Padilla Bay
National Estuarine Research Reserve

Reprint Series No. 36
Reprinted December 2001

Distribution and Abundance of Fishes Occurring in the Nearshore Surface Waters of Northern Puget Sound

Kurt Leigh Fresh

1979

Publication No. 01-06-030

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Bibliographic citation: Fresh, Kurt Leigh. 1979. Distribution and abundance of fishes occurring in the nearshore surface waters of northern Puget Sound, Washington. Master of Science Thesis, University of Washington, Seattle, Washington. Washington State Department of Ecology Publication No. 01-06-030, Padilla Bay National Estuarine Research Reserve Reprint Series No. 36.

DISTRIBUTION AND ABUNDANCE OF FISHES
OCCURRING IN THE NEARSHORE SURFACE WATERS
OF NORTHERN PUGET SOUND, WASHINGTON

by

Kurt Leigh Fresh

A thesis submitted in partial fulfillment of the
requirements for the degree of

Master of Science

UNIVERSITY OF WASHINGTON

1979

Approved by Bruce S Miller
(Chairperson of Supervisory Committee)

Program Authorized
to Offer Degree College of Fisheries

Date 12 December 1978

University of Washington

Abstract

DISTRIBUTION AND ABUNDANCE OF FISHES
OCCURRING IN THE NEARSHORE SURFACE WATERS OF
NORTHERN PUGET SOUND, WASHINGTON

by Kurt Leigh Fresh

Chairperson of Supervisory Committee: Professor Bruce S. Miller
College of Fisheries

Fishes occurring in the nearshore surface waters of northern Puget Sound, Washington, were studied during 1974-1976 using a two-boat surface trawl (townet). Five sites, each representing a different habitat type (as defined by degree of exposure and substrate type), were sampled in each of three geographic areas. Principal objectives of the study were to document the abundance, spatial and temporal distribution of fishes occurring in nearshore surface waters of northern Puget Sound.

Nearshore surface waters were utilized as nursery and rearing areas by numerous fish species. While the townet was not designed to sample larvae, larval fish were caught abundantly, primarily in spring. Mainly juvenile fish were found throughout the entire year in nearshore habitats studied. Few large fish were caught, perhaps because of avoidance.

Of the 71 fish species captured, the 6 most abundant species comprised 98 percent of the total numerical catch. Twenty species were schooling whereas 51 were demersal; schooling species generally were more frequently occurring and more abundant than non-schooling species. Catches of most species were highly seasonal and indicated a lack of permanent resident species. Young-of-the-year Pacific herring was the dominant fish species occurring in nearshore surface waters. Herring

catches were especially large at sites associated with protected eelgrass bays and in areas near known spawning grounds. Maximum catches of herring occurred during the spring and summer whereas minimum catches occurred in the fall and winter. Other abundant species included young-of-the-year Pacific sand lance, juvenile and adult threespine stickleback, larval to adult surf smelt, and larval to adult longfin smelt. While numerically not abundant, juvenile salmonids (mostly chinook salmon) occurred consistently in spring and summer primarily in the Cherry Point and Anacortes areas.

Seasonal trends were consistent between the two years sampled, although magnitudes of CPUE and numbers of species varied. Catches of all species were lowest during the winter and resulted in similar CPUE levels at all sites. CPUE and numbers of species increased at all sites during the spring, principally because of the occurrence of large numbers of larvae. Maximum CPUE occurred at most sites during the spring and summer due to large catches of herring, sand lance, and stickleback. A substantial fall decrease in CPUE suggested an offshore movement of fishes out of the nearshore surface zone, possibly in response to increased exposure levels, reduced food supplies, and/or reduced temperatures.

The dominant nearshore pelagic species were present throughout the various nearshore habitats of northern Puget Sound with little evidence of distinct assemblages in different habitats. However, even though the dominant species exploit the entire nearshore spectrum of habitats, there were preferred habitats and areas.

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ACKNOWLEDGEMENTS

I would like to express my thanks to my major professor, Dr. Bruce S. Miller, for his support and assistance throughout this study. I am also grateful for the advice and support provided by the other members of my committee, Dr. Ernest O. Salo and Dr. Gary Lord.

I gratefully acknowledge the assistance of all who participated in the field work, at times under very adverse conditions. Robert Waldron, Paul Schneidler, Larry Moulton, C.A. Simenstad, W.A. Karp, and Steve Quinnell were especially valuable in the field. Special appreciation is given to the skippers of the R.V. MALKA, D.T. Griggs, Robert Donnelly, Randy Hansen, and David Strickland, who all did a tremendous job running the boat.

Katie Swanson was a valuable source of help in the computer analysis of the data. I would like to thank Jeffrey N. Cross and R.C. Wingert for their many valuable comments on the manuscript. Wilma Boyd typed much of the manuscript, especially the later drafts, and did an exceptional job.

Finally, I would like to thank my wife Laurie for her love, encouragement, and understanding during the entire project.

Financial assistance was provided by the Washington State Department of Ecology "Puget Sound Baseline Program: Nearshore Fish Survey."

INTRODUCTION

The fish fauna of protected, inshore areas has received increasing attention from investigators in recent years (e.g., Bechtel and Copeland 1970, Subrahmanyam and Drake 1975, Adams 1976, Merriner et al. 1976). The motivation for these efforts is twofold. First, many commercially important fish feed and/or spawn in nearshore waters. Second, there is growing concern over the threat of both chronic and catastrophic pollution to those fishes utilizing the nearshore enviornment.

An important inshore region in the Northeast Pacific, Puget Sound, is in a relatively unpolluted condition. However, anticipated increases in the transportation of petroleum products through northern Puget Sound pose a potential threat to the biotic resources of that area.

In areas where pollution is a major threat, it is crucial to have preliminary baseline data against which future changes in the biota caused by pollution may be compared. However, in northern Puget Sound there is a lack of comprehensive, reliabile baseline information concerning the seasonal distribution and abundance of nearshore species.

For this reason, the Washington State Department of Ecology (DOE) initiated a comprehensive baseline survey of the marine, nearshore (defined as that part of the shoreline less than 20 meters in depth) fauna in northern Puget Sound. As part of the overall investigative effort, research was conducted on those species of fish occupying the nearshore surface (pelagic) waters.

Studies of nearshore pelagic species in the Northeast Pacific have emphasized juvenile salmonids. In Puget Sound, salmonids were studied by Tyler (1964) and Sjolseth (1969) in Bellingham Bay, Wetherall (1971) in Elliot Bay, Stober and Salo (1973) in Similk and Skagit Bays, Moore et al. (1977) in Port Townsend Bay, Fresh et al. (1978) in the Nisqually Reach, and Schreiner (1977) in the Hood Canal. In the nearshore areas of Alaska, Tyler (1966, 1972) investigated juvenile salmonids and Harris and Hartt (1977) surveyed nearshore pelagic species occurring in three bays of Kodiak Island, Alaska. A general survey of nearshore pelagic species was conducted in the Strait of Juan de Fuca, Washington, by Simenstad et al. (1977). Barraclough (e.g., 1967a) sampled pelagic fishes occurring in the Strait of Georgia.

The specific objectives of this study were to document the abundance, spatial and temporal distribution of fishes occurring in the nearshore surface waters of northern Puget Sound. I also wanted to define associations between specific fish assemblages and specific habitats and evaluate potential impacts of oil pollution.

DESCRIPTION OF STUDY AREA

Northern Puget Sound is located in northwest Washington and is bounded to the south by 48°25' N latitude (part of the Strait of Juan de Fuca), to the west by 123°13' W longitude (Haro Strait and Canadian border), to the north by 49° N (the Canadian border), and to the east by the Washington mainland (Fig. 1). The area is characterized by numerous bays, inlets, and channels. In the southern two-thirds of the area are located the ~172 islands of the San Juan Archipelago. The northern Puget Sound shoreline is ~1046 km, and is mostly faced by steep rocky bluffs which range in height to 150 m. Subtidal gradients are also usually steep. Substrates of northern Puget Sound beaches range from large cobble and boulders to soft, organic mud. Climate in the area is maritime, with cool summers and mild winters and, because of the "rain shadow" effect of the Olympic Mountains, low precipitation (Vagners 1972).

The net circulatory pattern of water in northern Puget Sound is counterclockwise (MacPhee and Clemens 1962). On the flood tide, oceanic water moves east in the Strait of Juan de Fuca and then northward through Rosario Strait, San Juan Channel, and Haro Strait. After moving through the San Juan Islands, the tidal flow then enters the Strait of Georgia and moves northward along the mainland coast of British Columbia (Tully and Dodimead 1957). On ebb tide, the major flow is south along the coast of Vancouver Island into Haro Strait with only minor ebb flows in San Juan Channel and Rosario Strait. At times, freshwater runoff comprises a component of the outgoing current. Because many northern Puget Sound channels and passages are narrow, flood and ebb tidal

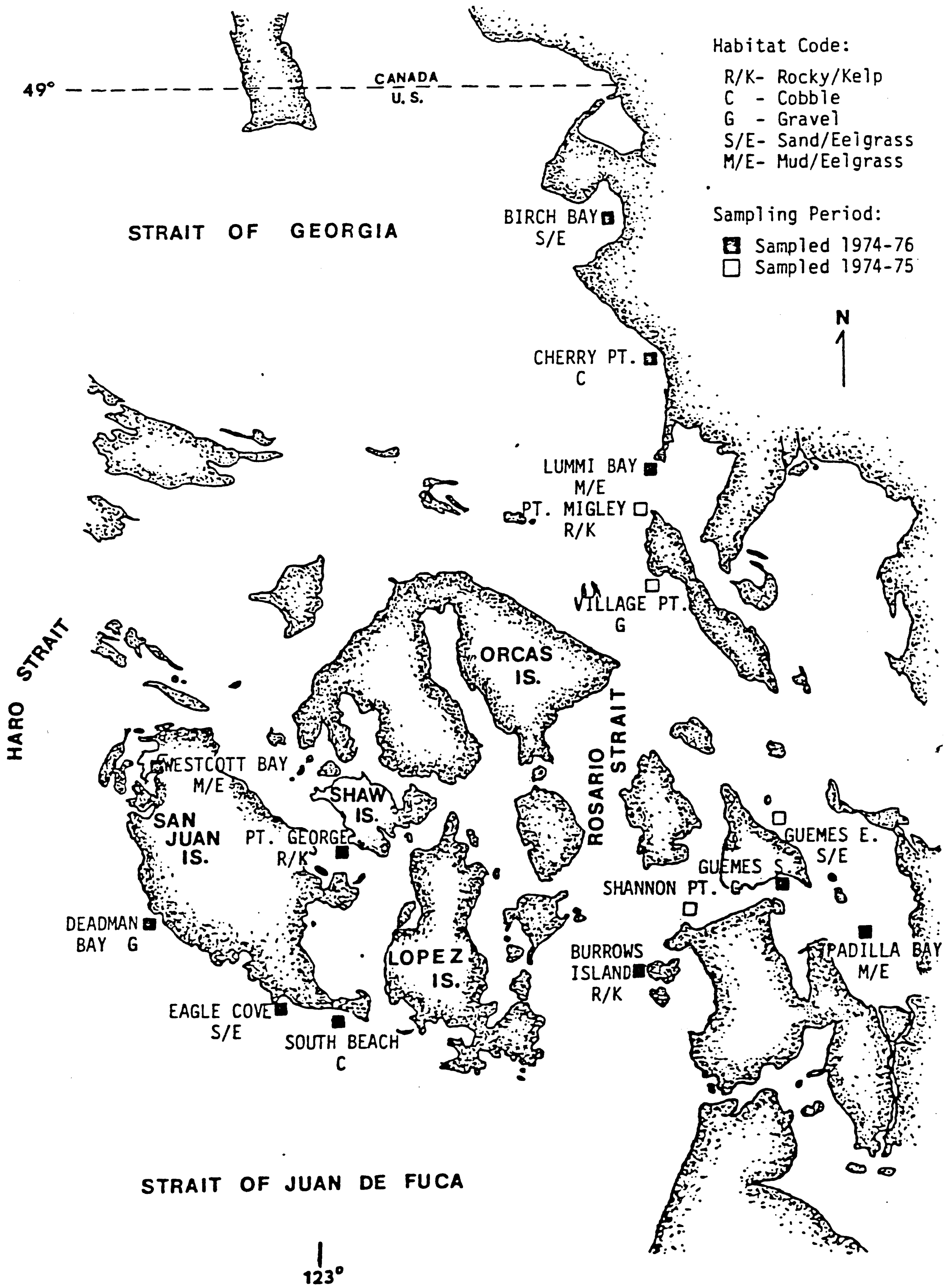


Fig. 1. Map of the northern Puget Sound study area showing location of sampling sites.

currents sometimes have relatively high velocities (3-7 knots) and are responsible for considerable turbulence (MacPhee and Clemens 1962).

During various times of the year, especially from October to March, parts of the northern Puget Sound shoreline are subjected to severe wave action from storms. At times wind generated waves can approach a height of 1.8 meters on the most exposed shorelines and can significantly alter sediment composition and contours on those beaches.

MATERIALS AND METHODS

Study Habitats

In accordance with the Department of Ecology Baseline Study guidelines, five habitat types considered representative of the northern Puget Sound shoreline were chosen for study. These habitats were: 1) High gradient, exposed rocky shoreline with associated kelp (*Nereocystis luetkeana*); 2) high gradient, exposed cobble beaches; 3) moderate gradient, semi-protected gravel beaches; 4) low gradient, protected sand beaches with associated eelgrass (*Zostera marina*) beds; 5) low gradient, protected mud flats with associated eelgrass beds (Table 1). A habitat approach was employed to investigate the theory that characteristic faunal assemblages could be associated with specific habitat types. A generalized description of each habitat type follows.

The rocky kelp bed habitat is characterized by a steep, rocky shoreline. The bottom drops off rapidly in the subtidal, at times almost vertically, with kelp growing at depths from 2-8 m. The bottom relief includes large rocks and boulders and/or solid rock ledges and cliffs; soft bottom sediments are rare. Exposure to extreme turbulence during inclement weather and strong tidal currents are characteristic of this habitat. Since kelp is an annual, much of the kelp dies off in winter months with subsequent regeneration usually beginning in the early spring. It was impossible to sample directly through the kelp so samples were taken as close as possible to the outside edge of the kelp beds.

Cobble habitat beaches are high gradient with a lower gradient slope in the subtidal. During periods of stormy weather, this habitat

Table 1. General characteristics of the habitat types sampled in northern Puget Sound, 1974-1976. (Most data in this table provided by the Department of Ecology)

Habitat type	Average particle size	Currents	Exposure	Beach gradient	Bottom gradient	Vegetation	Approximate % of total northern Puget Sound shoreline[3]
Rocky/kelp bed	-	Very strong	Exposed	Very high	Very high	Extensive *Nereocystis luetkeana*	39.8
Cobble	16-36 mm	Moderate to Strong	Very exposed	High	Moderate	Scattered patches of *N. luetkeana*	19.7
Gravel	2-8 mm	Moderate[1]	Semi-exposed[1]	Moderate	Moderate	Scattered *N. luetkeana* and *Zostera marina* patches	13.3
Sand/Eelgrass	1/16-1 mm	Weak	Protected[1]	Low	Low	*Z. marina*[2]	11.6
Mud/Eelgrass	~1/64 mm	Weak	Very Protected	Low	Low	*Z. marina*[2]	15.6

[1]Is somewhat variable depending on area where habitat is located.

[2]Densities and sizes of beds are variable.

[3]Does not include some of the smaller islands.

is characterized by extreme turbulence; tidal currents are also strong. Because of the turbulence, sediment composition and beach profile can vary during the year. At times, some kelp becomes temporarily attached to the cobble.

Intertidal and subtidal gradients of the gravel habitat sites are both moderate, and the sediment composition is usually gravel with some interstitial sand. However, the subtidal sediment composition often becomes predominantly sand with small quantities of attached eelgrass. Tidal currents and wave generated turbulence are variable in this habitat.

The sand/eelgrass habitat sites are typically sheltered from most wave generated turbulence and are not usually subject to the influence of tidal currents. Intertidal and subtidal gradients are gentle with sand the predominant sediment type. In the subtidal, eelgrass beds of varying sizes and densities occur.

The mud/eelgrass habitat is the most protected of the five habitats; partially enclosed, shallow bays with extensive mud flats are characteristic of this habitat type. Like the sand/eelgrass habitat, intertidal and subtidal slopes are gentle. Upper intertidal sediment composition is usually fine sand or silt while subtidal sediments are primarily mud with extensive, attached eelgrass beds.

Study Sites

In each of three general areas (Cherry Point, Anacortes, and San Juan Island), five sites were selected for study beginning in July, 1974 (Fig. 1, Table 2). Each site in an area represented a different habitat type. The Cherry Point and Anacortes areas, located along the eastern margin of northern Puget Sound, were selected because of the high risk

Table 2. Description of study sites sampled by townet in northern Puget Sound, 1974-1976.

Site	Habitat Type[1]	Area[2]	Slope	Substrate	Exposure	Vegetation
Pt. Migley	R/K	CP	Steep	Rocks and boulders	Very exposed	Dense *N. luetkeana*
Burrows Island	R/K	A	Steep	Rocks and boulders	Very exposed	Dense *N. luetkeana*
Pt. George	R/K	SJI	Steep	Rocks and boulders	Exposed	Dense *N. luetkeana*
Cherry Pt.	C	CP	Moderately steep	Boulders and cobbles Sand patches	Moderately exposed	Scattered patches of *N. luetkeana*
Shannon Pt.	C	A	Moderately steep	Cobble and sand patches Some boulders	Exposed	Scattered patches of *N. luetkeana*
South Beach	C	SJI	Moderately steep	Smaller cobble	Very exposed	None
Village Pt.	G	CP	Moderate (seasonally variable)	Gravel and interstitial sand	Exposed	Scattered *Z. marina*
Guemes South	G	A	Moderate	Gravels, sand, silt	Moderate	Scattered patches of *Z. marina* and *N. luetkeana*
Deadman Bay	G	SJI	Moderate	Gravels and sand, rocky areas flank beach	Exposed	Scattered areas of *Z. marina* and *N. luetkeana*
Birch Bay	S/E	CP	Gentle	Sand	Mostly protected	Dense *Z. marina* beds
Guemes East	S/E	A	Gentle	Sand	Moderate	*Z. marina* beds of varying densities
Eagle Cove	S/E	SJI	Gentle	Sand	Exposed	Scattered *Z. marina* patches
Lummi Bay	M/E	CP	Gentle	Sand/mud	Protected	Dense beds of *Z. marina*
Padilla Bay	M/E	A	Gentle	Mud	Protected	Dense beds of *Z. marina*
Westcott Bay	M/E	SJI	Gentle	Mud	Protected (nearly enclosed)	Dense beds of *Z. marina*

[1] R/K = Rocky/kelp, C = Cobble, G = Gravel, S/E = Sand/eelgrass, M/E = Mud/eelgrass

[2] CP = Cherry Point, A = Anacortes, SJI = San Juan Island

of oil pollution due to: 1) The existence of oil refineries in each area; 2) tanker routes to the existing refineries are along narrow, rocky channels; and 3) expansion of the refineries and concurrent increases in tanker traffic may occur in order to accommodate Alaskan North Slope oil. The San Juan Island area was selected as a "control" area because the risk of oil pollution was considered low.

For each particular habitat type, an attempt was made to select sites that were as similar as possible and conformed closely to the habitat descriptions. Because of the complexity of the nearshore environment, this was not always possible. As a result, sites of the same habitat type usually differed in some respects. For example, cobble sizes were dissimilar at the three cobble sites whereas exposure varied markedly among sand/eelgrass sites.

From July 1974 to September 1975 samples were obtained monthly at each site in the spring and summer and bimonthly in the fall and winter. However, because of site selection difficulties, sampling at the Eagle Cove site was not initiated until December 1974. Four sites (Village Point, Point Migley, Guemes East, and Shannon Point) were dropped from the sampling schedule beginning October 1975. From October 1975 through August 1976 each of the 11 remaining sites was sampled monthly (spring and summer) and bimonthly (fall and winter). Nineteen different townet cruises were made from July 1974 to August 1976.

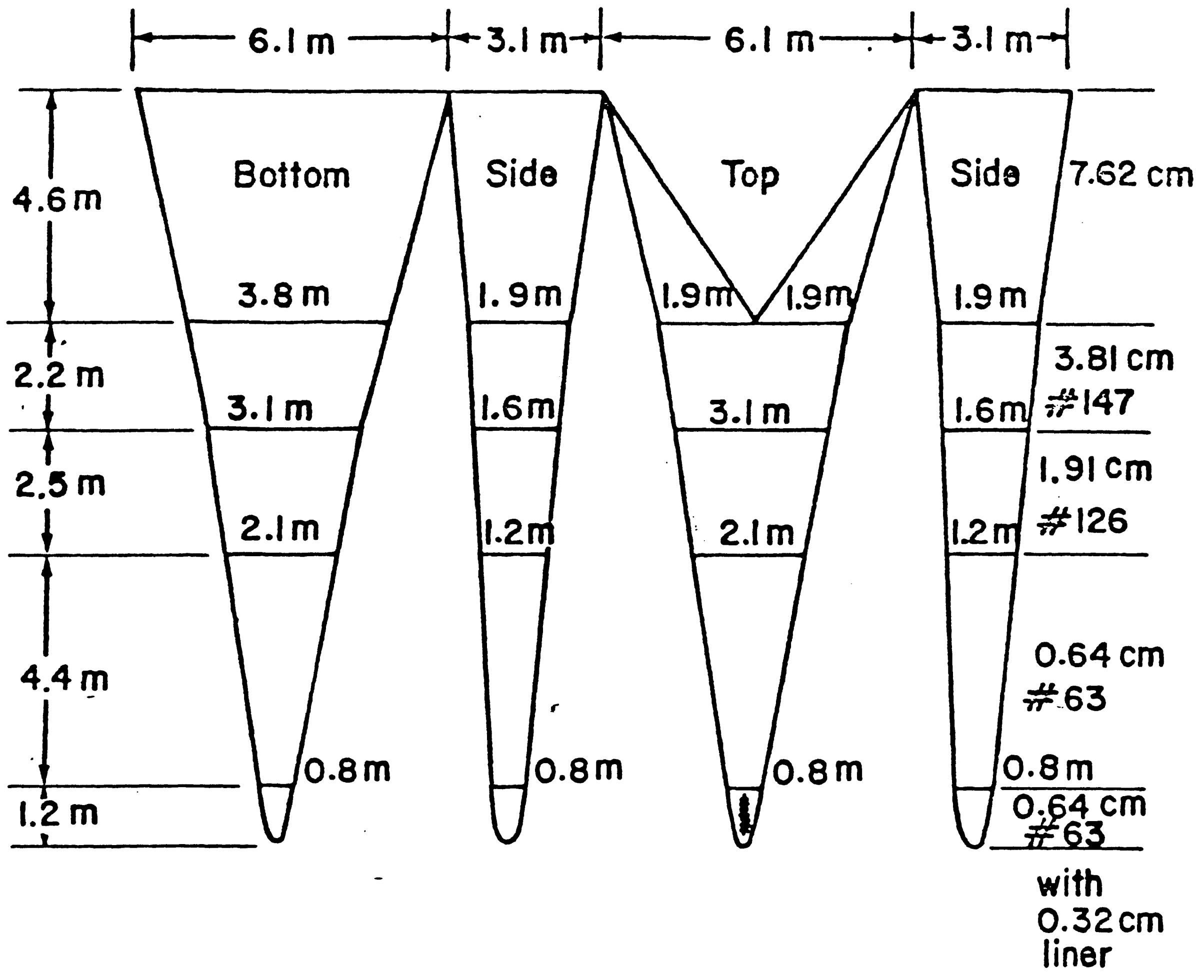
Townetting Technique

Fishes in nearshore surface waters were sampled by townet which is the high-speed towing of a net between two boats through the surface of the water. The townet dimensions were 3.1 x 6.1 m at the mouth opening and 15 m in length (Fig. 2). The net was constructed of knotless nylon with mesh sizes grading from 76 mm at the opening to 6.4 mm at the cod end. To facilitate removal of the catch, a zippered opening was located in the cod end. In order to maintain the mouth of the net open, a 4 m long steel pole was attached to each wing of the townet. A 9.0 kg weight and a large float were attached at the foot and head rope connections of each pole, respectively. All towing operations were conducted at night using a 11.6 m (38 ft) vessel (R. V. MALKA) and a 4.9 m (16 ft) purse seine skiff. The engine speed of the R. V. MALKA during net operations was standardized at 800 rpm (approximately 4 km/hr).

A collection at each site consisted of two ten-minute tows, except when problems such as inclement weather, gear failure, excessive floating debris, or large concentrations of fish occurred. The first tow was made in one direction along the shoreline, while the second was made in the opposite direction along approximately the same transect. This usually resulted in one tow occurring with the prevailing current and the other against the current. All sampling was conducted as close to the shoreline as depth and currents would allow. An attempt was made to schedule townet cruises during periods of minimal tidal currents and moonlight to reduce the effects of these variables on net performance.

Data Collection

For each tow, the location, date, time, habitat type, duration of tow, tidal height and stage, and water depth (determined by fathometer) were recorded. For each collection, temperature (°C), salinity (^{o}/oo), and dissolved oxygen (% saturation) of the water were measured at a depth of one meter. Temperature and salinity were determined using a



All seams are of 3.81 cm and smaller mesh reinforced with heavy 2.54 cm nylon tape including center lines of bottom and top panels. Rib lines are of 0.95 cm diameter polypropelene on four corner seams full length. A 0.9 m nylon zipper is in the cod end and on liner in the top panel. Six 4 oz lead weights are spaced evenly along the foot line.

Fig. 2. Surface townet utilized during sampling in northern Puget Sound.

Beckman salinity-temperature probe. Water samples taken for dissolved oxygen measurements were first fixed with standardized quantities of manganous sulfate and alkali-iodide-azide (AIA). Dissolved oxygen in mg/l was then determined by titration according to the Winkler method. Titrated mg/l was then converted to percent saturation using the formulas:

$$\text{Saturation level in mg/l} = \frac{475 - (2.65 \times \text{salinity } (^{o}/oo))}{\text{temperature } (^{\circ}C) + 33.5}$$

$$\text{Percent saturation} = \frac{\text{D.O. level in mg/l (titrated value)}}{\text{saturation level mg/l}},$$

Processing of the Catch

Once a townet sample was completed, the net was hauled onto the stern and all fish observed in the upper meshes of the net shaken into the cod end. The cod end was then opened and the catch gently shaken into a sorting table or bucket. This procedure was usually efficient in transferring the entire catch into the container. However, when larvae were abundant in samples, this procedure was not always effective in removing all fish from the cod end. Because of their size, many larvae became trapped in the cod end mesh and would not fall into the container even under vigorous shaking. Once in the container, debris was removed from the sample and unless the catch of one or more species was large enough to require subsampling, samples (in their entirety) were bagged, labeled, preserved in 10% formalin, and placed in coolers.

When subsampling was required (i.e., when large numbers of fish or invertebrates prevented proper sorting), a standard procedure was followed. The catch was initially sorted and those species not present in significant enough numbers to subsample were removed. The remainder of the catch was then thoroughly mixed and measured scoops removed with one or more being saved at random for preservation. An attempt was made to obtain a subsample of at least 10 percent of the original catch.

The catch from each tow was sorted according to species and general life history stage (LHS) using Hart (1973) as the source of identification. "Larvae" were recorded for fish that did not appear to have completely metamorphosed from the postlarval stage. "Juvenile" indicated young-of-the-year for most species sampled; however, pleuronectids were called "juvenile" when <150 mm TL since it was only above this size that the sexes were usually distinguishable. For some species a lack of life history infromation made a determination of life history stage difficult so that "juvenile" was recorded for individuals in the smallest length classes that were not larvae. "Adult" was recorded for any other specimen and typically indicated sexual maturity.

Total numbers of every species-life history stage were recorded per tow. Where subsampling was necessary, the abundance by life history stage of the subsampled species was estimated from the subsample group. If a sample had 50 or more individuals of a particular species-life history stage, 25 to 50 individuals were randomly selected for measuring total length (TL) to the nearest mm; otherwise, all specimens were measured.

Diel Study

Diel changes in the distribution of nearshore pelagic species were studied at the Lummi Bay site on June 10 and 11, 1977. Two ten-minute tows, in opposite directions, were made every two hours during the night and every four hours during the day beginning at 2145 on June 10. Two additional tows were conducted during the 2345 period to investigate short term changes. Because of the large numbers of larvae caught and limited processing time, it was only possible to identify larvae to family and estimate their abundance. For each tow, the length range and total number by life history stage of each species were recorded.

Methods of Analysis

All data were first recorded on computer-format forms and then keypunched and verified on 80 column IBM cards. A Randomized Information Retrieval System (RIRS) program was utilized on the University of Washington CDC 6400 computer (Gales 1975) to aid in sorting and retrieving different data subsets. Packaged programs from SPSS (Nie et al. 1975) were used for all statistical analysis.

In sampling with a net towed through the water, one of the most accurate method of reporting catch data is in terms of the number of fish per volume of water strained. However, since the design of the townet did not permit an accurate measurement of volume strained, catch data was represented as catch-per-unit-of-effort using 10 min as the standard length of tow and calculated as:

$$\text{CPUE} = \frac{\text{Number of Fish}}{\text{Number of Capture Attempts (10 min tows)}}$$

For the few tows (two percent) less than 10 min, abundance was assumed to be directly proportional to haul duration and the catch was extrapolated to a 10 min haul.

For most collections, the number of species was the total occurring in the combined two tows of a collection, regardless of tow duration.

In some collections, however, identification of some fish was only possible to genus or family (usually larvae in the spring). If the family or genus was not represented by a fish identified to species, then one species was added to the total species count of that collection. Thus in these cases the number of species in a collection is a minimum estimate if all fish were assumed correctly identified. As with abundance data, any tows not equal to 10 min would bias the data to some degree. The small number of tows not equal to 10 min likely resulted in an insignificant bias.

Overall and individual species CPUE, number of species, and frequency of occurrence (defined as the number of collections a species occurred in) were analyzed both on a monthly and seasonal basis. Winter was defined as January-March, spring as April-June, summer as July-September, and fall as October-December.

Several statistical procedures were used in data analysis. All data to be used in tests was first checked to determine whether it fit the assumptions required in the use of parametric statistics (Snedecor and Cochran 1967, Elliott 1971). CPUE and the number-of-species data were both non-normal. As a result, various transformations of the data and subsequent tests on the normality of the transformed data were done. None of the transformations utilized were satisfactory, possibly because between station variability was so great. Non-parametric statistical procedures as described by Siegel (1956) were therefore utilized on the non-normal data since these tests make no assumptions concerning data distribution.

Kendall's rank correlation coefficient was employed for correlation of catch data with environmental data. The data to be correlated (e.g., temperature with CPUE) were first ranked separately. Variable X was first arrayed in ascending order and the value S determined for the corresponding order of ranks on Variable Y (CPUE, number of species). S was computed by starting with the first rank of Y and counting the number of ranks to the right which were larger and subtracting the ranks to the right which were smaller. These values were then summed for all ranks moving from right to left and equal S. The value τ was then computed using the formula:

$$\tau = \frac{S}{1/2\ N(N-1)}$$

where N = number of individuals ranked on X and Y. The significance of τ was determined by computing a Z statistic and then determining the signifigance of that Z.

Wilcoxons paired-sample rank tests were employed to compare between years, seasons, or tows. Between year comparisons were done by first calculating a mean CPUE or number-of-species for each site in each of the two years. The difference between respective years was calculated for the same site, the absolute values of the differences for all sites ranked and the Wilcoxon statistic T (sum of ranks with less frequent sign) computed. This value was compared to an appropriate table of T distribution critical values and the significance determined. For between season differences, the same general procedure was followed only differences between respective seasons, both years included, were analyzed. To calculate the differences between the two tows of a collection, CPUE and species number data were used from June and August 1976 because these were the only months where the directions of the tows relative to the prevailing currents were recorded. Differences in catch data with and against the currents were calculated and used in the Wilcoxon test.

The relative importance (or dominance) of species in the study was assessed using the Biological Index (BI) modified slightly from Sanders (1960) (see also Fager 1957). This method uses both the relative abundance and frequency of occurrence of each species and incorporates this in one value. Species were ranked in each collection from most abundant to fifth most abundant, and the most abundant was assigned a value of 5 while the fifth most abundant was given a value of 1. For each of the 25 most abundant species, these rankings were then summed over all sites and for each site individually. Large BI's indicate species who are relatively abundant in most collections, hence at most sites, whereas small BI's indicate species who are spatially or temporally limited in distribution. Species that occur infrequently but in large numbers would have small BI values.

RESULTS

Environmental Conditions

Surface water (0-1 m) temperature, salinity, and dissolved oxygen data permitted analysis of surface water conditions directly corresponding to fish collections at each site. Sampling was too infrequent to permit conclusions concerning surface water oceanography but the data does indicate seasonal and annual trends at different sites, habitats, and areas.

Sites in all three areas exhibited similar annual cycles of temperature during both years (Fig. 3). Temperatures ranged from a low of 5.4° C (Birch and Westcott Bays - February 1975) to a high of 18.5° C (Birch Bay - July 1974). Winter temperatures at all sites were similar and ranged between 5° C and 7° C, whereas maximum differences among sites occurred in the summer. Shallow, protected bays such as Birch Bay and Padilla Bay were seasonally more variable than more exposed sites such as Eagle Cove and Burrows Island (Table 3). In general, San Juan Island sites had lower temperatures than corresponding Cherry Point and Anacortes area sites of the same habitat type.

Northern Puget Sound surface salinity ranged from a low of 18.8 $^{o}/oo$ at Birch Bay in July 1974 to a high of 32.8 $^{o}/oo$ at Westcott Bay in April 1976; most salinities ranged between 28 $^{o}/oo$ and 32 $^{o}/oo$ (Fig. 4). Lower salinities usually occurred during fall and winter and higher salinities occurred in the spring and summer. The highest salinities were characteristic of the five San Juan Island sites (Table 3).

Dissolved oxygen (D.O.) data (Fig. 5) was less complete than the other physical parameters because D.O. measurements were not obtained (due to

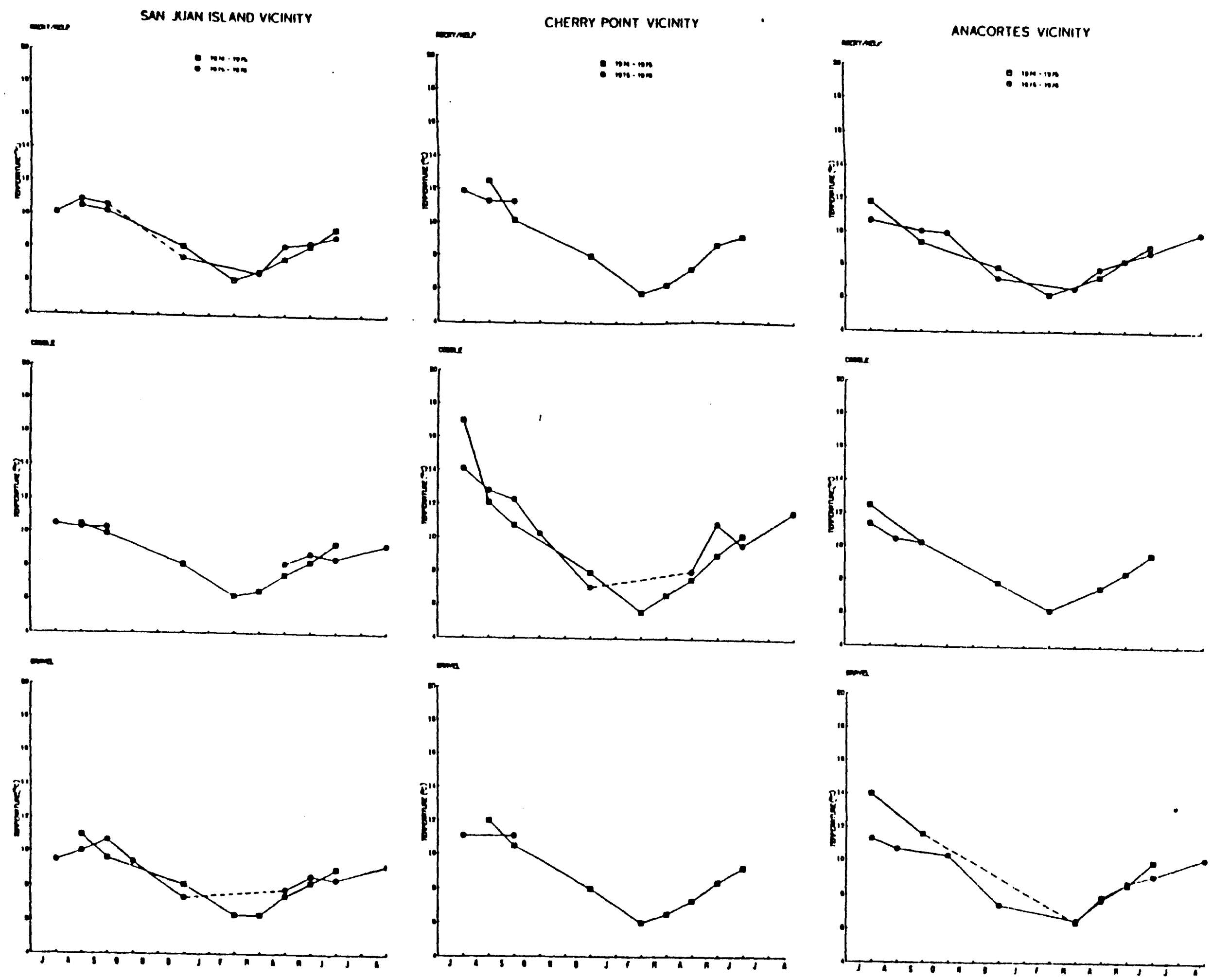


Fig. 3. Monthly surface water (0-1 m) temperature (°C) at northern Puget Sound study sites, 1974-76.

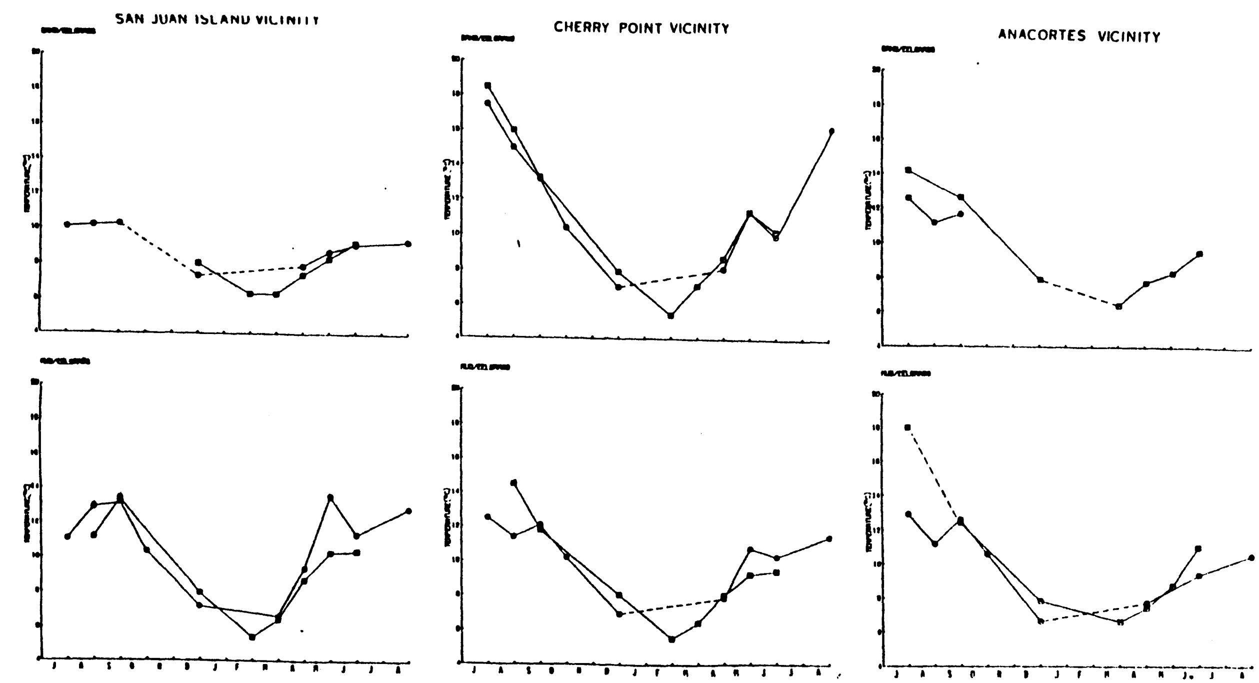


Fig. 3. Monthly surface water (0-1 m) temperature at northern Puget Sound study sites, 1974-76 (Continued)

Table 3. Number of measurements (n), mean ($\bar{x}$), standard deviation (S.D.) and coefficient of variation in percent (C.V.) for temperature (°C), salinity (o/oo), dissolved oxygen (% saturation) in nearshore surface waters of northern Puget Sound, 1974-76.

Site	Temperature (°C)				Salinity				Dissolved Oxygen (% saturation)			
	n	$\bar{x}$	S.D.	C.V.	n	$\bar{x}$	S.D.	C.V.	n	$\bar{x}$	S.D.	C.V.
Pt. Migley	11	9.3	2.3	24.7	11	28.1	3.3	11.7	9	85.0	12.8	15.1
Burrows Island	15	8.7	1.6	18.4	17	27.5	3.4	12.4	13	87.3	17.8	20.4
Pt. George	16	8.6	1.6	18.6	16	28.7	3.2	11.1	13	91.3	16.8	18.4
Cherry Pt.	18	10.2	2.9	28.4	18	26.6	3.7	13.9	14	106.7	15.0	14.1
Shannon Pt.	10	9.5	1.9	20.0	10	28.1	3.5	12.5	7	83.1	7.5	9.0
South Beach	15	8.8	1.4	15.9	15	30.2	2.6	8.6	12	84.0	10.3	12.3
Village Pt.	10	9.0	2.1	23.3	10	28.1	3.7	13.2	7	86.7	6.7	7.7
Guemes South	16	9.5	2.1	22.1	17	27.8	3.9	14.0	14	89.7	16.5	18.4
Deadman Bay	17	8.6	1.4	16.3	17	29.4	3.6	12.2	14	82.9	18.9	22.8
Birch Bay	18	11.5	3.9	33.9	18	26.6	3.7	13.9	14	119.6	29.4	24.6
Guemes East	10	10.3	2.5	24.2	11	26.9	3.9	14.5	7	94.7	6.1	6.4
Eagle Cove	14	8.5	1.3	15.3	14	29.9	3.0	10.0	14	86.1	13.1	15.2
Lummi Bay	18	9.2	3.3	35.8	17	27.3	3.4	12.5	14	97.0	16.2	16.7
Padilla Bay	15	10.3	3.0	29.1	16	26.6	4.1	15.4	12	94.3	9.1	9.7
Westcott Bay	18	10.1	2.6	25.7	18	28.6	3.8	13.3	14	117.7	33.1	28.1

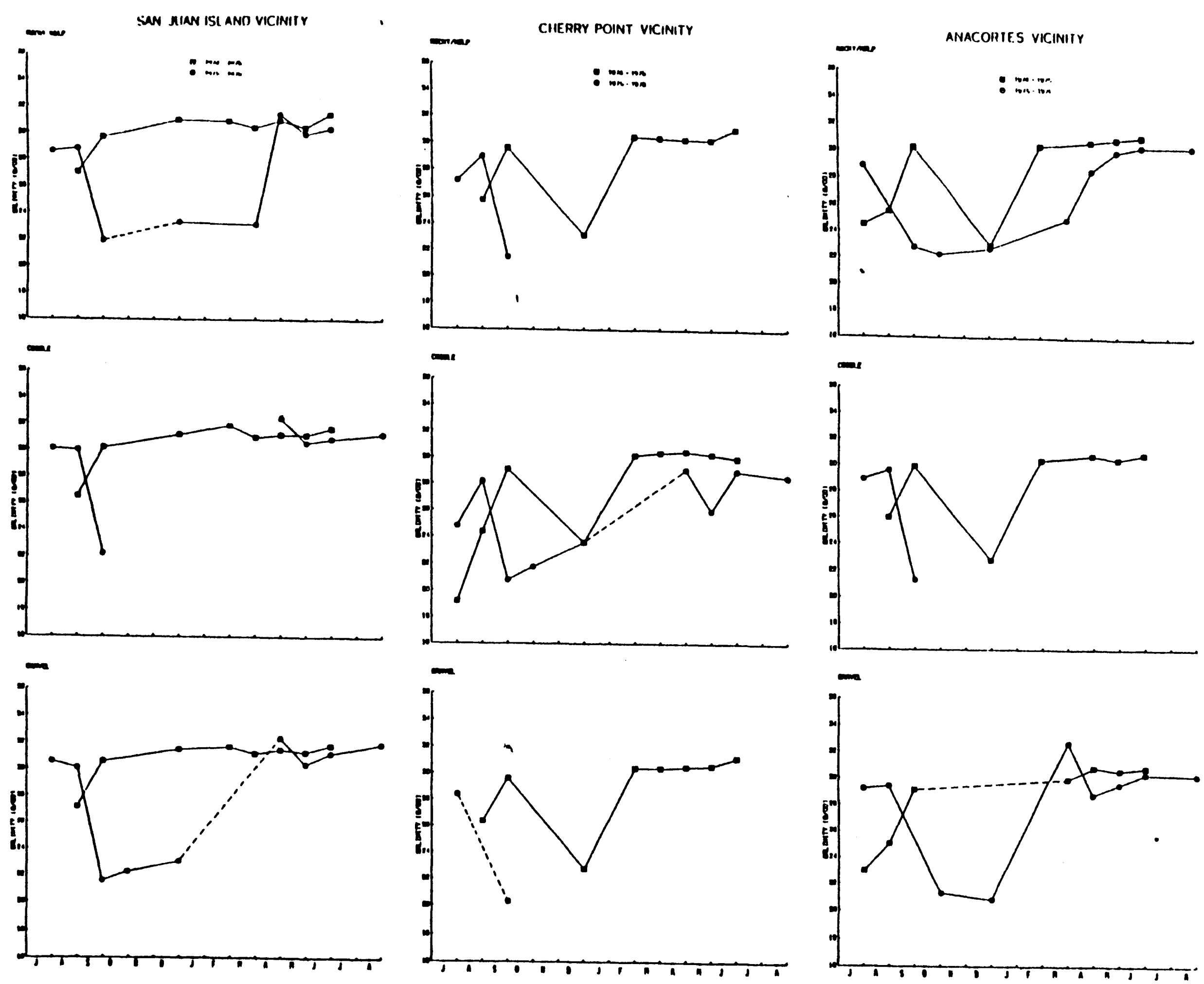


Fig. 4. Monthly surface water (0-1 m) salinity ($^{o}/oo$) at northern Puget Sound study sites, 1974-76.

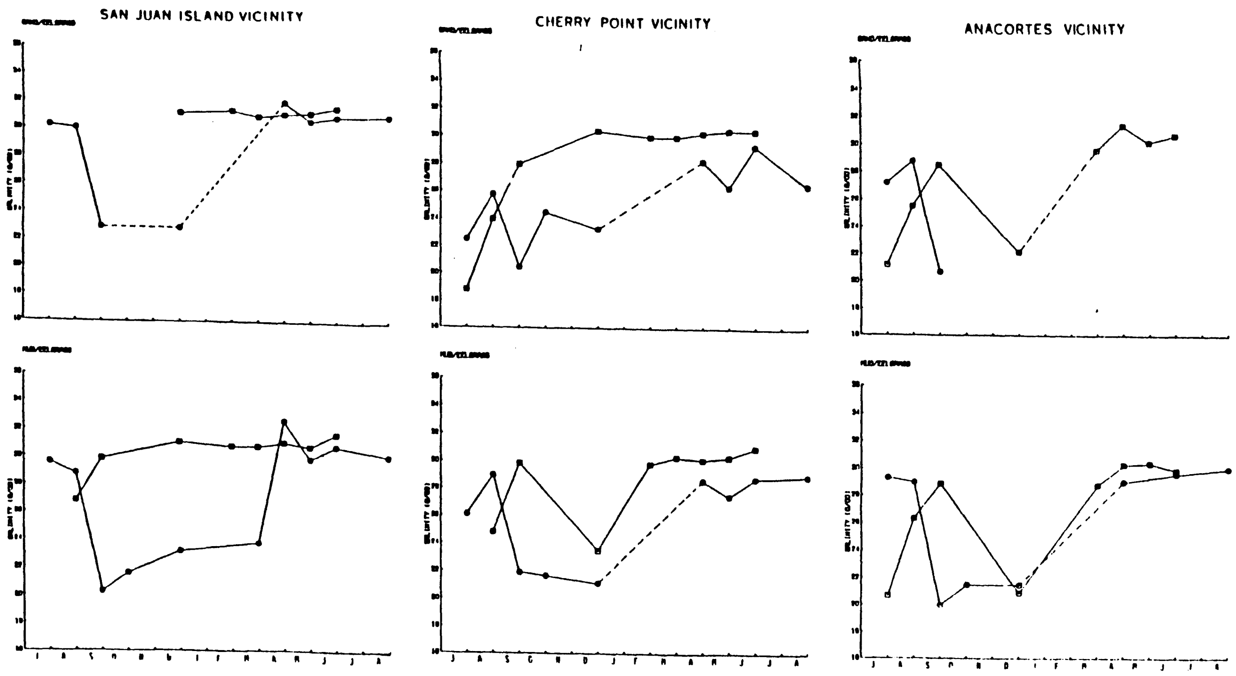


Fig. 4. Monthly surface water (0-1 m) salinity ($^{o}/oo$) at northern Puget Sound study sites, 1974-76 (Continued)

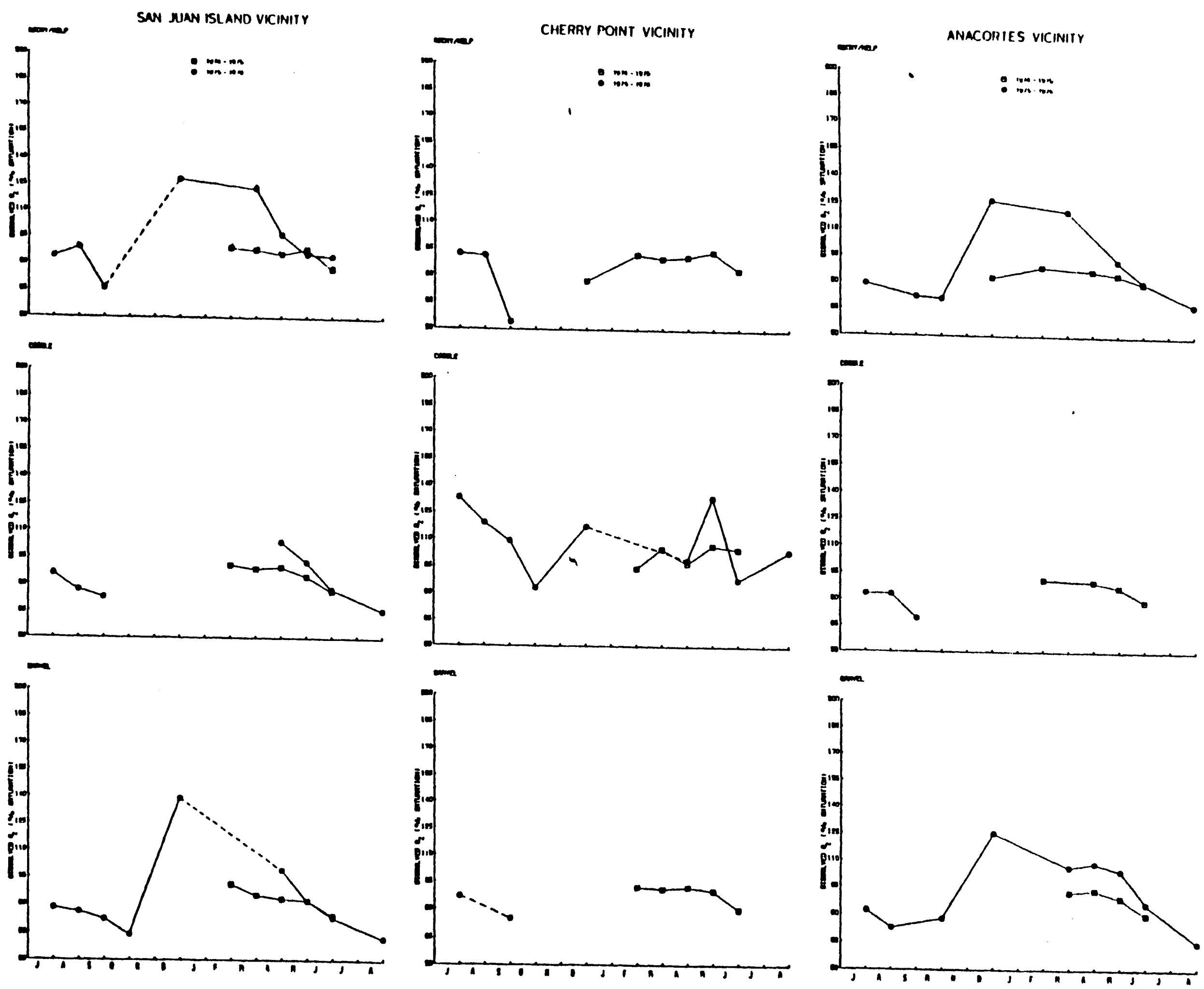


Fig. 5. Monthly surface water (0-1 m) dissolved oxygen (% saturation) at northern Puget Sound study sites, 1974-76.

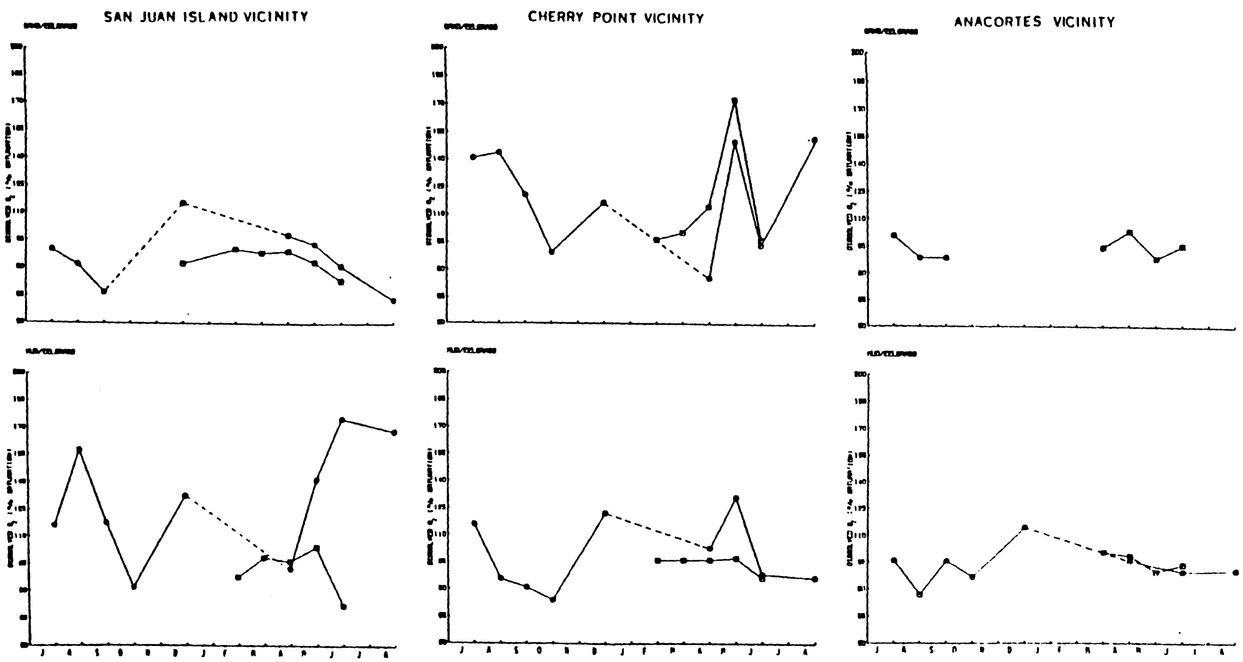


Fig. 5. Monthly surface water (0-1 m) dissolved oxygen (% saturation) at northern Puget Sound study sites, 1974-76 (Continued)

equipment malfunction) until after the December 1974 collection. Near-shore surface waters were generally well saturated although values ranged between 54 and 176 percent saturation; D.O. was highly variable and exhibited no consistent trends.

General Catch Results

Species Composition. Seventy-one positively identified species of fish were captured during the study, 63 in 1974-75 and 47 in 1975-76 (Appendix I). Twenty (27%) species, comprising over 99 percent of the total catch, were schooling, and 51 (73%) were more solitary. Twenty-three species were represented by only one or two individuals (Table 4); most infrequently occurring species were demersal fishes such as cottids, agonids, and pleuronectids. The number of species occurring at sites ranged between 41 (Lummi Bay) and 16 (Deadman Bay) (Table 5).

The BI index of dominance revealed the six dominant species were also the six most abundant species (Tables 6 and 7), although the order was different. Ninety-eight percent of the total catch was comprised of these six species. Schooling species were generally more dominant (BI value) than non-schooling species (Table 6).

Three schooling species--larvae and juvenile Pacific herring (*Clupea harengus pallasi*), larvae, juvenile and adult Pacific sand lance (*Ammodytes hexapterus*), and juvenile and adult threespine stickleback (*Gasterosteus aculeatus*)--were overwhelmingly the dominant species (Table 7), comprising 97 percent of the total fish captured. These three species generally ranked as the three most abundant and most dominant (BI value) species occurring at sites (Tables 4 and 8). Herring, sand lance, and stickleback occurred throughout the entire year but were most

Table 4. Total number of each species caught at each site, 1974-1976, listed in order of decreasing abundance.

Species	Pt. Migley	Burrows Island	Pt. George	Cherry Point	Shannon Point	South Beach	Village Point	Guemes South	Deadman Bay	Birch Bay	Guemes East	Eagle Cove	Lummi Bay	Padilla Bay	Westcott Bay	Total
Pacific herring	1376	1029	78623	17413	1462	768	1485	973	360	128031	4241	332	37004	7919	48586	329602
Pacific sand lance	17	41	35896	147	74	52	134	83	17	607	9	31	317	553	647	38625
Threespine stickleback	1042	391	90	2203	929	119	1165	1349	17	850	216	20	3250	3035	210	14886
Surf smelt	42	5		237	6	6	9	95	16	2025	45	5	125	72	32	2720
Longfin smelt	20	6		1284	2		5	39	1	632	7		354	11		2361
Tadpole sculpin	29	59	179	44	85	49	61	8	3	27	1	30	1630	69	1	2275
Shiner perch		4		224	1					516			10	124	187	1067
Snake prickleback	4	2		74	5	3	5	1		458			89	10	54	705
Staghorn sculpin	8	7		152	15	1	6	8	1	58	12		59	41	35	403
Pacific tomcod	1		55	29	1	247		5		299	2		16	1	6	662
Chinook salmon	11	62	4	92	32	3	12	15	6	94	11		54	100	4	500
Soft sculpin	1	12	23	3	6	2	2	22	5	6	9	58	103	45	4	301
Northern anchovy	4	4		84			1	6		47	1	1	26	31	2	207
Coho salmon	3	9	5	41	34	8	24	3	5	22	3		24	19	2	202
Chum salmon		17	25	8	19	8	18	13	7	1	2		19	4	3	144
Pink salmon	4	14	8	11	5	11	9	5	3	1	8	2	35	1	10	126
Darter sculpin										101						101
Spiny dogfish		1	1				1	5		6	4		4	66	1	89
English sole		2	1	10	1	6		5		24			31	1	1	82
Tubesnout		1		2		1				40		1	4		25	74
Walleye pollock		1	2	5	1	4		1		4			5		51	74
Kelp greenling	2			5	1			1	1	57		1	4			72
Starry flounder	1	2		9				1		50			3	3		69
Sockeye salmon		15			11		1	4		26				1		58
Bay pipefish	4	1		2			1	1		10			16	3	20	58
Crescent gunnel	2			1	7	1		1			2	1	1	18	4	38
Saddleback gunnel	1	3	1	4	1	1	1	3	1	1	3		1	10	4	35
Pacific sandfish				1		3		4		3		1	2	2	8	24
Dwarf wrymouth								14				1			8	23
Blackbelly eelpout					2			19				1				22
Grunt sculpin		4	1		1			5				1	2	7		21
Bay goby		1				15							2			18
Pile perch										16						16
Silverspotted sculpin						2				1					11	14
Midshipman				1						10			1			12
Tubenose poacher				2	1				1	1			2	1	3	11
Sturgeon poacher	1		1	2	1			1					3			9
Spiny lumpsucker		1													6	7
Lingcod									1				2		2	5
River lamprey				2	1					1			1			5
Dover sole			2								2					4
Sand sole								4								4
Pacific lamprey	3															3
Longfin gunnel							3									3
Spotted snailfish														3		3
Saddleback sculpin													3			3
Slipskin snailfish											1				2	3
Rock sole			1										1			2
Blacktip poacher								1					1			2
Sailfin sculpin								1						1		2
Arrow goby				2												2
Striped seaperch										1				1		2
Daubed shanny														2		2
Ratfish												1				1
Capelin													1			1
Eulachon				1												1
Bluebarred prickleback													1			1
Whitebarred prickleback					1											1
Northern lampfish													1			1
Smoothhead sculpin						1										1
Copper rockfish															1	1
Red Irish lord								1								1
Cabezon					1											1
Northern spearnose poacher												1				1
Tidepool snailfish														1		1
Pygmy poacher													1			1
Ringtail snailfish					1											1
Butter sole								1								1
Cray starsnout								1								1
Penpoint gunnel												1		2		3
Bluespotted poacher													1			1
Totals	2576	1694	114918	22095	2707	1131	2943	2699	445	134026	4579	489	43209	12157	49930	

Table 5. Total number of positively identified species caught by townet in 1974-1976, 1974-1975, and 1975-1976.

Site	Number of species 1974-1976	1974-1975	1975-1976
Pt. Migley	21	20	10*
Burrows Is.	26	16	23
Pt. George	18	14	12
Cherry Pt.	31	26	27
Shannon Pt.	29	28	13*
South Beach	21	17	11
Village Pt.	19	17	10*
Guemes South	35	27	20
Deadman Bay	16	14	12
Birch Bay	33	24	26
Guemes East	19	17	8*
Eagle Cove	18	14	7*
Lummi Bay	41	36	29
Padilla Bay	32	25	25
Westcott Bay	30	23	24

*Effort not comparable between 1974-1975 and 1975-1976.

Table 6. Frequency evaluation of the 234 collections. The 25 species listed represent those with the highest Biological Index (BI) value and are ranked in order of decreasing BI value.

Species	Occurrence in Each rank					Freq. as one of the five most common species	Total freq. of occurrence	Biological Index value (BI)
	1	2	3	4	5			
Pacific herring	114	46	15	4	1	180	182	808
Threespine stickleback	41	58	20	14	9	142	153	534
Pacific sand lance	13	28	27	18	8	94	117	302
Surf smelt	14	13	19	15	7	68	89	216
Longfin smelt	7	9	12	8	10	46	62	133
Tadpole sculpin	9	12	8	4	6	39	51	131
Soft sculpin	17	4	6	2	3	32	36	126
Chinook salmon	1	4	22	12	5	44	63	116
Staghorn sculpin	3	4	11	15	8	41	70	102
Coho salmon	1	3	3	10	3	20	47	49
Chum salmon	1	4	4	6	3	18	42	48
Pink salmon		5	2	9	2	18	32	46
Shiner perch		3	9	1		13	27	41
Northern anchovy		1	5	5	6	17	27	35
Kelp greenling	2	4	2	1		9	12	34
Snake prickleback			6	3	6	15	35	30
Bay pipefish	1	3	3	1	1	9	19	29
English sole	1	2	2	4	2	11	20	29
Pacific tomcod	1	1	3	2	3	10	18	25
Spiny dogfish		2	3	3		8	25	23
Crescent gunnel	2	1	1	2	2	8	21	23
Tube-snout		1	2	3	2	8	15	18
Walleye pollock		1	1	2	3	7	10	14
Dwarf wrymouth			3			3	4	9
Pacific sandfish		1		2		3	10	8

Table 7. The 25 most common species caught during the study, ranked in order of decreasing abundance. Columns 2,3,4, and 5 list, respectively, the total number of individuals caught, percent compostion by number, cumulative percent, and percent frequency of occurrence in the 234 total collections.

Species	Rank by No.	No.	% by No.	Cum. % by No.	% Freq. of Occur.
Pacific herring	1	329,602	82.93	82.93	77.78
Pacific sand lance	2	38,625	9.74	92.88	50.00
Threespine stickleback	3	14,886	3.75	96.63	65.38
Surf smelt	4	2,720	0.68	97.31	38.03
Longfin smelt	5	2,361	0.59	97.90	26.50
Tadpole sculpin	6	2,275	0.57	98.47	21.79
Shiner perch	7	1,067	0.27	98.74	11.54
Snake prickleback	8	705	0.18	98.92	14.96
Pacific tomcod	9	662	0.17	99.09	7.69
Chinook salmon	10	500	0.13	99.22	26.92
Pacific staghorn sculpin	11	403	0.10	99.32	29.91
Soft sculpin	12	301	0.08	99.40	15.38
Northern anchovy	13	207	0.05	99.45	11.54
Coho salmon	14	202	0.05	99.50	20.08
Chum salmon	15	144	0.04	99.54	17.95
Pink salmon	16	127	0.03	99.57	13.68
Darter sculpin	17	101	0.03	99.60	0.43
Spiny dogfish	18	89	0.02	99.62	10.68
English sole	19	82	0.02	99.64	8.55
Tube-snout	20.5	74	0.02	99.66	6.41
Walleye pollock	20.5	74	0.02	99.68	4.27
Kelp greenling	22	72	0.02	99.70	5.13
Starry flounder	23	69	0.02	99.72	8.97
Sockeye salmon	24.5	58	0.01	99.73	3.42
Bay pipefish	24.5	58	0.01	99.74	8.12
Totals		395,464	99.74		
Total-all fish		396,434			

Table 8. Biological Index values by sampling site of the 25 highest ranking species, 1974-1976.

Species	Pt. Migley	Burrows Is.	Pt. George	Cherry Point	Shannon Pt.	South Beach	Village Pt.	Guemes South	Deadman Bay	Birch Bay	Guemes East	Eagle Cove	Lummi Bay	Padilla Bay	Westcott Bay	Total
Pacific herring	44	64	52	67	40	38	43	47	50	77	38	41	69	60	78	808
Threespine stickleback	36	40	15	36	33	15	42	56	22	35	33	21	54	59	37	534
Pacific sand lance	25	25	31	14	18	34	15	27	13	15	11	27	13	11	23	302
Surf smelt	11	4	0	27	2	10	10	17	9	50	13	5	15	21	22	216
Longfin smelt	12	6	0	31	6	0	5	7	3	12	7	0	32	12	0	133
Tadpole sculpin	3	15	19	6	15	15	5	6	8	3	0	15	13	8	0	131
Soft sculpin	6	12	22	4	7	5	1	10	5	3	12	8	10	10	11	126
Chinook salmon	6	20	6	6	11	5	8	11	6	6	7	0	9	15	0	116
Staghorn sculpin	10	2	0	22	1	0	5	2	0	10	9	0	12	17	12	102
Coho salmon	3	2	6	4	5	6	4	0	0	3	6	0	4	2	4	49
Chum salmon	0	6	13	2	4	5	8	3	5	0	0	0	1	1	0	48
Pink salmon	2	7	6	0	4	5	2	5	2	0	4	0	3	0	6	46
Shiner perch	0	3	0	3	4	0	0	0	0	11	0	0	0	6	14	41
Northern anchovy	3	3	0	7	0	0	0	3	0	2	1	2	4	8	2	35
Kelp greenling	0	0	0	4	3	0	0	5	3	8	0	4	7	0	0	34
Snake prickleback	2	1	0	6	0	2	2	0	0	3	0	0	4	2	7	30
Bay pipefish	4	0	0	0	0	0	3	0	0	2	0	0	4	8	8	29
English sole	0	3	3	3	0	6	0	4	0	0	0	0	10	0	0	29
Pacific tomcod	0	0	5	5	0	8	0	3	0	2	0	0	1	0	1	25
Spiny dogfish	0	0	3	0	0	0	4	4	0	0	6	0	0	6	0	23
Crescent gunnel	0	0	0	2	2	0	0	0	0	0	3	4	1	6	5	23
Tube-snout	0	0	0	0	0	3	0	0	0	1	0	4	1	0	9	18
Walleye pollock	0	0	0	1	0	2	4	0	0	0	0	0	1	0	6	14
Dwarf wrymouth	0	0	0	0	0	0	0	0	3	0	0	3	0	0	3	9
Pacific sandfish	0	0	0	2	0	2	0	0	0	0	0	4	0	0	0	8

abundant in the spring and summer. From late spring through mid-fall, these three species typically accounted for over 85 percent of the monthly catch in each of the three geographic areas (Fig. 6).

Following herring, sand lance, and stickleback, the next most abundant species were two osmerids--larvae, juvenile, and adult surf smelt (Hypomesus pretiosus) and larvae, juvenile, and adult longfin smelt (Spirinchus thaleichthys) (Table 7). While total numbers of individuals of each species were similar, surf smelt had a substantially higher BI value (216) than did longfin smelt (133). Both species were most abundant in the Cherry Point area with the greatest catches occurring during spring and summer.

Three of the 12 most abundant species were cottids: tadpole sculpin (Psychrolutes paradoxus), Pacific staghorn sculpin (Leptocottus armatus), and soft sculpin (Gilbertidia sigalutes) (Table 7). Tadpole sculpin, occurring primarily as larvae and juveniles, was the sixth most abundant species and also ranked high in terms of BI value (131). Tadpole sculpin were most abundant during the spring, and even though occurring at all 15 sites, most tadpole sculpin (72%) were caught at Lummi Bay.

The second most abundant cottid was the staghorn sculpin with a total of 403 individuals (juveniles and adults) collected. While catches were usually less than five fish per tow, staghorn sculpin occurred in a relatively high percentage (30%) of the total collections. Staghorn sculpin were most abundant at the Cherry Point, Birch Bay, Lummi Bay, Padilla Bay, and Westcott Bay sites. These five sites accounted for 86 percent of all staghorn sculpin caught.

A total of 301 soft sculpin, mostly juveniles, was captured (Table 7). Soft sculpin had a relatively high BI value (126), primarily

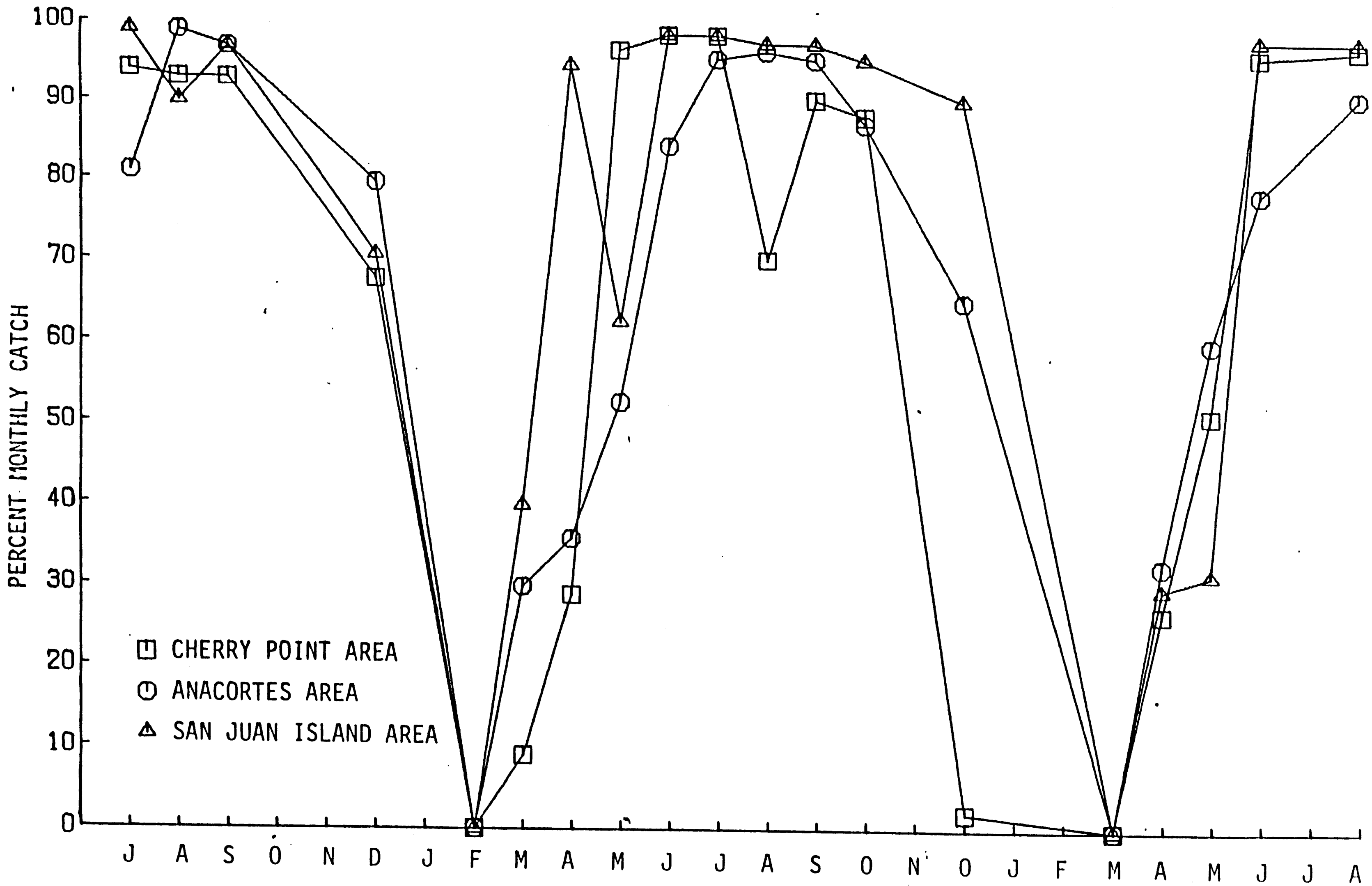


Fig. 6 . Combined monthly percentage of the total catch in each geographic study area comprised of Pacific herring, Pacific sand lance, and threespine stickleback, 1974-76.

because it was most abundant during winter and early spring when other species were scarce (Table 6).

All five species of salmon (Oncorhynchus spp) occurring in Washington waters were caught during the study. The most frequently occurring and most abundant salmonid was the chinook salmon (Oncorhynchus tshawytscha); the other four species were much less common. Most salmonids were caught between mid-spring and mid-fall and, with the exception of several adult coho salmon (O. kisutch), were juveniles.

Several species--northern anchovy (Engraulis mordax), shiner perch (Cymatogaster aggregata), darter sculpin (Radulinus boleoides), Pacific tomcod (Microgadus proximus), and snake prickleback (Lumpenus sagitta)--occurred infrequently but usually in large numbers (Table 7). Snake prickleback, anchovy, darter sculpin, and shiner perch were most abundant in a small number of collections at five sites: the three mud/eelgrass bays, Birch Bay, and Cherry Point. Most tomcod occurred in two collections (South Beach in August 1974, and Birch Bay in June 1976).

Seasonality. CPUE was lowest at all sites during the winter (usually <15 fish tow) and resulted in similar mean CPUE's at sites in the winter (Fig. 7, Table 9). The number of species occurring during the winter was also low at all sites and rarely exceeded five species per collection (Fig. 8, Table 10). Surf smelt and soft sculpin were the most abundant species caught in winter.

At many sites, a moderate to large increase in CPUE occurred in the spring, primarily due to catches of larval and juvenile herring and sand lance and adult stickleback. Total numbers of species at most sites also increased markedly in the early spring due to the occurrence of the larval stage of many species. Larval life history stages were abundant primarily

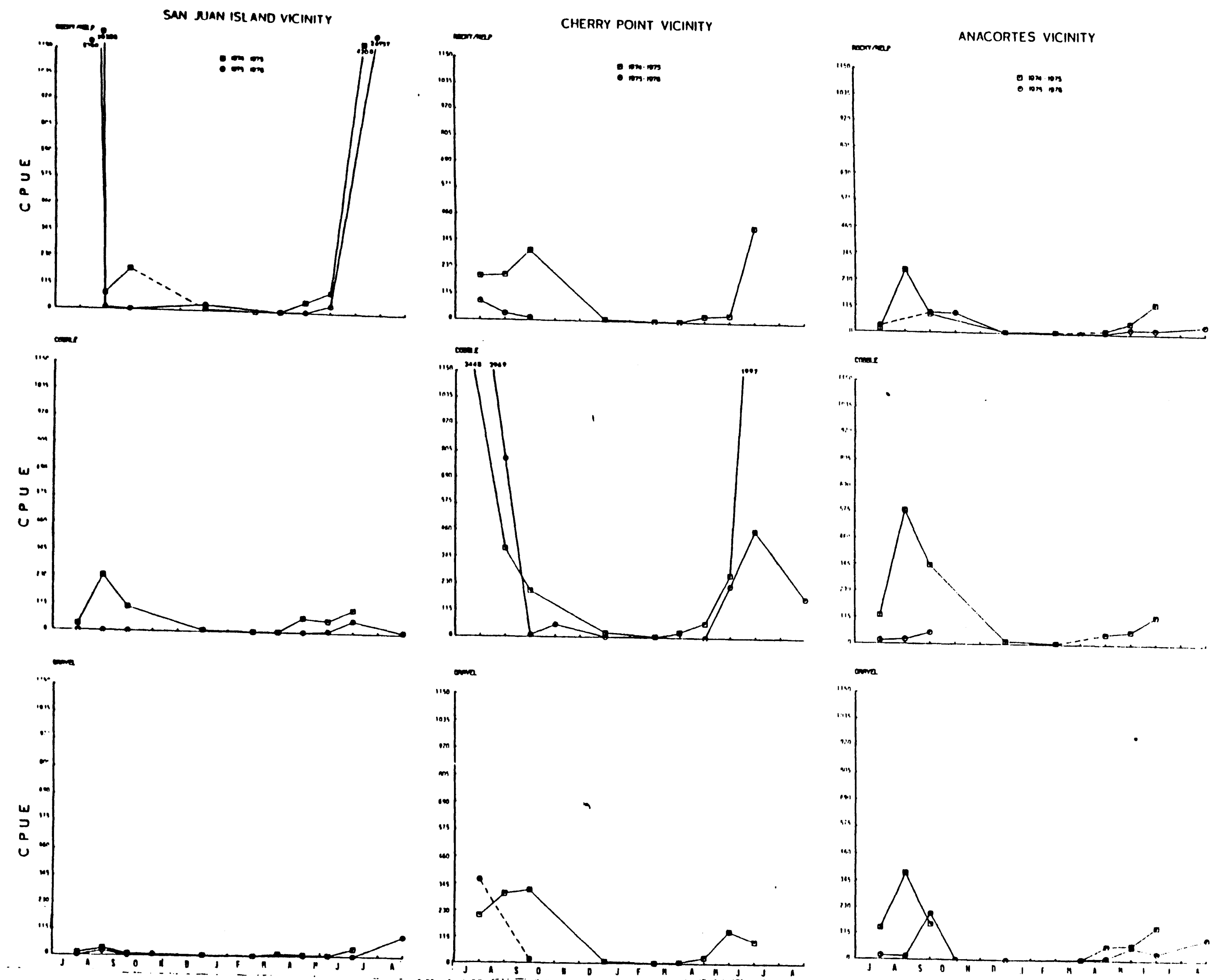


Fig. 7. Monthly CPUE of fish by site in the nearshore surface waters of northern Puget Sound, 1974-1976.

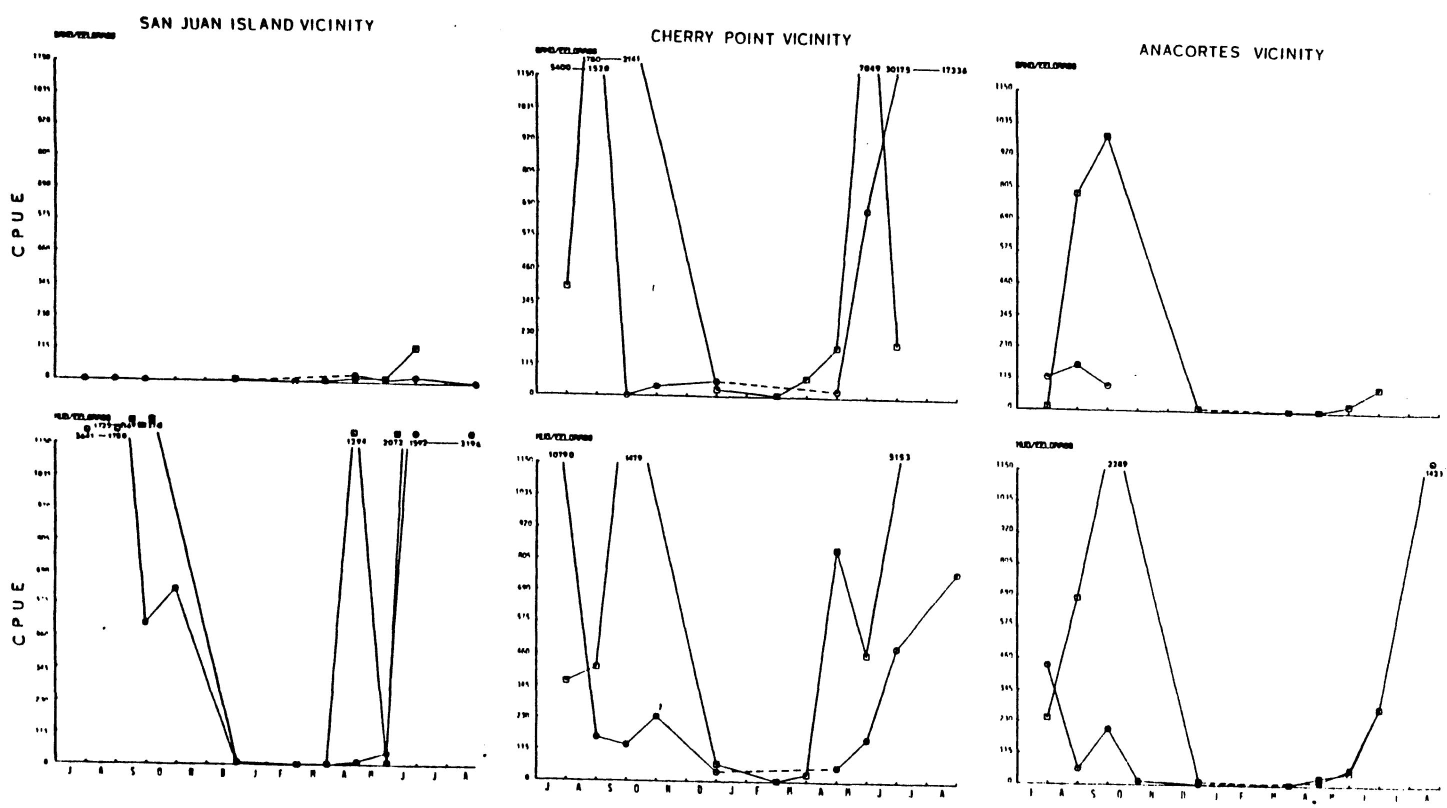


Fig. 7. Monthly CPUE of fish by site in the nearshore surface waters of northern Puget Sound, 1974-1976. (Continued)

Table 9. Comparison of winter and summer abundance of fish in northern Puget Sound nearshore surface waters, 1974-76. All values are mean CPUE. (SD = Standard Deviation)

Site	Total				Winter				Summer			
	$\bar{x}$	SD	Min	Max	$\bar{x}$	SD	Min	Max	$\bar{x}$	SD	Min	Max
Pt. Migley	108.7	138.4	2	419	4.0	3.4	2	8	184.0	149.9	29	419
Burrows Island	50.9	69.1	1	273	2.5	1.3	1	4	85.0	101.9	16	273
Pt. George	3380.7	7842.4	0	26757	7.4	11.4	0	27	9514.0	11271.2	9	26757
Cherry Pt.	614.6	1057.9	0	3448	10.0	8.9	1	20	1457.6	1340.6	174	3448
Shannon Pt.	125.5	180.6	5	585	9.0	5.7	5	12	173.4	236.1	15	585
South Beach	41.4	62.9	0	235	4.0	2.6	2	7	60.4	85.1	0	235
Village Point	135.2	139.7	2	361	5.7	3.5	2	9	241.5	115.3	97	361
Guemes South	81.9	99.6	0	377	4.3	1.5	1	4	118.0	126.8	15	377
Deadman Bay	12.7	21.1	0	87	4.8	4.3	1	11	26.1	30.0	0	87
Birch Bay	3725.0	7861.6	1	30175	38.9	29.1	5	69	8111.6	11438.9	198	30175
Guemes East	208.1	343.8	2	992	6.0	5.7	2	10	233.0	313.3	11	785
Eagle Cove	17.7	33.8	0	131	4.5	2.9	1	8	31.2	56.4	0	131
Lummi Bay	1201.3	2672.2	3	10791	32.8	25.6	3	65	2589.7	4024.9	157	10791
Padilla Bay	357.8	613.2	2	2289	5.7	6.4	2	13	487.3	454.9	58	1423
Westcott Bay	1399.3	2035.6	1	8375	3.8	3.1	1	8	2242.9	827.0	1592	3642

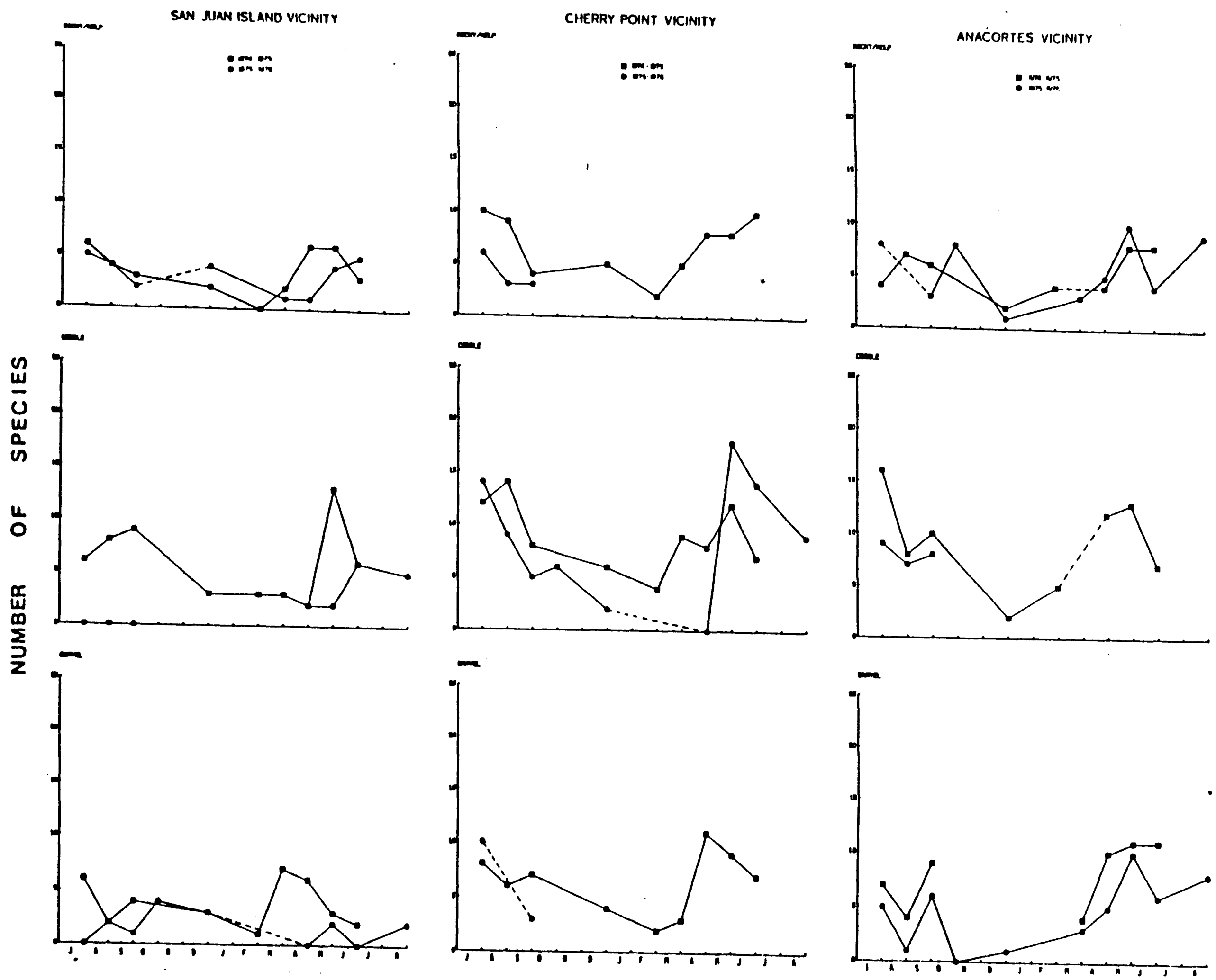


Fig. 8. Monthly numbers of species by site in the nearshore surface waters of northern Puget Sound, 1974-1976.

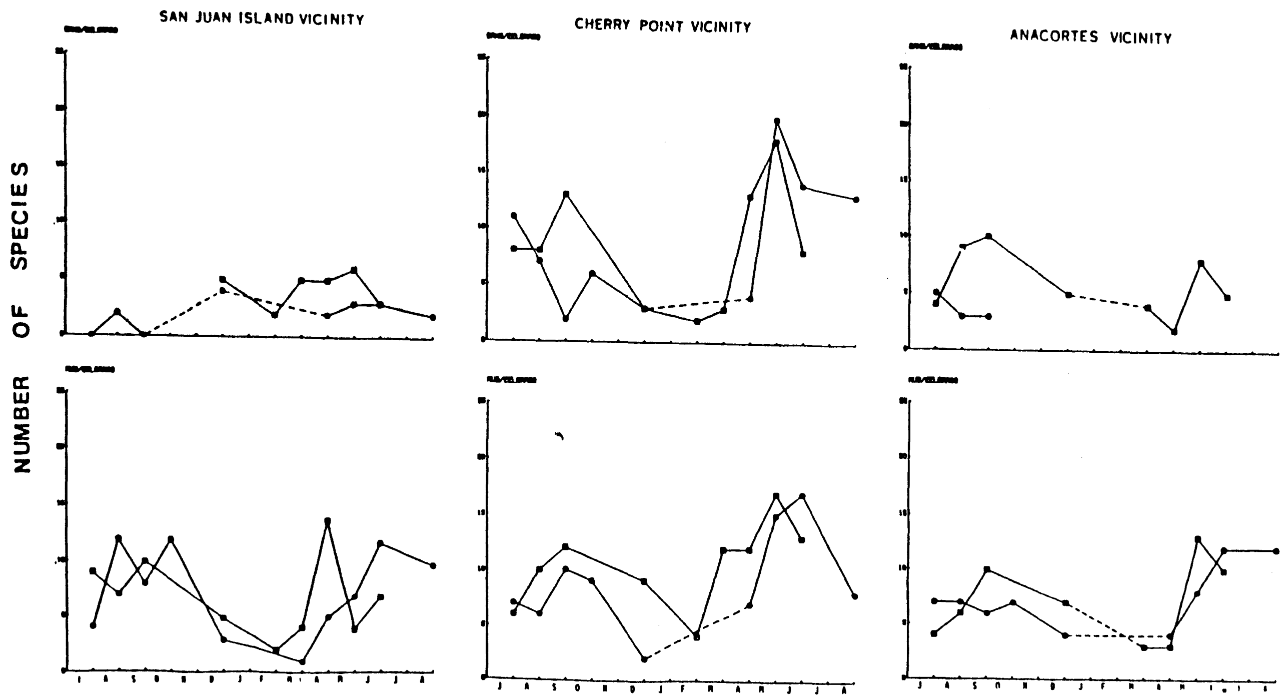


Fig. 8. Monthly numbers of species by site in the nearshore surface waters of northern Puget Sound, 1974-1976 (Continued)

Table 10. Comparison of number of species occurring in the winter and summer in northern Puget Sound, 1974-1976. ($\bar{x}$ = average number of species in collections, SD = Standard Deviation)

Site	Total				Winter				Summer			
	$\bar{x}$	SD	Min	Max	$\bar{x}$	SD	Min	Max	$\bar{x}$	SD	Min	Max
Pt. Migley	5.8	2.9	1	10	3.7	2.3	1	5	7.6	3.1	3	10
Burrows Island	5.6	2.6	1	12	2.5	1.3	1	4	6.8	1.9	4	9
Pt. George	3.3	1.9	0	6	1.6	1.5	0	4	4.5	1.1	3	6
Cherry Pt.	8.6	4.8	0	19	5.0	3.2	2	8	11.3	2.9	7	14
Shannon Pt.	8.6	3.4	2	15	3.5	2.1	2	5	9.8	3.1	7	15
South Beach	4.1	3.3	0	11	3.0	0	3	3	4.4	3.2	0	8
Village Pt.	6.2	2.8	2	10	3.0	1.0	2	4	7.8	1.7	6	10
Guemes South	5.9	3.7	0	14	2.3	1.2	1	3	6.4	4.1	1	14
Deadman Bay	2.6	2.0	0	7	3.5	2.6	1	7	2.0	2.0	0	6
Birch Bay	8.4	5.3	2	20	2.8	0.5	2	3	9.7	2.7	7	14
Guemes East	5.2	2.6	2	10	4.0	1.4	3	5	5.4	2.6	3	9
Eagle Cove	2.9	1.6	0	5	3.8	1.3	2	5	2.2	1.5	0	4
Lummi Bay	9.5	4.2	2	18	6.0	4.1	2	10	9.7	4.4	6	18
Padilla Bay	7.3	3.3	3	13	4.7	2.1	3	7	8.6	3.4	4	13
Westcott Bay	7.0	3.8	1	13	3.0	1.6	1	5	8.7	2.9	4	12

during the spring (Table 11), and many species collected in the spring as larvae did not occur during other seasons. Spring increases in CPUE and numbers of species were greatest at protected sites (e.g., Westcott Bay, Birch Bay) and least at exposed sites (e.g., Burrows Island, Eagle Cove).

The largest catches during the study, up to 54,000 fish in one 10 min tow, occurred from late spring through summer. Fifty-six percent of all fish caught occurred in the summer with juvenile fishes, particularly herring, stickleback, and sand lance, most abundant. Sporadic catches of shiner perch, snake prickleback, and tomcod contributed significantly to CPUE values at several sites. Catches of these species were generally high during a single month, that varied with species. Exposed sites had fewer species and lower CPUE values in the summer than did more protected sites. The greatest differences among sites in CPUE and numbers of species occurred in the summer (Tables 9 and 10), where differences in CPUE between sites often exceeded a factor of 300.

During the fall, both CPUE and species-numbers decreased (at times rapidly) to low winter levels (Fig. 7 and 8). Adults and juveniles were the predominant LHS and herring and threespine stickleback were the predominant species occurring in the fall.

Distributional Trends. Only 6 of the 71 species captured occurred at all 15 sites (Table 4). These 6 species included the three most abundant--herring, sand lance, and stickleback--along with soft sculpin, tadpole sculpin, and pink salmon. Three other species--surf smelt, chinook salmon and coho salmon--occurred at 14 of the 15 sites.

In general, sites associated with protected eelgrass bays, both mud and sand, had more marked seasonal changes in CPUE and numbers of species

Table 11. Seasonal number of positively identified species caught by townet in northern Puget Sound over all collections, 1974-1976.

Season	Number of Species			
	Total No. All LHS[1]	No. Larvae	No. Juveniles	No. Adults
Spring	49	25	33	27
Summer	42	2	38	22
Fall	30	2	21	20
Winter	22	3	8	16

[1]LHS= Life History Stages

than did more exposed sites. Mud and sand eelgrass and cobble habitats had larger numbers of species, particularly demersal, than rocky/kelp or gravel habitats (Table 4).

Substantial differences between sites of the same habitat type were evident, in particular for rocky/kelp bed, cobble, and sand/eelgrass habitats. At rocky/kelp bed sites, large, infrequent catches of herring and sand lance occurred during the summer at Point George but not at the other two sites of this habitat type. As a result, mean CPUE at Pt. George was over 30 times greater than at either of the other two rocky/kelp bed sites. CPUE at the three cobble sites were similar in the winter but differed substantially during spring through fall. CPUE at South Beach never exceeded 240 fish/tow, whereas Cherry Point CPUE ranged up to 3500 fish/tow. More species occurred at the two eastern shore cobble sites (Cherry Point, Shannon Point) than at the San Juan Island area site. Of the dominant species, herring, surf smelt, longfin smelt, threespine stickleback, chinook salmon, staghorn sculpin, and northern anchovy were all more abundant at the eastern shore cobble sites; tomcod was more numerous at South Beach. In the sand/eelgrass habitat type, catches at Birch Bay (mean CPUE=3725) were greater than at any of the other 14 sites whereas Eagle Cove catches (mean CPUE=18) were among the lowest of any site. Catches at the Guemes East site were intermediate between Birch Bay and Eagle Cove. As with cobble sites, most species were least abundant at the San Juan Island area site (Eagle Cove).

Forty different species were collected from the San Juan Island area as compared to 62 and 55 species from the Cherry Point and Anacortes areas, respectively. Within the same habitat type, San Juan Island area sites had fewer species than sites in the Cherry Point and Anacortes areas (Table 5). Seasonal CPUE of the 16 most abundant species was usually greater in the Cherry Point area than in the other two areas (Table 12). Differences between areas were more pronounced in spring and summer whereas fall and winter catches in the three areas were similar.

Annual Variations. Of the 396,434 total fish caught, 157,284 (624.1 fish/tow) occurred during 1974-75 and 239,150 (1128.1 fish/tow) occurred during 1975-76. Fewer tows in 1975-76 captured more fish and fewer species than in 1974-75. The difference between mean yearly CPUE from each site was not significant by Wilcoxon signed rank test ($p > 0.05$). Seasonal changes in CPUE and numbers of species occurred at approximately the same time during both years (Fig. 7 and 8). However, there were considerable differences in the magnitudes of catches during the same month of each of the years. This was especially true during spring and summer; winter and fall catches were generally similar during each year.

In both 1974-75 and 1975-76, the relative occurrence and abundance of the four dominant species (herring, sand lance, stickleback, and surf smelt) were similar (Table 13). Herring ranked as the most abundant, most frequently occurring species during both years. Of the rarer species, staghorn sculpin, tadpole sculpin, chum salmon, darter sculpin, and shiner perch were more abundant in 1974-75 and longfin smelt, northern anchovy, and snake prickleback were abundant in 1975-76.

Environmental Relationships. Seasonal changes in CPUE and species numbers paralleled seasonal changes in temperature. However, a significant correlation between monthly temperature and CPUE, by Kendall's

Table 12. Seasonal CPUE of the 16 most abundant species in each study area. Values are catch per 10-min tow (CPUE). (SJI=San Juan Island area, An=Anacortes area, CP=Cherry Point area)

Species	Spring			Summer			Fall			Winter		
	SJI	An	CP	SJI	An	CP	SJI	An	CP	SJI	An	CP
Pacific herring	810.4	23.5	1850.1	1319.4	225.2	1480.7	53.7	5.5	15.2	0.1	0.3	0.5
Pacific sand lance	440.3	15.1	21.9	181.6	0.8	2.6	0.4	0	0.2	0.2	0.3	0
Threespine stickleback	3.9	13.1	32.1	1.3	80.9	101.0	6.7	6.4	21.9	0.1	0.3	0.8
Surf smelt	0.1	0.9	21.1	0.4	0.7	18.9	0.2	0	4.7	0.9	0.2	5.4
Longfin smelt	0	0.9	21.7	0	0.2	17.4	<0.1	0.3	5.7	0	0.1	0.1
Tadpole sculpin	4.4	3.9	39.3	<0.1	0.4	0.1	0.1	0.3	0	<0.1	0	0
Shiner perch	0	0.1	0.4	3.0	1.9	11.4	0.1	0.1	0	0	0	0
Snake prickleback	0.2	0.3	12.9	0.2	0.2	0.1	1.6	0.1	0	0	0	0
Pacific tomcod	0.8	<0.1	6.5	4.1	<0.1	0.5	<0.1	0	0	0	0	0
Chinook salmon	0	0.1	0.5	0.2	3.3	3.8	0	0.1	0	0	0	0
Staghorn sculpin	0	0.1	0.3	0.6	1.0	3.8	<0.1	0.2	0.3	0	0	0.4
Soft sculpin	1.3	1.6	1.8	0	0.1	0	0.3	<0.1	0	0.1	1.1	1.4
Northern anchovy	<0.1	0.9	2.8	<0.1	0	0.5	<0.1	0	0	0	0	0
Coho salmon	<0.1	0.6	1.0	0.3	0.5	1.0	0	0	<0.1	0	0	0
Chum salmon	<0.1	0.3	0.5	0.7	0.4	0.3	0	0	0	0	0	0
Pink salmon	0.2	0	1.0	0.3	0.5	0.2	<0.1	0	0	0	0	0

Table 13. The most common species captured by townet in northern Puget Sound ranked according to occurrence and abundance in 1974-75 and 1975-76.

Species	1974-75 Occurrence	1974-75 Abundance	1975-76 Occurrence	1975-76 Abundance
Pacific herring juveniles, larvae	1	1	1	1
Threespine stickleback adults, juveniles	2	2	2	3
Pacific sand lance larvae to adults	3	3	3	2
Surf smelt larvae to adults	4	5	4	5
Pacific staghorn sculpin juveniles, adults	5	7	6	
Chinook salmon juveniles	6	10	7	9
Tadpole sculpin larvae to adults	7	4	10	7
Longfin smelt juveniles, adults	8	9	5	4
Chum salmon juveniles	9			
Soft sculpin larvae to adults	10			
Shiner perch juveniles, adults		6		10
Pacific tomcod juveniles		8		8
Coho salmon juveniles			9	
Northern anchovy adults			8	
Snake prickleback juveniles, adults				6

correlation coefficient, was observed at 11 of 15 sites, whereas only 4 of 15 sites exhibited a significant correlation between temperature and species number (Table 14 and 15). Significant relationships between CPUE and number of species with dissolved oxygen and salinity were infrequent.

<u>Occurrence, Abundance, and Distribution of Predominant and Commercially Important Species</u>

<u>Pacific Herring</u>. The schooling Pacific herring was the most abundant and most frequently occurring species collected. A total of 329,602 herring were caught and occurred in 182 (78%) of the 234 total collections. Herring was one of the five most common species in 180 (76%) collections and the most abundant species in 114 (49%) collections.

Most herring were juveniles and were caught in late spring and summer (Table 16). Collections during each year were mostly young-of-the-year, although some months (April 1974 and May and June 1976) clearly had several year classes represented (Fig. 9). Large numbers of larvae occurred, especially in the spring. Most larvae and juveniles caught during the study were herring. Even though extensive spawning occurs throughout northern Puget Sound, no spawning herring were caught.

During each year, herring accounted for a similar percentage of the total catch (82% in 1974-75 and 84% in 1975-76) and occurred in a similar percentage of the total collections (79% in 1974-75 and 77% in 1975-76). CPUE of herring in 1974-75 was nearly half the CPUE in 1975-76 (517 fish/tow vs 944 fish/tow). The difference in mean CPUE each year at the 15 sites was not significant ($p > 0.05$) by a Wilcoxon matched pairs test.

Herring were present in nearshore surface waters throughout the entire year and exhibited a distinct seasonal pattern in abundance

Table 14. Kendall correlation coefficients (τ) for monthly CPUE with temperature, salinity, and dissolved oxygen at each site, 1974-1976.

	Temperature		Salinity		Dissolved Oxygen	
Site	n	τ	n	τ	n	τ
Pt. Migley	11	0.50*	11	-0.02	9	0.14
Burrows Island	16	0.48**	17	0.18	13	-0.54**
Pt. George	16	0.37*	16	0.08	13	-0.35
Cherry Pt.	18	0.53**	18	-0.07	14	0.02
Shannon Pt.	10	0.31	10	0.11	7	-0.39
South Beach	15	0.05	15	0.03	12	-0.03
Village Pt.	10	0.63*	10	0.10	7	-0.30
Guemes South	16	0.39*	17	0.10	14	-0.36
Deadman Bay	17	0.17	17	-0.10	14	-0.23
Birch Bay	18	0.42*	18	0.02	14	0.35
Guemes East	10	0.63*	11	-0.11	7	-0.15
Eagle Cove	14	-0.13	14	0.45*	14	0.06
Lummi Bay	18	0.42*	17	0.24	14	-0.10
Padilla Bay	15	0.58**	16	0.14	12	-0.33
Westcott Bay	18	0.59**	18	-0.02	14	0.18

*Signifigant at $P \leq 0.05$
**Signifigant at $P \leq 0.01$

Table 15. Kendall correlation coefficients for monthly numbers of species with temperature, salinity, and dissolved oxygen at each of the 15 sites, 1974-1976.

Site	Temperature		Salinity		Dissolved oxygen	
	n	τ	n	τ	n	τ
Pt. Migley	11	0.15	11	0.15	9	0.09
Burrows Island	16	0.30	17	0.32	13	-0.36
Pt. George	16	0.22	16	0.02	13	-0.19
Cherry Pt.	18	0.37*	18	-0.04	14	0.28
Shannon Pt.	10	0.21	10	0.44	7	0.05
South Beach	15	-0.07	15	0.16	12	-0.08
Village Pt.	10	0.21	10	0.06	7	0.05
Guemes South	16	0.18	17	0.15	14	-0.13
Deadman Bay	17	-0.18	17	0.12	14	0.11
Birch Bay	18	0.36*	18	0.13	14	0.31
Guemes East	10	0.18	11	0.06	7	-0.17
Eagle Cove	14	-0.39*	14	0.04	14	0.21
Lummi Bay	18	0.23	17	0.24	14	-0.06
Padilla Bay	15	0.21	16	0.35	12	-0.46*
Westcott Bay	18	0.43*	18	0.02	14	0.18

*Significant at $P \leq 0.05$.
**Significant at $P \leq 0.01$.

Table 16. Seasonal distribution of Pacific herring in the nearshore surface waters of northern Puget Sound, 1974-1976.

Season	Total-Larvae and Juvenile			Larvae			Juvenile		
	% Freq. Occur[1]	No.[2]	CPUE[3]	% Freq. Occur	No.	CPUE	% Freq. Occur	No.	CPUE
Spring	75.6	138339	904.2	62.8	19684	128.7	50.0	118655	775.5
Summer	90.4	189669	1003.5	<0.1	10	0.1	91.6	189659	1002.9
Fall	84.3	1578	24.6	0	0	0	78.1	1578	24.7
Winter	37.9	16	0.3	0	0	0	37.9	16	0.3
Total	78.2	329602	710.3	20.9	19694	42.4	62.4	309908	667.7

[1] Percent frequency of occurrence in collections in each period

[2] Number of Fish

[3] Number of Fish Caught/Number of 10-min tow capture attempts

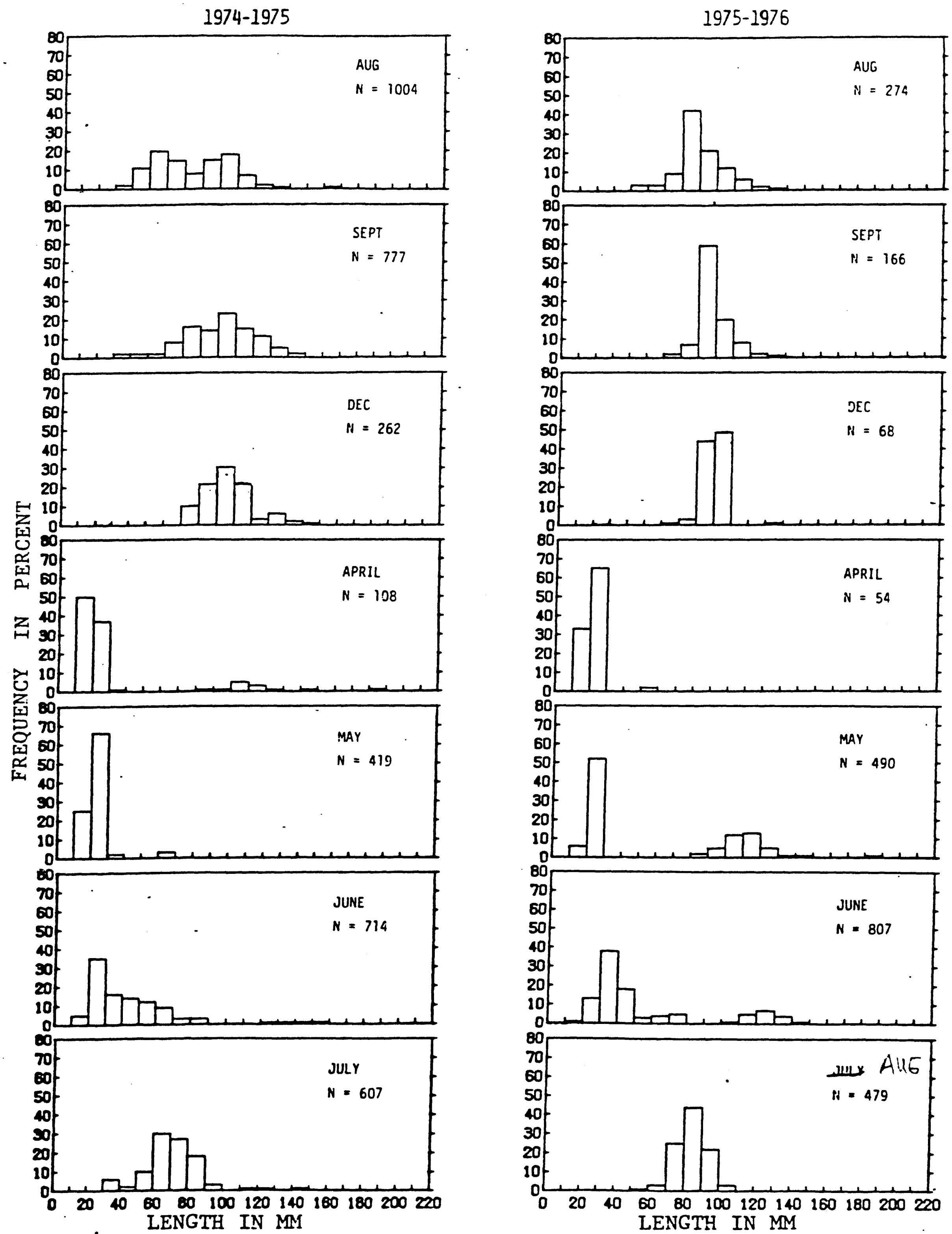


Fig. 9. Monthly length frequency of Pacific herring in northern Puget Sound, 1974-1976.

(Table 17). Seasonal abundance of herring was the lowest in winter with only scattered fish occurring at some sites. Larvae as small as 13 mm TL began appearing in catches as early as April (Fig. 9, Table 17), and were particularly common in Westcott Bay in 1975. A substantial increase in abundance occurred during May and June as juveniles predominated in catches. CPUE of herring was greatest from late spring through late summer, especially in the Cherry Point area. Herring was typically the dominant species occurring in the three geographic study areas in the summer, at times accounting for nearly 100 percent of the total monthly catch in an area (Fig. 10). By late fall, the number of herring at all sites was greatly reduced; less than 1 percent of the total herring catch occurred in the fall (Table 16). The greatest percentage of herring caught during the fall were from the San Juan Island area, particularly Westcott Bay.

Herring were captured at all sites and were the most abundant and most dominant (BI value) species at 14 of the 15 sites (Tables 4 and 8), accounting for 36 to 97 percent of the total catch at individual sites. Low abundances of herring characterized all sites during the fall and winter, and the largest catches occurred at sites only during spring and summer. The greatest between-site differences occurred during the spring and summer, and during this period, sites closely associated with eelgrass bays had the largest catches of herring. More exposed sites of varying habitat type had the smallest catches.

Fifty-six percent of the herring were caught at Cherry Point area sites, 39 percent at San Juan Island area sites, and 5 percent at Anacortes area sites.

Table 17. Monthly townet CPUE of Pacific herring at sites in northern Puget Sound, 1974-1976.

Month	Pt. Migley	Burrows Is.	Pt. George	Cherry Pt.	Shannon Pt.	South Beach	Village Pt.	Guemes South	Deadman Bay	Birch Bay	Guemes East	Eagle Cove	Lummi Bay	Padilla Bay	Westcott Bay	Mean monthly CPUE
July 1974	132	0	20,269	2,475	6	21	61	35	2	276	7	--	139	170	1,717	1,809
August	120	233	68	171	563	107	258	92	31	1,650	705	--	248	158	1,602	429
September	135	5	126	160	36	99	71	107	5	1,627	976	--	1,054	2,031	8,329	1,058
December	2	3	0	11	13	3	7	--	1	0	7	2	47	0	3	4
February 1975	0	1	0	0	1	1	0	--	0	0	--	0	1	--	0	< 1
March	1	--	0	2	--	0	1	1	1	0	0	0	1	0	0	< 1
April	1	0	0	0	2	0	3	0	1	86	0	1	0	15	1,096	80
May	1	28	46	123	21	12	3	14	0	6,819	1	5	86	5	3	478
June	201	112	17	1,963	80	98	61	54	23	189	65	130	5,101	69	2,062	682
July	77	2	242	2,903	2	0	277	2	0	5,342	113	0	10,782	15	3,634	1,559
August	20	--	5	243	1	0	--	0	20	1,326	163	2	55	10	1,754	277
September	1	86	2	3	9	0	2	60	1	1	86	0	13	128	488	117
October	--	24	--	36	--	--	--	0	4	17	--	--	25	7	546	164
December	--	1	25	0	--	--	--	0	2	1	--	2	0	1	4	7
March 1976	--	1	0	--	--	--	--	0	--	--	--	--	--	--	0	< 1
April	--	1	0	0	--	0	--	0	0	9	--	0	9	0	10	3
May	--	5	7	133	--	0	--	45	0	232	--	6	78	21	35	102
June	--	7	18,456	331	--	45	--	2	0	29,352	--	19	338	5	1,430	4,544
August	--	10	--	150	--	0	--	78	87	17,092	--	1	528	1,325	3,168	2,195
Mean site CPUE	57	31	2,312	484	66	25	68	30	10	3,557	193	12	1,028	233	1,313	

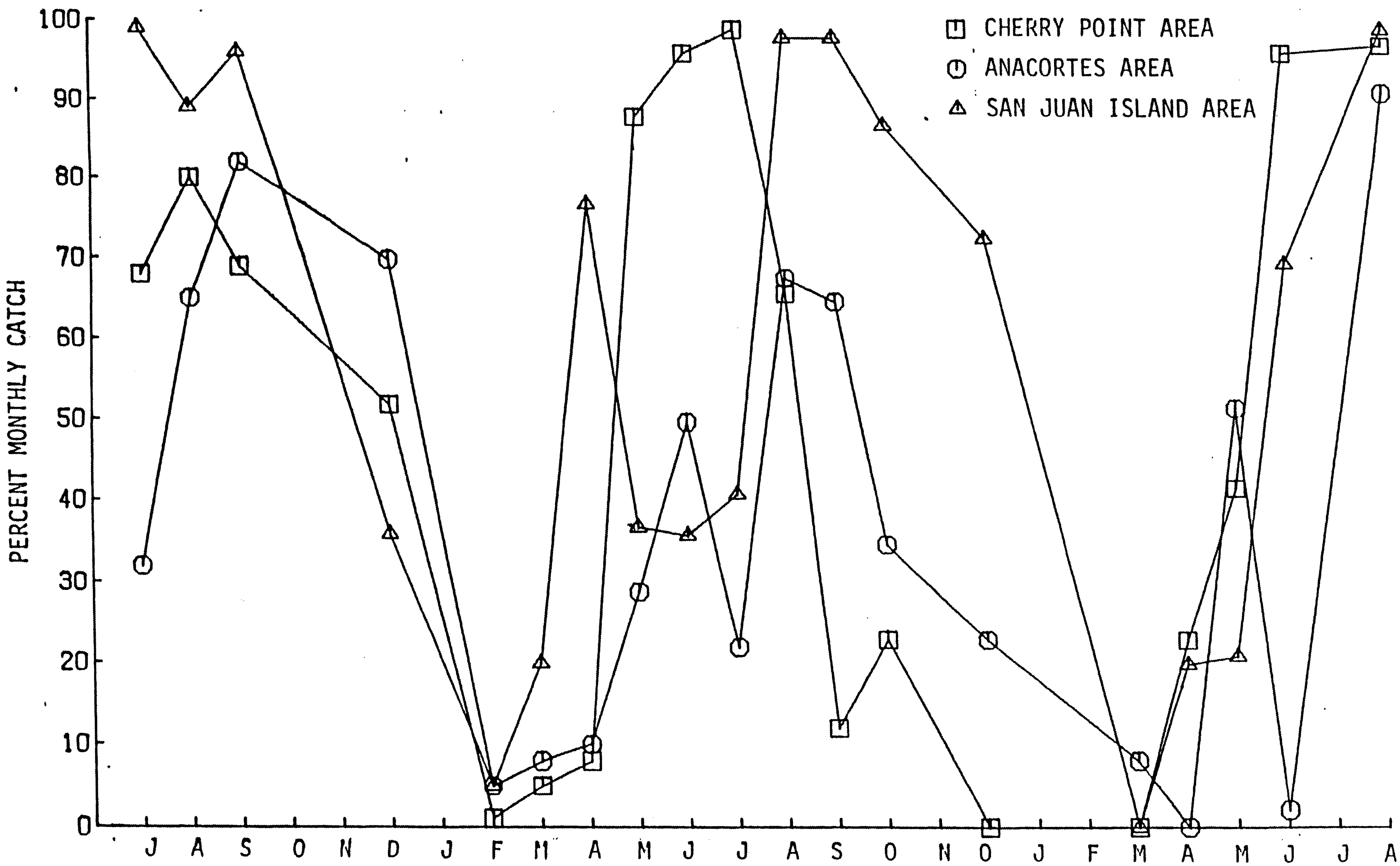


Fig. 10. Percentage of the total monthly catch in each geographic study area comprised of Pacific herring, 1974-1976.

A Kendall's correlation test indicated that mean site temperature and mean site CPUE of herring were correlated (τ=0.57, $p \leq .003$), whereas salinity and dissolved oxygen were not correlated with CPUE ($p > 0.05$).

Pacific Sand Lance. A total of 38,625 sand lance were caught, and these occurred in 50 percent (117) of the collections. The majority (28,707 = 74%) were collected during 1975-76; 6 percent of all fish caught in 1974-75 were sand lance and 12 percent in 1975-76. A Wilcoxon test indicated that there was no difference ($p > 0.05$) between the mean CPUE at each site the first and second year.

Nearly all sand lance captured were larvae and juveniles, and catches each year were composed of predominately one year class that could be followed by increasing modal length (Fig. 11 and Table 18). Larvae were caught entirely in the spring whereas juveniles were nearly all captured in spring and summer. The few adults collected were caught primarily during the summer.

Sand lance exhibited a distinct seasonal pattern in abundance (Table 19). Catches from late summer through late winter were very low when only 16 of the total 38,625 sand lance were caught. During 1974-75 an increase in CPUE occurred during April and May at many sites; however, in 1975-76 the spring increase in sand lance abundance occurred primarily in May. Most sand lance caught during April and May were classified as larvae (Fig. 11). Maximum sand lance abundance occurred at all sites between April and July the first year and between May and June during the second year which was when sand lance accounted for the greatest proportion of the monthly catch (Fig. 12). In August of both years, catches decreased abruptly and remained low until the following spring.

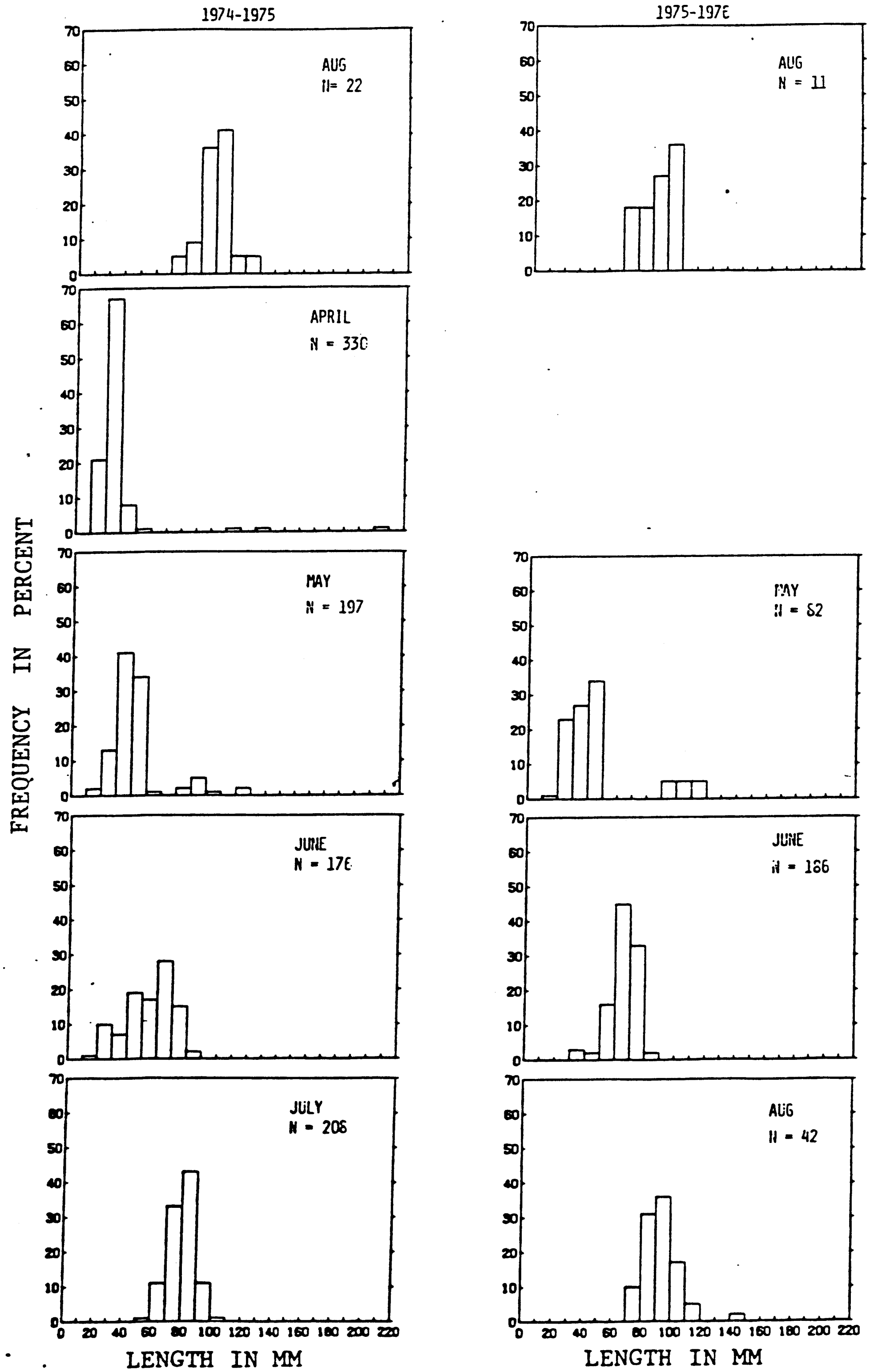


Fig. 11. Monthly length frequency of Pacific sand lance in northern Puget Sound, 1974-1976.

Table 18. Seasonal distribution of Pacific sand lance in the nearshore surface waters of northern Puget Sound, 1974-1976.

Season	Total all Life History Stages			Larvae			Juvenile			Adult		
	% Freq Occur.[1]	No.[2]	CPUE[3]	% Freq Occur.	No.	CPUE	% Freq Occur.	No.	CPUE	% Freq Occur.	No.	CPUE
Spring	78.2	27298	178.4	38.5	1435	9.4	48.7	25856	169.0	7.7	7	< 0.1
Summer	47.4	11307	59.8	0	0	0	33.7	11262	59.6	12.6	45	0.2
Fall	18.8	9	0.2	0	0	0	3.1	1	<0.1	15.6	8	0.1
Winter	20.7	7	0.2	0	0	0	3.4	1	<0.1	20.7	6	0.1
Total	50.0	38621[4]	83.2	12.8	1435	3.1	30.8	37120	80.0	12.4	66	0.1

[1]Percent frequency of occurrence in collections each period

[2]Number of Fish

[3]Number of Fish Caught/Number of 10-min capture attempts

[4]Plus 4 fish unstaged

Table 19. Monthly townet CPUE of Pacific sand lance in northern Puget Sound, 1974-1976.

Month	Pt. Migley	Burrows Is.	Pt. George	Cherry Pt.	Shannon Pt.	South Beach	Village Pt.	Guemes South	Deadman Bay	Birch Bay	Guemes East	Eagle Cove	Lummi Bay	Padilla Bay	Westcott Bay	Mean monthly CPUE
July 1974	0	0	0	0	1	0	1	0	0	0	0	--	0	0	0	< 1
August	0	1	2	1	1	3	0	0	0	0	0	--	2	0	0	< 1
September	0	1	0	0	1	1	1	2	1	0	1	--	1	1	1	< 1
December	1	0	0	0	0	1	0	--	0	0	0	1	2	0	0	< 1
February 1975	0	0	0	0	1	1	0	--	0	0	--	1	0	--	0	< 1
March	0	--	0	0	--	0	0	0	1	0	1	0	0	0	0	< 1
April	2	2	1	36	5	8	14	14	2	37	0	11	135	0	181	30
May	2	2	10	10	10	8	2	9	0	171	1	1	7	2	0	15
June	2	7	4,189	7	16	2	5	13	5	1	0	0	2	6	8	284
July	3	3	5,652	10	1	0	46	1	0	7	3	0	2	1	7	382
August	0	--	2	1	3	0	--	0	1	1	0	0	0	1	2	1
September	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	< 1
October	--	0	--	0	--	--	--	0	0	0	--	--	0	0	1	< 1
December	--	0	1	0	--	--	--	0	0	0	--	1	0	0	0	< 1
March 1976	--	0	0	--	--	--	--	1	--	--	--	--	--	--	0	< 1
April	--	1	0	0	--	2	--	0	0	1	--	1	0	0	0	< 1
May	--	2	2	6	--	3	--	1	0	74	--	0	1	3	2	9
June	--	0	8,227	1	--	0	--	1	0	13	--	1	0	263	120	784
August	--	4	--	4	--	0	--	2	0	0	--	0	8	2	10	3
Mean site CPUE	1	1	1,064	4	4	2	6	3	1	17	1	1	9	16	17	

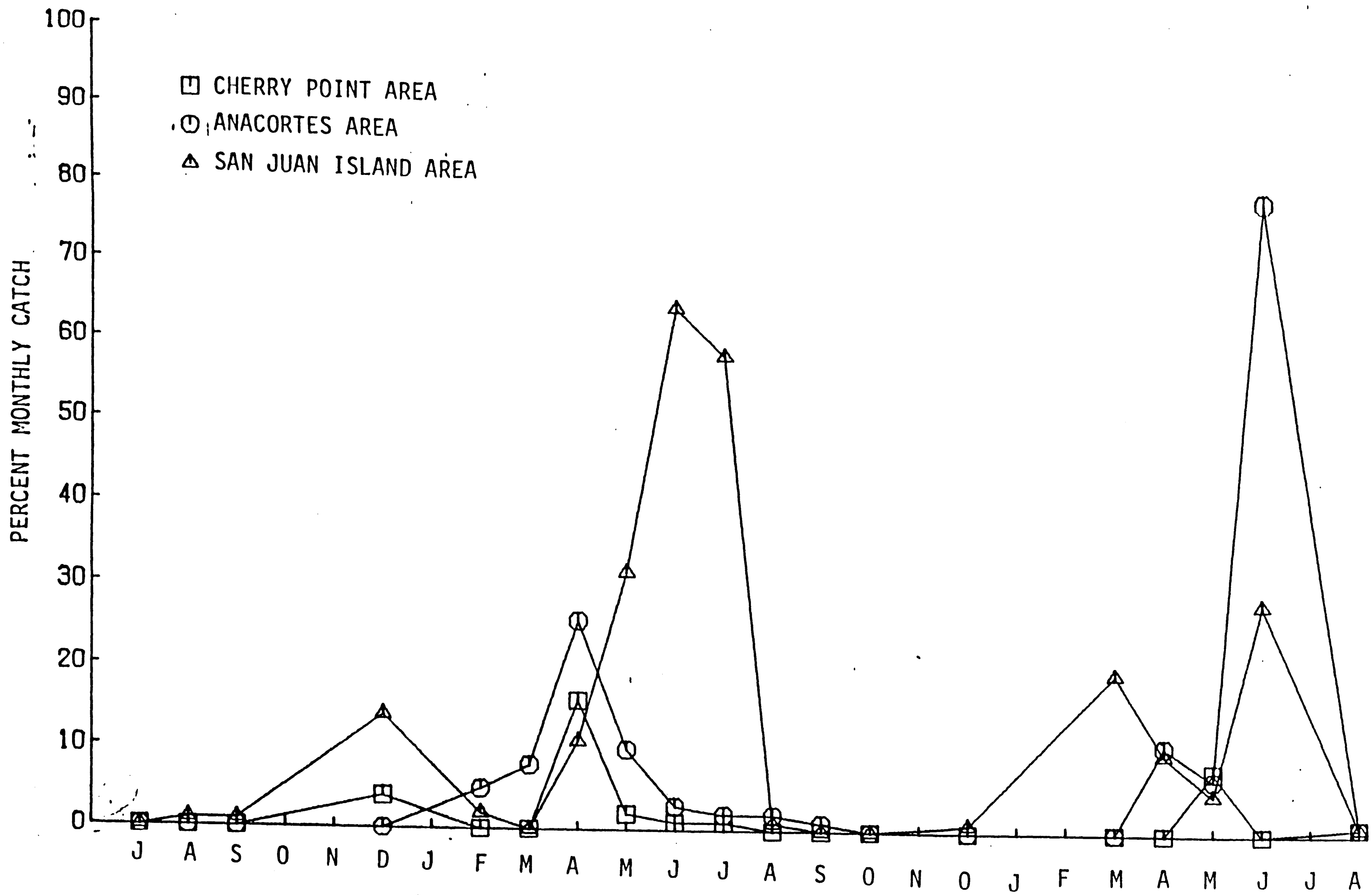


Fig. 12. Percentage of the total monthly catch in each geographic study area comprised of Pacific sand lance, 1974-1976.

Sand lance occurred in catches at all sites (Table 19), although the great majority (93%) were captured in three collections at Pt. George. Most of the remaining sand lance were captured in the four protected eelgrass bays: Birch Bay, Westcott Bay, Padilla Bay, and Lummi Bay. Sites with the lowest CPUE were Guemes East, Deadman Bay, Pt. Migley, Burrows Is., and Eagle Cove, which are all relatively exposed.

No significant correlations between mean site CPUE and physiochemical parameters were found ($p > 0.05$).

Threespine Stickleback. The threespine stickleback was the third most abundant and second most frequently occurring species (Table 7). Of the 14,886 total stickleback collected, 11,360 (75%) were caught in 1974-75, whereas 3,526 (25%) were caught in 1975-76. These values represent 7 percent and 2 percent of the total fish caught (all species) during the first and second year of sampling, respectively. Mean abundance of stickleback at each site during the first and second year was found to be significantly different ($Z = -3.18$, $p \leq 0.01$) using a Wilcoxon signed rank test.

Approximately half the stickleback caught were juveniles and half were adults; two distinct length classes were characteristic of most months (Table 20, Fig. 13). Juveniles (young-of-the-year) represented the smaller length classes and occurred almost entirely during the summer (Fig. 13), especially in the Cherry Point and Anacortes areas. Adult stickleback from previous years spawnings were the larger length classes and occurred primarily in the summer. Sixty-three percent of all adult fish caught during the study were stickleback.

Stickleback occurred in nearshore surface waters throughout the entire year and exhibited a definite seasonal pattern of abundance

Table 20. Seasonal distribution of threespine stickleback in the nearshore surface waters of northern Puget Sound, 1974-1976.

Season	Total all Life History Stages			Larvae			Juvenile			Adult		
	% Freq Occur.[1]	No.[2]	CPUE[3]	% Freq Occur.	No.	CPUE	% Freq Occur.	No.	CPUE	% Freq Occur.	No.	CPUE
Spring	62.8	2398	15.7	1.3	1	<0.1	1.3	2	<0.1	60.3	2395	15.7
Summer	74.7	11706	61.9	0	0	0	41.1	7926	41.9	70.5	3780	20.0
Fall	71.9	749	11.7	0	0	0	0	0	0	68.7	749	11.7
Winter	34.5	23	0.4	0	0	0	0	0	0	34.5	23	0.4
Total	65.4	14876[4]	32.1	<0.1	1	<0.1	17.1	7928	17.1	62.4	6947	14.8

[1]Percent frequency ofoccurrence in collections in each period

[2]Number of fish

[3]Number of fish caught/Number of 10-min capture attempts

[4]Plus 10 fish unstaged

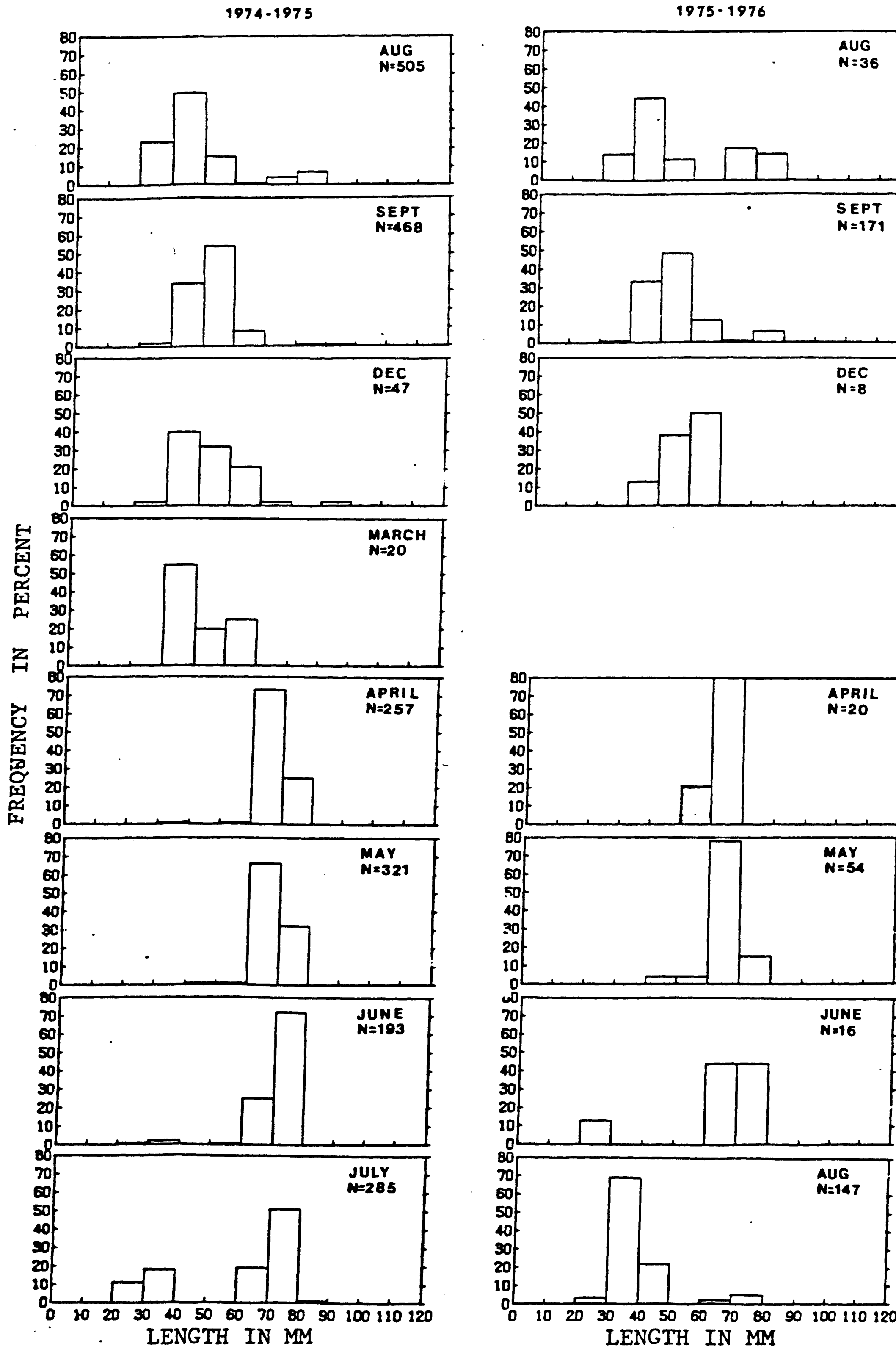


Fig. 13. Monthly length frequency of threespine stickleback in northern Puget Sound, 1974-1976.

(Table 21). This pattern was most pronounced during 1974-75 when the species was most abundant. Stickleback were scarce during the winter, when small, infrequent catches of adults occurred at several sites. Catches increased substantially in the spring as adults ranging from 60 mm to 80 mm TL were the dominant size class (Fig. 13 and Table 20). Catches remained high during the summer and were composed of both young-of-the-year juveniles and adults. By late fall, catches of stickleback were greatly reduced at all sites.

Stickleback occurred at all 15 sites and were usually the second or third most abundant and most dominant species at sites (Tables 4 and 8). The marked differences among sites that were characteristic of herring were not found for stickleback. Sites with the largest catches of stickleback were all in the Anacortes and Cherry Point areas, in particular Lummi Bay and Padilla Bay. Based upon CPUE and frequency of occurrence, three site groupings were characteristic. Lummi Bay and Padilla Bay comprised one group and had the highest CPUE values. Guemes South, Village Point, Shannon Point, Pt. Migley, Cherry Point, and Birch Bay represented a second group of sites with lower, more intermediate catches. The third group, composed of the five San Juan Island area sites, Burrows Island, and Guemes East, all had very low catches.

The majority of stickleback were caught in the Anacortes (40%) and the Cherry Point (57%) areas; only 3 percent of the stickleback were caught in the San Juan Island area. Threespine stickleback contributed the greatest percentage of the monthly catch in the Anacortes area followed to a lesser degree by the Cherry Point and San Juan Island areas (Fig. 14).

Table 21. Monthly townet CPUE of threespine stickleback in northern Puget Sound, 1974-1976.

Month	Pt. Migley	Burrows Is.	Pt. George	Cherry Pt.	Shannon Pt.	South Beach	Village Pt.	Guemes South	Deadman Bay	Birch Bay	Guemes East	Eagle Cove	Lummi Bay	Padilla Bay	Westcott Bay	Mean monthly CPUE
July 1974	48	7	0	752	91	1	138	98	0	106	3	--	207	68	2	108
August	69	33	0	125	19	1	38	284	1	30	75	--	127	511	1	94
September	170	72	0	9	291	1	246	41	0	219	5	--	401	187	28	119
December	1	0	0	5	0	2	1	--	2	4	1	4	3	1	3	2
February 1975	0	1	0	0	0	0	0	--	0	0	--	0	0	--	1	< 1
March	0	--	0	1	--	0	5	1	1	1	0	0	1	1	0	1
April	1	0	44	3	0	54	3	0	0	2	0	5	6	1	1	8
May	13	1	0	106	2	3	102	4	0	25	16	0	243	16	5	36
June	203	1	0	5	15	0	5	61	0	2	4	1	22	181	0	33
July	1	17	0	5	7	0	32	16	0	9	2	0	0	387	1	32
August	9	--	1	60	10	0	--	16	0	2	2	1	91	43	1	18
September	8	2	0	0	30	0	14	140	0	0	2	0	109	57	2	24
October	--	58	--	14	--	--	--	0	3	5	--	--	201	4	59	89
December	--	0	1	1	--	--	--	0	1	0	--	1	1	0	0	1
March 1976	--	0	0	--	--	--	--	1	--	--	--	--	--	--	0	< 1
April	--	2	0	0	--	0	--	6	0	1	--	0	2	3	0	1
May	--	2	0	16	--	0	--	2	2	3	--	0	1	0	2	2
June	--	0	0	0	--	0	--	0	0	7	--	0	7	0	1	1
August	--	2	--	2	--	0	--	12	0	3	--	0	206	60	0	30
Mean site CPUE	43	12	3	61	42	4	53	40	1	24	10	1	90	89	6	

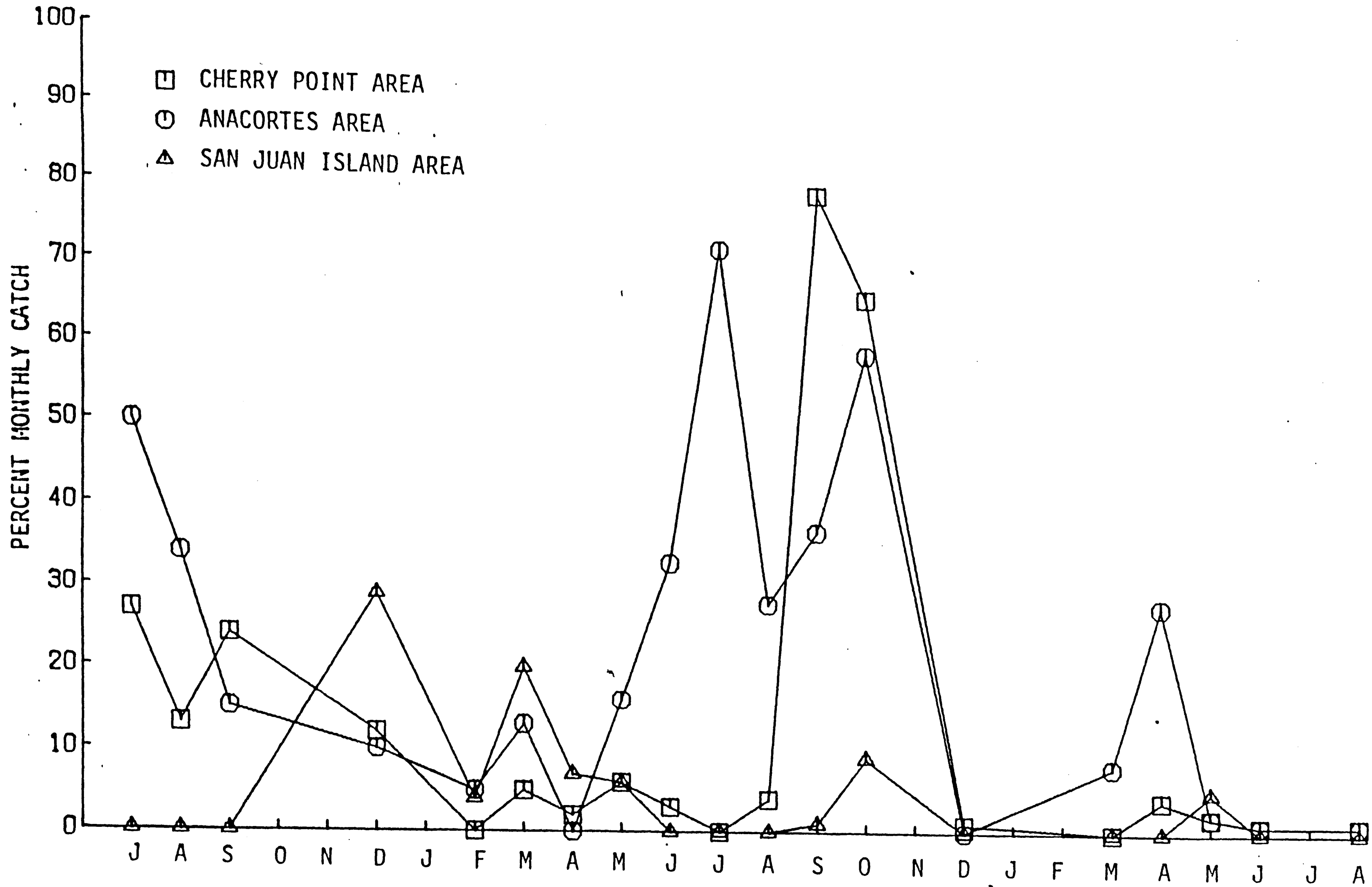


Fig. 14. Percentage of the total monthly catch in each geographic area comprised of threespine stickleback, 1974-1976.

A Kendall's correlation test of mean site CPUE of stickleback with mean site temperature was significant (τ=0.38, $p \leq 0.05$) as was mean CPUE with salinity (τ=-0.53, $p \leq 0.007$). No relationship was indicated between CPUE and dissolved oxygen ($p > 0.05$).

Surf Smelt. Surf smelt was the fourth most abundant and frequently occurring species (Table 7). Of the 2720 total surf smelt caught, 35 percent occurred during the first year and 65 percent the second year. Using a Wilcoxon test, the difference between the mean CPUE each year at the 15 sites was significant ($Z = -2.16$, $p \leq 0.05$). Most surf smelt were adults (Table 22), and surf smelt was one of the few species where adults were more abundant than juvenile or larval forms. Overall, 19 percent of all adult fish captured were surf smelt.

Unlike herring, sand lance, and stickleback, it was impossible to trace a year class throughout a year (Fig. 15). Larvae and young juvenile surf smelt typically occurred for several successive months before disappearing from collections. Bimodal length frequency distributions were common in several months.

A distinctive seasonal pattern in abundance of surf smelt was not clearly indicated, although the species was most numerous from late spring through early summer (Table 23). Large larval catches made surf smelt the most abundant species occurring in the winter. The majority of larvae were captured in March at Birch Bay, Cherry Point, Deadman Bay, and in April through June at Guemes South.

Most surf smelt were caught at Cherry Point area sites, in particular at Birch Bay and Cherry Point. Eighty-three percent of all surf smelt caught in the study came from these two sites, 74 percent from Birch Bay and 9 percent from Cherry Point.

Table 22. Seasonal distribution of surf smelt in the nearshore surface waters of northern Puget Sound, 1974-1976.

Season	Total all Life History Stages			Larvae			Juvenile			Adult		
	% Freq Occur.[1]	No.[2]	CPUE[3]	% Freq Occur.	No.	CPUE	% Freq Occur.	No.	CPUE	% Freq Occur.	No.	CPUE
Spring	38.5	1195	7.8	26.9	381	2.5	9.0	11	0.1	9.0	803	5.2
Summer	41.1	1282	6.8	0	0	0	10.5	63	0.3	37.9	1219	6.4
Fall	21.9	108	1.7	0	0	0	9.3	103	1.6	12.5	5	0.1
Winter	44.8	135	2.3	44.8	124	2.2	0	0	0	3.4	11	0.2
Total	38.0	2720	5.9	14.5	505	1.1	8.5	177	0.4	20.5	2038	4.4

[1]Percent frequency of occurrence in collections in each period.

[2]Number of fish.

[3]Number of fish caught/Number of 10-min capture attempts.

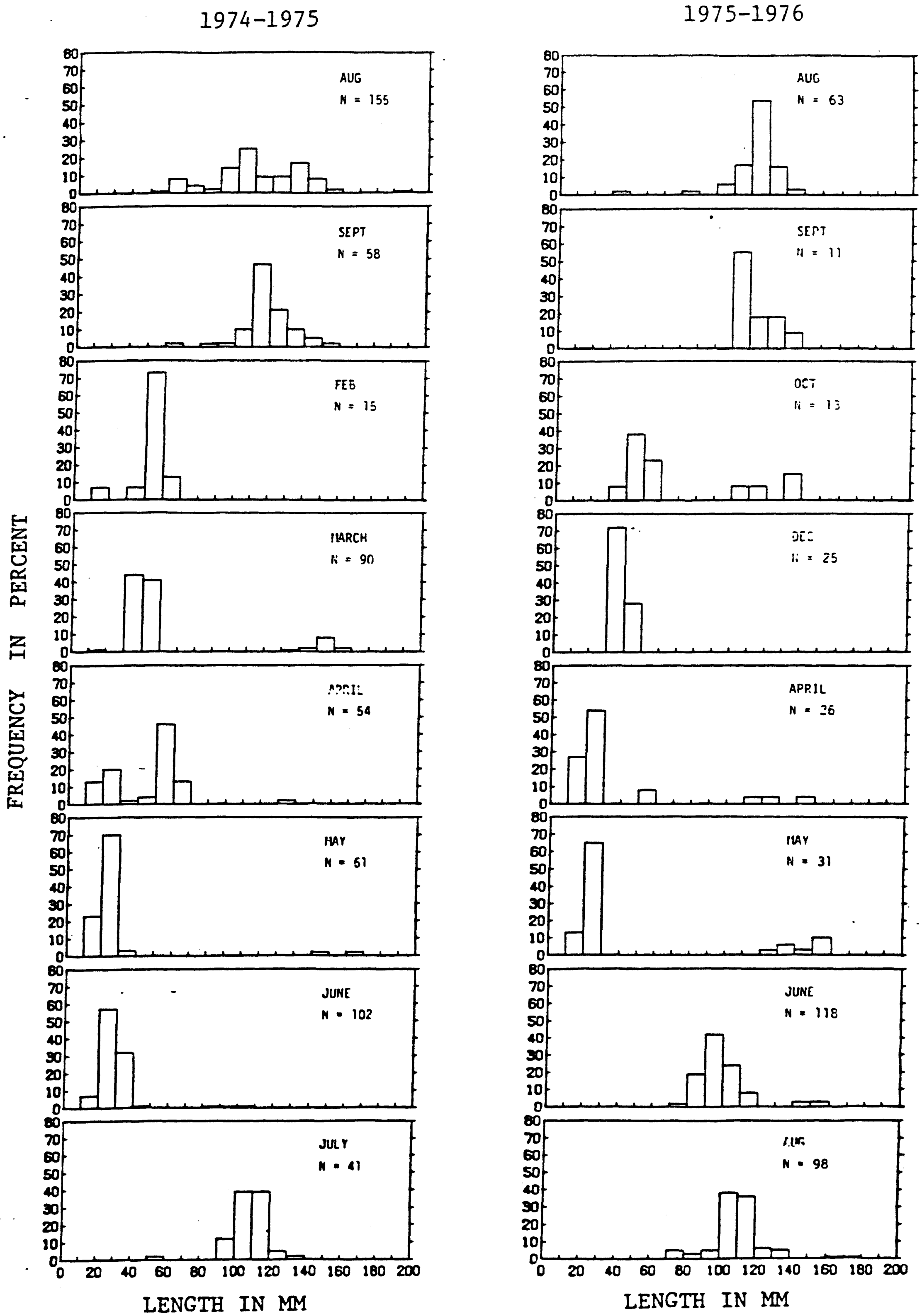


Fig. 15. Monthly length frequency of surf smelt in northern Puget Sound, 1974-1976.

Table 23. Monthly townet CPUE of surf smelt in northern Puget Sound, 1974-1976.

Month	Pt. Migley	Burrows Is.	Pt. George	Cherry Pt.	Shannon Pt.	South Beach	Village Pt.	Guemes South	Deadman Bay	Birch Bay	Guemes East	Eagle Cove	Lummi Bay	Padilla Bay	Westcott Bay	Mean monthly CPUE
July 1974	4	0	0	47	0	0	0	0	0	6	0	--	7	4	3	5
August	1	0	0	17	0	1	0	0	0	73	0	--	20	0	3	8
September	0	0	0	2	1	0	1	1	0	76	0	--	1	0	3	6
December	0	0	0	1	0	0	0	--	0	0	0	0	0	0	1	< 1
February 1975	0	1	0	1	0	0	2	--	0	5	--	0	0	--	0	1
March	1	--	0	6	0	2	0	0	7	41	1	3	1	1	0	5
April	12	0	0	2	1	0	3	9	0	0	1	0	0	0	3	2
May	0	0	0	0	0	0	0	25	0	1	0	0	0	5	0	2
June	5	1	0	8	0	1	0	10	0	3	22	0	18	12	0	5
July	0	1	0	18	1	0	0	0	0	2	0	0	0	0	0	1
August	0	--	0	4	0	0	--	0	0	178	0	0	0	3	3	14
September	0	0	0	0	1	0	0	1	0	0	0	0	1	4	1	1
October	--	0	--	0	--	--	--	0	1	2	--	--	3	0	1	1
December	--	0	0	0	--	--	--	0	0	47	--	0	0	0	0	5
March 1976	--	0	0	--	--	--	--	0	--	--	--	--	--	--	0	0
April	--	0	0	0	--	0	--	3	0	12	--	0	0	0	1	1
May	--	1	0	3	--	0	--	0	0	42	--	0	6	1	0	5
June	--	0	0	8	--	0	--	0	0	385	--	0	3	0	0	36
August	--	0	--	2	--	0	--	1	1	145	--	0	3	7	2	16
Mean site CPUE	2	< 1	0	7	< 1	< 1	1	2	1	57	2	< 1	4	2	1	

On the basis of a Kendall correlation test, mean site temperature and mean site CPUE were positively correlated ($\tau = +0.57$, $p \leq 0.01$) and CPUE and salinity were negatively correlated ($\tau = -0.49$, $p \leq 0.05$). No relationship was found between CPUE and dissolved oxygen.

Longfin Smelt. Of the 2361 total longfin smelt caught, 89 percent occurred in second year collections. The difference in the CPUE between the first and second year was signifigant ($Z = -3.2$, $p \leq 0.05$) by Wilcoxon signed rank test. Most longfin smelt were juveniles (Table 24); few larvae and adults were caught during the study (Fig. 16).

Longfin smelt occurred in nearshore surface waters in all 19 collection months (Table 25). Ninety-six percent were caught at three sites of dissimilar habitat in the Cherry Point area--Cherry Point, Birch Bay, and Lummi Bay. Four different collections occurring at these sites caught 77 percent of the total longfin smelt captured. In 82 collections in the San Juan Island area, one longfin smelt was captured.

Analysis of seasonal abundance patterns was complicated by the overall small catches and the occurrence of most longfin smelt in only a few collections. The greatest proportion was caught from late spring through fall.

Mean site CPUE of longfin smelt and temperature were signifigantly correlated ($\tau = +0.67$, $p \leq 0.01$) as was CPUE and salinity ($\tau = -0.72$, $p \leq 0.01$). No relationship was indicated between CPUE and dissolved oxygen.

Pacific Salmon. A total of five species of Pacific salmon were caught during the study; however, as sockeye were relatively rare, only chinook, coho, chum, and pink will be considered further.

The most abundant salmonid and tenth most abundant species overall was the chinook salmon (Table 7). Five hundred juvenile chinook, ranging

Table 24. Seasonal distribution of longfin smelt in the nearshore surface waters of northern Puget Sound, 1974-1976.

Season	Total all Life History Stages			Larvae			Juvenile			Adult		
	% Freq Occur.[1]	No.[2]	Catch CPUE[3]	% Freq Occur.	No.	Catch CPUE	% Freq Occur.	No.	Catch CPUE	% Freq Occur.	No.	Catch CPUE
Spring	26.9	1097	7.2	6.4	197	1.3	11.5	859	5.6	12.8	41	0.3
Summer	27.4	1129	6.0	0	0	0	17.9	986	5.2	16.8	143	0.8
Fall	37.5	132	2.1	0	0	0	25.0	123	1.9	12.5	9	0.1
Winter	6.9	3	0.1	0	0	0	6.9	3	0.1	0	0	0
Totals	26.5	2362	5.1	2.1	197	0.4	15.8	1971	4.2	12.8	193	0.4

[1] Percent frequency of occurrence in collections in each period

[2] Number of fish

[3] Number of fish caught/Number of 10-min capture attempts

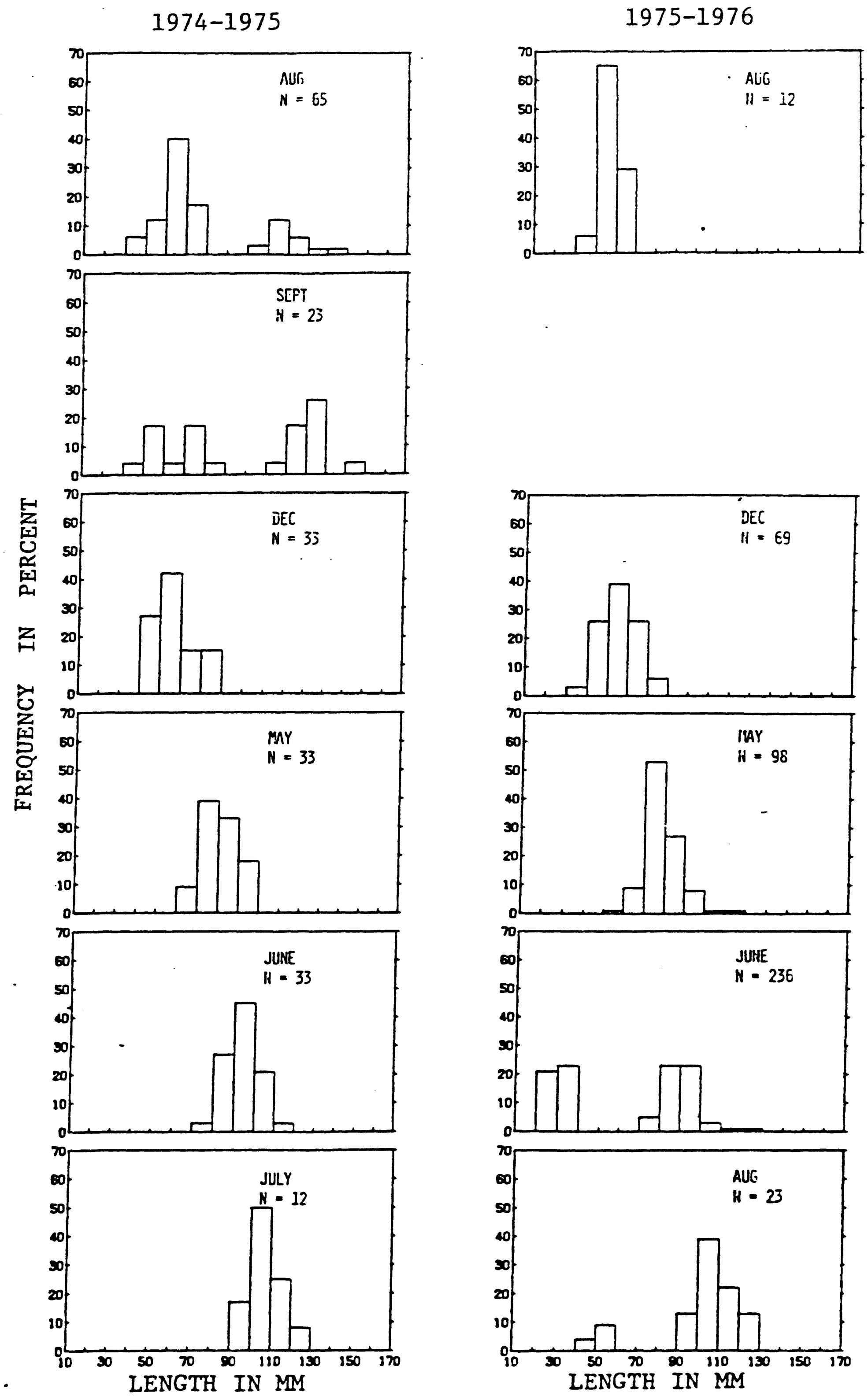


Fig. 16. Monthly length frequency of longfin smelt in northern Puget Sound, 1974-1976.

Table 25. Monthly townet CPUE of longfin smelt in northern Puget Sound, 1974-1976.

Month	Pt. Migley	Burrows Is.	Pt. George	Cherry Pt.	Shannon Pt.	South Beach	Village Pt.	Guemes South	Deadman Bay	Birch Bay	Guemes East	Eagle Cove	Lummi Bay	Padilla Bay	Westcott Bay	Mean monthly CPUE
July 1974	1	0	0	34	0	0	0	1	0	0	0	--	0	0	0	3
August	4	0	0	24	1	0	2	0	0	0	1	--	1	0	0	2
September	0	1	0	6	0	0	0	1	0	0	2	--	2	0	0	1
December	3	0	0	3	0	0	1	--	0	0	0	0	10	2	0	1
February 1975	0	0	0	0	1	0	0	--	0	0	--	0	0	--	0	< 1
March	0	--	0	0	--	0	0	0	0	0	0	0	1	0	0	< 1
April	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	< 1
May	0	0	0	4	0	0	0	0	0	9	0	0	6	0	0	1
June	2	0	0	12	0	0	0	0	0	1	1	0	2	0	0	1
July	1	0	0	5	0	0	1	0	0	0	0	0	3	0	0	1
August	0	--	0	451	0	0	--	0	0	0	0	0	10	0	0	35
September	0	0	0	2	0	0	0	0	0	0	0	0	1	0	0	< 1
October	--	0	--	1	--	--	--	0	0	0	--	--	2	1	0	< 1
December	--	0	0	1	--	--	--	0	1	9	--	0	35	1	0	5
March 1976	--	1	0	--	--	--	--	0	--	--	--	--	--	--	0	< 1
April	--	0	0	0	--	0	--	0	0	0	--	0	3	1	0	< 1
May	--	0	0	5	--	0	--	0	0	286	--	0	6	2	0	27
June	--	2	0	145	--	0	--	18	0	7	--	0	77	0	0	23
August	--	1	--	1	--	0	--	0	0	5	--	0	8	0	0	1
Mean site CPUE	1	< 1	0	39	< 1	0	< 1	1	< 1	18	< 1	0	9	< 1	0	

in lengths up to 190 mm TL ($\bar{x}$ = 126.3 mm) were caught, and all occurred from May through October with peak catches in July, August, and September (Table 26). Chinook salmon occurred at all sites except Eagle Cove, although most (94%) were collected in the Cherry Point and Anacortes areas (Table 27). CPUE of chinook was greatest at Padilla Bay, Birch Bay, and Cherry Point.

The second most abundant salmonid and the 14th most abundant species overall was the coho salmon; 202 coho were collected. Coho had a similar length frequency distribution to that of chinook salmon and had a slightly higher mean length, 132.4 mm TL. Coho salmon occurred in the nearshore surface waters longer than any salmonid (April until October) and peak abundance was between June and August. Like chinook salmon, coho occurred at all sites except Eagle Cove and were more abundant in the Cherry Point and Anacortes areas. CPUE of coho was highest at two cobble habitat sites, Shannon Point and Cherry Point, and a gravel site, Village Point (Table 27).

A total of 144 chum salmon were caught, most of which (78%) were collected during 1974-75. Lengths of chum salmon ranged up to 146 mm TL with a mean of 105.6 mm TL. Chum salmon were caught from April through September with peak abundances in June and July. Chum CPUE was similar in the three geographic areas, averaging between 0.30 in the Cherry Point area and 0.38 in the Anacortes area, and was greatest at two exposed sites, Shannon Point and Village Point.

Pink salmon was the fourth most abundant salmonid. Of the 127 pink salmon caught during the study, 82 percent were caught during 1975-76. The mean length of pink, 101.9 mm TL, was the smallest of the salmonids All pink salmon were caught between May and August with the largest

Table 26. Monthly CPUE of juvenile salmonids in the nearshore surface waters of northern Puget Sound, 1974-1976.

Month	Chinook Salmon			Coho salmon			Chum salmon			Pink salmon		
	Occur.[1] (%)	No.[2]	CPUE[3]	Occur. (%)	No.	CPUE	Occur. (%)	No.	CPUE	Occur. (%)	No.	CPUE
July 1974	78.6	69	2.46	50.0	20	0.71	50.0	74	2.64	57.1	16	0.57
August	78.6	76	2.71	21.4	5	0.18	28.6	7	0.25			
September	85.7	90	3.21	21.4	5	0.18	21.4	3	0.11			
December												
February 1975												
March												
April				6.7	2	0.07	6.7	1	0.03			
May				13.3	2	0.07	53.3	21	0.70			
June	6.7	5	0.17	46.7	69	2.27	6.7	1	0.03	20.0	7	0.23
July	60.0	104	3.47	33.3	27	0.90	20.0	3	0.10	46.7	34	1.13
August					36	1.38	30.8	6	0.23	7.8	2	0.08
September	33.3	11	0.37	6.7	1	0.03	13.3	2	0.07			
October	25.0	2	0.13	25.0	2	0.13						
December										12.5	1	0.06
March 1976												
April							10.0	1	0.05			
May	27.3	5	0.23	18.2	11	0.50	18.2	5	0.23	18.2	2	0.09
June	27.3	18	0.86	27.3	5	0.24	27.3	13	0.62	36.4	50	2.38
August	60.0	120	6.32	40.0	17	0.89	30.0	7	0.37	60.0	15	0.79
Totals	26.9	500	1.07	20.1	202	0.43	17.9	144	0.31	13.7	127	0.27

[1] Percent occurrence in the total collections made each month

[2] Number of fish

[3] Number of fish caught/Number of 10-min capture attempts

Table 27. Distribution of juvenile salmonids by site in the nearshore surface waters of northern Puget Sound, 1974-1976.

Site	Chinook salmon			Coho salmon			Chum salmon			Pink salmon		
	% Freq occur	No.	CPUE	% Freq occur	No.	CPUE	% Freq occur	No.	CPUE	% Freq occur	No.	CPUE
Pt. Migley	25.0	11	0.46	16.7	3	0.13	0	0	0	8.3	4	0.13
Cherry Pt.	33.3	92	2.56	33.3	41	1.11	27.7	8	0.22	22.2	11	0.30
Village Pt.	36.3	12	0.55	9.1	24	1.09	54.5	18	0.81	18.2	9	0.36
Birch Bay	38.9	94	2.61	38.9	22	0.61	5.6	1	0.01	5.6	1	0.01
Lummi Bay	38.9	54	1.50	44.4	24	0.67	22.2	19	0.53	11.1	35	0.97
Total	35.1	263	1.80	31.2	114	0.78	20.8	46	0.30	12.9	60	0.39
Burrows I.	36.8	62	1.88	11.8	9	0.26	11.8	17	0.51	17.6	14	0.42
Shannon Pt.	36.3	32	1.45	54.5	34	1.54	27.2	19	0.86	18.2	5	0.23
Guemes South	29.4	15	0.45	5.9	3	0.09	29.4	13	0.39	11.7	5	0.15
Guemes East	36.3	11	0.50	18.2	3	0.14	18.2	2	0.09	9.1	8	0.37
Padilla Bay	47.1	100	2.94	23.5	19	0.55	17.6	4	0.12	5.9	1	0.03
Total	38.3	220	1.53	20.5	68	0.47	20.5	55	0.38	12.3	33	0.23
Pt. George	11.7	4	0.12	5.9	5	0.15	23.5	25	0.73	17.6	8	0.24
South Beach	12.5	3	0.10	12.5	8	0.26	18.8	8	0.26	12.5	11	0.35
Deadman Bay	11.1	6	0.17	5.6	5	0.14	5.6	7	0.20	11.1	3	0.09
Eagle Cove	0	0	0	0	0	0	0	0	0	7.1	2	0.07
Westcott Bay	10.5	4	0.11	10.5	2	0.05	10.5	3	0.08	21.1	10	0.27
Total	9.5	17	0.10	9.5	20	0.14	13.1	43	0.26	14.3	34	0.20
Overall total	26.9	500	1.07	20.1	202	0.43	17.9	144	0.31	13.7	127	0.27

catches in June and July (Table 25). Pink salmon was the only salmonid that occurred at all 15 sites. Catches at all sites were typically small and CPUE in the three geographic areas was, like the chum salmon, very similar.

Twenty-Four-Hour Study

A total of 13,227 fish and 20 taxa (18 positively identified species and two family taxa) were caught during the 24-hour study at Lummi Bay, June 10-11, 1977 (Table 28). Of the 20 taxa, a maximum of 12 occurred in any single collection. The dominant taxa (herring and the unidentified osmerids) occurred consistently in most collections while the composition of the rarer taxa varied considerably from collection-to-collection. Nighttime catches averaged 1509 fish/tow and decreased steadily during the night whereas daytime catches were generally smaller, averaging 421 fish/tow, and varied considerable in the series.

Herring was the most abundant taxa and occurred in all tows and collections. Nighttime CPUE of herring was over 5 times greater than daytime CPUE. The osmerid taxa (probably surf smelt and longfin smelt) was the second most abundant taxa and, like herring, was relatively more abundant at night. Of other abundant taxa, the pleuronectidae were more abundant at night whereas surf smelt and stickleback were more numerous during the day.

The largest non-salmonid individuals generally occurred during the day whereas the largest salmonid individuals occurred in nighttime catches. The largest salmonid catches were of coho salmon and occurred during the first nighttime collection. Chum, while occurring in few numbers, occurred in a large number of collections, and chinook and pink were caught only sporadically.

Table 28. Diel distribution of fishes caught by townet at Lummi Bay, June 10-11, 1977. All values except those at 1345 are the mean of two tows. The values under 1345 are for one tow.

Taxa	LHS[1]	Time[2] D 2145	N 2345	N 0145	N 0345	D 0545	D 0945	D 1345	D 1745
River lamprey	A	1.0		1.5		0.5			
Spiny dogfish	J	0.5							
Pacific herring	L,J	32.5	1975.0	650.0	175.0	17.5	162.5	2.0	460.0
Pink salmon	J		0.5	1.0		1.0	1.5		
Chum salmon	J	1.5	1.0	1.0		2.0	1.5	2.5	1.5
Coho salmon	J	6.0	18.0	1.5			0.5		1.0
Chinook salmon	J		2.0			1.5			1.0
Steelhead trout	J					0.5		1.0	
Surf smelt	J,A					55.0	88.0	0.5	3.5
Longfin smelt	J,A	2.0	3.0		2.0				
Osmeridae	L	85.0	925.0	487.5	210.0	175.0	225.0		650.0
Threespine stickleback	J,A				1.0	5.0	5.0	11.0	40.0
Shiner perch	J	1.0							
Snake prickleback	J		3.0	1.0	0.5	0.5			
Penpoint gunnel	A		0.5						
Pacific sand lance	J	0.5	0.5		0.5	28.0			0.5
Pacific staghorn sculpin	J	0.5							
Tadpole sculpin	J,A			2.0		2.0			0.5
Starry flounder	A	0.5							
Pleuronectidae	L			40.0	25.0				
Total Overall CPUE		141.0	2928.5	1185.0	412.5	288.5	484.0	16.0	1158.0

[1] Life History Stage: L=Larvae, J= Juvenile, A=Adult.

[2] Time of Day: D= Day, N= Night.

Between Tow Variability

A salient feature of the data was the substantial variation that occurred between the two tows of the same collection. This study did not attempt to analyze between-tow variability, however, some observations can be made. Considerable differences between tows were noted periodically for most of the dominant species. At Pt. George in June 1976, the first of two tows yielded less than 40 fish while the following tow, less than 10 minutes later along about the same transect line, resulted in the capture of over 50,000 fish. Coefficients of Variation (CV) for overall CPUE between two tows were frequently as high as 142 percent. There was no definitive geographic or seasonal pattern to this variation although there was some indication that between-tow varibility was greater in the fall and winter than at other times of the year.

During the course of the 24-hr study, four tows were made within a one-hour period. Of the 13 taxa caught during the series, a maximum of 8 were caught in any single tow (Table 29). CV for overall CPUE, herring CPUE, and osmeridae CPUE were all greater than 100 percent for these four tows. During the series, the number of species captured remained relatively constant while the actual species composition (especially of rarer species) and relative abundances varied considerably.

Current was felt to be a variable that could have caused the observed between-tow differences. Using Wilcoxon signed rank tests, there were no significant differences ($p > 0.05$) between overall CPUE and number of species in tows with and against the current. Wilcoxon tests were also performed on herring CPUE data; again, no signifigant differences were noted.

Table 29. Study of the short-term variability in townet catches. The four hauls were made within a one hour period on June 11, 1977 at Lummi Bay.

Taxon	LHS[1]	Haul[2] 1	2	3	4
River lamprey	A				2
Pacific herring	L,J	3610	305	600	500
Pink salmon	J		1		3
Chum salmon	J		2		
Coho salmon	J	18	18	1	9
Chinook salmon	J		4	2	
Longfin smelt	J	6		4	12
Osmeridae	L	1400	450	500	400
Snake prickleback	J	5	1		1
Penpoint gunnel	A	1			
Pacific sand lance	J	1			1
Pacific staghorn sculpin	J			1	
Pleuronectidae	L			3	
Total Taxa		7	7	7	8
Total fish		5041	781	1111	928

[1]Life History Stage. L= Larvae, J= Juvenile, A= Adult.
[2]Values are the number of fish caught in a haul.

DISCUSSION

Sources of Variation and Sampling Bias

The analysis and interpretation of biological data collected by any type of sampling gear is greatly facilitated by an understanding of possible sources of variation and inherent limitations of the gear. While published information of this nature can be found for many types of sampling gear (e.g., Taylor 1953 - trawl, Barkley 1972 - towed net samplers, Pristas and Trent 1977 - gillnet), it is lacking for the townet.

The variable sized mesh of the townet has a limitation as to the size of an individual fish it can capture; this varies with species and sampling conditions. Nearly all the very small, planktonic larvae were caught in the finer meshed cod end which represented only about 5-10 percent of the effective fishing surface of the net. Thus, the abundance of the larvae of such species as herring, surf smelt, and soft sculpin was probably underestimated.

Large individuals were probably also undersampled because of their ability to avoid the net. The size where net avoidance becomes a factor is species specific and was not investigated as part of this study. Avoidance may partially explain the reduction in catches of mobile, schooling species, such as herring and salmon, in the fall.

The problem of net avoidance was further compounded by several uncontrollable factors including water turbidity, weather, moonlight, and bioluminescence. On several occasions, avoidance by large numbers of fish was observed in clear water and moonlight conditions. Sites in the Cherry Point and Anacortes areas were characterized by water conditions that would tend to decrease net visibility, whereas sites along the south-southwestern shore of the San Juan Islands had water conditions characteristic of high visibility and consequently high avoidance. As a result, some of the variations in catch among regions may be a function of greater net avoidance by fish in the San Juan Islands.

The volume of water strained probably directly influences the size of the catch, at least for some species and life history stages. The calm conditions and unbroken shoreline at some sites (e.g., Birch Bay and Westcott Bay) resulted in the net being fished at a maximum and constant spread on most tows. At other sites (e.g., Burrows Island and Deadman Bay), strong tidal currents, irregular shoreline, and large amounts of flotsam resulted in considerable variations in the volumes of water strained during each sample.

Tidal stage may also have influenced catches to some degree. Current direction and velocity, largely a function of tides, could influence how pelagic species orient themselves in the water column, and as a result may affect their relative catchabilities. The assumption was made that straining the same approximate volume of water by towing for 10 min with and against the current would yield more accurate results than making replicate tows in the same direction relative to the current. The tests done on current effects support this assumption, indicating no significant differences between tows with and against the current. It is possible, however, that current orientation is a species-specific phenomenon, or between-site variations may have masked any differences.

Another variable which may have influenced catches was the depth of water over which the tows occurred; this was a function of distance from shore that tows occurred. The horizontal zonations of species captured by the townet were not investigated as part of this study. Some species, particularly some demersal fishes, may be more closely associated with the shore than others; thus, transects in shallower areas close to shore would be expected to catch these species. Catches of many of the rarer species (that were mostly demersal) could be a function of this, especially in the bays. Other species, particularly the mobile schooling species, may range widely within the pelagic surface waters and occur a considerable distance offshore over deeper water.

The time of night when collections occurred no doubt influenced catches to some degree. Unfortunately, due to short summer nights, some tows unavoidably occurred at dusk or dawn. Because of their relative geographic locations and the resultant order in which they were collected, some sites were often sampled during twilight periods whereas others were sampled in the middle of the night. Species may change their relative vertical and horizontal positions in the water column during twilight periods. Hobson (1972), Domm and Domm (1973), and Major (1977), among others, have demonstrated the importance of twilight periods on behavioral changes in reef fishes. Species during twilight periods were found to change over from feeding to sheltering and vice versa. Moulton (1977), studying fishes inhabiting rocky nearshore areas in northern Puget Sound, indicated a number of large species were primarily active during crepuscular periods. If nearshore pelagic species exhibit similar behavior, tows during twilight periods may have caught fish that normally would not have been available during night collections.

The one source of variation that could be examined more closely was the short-term or between-tow variability of the two tows comprising a collection. Nearly all the variables previously discussed (e.g., tide, moonlight, etc.), with the possible exception of current and depth of water over which the tow occurred, would not vary greatly between two tows of the same collection. If the differences associated with currents are assumed insignificant (as the analysis indicated), much of the variability between tows would be a function of the distributions of fish. The large standard deviations relative to means (CV) thus reflect aggregated (or schooling) distributions of the dominant species in nearshore surface waters. An aggregated distribution may account for much of the spatial and temporal variability characteristic of this study.

This discussion of the sampling gear and design clearly indicates that there were many variables that were not controlled nor were experimentally evaluated. The sampling variability characteristic of townetting makes it difficult to separate the natural variability of the fish populations from that due to the gear and sampling design. However, because of the schooling behavior of the major species sampled, I feel much of the variability was probably biological variability rather than sampling bias. Thus, assuming the later statement is true, the townet represents a practical means of sampling nearshore pelagic fishes which, because of their mobility, require a fast, maneuverable net that samples a large area.

Species Composition

The nearshore surface waters of northern Puget Sound were numerically dominated by schooling species. Of these, herring, sand lance, and threespine stickleback, represented a small proportion of the total numbers of species present, but comprised the vast majority of individuals caught. Data collected from other areas in the Northeast Pacific Ocean have found that nearshore surface waters are usually dominated by only a few species. In the Strait of Juan de Fuca, Washington, Simenstad et al. (1977) found herring overwhelmingly the most abundant nearshore pelagic species. In several bays of Kodiak Island, Alaska, capelin (Mallotus villosus) was most abundant in townet catches (Harris and Hartt 1977). Townet samples from the Kiket Island region of Puget Sound were also dominated by only a few species (Stober and Salo 1973). In Bellingham Bay, Washington, threespine stickleback were 40 times more abundant than any other species in townet samples (Tyler 1964).

The dominance of the open, nearshore surface waters of northern Puget Sound by schooling species reflects the adaptations necessary to survive in this zone. Schooling may have evolved as a strategy to deal with an environment where there are few refuges from predators, few visual landmarks, and where the food supply is usually patchily distributed (Shaw 1978). One of the major advantages attributed to schooling is protection from predation (Brock and Riffenburgh 1960, Breder 1967, Eibl-Eibesfeldt 1970, Radakov 1973) since the school makes it difficult for a predator to focus on a single prey. Some other advantages that schooling provides include: enhanced reproductive opportunities, expeditiong of learning process, and a greater tolerance to toxic substances (Shaw 1978). Other adaptations species in the open near-shore surface zone employ are increased mobility, a more streamlined body shape (Breder 1967), and silvery coloration (Alexander 1974). Mobility may be important in lessening encounters with predators and increasing encounters with patchily distributed prey, although schooling may reduce foraging efficiency of schooling species unless the prey has a highly contagious distribution (Eggers 1976).

As vision is important in the maintenance of schools (e.g., Bowen 1931, Hemmings 1966, Shaw 1978), schooling would not be expected to be as great at night. Shaw (1978) mentions, however, that fish can form schools in very little light, as little as that provided by a full moon. Low catches of some species, particularly juvenile salmonids, may be due to diurnal schooling followed by nocturnal dispersal because of lack of visual cues. The diel study indicates several of the dominant nearshore species may be more abundant at night, possibly due to: 1) greater avoidance during the day; and/or 2)nocturnal inshore movements into nearshore surface waters.

The majority of species caught were more sedentary and bottom associated. Some occurrences of these species were undoubtedly related to the net being close to the bottom.

Larval and juvenile forms of most species were the predominant life history stages found; adult stages of most species occurred in small numbers. This suggests the importance of the nearshore pelagic environment as a nursery and rearing area.

Seasonal Patterns

Definite seasonal patterns in the abundance of nearshore pelagic fishes were indicated. During both years of the study, there was a marked increase in CPUE in early spring, primarily of larvae. This pulse indicated most larvae were spawned in late fall and winter and then became available to the gear with an increase in size. Many species were present in catches primarily as larvae in the spring, suggesting movements out of nearshore surface waters into other habitats with an increase in size.

In the late spring and summer, overall CPUE was highest at all sites, primarily due to catches of juvenile herring, sand lance, and threespine stickleback. Maximum differences among sites in CPUE and species composition occurred during late spring and summer. Temporal changes in overall CPUE were directly correlated with temperature at most sites. Temperature may affect species directly by controlling activities such as breeding and feeding, or indirectly by affecting food supplies.

In the fall, an emigration of species from the nearshore surface waters was indicated by a decline in CPUE and reduction in the number of species. It is possible that movements into other nearshore areas that were not sampled by this study and avoidance by the larger individuals accounted for some reduction in CPUE. The lack of sampling effort in the fall compounded analysis of fall migration patterns.

The winter fish fauna was very sparse, and I believe most individuals had probably left the sites. Sparse winter catches may be a function of fish seeking a less physically stressful environment. Due to an increase in exposure (from winter storms) and a decrease in temperature in nearshore surface waters, much of the nearshore environment probably becomes physically stressful to many species, hence prompting their movements to areas of lesser environmental extremes offshore. A reduction in food supply may also cause species to move into deeper water, similar to that observed for rockfish (Moulton 1977).

Changes in CPUE between months were often very pronounced; at times differences of two orders of magnitude occurred. This was especially true of changes occurring in the spring and fall. Because of the monthly sampling frequency, it was difficult to determine whether these changes in

CPUE were the result of actual fish movements in the nearshore zone or insufficient sampling of clustered (schooled) fishes.

The marked seasonal changes in CPUE of all species and the complete lack of some species during several seasons indicates that most species are not permanent residents in nearshore surface waters. Most of these species could be classified as temporary residents, occasional migrants, or temporal visitors, according to Kikuchi and Peres (1977).

Individual Species Accounts

Pacific Herring. Herring were caught by townet in northern Puget Sound throughout the entire year. Most herring caught during each year were young-of-the-year (larvae and juveniles); few fish over one year of age were collected and, even though extensive spawning occurs in the intertidal and shallow subtidal regions of northern Puget Sound, no sexually mature fish occurred. Thus, herring are temporary residents of nearshore surface waters and use nearshore surface water mainly as a nursery, as indicated by the large catches of juveniles.

The earliest herring collected were larvae caught in April (1975) in Westcott Bay and were probably recruits from the January-March spawning population known to occur in the San Juan Islands (Trumble et al. 1977). The wide spread in lengths in some months (e.g., June 1975) reflects the wide spawning period of herring in northern Puget Sound. In the study area, spawning has been documented from January through June (Trumble et al. 1977) and timing of spawning varies with area. Larvae and juveniles were caught in the greatest numbers at the Cherry Point area sites and reflect the sizable stock that spawns along the shores of Whatcom County, Washington, in April and May (Penttilla personal communication).

Herring spawn moderately large numbers of eggs (fecundity estimates of 9,000-38,000 eggs per female in British Columbia waters, Hart 1973), so the fact that less than 20,000 total herring larvae were caught was surprising, even taking into account the reduced fishing effectiveness of the net for larvae and the substantial mortality from the egg to larval stage. Washington State Department of Fisheries herring studies have also indicated a paucity of herring larvae in nearshore areas, particularly after large hatches on the Gulf of Georgia late-run spawning grounds (Penttilla and Aguero 1978, Penttilla personal communication). Townet catches of herring larvae of up to 10,000/tow in the spring in the Strait of Juan de Fuca (Fresh unpublished data) indicate that potentially the townet can catch more larvae than northern Puget Sound catches indicated. As herring larvae are planktonic (Stevenson 1962, Taylor 1964, Barraclough 1967b) and consequently subject to currents in an area, larvae may be transported out of areas sampled, possibly into open surface waters (such as the Strait of Georgia) as indicated from catches by Barraclough (1967b).

The marked increase in abundance of herring juveniles in the summer suggests a dispersal back into nearshore areas. Several sites with the largest summer catches of juveniles do not receive heavy spawning. Thus, herring rear in areas other than that where they were spawned. Hourston (1959) in Barkley Sound (Canada) found herring abundant in various protected bays, inlets, and channels and hypothesized that juvenile herring moved into areas that were more physically stable (less exposed). My largest catches of herring also came from sites associated with areas where exposure was minimal. As protected bays were typically the warmest sites in the summer, the signifigant correlation between mean-site herring CPUE and temperature may be a reflection of herring concentrating in certain size, sand lance move out of nearshore surface areas into other habitats characteristic of their complex life history (Hart 1973).

Threespine Stickleback. Stickleback appeared initially as adults in nearshore surface waters in April, primarily in the San Juan Island region. By May, few stickleback remained in the San Juan Island region, while catches at sites along the eastern shore of the mainland had increased substantially. This suggests a movement in spring of the stickleback from the San Juan Island region east to the mainland. It was impossible to determine the origin of the fish prior to their appearance in spring in the San Juan Island area. The stickleback may have wintered in: 1) offshore, open ocean areas as Andriashyev (1964) indicated for stickleback in Russian areas, 2) the Strait of Juan de Fuca; and/or 3) deeper, more offshore areas of Puget Sound.

Small young-of-the-year (~30 mm TL) first appeared in June and occurred in catches through September, suggesting spawning first occurred sometime in mid-spring and lasted through mid-summer. Andriashyev (1964), Wheeler (1969), and Wooton (1976) in their studies of stickleback also reported spawning from mid-spring through mid-summer. The location of northern Puget Sound spawning areas could not be determined from this study. Vrat (1949) indicated that poor egg development occurred in salt water, and Wooton (1976) reports that fish that overwinter in the sea spawn in brackish or freshwater. Thus, it is likely that spawning occurs close to salt water in freshwater or brackish estuaries and marshes such as those of the Nooksack River. Lack of suitable spawning habitat in the San Juan Islands may partly account for the scarcity of stickleback in the region. Large catches of juvenile stickleback in several eelgrass bays indicate these areas are of particular importance for rearing.

protected areas. Other factors such as food availability and predator avoidance also influence distribution.

Reduced fall catches of juveniles suggest a fall emigration from nearshore surface waters. Most of these juveniles may remain in northern Puget Sound until nearly two years of age before migrating out of the area (Penttilla personal communication). Avoidance by the larger individuals that occur in the fall may also partly account for reduced fall catches. A life history change to a more midwater habitat, reduced food supplies, as indicated for rockfish by Moulton (1977), increased exposure and decreased temperatures in nearshore areas may cause movements out of nearshore surface waters.

Pacific Sand Lance. Most sand lance were larvae and juveniles and occurred almost entirely in collections between April and July. The occurrence of large numbers of larvae initially in April suggests that spawning occurs during the winter. Locations of spawning areas are poorly understood and could not be determined in this study, although there is some indication (Fitch and Lavenberg 1975, Penttilla and Aguero 1978) that spawning takes place in shallow water. Catches of sand lance larvae in the Strait of Georgia by Barraclough (1967a) suggest that, like herring, sand lance are probably transported offshore in their planktonic state by prevailing currents.

Catches of juvenile sand lance were very large at sites associated with several protected, eelgrass bays. Like herring, sand lance may use these areas for rearing because of minimal exposure, food availability, and protection from predators.

By August, the rapid decrease in sand lance abundance indicates a rapid migration out of nearshore surface waters. With the onset of a

Salinity, exposure, and eelgrass are likely factors influencing stickleback distribution. Stickleback, particularly juveniles, were most abundant at protected sites of lower salinity with extensive eelgrass coverage. In the Strait of Juan de Fuca, Simenstad et al. (1977) found very few stickleback occurring in townet catches. Nearshore waters of the Strait of Juan de Fuca are highly exposed and eelgrass areas of reduced salinity are scarce, although numerous rivers where stickleback could possibly spawn do occur. This indicates the importance of eelgrass bays as nurseries for the juvenile stickleback until they emigrate in the fall.

By fall, a simultaneous reduction in adult and juvenile CPUE occurred. Adults finish spawning by fall and most probably move offshore to die (Andriashyev 1964), although some individuals may live and return to spawn for a second time (Wooton 1976).

Surf Smelt. Surf smelt spawn during most months of the year (Schaeffer 1936, Hart and McHugh 1944). February-April and October-December catches of larvae were primarily from Birch Bay and indicate winter and summer-fall spawning populations occurring in that area. Other larvae caught during the winter were from Deadman Bay, suggesting an as-yet undocumented spawning population somewhere in the San Juan Islands. May and June 1975 larval catches were from Guemes South and were probably from the spawning population occurring in the Fidalgo Bay area.

Larvae and small juveniles had largely disappeared from catches within a few months of their initial occurrence, suggesting extensive juvenile rearing does not occur in nearshore surface waters. Other areas, either inshore (Penttilla and Aguero 1978) or deeper (Stober and Salo 1973), may be used for rearing.

The occurrence of multiple and widely occurring spawning populations compounded the analysis of seasonal trends. However, the largest catches occurred in the summer and were primarily adults, most of sufficient size to spawn (Schaeffer 1936).

The nearshore surface distribution of surf smelt was primarily a function of proximity of spawning locations since catches of surf smelt (mostly adults) were much greater at sites close to known spawning grounds.

Longfin Smelt. Longfin smelt were probably more abundant in deeper areas, and hence were largely missed by the townet. Stober and Salo (1973) in Skagit Bay - Similik Bay found large numbers of osmerids (both longfin and surf smelts) occurring below the range of the townet. In addition, Dryfoos (1965) and Moulton (1970) utilized a midwater trawl rather than surface gear to collect longfin smelt in Lake Washington. Miller (personal communication) reports that bottom trawls in East Sound, Orcas Island, have often captured large numbers of longfin smelt.

Reproductive behavior may be important in determining the distribution of longfin smelt in nearshore surface waters. Longfin smelt are anadromous and spawn only in select streams in the Puget Sound region (Schultz and Chapman 1934, Dryfoos 1965). The majority of longfin smelt in my samples came from sites (Birch Bay, Cherry Point, and Lummi Bay) near the Nooksack River which is a known spawning ground (Schultz and Chapman 1934). Studies in the Strait of Juan de Fuca found most longfin smelt (juveniles and adults) occurred at sites close to particular rivers where they presumably spawn (Simenstad et al. 1977).

Adults and larvae were scarce in townet samples; juvenile was the major life history stage caught. Catches of juveniles were erratic, even at sites where they occurred frequently. The scarcity of larval longfin smelt indicates that they remain in the natal river or in the immediate vicinity of the estuary, as Hart and McHugh (1944) suggested. Low abundance of spawning longfin smelt suggest adults do not extensively use nearshore surface waters when migrating to spawning streams.

Pacific Salmon. Of the five species of juvenile salmon collected during the study, sockeye salmon was the rarest which was not surprising, since sockeye are known to move rapidly from the estuary to the offshore pelagic environment (Ricker 1966). Periodic inshore feeding movements may explain the occasional presence of sockeye in nearshore waters.

In areas closer to natal streams than my sites, Tyler (1964), Sjolseth (1969), and Stober and Salo (1973) reported earlier peak catches and smaller sizes of chum, pink, chinook, and coho. Juveniles initially concentrate in and around estuaries after entering salt water from freshwater streams before dispersing into other nearshore areas away from natal streams.

Differences in the relative spatial distributions of the juvenile salmonids were apparent. Pink and chum salmon had nearly equal CPUE in each of the three areas sampled, whereas chinook and coho were both more abundant in the Cherry Point and Anacortes areas. These differences suggest that the migratory paths of the salmon species through northern Puget Sound are different. However, since it was impossible to determine the origin of the fish, conclusions about migratory patterns are highly speculative. Unlike areas such as Hood Canal and southern Puget Sound, outmigrating juveniles can migrate along numerous routes through northern Puget Sound. Different routes may be followed depending on species, food supply, season, and other factors.

The larger catches of chinook and coho relative to pink and chum were somewhat surprising. Studies in other areas of Puget Sound have usually found the opposite to be true (Stober and Salo 1973, Schreiner 1977, Fresh et al. 1978). Location of my sites relative to spawning areas combined with life history differences of the salmonid species could result in differing availabilities to the gear and, consequently, account for much of the catch differences. Life history differences that could influence availability include: 1) Migratory behavior, 2) residence period in nearshore areas, 3) size and month of entry into salt water, and 4) food habits.

Analysis of salmonid data was complicated by the overall small numbers of fish that were caught. Catches of all salmonid species were usually less than five fish/tow. The small catches of salmon could be a result of: 1) Sampling frequency (sampling intensity of other salmonid studies has usually been greater--e.g., Wetherall 1971, Schreiner 1977); 2) location of sites away from natal streams; 3) sampling at night when the schools may have been dispersed (Iwamoto and Salo 1977); 4) a more inshore or offshore location of fish; 5) mobility and movement; and/or 6) patchy fry distribution. While small, the consistency of the salmon catches indicates that given the sampling design employed, these catches may reflect the relative abundances of the salmonids.

Habitat Associations of Nearshore Pelagic Fishes

An objective of this study was to investigate the associations of specific fish assemblages with specific, predetermined habitats. These habitats were determined primarily by beach and bottom substrate and degree of exposure.

Most species were relatively rare and do not represent a significant component of the nearshore pelagic fish assemblage. The dominant species did not appear to form specific fish assemblages associated with specific habitats. Instead, the principal species, especially, herring, sand lance and stickleback, were not confined to any particular habitat and were abundant over the entire spectrum of habitats. Although the absolute magnitude of catches varied site to site, the abundance and occurrence of a species relative to other species was remarkably consistent at sites, especially for the three most abundant species. Herring, stickleback, and sand lance usually ranked as the first to third in abundance, frequency of occurrence (BI value) over all sites (Table 30). Thus, these three species represent a very signifigant and constant part of the nearshore pelagic enviornment. The less abundant species--surf smelt, longfin smelt, tadpole and soft sculpin, staghorn sculpin, and the juvenile salmonids--exhibited similar trends in abundance. The dominant nearshore pelagic species appear capable of exploiting all or a signifigant portion of the nearshore surface region. It thus seems more appropriate to consider the entire nearshore surface enviornment as the habitat these species utilize.

Ranging over a wide area would be of advantage to these schooling species in avoiding predators and exploiting a pelagic food resource, indicated by feeding studies on the dominant fish species encountered in this study (Miller et al. 1977, Simenstad et al. 1977). It seems unlikely that bottom substrate type would be important to mobile, schooling species.

However, there were indications that there were preferred habitats for some of the species studied. Spawning behavior was responsible for

Table 30. Relative dominance (BI value) by site of the dominant species in nearshore surface waters. Letters represent the percent of the total BI value at a site (all species added) a species accounts for. (A≥ 30%, C= 20% to 29.9%, I= 10% to 19.9%, R≤ 10%)*

Species	Pt. Migley	Burrows Is.	Pt. George	Cherry Pt.	Shannon Pt.	South Beach	Village Pt.	Guemes South	Deadman Bay	Birch Bay	Guemes East	Eagle Cove	Lummi Bay	Padilla Bay	Westcott Bay
Pacific herring	C	A	A	A	C	C	C	C	A	C	A	A	A	C	A
Threespine stickleback	C	C	R	I	C	R	C	C	I	I	C	I	C	C	I
Pacific sand lance	I	I	C	R	I	C	I	I	I	R	R	I	R	I	I
Surf smelt	R	R	R	I	R	R	R	R	R	C	R	R	R	R	R
Longfin smelt	R	R	R	I	R	R	R	R	R	R	R	R	I	R	R
Tadpole sculpin	R	R	I	R	R	R	R	R	R	R	R	R	R	R	R
Soft sculpin	R	R	I	R	R	R	R	R	R	R	R	RR	R	R	R
Chinook salmon	R	I	R	R	R	R	R	R	R	R	R	R	R	R	R
Staghorn sculpin	R	R	R	I	R	R	R	R	R	R	R	R	R	R	R

* A= Abundant, C= Common, I= Infrequent, R= Rare

defining preferred areas for some species. Herring were abundant in the Cherry Point area because larger spawning populations of herring occur there than in other areas sampled. Stickleback were probably more abundant in the Cherry Point and Anacortes areas because of a lack of suitable spawning habitat in the San Juan Islands. Surf smelt and longfin smelt were also more abundant in the Cherry Point area because of proximity to spawning areas.

Most species were most abundant at sites near protected, eelgrass bays in all three geographic areas. The typically high catches of demersal species in eelgrass bays may be due to the uniform bottom characteristic of these sites and proximity of the net to the bottom. Numerous studies have noted the importance of eelgrass areas, and concluded that providing food and protection are among the important functions of this habitat. Reid (1954) found some of the highest population densities of fish in Flordia were associated with eelgrass beds which provided adequate food and protection. Thayer and Phillips (1977) noted the local and overall importance of seagrass areas, and concluded these areas provide habitat and protection for organisms associated with them. Phillips (1969) concluded that the ocean eelgrass system is one of the richest in variety and abundance of sea life. Briggs and O'Connor (1971) found that many species in Great South Bay, New York, preferred eelgrass vicinities to bare, sandy bottoms.

One reason for a lack of more definite habitat associations of nearshore pelagic fishes may be the habitat approach used in this study. Site selection probably resulted in some bias. In some habitat types, the habitat variables differed greatly among sites. Exposure and absolute area of the different sand/eelgrass sites varied greatly. Composition of the adjoining habitats at gravel sites varied markedly site to site; exposure varied substantially among the cobble habitat type sites. More accurate replication of sites of the same habitat among the three geographic areas could have resulted in reduced variations in species composition and numbers of fish caught. The within-habitat variation observed may be due to physical differences among the sites rather than attributable to species distributions.

Other problems resulted from the towing proceedure itself. The duration of a tow often resulted in sampling waters adjacent to several different habitats. For instance, at Deadman Bay (a gravel habitat), each tow sampled rocky/kelp bed, eelgrass, and gravel areas. Thus at sites such as this, it was impossible to seperate catches associated with the adjacent habitats from the type-habitat. Other biases may have been introduced from some of the previously mentioned problems.

Some Potential Impacts of Oil Pollution on Nearshore Pelagic Species

Predicting and assessing the impacts of oil pollution in the marine environment is made difficult by the many complex factors involved (Evans and Rice 1974). Straughan (1972) identified several factors that could influence the biological damage caused by an oil spill: 1) Type of oil spilled, 2) amount of oil involved, 3) physiography of the spill area, 4) weather conditions at the time of the spill, 5) biota of the area, 6) season of the spill, 7) previous exposure of the area to oil, 8) exposure to other pollutants, and 9) treatment of the spill. Thus, the impact of an oil spill on a particular area can vary tremendously, depending on the particular circumstances of the spill.

The nearshore surface zone of northern Puget Sound represents a critical habitat with respect to oil pollution since this area would receive immediate and direct effects. Oil would remain on the surface of the water after a spill releasing toxic chemicals which, because of the cold waters of northern Puget Sound, could be released over an extended period of time. Spilled oil could eventually be moved onto the shore by currents and wind.

Certain critical or sensitive life history stages such as eggs and larvae could be severely affected by an oil spill. Studies (primarily in the laboratory) have shown eggs and larvae of a number of fish species to be adversely affected by hydrocarbons (e.g., Kuhnhold 1972, Mironov 1972, Struhsaker et al. 1974, Hyland and Schneider 1976, Longwell 1977, Linden 1978). Impacts could be most severe on passively drifting planktonic stages and there may be synergistic effects with other factors. The larvae of many species (particularly herring, sand lance, and surf smelt) were common in northern Puget Sound surface waters, and if they are susceptible to hydrocarbons, as the above studies suggest, significant mortalities could result from exposure to oil.

Herring are of special concern, because they spawn in inshore areas where the dilution and evaporation potential is minimal, are planktonic in the larval stage, and are an important forage fish (Hart 1973). Depending on the amount of herring affected and the recovery abilities of the population, a significant impact on the herring populations of northern Puget Sound could result from an oil spill. Spills impacting the Whatcom County area would be especially damaging because of the sizable spawning stock that occurs in the area. As herring at all life history stages are a significant part of the diet of many marine species (Hart 1973), a substantial reduction in the availability of herring as prey would cause switching to other, possibly less energetically useful, prey. Whether this would reduce the survival of other species is largely speculative, although Hyland and Schneider (1976) suggest removal or reduction of an important component such as herring could destabilize an ecosystem. Since herring are an important commercial resource in Washington, economic impacts could also result from a reduction in herring stocks or tainting of commercial herring produces (Nelson-Smith 1972, Clark 1976).

Other particularly sensitive stages of fish to oil pollution effects include fish that are already stressed, especially physiologically such as during spawning. In northern Puget Sound, many species, notably herring, salmon, surf smelt, longfin smelt, and stickleback, utilize nearshore areas for reproductive purposes. In a reproductive condition, these species are exposed to both environmental and reproductive stresses. This is especially true for the anadromous species (salmon, longfin smelt, and stickleback) which move from salt to fresh water to spawn. As Struhsaker (1977) indicated for herring, oil could seriously affect spawning fish in addition to becoming incorporated into gonads and reducing gametic, embryonic, and larval survival. Local breeding populations of these and other species which spawn in small areas would be greatly threatened by an oil spill during the spawning season.

Even though direct kills from oil could result from coating or contact with the toxic fractions (Blumer 1972), mobility of the dominant species would probably allow them to avoid a spill area. However, serious, sublethal effects could occur as a result of avoidance of the spill. Movements out of normal habitats and areas could expose fish to increased levels of predation or require the exploitation of sub-optimal habitats and food supplies. Rice (1973 - cited in Hyland and Schneider 1976) suggested that even though pink salmon fry could possibly detect and avoid oil-contaminated areas, confused or non-adaptive migratory behavior could be the result. By being forced to move offshore when still small, pink fry could be subject to increased predation pressures that would increase mortality during the early marine phase. While data are lacking for other salmonids, the same pattern may also be true. Adult salmonids passing through estuaries to spawn may not be able to avoid oil-contaminated areas. Direct mortality or severe stress could result in reduced adult survival and poor spawning. Serious impacts on the commercially important salmon species would result in serious economic loss to Washington State.

Juvenile rearing, particularly in protected eelgrass bays, was found to be a major use of the nearshore surface environments. Several studies indicate juvenile stages may be especially susceptible to pollution effects (Nelson-Smith 1972, Blumer 1972, Neff et al. 1976). An oil spill may force juveniles out of optimal nursery areas into other less desirable areas where survival may be reduced.

In addition to killing fish directly and causing forced migration of species out of optimal areas, oil pollution could alter numerous ecological processes such as predation, migration, and sex attraction by disrupting or blocking chemical cues. Numerous aspects of the life histories of many species that are dependent upon chemical agents (Kittredge et al. 1973) may be blocked or mimicked by oil (Blumer 1972). This could be especially important to migrating adult salmon that depend on chemical cues during parts of their spawning migrations.

Because hydrocarbons have been shown to be directly ingested and retained by marine organisms (Blumer 1972, Teal 1977, Lee 1977), accumulation and spread through the marine food web may result (Blumer 1972, Hyland and Schneider 1976) and eventually could result in toxic levels (Blumer 1972, Evans and Rice 1974). Prey population levels may also be depleted and force switching by predators to other prey.

The result of a serious oil spill viewed over a long time span could be a significant alteration of the structure of the nearshore pelagic fish assemblages. Species that are able to tolerate the stress from oil may dominate as other more sensitive species experience significant mortality. In a temperate area such as northern Puget Sound where recruitment is mostly seasonal, entire year classes could be affected. Thus, periods of the year when spawning occur and when larvae are present in the plankton (mostly winter to early summer) are especially critical periods. Spills in the fall may be least detrimental, especially if salmon have already moved upstream.

Recovery of a spill area will depend largely on the adaptability and tolerance of the organisms affected. Nearshore pelagic species, because they exploit a more general habitat, may adapt better than other species which have more precise habitat requirements. Fish that are stationary, territorial, or have definite home ranges would be disadvantaged.

SUMMARY

1. A townet was used to sample fish occurring in the nearshore surface waters of northern Puget Sound between July 1974 and August 1976. Five sites, each representing a different habitat type (defined by substrate type and exposure), were sampled in each of three distinct, geographic areas. Nineteen different cruises were made on an approximately monthly (spring, summer) and bimonthly (fall, winter) schedule.

2. Of the 71 total species captured, schooling species, particularly juvenile Pacific herring, juvenile sand lance, and juvenile and adult threespine stickleback, numerically dominated catches at all sites. The six most abundant species (herring, sand lance, stickleback, surf smelt, longfin smelt, and tadpole sculpin) comprised 98 percent of the total catch.

3. Nearshore surface areas were utilized as nursery and rearing areas by many species; mainly juvenile fish were caught throughout the entire year. Larval stages were caught abundantly in the spring. Few large fish were caught, perhaps because of avoidance.

4. Distinct seasonal patterns in overall CPUE and numbers of species occurred. Mean CPUE and numbers of species were lowest during the winter at all sites and increased in the spring. Larval stages predominated in catches in the spring. The greatest numbers of species and CPUE levels occurred during the summer; catches then decreased rapidly in the fall to low winter levels.

5. Most of the dominant schooling species were caught at all but a few of the sites. San Juan Island area sites had fewer species than Anacortes and Cherry Point area sites. Seasonal abundance of most species was usually greater in the Cherry Point area. In general, catches of most species were greatest in the Cherry Point area and in protected eelgrass bays. Exposed sites and habitat types had fewer species and smaller catches than protected sites and habitats.

6. Seasonal trends were consistent between the two years; however, the magnitude of catches varied. In general, the rankings of the most abundant species were the same each year.

7. Pacific herring was the most abundant and frequently occurring species. Most herring were juveniles ranging in length between 40 mm and 100 mm TL and occurred in late spring and summer. Catches were greatest at protected eelgrass bays and in the Cherry Point area.

8. Pacific sand lance was overall the second most abundant fish caught. Sand lance occurred primarily as young-of-the-year larvae and juveniles in the spring and summer and were almost totally absent from fall and winter catches. Most sand lance were caught in the San Juan Island area, in particular at one site, Pt. George.

9. Threespine stickleback occurred as juveniles and adults primarily in the Cherry Point and Anacortes areas. Juveniles were young-of-the-year whereas adults were from previous year classes.

10. Catches of surf smelt were greatest from late spring through early summer; however, surf smelt was the most abundant species caught during

the winter. The majority of surf melt were caught in the Cherry Point geographic study area. Several different spawning populations were indicated.

11. Cherry Point area sites yielded the greatest catches of longfin smelt, which were probably from the Nooksack River. Most longfin smelt were caught in only a few tows, making analysis of seasonal trends diffucult. Few larvae and adults were captured; most longfin smelt were immature juveniles.

12. Five species of Pacific salmon occurred in northern Puget Sound townet catches. Chinook salmon was the most abundant salmonid followed by coho, chum, pink, and sockeye salmon. Chinook and coho catches were highest in the Cherry Point and Anacortes area and chum and pink were caught in relatively even numbers in all three areas.

13. There were numerous variables in townetting that were not controlled nor were experimentally evaluated. However, it was concluded that the townet represents a practical means to sample pelagic fishes.

14. The dominant nearshore pelagic species were present in the various nearshore habitats of northern Puget Sound, with little evidence of distinct assemblages occurring in different habitats; instead, the entire nearshore surface zone is probably exploited as a single habitat.

15. Impacts of an oil spill on northern Puget Sound nearshore fish species will depend on may factors such as season of spill, prevailing weather conditions, and actual spill area. The occurrence of economically

important species (herring, salmon, surf smelt) and important forage fishes (herring, sand lance) indicate oil impacts could be severe if they occur during critical periods (e.g., spawning). Protected eelgrass bays are critical areas because of the use by numerous juvenile stages of these bays as rearing areas.

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APPENDIX I

List of Species Caught During the
First and Second Year of
Sampling

Appendix Table Ia. Species of fish captured by townet during the first year, July 1974–June 1975.

Species	Common Name	LHS[1]	Number of occurrences	Abundance
Entosphenus tridentatus	Pacific lamprey	J	1	3
Lampetra ayresi	river lamprey	J	3	3
Squalus acanthias	spiny dogfish	J,A	13	30
Hydrolagus colliei	ratfish	J	1	1
Clupea harengus pallasi	Pacific herring	L,J	100	129,649
Engraulis mordax	northern anchovy	L,J,A	7	31
Oncorhynchus gorbuscha	pink salmon	J	9	23
O. keta	chum salmon	J	22	107
O. kisutch	coho salmon	J	24	102
O. nerka	sockeye salmon	J	5	29
O. tshawytscha	chinook salmon	J	31	240
Hypomesus pretiosus	surf smelt	L,J,A	53	940
Spirinchus thaleichthys	longfin smelt	L,J,A	31	269
Stenobrachius leucopsarus	northern lampfish	J	1	1
Porichthys notatus	plainfin midshipman	J	1	1
Microgadus proximus	Pacific tomcod	J,A	8	290
Lycodopsis pacifica	blackbelly eelpout	J	4	22
Aulorhynchus flavidus	tube-snout	J,A	8	58
Gasterosteus aculeatus	threespine stickleback	J,A	90	11,360
Syngnathus griseolineatus	bay pipefish	J,A	11	24
Cymatogaster aggregata	shiner perch	J,A	14	877
Embiotoca lateralis	striped seaperch	J	1	1
Rhacochilus vacca	pile perch	J	1	16
Trichodon trichodon	Pacific sandfish	J,A	4	7
Lumpenus sagitta	snake prickleback	J,A	16	100
Poroclinus rothrocki	whitebarred prickleback	A	1	1
Apodichthys flavidus	penpoint gunnel	J	1	2
Pholis clemensi	longfin gunnel	A	1	3
P. laeta	crescent gunnel	A	14	30
P. ornata	saddleback gunnel	J,A	16	22
Lyconectes aleutensis	dwarf wrymouth	L	4	23
Ammodytes hexapterus	Pacific sand lance	L,J,A	66	9,918
Clevelandia ios	arrow goby	A	1	1
Lepidogobius lepidus	bay goby	L	4	15

Appendix Table Ib. Species of fish captured by townet during the second year, July 1975-August 1976.

Species	Common Name	LHS[1]	Number of occurrences	Abundance
Lampetra ayresi	river lamprey	J,A	2	2
Squalus acanthias	spiny dogfish	J,A	12	59
Clupea harengus pallasi	Pacific herring	L,J	82	199,953
Engraulis mordax	northern anchovy	J,A	20	176
Oncorhynchus gorbuscha	pink salmon	J	23	104
O. keta	chum salmon	J	20	37
O. kisutch	coho salmon	J,A	23	100
O. nerka	sockeye salmon	J	3	29
O. tshawytscha	chinook salmon	J	32	260
Hypomesus pretiosus	surf smelt	L,J,A	36	1,780
Mallotus villosus	capelin	J	1	1
Spirinchus thaleichthys	longfin smelt	L,J,A	31	2,092
Thaleichthys pacificus	eulachon	A	1	1
Porichthys notatus	plainfin midshipman	J	3	11
Microgadus proximus	Pacific tomcod	J	10	372
Theragra chalcogramma	walleye pollock	J	15	74
Aulorhynchus flavidus	tubesnout	J,A	7	16
Gasterosteus aculeatus	threespine stickleback	J,A	63	3,525
Syngnathus griseolineatus	bay pipefish	J,A	8	34
Cymatogaster aggregata	shiner perch	J,A	13	190
Embiotoca lateralis	striped seaperch	J	1	1
Trichodon trichodon	Pacific sandfish	J,A	6	17
Lumpenus maculatus	daubed shanny	A	1	2
L. sagitta	snake prickleback	J,A	19	605
Plectobranchus evides	bluebarred prickleback	J	1	1
Apodichthys flavidus	penpoint gunnel	J	1	1
Pholis laeta	crescent gunnel	J,A	7	8
P. ornata	saddleback gunnel	J	11	15
Ammodytes hexapterus	Pacific sandlance	L,J,A	51	28,707
Clevelandia ios	arrow goby	A	1	1
Lepidogobius lepidus	bay goby	A	3	3
Ophiodon elongatus	lingcod	J	2	3
Blepsias cirrhosus	silverspotted sculpin	J,A	6	10
Gilbertidia sigalutes	soft sculpin	L,J,A	16	189

Appendix Table Ib. Species of fish captured by townet during the second year, July 1975-August 1976. (Continued)

Species	Common Name	LHS[1]	Number of occurrences	Abundance
Hemilepidotus hemilepidotus	red Irish lord	A	1	1
Leptocottus armatus	Pacific staghorn sculpin	J,A	30	149
Psychrolutes paradoxus	tadpole sculpin	J,A	18	383
Rhamphocottus richardsoni	grunt sculpin	L,J	4	8
Agonus acipenserinus	sturgeon poacher	J	3	3
Asterotheca alascana	gray starsnout	J	1	1
Pallasina barbata	tubenose poacher	J	4	5
Eumicrotremus orbis	Pacific spiny lumpsucker	A	3	4
Liparis florae	tidepool snailfish	J	1	1
L. fucensis	slipskin snailfish	J	1	2
Lepidopsetta bilineata	rock sole	J	1	1
Parophrys vetulus	English sole	J	7	58
Platichthys stellatus	starry flounder	J,A	8	42
Unidentified				113
Total: 47 species in 108 total collections				239,150

[1]LHS= Life History Stage: L= Larvae, J= Juvenile, A= Adult