcod	--	--	0.5	--	6.5	3.0	25.0	118.0	122.0	37.5	25.0	--	--	--
7	C-O sole	--	--	6.5	14.0	8.0	3.0	6.0	7.0	12.0	7.5	6.0	10.5	21.5	20.0
8	Staghorn sculpin	0.5	--	7.0	6.0	1.0	3.5	6.0	14.0	32.0	19.5	5.0	0.5	4.5	6.5
9	Padded sculpin	1.0	--	4.0	17.0	5.0	7.5	17.5	21.0	13.0	1.5	3.0	--	1.5	7.5

Table 9. Monthly catch per haul (CPH) of the six most abundant and frequently occurring species taken with the 37-m beach seine at Point Pully during 1975-76. Dash indicates no fish collected.

Rank	Species	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
1	Shiner perch	191.5	--	0.5	1.5	138.0	486.5	83.0	667.5	860.0	417.0	183.5	60.5	26.5	--	0.5	1.5	84.5
2	English sole	27.0	2.5	3.5	9.5	41.5	55.0	119.0	83.0	290.0	97.0	75.0	37.5	10.0	--	3.5	11.5	66.5
3	Rock sole	16.5	1.5	2.0	27.0	67.0	72.0	73.5	38.5	92.5	35.0	49.0	13.0	16.0	0.5	2.0	65.0	64.5
4	Striped perch	--	--	--	14.0	29.5	57.0	10.5	103.5	17.5	75.0	25.5	8.0	--	--	5.0	16.0	25.0
5	Staghorn sculpin	5.5	0.5	--	--	25.0	4.5	7.0	13.0	12.0	13.5	9.0	10.0	9.5	0.5	0.5	2.0	13.5
6	C-O sole	8.5	4.0	--	15.5	37.5	25.1	1.5	2.5	1.5	26.5	17.0	10.0	2.5	1.0	8.5	18.5	25.0

Table 10. Seasonal bathymetric distribution of species groups I (ratfish, Dover sole, and rex sole) and II (roughback sculpin and rock sole) at West Point during 1975-1976.

Group	Depth	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
I	5 m															
	25															
	45						X		X							
	70	X	X	X	X	X	X	X	X	X			X	X		
	95			X	X	X		X	X				X	X	X	X
II	5 m	X	X					X								
	25	X	X	X		X	X	X	X						X	X
	45	X	X	X	X			X					X	X	X	X
	70															
	95															

Table 11. Seasonal bathymetric distribution of species groups I (roughback sculpin, English sole, and rock sole); II (ratfish, slender sole, and Dover sole); and III (northern ronquil and tomcod) at Alki Point during 1975-76.

Group	Depth	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
I	5m		X					X	X	X	X			X	
	25												X	X	X
	45	X	X		X	X	X	X			X		X	X	X
	70	X											X		
	95														
II	5m														
	25														
	45										X				X
	70	X	X			X	X		X				X	X	X
	95													X	
III	5m														
	25														
	45		X	X		X	X		X	X	X		X	X	X
	70	X													
	95														

Table 12. Seasonal bathymetric distribution of species groups I (English sole, Pacific sanddab, rock sole, and roughback sculpin) and II (Dover sole, slender sole, and ratfish) at Point Pully during 1975-1976.

Group	Depth	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
I	5 m						X									
	25			X	X		X			X					X	
	45	X	X	X		X	X		X	X	X	X	X		X	
	70												X			
	95															
II	5 m															
	25															
	45			X						X	X		X	X	X	
	70		X	X			X			X		X	X	X	X	
	95	X	X	X			X						X	X	X	

Table 13. Species collected at Alki Point with the 9-m beach seine from May 1976 through January 1977.

Species	Total number	Eelgrass Number	Eelgrass Frequency of occurrence	Sand Number	Sand Frequency of occurrence
Pacific sandlance	1,250	1,250	0.04		
Striped seaperch	992	988	0.76	4	0.08
Shiner perch	846	758	0.84	88	0.21
Tube-snout	655	655	0.64		
Padded sculpin	417	400	0.88	17	0.46
English sole	710	385	1.00	325	0.79
Crescent gunnel	334	328	0.88	6	0.25
Pacific tomcod	390	306	0.36	84	0.33
Rock sole	110	94	0.84	16	0.33
Sharpnose sculpin	122	86	0.52	36	0.42
Buffalo sculpin	88	72	0.88	16	0.50
Saddleback gunnel	73	63	0.76	10	0.29
Bay pipefish	60	60	0.64		
C-O sole	59	59	0.68		
Penpoint gunnel	59	57	0.68	2	0.08
Sturgeon poacher	42	42	0.44		
Pacific staghorn sculpin	55	34	0.60	21	0.38
Silverspotted sculpin	30	28	0.52	2	0.08
Coho salmon	22	22	0.08		
Sailfin sculpin	16	16	0.28		
Pile perch	13	13	0.24		
Smoothhead sculpin	8	8	0.24		
Great sculpin	7	6	0.20	1	0.04
Scalyhead sculpin	4	4	0.12		
Walleye pollock	4	4	0.16		
Threespine stickleback	6	3	0.08	3	0.04
Cabezon	3	3	0.12		
Snake prickleback	5	3	0.12	2	0.08
Tadpole sculpin	3	3	0.08		
Sand sole	5	2	0.08	3	0.13
Speckled sanddab	2	2	0.08		
Pink salmon	2	2	0.04		
Starry flounder	3	2	0.04	1	0.04
Pacific cod	2	2	0.08		
Brown rockfish	2	2	0.08		
Whitespotted greenling	2	2	0.08		
Roughback sculpin	2	2	0.08		
Manacled sculpin	1	1	0.04		
High cockscomb	1	1	0.04		
Quillback rockfish	1	1	0.04		
Surf smelt	5	1	0.04	4	0.13
Tidepool sculpin	6			6	0.17
Pacific herring	15			15	0.21
Slender sole	1			1	0.04
	6,433	5,770		663	

Table 14. Species collected by trammel net at dusk and dawn during 24-hour studies conducted at West Point in the fall, winter, and spring, 1975-76.

	Fall (1975)	Winter (1976)		Spring (1976)	
Species	Dusk	Dusk	Dawn	Dusk	Dawn
Spiny dogfish	9			4	
Ratfish	2		1	3	
Pacific cod	2	1		10	4
Walleye pollock	19	11			
Pacific tomcod	15	10		1	
Pacific hake	5				
Shiner perch	1			4	
Striped perch	2				
Prickleback					1
Quillback rockfish	1				
Brown rockfish	1		1	5	1
Copper rockfish	2		1		
Sailfin sculpin		1		1	
Cabezon			1	3	1
Staghorn sculpin	6	21		10	4
Sturgeon poacher	5	2		6	1
C-O sole				1	1
Rock sole		3		10	5
Pacific sanddab	5				
Speckled sanddab				3	
Slender sole	4	4		5	4
Dover sole				4	8
English sole	16	46		104	26

Table 15. Percent incidence of tumor-bearing English sole (*Parophrys vetulus*) collected at West Point during 1975-6(37-m and 9-m beach seine catches are combined).

	Beach seine			Otter trawl		
Month	Age 0	Age I	Age II+	Age 0	Age I	Age II+
February	0.0 (0/10)	18.4 (7/38)	0.0 (0/40)	NO SAMPLING		
March	NO SAMPLING			0.0 (0/0)	8.7 (2/23)	0.0 (0/130)
April	3.2 (1/31)	100.0 (1/1)	100.0 (1/1)	0.0 (0/13)	2.5 (1/40)	0.0 (0/105)
May	0.0 (0/42)	0.0 (0/3)	0.0 (0/13)	0.0 (0/0)	20.0 (1/5)	0.0 (0/44)
June	0.0 (0/129)	0.0 (0/33)	0.0 (0/52)	0.0 (0/0)	3.2 (1/31)	0.0 (0/72)
July	0.0 (0/144)	0.0 (0/11)	0.0 (0/24)	0.0 (0/3)	0.0 (0/14)	0.0 (0/58)
August	0.0 (0/235)	7.1 (1/14)	0.0 (0/15)	0.0 (0/6)	0.0 (0/14)	0.0 (0/30)
September	7.0 (12/171)	17.6 (3/17)	0.0 (0/7)	7.7 (3/39)	2.5 (1/40)	0.0 (0/58)
October	4.2 (7/165)	3.3 (6/180)	0.0 (0/85)	6.3 (1/16)	2.6 (1/39)	0.0 (0/49)
November	7.8 (4/51)	0.0 (0/0)	0.0 (0/0)	0.0 (0/0)	0.0 (0/0)	0.0 (0/0)
December	9.5 (8/84)	10.4 (8/77)	0.0 (0/73)	NO SAMPLING		
January	0.0 (0/5)	5.7 (4/69)	0.0 (0/69)	0.0 (0/0)	25.0 (1/4)	0.0 (0/0)
February	0.0 (0/4)	4.1 (2/49)	0.0 (0/22)	0.0 (0/0)	1.5 (2/133)	0.8 (1/125)
March	0.0 (0/226)	0.0 (0/0)	0.0 (0/2)	0.0 (0/0)	0.0 (0/20)	0.0 (0/46)
April	0.0 (0/175)	0.0 (0/2)	0.0 (0/1)	0.0 (0/0)	3.1 (5/165)	0.0 (0/70)
May	0.0 (0/130)	0.0 (0/2)	0.0 (0/4)	0.0 (0/4)	0.0 (0/10)	0.0 (0/62)

Table 16. Percent incidence of tumor-bearing English sole (*Parophrys vetulus*) collected at Alki Point during 1975-76. (37-m and 9-m beach seine catches are combined.

	Beach seine			Otter trawl		
Month	Age 0	Age I	Age II+	Age 0	Age I	Age II+
April	0.0 (0/19)	0.0 (0/2)	0.0 (0/0)	0.0 (0/1)	33.3 (1/3)	0.0 (0/40)
May	NO SAMPLING			0.0 (0/0)	0.0 (0/15)	0.0 (0/29)
June	0.0 (0/29)	8.1 (3.37)	15.4 (2/13)	0.0 (0/0)	0.0 (0/3)	0.0 (0/17)
July	0.0 (0/90)	6.6 (2/30)	0.0 (0/2)	0.0 (0/0)	0.0 (0/14)	0.0 (0/22)
August	0.0 (0/30)	0.0 (0/0)	0.0 (0/0)	0.0 (0/0)	0.0 (0/4)	0.0 (0/9)
September	0.0 (0/9)	0.0 (0/0)	0.0 (0/0)	0.0 (0/2)	0.0 (0/10)	0.0 (0/35)
October	10.0 (2/20)	0.0 (0/5)	0.0 (0/18)	8.3 (1/12)	0.0 (0/3)	0.0 (0/6)
November	9.1 (4/44)	3.6 (1/28)	0.0 (0/39)	0.0 (0/0)	0.0 (0/0)	0.0 (0/7)
December	6.6 (4/61)	1.9 (2/106)	0.0 (0/98)	0.0 (0/0)	0.0 (0/0)	0.0 (0/3)
January	0.0 (0/1)	28.6 (2/7)	1.3 (1/80)	0.0 (0/0)	100.0 (1/1)	0.0 (0/33)
February	0.0 (0/2)	25.0 (2/8)	2.0 (1/51)	NO SAMPLING		
March	0.0 (0/0)	66.7 (2/3)	0.0 (0/2)	0.0 (0/0)	0.0 (0/37)	0.0 (0/122)
April	0.0 (0/37)	0.0 (0/0)	0.0 (0/2)	0.0 (0/0)	12.5 (4/32)	0.0 (0/147)
May	0.0 (0/35)	22.2 (2/9)	0.0 (0/13)	0.0 (0/0)	0.0 (0/2)	0.0 (0/54)
June	0.0 (0/68)	0.0 (0/4)	0.0 (0/0)	NO SAMPLING		

Table 17. Percent incidence of tumor-bearing English sole (<u>Parophrys vetulus</u>) collected at Pt. Pully during 1975-6. Dash (--) indicates that no sampling was conducted. 37-m and 9-m beach seine catches are combined.

	Beach seine			Otter trawl		
Month	Age 0	Age I	Age II+	Age 0	Age I	Age II+
February	0.0 (0/9)	6.3 (3/48)	13.3 (2/15)	--	--	--
March	0.0 (0/2)	0.0 (0/2)	0.0 (0/2)	--	--	--
April	0.0 (0/7)	20.0 (1/5)	0.0 (0/0)	0.0 (0/1)	0.0 (0/10)	0.0 (0/41)
May	0.0 (0/8)	0.0 (0/7)	0.0 (0/13)	0.0 (0/0)	20.0 (4/20)	0.0 (0/31)
June	0.0 (0/60)	23.5 (8/34)	0.0 (0/45)	0.0 (0/0)	18.5 (5/27)	0.0 (0/57)
July	0.0 (0/145)	18.5 (12/65)	0.0 (0/44)	0.0 (0/0)	7.1 (2/28)	0.0 (0/15)
August	0.0 (0/343)	21.2 (11/52)	0.0 (0/8)	0.0 (0/0)	11.1 (1/9)	0.0 (0/17)
September	6.3 (13/207)	7.9 (10/126)	0.0 (0/45)	0.0 (0/3)	4.5 (1/22)	0.0 (0/36)
October	14.7 (50/340)	6.3 (9/144)	2.1 (2/97)	13.3 (2/15)	0.0 (0/13)	0.0 (0/7)
November	4.2 (1/24)	1.4 (1/71)	0.0 (0/102)	6.7 (1/15)	10.0 (3/30)	0.0 (0/15)
December	12.5 (2/16)	6.3 (2/32)	0.0 (0/106)	0.0 (0/6)	5.3 (1/19)	0.0 (0/32
January	0.0 (0/0)	14.7 (5/34)	0.0 (0/42)	0.0 (0/0)	16.6 (1/6)	0.0 (0/35)
February	0.0 (0/0)	8.3 (1/12)	0.0 (0/10)	0.0 (0/0)	2.6 (1/38)	1.6 (1/60)
March	0.0 (0/3)	0.0 (0/0)	0.0 (0/0)	0.0 (0/0)	4.0 (1/25)	0.0 (0/50)
April	0.0 (0/6)	0.0 (0/0)	0.0 (0/6)	0.0 (0/0)	0.0 (0/4)	0.0 (0/60)
May	0.0 (0/67)	50.0 (1/2)	0.0 (0/21)	0.0 (0/0)	100.0 (1/1)	0.0 (0/22)
June	0.0 (0/106)	3.8 (2/52)	1.2 (1/81)	--	--	--

Table 18. Percent incidence of *Philometra*-infested English sole (*Parophrys vetulus*) and rock sole (*Lepidopsetta bilineata*) collected at West Point during 1975-6(beach seine and otter trawl catches are combined).

	English sole		Rock sole	
	Total length		Total length	
Month	< 150 mm TL	≥ 150 mm TL	< 150 mm TL	≥ 150 mm TL
February	0.0 (0/47)	0.0 (0/41)	0.0 (0/0)	0.0 (0/1)
March	0.0 (0/31)	5.5 (7/126)	0.0 (0/2)	10.6 (11/104)
April	0.0 (0/54)	12.1 (17/140)	0.0 (0/79)	12.3 (19/154)
May	0.0 (0/56)	7.8 (4/51)	0.0 (0/36)	5.3 (3/62)
June	0.0 (0/153)	3.7 (6/164)	0.0 (0/10)	3.4 (4/117)
July	0.0 (0/152)	5.9 (6/102)	0.0 (0/23)	6.2 (9/145)
August	0.0 (0/249)	4.7 (3/64)	0.0 (0/22)	1.6 (1/86)
September	0.0 (0/247)	14.1 (12/85)	0.0 (0/22)	8.9 (8/90)
October	0.0 (0/191)	3.9 (13/334)	0.0 (0/20)	8.0 (6/75)
November	0.0 (0/13)	10.3 (3/29)	0.0 (0/19)	9.7 (3/31)
December	0.0 (0/88)	8.2 (12/146)	0.0 (0/23)	15.0 (6/40)
January	0.0 (0/103)	3.6 (2/55)	0.0 (0/16)	5.8 (5/86)
February	0.0 (0/164)	0.0 (0/169)	0.0 (0/50)	8.8 (8/90)
March	0.0 (0/245)	4.1 (2/49)	0.0 (0/9)	9.2 (6/65)
April	0.0 (0/307)	3.7 (4/106)	0.0 (0/31)	6.6 (7/106)
May	0.0 (0/141)	5.6 (4/71)	0.0 (0/4)	7.5 (7/93)

Table 19. Percent incidence of *Philometra*-infested English sole (*Parophrys vetulus*) and rock sole (*Lepidopsetta bilineata*) collected at Alki Point during 1975-76. Beach seine and otter trawl catches are combined.

	English sole		Rock sole	
	Total length		Total length	
Month	< 150 mm	≥ 150 mm	< 150 mm	≥ 150 mm
April	0.0 (0/32)	40.0 (16/40)	0.0 (0/9)	11.9 (5/42)
May	0.0 (0/10	14.7 (5/34)	0.0 (0/10)	5.3 (2/38)
June	0.0 (0/36)	10.0 (6/60)	0.0 (0/6)	14.4 (24/167)
July	0.0 (0/101)	14.0 (8/57)	0.0 (0/25)	14.8 (8/54)
August	0.0 (0/33)	10.0 (1/10)	0.0 (0/1)	0.9 (1/106)
September	0.0 (0/11)	24.4 (11/45)	0.0 (0/6)	7.6 (8/105)
October	0.0 (0/32)	21.8 (7/32)	0.0 (0/3)	3.4 (1/29)
November	0.0 (0/50)	14.7 (10/68)	0.0 (0/21)	2.9 (1/34)
December	0.0 (0/85)	23.5 (14/183)	0.0 (0/5)	18.2 (8/44)
January	0.0 (0/9)	23.0 (26/113)	0.0 (0/10)	22.9 (16/70)
February	0.0 (0/7)	14.8 (8/54)	0.0 (0/2)	30.0 (3/10)
March	0.0 (0/39)	15.2 (19/125)	0.0 (0/51)	11.4 (21/185)
April	0.0 (0/59)	27.0 (43/159)	0.0 (0/36)	9.8 (18/184)
May	0.0 (0/39)	17.6 (13/74)	0.0 (0/35)	5.2 (13/251)
June	0.0 (0/68)	0.0 (0/4)	10.0 (1/10)	4.8 (3/62)

Table 20. Percent incidence of *Philometra*-infested English sole (*Parophrys vetulus*) and rock sole (*Lepidopsetta bilineata*) collected at Point Pully during 1975-76. Beach seine and otter trawl catches are combined.

	English sole		Rock sole	
	Total length		Total length	
Month	< 150 mm	≥ 150 mm	< 150 mm	≥ 150 mm
February	0.0 (0/28)	16.7 (3/18)	5.6 (1/18)	33.3 (7/21)
March	0.0 (0/4)	0.0 (0/2)	0.0 (0/1)	0.0 (0/1)
April	0.0 (0/18)	46.7 (21/45)	7.1 (2/28)	35.2 (32/91)
May	0.0 (0/32)	27.1 (13/48)	0.0 (0/27)	35.2 (51/145)
June	0.0 (0/69)	15.9 (23/145)	0.0 (0/32)	38.3 (54/141)
July	0.0 (0/147)	12.7 (19/150)	0.0 (0/30)	46.5 (73/157)
August	0.0 (0/371)	18.6 (11/59)	0.6 (1/160)	41.2 (47/114)
September	0.0 (0/283)	16.6 (26/157)	2.0 (1/49)	38.2 (58/152)
October	0.0 (0/367)	12.9 (32/249)	1.4 (1/73)	44.5 (65/146)
November	0.0 (0/71)	25.8 (48/186)	0.0 (0/46)	40.8 (60/147)
December	0.0 (0/34)	37.3 (66/177)	0.0 (0/64)	55.5 (81/146)
January	0.0 (0/39)	38.4 (30/78)	0.0 (0/41)	45.2 (14/31)
February	0.0 (0/67)	26.4 (14/53)	0.0 (0/142)	53.7 (100/186
March	0.0 (0/25)	22.6 (12/53)	0.0 (0/36)	47.6 (60/126)
April	0.0 (0/16)	25.0 (15/60)	0.0 (0/13)	25.7 (9/35)
May	0.0 (0/68)	28.8 (13/45)	0.0 (0/35)	41.2 (89/213)
June	0.0 (0/50)	20.5 (17/83)	0.0 (0/24)	25.0 (27/108)

Table 21. Catch per haul (CPH) by site for the 15 most abundant species collected with the 37-m beach seine during 1975-76.

	Point Pully		West Point		Alki Point	
	Species	CPH (N=36)	Species	CPH (N=29)	Species	CPH (N=22)
1	Shiner perch	303.94	Tomcod	104.68	Shiner perch	291.95
2	English sole	66.47	Shiner perch	90.75	Striped perch	87.36
3	Pacific herring	63.41	English sole	51.58	Tubesnout	81.81
4	Rock sole	43.44	Rock sole	19.24	English sole	35.54
5	Striped perch	29.86	Staghorn sculpin	4.82	Rock sole	31.44
6	Staghorn sculpin	13.14	Striped perch	2.96	Tomcod	18.68
7	Tomcod	13.14	Chum salmon	1.68	C-O sole	9.27
8	C-O sole	12.38	Sturgeon poacher	1.55	Staghorn sculpin	6.59
9	Pile perch	6.72	Padded sculpin	1.48	Padded sculpin	6.59
10	Tubesnout	4.36	Buffalo sculpin	1.37	Pile perch	3.82
11	Padded sculpin	3.86	Surf smelt	1.31	Penpoint gunnel	2.90
12	Speckled sanddab	1.13	Roughback sculpin	0.96	Speckled sanddab	2.86
13	Roughback sculpin	1.08	Starry flounder	0.96	Coho salmon	2.50
14	Sailfin sculpin	0.92	Snake prickleback	0.93	Buffalo sculpin	2.10
15	Brown rockfish	0.67	Pacific sandlance	0.83	Silverspotted sculpin	2.00

Table 22. Frequency of occurrence by site for the fifteen most abundant species collected by beach seine during 1975-1976.

Species	Frequency of occurrence Alki Point	 Point Pully	 West Point
English sole	0.91	0.89	0.91
Pacific staghorn sculpin	0.75	0.76	0.71
Rock sole	0.68	0.62	0.42
Padded sculpin	0.66	0.33	0.27
Tube-snout	0.66	0.19	0.05
Buffalo sculpin	0.64	0.05	0.53
Penpoint gunnel	0.55	0.23	0.10
C-O sole	0.49	0.48	0.13
Striped seaperch	0.49	0.46	0.23
Shiner perch	0.49	0.62	0.40
Pacific tomcod	0.40	0.29	0.41
Bay pipefish	0.38	0.32	0.01
Saddleback gunnel	0.36	0.19	0.03
Silverspotted sculpin	0.34	0.09	0.06
Pile perch	0.32	0.19	0.11

Table 23. Catch per haul (CPH) by site for the six most abundant species collected at 5 m during 1975-76.

	West Point		Alki Point		Point Pully	
Rank	Species	CPH (N=32)	Species	CPH (N=28)	Species	CPH (N=28)
1	Rock sole	8.3	Rock sole	8.3	English sole	11.2
2	English sole	4.8	Striped perch	7.0	Rock sole	7.9
3	Tubesnout	2.9	C-O sole	5.2	C-O sole	2.0
4	C-O sole	1.8	English sole	4.8	Shiner perch	0.7
5	Padded sculpin	1.1	Padded sculpin	1.7	Speckled sanddab	0.5
6	Speckled sanddab	0.4	Roughback sculpin	1.3	Striped perch	0.3

Table 24. Catch per haul (CPH) by site for the five most abundant species collected at 25 m during 1975-76.

	West Point		Point Pully	
Rank	Species	CPH (N=29)	Species	CPH (N=30)
1	Rock sole	11.4	Rock sole	10.5
2	English sole	6.7	English sole	4.1
3	Roughback sculpin	2.1	Roughback sculpin	3.3
4	Tomcod	1.5	Tomcod	0.8
5	Shiner perch	1.2	Ratfish	0.8

Table 25. Catch per haul (CPH) by site for the six most abundant species collected at 45 m during 1975-76.

	West Point		Alki Point		Point Pully	
Rank	Species	CPH	Species	CPH	Species	CPH
1	English sole	27.7	Rock sole	14.2	Rock sole	19.0
2	Rock sole	16.3	English sole	10.8	English sole	10.6
3	Tomcod	3.8	Tomcod	2.9	Roughback sculpin	3.9
4	Shiner perch	3.0	Roughback sculpin	2.8	Pacific sanddab	2.9
5	Pacific sanddab	2.7	Ratfish	2.5	Tomcod	2.3
6	Roughback sculpin	1.9	Spotfin sculpin	1.7	Ratfish	1.9

Table 26. Catch per haul (CPH) by site for the seven most abundant species collected at 70 m during 1975-76

	West Point		Alki Point		Point Pully	
Rank	Species	CPH	Species	CPH	Species	CPH
1	Ratfish	29.3	Ratfish	10.4	Ratfish	4.7
2	Dover sole	3.3	English sole	4.9	English sole	1.8
3	English sole	2.9	Dover sole	3.8	Slender sole	1.6
4	Rex sole	1.4	Bluespotted poacher	1.6	Dover sole	1.1
5	Bluespotted poacher	1.0	Slender sole	1.5	Bluespotted poacher	1.1
6	Tomcod	0.8	Tomcod	1.4	Rex sole	0.7
7	Shiner perch	0.8	Rex sole	0.9	Quillback rockfish	0.6

Table 27. Catch per haul (CPH) by site for the five most abundant species collected at 95 m during 1975-76.

	West Point		Point Pully	
Rank	Species	CPH	Species	CPH
1	Ratfish	25.4	Ratfish	10.3
2	Dover sole	2.6	Dover sole	1.4
3	English sole	0.7	Slender sole	1.2
4	Quillback rockfish	0.6	English sole	1.2
5	Rex sole	0.6	Rex sole	1.0

Table 28. Frequency of occurrence by site for the fifteen most abundant species collected by otter trawl during 1975-1976.

	Frequency of occurrence		
Species	West Point	Point Pully	Alki Point
English sole	0.69	0.69	0.74
Rock sole	0.62	0.66	0.65
Ratfish	0.54	0.51	0.53
Dover sole	0.46	0.36	0.38
Quillback rockfish	0.31	0.23	0.19
Roughback sculpin	0.27	0.45	0.44
Rex sole	0.26	0.22	0.18
Tomcod	0.25	0.22	0.31
Slender sole	0.23	0.37	0.31
Speckled sanddab	0.21	0.15	0.09
Northern ronquil	0.20	0.19	0.19
Shiner perch	0.19	0.18	0.23
Pacific sanddab	0.18	0.23	0.13
C-O sole	0.18	0.26	0.31
Brown rockfish	0.15	0.16	0.17

Table 29. List of species collected in Duwamish River, all stations combined, during 1975-76. "F" (frequent) indicates species occurred in > 70% of samples; "C" (common) indicates species occurred in 30-70% of samples; "R" (rare) indicates species occurred in < 30% of samples.

Species	Total number	Frequency of occurrence
Spiny dogfish	1	R
Ratfish	1	R
Pacific herring	73	C
Coho salmon	11	R
Longfin smelt	1555	C
Eulachon	2	R
Pacific cod	1	R
Pacific tomcod	639	C
Tubesnout	1	R
Shiner perch	209	C
Striped seaperch	3	R
Pile perch	11	R
Snake prickleback	1971	C
Saddleback gunnel	1	R
Bay goby	15	R
Padded sculpin	49	C
Roughback sculpin	7	R
Buffalo sculpin	8	R
Pacific staghorn sculpin	964	F
Prickly sculpin	2	R
Sturgeon poacher	1	R
Pygmy poacher	3	R
Rock sole	120	C
Slender sole	8	R
Dover sole	69	R
English sole	1610	F
Starry flounder	1361	C
Sand sole	103	C
English sole x starry flounder hybrid	3	R
Total No. Individuals	8802	
Total No. Species	29	

Table 30. Ranking for 1974 and 1975-76 of the 10 most abundant species collected in the Duwamish River.

	1974		1975-76	
Species	Rank	% Total	Rank	% Total
Snake prickleback	5	10.4	1	23.2
English sole	3	17.5	2	18.4
Longfin smelt	1	21.5	3	17.4
Starry flounder	2	18.8	4	15.5
Staghorn sculpin	4	11.8	5	10.5
Pacific tomcod	6	2.7	6	7.2
Shiner perch	9	0.8	7	2.2
Rock sole	7	1.7	8	1.4
Sand sole	8	1.3	9	1.2
Pacific herring[a]	10	< 0.1	10	0.8
Total		86.6		97.7
		(5551/6380)		(8289/8483)

Table 31. Percent incidence by month (all stations combined) of tumor-bearing starry flounder (<u>Platichthys</u> <u>stellatus</u>) collected in the Duwamish River during 1975-76.

Total length (mm): Date	50-99	100-149	150-199	200-249	≥ 250
February 1975	53.8 (7/13)	16.7 (11/66)	2.1 (2/92)	0.0 (0/75)	0.0 (0/10)
March	0.0 (0/0)	18.0 (11/61)	1.0 (1/97)	0.0 (0/25)	0.0 (0/2)
April	0.0 (0/0)	22.5 (9/40)	0.0 (0/24)	0.0 (0/8)	0.0 (0/1)
May	0.0 (0/0)	30.6 (34/111)	0.0 (0/54)	0.0 (0/40)	0.0 (0/8)
June	0.0 (0/0)	20.0 (3/15)	6.3 (1/16)	0.0 (0/18)	0.0 (0/4)
July	0.0 (0/0)	11.1 (1/9)	0.0 (0/12)	0.0 (0/10)	0.0 (0/3)
August	0.0 (0/0)	0.0 (0/10)	0.0 (0/14)	0.0 (0/6)	0.0 (0/0)
September	0.0 (0/1)	20.0 (1/5)	0.0 (0/13)	0.0 (0/28)	0.0 (0/8)
October	46.7 (42/90)	29.1 (32/110)	2.4 (2/85)	0.0 (0/30)	0.0 (0/0)
November	23.1 (3/13)	37.0 (10/27)	0.0 (0/38)	0.0 (0/19)	0.0 (0/0)
January 1976	42.9 (3/7)	5.9 (1/17)	0.0 (0/12)	0.0 (0/10)	0.0 (0/1)

Table 32. Percent incidence by station (all months combined) of tumor-bearing starry flounder (*Platichthys stellatus*) collected in the Duwamish River during 1975-76.

Total length (mm): Station	50-99	100-149	150-199	200-249	≥ 250
E	50.0 (1/2)	22.2 (10/45)	0.0 (0/69)	0.0 (0/60)	0.0 (0/11)
F	40.0 (4/10)	27.2 (49/180)	1.4 (2/147)	0.0 (0/101)	0.0 (0/16)
G	43.6 (17/39)	10.0 (10/100)	5.5 (3/55)	0.0 (0/25)	0.0 (0/2)
H	45.8 (33/72)	32.3 (33/102)	2.3 (2/86)	0.0 (0/16)	0.0 (0/0)

Table 33. Number of tumors on the eyed and blind sides of individual starry flounder (<u>Platichthys stellatus</u>) collected in the Duwamish River during 1975-76.

	Eyed side	Blind side	Both sides	Number of fish afflicted
February 1975	21	1	13	20
March	14	3	38	12
April	7	4	12	9
May	20	5	37	34
June	3	2	2	4
July	1	0	0	1
August	0	0	0	0
September	0	0	1	1
October	99	27	86	76
November	11	2	15	13
January 1976	23	9	2	4
Total	199	53	206	174
Percentage of total	43.4	11.6	45.0	

Table 34. Percent incidence by month (all stations combined) of fin erosion on starry flounder (*Platichthys stellatus*) collected in the Duwamish River during 1975-76.

Total length (mm):	50-99	100-149	150-199	200-249	≥ 250
Date					
February 1975	0.0 (0/13)	7.6 (5/66)	15.2 (14/92)	13.3 (10/75)	30.0 (3/10)
March	0.0 (0/0)	8.2 (5/61)	14.4 (14/97)	52.0 (13/25)	50.0 (1/2)
April	0.0 (0/0)	10.0 (4/40)	12.5 (3/24)	12.5 (1/8)	0.0 (0/1)
May	0.0 (0/0)	0.0 (0/111)	20.4 (11/54)	17.5 (7/40)	50.0 (4/8)
June	0.0 (0/0)	0.0 (0/15)	0.0 (0/16)	11.1 (2/18)	0.0 (0/4)
July	0.0 (0/0)	0.0 (0/9)	16.6 (2/12)	0.0 (0/10)	33.3 (1/3)
August	0.0 (0/0)	0.0 (0/10)	0.0 (0/14)	66.6 (4/6)	0.0 (0/0)
September	0.0 (0/1)	0.0 (0/5)	23.1 (3/13)	57.1 (16/28)	5.5 (1/8)
October	0.0 (0/90)	0.9 (1/110)	9.4 (8/85)	26.6 (8/30)	0.0 (0/0)
November	0.0 (0/13)	7.4 (2/27)	2.6 (1/38)	0.0 (0/19)	0.0 (0/0)
January 1976	0.0 (0/7)	0.0 (0/17)	0.0 (0/12)	30.0 (3/10)	0.0 (0/1)

Table 35. Percent incidence by station (all months combined) of fin erosion on starry flounder (<u>Platichthys stellatus</u>) collected in the Duwamish River during 1975-76.

Total length (mm): Station	50-99	100-149	150-199	200-249	≥ 250
C	0.0 (0/0)	0.0 (0/1)	25.0 (2/8)	21.4 (3/14)	0.0 (0/14)
D	0.0 (0/0)	5.9 (1/17)	9.3 (4/43)	25.0 (11/44)	0.0 (0/2)
E	0.0 (0/2)	1.8 (1/55)	11.6 (8/69)	13.3 (8/60)	27.3 (3/11)
F	0.0 (0/10)	4.4 (8/180)	20.4 (30/147)	39.6 (40/101)	31.3 (5/16)
G	0.0 (0/39)	3.0 (3/100)	12.7 (7/55)	4.0 (1/25)	50.0 (1/2)
H	0.0 (0/72)	1.0 (1/102)	8.1 (7/86)	6.3 (1/16)	0.0 (0/0)

Table 36. Occurrence of fin erosion by month (all stations combined) and by fin on individual starry flounder (*Platichthys stellatus*) collected in the Duwamish River during 1975-76.

Month and year	Dorsal	Anal	Caudal	Eyed pectoral	Blind pectoral	Eyed pelvic	Blind pelvic	Number of fish afflicted
February 1975	20	15	6	0	1	0	0	42
March	29	12	9	0	8	4	2	64
April	5	5	2	1	2	1	0	16
May	29	12	9	0	8	4	2	42
June	2	0	0	0	0	0	0	2
July	2	1	1	0	0	0	0	4
August	3	2	2	0	0	0	0	7
September	10	13	4	0	1	0	1	29
October	13	8	3	0	3	1	0	28
November	4	3	2	0	0	1	1	11
January 1976	3	2	1	0	0	0	0	3
Total	120	73	39	1	23	10	6	248

Table 37. Percent incidence by month of *Philometra*-infested English sole (*Parophrys vetulus*) and rock sole (*Lepidopsetta bilineata*) collected in the Duwamish River during 1975-76. Dash indicates no fishes were collected.

	English sole		Rock sole	
	Total length		Total length	
Date	< 150 mm	≥ 150 mm	< 150 mm	≥ 150 mm
February 1975	0.0 (0/10)	13.5 (7/52)	0.0 (0/9)	0.0 (0/6)
March	0.0 (0/7)	10.8 (4/37)	0.0 (0/1)	0.0 (0/1)
April	0.0 (0/3)	11.1 (9/81)	0.0 (0/9)	0.0 (0/1)
May	0.0 (0/5)	16.4 (46/280)	0.0 (0/1)	0.0 (0/9)
June	0.0 (0/8)	10.7 (23/215)	0.0 (0/10)	0.0 (0/5)
July	--	10.6 (19/179)	0.0 (0/3)	0.0 (0/7)
August	0.0 (0/26)	10.9 (15/137)	0.0 (0/1)	10.0 (1/10)
September	0.0 (0/25)	7.9 (10/203)	0.0 (0/4)	15.8 (3/19)
October	0.0 (0/29)	18.2 (33/181)	0.0 (0/9)	0.0 (0/4)
November	0.0 (0/4)	11.9 (10/84)	0.0 (0/4)	0.0 (0/3)
January 1976	0.0 (0/3)	4.3 (2/46)	0.0 (0/2)	7.1 (1/14)

Table 38. Percent incidence by station of *Philometra*-infested English sole (*Parophrys vetulus*) and rock sole (*Lepidopsetta bilineata*) collected in the Duwamish River during 1975-76. Dash indicates no fishes were collected.

	English sole		Rock sole	
	Total length		Total length	
Station	< 150 mm	≥ 150 mm	< 150 mm	≥ 150 mm
A	0.0 (0/7)	12.9 (9/70)	0.0 (0/31)	8.3 (1/12)
B	0.0 (0/4)	3.7 (2/66)	0.0 (0/19)	12.5 (4/32)
C	0.0 (0/6)	14.6 (45/308)	--	0.0 (0/5)
D	0.0 (0/16)	8.1 (33/408)	0.0 (0/4)	0.0 (0/9)
E	0.0 (0/58)	17.8 (53/297)	--	0.0 (0/3)
F	0.0 (0/12)	15.8 (27/171)	--	12.5 (1/8)
G	0.0 (0/11)	9.4 (13/138)	--	--

Table 39. PCB concentrations (Arochlors 1242, 1254, and 1260) in ppm wet weight for starry flounder taken from the Duwamish River and McCalister Creek. Each sample value represents a composite of tissues taken from three fish.

Tissue	McCalister Creek control				Duwamish River No fin erosion				Duwamish River Fin erosion			
source	A-1242	A-1254	A-1260	Total	A-1242	A-1254	A-1260	Total	A-1242	A-1254	A-1260	Total
Liver	0.04	0.26	0.23	0.53	1.63	5.97	4.29	11.89	2.03	7.61	9.13	18.77
Muscle	0.08	0.01	0.02	0.11	0.08	0.27	0.23	0.59	0.06	0.17	0.27	0.51
Skin (blindside)	0.03	0.03	0.05	0.11	*	*	*	*	0.66	2.49	1.78	4.94
Gonad	0.02	0.02	0.05	0.08	0.09	0.18	0.104	0.37	0.05	0.19	0.14	0.38
Brain	0.07	0.03	0.21	0.31	0.08	0.41	0.42	0.92	0.27	1.32	0.55	2.14

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*Analysis not performed.

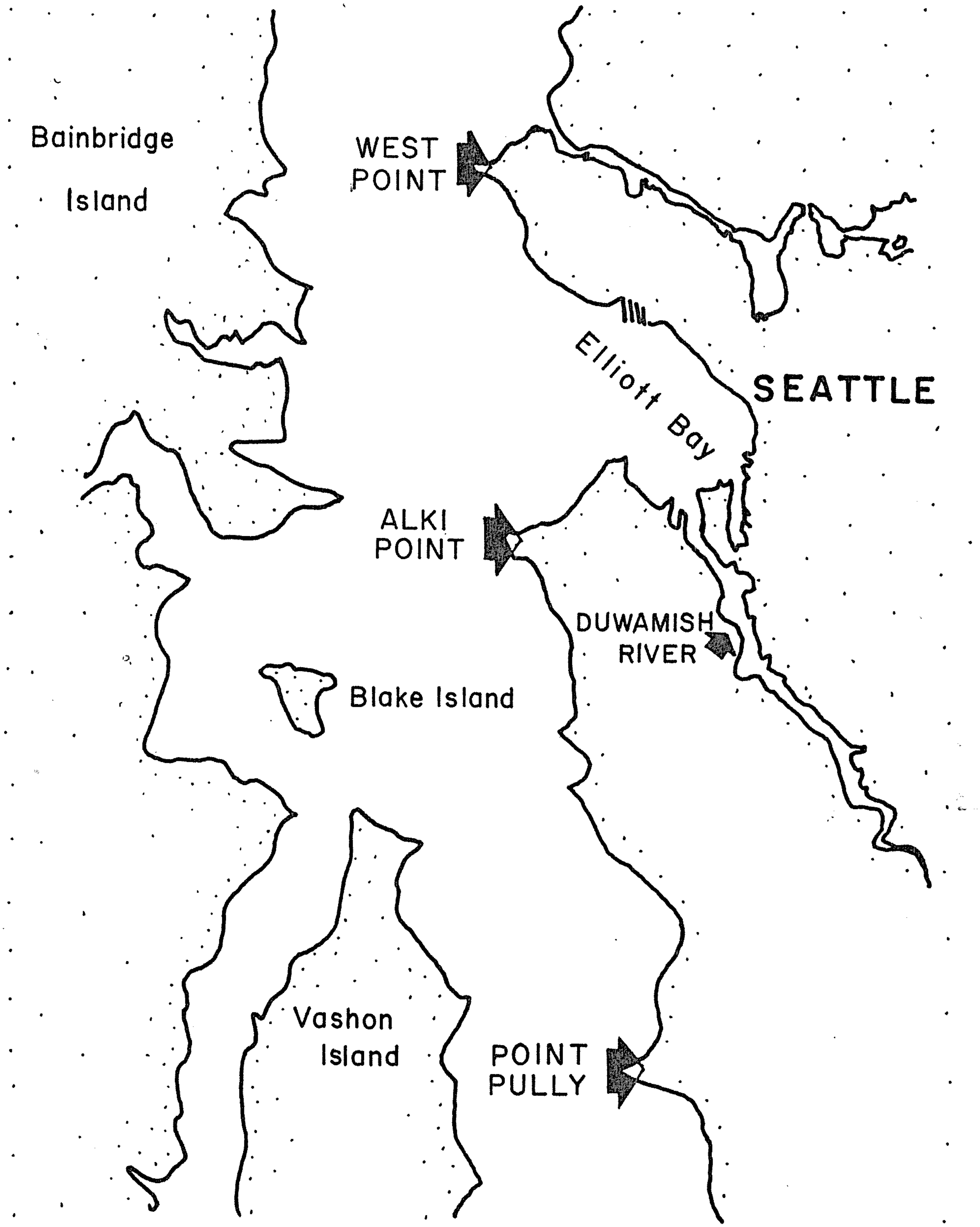


Fig. 1. Central Puget Sound showing outfall and Duwamish River study sites.

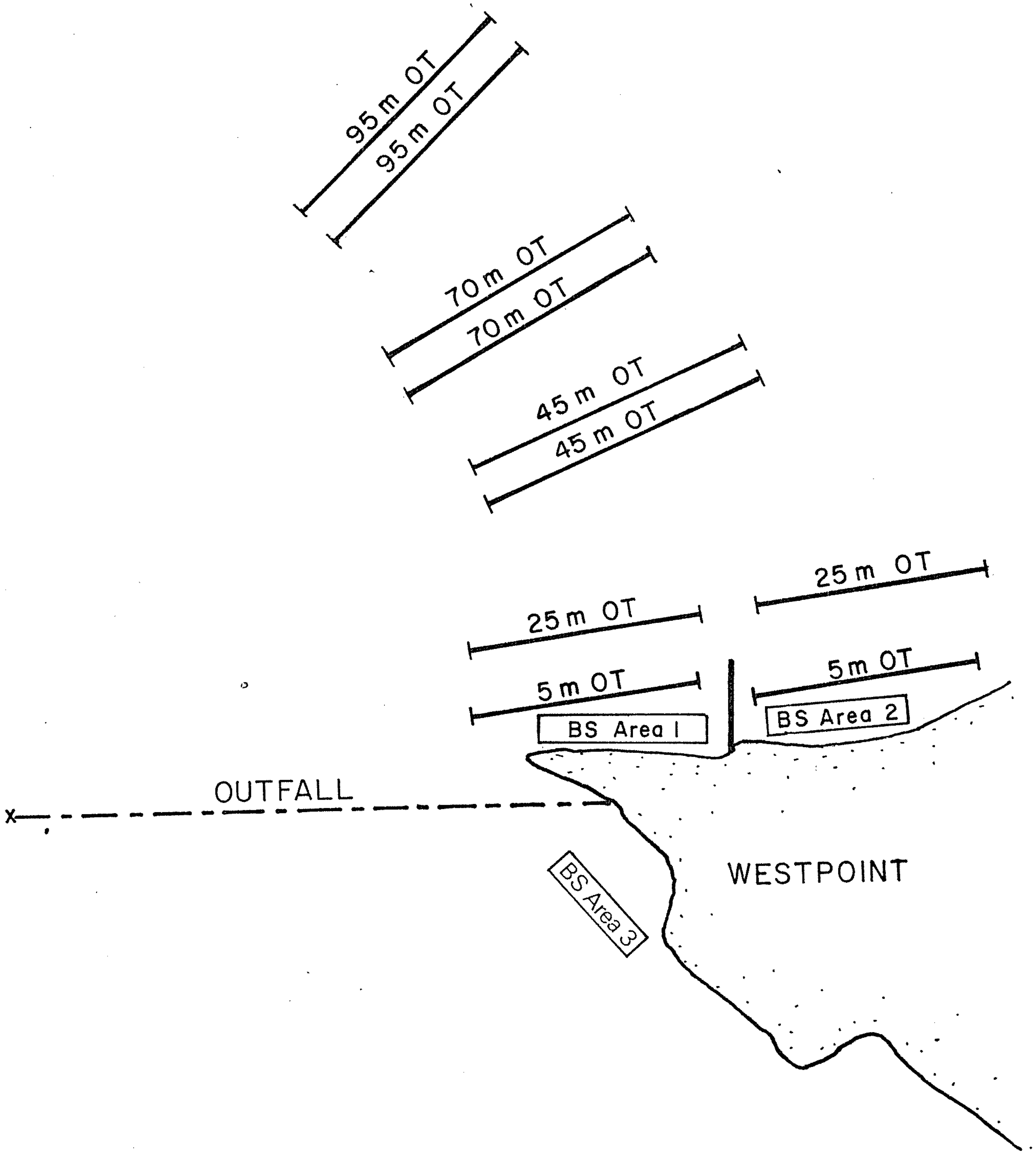


Fig. 2. West Point study site showing beach seine (BS) and otter trawl (OT) sampling stations (depth in meters).

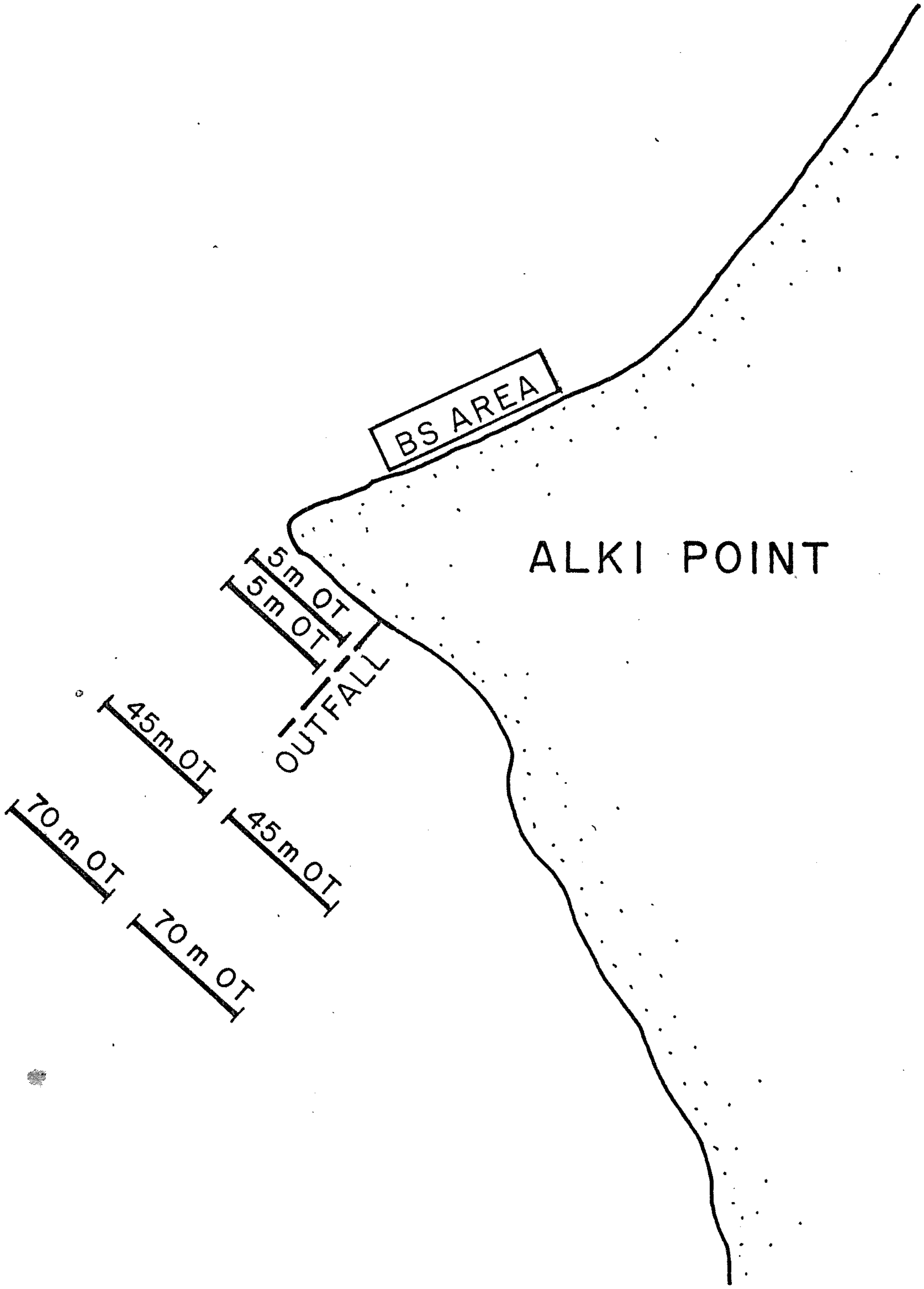


Fig. 3. Alki Point study site showing beach seine (BS) and otter trawl (OT) sampling stations (depth in meters).

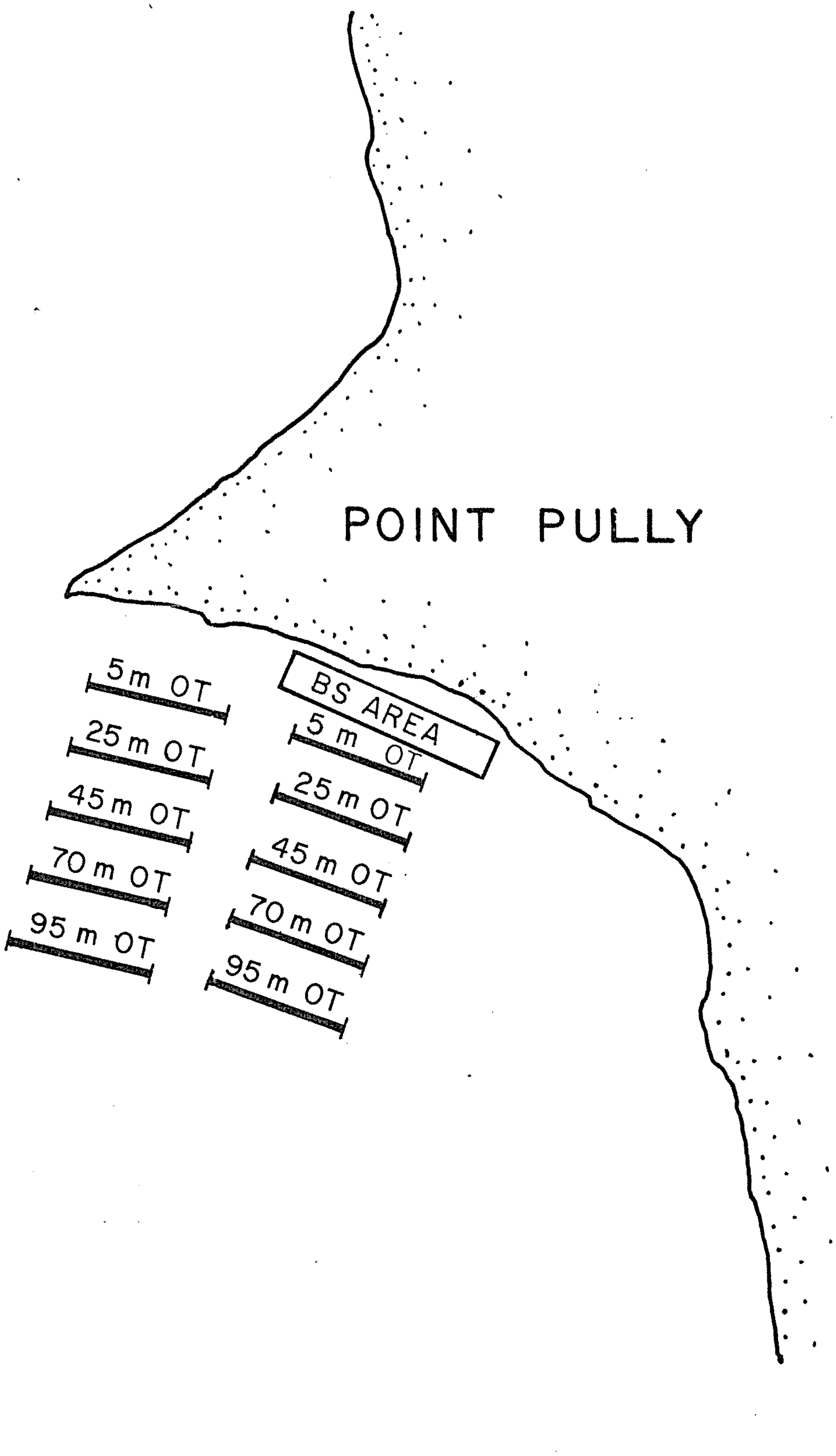


Fig. 4. Point Pully study site showing beach seine (BS) and otter trawl (OT) sampling stations (depth in meters).

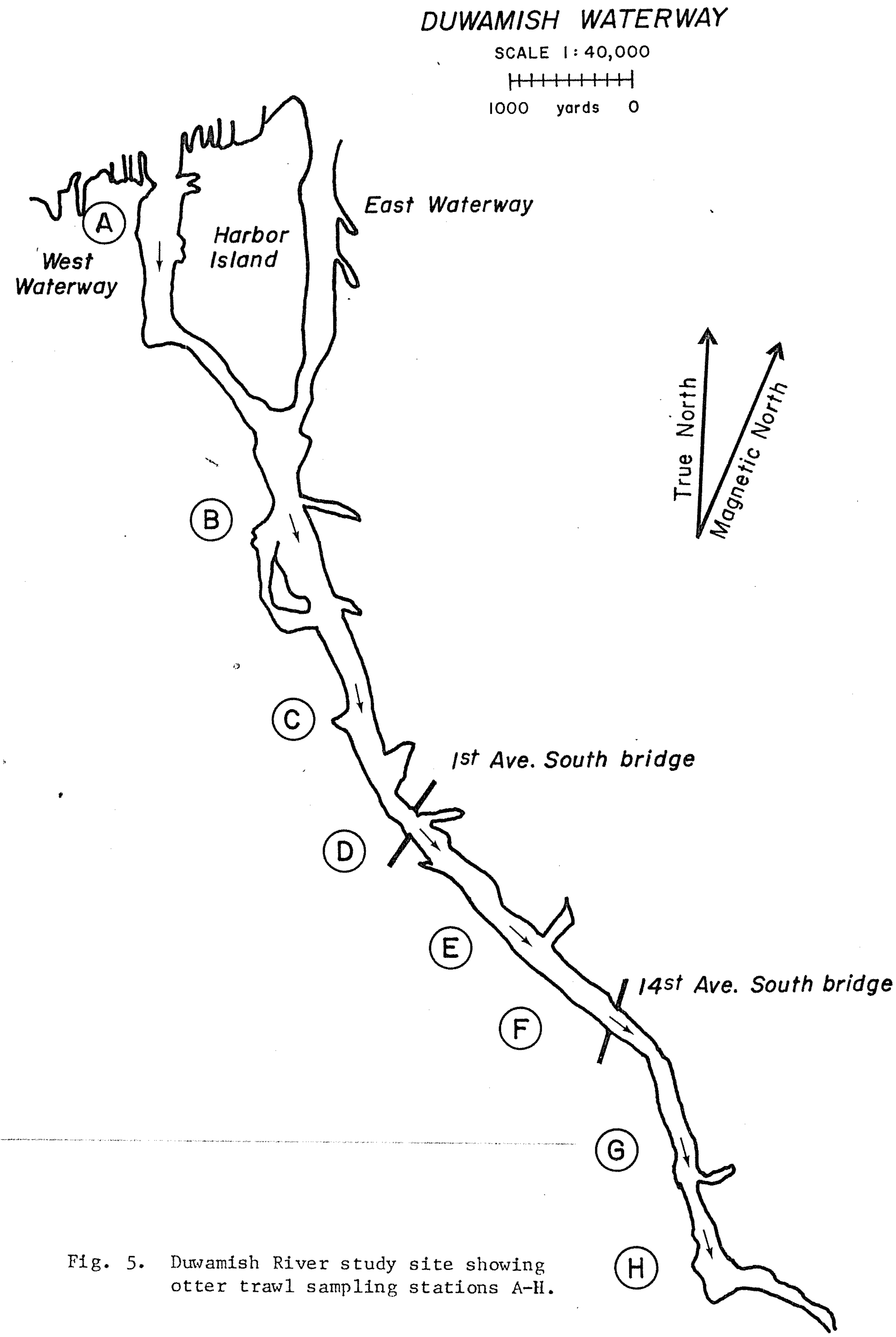


Fig. 5. Duwamish River study site showing otter trawl sampling stations A-H.

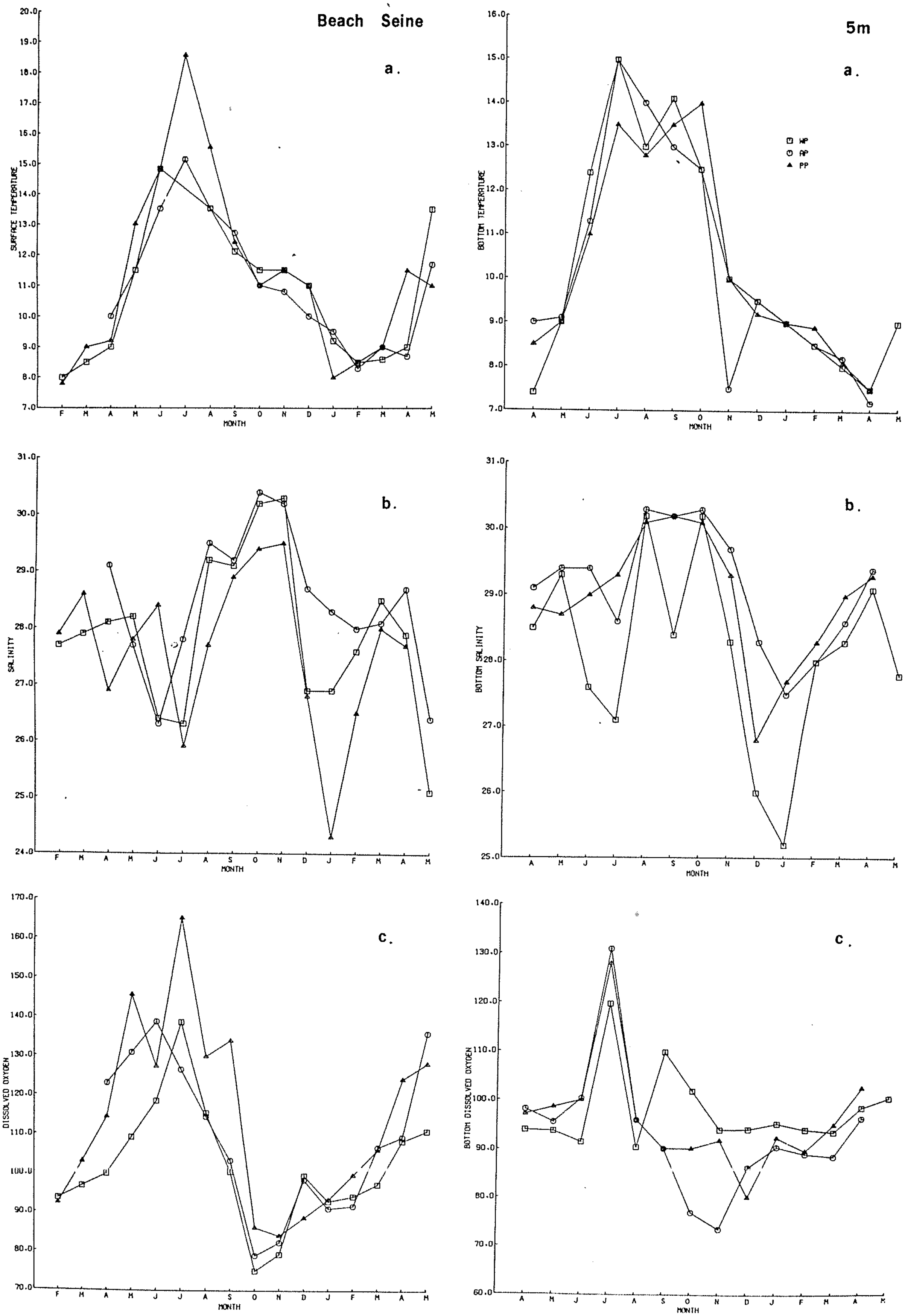


Fig. 6. Temperature (a), salinity (b), and dissolved oxygen in percentage saturation (c) for the beach seine and 5-m otter trawl stations at West Point (WP), Alki Point (AP), and Point Pully (PP).

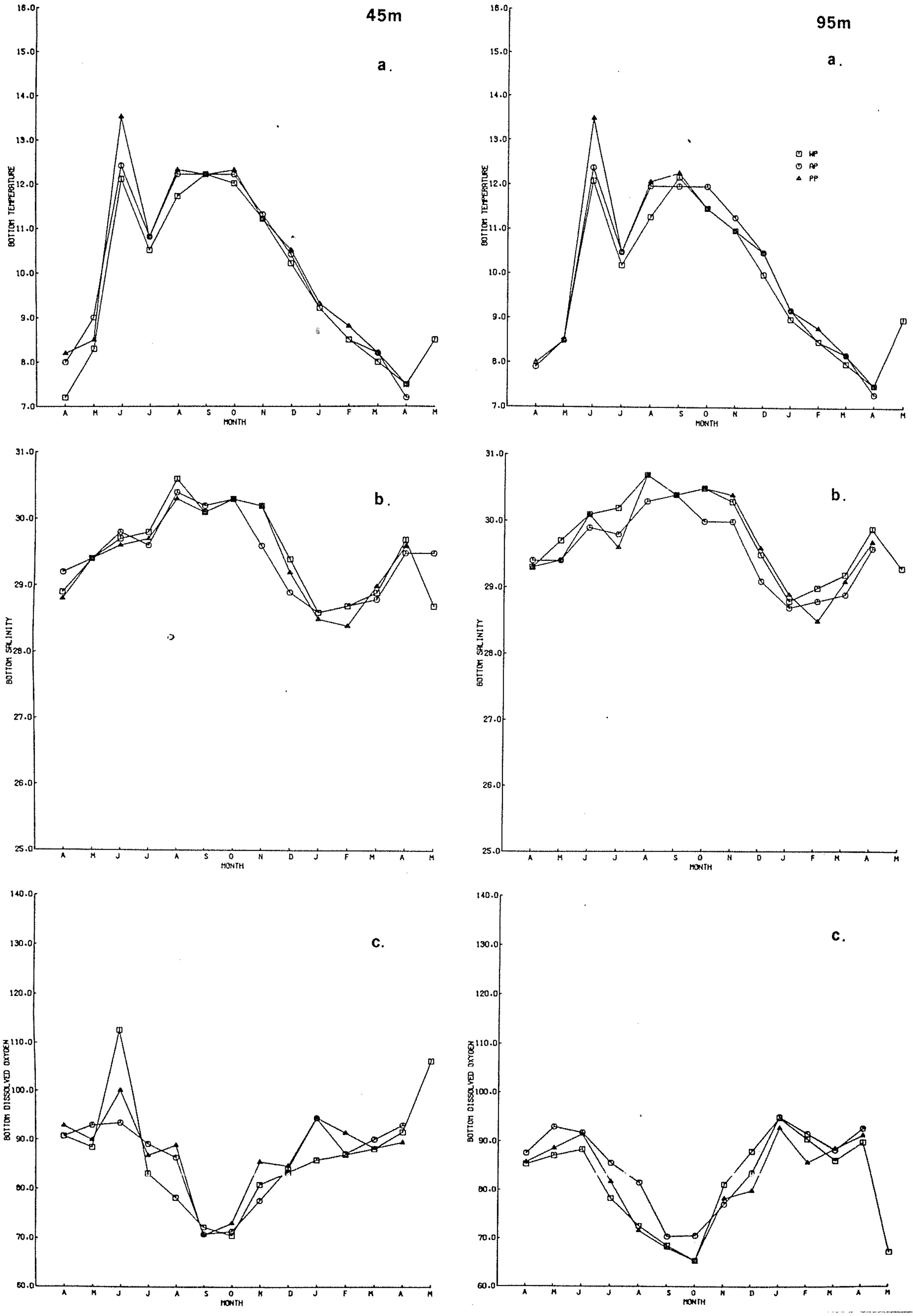


Fig. 7. Temperature (a), salinity (b), and dissolved oxygen in percentage saturation (c) for the 45-m and 95-m otter trawl stations at West Point (WP), Alki Point (AP), and Point Pully (PP).

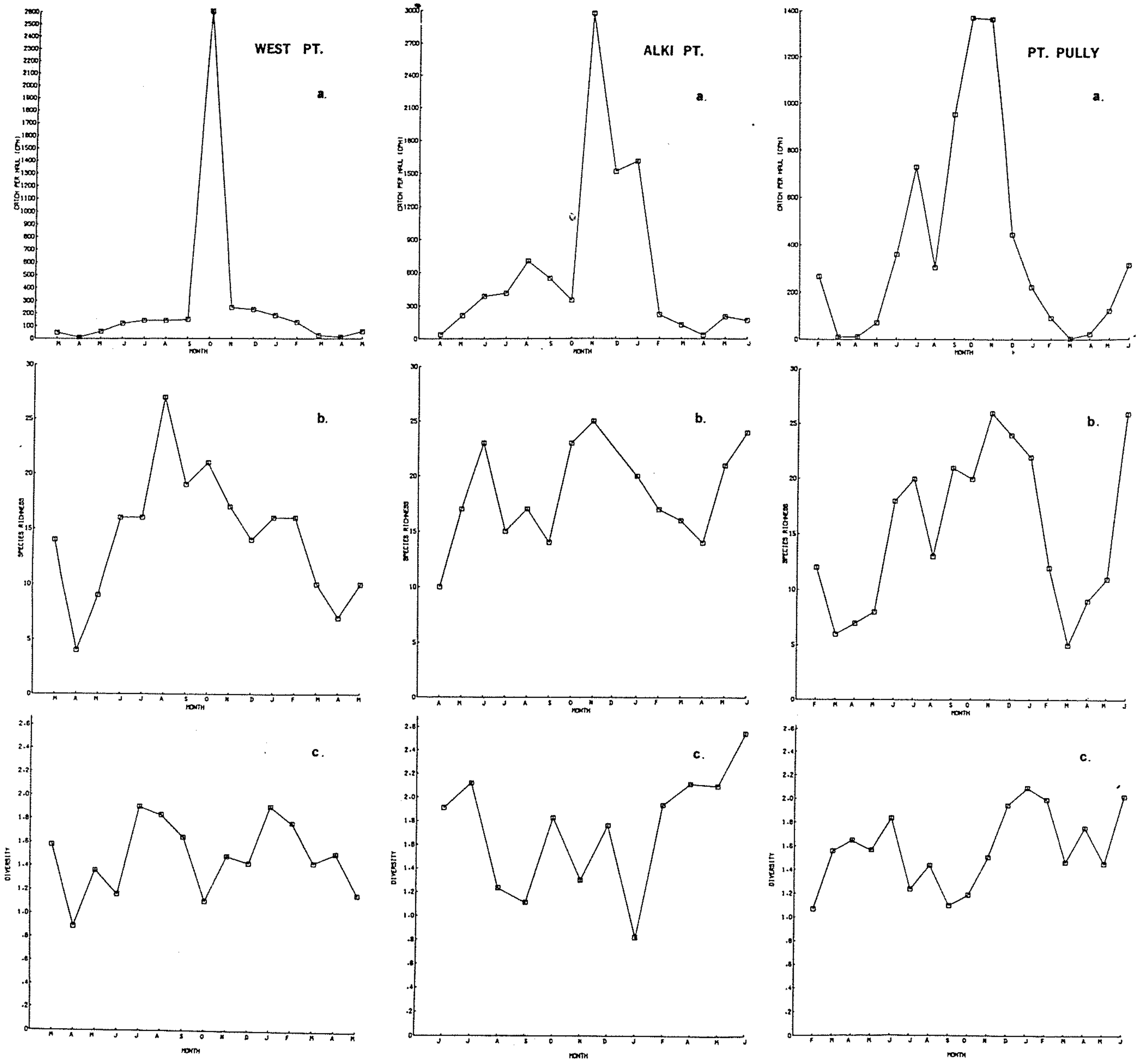


Fig. 8. Catch per haul (a), species richness (b), and Shannon-Wiener diversity (c) for 37-m beach seining stations at West Point, Alki Point, and Point Pully.

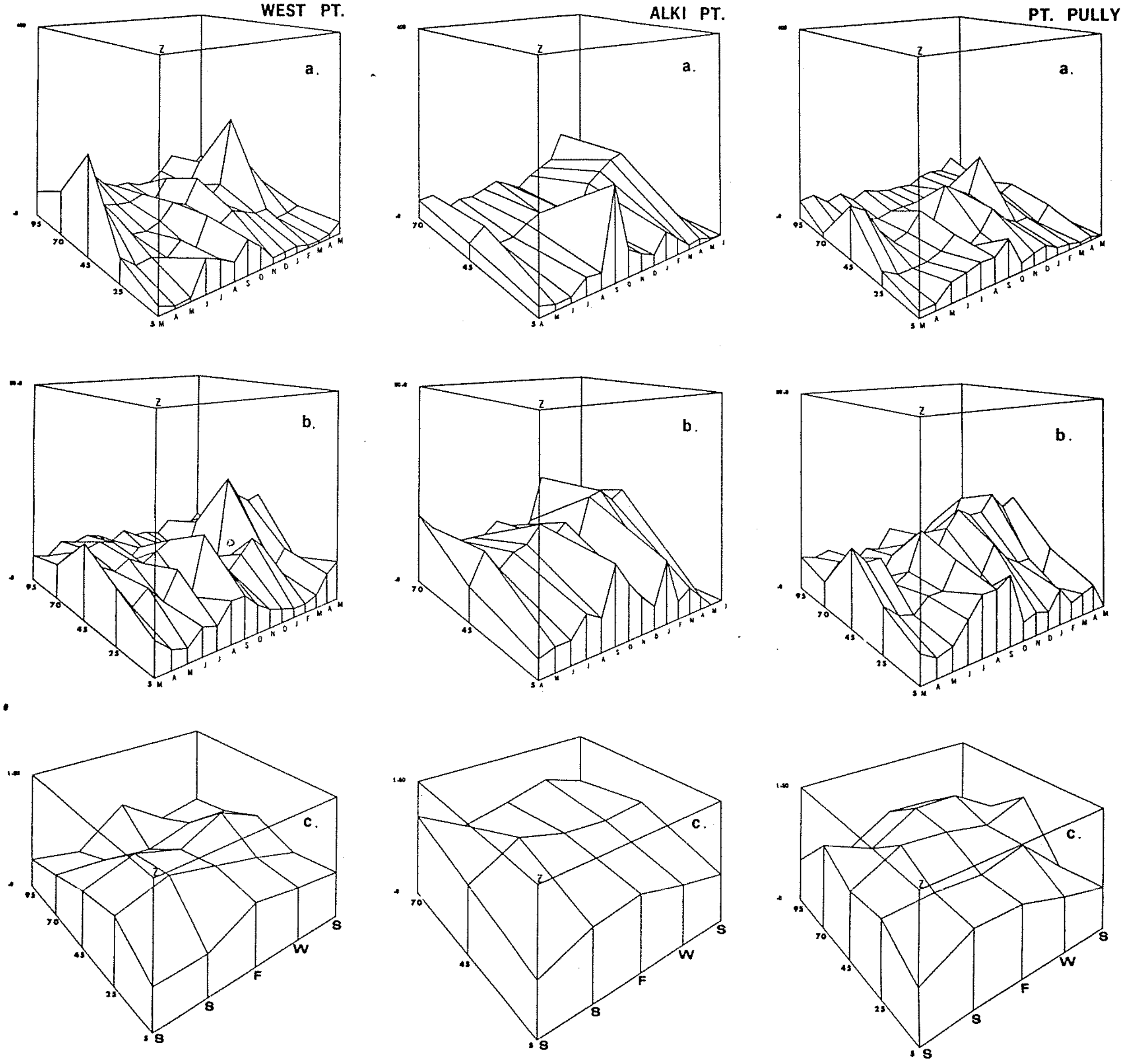


Fig. 9. Seasonal and bathymetric patterns of catch per haul (a), species richness (b), and Shannon-Wiener diversity (c) at West Point, Alki Point, and Point Pully.

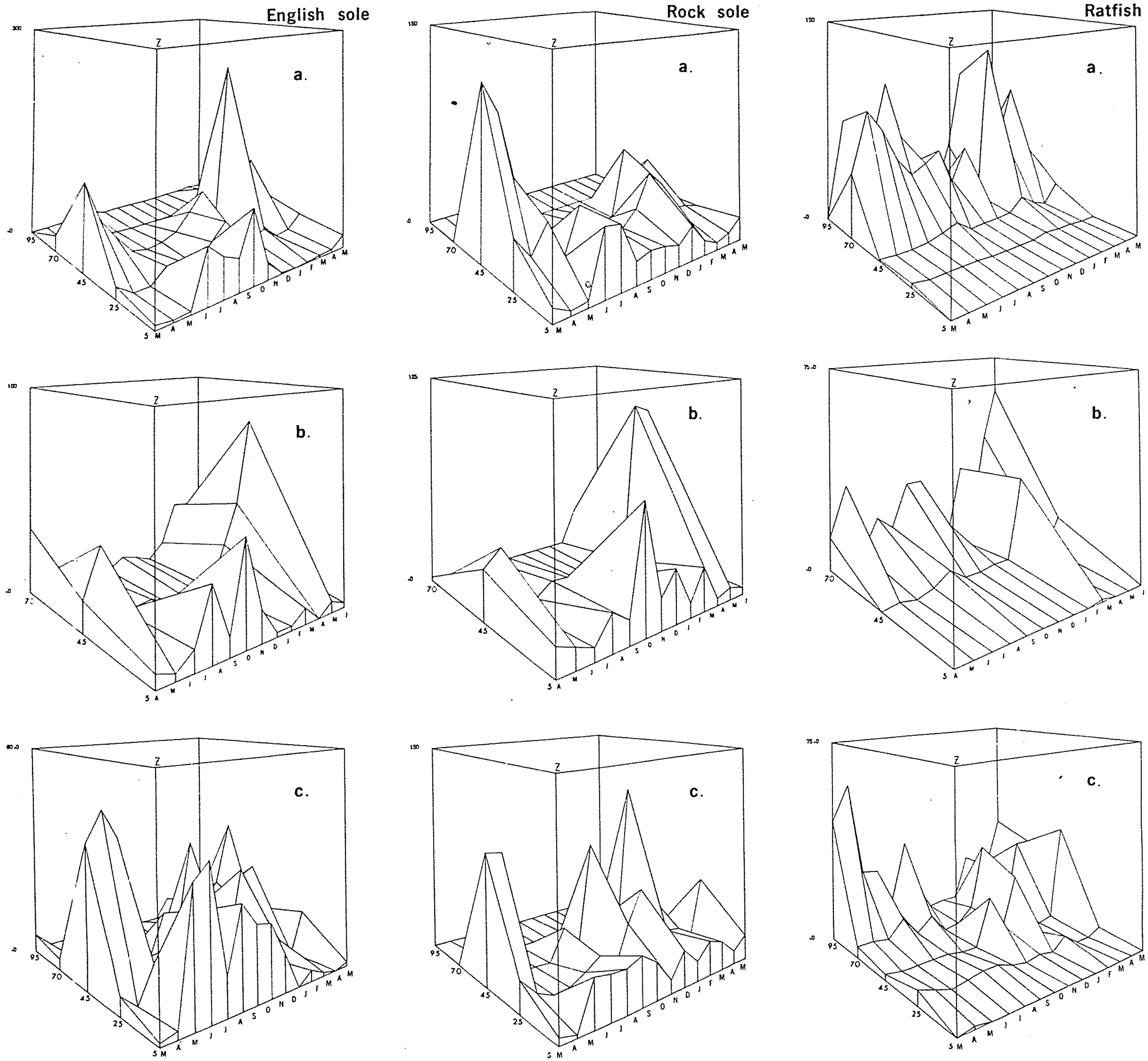


Fig. 10. Seasonal and bathymetric patterns of catch per haul for English sole, rock sole, and

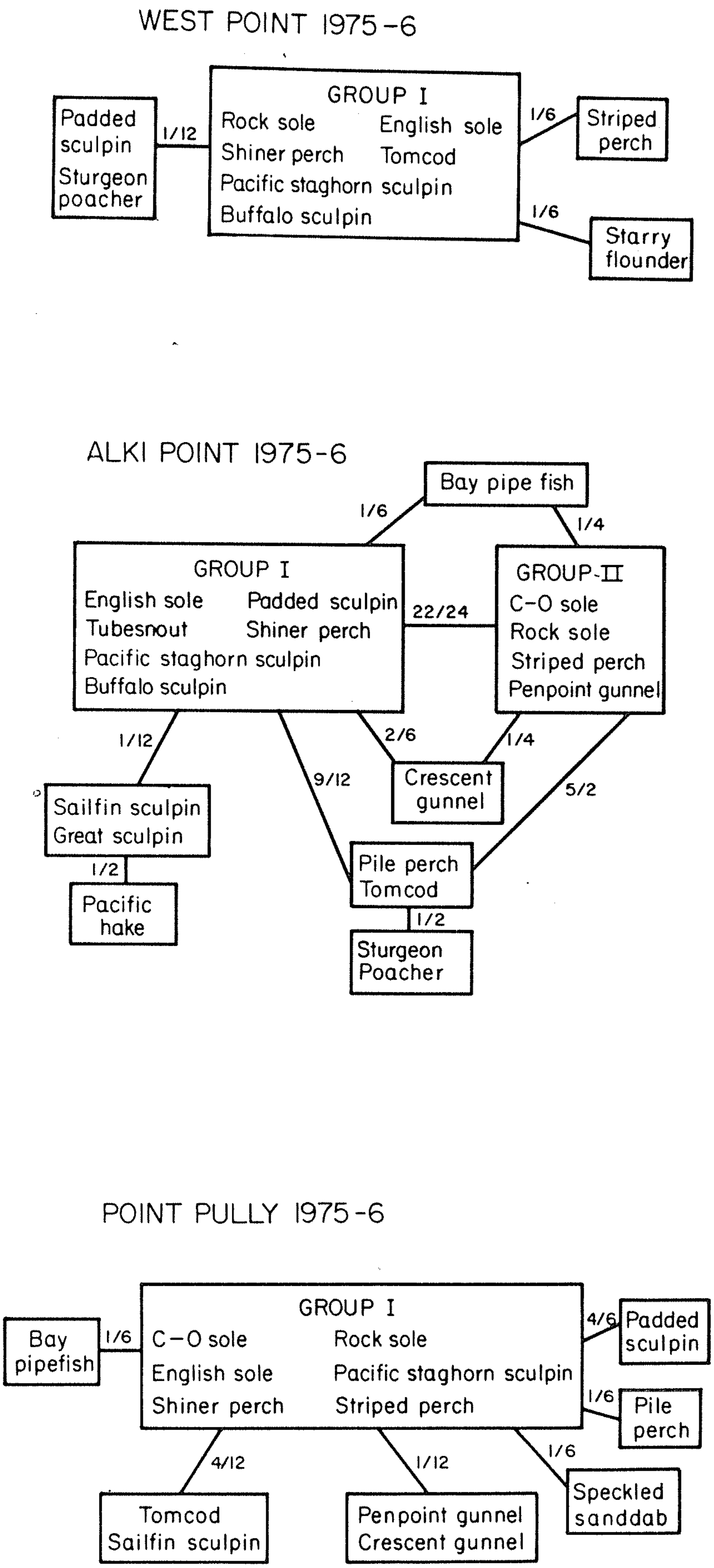
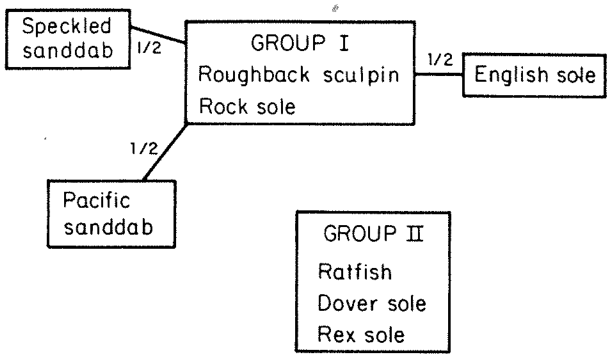
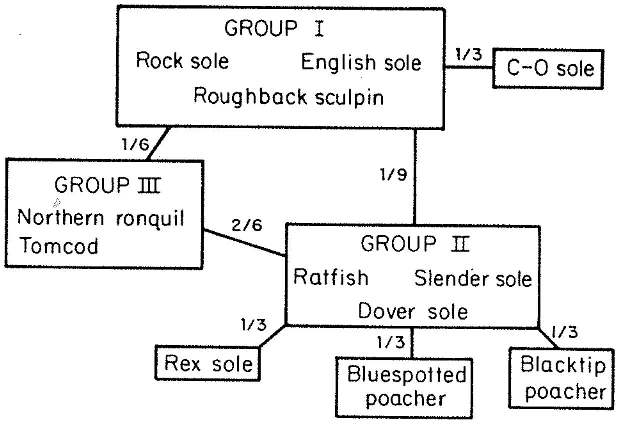


Fig. 11. Recurrent species groups based on beach seine data from West Point, Alki Point, and Point Pully.

WEST POINT 1975-6
(55 species; 137 samples)



ALKI POINT 1975-6
(55 species; 102 samples)



POINT PULLY 1975-6
(57 species; 158 samples)

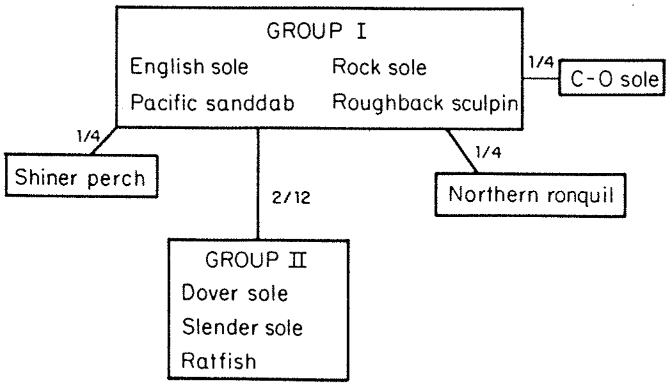


Fig. 12. Recurrent species groups based on otter trawl data from West Point, Alki Point, and Point Pully.

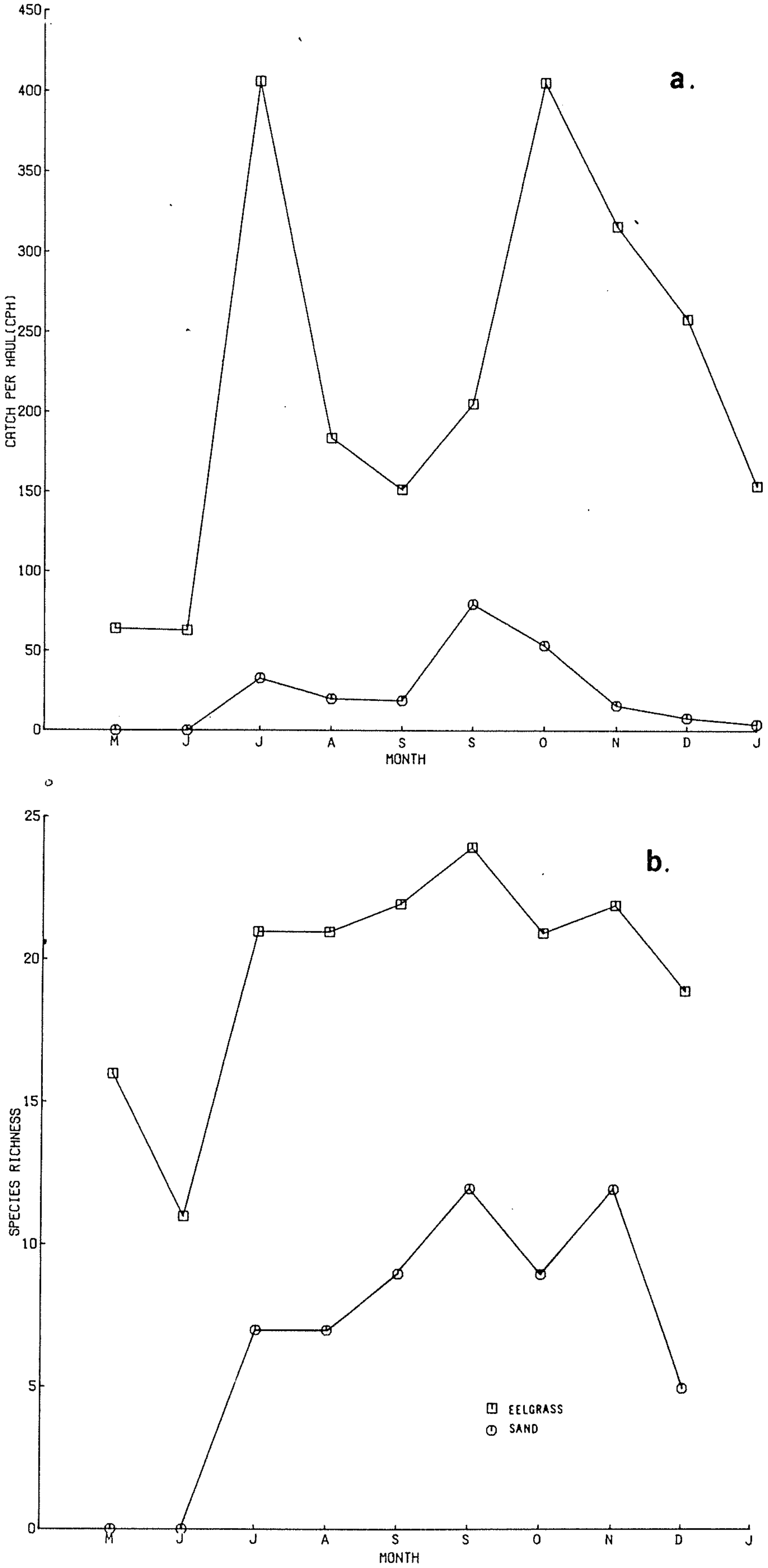


Fig. 13. Catch per haul (a) and species richness (b) from sand and eelgrass habitats at Alki Point.

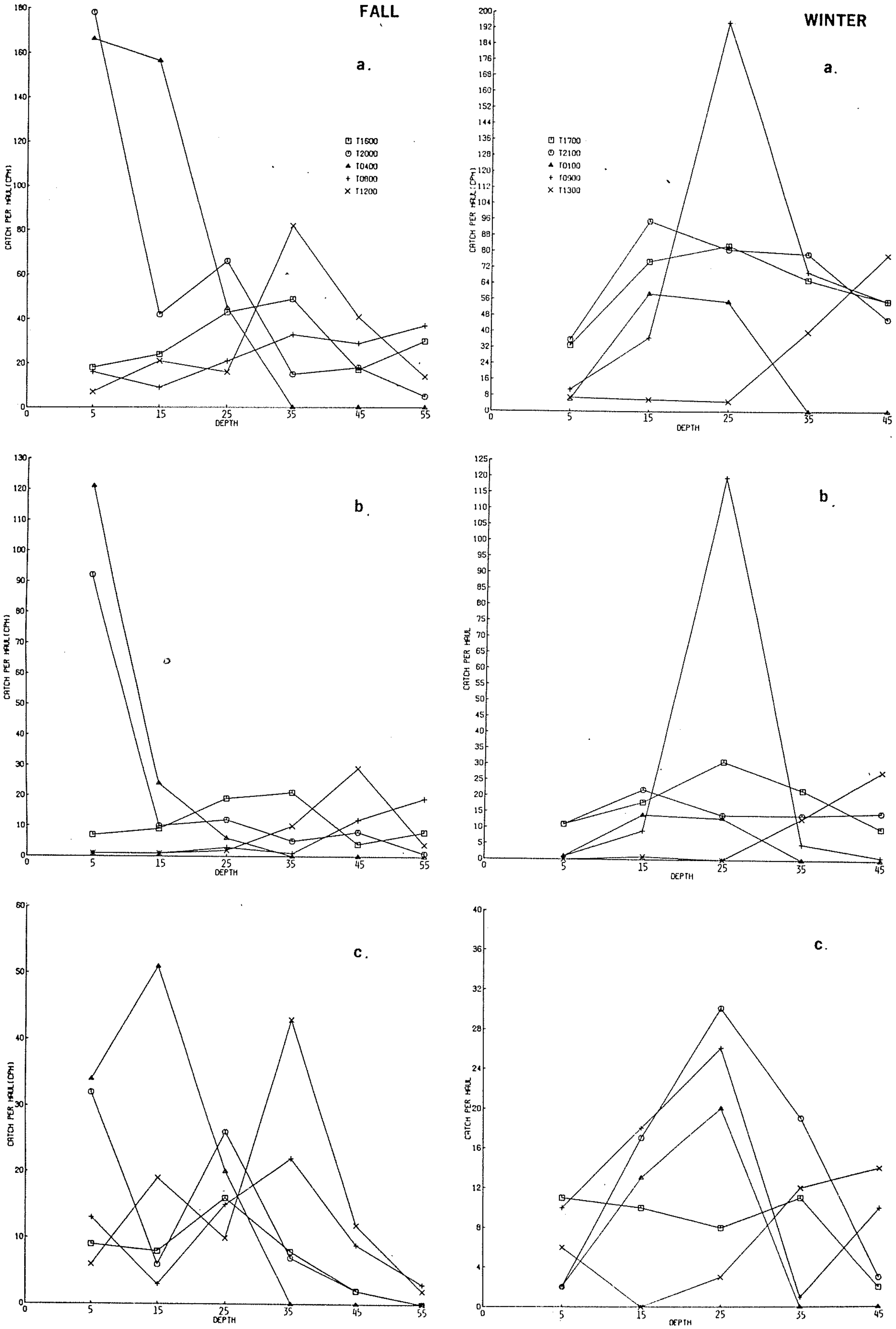


Fig. 14. Total catch per haul (a), catch per haul of English sole (b), and catch per haul of rock sole (c) by depth and time of day during fall and winter 24-hour trawling studies at West Point.

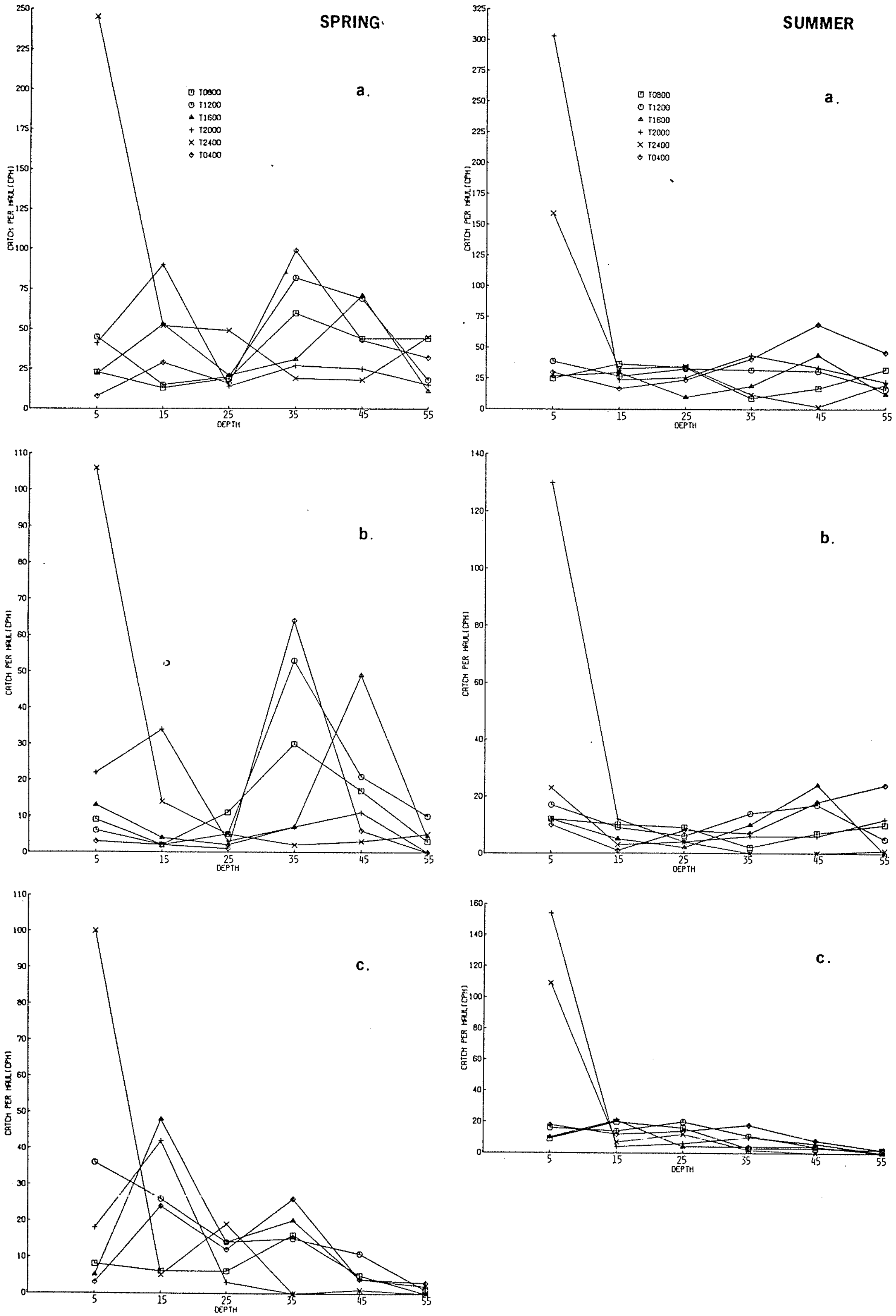
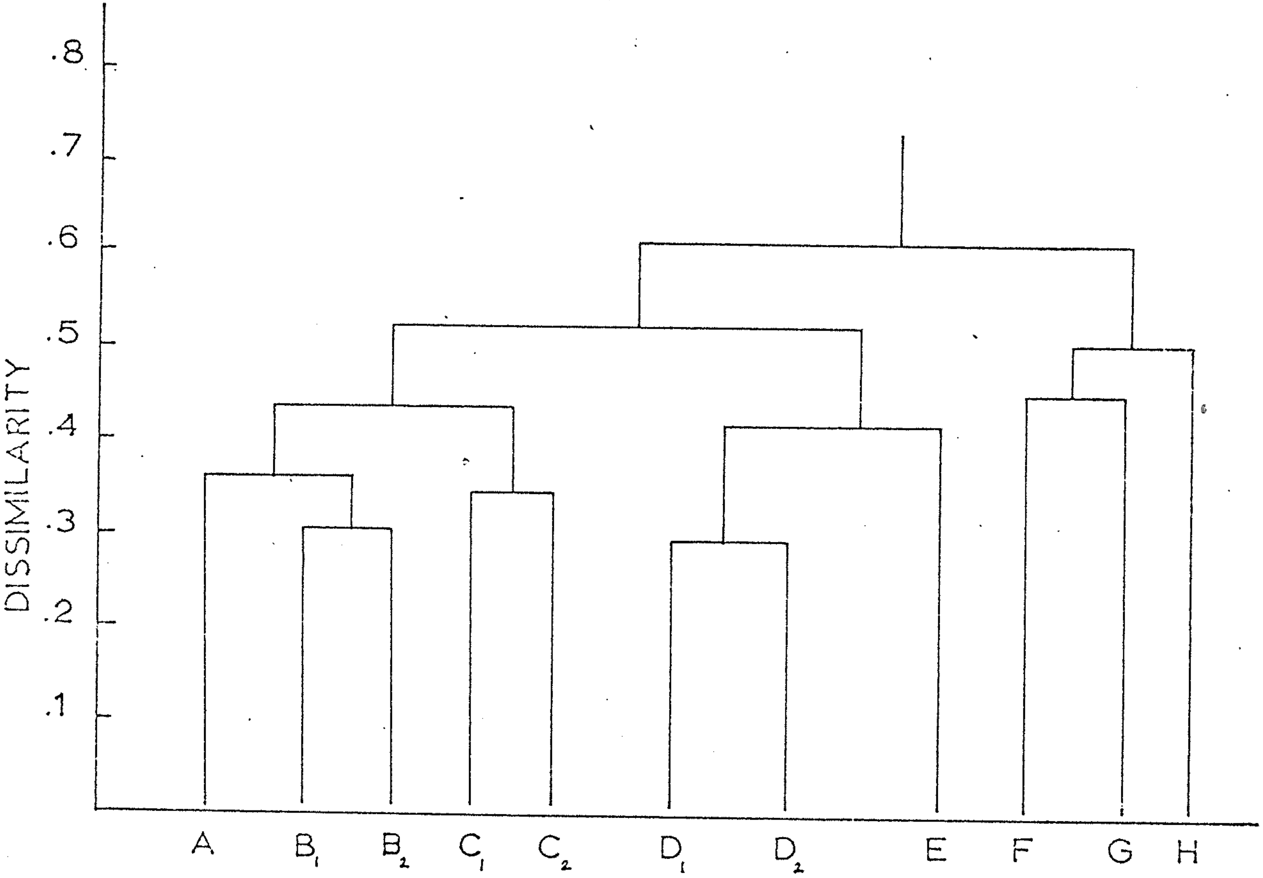


Fig. 15. Total catch per haul (a), catch per haul of English sole (b), and catch per haul of rock sole (c) by depth and time of day during spring and summer 24-hour trawling studies at West Point.



GROUP A- Late spring-early summer samples from Point Pully and Alki Point.

GROUP B_1- Late summer to early winter samples from Point Pully and Alki Point.

GROUP B_2- Summer samples from Alki Point.

GROUP C_1 - Spring samples from West Point.

GROUP C_2- Spring samples from Point Pully.

GROUP D_1- Winter-fall samples from Point Pully.

GROUP D_2- Winter-fall samples from West Point.

GROUP E- Summer-spring samples from West Point.

GROUP F- Late winter-early spring samples from all three sites. These samples were taken during the period of the year where temperatures are lowest and eelgrass habitat availability is minimal.

GROUP G - Spring samples from West Point.

GROUP H- Late winter-spring samples from Point Pully.

Fig. 16. Normal classification of beach seine samples taken at three sites (West Point, Alki Point and Point Pully) in central Puget Sound. West Point, Alki Point and Point Pully are characterized as sand, sand-eelgrass and sand-scattered eelgrass habitats respectively.

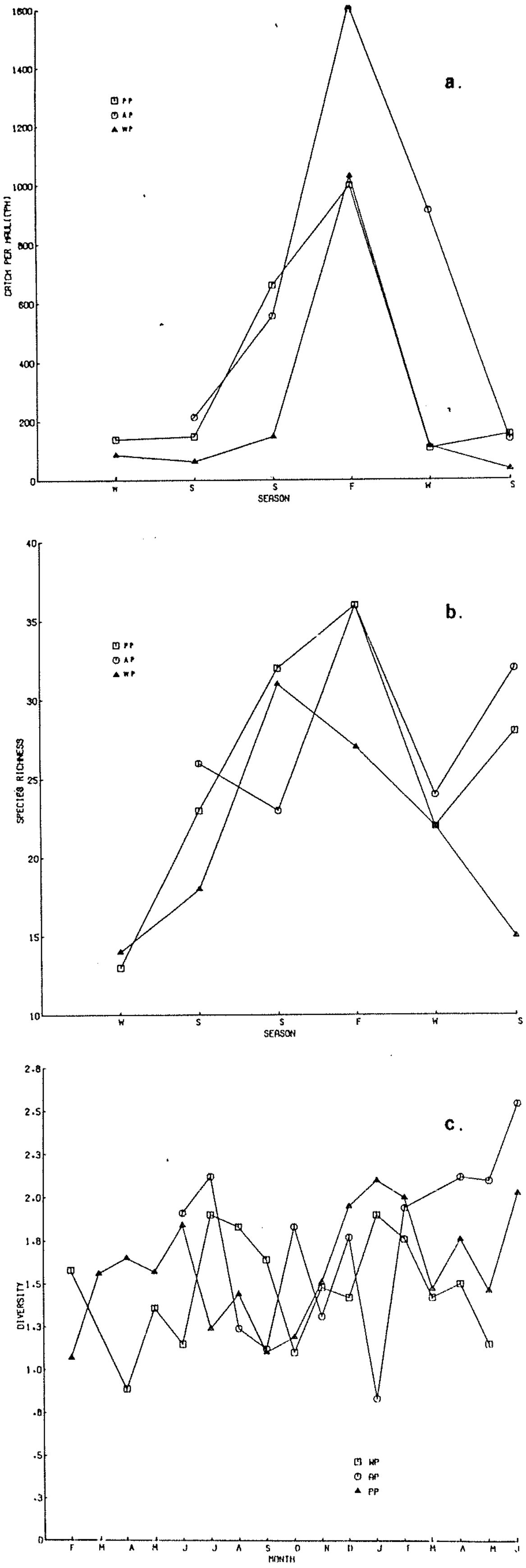


Fig. 17. Comparisons of catch per haul (a), species richness (b), and Shannon-Wiener diversity (c) from the 37-m beach seine stations at West Point (WP), Alki Point(AP), and Point Pully (PP).

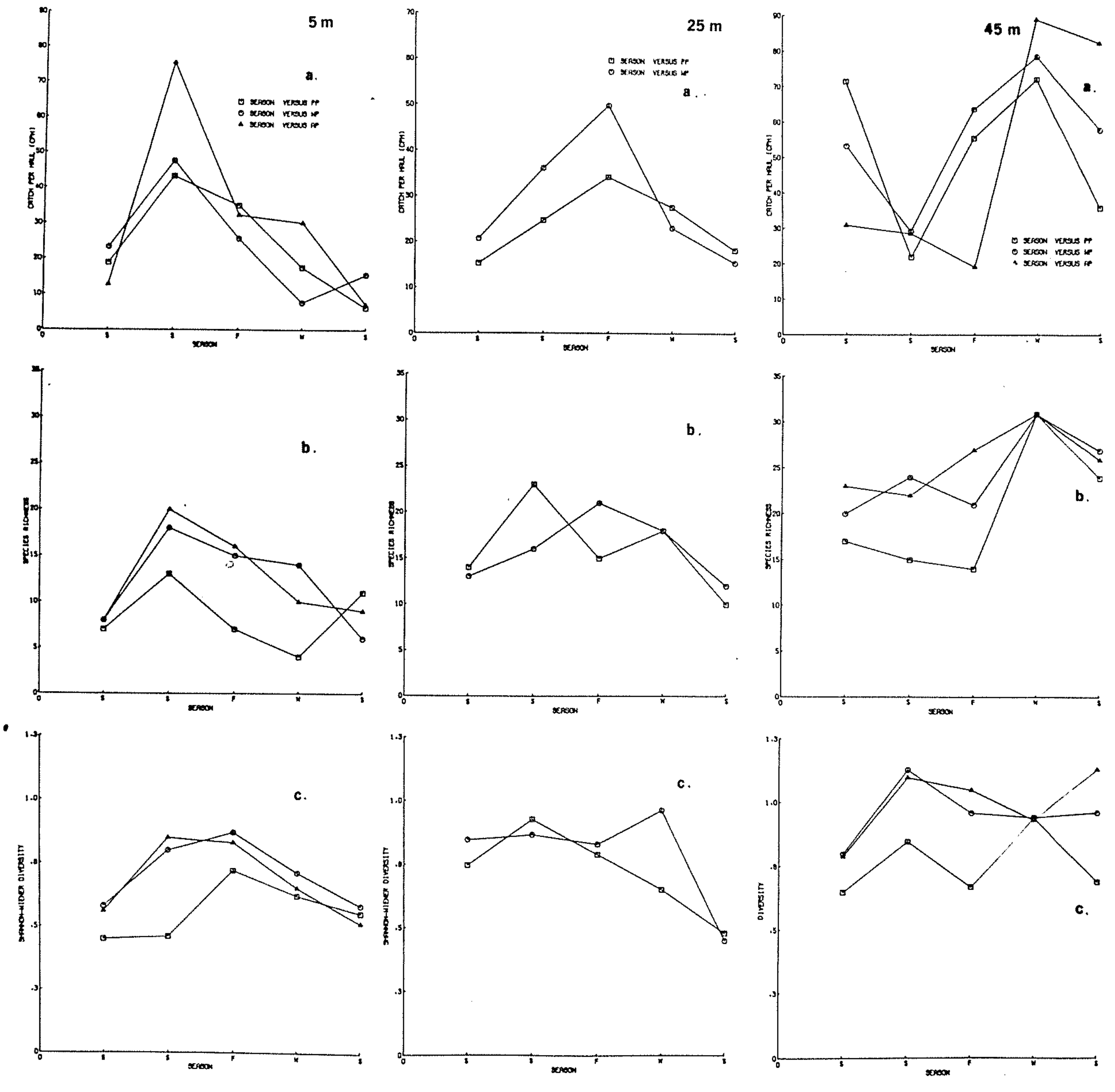


Fig. 18. Seasonal comparisons of catch per haul (a), species richness (b), and Shannon-Wiener diversity (c) from the 5-m, 25-m, and 45-m otter trawl stations at West Point (WP), Alki Point (AP), and Point Pully (PP).

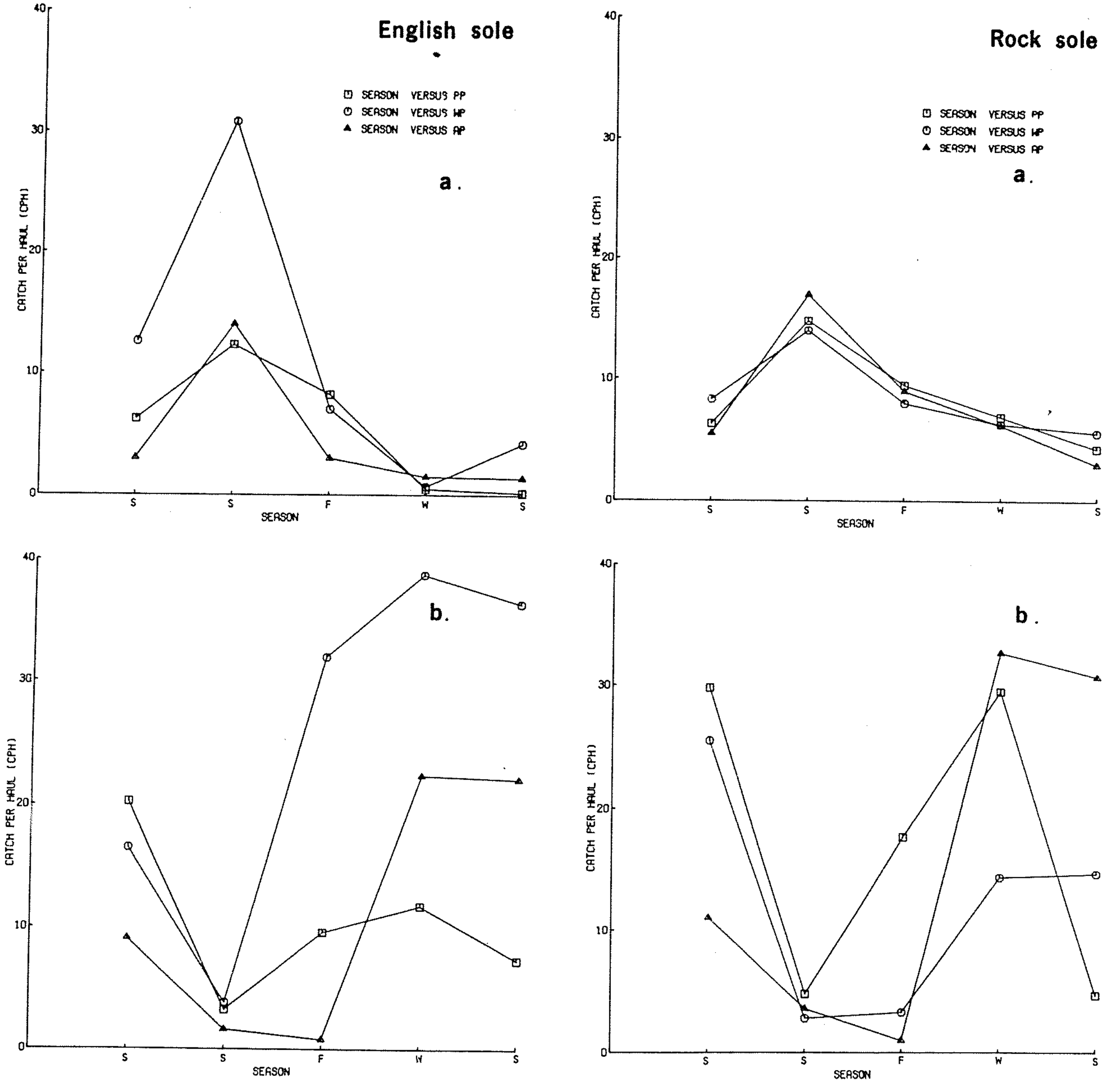


Fig. 19. Seasonal comparisons of catch per haul for English sole and rock sole from the 5-m (a) and 45-m (b) otter trawl stations at West Point (WP), Alki Point (AP), and Point Pully (PP).

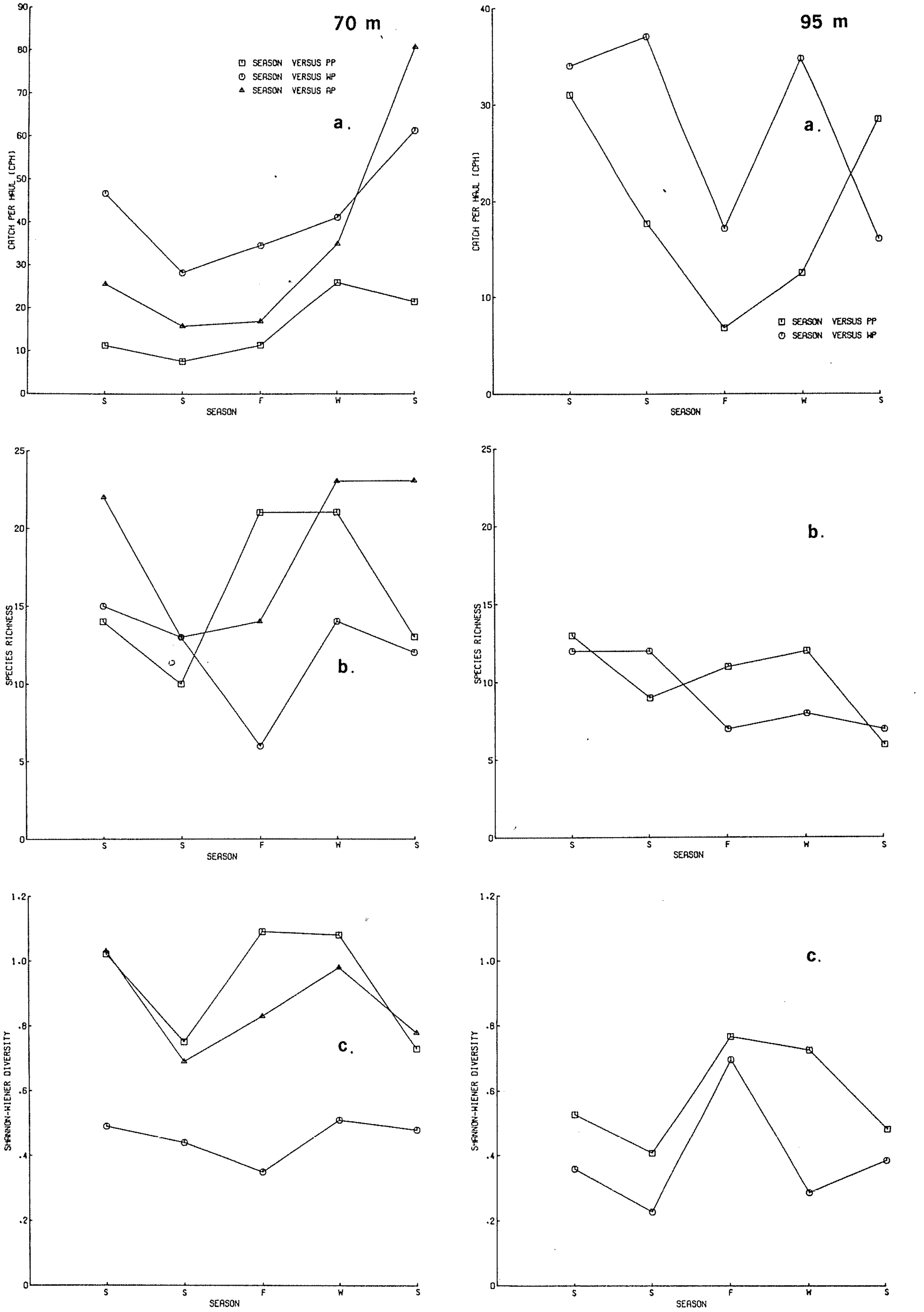


Fig. 20. Seasonal comparisons of catch per haul (a), species richness (b), and Shannon-Wiener diversity from the 70-m and 95-m otter trawl stations at West Point (WP), Alki Point (AP), and Point Pully (PP).

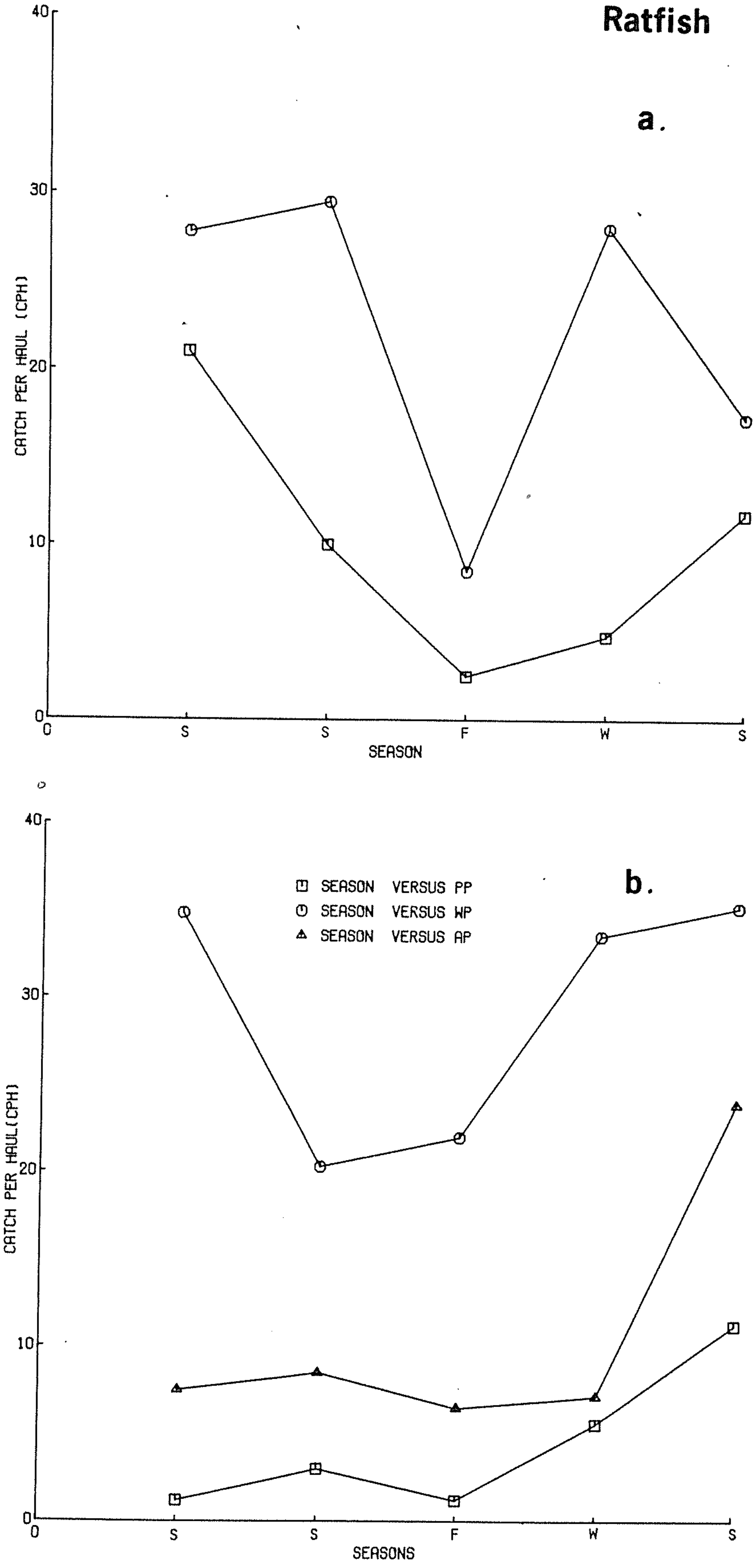


Fig. 21. Seasonal comparisons of catch per haul for ratfish from the 95-m (a) and 70-m (b) otter trawl stations at West Point (WP), Alki Point (AP), and Point Pully (PP).

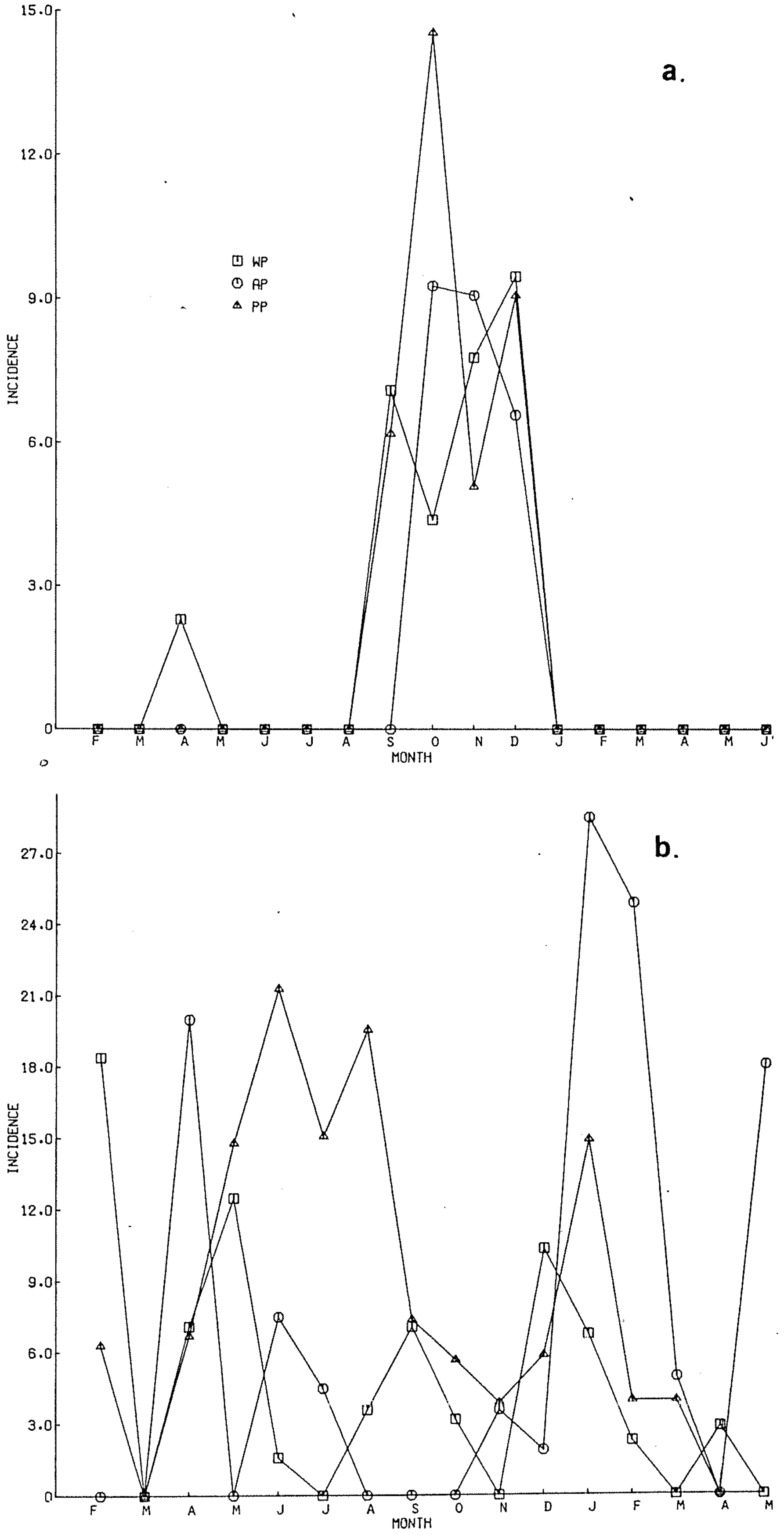


Fig. 22. Incidence of tumor-bearing age group 0 (a) and age group I (b) English sole from West Point (WP), Alki Point (AP), and Point Pully (PP).

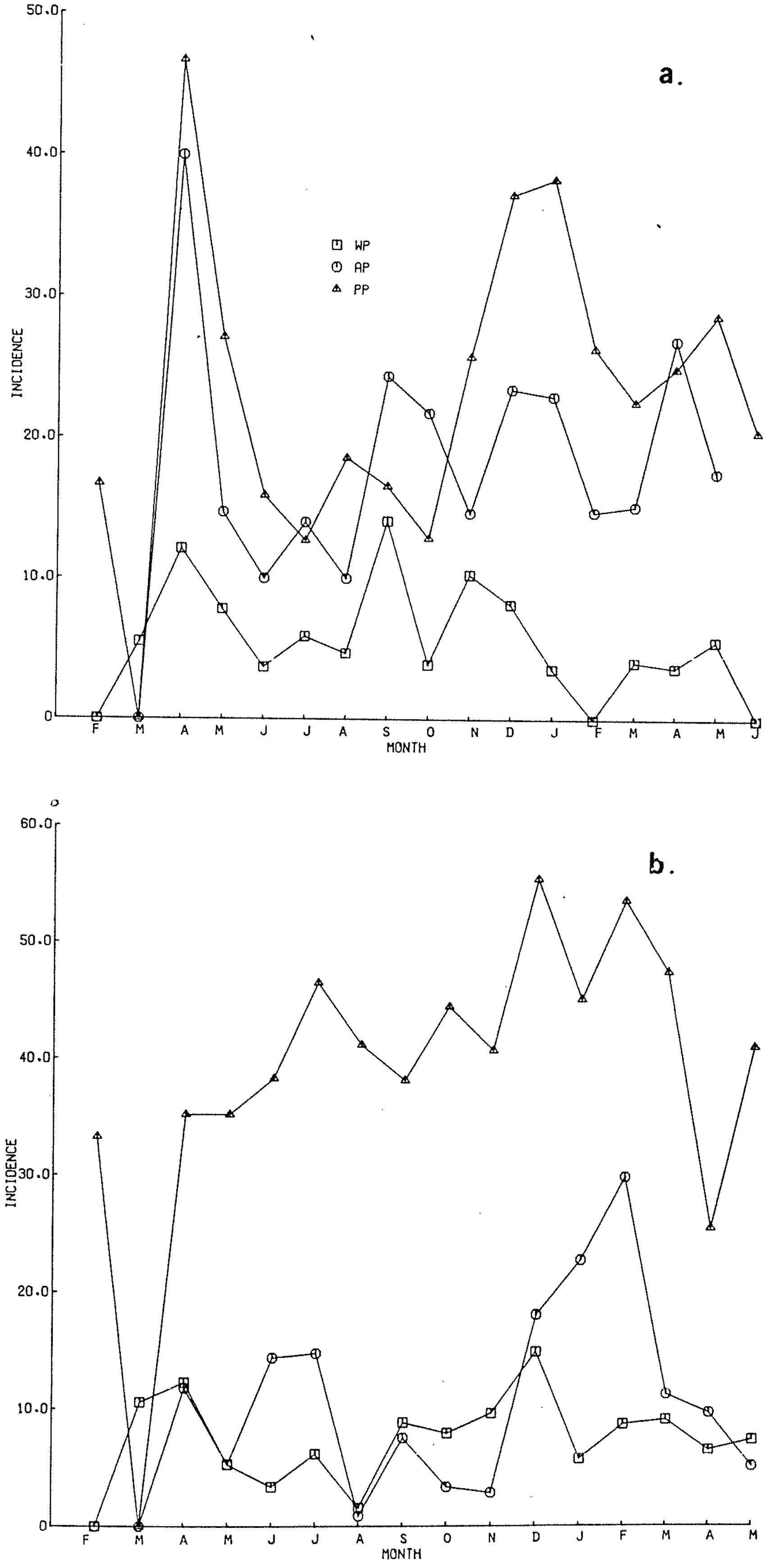


Fig. 23. Incidence of Philometra-infested English sole (a) and rock sole (b) from West Point (WP), Alki Point (AP), and Point Pully (PP).

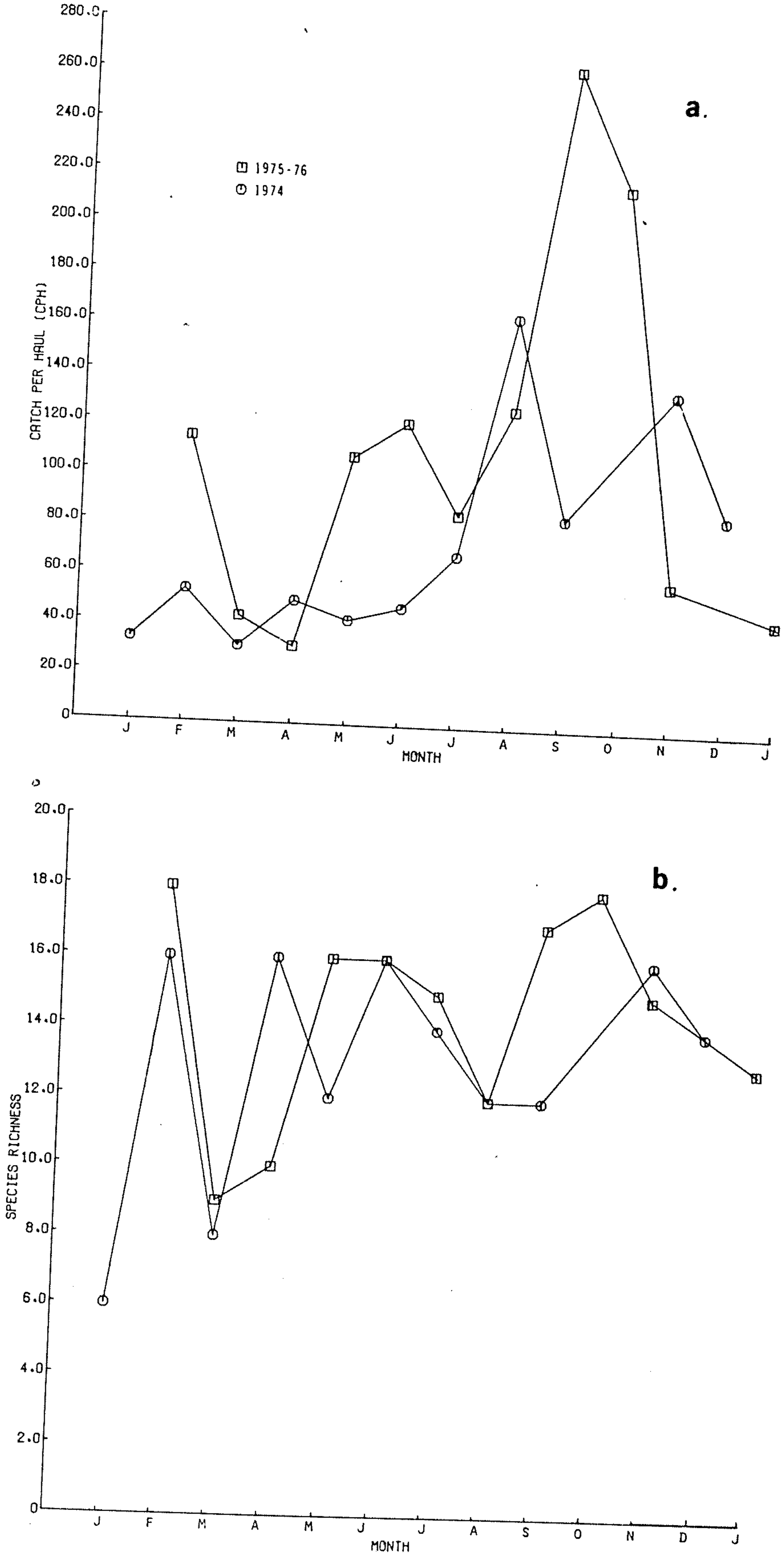


Fig. 24. Comparisons of catch per haul (a) and species richness (b) in the Duwamish River during 1974 and 1975-76.

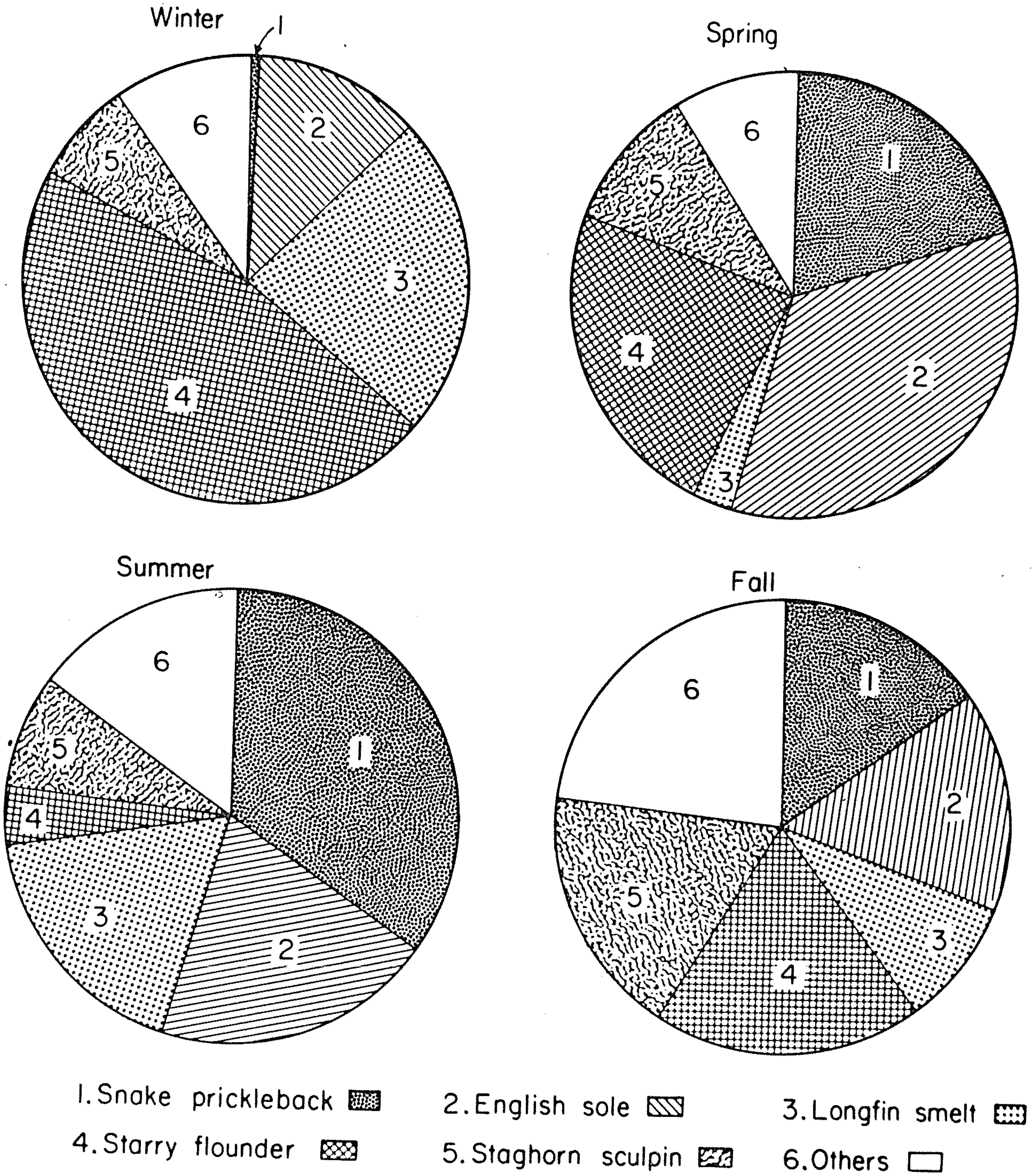


Fig. 25. Relative seasonal abundance of the five most abundant fish species in the Duwamish River during 1975-76.

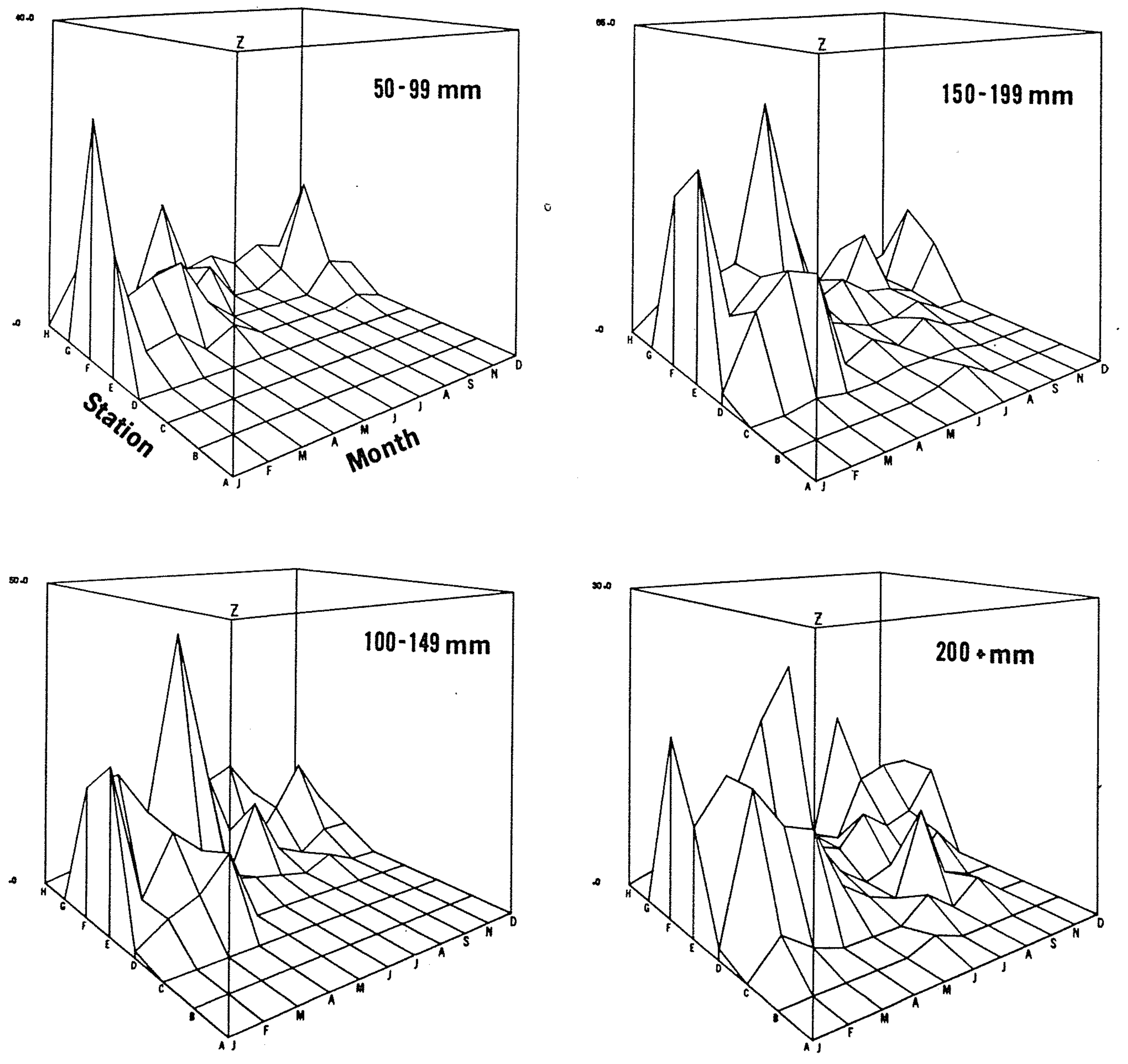


Fig. 26. Distribution by station and monthly abundance of four size classes of starry flounder in the Duwamish River, 1975-76.

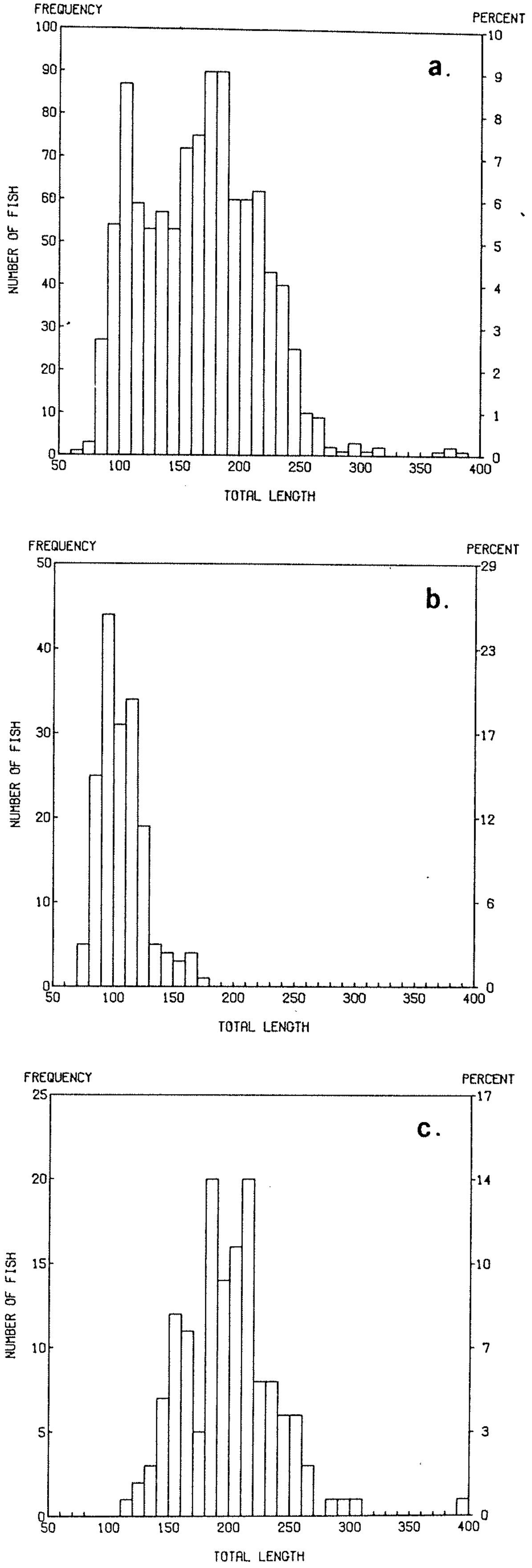


Fig. 27. Length frequency histograms of normal (a), tumor-bearing (b), and fin-eroded (c) starry flounder collected in the Duwamish River.

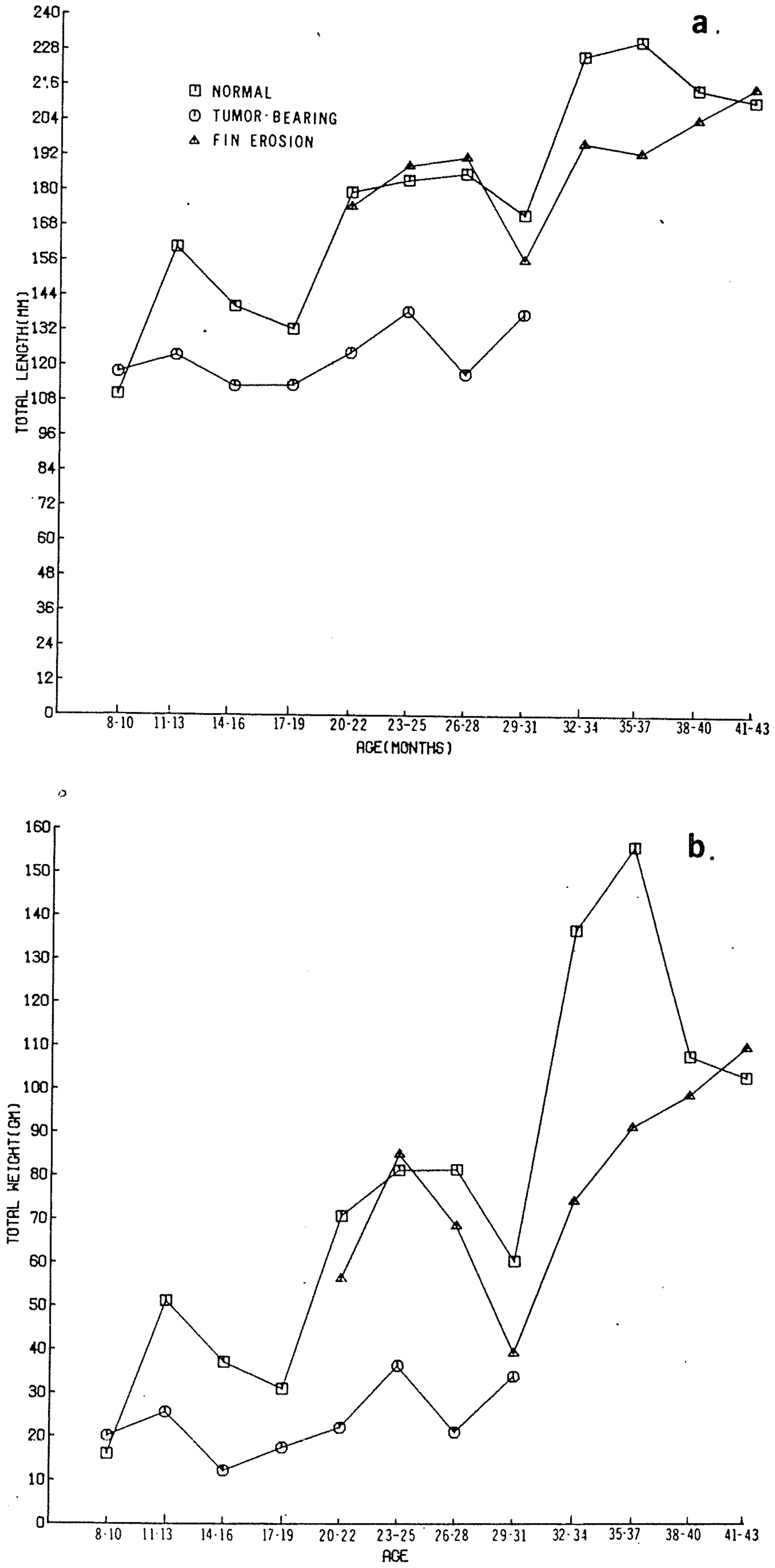


Fig. 28. Growth in length (a) and weight (b) of normal, tumor-bearing, and fin-eroded starry flounder from the Duwamish River.

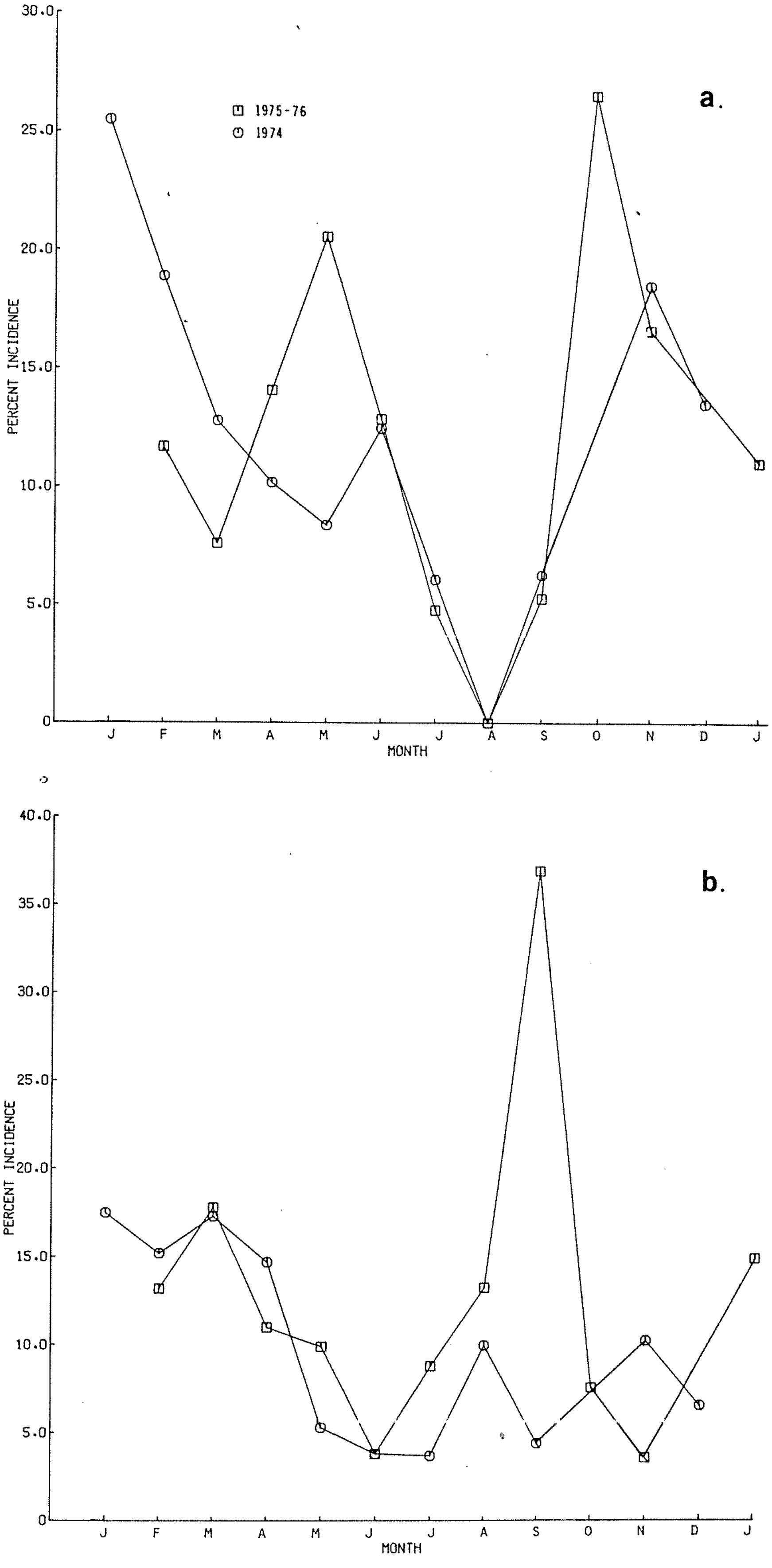


Fig. 29. Monthly incidence of tumor-bearing (a) and fin-eroded (b) starry flounder collected in the Duwamish River during 1974 and 1975-76.

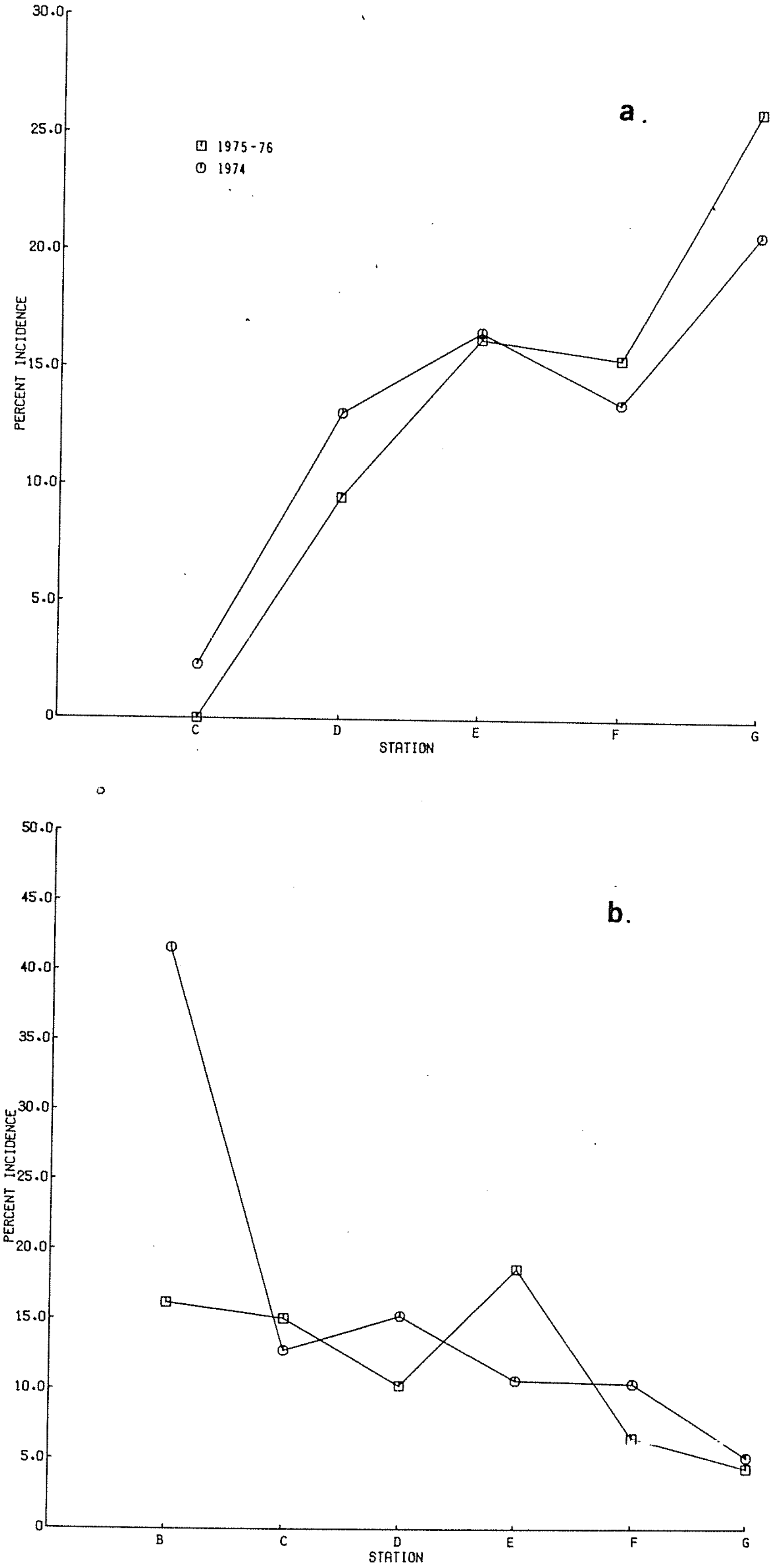


Fig. 30. Incidence by station for tumor-bearing (a) and fin-eroded (b) starry flounder collected in the Duwamish River, 1974 and 1975-76.

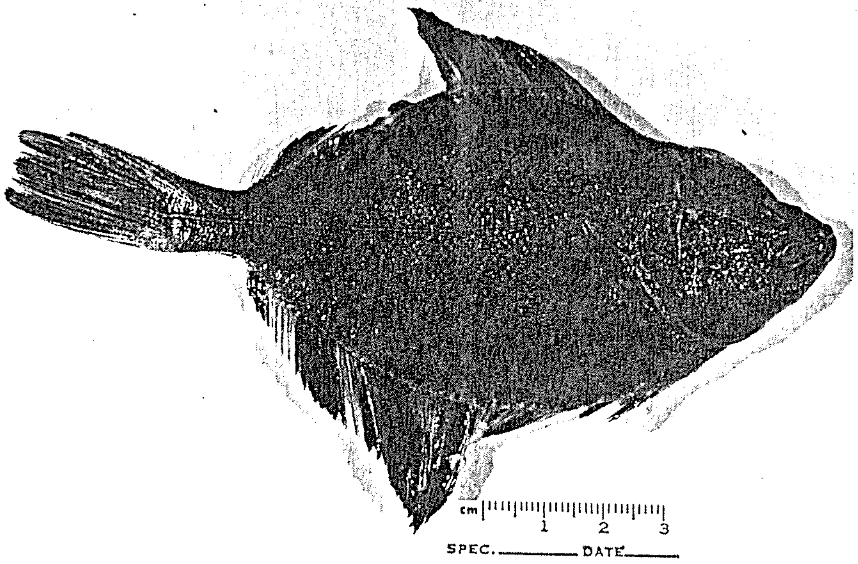


Fig. 31. Starry flounder with the advanced form of fin erosion involving the anterior half of the anal fin and the posterior half of the dorsal fin.

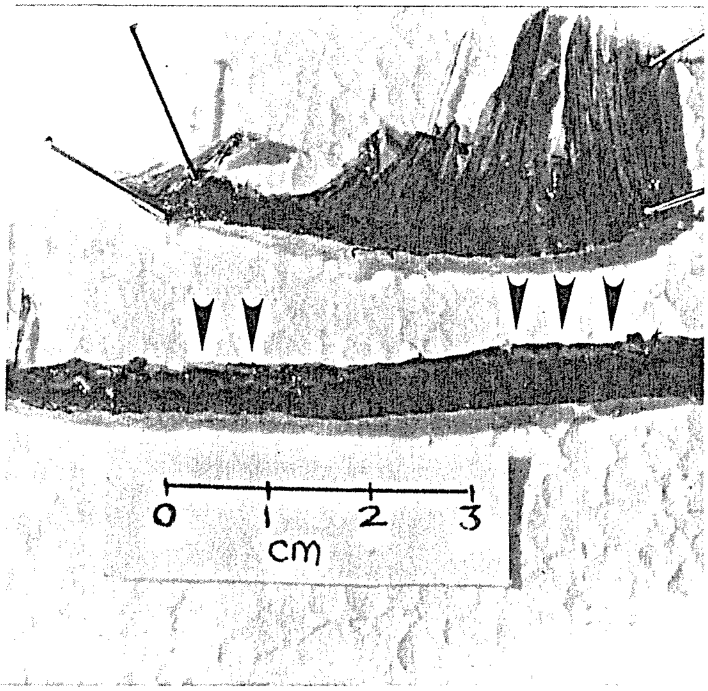


Fig. 32. Eroded portion of fins from an English sole. Note denuded fin ray and line of hyperpigmentation (arrows).

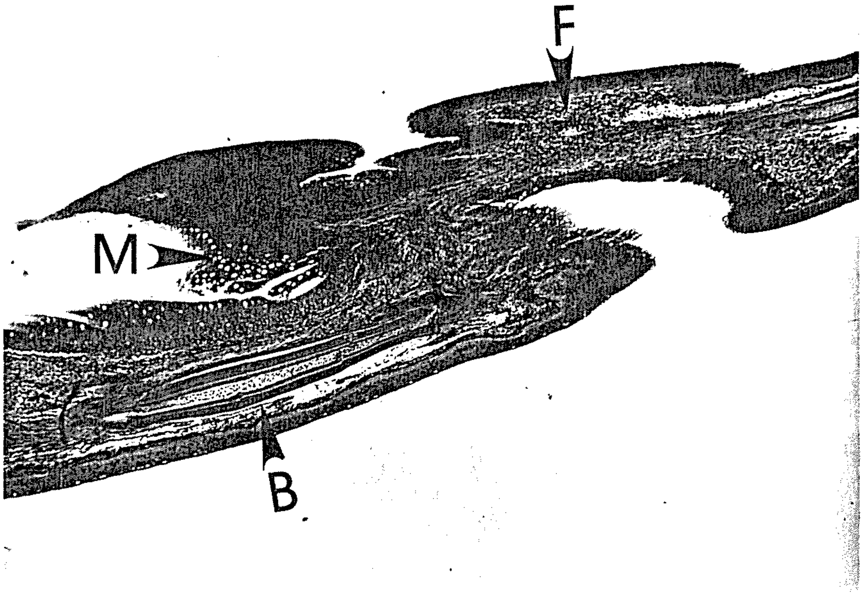


Fig. 33. A section of fin tissue from a starry flounder with fin erosion. Normal-appearing bone spicules (B) are being resorbed and replaced by fibrotic and granulocytic tissue (F). The fin tissue which has lost the fin ray has collapsed and folded back onto itself. Some mucous cell hyperplasia is also present (M).

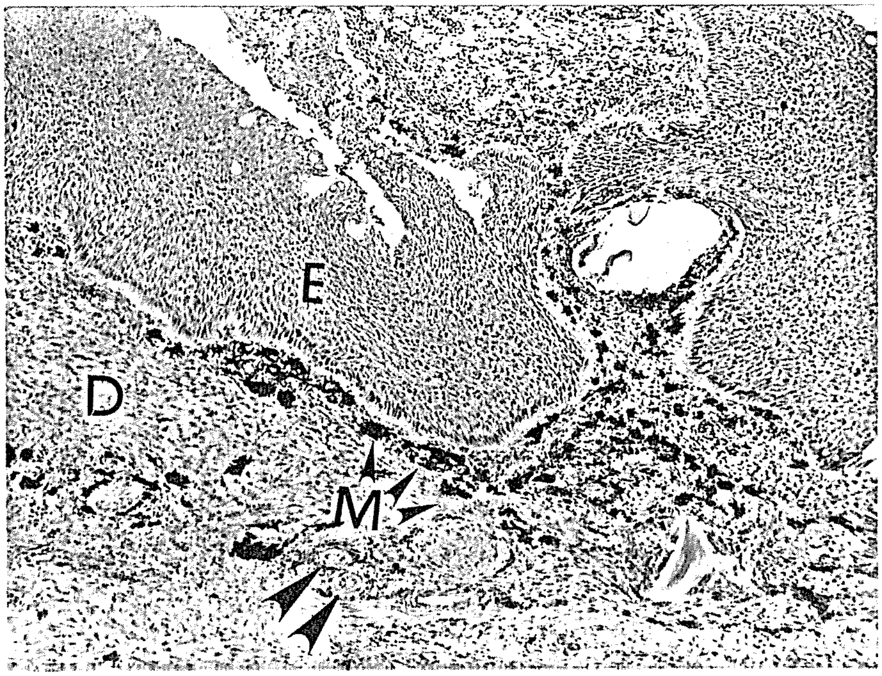


Fig. 34. Section of an eroded fin from an English sole with a hyperplastic epidermis (E), irregular distribution of melanophores (M), a fibrotic dermis (D), and sclerotic blood vessels (arrows).

Fig. 35. A transverse section of fin tissue from a starry flounder with fin erosion. Bone spicules (B) are being resorbed unequally, with accumulations of melanophores (M) at the edge of the resorbing spicule.

Fig. 36. Liver in an English sole with one type of grossly visible hepatomas (arrows).

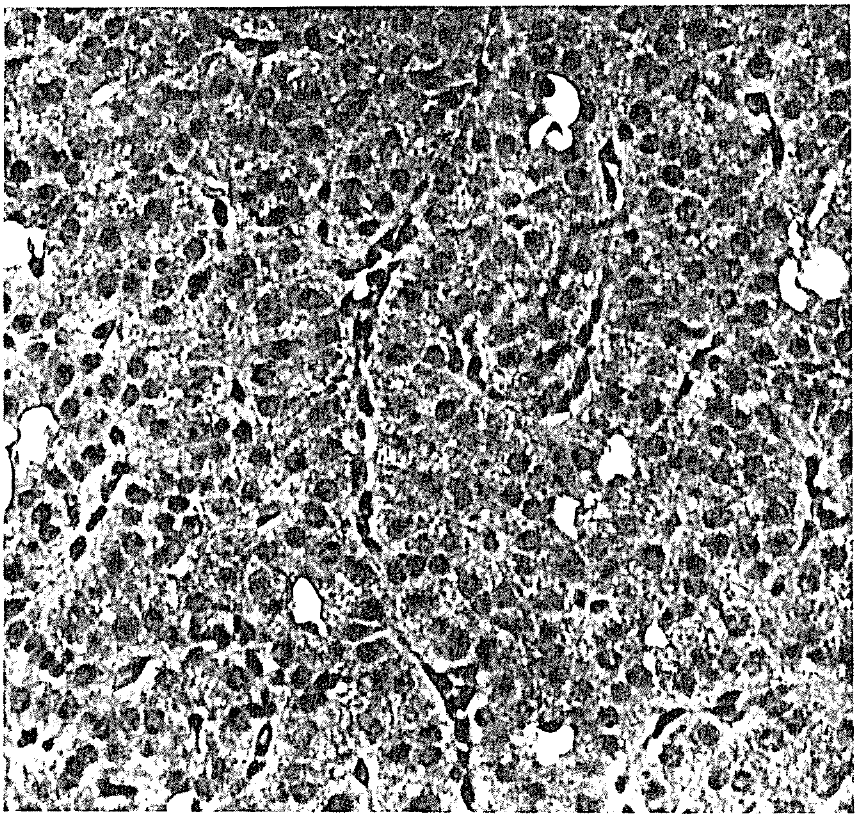


Fig. 37. A section of a normal-appearing liver from a starry flounder.

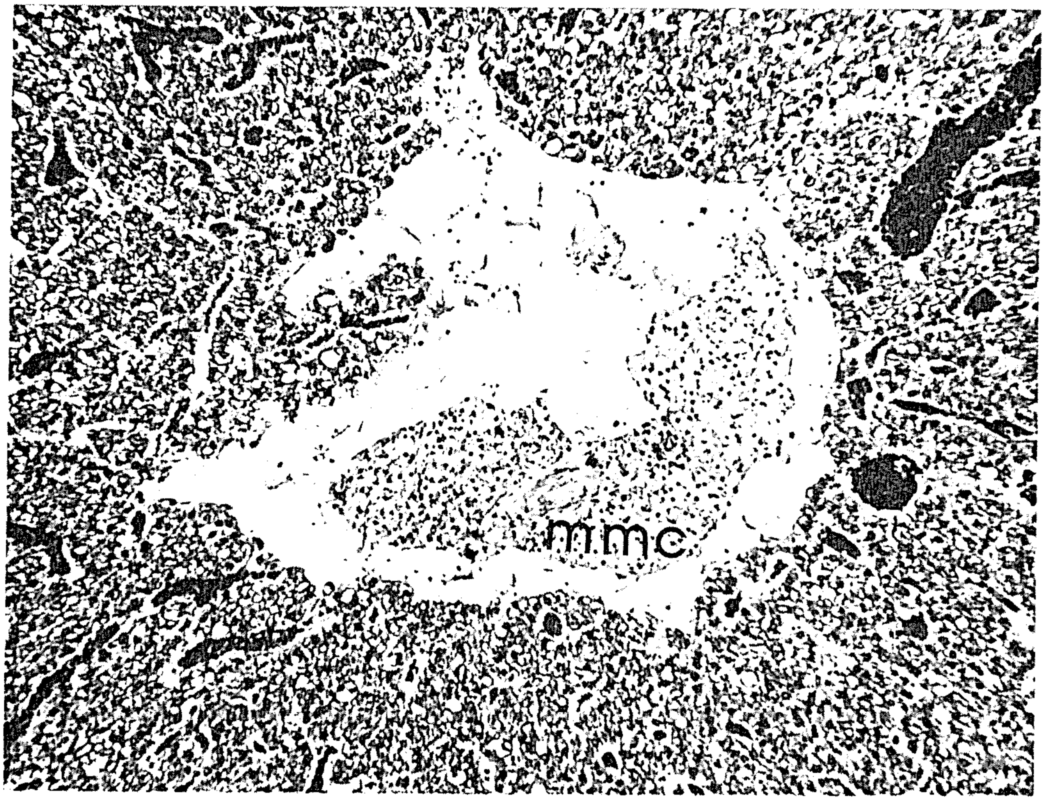


Fig. 38. Abnormal liver from a starry flounder with fatty vacuolization, loss of structure, congestion, and a large degenerating melanin macrophage center (mmc).

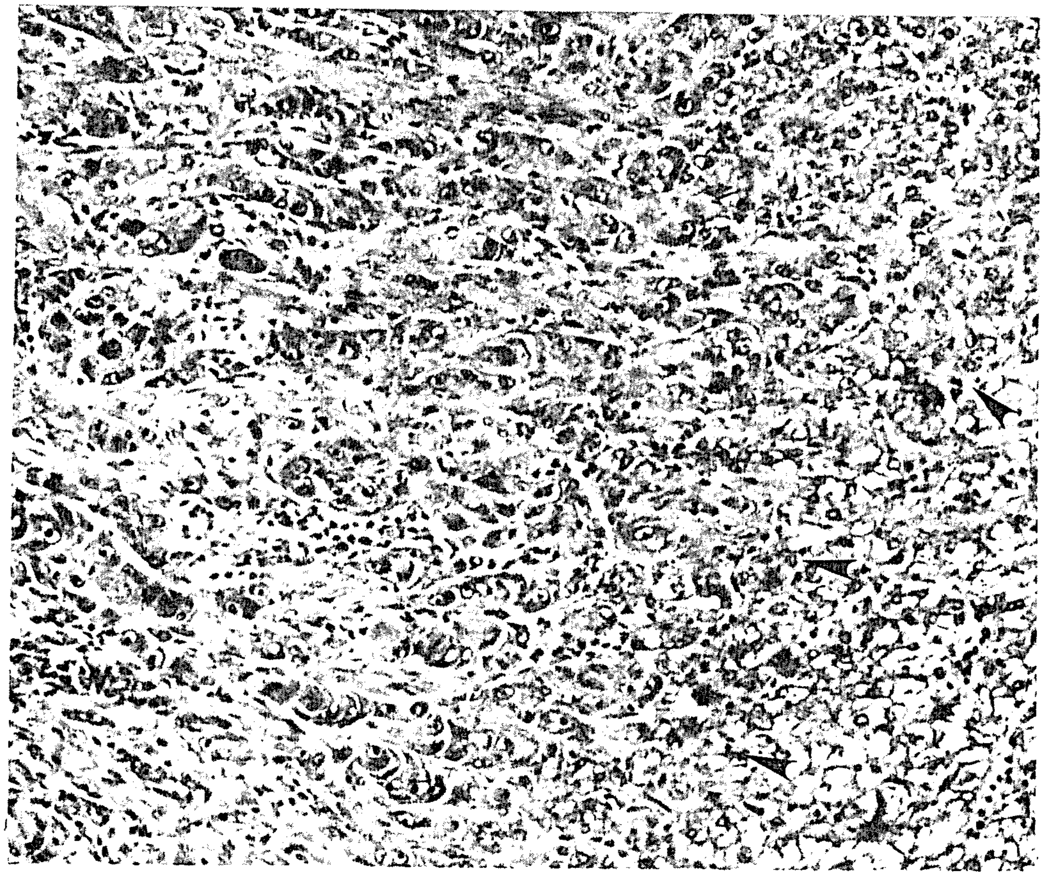


Fig. 39. A portion of a basophilic nodule (hepatoma) in an English sole liver. The undefined edge of the nodule (arrows) is adjacent to highly vacuolated hepatocytes.