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State of Washington
DEPARTMENT OF FISHERIES

# PROGRESS REPORT
No. 145

## Food Habits of Pacific Salmon, Baitfish, And Their Potential Competitors and Predators In the Marine Waters of Washington, August 1978 to September 1979


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Rick D. Cardwell
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August 1981

This project partially supported by grants from Pacific Northwest Regional Commission and National Marine Fisheries Service with funds from the Anadromous Fish Conservation Act

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# FOOD HABITS OF PACIFIC SALMON, BAITFISH, AND THEIR POTENTIAL COMPETITORS AND PREDATORS IN THE MARINE WATERS OF WASHINGTON, AUGUST 1978 TO SEPTEMBER 1979[1/]

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ABSTRACT

During the first segment of a multi-year project, the feeding ecology and trophic interactions of salmon, baitfish, and other selected species of Puget Sound marine fish were studied between August 1978 and September 1979. Pelagic zooplankton occurring in nearshore surface waters of Puget Sound were sampled to compare with the prey consumed by fish occurring in nearshore habitats. Food habits of subadult and adult chinook and coho salmon from the Pacific Ocean near the mouth of the Columbia River were also studied. We employed sampling techniques (beach seine, townet, purse seine, and hook-and-line) that have been proven effective in capturing salmon and baitfish from habitats they utilize during their ontogeny in Puget Sound.

The contents of 3,813 (2,838 full and 975 empty) stomachs from 24 species of fish were analyzed. Calanoid copepods, euphausiids, brachyuran crab larvae, insects, larvacea, and gammarid and hyperiid amphipods were the primary food items of juvenile salmon and baitfish occupying shallow sublittoral and nearshore pelagic habitats ( $<20$ m in depth). The diets of juvenile ( $<150$ mm in length) chum salmon, herring, sand lance, and surf smelt in these habitats were similar, comprising mostly smaller invertebrates such as harpacticoid and cyclopoid copepods, and suggesting these species may compete for food. The prey spectra of juvenile chinook and coho salmon ($<200$ mm) from sublittoral and nearshore pelagic habitats were similar, comprising mostly large crustaceans such as brachyuran crab larvae, and suggesting competition between chinook and coho salmon juveniles in these habitats. Diets of larger coho salmon ( $\geq 200$ mm) and herring ($\geq 150$ mm) caught in more offshore pelagic habitats ( $\geq 20$ m in depth) of Puget Sound were primarily larger crustaceans (euphausiids, amphipods, and brachyurans) whereas larger ( $\geq 200$ mm) chinook mainly ate fish (mostly herring). Chinook in this habitat likely would compete with other piscivorous species such as pollock and hake. On the other hand, coho and herring may compete in this habitat because of their emphasis on similar invertebrate prey.

Subadult and adult chinook and coho salmon from the Pacific Ocean near the mouth of the Columbia River ate mostly fish (northern anchovy and whitebait smelt).

Four species of fish, all salmonids, consumed juvenile salmon although rates of predation were relatively low. However, the implication of these low predation rates cannot be established without knowledge of the size of predator standing stocks and consumption rates.

Brachyuran larvae, calanoid copepods, barnacle larvae, and hydrozoans were the dominant nearshore, pelagic zooplankters. The diet of juvenile herring was the most similar to zooplankton occurring in nearshore surface waters whereas the diet of juvenile chinook was least similar.

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# INTRODUCTION

The consequences of trophic interactions on the production of Pacific salmon (Oncorhynchus spp.) have recently begun to occupy the attention of management agencies. Such factors as food limitation, competition, and predation involving salmon and other marine fish, especially baitfish species such as Pacific herring (Clupea harengus pallasi), Pacific sand lance (Ammodytes hexapterus), and surf smelt (Hypomesus pretiosus), may significantly influence the growth and survival of salmon (e.g., Gonsolus, 1978; Healey, 1979; Simenstad et al., 1980; Walters et al., 1978). Some of our proposed and ongoing salmon enhancement programs could, through inappropriate species mixtures, release schedules, etc., inadvertently exacerabate the consequences of deleterious trophic interactions and thus reduce our ability to produce these fish. Our understanding of food-web relationships in the ecological communities that salmon reside in, is presently incomplete. Clearly, a better understanding of trophic relationships is required so that factors identified as limiting salmon production can be incorporated into fishery management plans and models to help maximize salmon production (e.g., Johnson, 1974, 1977).

The Washington State Department of Fisheries (WDF) initiated the "Salmon-Herring Predator/Competitor Interactions Project" to address these fundamental concerns. Objectives of this multi-year project are to characterize the feeding ecology and trophic relationships of salmon, baitfish, and other selected species of Puget Sound fish. Results of Phase I of the project (occurring from August 1978 to June 1979 and funded by the Pacific Northwest Regional Commission) have been presented in Fresh and Cardwell (1979). This report includes an expanded version of those results in addition to results of Phase II studies occurring between July and September 1979 (funded by the National Marine Fisheries Service). Results, interpretations, and conclusions presented in this interim report are preliminary and subject to revision when the data from the whole multiyear project are analyzed.

Objectives of this phase of the project were to: (1) assess the food habits of chinook (O. tshawytscha), coho (O. kisutch), and chum (O. keta) salmon in Puget Sound and of subadult[1/] and adult chinook and coho in the nearshore Pacific Ocean area near the mouth of the Columbia River;

[1/] Subadult salmon are considered those greater than 200 mm Fork Length that are sexually immature.

(2) determine the food habits of herring, other baitfish and selected species of marine fish that may be competitors or predators of salmon and herring; (3) define competition and predation of the species studied; and (4) compare food of salmon and herring that occur in nearshore (< 20 m in depth) habitats to the available nearshore surface pelagic zooplankton.

## MATERIALS AND METHODS

### Study Areas

In Puget Sound, stomach samples for food habits analysis of salmon, baitfish, and other species came from two regions: Central Puget Sound (CPS) (Possession Point to the Tacoma Narrows) and Southern Puget Sound (SPS) (south of the Tacoma Narrows) (Fig. 1). These two regions were compared because: (1) oceanographic conditions may vary between areas and consequently produce different feeding conditions; and (2) they are the first marine areas encountered by juvenile salmon from major enhancement programs. South Puget Sound is the focus of a significant part of the state's recent salmon enhancement efforts. Much of the emphasis will be on increasing production of chum salmon, a species whose culture historically has been subordinate to chinook and coho (Fig. 2).

To study whether predation in the Pacific Ocean off the mouth of the Columbia River might be limiting the production of coho from the Columbia River, stomachs from subadult and adult chinook and coho salmon were obtained from the charter boat fishery of Ilwaco, Washington (this was the only collection of specimens outside Puget Sound).

### Study Sites

Most sampling sites in SPS were located near Anderson Island whereas those in CPS were primarily near Bainbridge Island (Figure 1). We attempted to select sites that were similar with respect to such variables as habitat type, beach and bottom substrate, exposure, and composition of adjoining habitats.

### Sampling Techniques

We utilized sampling techniques that have proven efficient in collecting salmon and baitfish from habitats they utilize during their ontogeny in Puget Sound (Bax et al., 1979; Cardwell et al., 1978; Fresh et al., 1979; Healey, 1978; Miller et al., 1977). Many specimens were collected as part

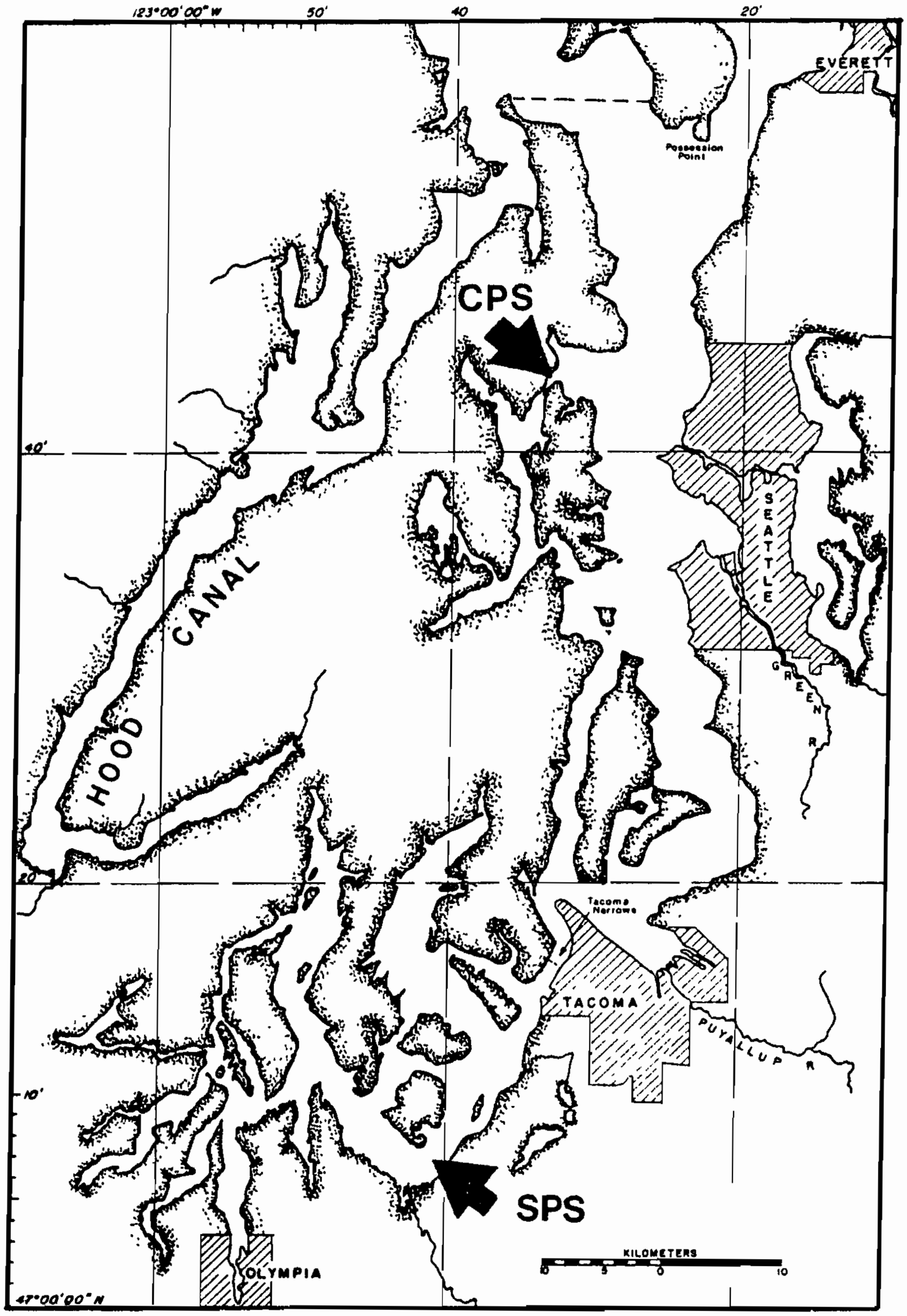


Fig. 1. Map of the Puget Sound study area showing general location of CPS and SPS sampling sites (large arrows).

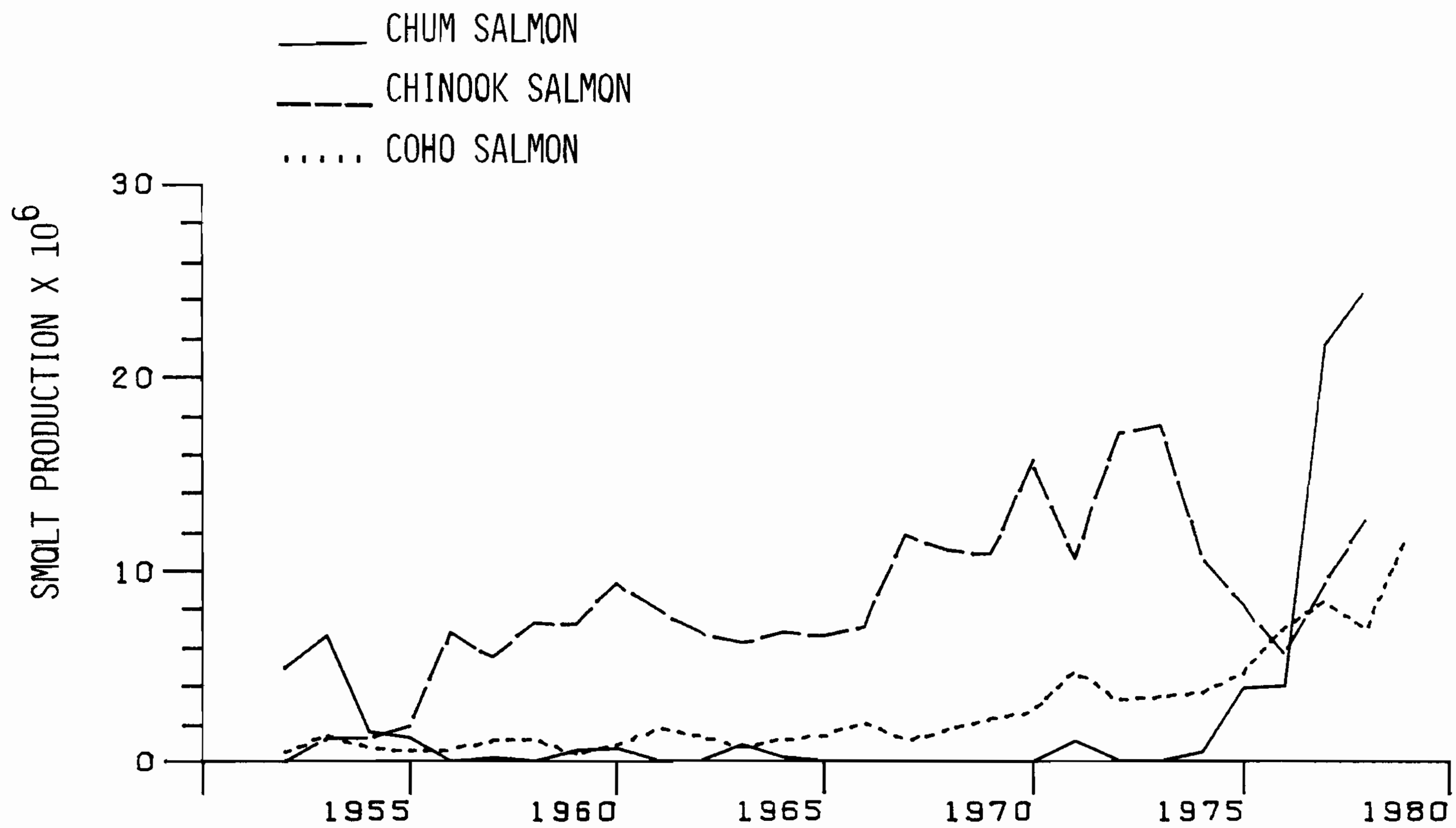


Fig. 2. Releases of chum, chinook, and coho salmon from hatcheries, pens, and egg incubation boxes in south Puget Sound (1951-1979).

of other fishery research projects of WDF and sampling frequency varied with gear type (Table 1). Where possible, we standarized sampling by collecting at night in order to minimize problems with gear avoidance and variability from vertical and horizontal migrations of fish and zooplankton.

Fish occurring in the shallow sublittoral habitats (primarily salmon and baitfish < 150 mm) of CPS and SPS were sampled monthly during periods of minimal tidal exchange with a 37-m floating beach seine, using methods described in Miller et al. (1977). Pelagic zooplankton occurring in near-shore surface waters were sampled monthly concurrent with beach seining using a push net procedure (Cardwell et al., 1978). Zooplankton were collected 1 m below the surface at inshore ( ~ 50 m offshore in water 3-4 m in depth) and offshore ( ~ 250-400 m offshore in water 20 m in depth) stations. Tows were made parallel to shore directly adjacent to each of two beach seine sites in each region.

Specimens from nearshore pelagic habitats ( < 20 m in depth) were collected by townet (3.1 X 6.1 m by 15 m long with mesh grading from 76 mm to 6.4 mm) during cruises conducted by the Marine Fish Program of WDF; methods are described by Penttila and Stinson (in prep). Fish occurring in more offshore pelagic habitats ( ≥ 20 m in depth) were collected with a purse seine 500 m long by 55 m deep with 2-cm mesh.

In Puget Sound, stomachs from subadult and adult chinook and coho salmon caught by anglers were collected by WDF's Harvest Management Division. Chinook stomachs were collected beginning in August 1978 in SPS only; chinook in CPS and coho in both areas were collected beginning in January 1979. During the 1979 sport fishing season (May 12 to September 2) in the Pacific Ocean, stomach samples were collected near the mouth of the Columbia River from the Ilwaco fishery. Coho (2- and 3-year olds) and chinook ( 2 years +) were the principal target species. Similar stomach sampling methods were employed in both Puget Sound and the Pacific Ocean, except that Pacific Ocean fish were processed immediately upon capture, whereas Puget Sound fish were up to 4 hours old when processed.

A mid-water trawl with a 6.1 x 6.1 m opening was used to collect herring in the fall of 1978 during hydroacoustic herring surveys conducted in SPS by WDF's Marine Fish Program.

## Target Species

Although chinook, coho, and chum salmon and Pacific herring were the

Table 1. Sampling frequency by gear type in Puget Sound and the Pacific Ocean from August 1978-September 1979.

| Area/gear | Aug. | Sept. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Puget Sound | | | | | | | | | | | | | | |
| Beach seine | | | | | | | X[1/] | X | X | X | X | X | X | |
| Townet | X | X | | | | | | | | | X | | | |
| Purse seine | | | | | | | X | | | | X | | | |
| Midwater trawl | | | | X | X | | | | | | | | | |
| Zooplankton tows | | | | | | | X[1/] | X | X | X | X | X | X | X |
| Angler[2/] | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| Pacific Ocean | | | | | | | | | | | | | | |
| Angler | | | | | | | | | | X | X | X | X | X |

1/ Beach seine and plankton tows were not begun until March in CPS.
2/ Only SPS was sampled August through December 1978.

primary target species, a variety of their potential predators and competitors were also studied (Table 2). Literature sources and unpublished data from the University of Washington were used to select these potential competitors and predators. Those species which were captured are listed in Table 2.

## Sample Processing

Whole fish and stomachs were preserved in 10% formalin, with a pH of 7 and salinity of 9 o/oo. Stomachs from specimens $\gtrsim$ 350 mm were generally excised in the field. For each month and gear type, a pool of specimens of each species was compiled from as many of the sites within each region (CPS or SPS) as possible and specimens for stomach content analysis randomly chosen from this pool. All specimens selected for stomach analysis were measured (fork length FL - all salmonids; standard length SL - all other fish) and weighed (nearest 0.01 g). Stomachs were analyzed using standardized procedures describing the frequency of occurrence and the numeric and gravimetric proportion of prey (Cross et al., 1978; Terry, 1977). Qualitative measures of digestion (1= complete to 6= no digestion) and fullness (1= empty to 7= full) of the stomachs also were made.

Food organisms were identified to species where possible, although precision in identifying organisms depended on the degree of prey digestion, prey life history stage, and the staff's identification capabilities. Consequently, food habits data frequently encompassed several taxonomic levels (e.g., crustacea, brachyura, Cancer) for perhaps the same or homologous species. For the most part these distinctions were retained, although the contribution of completely unidentified (i.e., digested) material was ignored in calculating the percentages that prey taxocenes contributed to total prey biomass and numbers. A taxonomic breakdown of all invertebrates, including common names, identified from stomach contents and plankton samples is presented in Appendix 1.

## Data Analysis

All data were coded on computer sheets according to National Oceanographic Data Center/Marine Ecosystems Analysis (NODC/MESA) specifications, punched on 80-column IBM cards, and read onto computer tapes. Programs developed by the University of Washington and WDF were used in data analysis.

We have depicted some of the food habits data graphically using a modification of the Index of Relative Importance (IRI) (Pinkas et. al., 1971).

Table 2. Target species and number of full and empty stomachs analyzed by gear type in Puget Sound, August 1978-September 1979.

| | | Number of specimens processed | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Beach seine | | Townet | | Purse seine | | Angler[3/] | | Midwater trawl | | Total | |
| Common name | Scientific name | F[1/] | E[2/] | F | E | F | E | F | E | F | E | F | E |
| Chum salmon | Oncorhynchus keta | 229 | 16 | 58 | 23 | 12 | 2 | 0 | 0 | 0 | 0 | 299 | 41 |
| Chinook salmon | O. tshawytscha | 105 | 6 | 105 | 7 | 157 | 47 | 337 | 147 | 0 | 0 | 704 | 207 |
| Coho salmon | O. kisutch | 135 | 10 | 31 | 2 | 157 | 15 | 613 | 220 | 0 | 0 | 936 | 247 |
| Pacific herring | Clupea harengus pallasi | 174 | 30 | 92 | 63 | 163 | 31 | 0 | 0 | 118 | 203 | 547 | 327 |
| Surf smelt | Hypomesus pretiosus | 89 | 69 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 89 | 69 |
| Sand lance | Ammodytes hexapterus | 41 | 40 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 41 | 40 |
| Cutthroat trout | Salmo clarki | 21 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 21 | 2 |
| Steelhead trout | S. gairdneri | 1 | 0 | 0 | 0 | 17 | 3 | 15 | 1 | 0 | 0 | 33 | 4 |
| Pink salmon | O. gorbuscha | 0 | 1 | 0 | 0 | 15 | 1 | 4 | 1 | 0 | 0 | 19 | 3 |
| Pacific cod | Gadus macrocephalus | 1 | 0 | 0 | 0 | 1 | 0 | 10 | 2 | 0 | 0 | 12 | 2 |
| Pacific hake | Merluccius productus | 1 | 7 | 0 | 0 | 15 | 7 | 9 | 1 | 0 | 0 | 25 | 15 |
| Pacific tomcod | Microgadus proximus | 9 | 0 | 0 | 0 | 7 | 0 | 0 | 0 | 0 | 0 | 16 | 0 |
| Walleye pollock | Theragra chalcogramma | 5 | 0 | 0 | 0 | 22 | 3 | 24 | 2 | 0 | 0 | 51 | 5 |
| Copper rockfish | Sebastes caurinus | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 6 | 0 |
| Black rockfish | S. melanops | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 4 | 0 | 0 | 10 | 4 |
| Yellowtail rockfish | S. flavidus | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| Cabezon | Scorpaenichthys marmoratus | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| American shad | Alosa sapidissima | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 6 | 0 |
| Threespine stickleback | Gasterosteus aculeatus | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0 |
| Spiny dogfish | Squalus acanthias | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 3 |
| Pacific staghorn sculpin | Leptocottus armatus | 12 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 3 |
| Great sculpin | Myxocephalus polyacanthocephalus | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| Starry flounder | Platichthys stellatus | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 3 |
| Butter sole | Isopsetta isolepis | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 |
| Totals | | 832 | 184 | 286 | 95 | 573 | 109 | 1029 | 384 | 118 | 203 | 2838 | 975 |

1/ F = Full.

2/ E = Empty.

3/ Includes both the Puget Sound and Ilwaco areas.

These three-axis graphs illustrate frequency of occurrence (the proportion of stomachs containing a specific prey organism) plotted cumulatively on the horizontal axis and percentage of total prey abundance and percentage of total prey biomass (normalized) plotted above and below the horizontal axis, respectively. The prey categories have been arranged from left to right by decreasing frequency of occurrence and include only those occurring in at least 1% of the stomachs.

# RESULTS AND DISCUSSION

## Food Habits by Species

### Chum salmon

Sublittoral habitats -- Juvenile chum salmon were collected by beach seine in shallow sublittoral habitats from March through August 1979, with most caught in May and June. Of the 245 chum stomachs analyzed from this habitat only 7% were empty. The mean fork length of chum from shallow sublittoral habitats (± one standard deviation) was 69 ± 22 mm FL. Mean stomach fullness and digestion were both relatively high ($\bar{x}$ = 4.4 and $\bar{x}$ = 4.3, respectively), suggesting that most chum had recently fed.

Chum caught in the shallow sublittoral had fed predominantly upon calanoid copepods (primarily *Calanus* spp., *Aetedius* spp., and *Epilabidocera amphitries*), larvacea (*Oikopleura*), harpacticoid copepods, and euphausiids (Fig. 3). Primary prey of juvenile chum was calanoids in March, harpacticoids in April, euphausiids in May, calanoids in June, decapods and larvaceans in July, and myodocopa in August. The importance of these prey in chum diets generally is consistent with other studies (e.g., Fresh et al., 1979; Simenstad and Kinney, 1978; Simenstad et. al., 1980), although harpacticoids were somewhat less important than some other studies found (e.g., Simenstad et al., 1980).

Pelagic habitats -- Of the 81 juvenile chum salmon ($\bar{x}$ = 100 ± 28 mm FL) stomachs collected by townet in nearshore pelagic waters, 28% were empty. Stomach fullness ($\bar{x}$ = 3.3) and digestion ($\bar{x}$ = 3.8) indices were both lower than in shallow sublittoral habitats. The diet of townet-caught fish (based on percent biomass) was largely euphausiids, gammarid amphipods, and brachyuran crab larvae (mostly *Cancer* spp. and pinnotherid crabs) (Fig. 3). Euphausiids, while accounting for the greatest proportion of the biomass (37%), occurred in only 18% of the stomachs. Calanoids were not as prominent gravimetrically as some other prey, but were eaten by 48% of the fish.

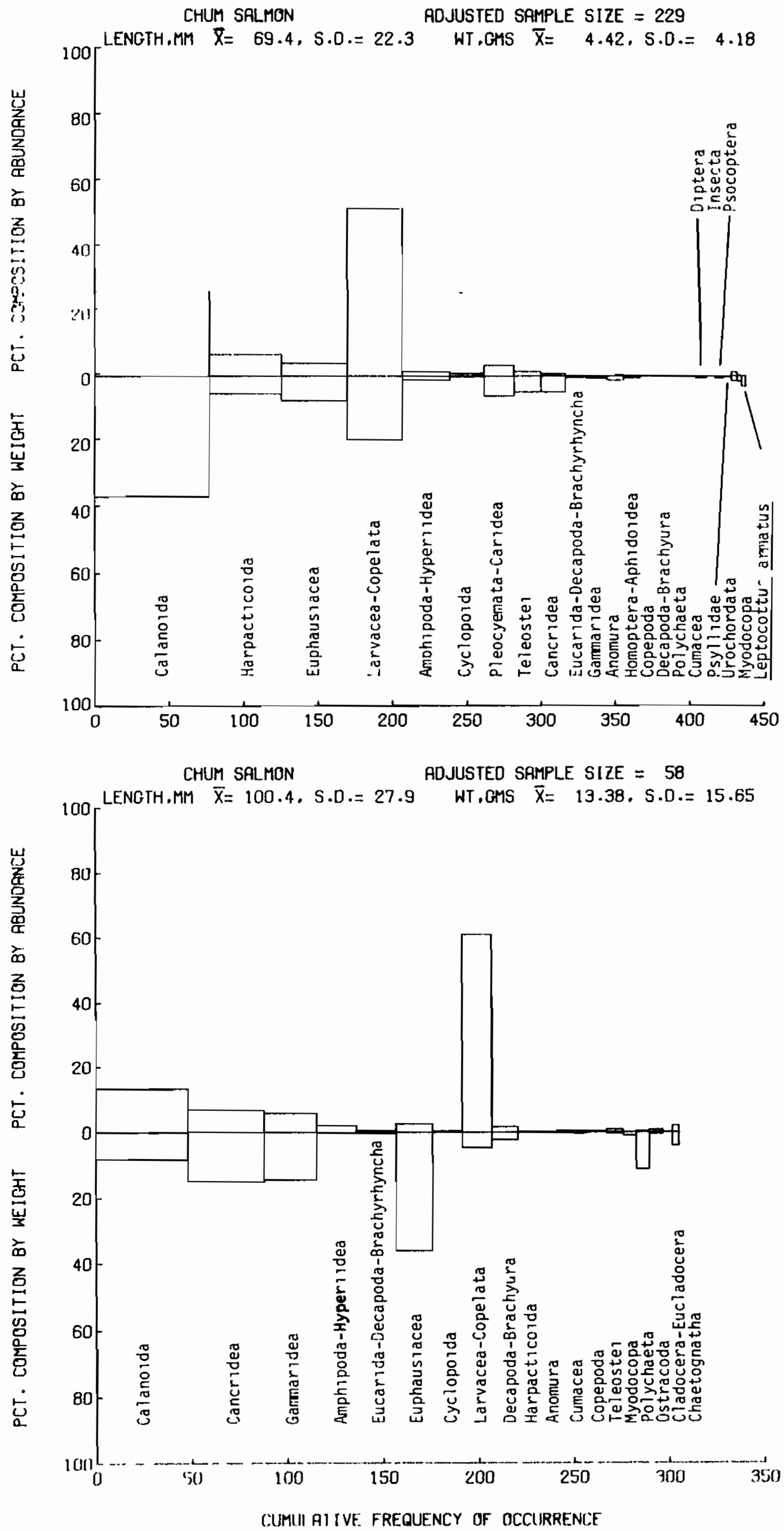


Fig. 3. Prey spectrum of chum salmon caught in shallow sublittoral (upper) and nearshore pelagic (lower) habitats of Puget Sound broken down by percent numeric and gravimetric composition and prey frequency of occurrence.

In May 1979, stomachs of 14 (12 with food) larger chum ($\bar{x}$ = 290 ± 13 mm FL) were collected by purse seine. Brachyuran crab larvae were the primary prey item, particularly Cancer spp. which occurred in 83% of stomachs and accounted for 68% and 90% of the total numbers and biomass of prey, respectively.

Geographic comparisons -- Utilizing months of adequate sample sizes (April and May beach seine and June townet), it was possible to compare chum diets geographically (Table 3). Some differences in prey composition were apparent. For instance, larvacea were relatively unimportant in the diets of chum from CPS, but were important in SPS, while fish larvae were important prey in CPS, but not in SPS.

Chinook salmon

Sublittoral habitats -- Most chinook collected in shallow sublittoral habitats by beach seine were juveniles ($\bar{x}$ = 124 ± 68 mm FL) and primarily occurred from June through August. Only 5% of the 111 stomachs analyzed were empty. Chinook caught in this habitat consumed a diverse array of benthic, epibenthic, and pelagic organisms, including fish (primarily herring and sand lance), brachyuran crab larvae (mostly Cancer spp.), polychaetes, insects, and hyperiid and gammarid amphipods (Fig. 4). Primary prey of the juvenile chinook was fish and crab larvae in June and July, and fish, polychaetes, and insects in August. The occurrence of insects is of particular note since they are probably surface drift from either rivers or directly off the land (e.g., falling from plants along the shoreline).

Nearshore pelagic habitats -- Of 112 juvenile chinook salmon ($\bar{x}$ = 118 ± 26 mm FL) obtained for analysis from townet samples in nearshore pelagic habitats, 6% were empty. Although occurring in only 10% of stomachs, euphausiids accounted for the greatest proportion (32%) of the prey biomass (Fig. 4); decapod larvae (primarily brachyura), fish, and polychaetes were other important prey in terms of gravimetric contribution. Decapod larvae were the most important numeric component of the diet, contributing 55% of the total numbers of prey eaten. As in sublittoral habitats, numerous varieties of insects comprised a significant dietary component of these chinook (Fig. 4), especially in late summer.

Offshore pelagic habitats (purse seine collections) -- Chinook salmon were collected by purse seine in February (n=130) and May (n=74) and were

Table 3. Geographic comparisons of chum food habits in Puget Sound, 1979.

| Parameter | Beach seine | | | | Townet | |
|---|---|---|---|---|---|---|
| | April | | June | | June | |
| | CPS | SPS | CPS | SPS | CPS | SPS |
| Predator characteristics | | | | | | |
| No. examined | 9 | 20 | 26 | 49 | 35 | 17 |
| No. empty | 0 | 0 | 6 | 2 | 3 | 0 |
| Mean fork length(mm) | 54 | 51 | 81 | 65 | 92 | 100 |
| Mean fullness | 6.0 | 4.7 | 4.0 | 4.2 | 3.4 | 3.3 |
| Mean digestion | 4.9 | 4.6 | 3.8 | 4.1 | 3.7 | 3.8 |
| Major prey items (percent biomass) | | | | | | |
| Calanoida | 1 | 15 | 46 | 68 | 22 | 15 |
| Harpacticoida | 18 | 67 | 1 | 2 | 0 | 0 |
| Fish (larvae) | 81 | 3 | 29 | 1 | 1 | 1 |
| Larvacea | 0 | 11 | 0 | 23 | 0 | 36 |
| Decapoda | 1 | 0 | 22 | 2 | 37 | 47 |
| Euphausiacea | 0 | 0 | 1 | 7 | 16 | 1 |
| Chaetognatha | 0 | 0 | 0 | 0 | 15 | 0 |

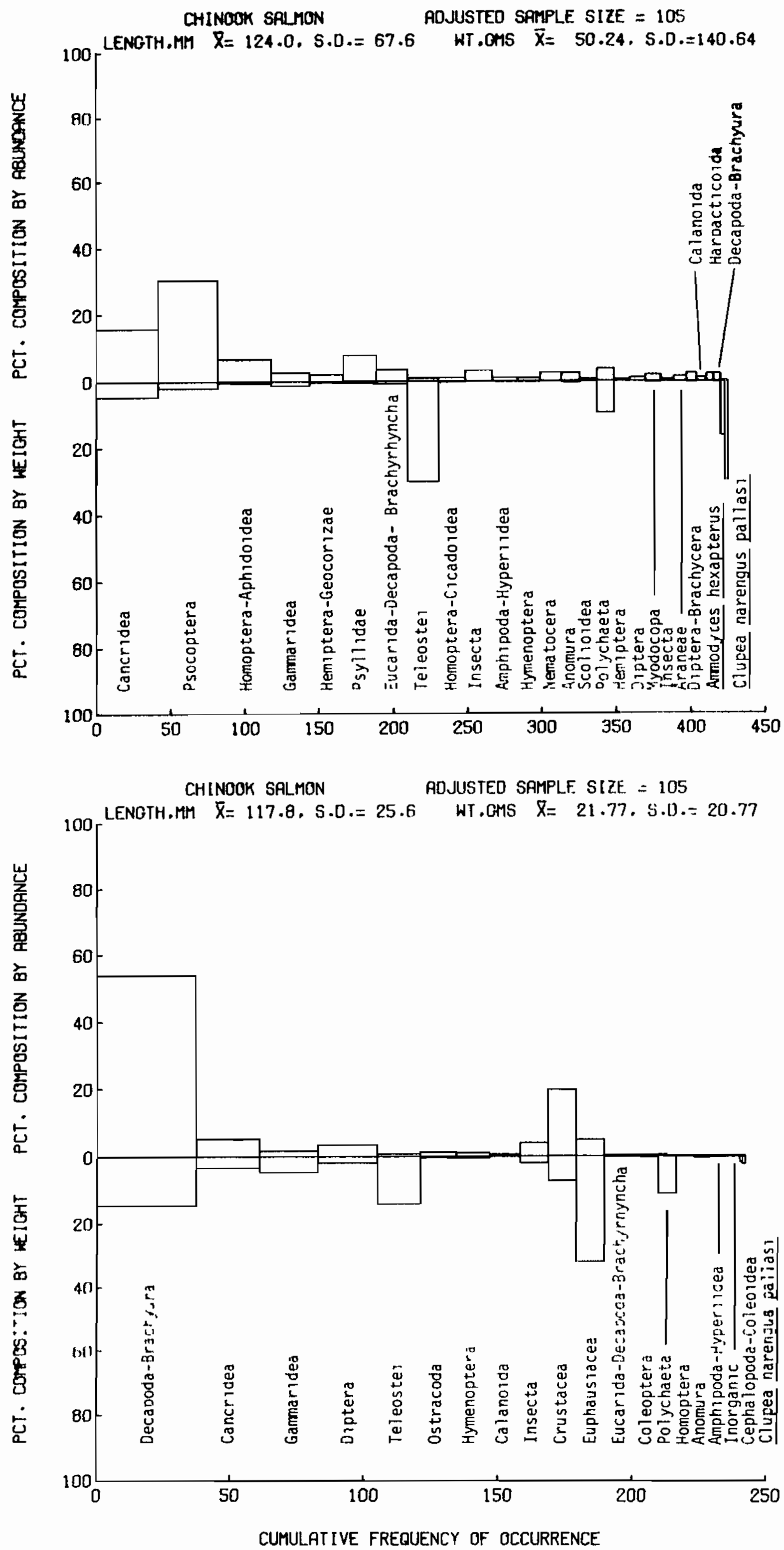


Fig. 4. Prey spectrum of chinook salmon caught in shallow sublittoral (upper) and nearshore pelagic (lower) habitats in Puget Sound broken down by percent numeric and gravimetric composition and prey frequency of occurence, 1978-1979.

primarily $\gtrsim$ 200 mm FL; 18% of the stomachs were empty in May as compared to 25% in February. Mean stomach fullness and digestion both decreased slightly from February to May, possibly due to more rapid digestion in the warmer waters of May. Their major prey was fish (mostly herring), although crustaceans (euphausiids, gammarid amphipods, and mysids) were also eaten, particularly in CPS in February (Table 4). Invertebrates accounted for the greatest numerical proportion of prey consumed (95%), while fish made up most (80%) of the prey biomass. Chinook typically fed either on large numbers of invertebrates or on several fish. Chinook < 350 mm FL tended to eat more invertebrates than the larger chinook which ate more fish. Herring and sand lance were the only fish positively identified from stomachs, with herring occurring in 13% of stomachs with food and accounting for 62% of the overall prey biomass.

Offshore pelagic habitats (angler collections) -- Considerable emphasis was placed on the food habits of legal-sized chinook salmon that could be obtained from the sport fishery because of concerns about their relationship as predators of herring in Puget Sound and of salmonid smolts from the Columbia River. Of the 251 chinook stomachs analyzed (24% were empty), 65 were from CPS and 186 from SPS. The average length of the chinook was 571 $\pm$ 78 mm FL. Most SPS specimens were from Anderson Island (46%) and Pt. Gibson (23%) and most CPS specimens from Pt. Jefferson (25%), Elliot Bay (22%), and Shilshole Bay (20%).

Prey digestion rated four or higher in 50% of stomachs indicating most Puget Sound chinook had fed relatively recently prior to being caught; stomach contents were, in general, more digested in summer, probably due to higher water temperatures. There were no discernible temporal or spatial trends in degree of stomach fullness.

Chinook prey items included 13 invertebrate taxa and six fish species. Chinook usually had eaten only one or two prey categories ($\bar{x}$ = 1.4) and the total number of categories varied little between months (range: 4 to 6). Puget Sound sport-caught chinook were almost entirely piscivorous with fish comprising 96% of the prey biomass (Fig. 5). Sixty percent of the total prey biomass was herring, 30% unidentified fish, 5% gadids, 0.2% sand lance, 0.2% northern anchovy (Engraulis mordax), and 0.1% shiner perch (Cymatogaster aggregata.

Herring were the most important food item in the diet of the sport-caught chinook. Herring were a major dietary item each month, occurring in 44% of chinook stomachs with food. The gravimetric proportion in diets was least in

Table 4. Food habits of chinook salmon from February and May 1979 purse seine collections in Puget Sound.

| Parameter | February | | | May | | |
|---|---|---|---|---|---|---|
| | Overall | CPS | SPS | Overall | CPS | SPS |
| Predator characteristics | | | | | | |
| No. examined | 130 | 50 | 80 | 74 | 14 | 60 |
| No. empty | 33 | 19 | 14 | 14 | 5 | 9 |
| Mean fork length(mm) | 286 | 298 | 281 | 315 | 272 | 323 |
| Mean fullness | 4.1 | 3.3 | 4.5 | 3.7 | 2.8 | 3.7 |
| Mean digestion | 4.5 | 4.4 | 4.5 | 3.7 | 3.2 | 3.8 |
| Mean no. prey categories/stomach | 1.6 | 1.9 | 1.4 | 3.0 | 2.4 | 3.1 |
| Major prey items (percent biomass) | | | | | | |
| Herring | 60 | 21 | 71 | 60 | 82 | 52 |
| Total fish | 66 | 39 | 75 | 93 | 94 | 83 |
| Euphausiacea | 19 | 1 | 23 | 4 | 0 | 5 |
| Gammaridea | 11 | 23 | 1 | 0 | 0 | 0 |
| Mysidacea | 5 | 22 | 1 | 0 | 0 | 0 |

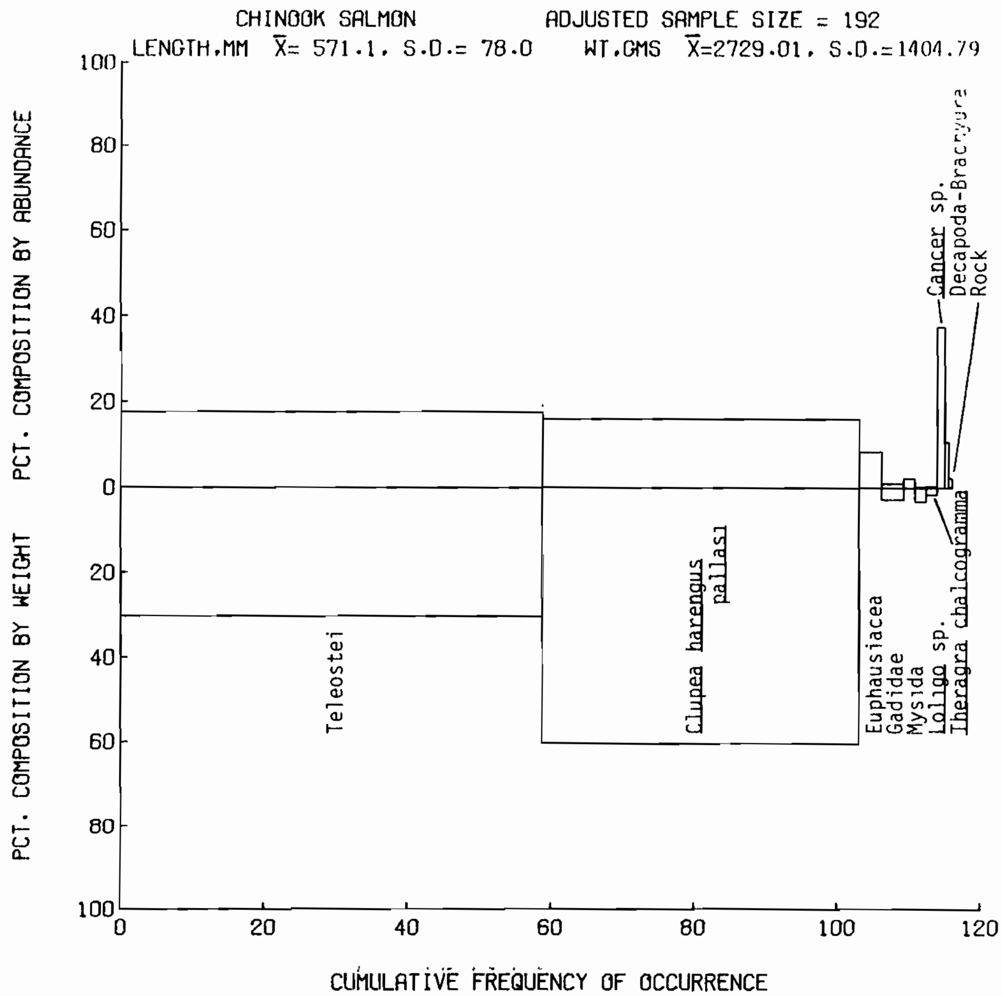


Fig. 5. Prey spectrum of chinook salmon caught by anglers in Puget Sound broken down by percent numeric and gravimetric composition and prey frequency of occurrence, August 1978-September 1979.

summer and fall and greatest in winter and spring (Fig. 6), and was probably even higher than our results suggest because there was usually a portion of the stomach contents that, because of advanced digestion, only could be identified as teleost fish. When herring occurred, there were usually several per stomach ($\bar{x}$ = 2.2). The mean standard length of 120 whole herring from chinook stomachs was 110 ± 35 mm SL (Fig. 7) and the majority (66%) were 75-115 mm SL. Most herring consumed would thus seem to be 3 years old of age or less, a finding similar to that by Healey (1976) for the Strait of Georgia.

From the Pacific Ocean near the mouth of the Columbia River, stomachs of 233 chinook ($\bar{x}$ = 539 ± 132 mm FL) (38% were empty) were obtained for analysis. As was observed in Puget Sound, fish was the primary food item of these chinook, accounting for over 99% of the prey biomass (Fig. 8). Northern anchovy, herring, whitebait smelt (Allosmerus elongatus), juvenile chinook salmon, unidentified smelts, and juvenile rockfish were all identified from stomach contents. Anchovy was by far the dominant prey, occurring in 58% of the stomachs and accounting for 85% of the overall prey biomass. Anchovy were a more significant component of the diet for larger chinook ($\geq$400 mm FL) (Table 5), whereas whitebait smelt were more prominent in the diet of chinook less than 400 mm FL. When anchovy did occur in stomachs, the average per stomach was 2.4. The mean standard length of 159 whole anchovy measured from chinook stomachs was 118 ± 18 mm SL (Fig. 9), similar to the size of herring found in sport-caught chinook stomachs from Puget Sound.

Chinook from Puget Sound and the Pacific Ocean were similar in their food habits; fish was the major prey item from both areas with invertebrates of relatively minor importance. The major difference between areas was that the dominant fish prey was anchovy in the Pacific Ocean and herring in Puget Sound, although the size of herring and anchovy was comparable. This probably reflects availability of prey since herring are abundant in Puget Sound and relatively rare in the Columbia River area of the Pacific Ocean, while anchovy has the opposite abundance pattern. A number of other studies have also found chinook subadults and adults to be mostly piscivorous (e.g., Kirkness, 1948; Merkel, 1957; Prakash, 1962), although their diet can consist largely of invertebrates (e.g., Silliman, 1941). Caution should be used, however, when examining the food habits of chinook based on sport-caught fish. Sport sampling may be biased towards chinook which are feeding on fish, especially herring, because herring is the primary bait used by anglers in each area, and the sport fishery may not randomly sample the chinook population. Thus, these results may not truly reflect the population as a whole.

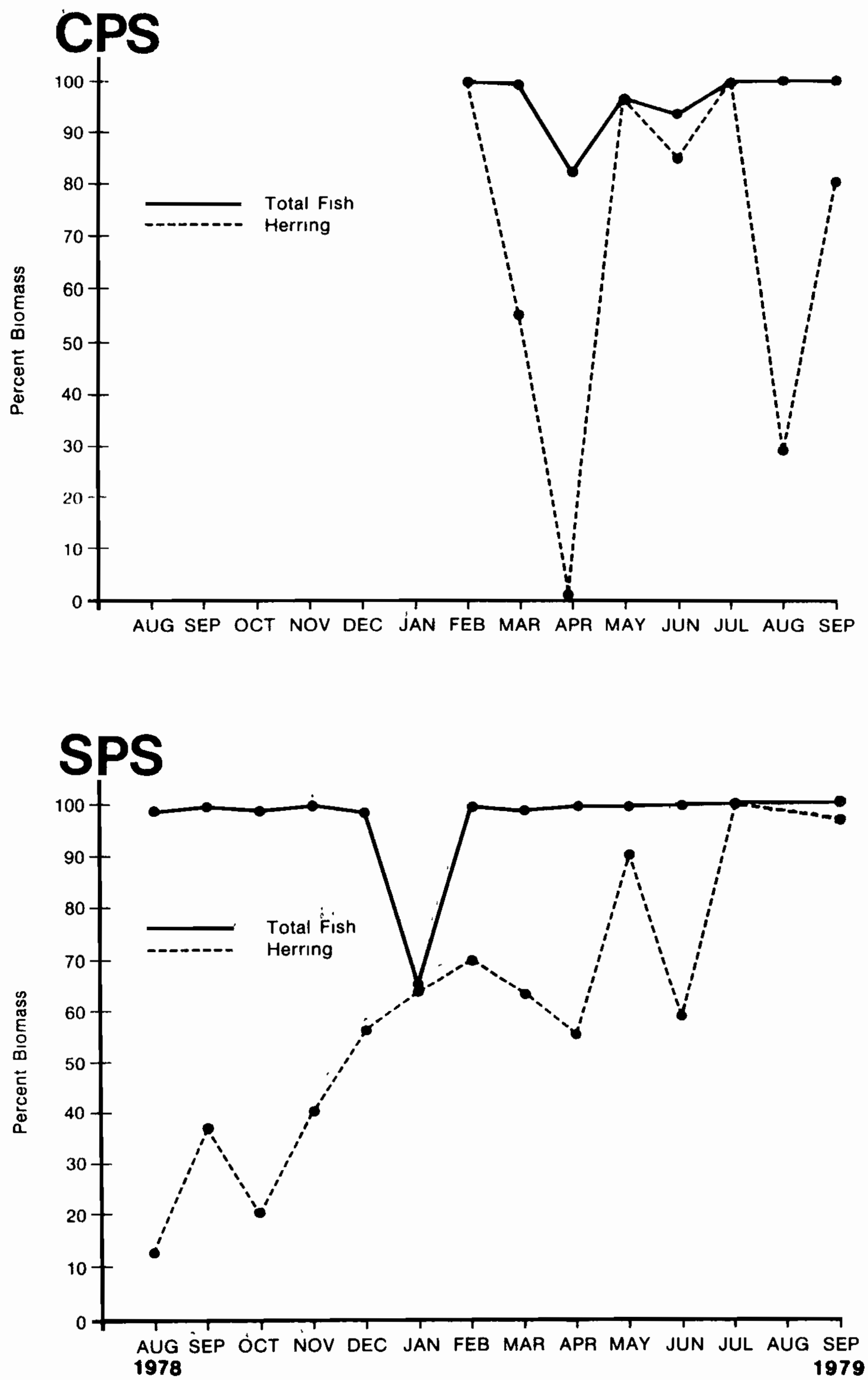


Fig. 6. Monthly changes in the percent biomass of herring and total fish in the diet of chinook salmon caught by anglers in CPS (upper) and SPS (lower), August 1978-September 1979.

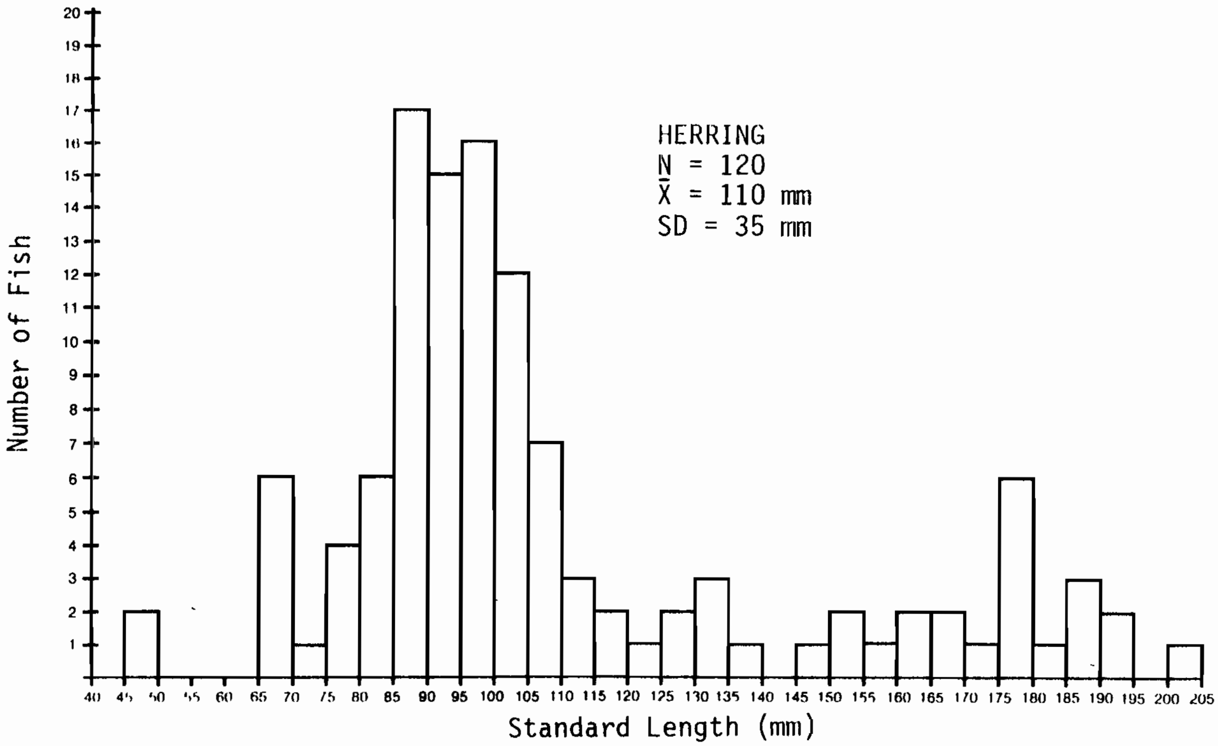


Fig. 7. Length frequency distribution of Pacific herring from the stomachs of chinook salmon caught by anglers in Puget Sound, August 1978- September 1979.

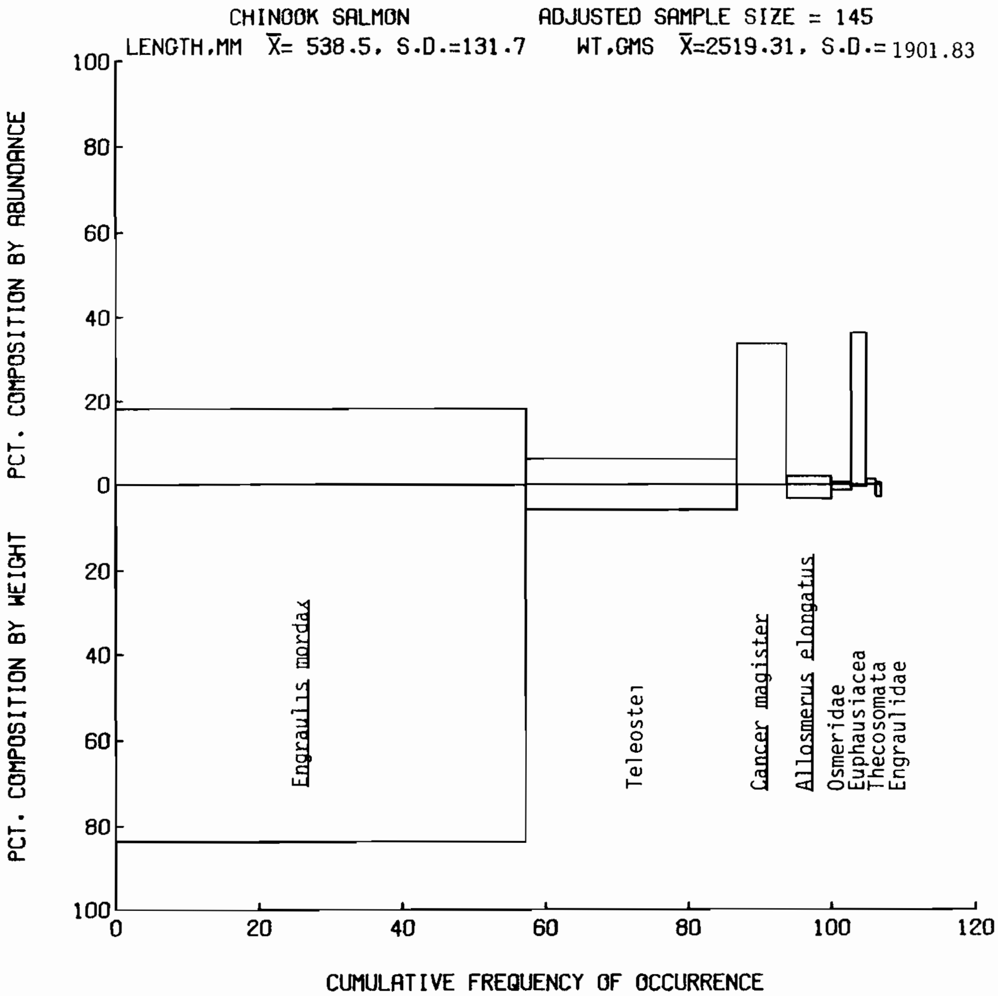


Fig. 8. Prey spectrum of chinook salmon caught by anglers in the Pacific Ocean (near the mouth of the Columbia River) broken down by percent numeric and gravimetric composition and prey frequency of occurrence, May-September 1979.

Table 5. Percent biomass of the major prey items of Pacific Ocean sport-caught chinook by size class, May-September 1979.

| Predator Characteristics | Fork length (mm) categories of chinook | | | | |
|---|---|---|---|---|---|
| | 400 | 400-499 | 500-599 | 600-699 | 700 |
| No. examined | 43 | 36 | 72 | 55 | 27 |
| No. empty | 16 | 16 | 22 | 19 | 15 |
| **Major Prey Items (percent biomass)** | | | | | |
| Euphausiacea | .6 | 6.8 | | | |
| Brachyura | 1.4 | .1 | .3 | .1 | |
| Teleostei | 13.2 | 10.5 | 3.2 | 5.1 | 11.8 |
| Pacific herring | 5.0 | | | 1.8 | |
| Northern anchovy | 36.7 | 73.4 | 94.1 | 86.0 | 88.2 |
| Chinook salmon | | | .9 | | |
| Whitebait smelt | 26.7 | 7.2 | | 4.7 | |
| Smelts | 8.4 | | 1.1 | 1.5 | |
| Rockfishes | 6.9 | 2.0 | .3 | | |

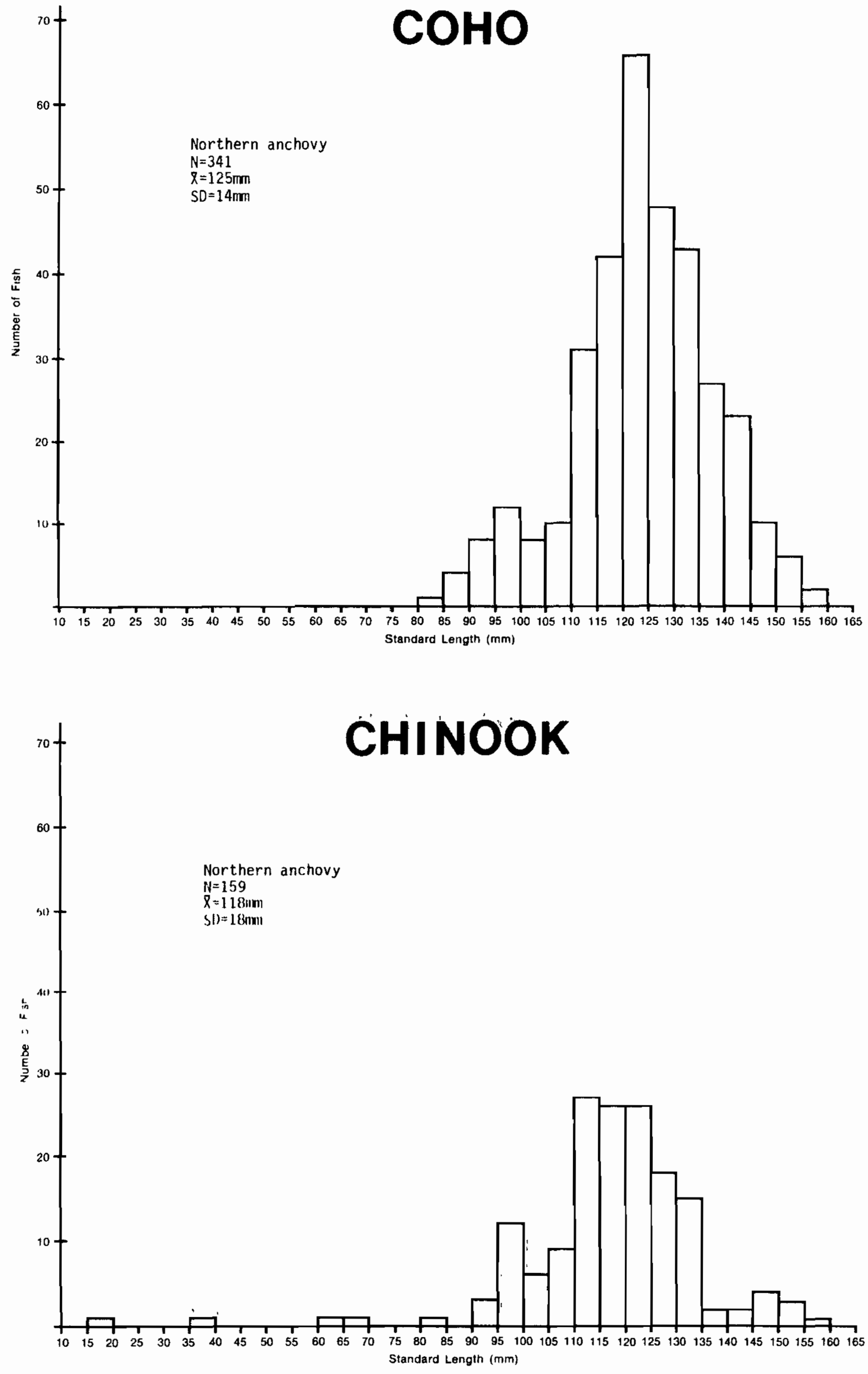


Fig. 9. Length frequency distributions of northern anchovy from the stomachs of coho and chinook salmon caught by anglers in the Pacific Ocean (near the mouth of the Columbia River), May - September 1979.

Coho salmon

Sublittoral habitats -- Most coho salmon caught by beach seine in shallow sublittoral habitats were juveniles ($\bar{x}$ = 180 $\pm$ 95 mm FL) and were primarily caught from May through August. Of the 145 coho salmon analyzed, 7% were empty. The mean digestion factor was relatively high ($\bar{x}$ = 4.3), suggesting the coho had recently fed. Coho caught in shallow sublittoral habitats had an extremely diverse diet that was comprised of benthic, epibenthic, and pelagic prey. The primary prey was decapod larvae (cancridae and pinnotheridae), which accounted for 81% of the total organisms and 32% of the total prey biomass (Fig. 10). Other important prey items included fish (primarily herring), gammarid and hyperiid amphipods, and polychaetes.

Nearshore pelagic habitats -- June 1979 was the only month that juvenile coho salmon ($\bar{x}$ = 166 $\pm$ 53 mm FL) were analyzed from townet collections made in nearshore pelagic habitats. Only two empty stomachs (6%) were recorded out of 33 stomachs analyzed. As in sublittoral habitats, brachyuran crab larvae were their primary food item (Fig. 10).

Offshore pelagic habitats (purse seine collections) -- From purse-seine collections in offshore pelagic habitats, 61 coho stomachs (20% were empty) were analyzed from February and 111 (4% were empty) from May. As was also the case with purse seine-caught chinook, coho stomach contents were more digested in May than in February. Euphausiids, fish ( primarily herring), gammarid amphipods, and decapod larvae were the dominant prey (Table 6), and the coho typically ate either large numbers of invertebrates or small numbers of fish.

Offshore pelagic habitats (angler collections) -- Due to poor angler catches, coho stomach samples were not obtained from the Puget Sound sport fishery until March 1979. Eighty-eight stomachs were collected from CPS and 67 from SPS; overall, 13 stomachs (8%) were empty. In SPS, most specimens (48%) came from Anderson Island and in CPS from Pt. Jefferson (36%) and Shilshole Bay (22%). The mean size of Puget Sound sport-caught coho analyzed was 451 $\pm$ 76 mm FL. Fish contributed the greatest proportion of the overall prey biomass (72%), but occurred in only 30% of the stomachs (Fig. 11). Identifiable fish in sport-caught coho stomachs were herring, juvenile chinook salmon, sand lance, gadids, and cottids. Invertebrate prey were a more

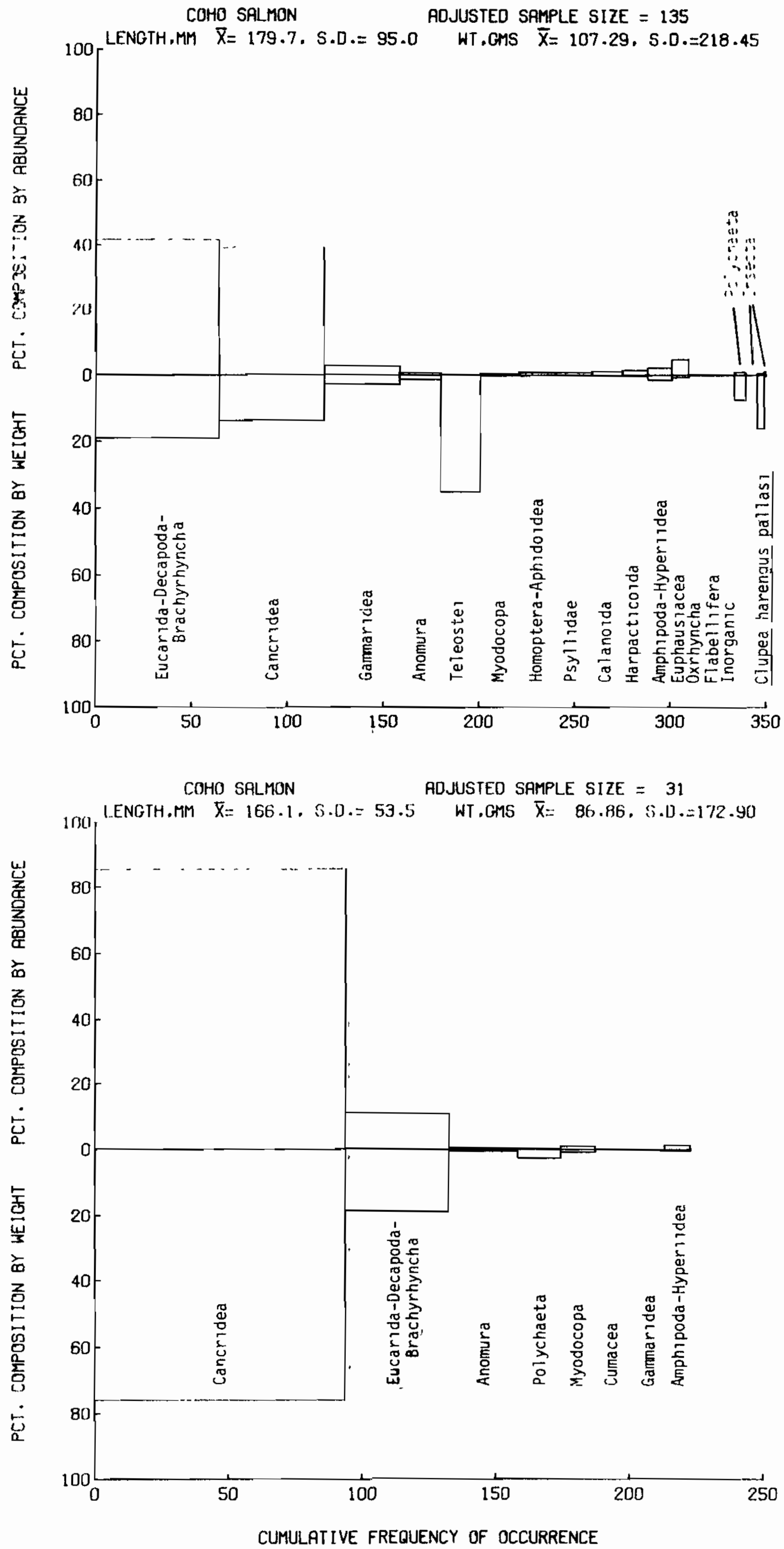


Fig. 10. Prey spectrum of coho salmon caught in shallow sublittoral (upper) and nearshore pelagic (lower) habitats of Puget Sound broken down by percent numeric and gravimetric composition and prey frequency of occurrence, 1979.

Table 6. Food habits of coho salmon from February and May 1979 purse seine collections in Puget Sound.

| Parameter | February | | | May | | |
|---|---|---|---|---|---|---|
| | Overall | CPS | SPS | Overall | CPS | SPS |
| **Predator characteristics** | | | | | | |
| No. examined | 61 | 37 | 24 | 111 | 28 | 83 |
| No. empty | 12 | 12 | 0 | 3 | 3 | 0 |
| Mean fork length(mm) | 350 | 334 | 368 | 386 | 317 | 407 |
| Mean fullness | 4.4 | 2.9 | 5.9 | 4.4 | 4.3 | 3.9 |
| Mean digestion | 4.5 | 4.2 | 4.9 | 4.0 | 4.6 | 4.4 |
| Mean no. prey categories/stomach | 1.8 | 1.8 | 1.7 | 4.2 | 3.8 | 4.4 |
| **Major prey items (percent biomass)** | | | | | | |
| Euphausiacea | 70 | 0 | 87 | 28 | 38 | 24 |
| Gammaridea | 14 | 27 | 11 | 21 | 15 | 23 |
| Decapoda | 0 | 0 | 0 | 17 | 31 | 13 |
| Herring | 10 | 56 | 0 | 26 | 14 | 27 |
| Total Fish | 12 | 56 | 2 | 32 | 15 | 38 |

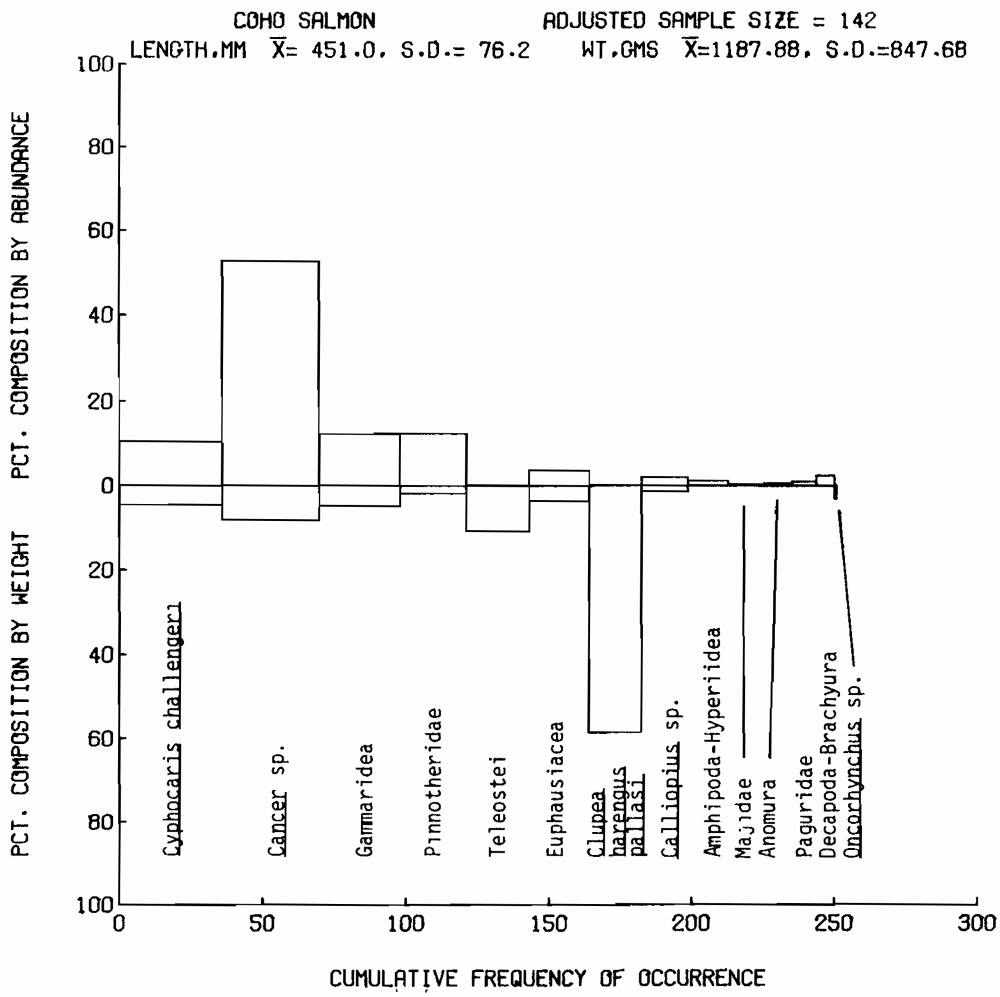


Fig. 11. Prey spectrum of coho salmon caught by anglers in Puget Sound broken down by percent numeric and gravimetric composition and prey frequency of occurrence, March- September 1979.

significant component of the diet than fish both numerically and in terms of frequency of occurrence, especially for coho $<350$ mm FL. Primary invertebrate prey included gammarid amphipods (11% of the total biomass), euphausiids (4%), and brachyuran crab larvae (10%).

From the Pacific Ocean near the mouth of the Columbia River, 471 full and 207 empty (31%) coho stomachs were analyzed from angler catches. Coho from the Pacific Ocean were considerably larger ($\bar{x}$ = 566 $\pm$ 86 mm FL) than their Puget Sound cohorts. Unlike Puget Sound coho, their primary food item was fish, comprising 96% of the overall prey biomass (Fig. 12) and including northern anchovy, surf smelt, whitebait smelt, herring, juvenile chinook salmon, and juvenile rockfish. Anchovy, the dominant prey item, occurred in 38% of the stomach and accounted for 65% of the prey biomass. Anchovy was eaten most extensively by coho $\geq$ 500 mm FL (Table 7). The size of anchovy consumed by coho was similar to that of anchovy eaten by oceanic chinook; the mean standard length of 341 whole anchovy measured from coho stomachs was $\bar{x}$ = 125 $\pm$ 14 mm SL (Fig. 9).

Pacific herring

Sublittoral habitats -- Juvenile herring ($\bar{x}$ = 96 $\pm$ 12 mm SL) were captured in shallow sublittoral habitats by beach seine in all months sampled except April, and of the 204 specimens analyzed, 15% were empty. Calanoid copepods (42% of the overall biomass), decapod crab larvae (23%), and chaetognaths (10%) were the primary prey (Figure 13). Cyclopoid copepods, while not a significant dietary component gravimetrically, nevertheless occurred in 45% of the stomachs and represented 24% of the prey organisms enumerated.

Pelagic habitats -- Of the 155 juvenile herring ($\bar{x}$ = 82 $\pm$ 19 mm SL) analyzed from townet collections in nearshore pelagic habitats, 41% were empty. Herring examined from townet (and also beach seine) samples had low mean stomach fullness and digestion factors and relatively high numbers of empty stomachs, suggesting herring are primarily daytime feeders or rapidly evacuate contents. Calanoid copepods were the primary food items, occurring in 51% of the stomachs with food and accounting for 68% of the prey biomass (Figure 13). Other important prey of juvenile herring included harpacticoid copepods and euphausiids. Harpacticoids were insignificant gravimetrically but occurred in 37% of the stomachs and represented 24% of the total of prey organisms enumerated. Euphausiids contributed 26% of the overall prey biomass but occurred in 4% of stomachs.

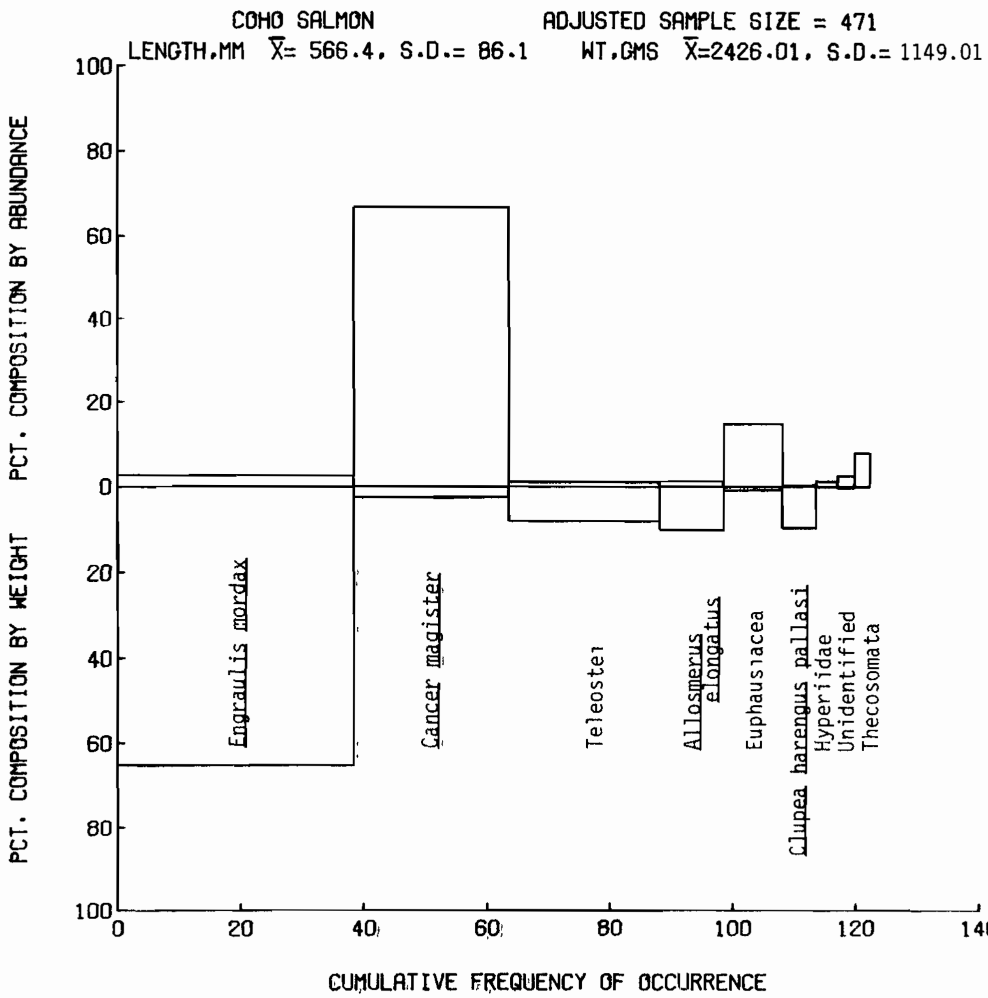


Fig. 12. Prey spectrum of coho salmon caught by anglers in the Pacific Ocean (near the mouth of the Columbia River) broken down by percent numeric and gravimetric composition and prey frequency of occurrence, May- September 1979.

Table 7. Percent biomass of the major prey items of Pacific Ocean sport-caught coho by size class, May-September 1979.

| Predator Characteristics | Fork length (mm) categories of coho | | | | |
|---|---|---|---|---|---|
| | 400 | 400-499 | 500-599 | 600-699 | 700 |
| No. examined | 47 | 70 | 311 | 220 | 30 |
| No. empty | 23 | 24 | 78 | 71 | 11 |
| **Major Prey Items (percent biomass)** | | | | | |
| Cephalopoda | | | .2 | 2.1 | |
| Euphausiacea | .8 | 6.1 | .7 | .7 | |
| Brachyura | 6.8 | 1.3 | 2.7 | 3.0 | |
| Teleostei | 17.4 | 27.1 | 4.2 | 11.2 | 12.0 |
| Pacific herring | 20.2 | | 11.6 | 7.4 | 9.1 |
| Northern anchovy | 25.6 | 50.6 | 69.3 | 57.9 | 78.9 |
| Chinook salmon | | | | 1.7 | |
| Whitebait smelt | 13.8 | 9.7 | 10.4 | 15.6 | |
| Rockfishes | 14.3 | 1.8 | .5 | .3 | |

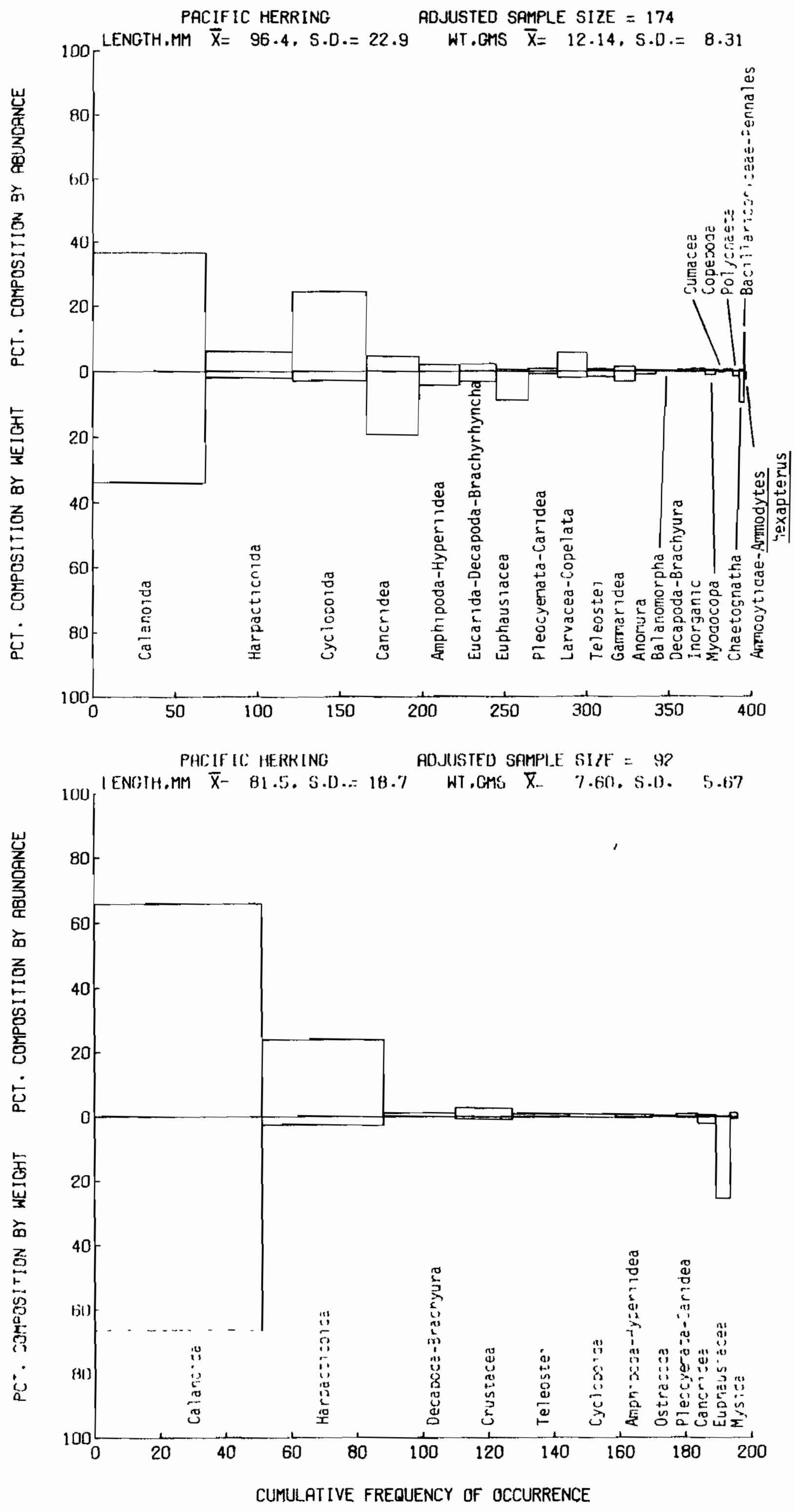


Fig. 13. Prey spectrum of Pacific herring caught in shallow sublittoral (upper) and nearshore pelagic (lower) habitats of Puget Sound broken down by percent numeric and gravimetric composition and prey frequency of occurrence, 1978-1979.

Purse seine collections yielded 194 ($\bar{x}$ = 170 ± 43 mm SL) herring for analysis, of which 16% were empty. Euphausiids were the primary prey, occurring in nearly 50% of stomachs and accounting for 85% of the total prey biomass (Table 8). Euphausiids were less important in May (46% of the total biomass) than in February (96%) due to greater contributions in May by brachyuran larvae (25%) and calanoid copepods (15%). Dominant food items were generally the same in both CPS and SPS, although a greater variety of prey generally occurred in SPS.

Many (63%) of the 321 herring ($\bar{x}$ = 123 ± 50 mm SL) stomachs analyzed from mid-water trawl collections were empty and well digested ($\bar{x}$ stage of digestion = 2.2), suggesting regurgitation of contents after capture and diurnal feeding behavior. Identifiable prey were primarily euphausiids, which occurred in 28% of stomachs with food and accounted for 98% of the prey biomass.

## Other baitfish

Two other baitfish species--surf smelt and sand lance--were captured by all gears utilized except hook-and-line; however, only specimens from beach seine samples were analyzed for stomach contents. Surf smelt were captured in all months sampled except April, and of 158 surf smelt ($\bar{x}$ = 110 ± 26 mm SL) stomachs analyzed, 44% were empty. The contents of these fish were not well digested ($\bar{x}$ digestion = 4.4), although containing relatively little food ($\bar{x}$ fullness = 3.5). Surf smelt ate primarily pelagic prey, particularly calanoids (24% of the overall prey biomass), unidentifiable urochordates (25%), carideans (10%), and euphausiids (10%) (Fig. 14). Cyclopoids and larvaceans were not important prey gravimetrically but were important numerically. The occurrence of small numbers of harpacticoids in a large proportion (61%) of stomachs suggests the smelt are also epibenthic feeders.

Sand lance stomach samples were exclusively from CPS and were collected mostly from May through August. Eighty-one sand lance ($\bar{x}$ = 64 mm ± 17 SL) were analyzed, of which 49% had no identifiable prey items. Calanoids were by far the most important prey item of sand lance, occurring in 71% of sand lance stomachs and accounting for 87% of the prey biomass (Fig. 15).

## Other marine fish

Stomachs from additional fish species were analyzed as possible competitors or predators of juvenile salmon and herring (Table 2). A brief description of their food habits by species follows. IRI diagrams are pre-

Table 8. Food habits of Pacific herring from February and May 1979 purse seine collections in Puget Sound.

| Parameter | February | | | May | | |
|---|---|---|---|---|---|---|
| | Overall | CPS | SPS | Overall | CPS | SPS |
| Predator characteristics | | | | | | |
| No. examined | 75 | 34 | 41 | 119 | 40 | 79 |
| No. empty | 22 | 21 | 1 | 9 | 1 | 8 |
| Mean standard length(mm) | 185 | 175 | 188 | 120 | 181 | 153 |
| Mean fullness | 4.0 | 3.2 | 4.3 | 4.0 | 4.4 | 3.8 |
| Mean digestion | 3.0 | 3.6 | 2.8 | 3.6 | 4.1 | 3.2 |
| Mean no. prey categories/stomach | 1.9 | 2.0 | 1.9 | - | - | - |
| Major prey items (percent biomass) | | | | | | |
| Euphausiacea | 96 | 85 | 96 | 46 | 43 | 36 |
| Calanoida | 2 | 1 | 2 | 16 | 3 | 43 |
| Brachyura | 0 | 0 | 0 | 31 | 43 | 15 |
| Total fish | 1 | 9 | 0 | 5 | 9 | 1 |

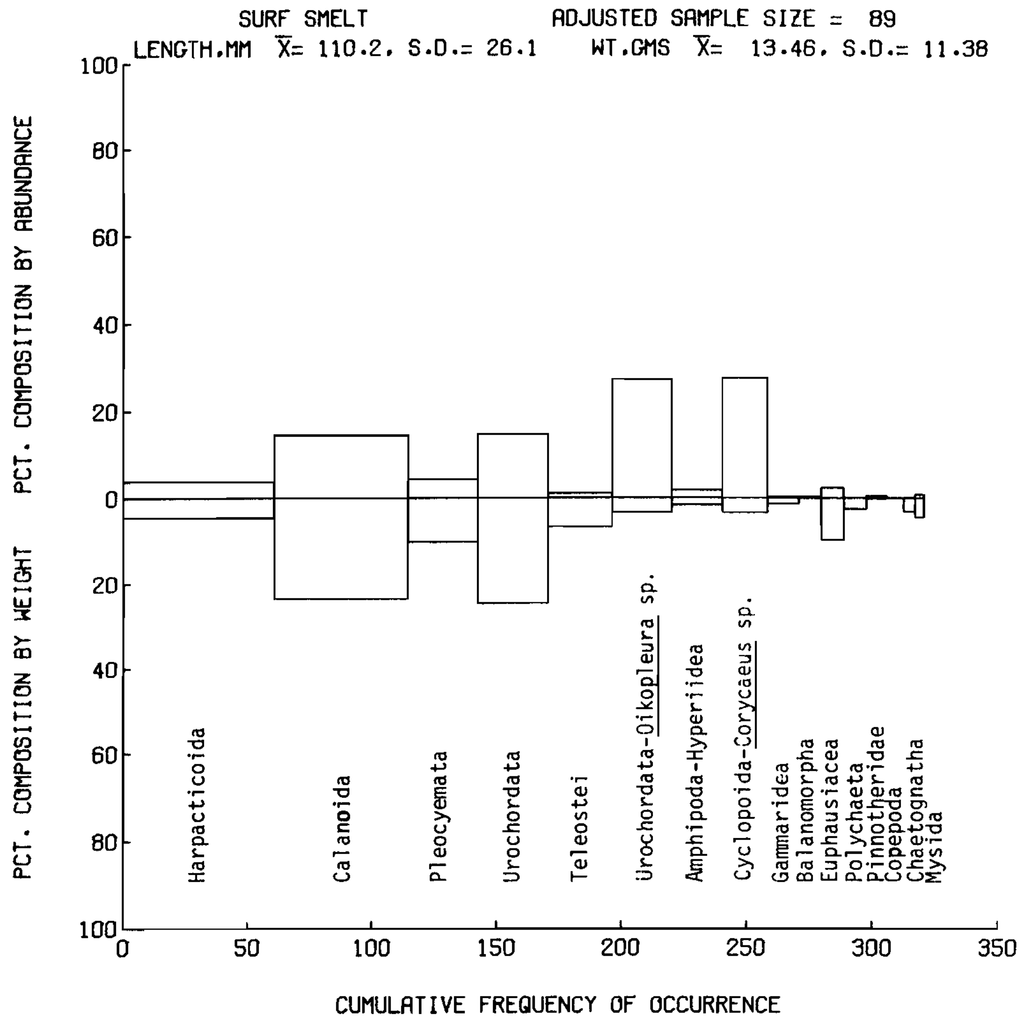


Fig. 14. Prey spectrum of surf smelt caught in the shallow sublittoral habitats of Puget Sound broken down by percent numeric and gravimetric composition and prey frequency of occurrence, February- August 1979.

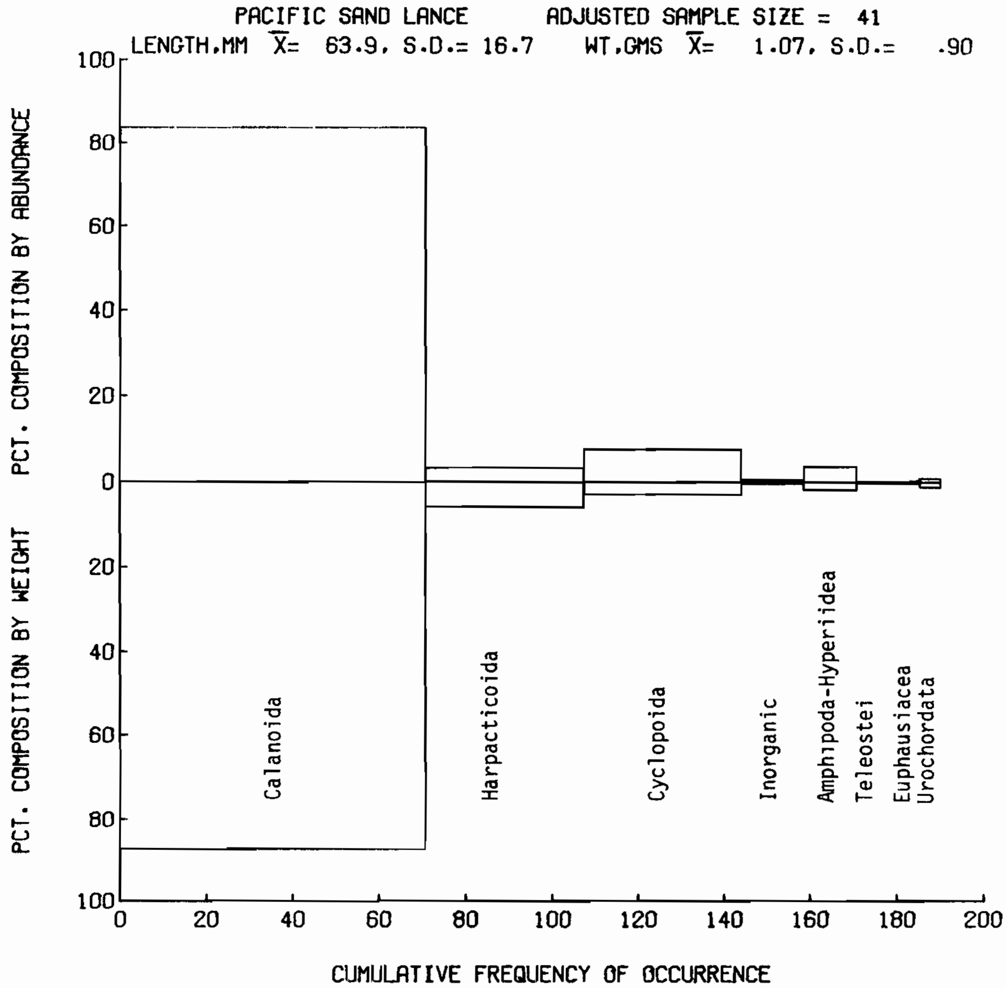


Fig. 15. Prey spectrum of Pacific sand lance caught in the shallow sublittoral habitats of Puget Sound broken down by percent numeric and gravimetric composition and prey frequency of occurrence, February- August 1979.

sented in Appendix 2 for those species where at least 10 stomachs containing food were analyzed.

Pink salmon -- Sixteen stomachs (all but one with food) from pink salmon ($\bar{x}$ = 338 ± 87 mm FL) resident in Puget Sound were collected by purse seine in May 1979. Mean abundance of organisms per stomach ($\bar{x}$ = 984) was the highest for any species analyzed from any habitat; euphausiids and decapod larvae (mostly cancridea) were the primary prey consumed (Appendix Fig. 2-A). Five pink salmon stomachs (4 with food) were also collected from anglers in the Pacific Ocean; anchovy and *Cancer magister* larvae were the primary prey.

Cutthroat trout -- The stomach contents of 23 cutthroat trout ($\bar{x}$ = 356 ± 82 mm FL) were examined from beach seine collections, and all but two contained identifiable prey items. Cutthroat were mostly piscivorous, as 74% of their overall prey biomass was fish (Appendix Fig. 2-B). Sand lance was the major fish species eaten, occurring in 43% of the stomachs and accounting for 60% of the prey biomass. The major invertebrate prey was gammarid amphipods (16% biomass).

Steelhead trout -- Twenty-one (14% were empty) steelhead trout ($\bar{x}$ = 259 ± 125 mm FL) were collected from Puget Sound, and 16 ($\bar{x}$ = 350 ± 49 mm FL) (all but one with food) from the Pacific Ocean. In Puget Sound, their prey spectrum was comprised of a diverse array of crustaceans: euphausiids, gammarids, insects, and decapod larvae (Appendix Fig. 2-C). One herring accounted for 50% of the overall prey biomass.

With the exception of crab larvae, fish was the only food item identified from the stomachs of Pacific Ocean steelhead; anchovy (35% of the overall prey biomass), chinook salmon (33%), herring (2%), and whitebait smelt (17%) were the primary fish prey.

Pacific cod -- Fourteen adult Pacific cod ($\bar{x}$ = 534 ± 69 mm SL) were analyzed; 12 stomachs had identifiable food and 11 of the 14 cod were collected by anglers. Cod were mostly piscivorous as 56% of the prey biomass was fish (Appendix Fig. 2-D); most of the remainder of the prey (31%) were decapods.

Pacific hake -- Fourteen (47%) of the 30 hake ($\bar{x}$ = 425 ± 34 mm SL) analyzed from Puget Sound were empty. Herring contributed the greatest proportion of the prey biomass (73%), but occurred in only two stomachs. Euphausiids were the other major food item, occurring in 93% of stomachs and accounting for 97% of prey numbers and 17% of the prey biomass (Appendix Fig. 2-E).

Ten hake stomachs (one was empty) were also analyzed from angler catches in the Pacific Ocean; the mean size of hake specimens was 546 ± 50 mm SL. The only prey eaten by Pacific Ocean hake was fish (whitebait smelt and anchovy).

Pacific tomcod -- Sixteen Pacific tomcod ($\bar{x}$ = 179 ± 67 mm SL), all with food, were characterized by full stomachs ($\bar{x}$ fullness = 5.4) with contents that were relatively undigested ($\bar{x}$ digestion = 4.4). Polychaetes (50% of the total biomass), cancridae (17%), gammarids (12%), and fish (9%) were major prey eaten (Appendix Fig. 2-F).

Walleye pollock -- Fifty-six pollock (9% were empty) analyzed were mostly adults ($\bar{x}$ = 349 ± 135 mm SL) from purse seine and angler samples in SPS. Gravimetrically, the major prey was fish (92% biomass) (Appendix Fig. 2-G) whereas invertebrate prey (mostly gammarids, calanoids, cancridae, and hyperiids) were more important components of the diet numerically and in terms of frequency of occurrence.

Rockfish -- Copper, black, and yellowtail rockfish (*Sebastes* spp.) stomachs were collected primarily from sports fishermen in Puget Sound and the Pacific Ocean. The 21 stomachs (14 black, 6 copper, 1 yellowtail) were all from adults, and all but four blacks had identifiable prey. Fish was the most important prey item, comprising 50% to 100% of the prey biomass of each species. Shiner perch and sculpins were identified from rockfish stomachs collected in Puget Sound and anchovy from those collected in the Pacific Ocean.

Cabezon -- One adult cabezon stomach collected by beach seine had eaten algae and one juvenile *Cancer gracilis*.

American shad -- Six adult shad from the May purse seine collection all had food in their stomachs and had consumed principally euphausiids (92% biomass).

Threespine stickleback -- Cyclopoid copepods (32% prey biomass), calanoid copepods (32%), and fish eggs (24%) made up the bulk of the food consumed by 7 adult stickleback.

Spiny dogfish -- Three spiny dogfish stomachs collected by anglers from the Pacific Ocean were empty.

Pacific staghorn sculpin -- Fifteen staghorn sculpin (17% were empty) analyzed from beach seine collections in Puget Sound averaged 177 ± 28 mm SL. Fish (herring, shiner perch, and sand lance) accounted for 67% of the prey biomass of these staghorn sculpins (Appendix Fig. 2-H).

Great sculpin --One great sculpin had eaten algae (8% biomass), one *Hemigrapsus nudus* (21%), and two unidentified fish (71%).

Starry flounder -- The stomachs of three starry flounder caught by anglers in the Pacific Ocean were empty.

Butter sole -- One butter sole from the Pacific Ocean had 4 gammarids and one *Crangon* sp.

## Predation on Juvenile Salmon

Predation, especially by other salmonids, has been suggested as a principal cause of marine and estuarine mortality of juvenile salmon. As shown below, four species of fish, all salmonids, were identified by this study as predators on juvenile salmon:

| Predator | Salmonid prey | Month/area of occurence | Percentage of predators containing salmon | Mean number salmon per predator |
|---|---|---|---|---|
| Coho juveniles | Chum | May/SPS | 7 | 0.1 |
| Coho subadults | Chinook | April/CPS | 11 | 0.9 |
| Coho subadults | Chirook | August/CPS | 11 | 0.7 |
| Cutthroat trout | Chum | April/SPS | 50 | 0.5 |
| Steelhead trout | Chinook | June/Pacific Ocean | 20 | 1.0 |
| Steelhead trout | Chinook | July/Pacific Ocean | 10 | 0.1 |
| Chinook subadults | Chinook | June/Pacific Ocean | 10 | 0.1 |

While most of these rates are relatively low, their implication is uncertain because of the lack of data on predator standing stocks. If predator standing stocks are very large, low predation rates may be significant.

## Competitive Interactions

Competition is essentially the demand by two or more individuals of the same or different species for a common resource that is actually or potentially limiting. This study was not designed to assess intraspecific interactions and, without detailed data on resource availability (e.g., standing stocks of herring, euphausiids, and other prey), conclusions concerning interspecific competition based on diet similarity are speculative. However, when we obtain sufficient data on nearshore pelagic zooplankton, competition between zooplanktivorous species (e.g., herring and chum juveniles) for this particular prey resource can be investigated. Comparisons of diet similarity between species were made with as much specificity (e.g., predator size, area, month, habitat) as possible to minimize variability. It was assumed that the more similar diets were, the greater the likelihood of competition.

Juvenile chinook and coho salmon diets generally were similar in sublittoral and nearshore pelagic habitats, emphasizing somewhat larger crustaceans such as brachyuran crab larvae. Juvenile chum diets were quite different from those of juvenile chinook and coho. They tended to consume fewer larger prey and instead ate smaller prey such as cyclopoid and harpacticoid copepods. Differences between the diet of chum and those of chinook and coho may be related to predator and prey sizes. Chum occurring in these habitats were smaller than the chinook and coho, and thus may have been unable to eat the larger food items characterizing the diets of chinook and coho. Chinook and coho, on the other hand, could find it difficult to obtain an adequate ration by eating small prey such as calanoids and cyclopoids.

The diets of juvenile herring and surf smelt were more intermediate between chum and chinook and coho, being characterized by both smaller prey such as copepods and larger prey such as brachyuran crab larvae. Sand lance, which ate almost exclusively calanoids, could compete with chum, herring, and surf smelt since calanoids were important prey of all three species.

In the more offshore pelagic habitats sampled by purse seine, we were only able to compare larger herring ( $\geq$ 150 mm SL), chinook ( $\geq$ 200 mm FL), and coho ( $\geq$ 200 mm FL) because sample sizes of other species were too small. Herring, chinook, and coho food habits in this habitat generally were similar insofar as prey composition was concerned; euphausiids, gammarids, decapod larvae, and fish (mostly herring) were their primary prey. Diets of the three species differed in the proportion of these items, particularly fish; fish were most important to chinook, less so to coho, and least to herring. Herring and coho diets were the most similar although coho ate a greater variety of crustaceans than did herring. As a result, herring and coho in this habitat may compete for some prey resources. It is likely that chinook in the offshore pelagic habitats of Puget Sound would compete with other piscivorous species such as pollock, hake and rockfish.

## Pelagic Prey Selectivity

The nearshore, surface pelagic zooplankton was dominated numerically by brachyuran crab larvae (especially *Cancer* sp.), calanoid copepods (mostly *Calanus* sp.), and barnacle larvae (Table 9); brachyuran larvae, hydrozoans, and calanoid copepods were the dominant zooplankters gravimetrically. Insects, an important component of chinook and coho diets in some months, were rare in the zooplankton. Because they occur directly on the surface, our plankton nets probably did not sample these organisms. Not surprisingly, few epibenthic crustaceans (e.g., harpacticoids and gammarids), important prey items of some fish, were collected. The density (numbers $m^{-3}$) and biomass (g $m^{-3}$) of surface zooplankton were greatest in April, May, and June due primarily to calanoids in April and calanoids and brachyuran larvae in both May and June (Fig. 16 & 17). In general, the density and biomass of zooplankton were greater in the offshore transects (>250 m from shore) than in the inshore transects (25-50 m from shore) (Fig. 16 & 17).

Of the species analyzed from beach seine samples (collected concurrent with zooplankton samples), the diet of herring was the most similar to surface pelagic zooplankton. The primary difference was in the consumption by herring of some organisms (especially harpacticoid and cyclopoid copepods) that were not prominent in zooplankton samples. The prey spectra of chum salmon and surf smelt were also generally similar to the zooplankton composition. Chum salmon and surf smelt consumed a greater proportion of larvacea than was represented in the zooplankton, and as with herring, they at times consumed some epibenthic organisms Coho salmon juveniles ate primarily brachyuran crab larvae in a higher proportion than was represented in zooplankton samples. Other abundant pelagic zooplankters were poorly represented in juvenile coho diets. Chinook diets were the least similar to the surface zooplankton samples as they largely consumed organisms that were not well represented in the zooplankton samples (e.g., gammarid amphipods and insects).

Table 9. Percent numeric and gravimetric composition of nearshore surface pelagic zooplankton from Puget Sound, February-September, 1979.

| Category | Percent numeric composition | Percent gravimetric composition |
|---|---|---|
| Cnidaria | .01 | .01 |
| Hydrozoa | 7.16 | 22.61 |
| Scyphozoa | .01 | .07 |
| Anthozoa | .01 | .03 |
| Ctenophora | .44 | 3.80 |
| Nematoda | .01 | .01 |
| Polychaeta | .13 | .55 |
| Gastropoda | .65 | .07 |
| Cephalopoda | .01 | .01 |
| Arachnida | .01 | .01 |
| Crustacea | .01 | .01 |
| Cladocera | .10 | .01 |
| Myodocopa | .06 | .08 |
| Copepoda | .01 | .01 |
| Calanoida | 26.46 | 17.94 |
| Harpacticoida | .05 | .01 |
| Cyclopoida | .05 | .01 |
| Monstrilloida | .01 | .01 |
| Caligoida | .01 | .01 |
| Balanomorpha | 20.32 | 1.75 |
| Mysidacea | .46 | .45 |
| Cumacea | .10 | .06 |
| Isopoda | .01 | .01 |
| Gammaridea | .15 | .35 |
| Hyperiidea | .59 | .45 |
| Caprellidea | .26 | .14 |
| Euphausiacea | 4.05 | 2.78 |
| Penaeidea | .01 | .01 |
| Caridea | 3.78 | 2.00 |
| Anomura | 1.25 | 1.33 |
| Brachyura | 27.68 | 39.35 |
| Insecta | .02 | .01 |
| Chaetognatha | 1.54 | 3.83 |
| Larvacea | 2.57 | .24 |
| Teleostei | 2.15 | 2.09 |

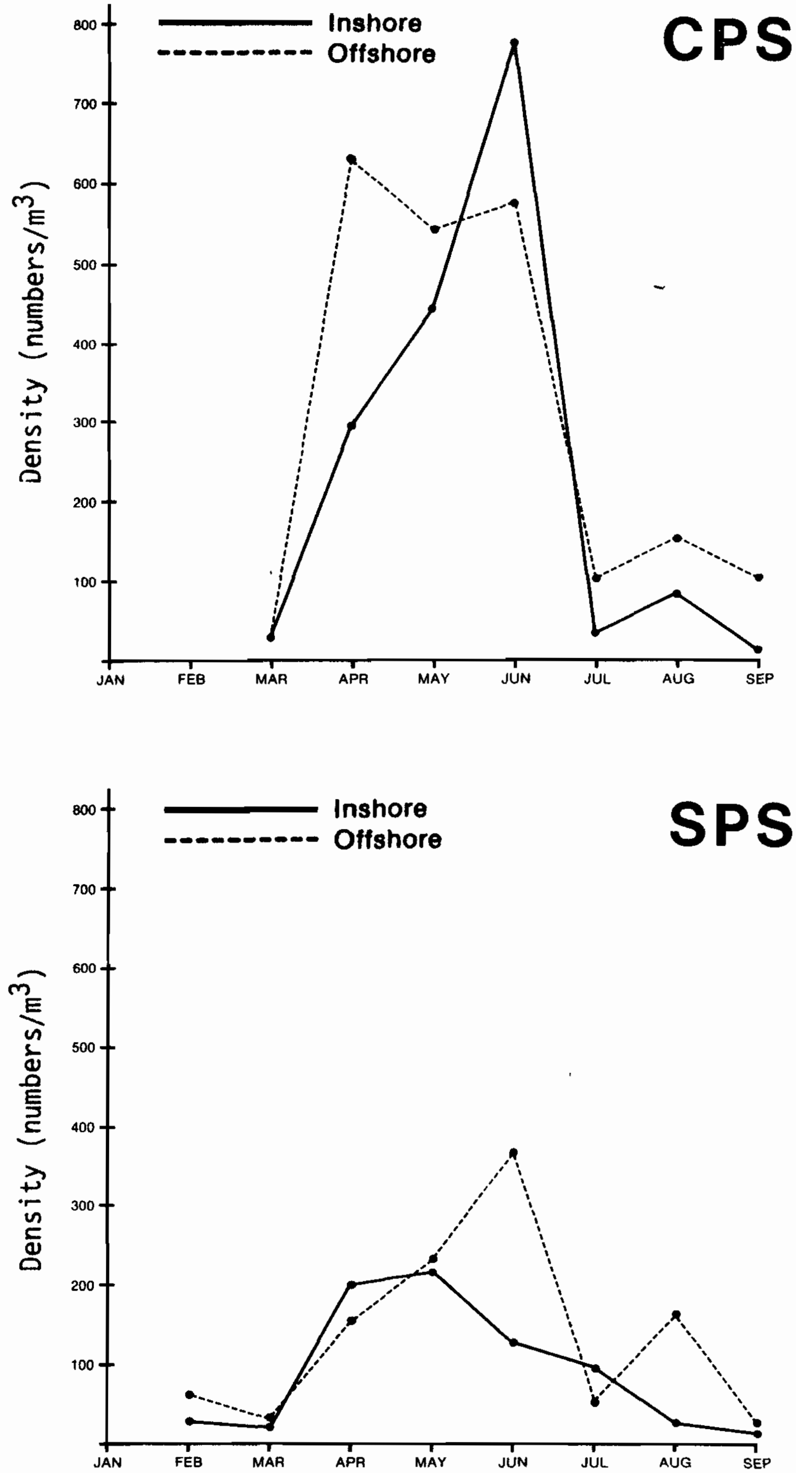


Fig. 16. Density (numbers/$m^3$) of nearshore surface pelagic zooplankton from inshore (~3-4m in depth) and offshore (~20-25m in depth) tows in CPS (upper) and SPS (lower), February - September 1979.

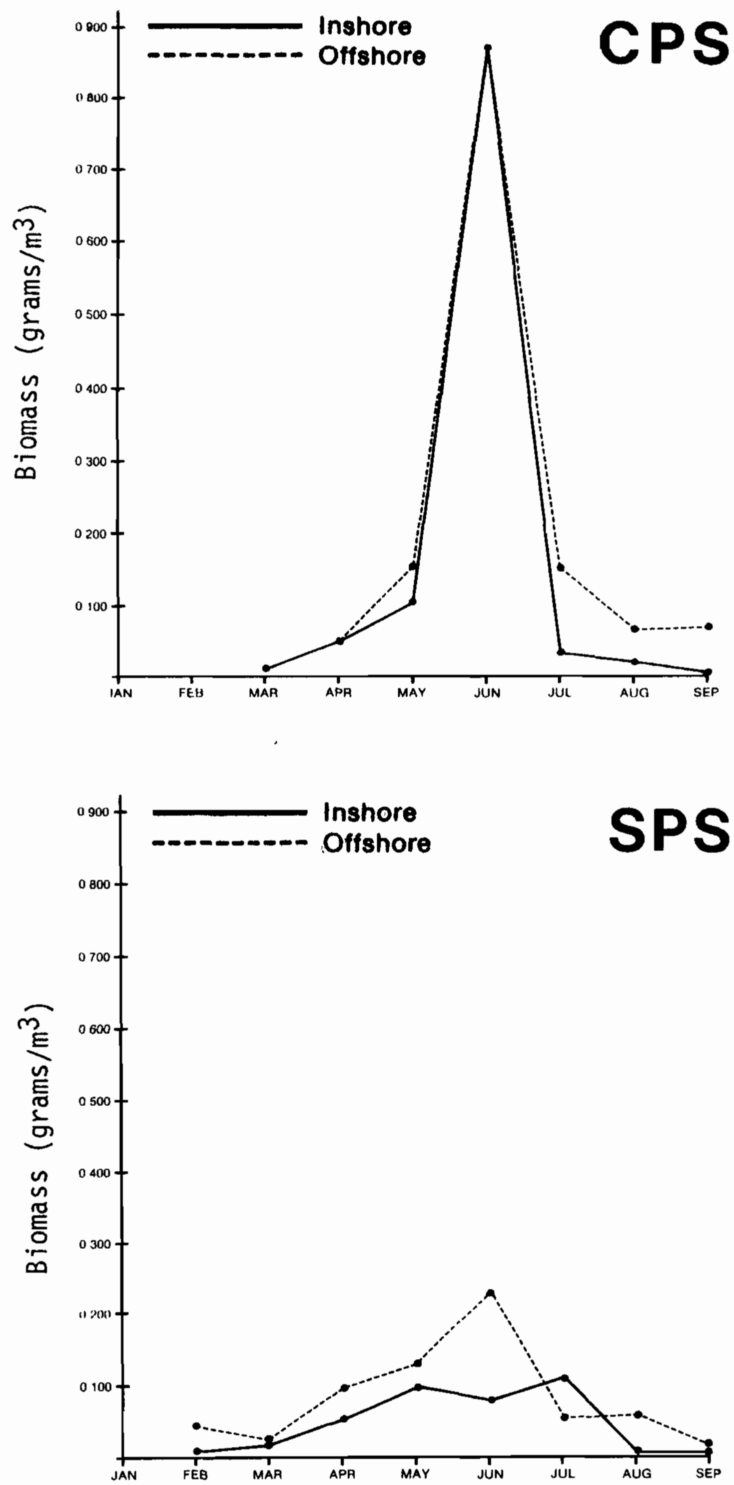


Fig. 17. Standing crop (gr/m$^3$) of nearshore surface pelagic zooplankton from inshore (~3-4m in depth) and offshore (~20-25m in depth) tows in CPS (upper) and SPS (lower), February - September 1979.

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# APPENDIX 1

## Scientific Classification of Invertebrates Recorded From Zooplankton Samples and Stomach Contents

Appendix 1. Taxonomic list of invertebrates identified from zooplankton samples and stomach contents.

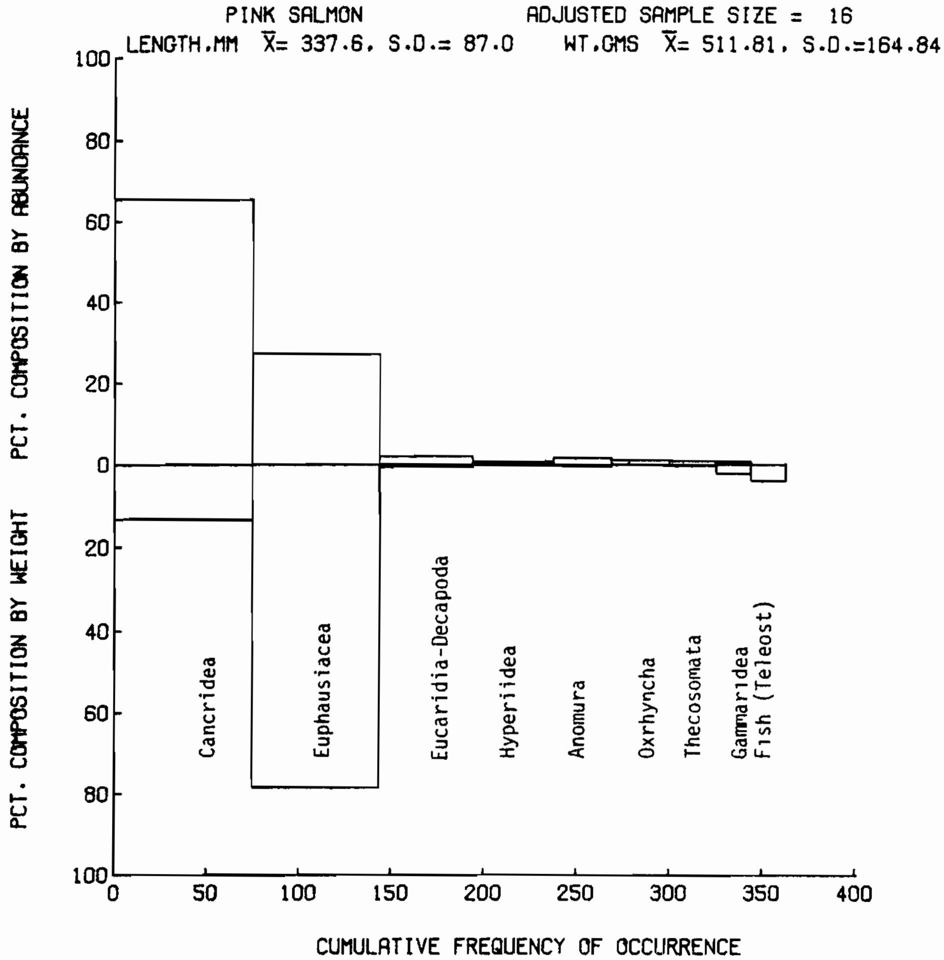
| Scientific Classification | Common Name |
|---|---|
| Phylum Cnidaria | Coelenterates |
| Class Hydrozoa | |
| Genus _Velella_ | "purple sailor" |
| Class Scyphozoa | |
| Class Anthozoa | |
| Phylum Ctenophora | |
| Phylum Nematoda | Round worms |
| Phylum Mollusca | |
| Class Gastropoda | |
| Order Mesogastropoda | Snails |
| Genus _Littorina_ | |
| Order Thecosomata | Sea butterflies |
| Class Bivalvia | Clams, oysters |
| Class Cephalopoda | |
| Subclass Coleoidea | |
| Genus _Loligo_ | Squids |
| Genus _Octopus_ | Octopus |
| Phylum Annelida | Segmented worms |
| Class Polychaeta | |
| Subclass Errantia | |
| Family Syllidae | |
| Genus _Autolytus_ | |
| Family Nereidae | |
| Genus _Platynereis_ | |
| Subclass Sedentaria | |
| Family Spionidae | |
| Family Opheliidae | |
| Phylum Arthropoda | |
| Class Arachnida | Spiders, mites |
| Order Araneae | Spiders |
| Class Crustacea | |
| Subclass Branchiopoda | |
| Order Cladocera | Water fleas |
| Genus _Podon_ | |
| Subclass Ostracoda | Mussel or seed shrimp |
| Order Myodocopa | |
| Subclass Copepoda | Copepods |
| Order Calanoida | Calanoids |
| Genus _Calanus_ | |
| Genus _Eucalanus_ | |
| Genus _Paracalanus_ | |
| Genus _Aetidius_ | |
| Genus _Metridia_ | |
| Genus _Epilabidocera_ | |
| Genus _Acartia_ | |
| Genus _Candacia_ | |

| | |
|---|---|
| Order Harpacticoida | Harpacticoids |
| Order Cyclopoida | |
| Genus *Oncaea* | |
| Genus *Corycaeus* | |
| Order Monstrilloida | |
| Order Caligoida | |
| Subclass Cirripedia | Barnacles |
| Suborder Balanomorpha | Sessile barnacles |
| Genus *Balanus* | |
| Subclass Malacostraca | |
| Order Mysidacea | |
| Family Mysidae | Opossum shrimp |
| Genus *Boreomysis* | |
| Order Cumacea | |
| Genus *Cumella* | |
| Order Tanaidacea | |
| Order Isopoda | |
| Suborder Epicaridea | |
| Suborder Flabellifera | |
| Order Amphipoda | |
| Suborder Hyperiidea | |
| Genus *Parathemisto* | |
| Genus *Hyperia* | |
| Suborder Gammaridea | Sand fleas |
| Genus *Calliopius* | |
| Genus *Corophium* | |
| Genus *Anisogammarus* | |
| Genus *Paraphoxus* | |
| Genus *Accedomoerra* | |
| Suborder Caprellidea | |
| Genus *Caprella* | |
| Superorder Eucaridia | |
| Order Euphausiacea | Krill |
| Family Euphausiidae | |
| Genus *Euphausia* | |
| Genus *Thysanoessa* | |
| Order Decapoda | |
| Suborder Natantia | Shrimps, crabs |
| Section Penaeidea | Shrimps |
| Section Pleocyemata-Caridea | |
| Family Hippolytidae | |
| Genus *Heptacarpus* | |
| Family Pandalidae | |
| Genus *Pandalus* | |
| Genus *Pandalopsis* | |
| Family Crangonidae | |
| Genus *Crangon* | Sand shrimps |
| Section Anomura | Crabs |
| Family Callianassidae | |
| Genus *Callianassia* | |

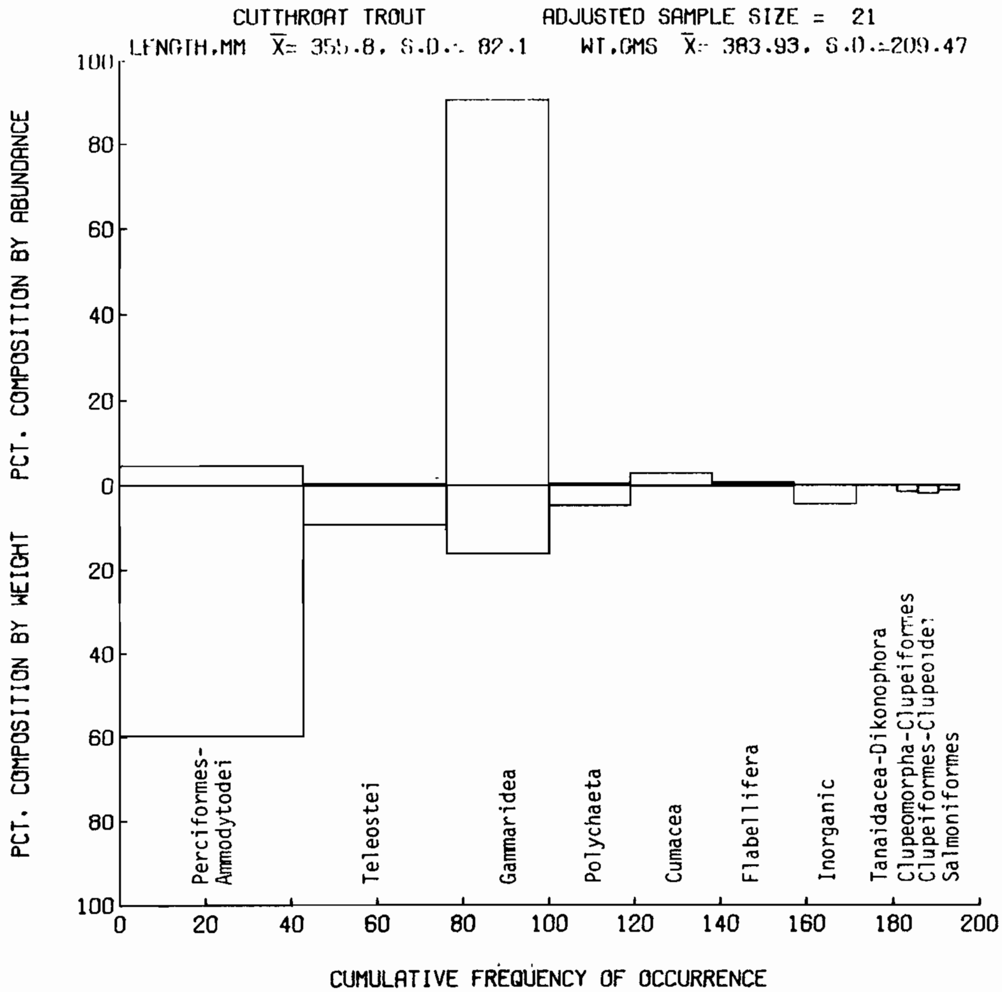
| | |
|---|---|
| Family Paguridae | Hermit crabs |
| Genus <u>Pagurus</u> | |
| Section Brachyura | True crabs |
| Infrasubsection Brachyrhyncha | |
| Family Cancridae | Cancer crab |
| Genus <u>Cancer</u> | |
| Family Pinnotheridae | Pea crabs |
| Infrasubsection Oxyrhyncha | Decorator crabs |
| Family Majidae | |
| Class Insecta | Insects |
| Order Ephemeroptera | Mayflies |
| Order Isoptera | Termites |
| Order Plecoptera | Stone flies |
| Order Psocoptera | Lice |
| Order Homoptera | Aphids |
| Family Psyllidae | |
| Order Neuroptera | Alder flies |
| Order Diptera | True flies |
| Family Chironomidae | Midges |
| Order Hymenoptera | Ants, bees, wasps |
| Phylum Chaetognatha | |
| Genus <u>Sagitta</u> | Arrow worms |
| Phylum Chordata | |
| Subphylum Urochordata | |
| Class Larvacea | |
| Genus <u>Oikopleura</u> | Tunicates |

# APPENDIX 2

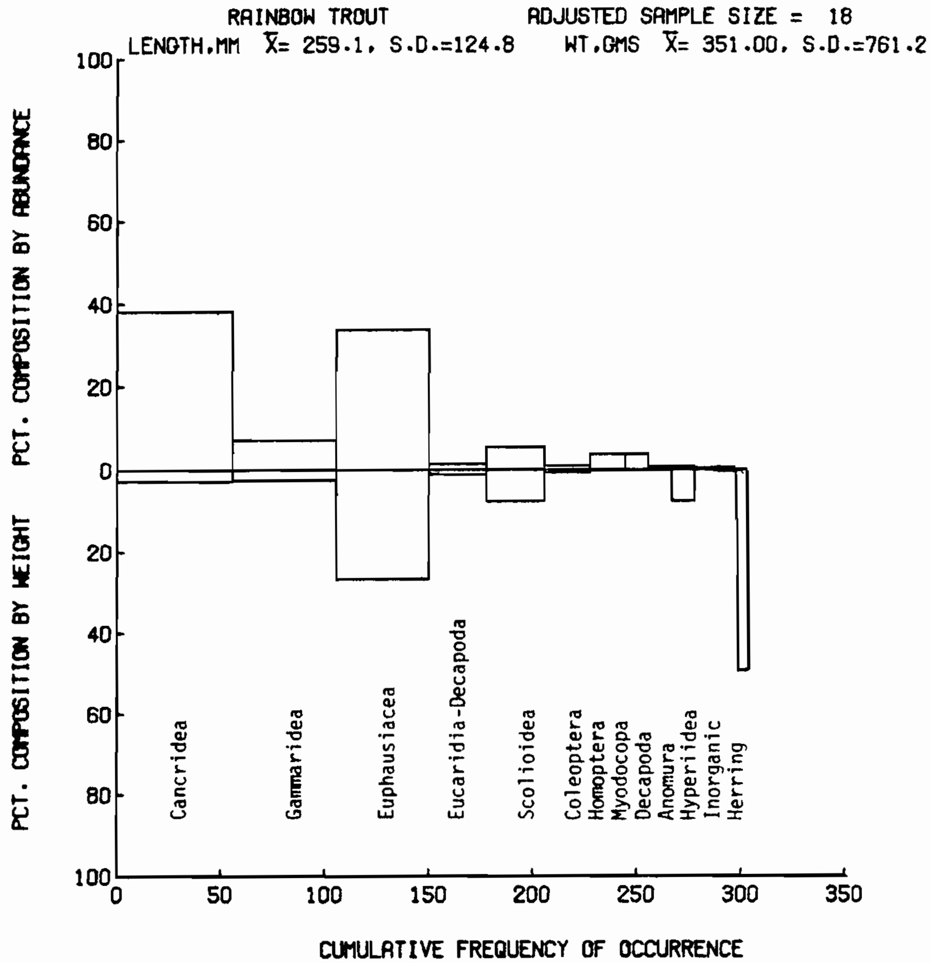
## Prey Spectra of Other Marine Fish Species From Puget Sound



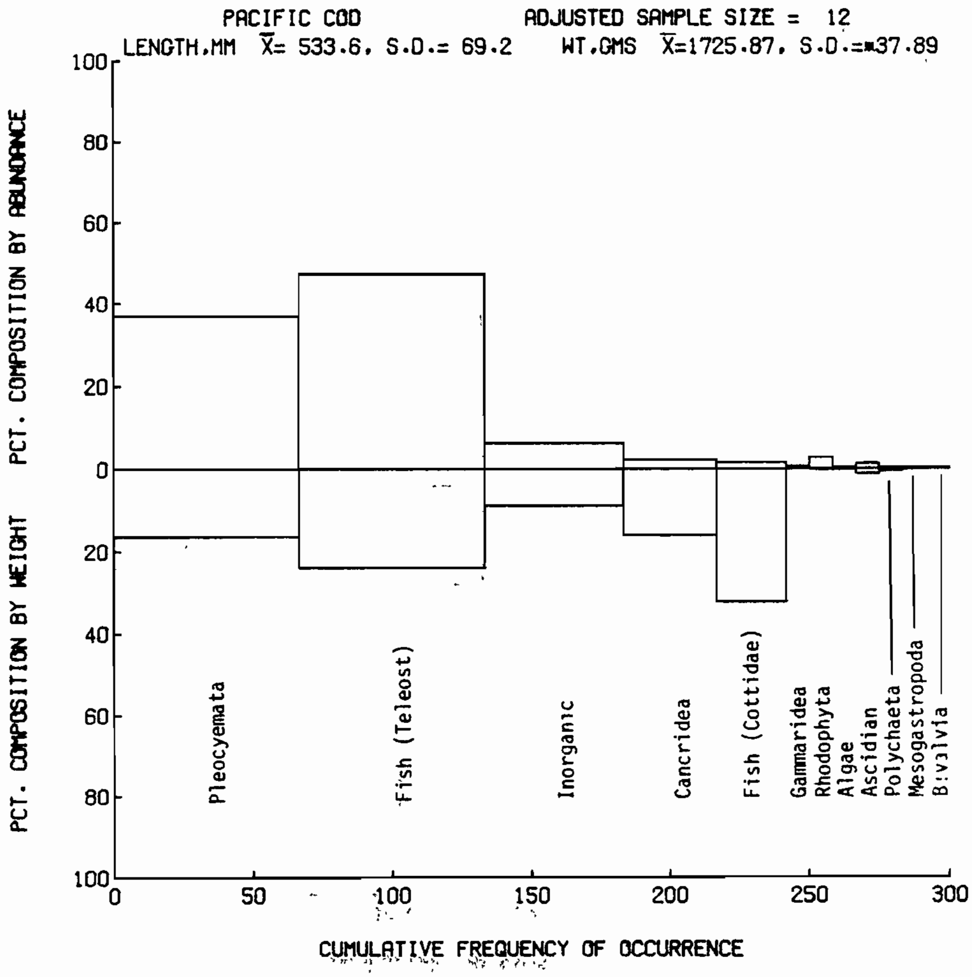

Appendix Fig. 2-A. Prey spectrum of pink salmon caught in Puget Sound broken down by percent numeric and gravimetric composition and prey freauency of occurrence, February-June 1979.



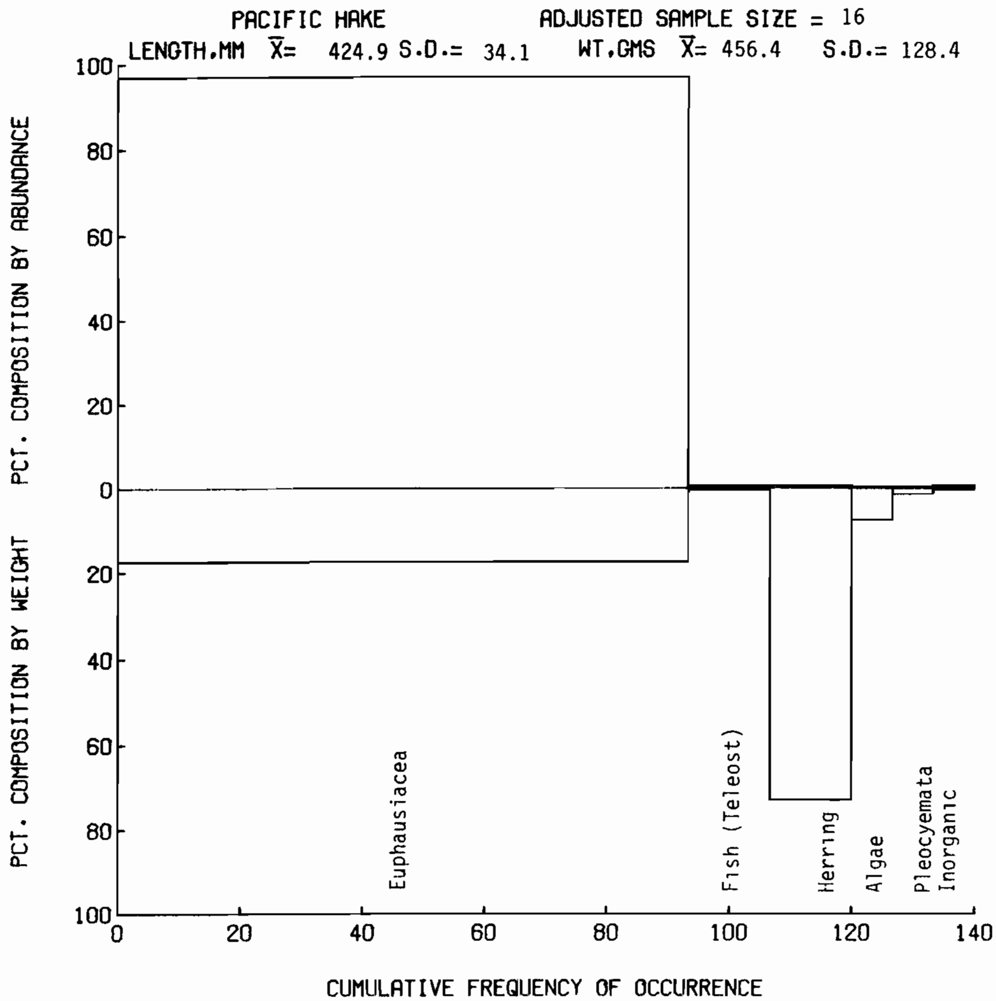

Appendix Fig. 2-B. Prey spectrum of cutthroat trout caught in Puget Sound broken down by percent numeric and gravimetric composition and prey frequency of occurrence, February- August 1979.



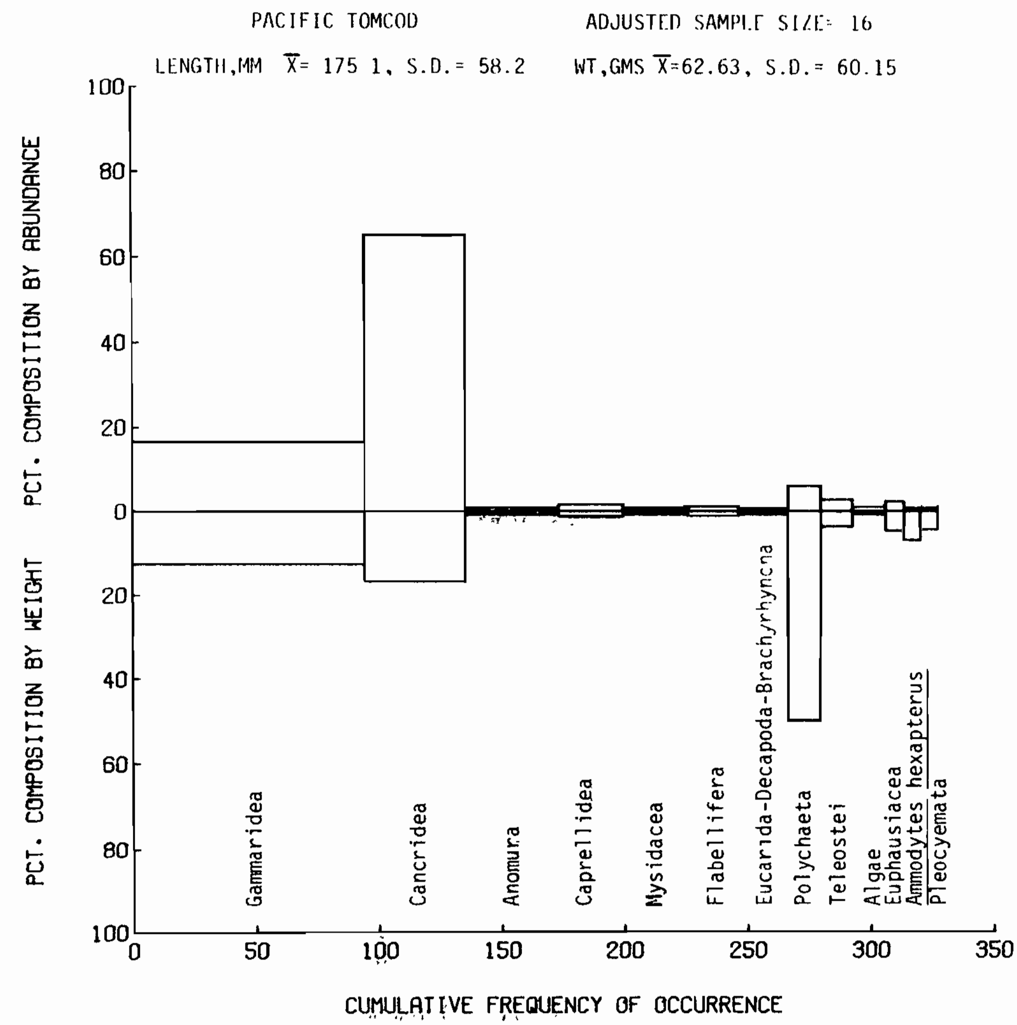

Appendix Fig. 2-C. Prey spectrum of steelhead (rainbow) trout caught in Puget Sound broken down by percent numeric and gravimetric composition and prey frequency of occurrence, February- August 1979.



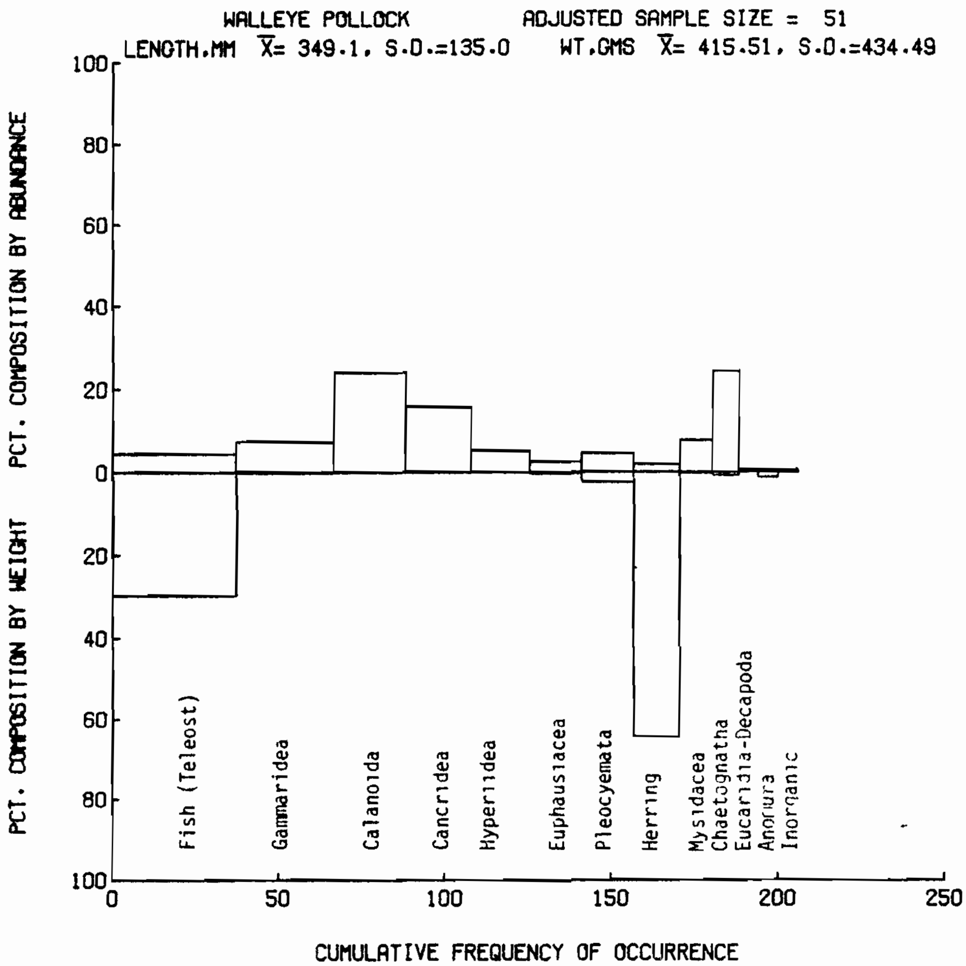

Appendix Fig. 2-D. Prey spectrum of Pacific cod caught in Puget Sound broken down by percent numeric and gravimetric composition and prey frequency of occurrence, February-June 1979.



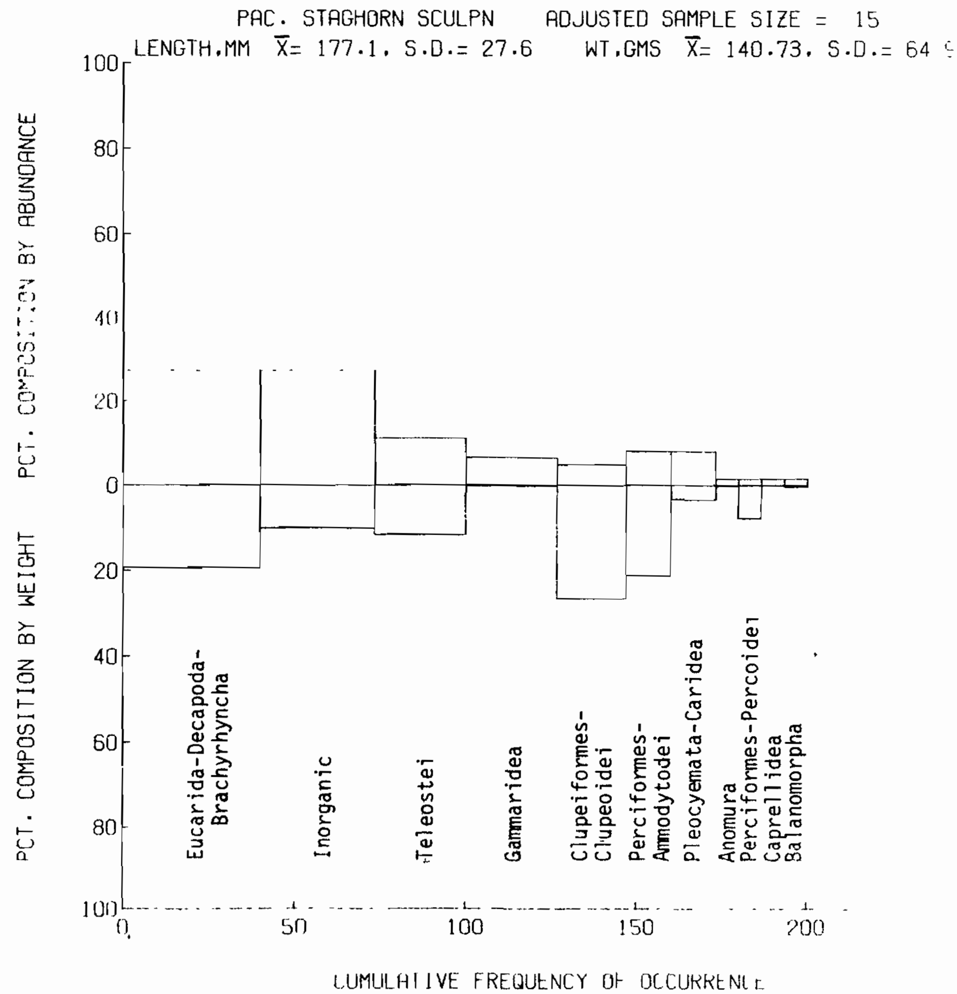

Appendix Fig. 2-E. Prey spectrum of Pacific hake caught in Puget Sound broken down by percent numeric and gravimetric composition and prey frequency of occurrence, February-August 1979.




Appendix Fig. 2-F. Prey spectrum of Pacific tomcod caught in Puget Sound broken down by percent numeric and gravimetric composition and prey frequency of occurrence, February-August 1979.




Appendix Fig. 2-G. Prey spectrum of walleye pollock caught in Puget Sound broken down by percent numeric and gravimetric composition and prey frequency of occurrence, February- August 1979.




Appendix Fig. 2-H. Prey spectrum of Pacific staghorn sculpin caught in in Puget Sound broken down by percent numeric and gravimetric compostion and prey frequency of occurrence, February- August 1979.