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JUVENILE SALMONID AND BAITFISH DISTRIBUTION, ABUNDANCE, AND PREY RESOURCES IN SELECTED AREAS OF GRAYS HARBOR, WASHINGTON

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ABSTRACT

Between March and October 1980, the Fisheries Research Institute conducted comprehensive studies on juvenile salmonids, English sole, and baitfish and their epibenthic and neritic prey communities in Grays Harbor in order to evaluate the potential effects of dredging proposed for widening and deepening the existing navigation channel. The objectives of this research were to: (1) determine the temporal and spatial distribution and abundance of juvenile salmonids and baitfish in several habitats throughout the estuary; (2) determine the prey organisms most important to juvenile chinook and chum salmon, steelhead trout, and English sole during their estuarine residence; (3) determine the abundance of fish and Dungeness crab larvae and other neritic prey of juvenile salmonids at several times and locations in Grays Harbor; (4) determine the composition and abundance of epibenthic meio- and macroinvertebrate assemblages at one time and location; (5) determine whether or not Pacific herring spawning occurs in eelgrass beds in the vicinity of the navigation channel; and (6) evaluate the potential effects of the proposed dredging project on these important resources. Juvenile salmonids, English sole, and baitfish were sampled in shallow sublittoral and lower littoral habitats by beach seine, and in neritic habitats by purse seines. Neritic and epibenthic zooplankton were sampled with 60-cm bongo nets and an epibenthic suction pump, respectively.

Juvenile salmonids were present in Grays Harbor throughout the eight-month sampling period, chums migrated through the estuary between March and mid-May, coho between mid-April and late June, chinook between early April and the end of the sampling period in late October, and steelhead between mid-May and late July. Yearling English sole were also present in shallow sublittoral and lower littoral habitats throughout the sampling period, the apparent 1979 age class emigrating from the estuary by early July and young-of-the-year recruiting into the estuary through late May. Seven species of baitfish were captured, but only four species or life history stages--adult and juvenile northern

anchovy, juvenile Pacific herring, and juvenile longfin smelt--were consistently abundant over the sampling period to indicate extended residence and utilization of the estuary. Only Pacific herring and longfin smelt appear to be directly associated with the estuary during reproduction and subsequent early life history development. While no evidence of spawning by adult Pacific herring was found in the vicinity of the existing navigation channel, the abundance of larvae and postlarvae suggests that spawning probably occurred in other regions of the estuary or prior to the initiation of sampling in March or subsequent to the termination of sampling in early June.

Quantitative stomach analyses of juvenile salmonids and English sole indicated that they fed mainly in the epibenthic and neritic habitats in which they were captured. Fishes occupying shallow sublittoral or lower littoral habitats fed mainly on epibenthic crustaceans--primarily harpacticoid copepods, cumaceans, and gammarid amphipods--while those captured in neritic habitats tended to be larger in size and fed upon more pelagic prey such as larval northern anchovy and drift insects.

The epibenthic zooplankton community in the shallow sublittoral and lower littoral habitat at Moon Island in May was dominated by harpacticoid and calanoid copepods and was found to vary in structure and standing stock with tidal stage, increasing during flood tides presumably because of the influx of exogenous neritic zooplankters and the resuspension of endogenous epibenthic animals. The neritic zooplankton community was dominated numerically by barnacle larvae and calanoid copepods and gravimetrically by sand shrimp, mysids, and calanoid copepods. Standing stock estimates illustrated three sustained declines--in May, July, and September. Three sources--riverine, estuarine, and marine--of neritic zooplankters were identified, the true estuarine assemblages being the most abundant in the inner estuary between Moon Island and Cow Point.

Potential impacts of the proposed dredging project were considered to be either a direct reduction in the fish populations as a result of dredging operations or an indirect reduction of the carrying capacity by removal of preferred habitat or alteration of migration or residence patterns. Of the indirect effects assessed in this report, only the permanent loss of shallow sublittoral habitat, estimated to involve 1.1% of the total sublittoral habitat in the estuary, may be deleterious particularly to juvenile chinook and chum salmon, and young-of-the-year English sole, which forage and rear almost exclusively in this habitat in Grays Harbor.

1.0 INTRODUCTION

by Charles A. Simenstad

1.1 History of Study of Juvenile Salmonids, Baitfish and English Sole and Their Prey Resources in Grays Harbor

The Seattle District, U.S. Army Corps of Engineers has proposed a project to widen and deepen the existing navigation channel in Grays Harbor, Washington. The proposed plan includes modifying the size of (1) the existing 4.8-km channel across the outer bar from 183 meters by 9.2 meters to 366 meters by 14.6 meters, (2) the existing 4.8-km estuary channel from 91.5 meters by 9.2 meters to 122 meters by 12.2 meters, and (3) the 29-km channel up the Chehalis River to Cosmopolis from 61 meters by 9.2 meters to 122 meters by 12.2 meters.

Environmental studies initiated by the Corps of Engineers to assess the impact of the proposed widening and deepening project include research programs on the biological resources, estuarine and upstream aquatic habitats, water quality and circulation, sediment chemistry, primary productivity, and culture resources of the estuary. The Fisheries Research Institute (FRI), University of Washington, conducted comprehensive studies on juvenile salmonids, baitfish, and English sole and their prey communities in Grays Harbor in order to evaluate the potential effects of dredging on these resources.

1.2 Study Objectives

The objectives of this study were to:

a. Determine the temporal and spatial distribution and abundance of juvenile salmonids (genus *Oncorhynchus*) and baitfish in several habitats that could be affected by the proposed alterations to the navigation channel;

b. Determine the food items most important to juvenile chinook (*O. tshawytscha*), and chum salmon (*O. keta*), steelhead trout (*Salmo gairdneri*), and English sole (*Parophrys vetulus*) during their residence in Grays Harbor;

c. Determine the abundance of fish larvae, Dungeness crab larvae, and other juvenile salmonid food items in the plankton at several times and locations in the waters of Grays Harbor;

d. Determine the composition and abundance of epibenthic meio- and macroinvertebrate assemblages at one location in Grays Harbor; and

e. Determine whether or not Pacific herring (*Clupea harengus pallasi*) spawning occurs in eelgrass beds in the vicinity of the navigation channel in Grays Harbor.

f. Evaluate the potential effects of the proposed dredging project on the resources and parameters listed in a-e.

In addition to these objectives, we designed the study to elucidate the functional relationship of juvenile salmonid and English sole populations to the dynamics of the estuary, including the availability of prey resources in different estuarine habitats. We hoped that, in the final synthesis of the total information base, we might be able to generate hypotheses about the factors affecting migration rate, behavior, and residence time of these fishes in Grays Harbor in relation to habitats and sites of concern.

1.3 Description of Study Area

Grays Harbor estuary is located on the southwest coast of Washington State (Fig. 1-1). It covers an area of 23,504 hectare (at MHHW from mouth to Montesano) and was formed by the drowning of the seaward portion

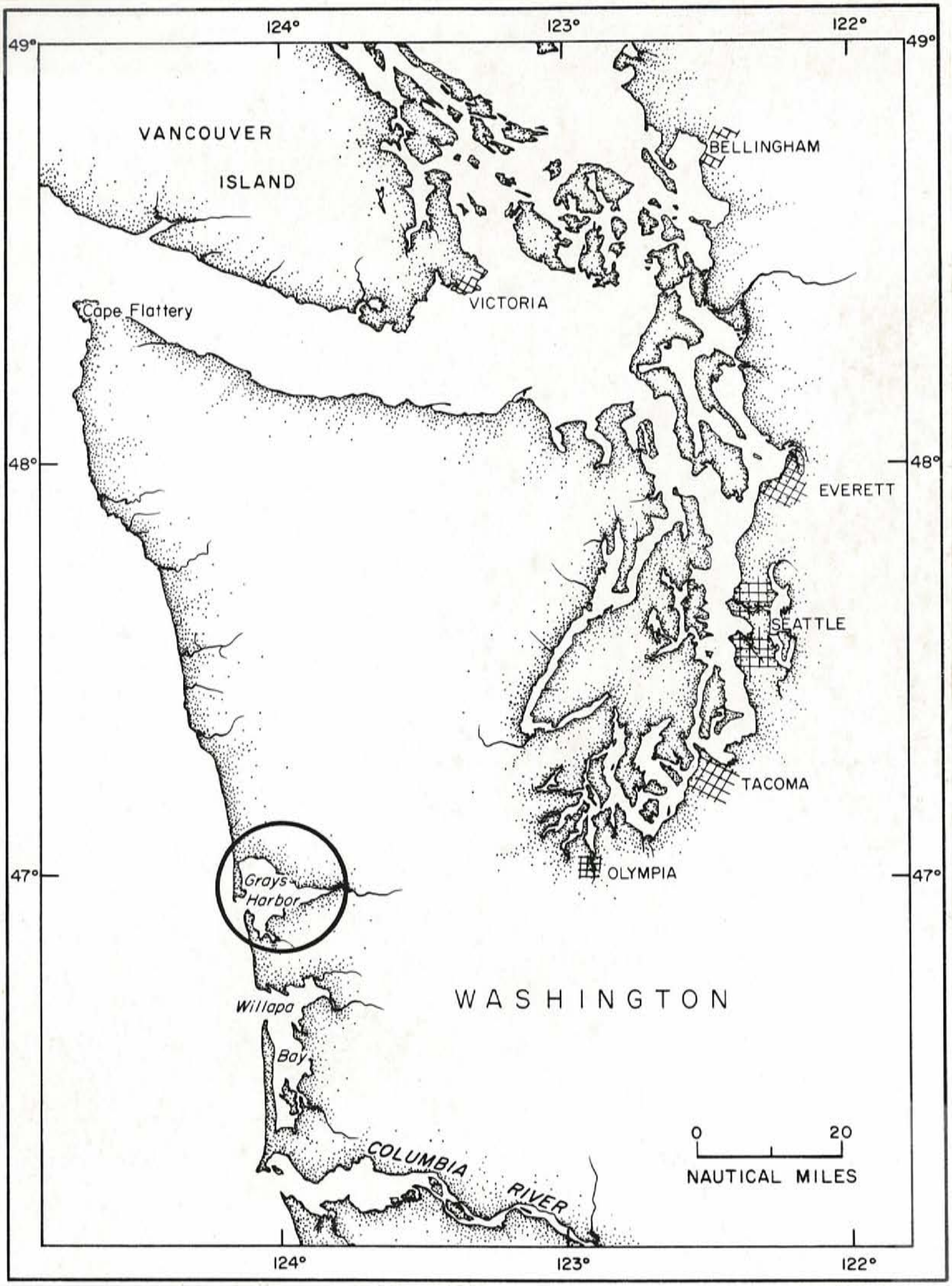

Fig. 1-1. Location of Grays Harbor on the southwest coast of Washington State.

of the Chehalis River Delta (Loehr and Collias 1981). Six watersheds, of the Chehalis, Humptulips, Hoquiam, Wishkah, Johns and Elk rivers, drain into Grays Harbor, accounting for the extensive system of mudflats and intervening channels (Fig. 1-2). Loehr and Collias (1981) characterized two major areas in the estuary based on water characteristics data: the outer harbor extending from the entrance to the Pacific Ocean east to Point New and the inner harbor extending eastward from Point New to Cosmopolis. The course of the Chehalis River, the major tributary to Grays Harbor, is divided into two major channels (the North and South Channels) within the estuary.

1.4 History of Previous Investigations

Published information concerning the biological resources or ecological processes characterizing Grays Harbor is meager. Smith et al. (1980) conducted an extensive literature review and documented that little quantitative data exist for neritic zooplankton and fish and demersal fish in the region of Grays Harbor, while essentially no data was described for the estuary itself.

Despite the economic importance of anadromous salmonids in Grays Harbor, little comprehensive information exists on the distribution and abundance of outmigrating juveniles. Tokar and Tollefson (1969) reported upon the abundance and stomach contents of juvenile chinook salmon captured in the vicinity of Moon Island when low dissolved oxygen levels were present; Tokar et al. (1970) described an expanded beach seine survey of juvenile salmonids in the estuary, encompassing seven locations sampled through almost a year's time.

Deschamps et al. (1971) also described an inventory conducted in the lower Chehalis River and upper Grays Harbor which documented that chinook, coho and chum salmon and cutthroat and steelhead trout were important species utilizing the inner estuary.

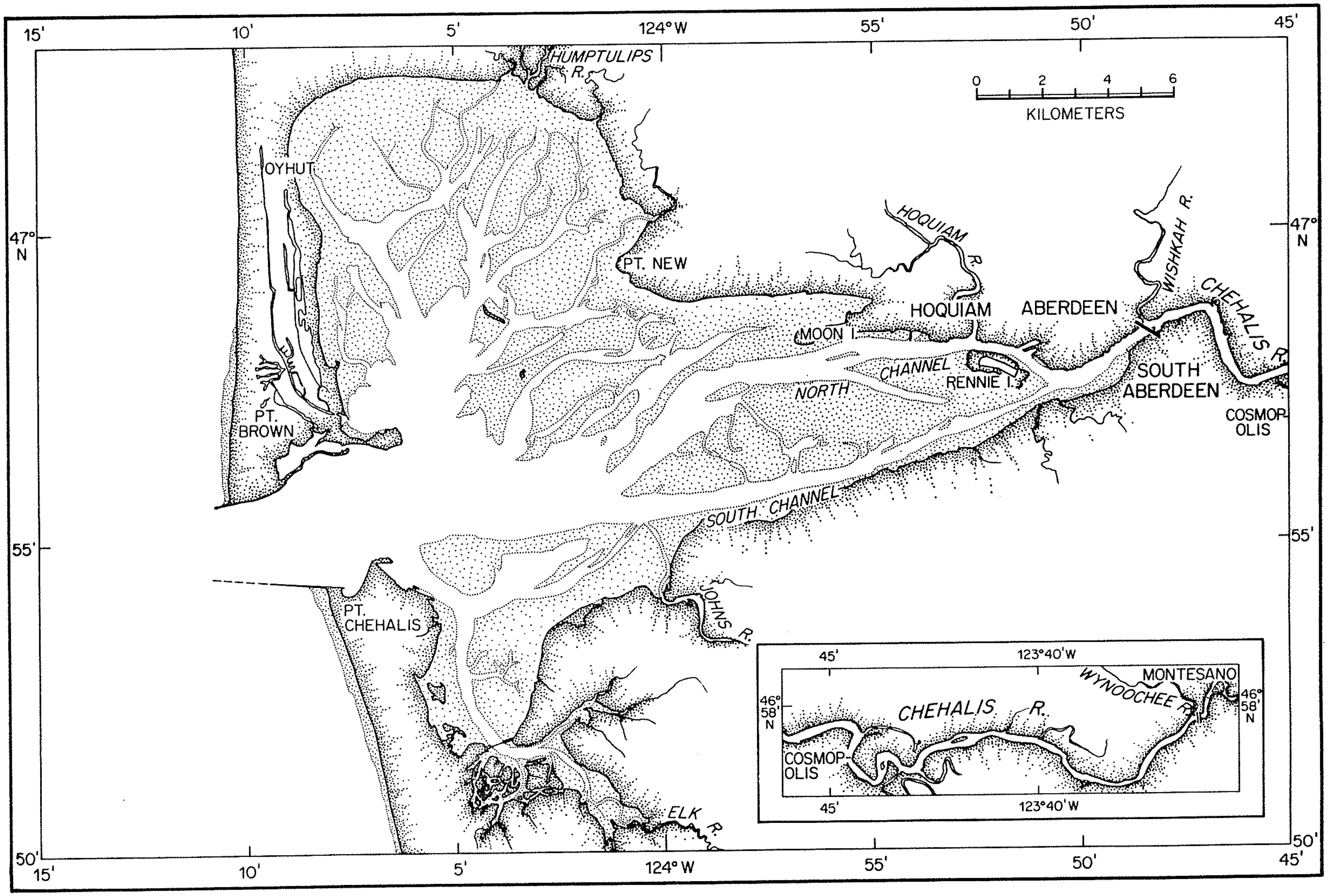

Fig. 1-2. Detailed map of Grays Harbor, illustrating principal features of the estuary. Stippled area represents littoral mudflats exposed at MLLW.

Herrmann (1971) provided the earliest information available on the food habits of juvenile salmonids migrating through the estuary.

Data on the abundance, life history stages and sizes of fish, specifically juvenile salmonids, at Moon Island in the upper estuary during 1973 and 1974 was contained within reports by Brix (1974), Brix et al. (1974), and Wolfe and Moore (1973, 1974).

Smith et al. (1976) assembled one of the more extensive studies of fishes in Grays Harbor, documenting the species composition, relative abundance and distribution and food habits of the fish assemblages in the estuary; they concluded that Grays Harbor constitutes an important spawning and nursery area for many of the 53 species of fish which they documented.

While quantitative data are available for benthic (infaunal) invertebrate communities off the mouth (Smith et al. 1980) and within Grays Harbor (Wolfe and Moore 1973, 1974; Wolfe et al. 1974; Smith et al. 1976) there is no information on either community structure or standing stock of epibenthic invertebrates, especially meiofauna, in shallow sublittoral or lower littoral habitats in the estuary, where many of the outmigrating juvenile salmonids are known to feed. Data on the distribution and relative abundance of some important epibenthic organisms--gammarid amphipods, cumaceans, tanaids, isopods--as infauna were included in the reports listed above and, although they were not necessarily indicative of the epibenthic populations, they did provide some qualitative information on the larger components of the epifaunal invertebrate community in the estuary.

Appendix tables and figures referenced in this report are included in a separate data report, Simenstad 1981; a total fish species list is included as Appendix Table 1-1.

1.5 Acknowledgments

Many individuals contributed to the successful execution and completion of the Grays Harbor Studies. Although we wish to gratefully acknowledge all those who contributed their time and effort, we would like to especially thank a select group of individuals who were instrumental in the field and laboratory research. Andrew Palmer operated and maintained the R/V *Monty Python* zooplankton sampling boat and assisted in all phases of the field operations. Coleman Lawrence, Greg Jensen and Jay Nelson processed the multitude of fish captured in the estuary and returned to the laboratory for detailed examination and, in some cases, also assisted in the fieldwork. Robert Lake contracted to provide his boat, the F/V *Mako*, for the purse seining operations and maintained it through many hard operating hours conducting our sampling.

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2.0 PHYSICAL ENVIRONMENT

by Charles A. Simenstad, Thomas E. Prinslow, and K. Michael McDowell

2.1 Introduction

Grays Harbor fits the classical definition of an estuary, a semi-enclosed coastal water body which has free access to the sea; the water in which is measurably diluted below the salinity of open ocean water by freshwater associated with land runoff. Freshwater input into Grays Harbor closely follows the local precipitation. The 660,450 hectare drainage basin of the six watersheds (i.e., Chehalis, Humptulips, Hoquiam, Wiskah, Johns, and Elk) combined is little affected by snowmelt runoff from the Olympic Mountains located to the north (Loehr and Collias 1981); seventy-nine percent of the total drainage basin area is made up by the Chehalis River watershed. Maximum runoff of approximately 850 m^3 sec^{-1} occurs in December and January while minimum runoff of below 70 m^3 sec^{-1} occurs from June through September. Tidal action produces a saltwater wedge extending to within approximately 9.7 km of Montesano during low flow periods (estimated from Figs. 3-9 and 3-10; from Loehr and Collias 1981). Coastal upwelling, which tends to develop during the summer when river flow is low, can result in cold, saline, nutrient-rich water of oceanic origin with a low dissolved oxygen content entering Grays Harbor (Loehr and Collias 1981).

This section documents the variations in water temperature, salinity, dissolved oxygen (DO) and concentration of suspended solids at the biological sampling sites during this study. As such, they should only be considered from the standpoint of describing the environmental conditions at the time of the collection of fish and zooplankton. A detailed review of the water characteristics of Grays Harbor over 40 years (1938-1979), with a discussion of the various processes affecting these variables, is available in Loehr and Collias (1981).

2.2 Materials and Methods

The method of fish or zooplankton collection used at each of the sites determined which water quality parameters were measured and the depth of measurement of water from which these measurements were made. During each collection at shallow sublittoral beach seine sites--Sand Island, Cow Point, Moon Island, Stearn's Bluff, and Westport--subsurface (0-1 m deep) water temperature and salinity were measured in situ at approximately low slack tide using a Beckman electrode inductor salinometer. At the purse seine sites-Cosmoplis, Cow Point, Moon Island, Stearn's Bluff, and Westport--water temperature and salinity were measured at approximately high slack tide in situ at subsurface, mid-depth, and at the bottom of the water column. Temperature was recorded to the nearest 0.1°C, and salinity to the nearest 0.1°/oo (ppt). Dissolved oxygen and suspended solids samples were collected using a VanDorn water bottle. The DO sample was immediately fixed according to the azide modification of the Winkler method (American Public Health Association et al. 1976). These samples were kept cool until titrated in the laboratory (less than one week after collection) and the percentage oxygen supersaturation determined according to:

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

$$\text{Percent saturation} = 100 \times \frac{\text{DO level in mg/l (titrated value)}}{\text{Calculated saturation level (mg/l)}}$$

Suspended solids were measured as total nonfilterable residue (TNFR) and were determined by filtering water samples under suction through prewashed, dried and weighed Whatman 4.25-cm diameter GFC paper, dried at 103°C for 24 hr, then weighted to the nearest mg.

Water depth during sampling was determined using current NOAA tide tables (U.S. Dep. Commerce 1979).

2.3 Results

2.3.1 River Flows: While the rate of freshwater flow into Grays Harbor was not monitored by us during the course of the project, information from the U.S. Geological Survey[1] provided an indication of the freshwater input into the estuary. The mean of the daily estimated riverflow rate of the Chehalis River at Hoquiam during the weeks of biological sampling (Fig. 2-1) indicates a variable, though declining, rate during the early months of sampling; the maximum daily flow rate during this period was on the order of 880,000 m^3 sec^{-1}. Riverflow declined gradually from May through August, when a minimum daily rate of 27,800 m^3 sec^{-1} was estimated. A measurable increase was recorded in September during an otherwise gradual increase in riverflow rate between August and late October.

2.3.2 Temperature: Water temperatures at the shallow sublittoral[2] beach seine sites (Fig. 2-2) between March and October appeared to reflect both exogenous (i.e., river runoff, coastal upwelling) and endogenous (i.e., solar insolation) influences. Between March and July, except for brief declines in late March and May, the subsurface water temperatures steadily increased from minima of 5°C to 10°C to maxima of 16°C to 20°C with little intersite variation. Between July and October, however, the subsurface temperatures declined. A high degree of intersite variation was evident during this period. The riverine site at Sand Island tended to have lower temperatures than most of the other sites through the spring increase, but generally had the higher temperatures through the summer

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[1] U.S. Geological Survey, Water Resources Division, Tacoma; daily estimates of combined riverflow at Hoquiam.

[2] Shallow sublittoral is here defined as that region between 0.0 and -5.0 m tidal elevations.

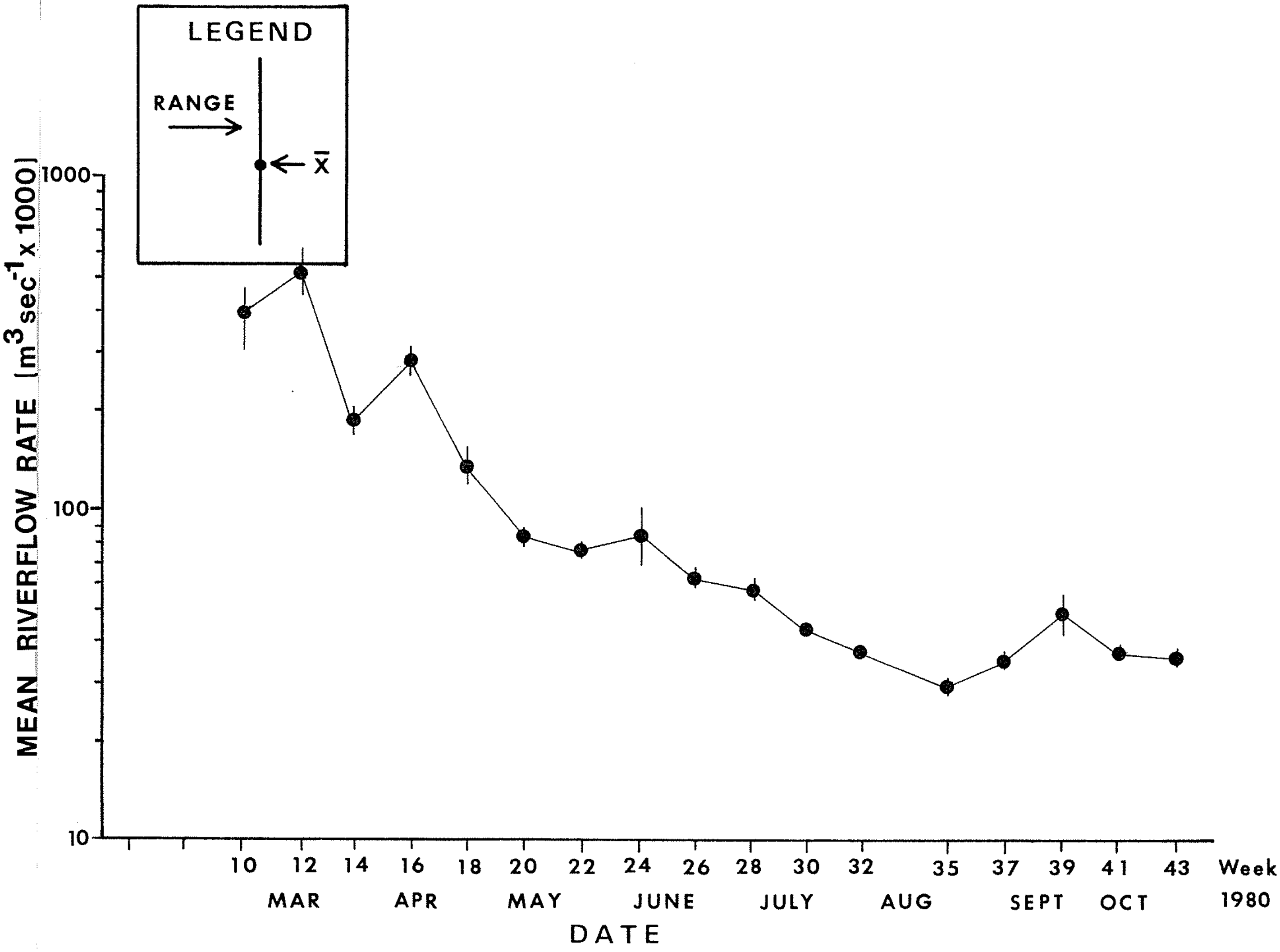

Fig. 2-1. River flow rate (m^3 sec^{-1}) of Chehalis River at Hoquium. Data based upon estimates provided by U.S. Geological Survey, Water Resources Division, Tacoma.

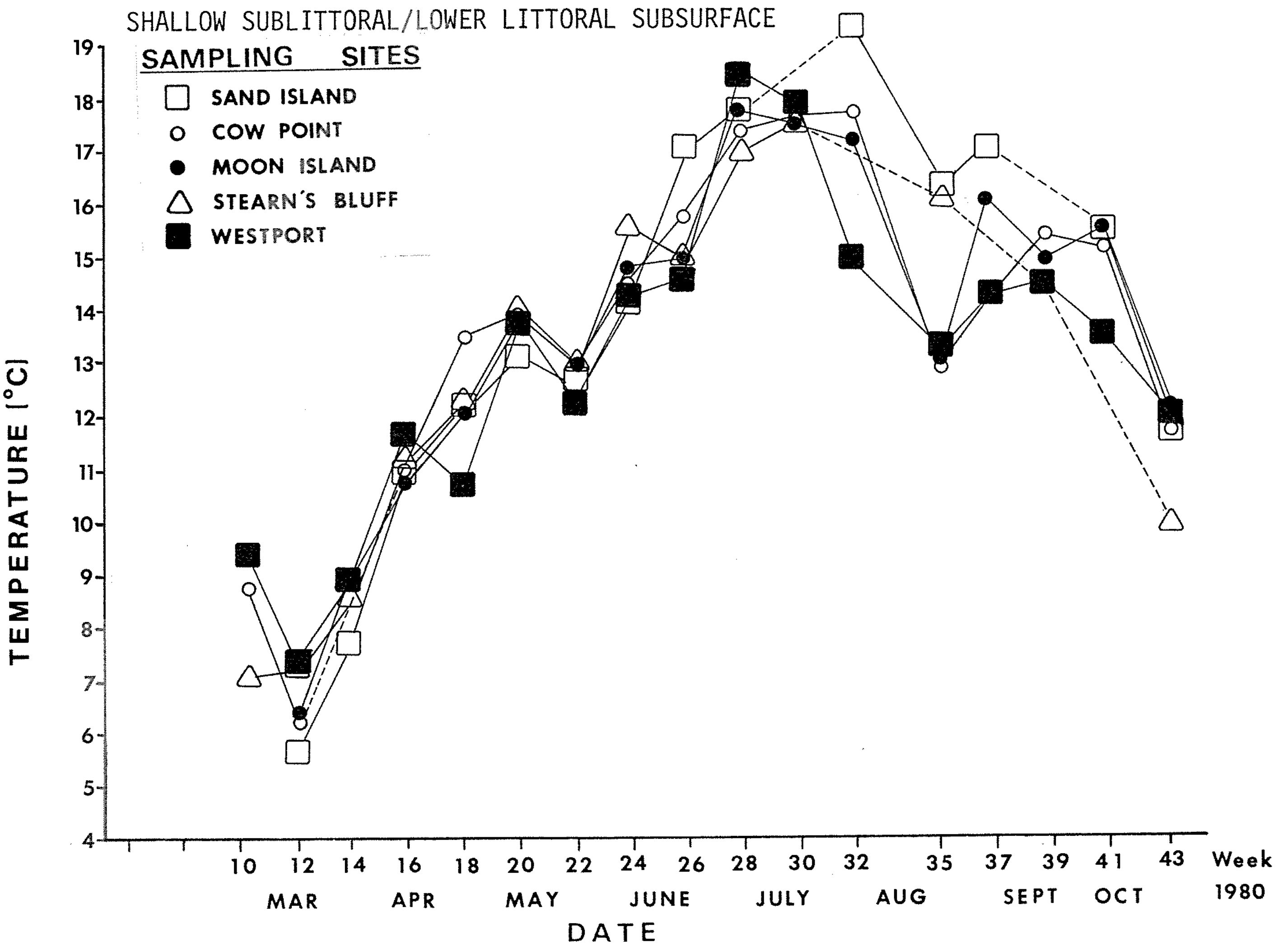

Fig. 2-2. Subsurface water temperatures ($^{\circ}C$) at five shallow sublittoral sampling sites in Grays Harbor, Washington, March-October 1980.

and early fall. This would seem to indicate that subsurface water temperatures in shallow sublittoral habitats are predominantly affected by riverine runoff during the winter and spring, while during low freshwater flow periods in the summer and fall the temperatures are a function of more variable factors such as tidal flows, entry of coastal upwelling water into the estuary, and solar insolation.

Subsurface, mid-depth and bottom water temperatures recorded at neritic sampling sites (Figs. 2-3 to 2-5) illustrate the same general relationships, with even more intersite variation evident during the low freshwater flow period. The outer-estuary sites at Stearn's Bluff and Westport typically had the lower temperatures at all three depth strata and often fluctuated the greatest between July and October. This was especially evident in Westport mid-depth and bottom temperatures, which were colder (by three to four °C) than the other sites between July and September. By October, despite relatively little change in the riverflow rate (Fig. 2-1), these temperatures had become more uniform.

2.3.3 Salinity: Salinity regimes at shallow sublittoral sites were relatively consistent, increasing throughout the period beteen March and October (Fig. 2-6). Site variability, however, was opposite that of the temperatures, in that intrasite variability was greater that intersite variability (rank order) and salinities appeared to be more variable during the period between March and July. As would be predicted, salinities decreased (almost proportionally) with the location of the sampling site moving up the estuary. The highest salinities recorded at Sand Island, the most upriver site, were during the low freshwater flow period in July and August.

Subsurface, mid-depth and bottom water salinities recorded at neritic sampling sites also illustrated trends similar to the shallow sublittoral salinities but tended to be more variable (intrasite) between March and June, but less variable (intersite) between July and October. The Cosmopolis sampling site also deviated significantly from the other

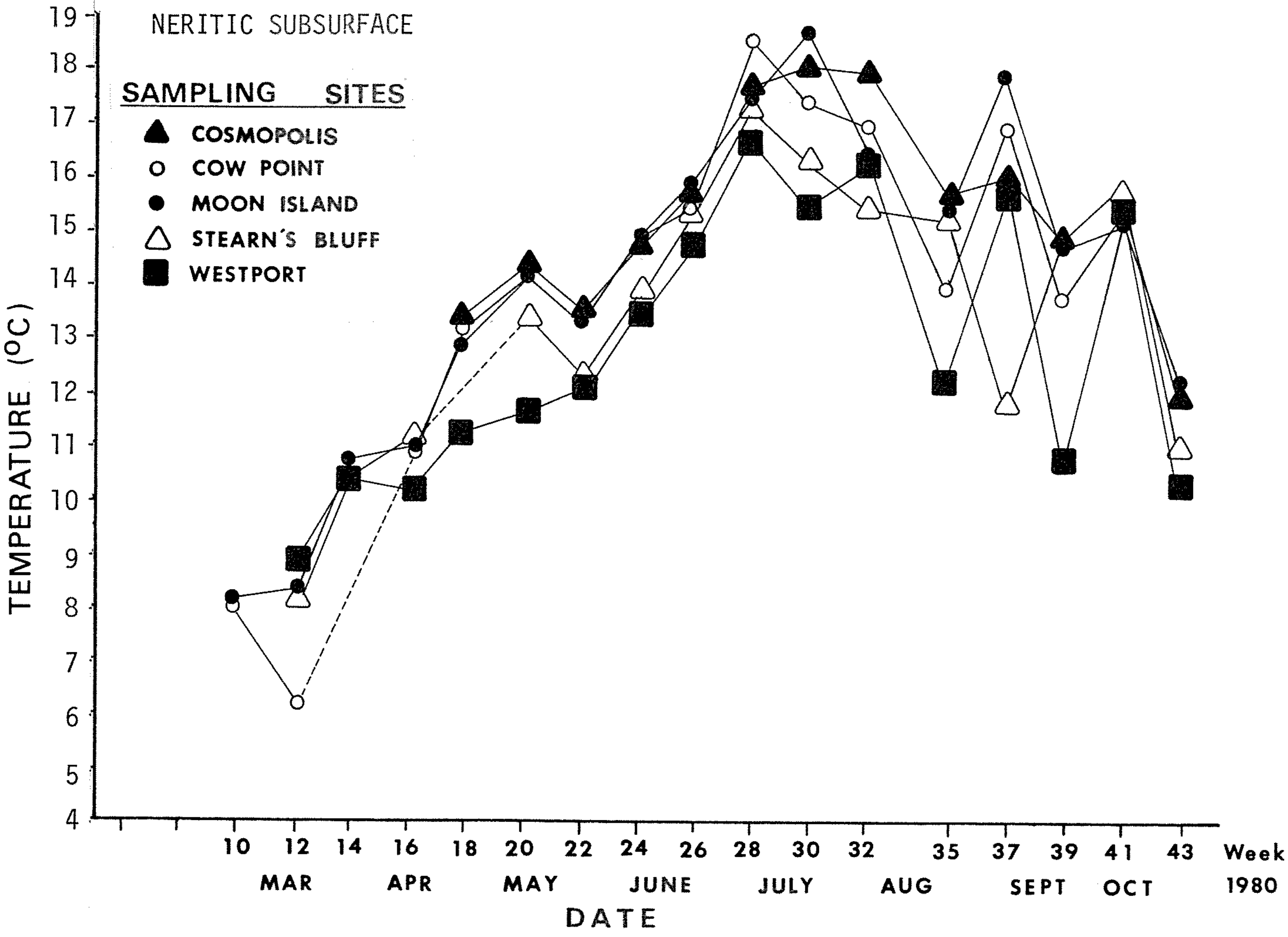

Fig. 2-3. Subsurface water temperatures (°C) at five neritic sampling sites in Grays Harbor, Washington, March-October 1980.

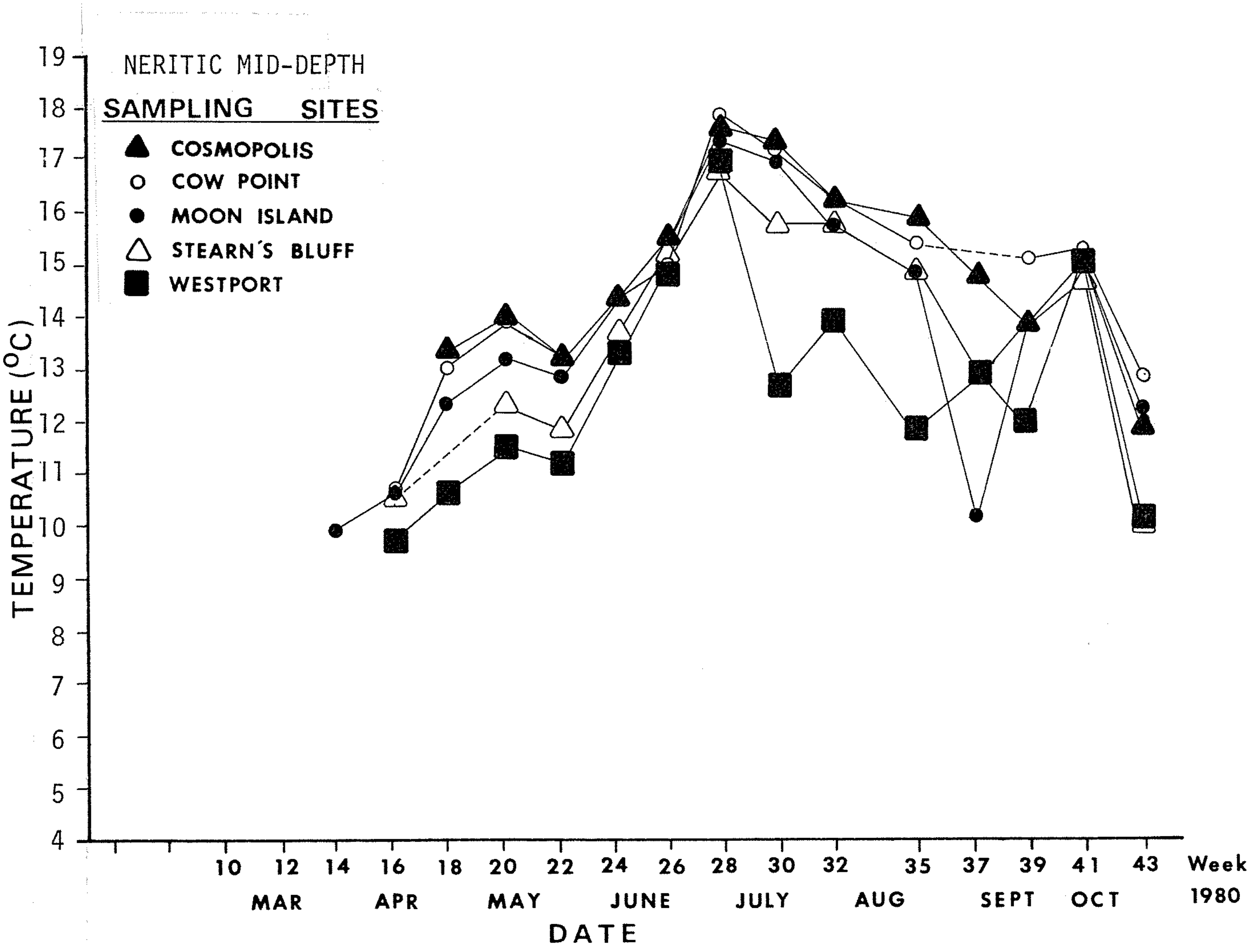

Fig. 2-4. Mid-depth water temperatures (°C) at five neritic sampling sites in Grays Harbor, Washington, March-October 1980.

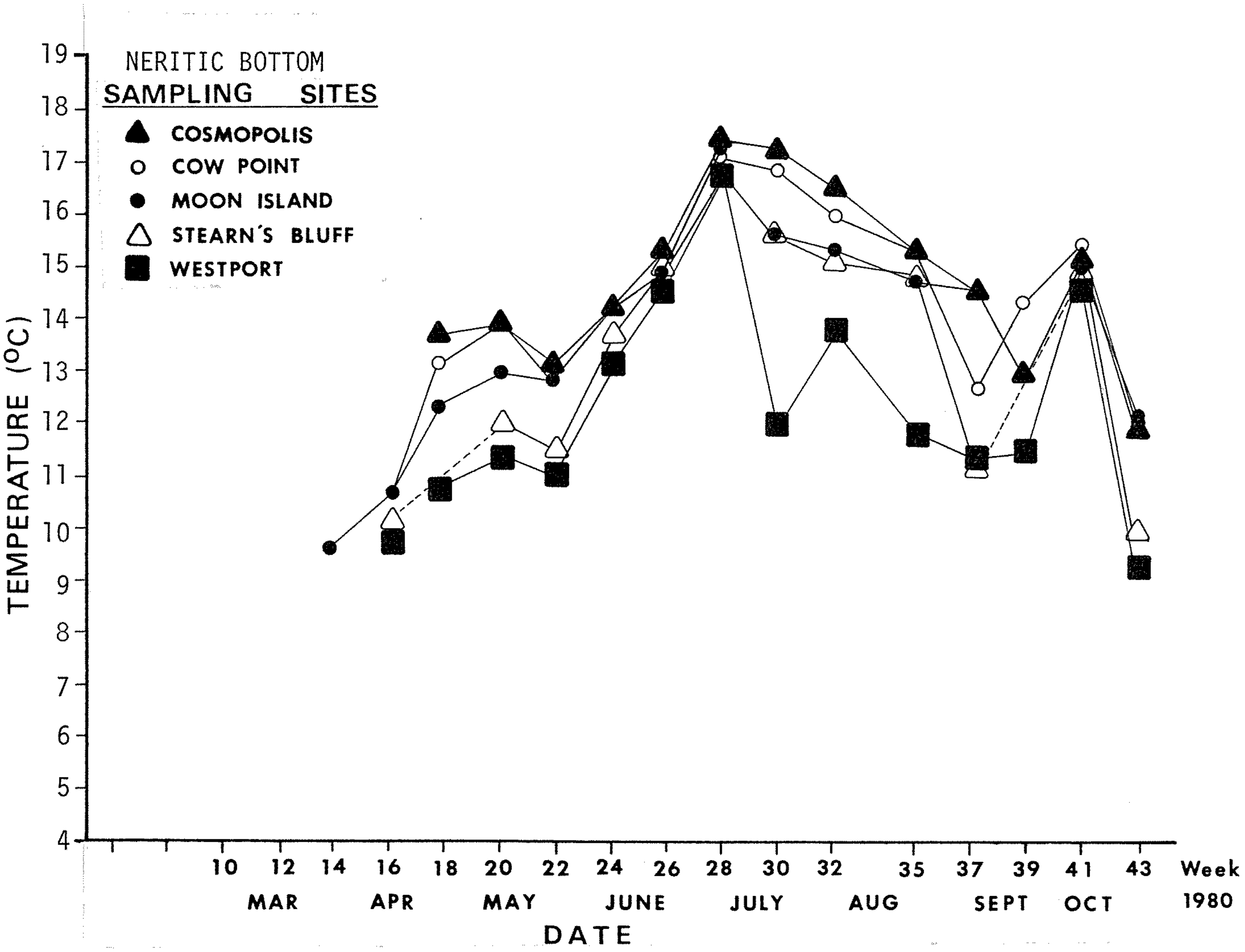

Fig. 2-5. Bottom water temperatures (°C) at five neritic sampling sites in Grays Harbor, Washington, March--October 1980.

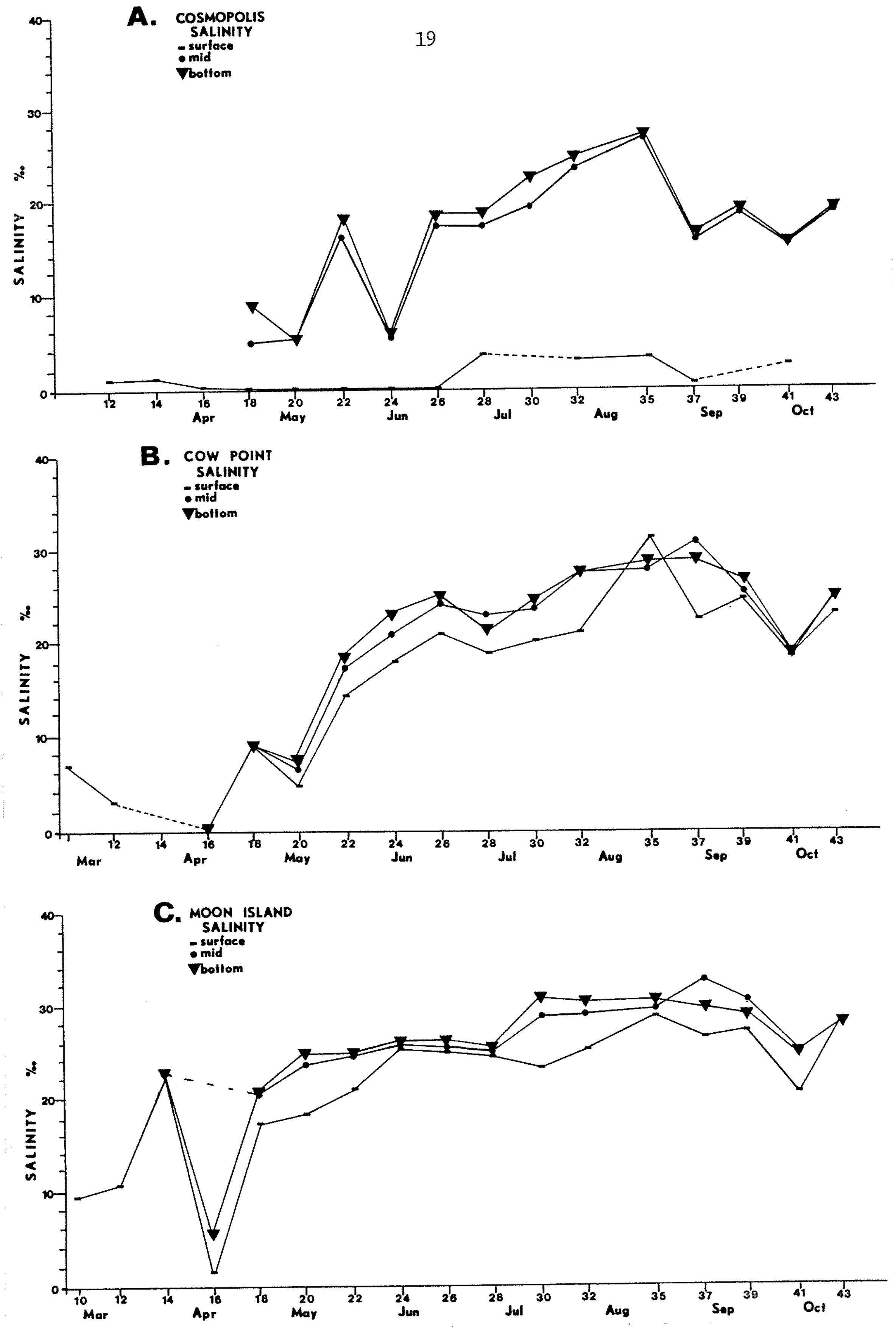

Fig. 2-6. Salinity at three depths at (a) Cosmopolis, (b) Cow Point, (c) Moon Island, (d) Stearn's Bluff, and (e) Westport in Grays Harbor, Washington, March-October 1980.

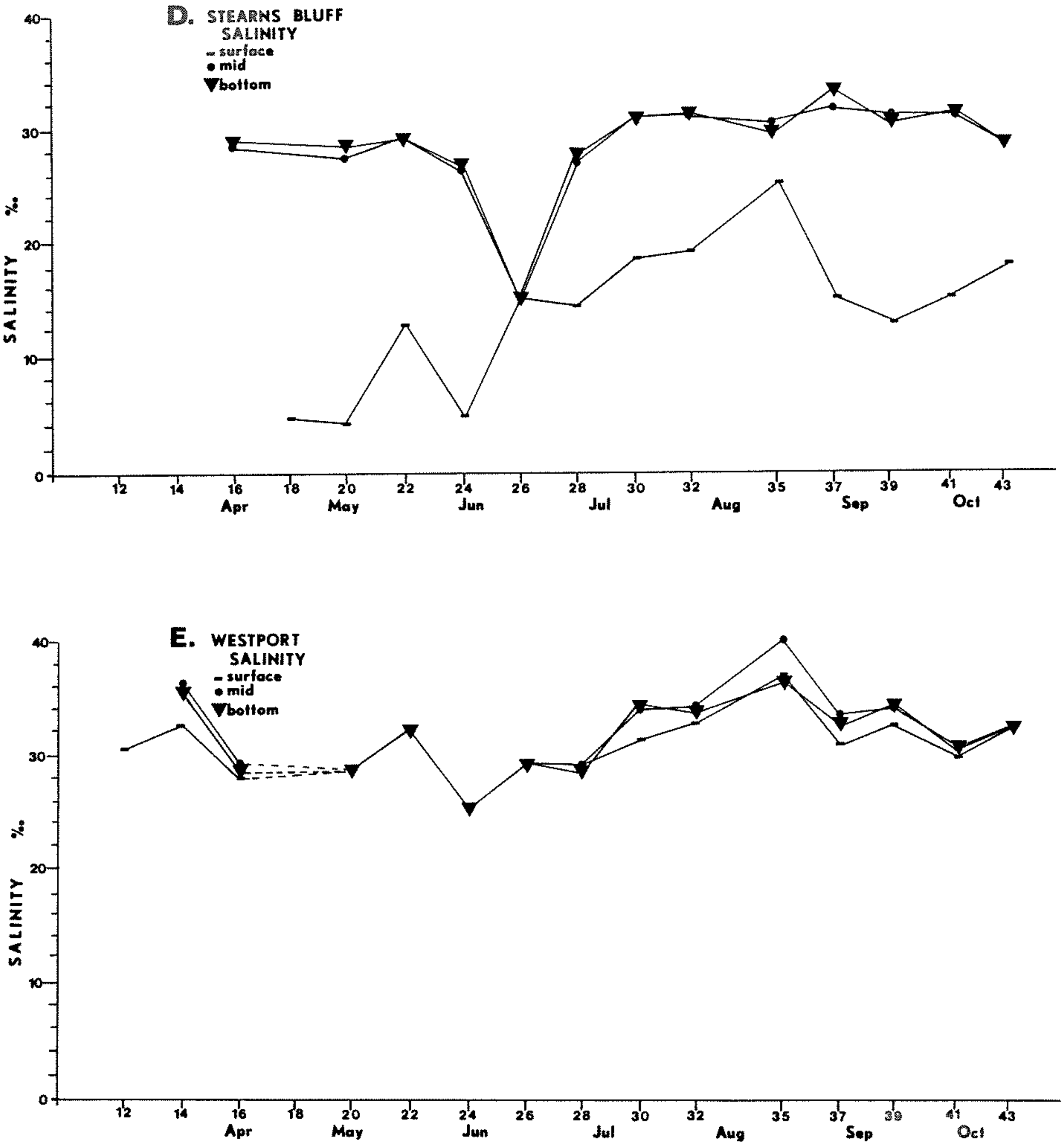

Fig. 2-6. Salinity at three depths at (a) Cosmopolis, (b) Cow Point, (c) Moon Island, (d) Stearn's Bluff, and (e) Westport in Grays Harbor, Washington, March-October 1980 - continued.

sites in late August, when a rapid drop in salinity was reported. This depression continued through September in the subsurface waters.

While early declines in salinity were correlated with variable increases in riverflow rate (Fig. 2-1), fluctuations in salinity late in the sampling period could not necessarily be attributed to the relatively minor changes in riverflow rate. As the salinity measurements were consistently made at approximately the same tide stage (within beach seine or purse seine collection), tidal influences upon salinity values should have been minimal; differences between sampling dates, however, may reflect seasonal variations in tidal height.

2.3.4 Dissolved Oxygen: Except for one extreme decline in the percent saturation level of dissolved oxygen at Stearn's Bluff in April (which may have been the consequence of an unfixed sample), the DO levels at the five neritic sampling sites were greater than 60%; most values, in fact, fluctuated aroung 100% except for the Cosmopolis site, which consistently fluctuated around the 90% saturation level (Fig. 2-7).

2.3.5 Suspended Solids: Concentrations of suspended solids, measured as Total Nonfilterable Residue (TNFR), were typically maximum at the Cosmopolis, Cow Point, or Moon Island sites, although all sites illustrated the same general trends of maxima in late April through June (Fig. 2-8). Most of the values above 40 mg/l TNFR coincided with the occurrence of Corps of Engineers maintenance dredging in the vicinity of the sampling site, although periods of high freshwater flow usually accounted for increased concentrations of suspended solids at all sites.

2.4 Literature Cited:

American Public Health Association, American Water Work Association, and Water Pollution Control Federation. 1976. Standard methods for the examination of water and wastewater. Fourteenth Edition. American Public Health Association, Washington, D.C. 1193 pp.

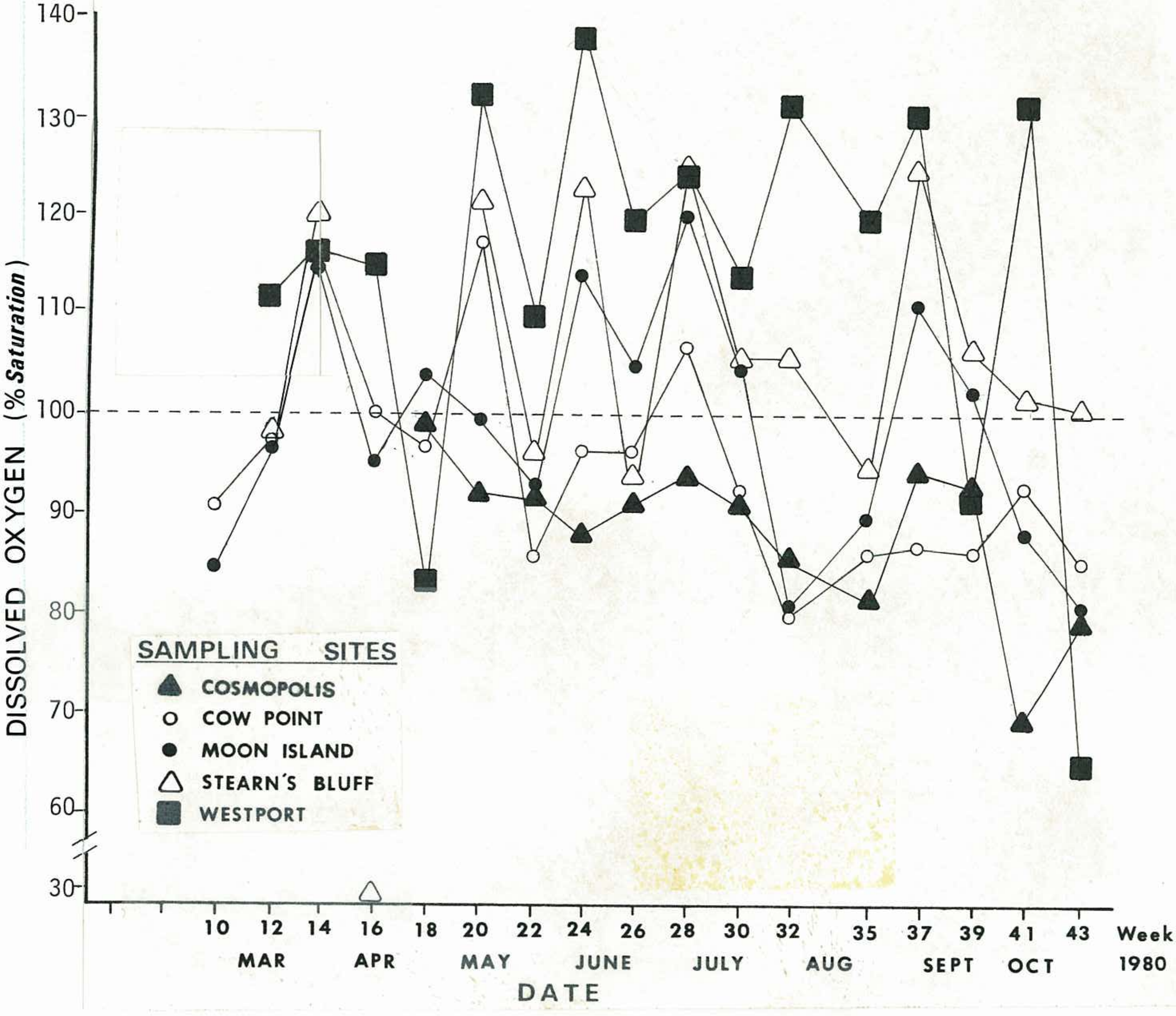

Fig. 2-7. Dissolved oxygen levels (% saturation) at five neritic sampling sites in Grays Harbor, Washington, March-October 1980.

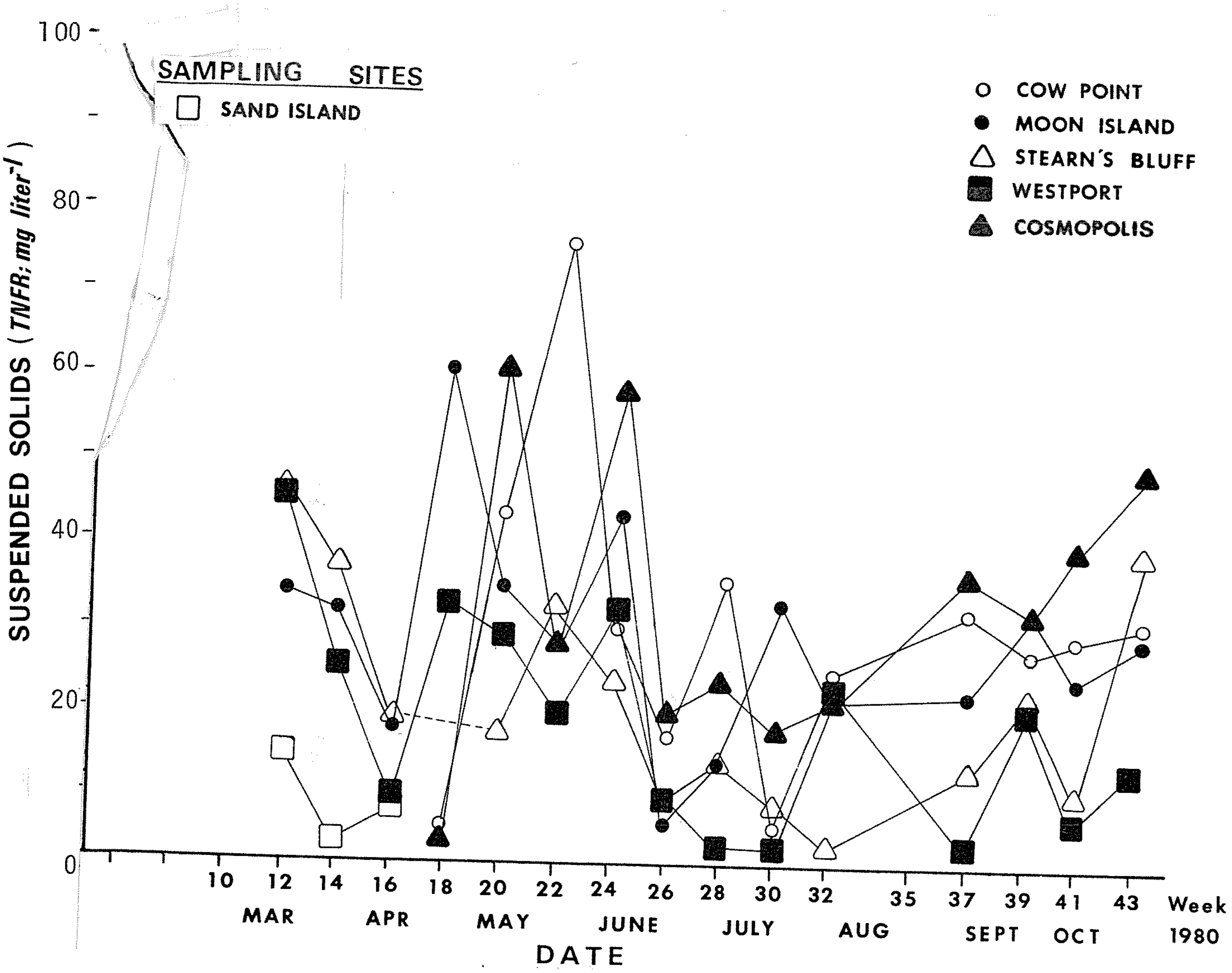

Fig. 2-8. Suspended solids (TNFR, mg liter^{-1}) at one shallow sublittoral and five neritic sampling sites in Grays Harbor, Washington, March-October 1980.

Loehr, L. C., and E. E. Collias. 1981. A review of water characteristics of Grays Harbor 1938-1979 and an evaluation of possible effects of the widening and deepening project upon present water characteristics. Grays Harbor and Chehalis River Improvements to Navigation Project Environmental Studies. Seattle District, U.S. Army Corps of Engineers, Seattle, WA. 97 pp.

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3.0 DISTRIBUTION AND ABUNDANCE OF JUVENILE SALMONIDS

by Thomas E. Prinslow, K. Michael McDowell, and Charles A. Simenstad

3.1 Introduction

Grays Harbor constitutes a common receiving area for juveniles of chinook (*Oncorhynchus tshawytscha*), coho (*O. kisutch*), and chum salmon (*O. keta*), steelhead (*Salmon gairdneri*) and cutthroat (*S. clarki clarki*) trout which populate the six major river systems and multitude of small streams and creeks feeding the estuary. As measured by the commercial salmon catch within Grays Harbor, coho salmon are the most numerous followed by chum and chinook (Smith et al. 1976; R. Brix, WDF Montesano Coastal Station, unpublished data). Hatcheries produce the majority of coho and steelhead trout and supplement existing natural chum and fall chinook salmon populations (Table 3-1). This complex of salmonid populations produces an equally complex temporal and spatial distribution of juveniles passing through or residing within the estuary. Furthermore, these distributions are dynamic. They utilize various estuarine habitats over short time periods compared to the total residence time of the juveniles in Grays Harbor.

Thus, in order to adequately document the temporal and spatial movements of juvenile salmonids through the Grays Harbor estuary, the sampling design had to incorporate quantitative collection of the fish in representative habitats, tidal stages and locations through the estuary. The sampling had to be repeated frequently in a consistent manner during the outmigration periods of each species.

3.2 Materials and Methods

3.2.1 Study Site: Six sites were selected for fish collections (Fig. 3-1), which extended from Sand Island (11.8 km from Montesano) to Westport (inside the mouth of the estuary); four sites (Sand Island, Cosmopolis, Cow Point, and Moon Island) were considered to be located in

Table 3-1. Hatchery releases of juvenile salmon into watersheds and tributaries to Grays Harbor during 1980.[1]

Species	Age	Date of Release	Tributary Where Released	Approximate Numbers Released	Average Weight Per Fish (g)[2]
chum	0+	15 March	Hoquium River	400,000[3]	0.5
		9 April	Humptulips River	24,480	1.1
		15 April	Wishkah River	1,400,000[3]	0.4
fall chinook	1+	25 February	Chehalis River	42,642	50.0
	0+	2 June	Humptulips River	850,451	4.0
		3 June	Chehalis River	15,480	5.0
		27 August	Humptulips River	305,239	25.0
coho	1+	4 March	Chehalis River	39,996	50.0
		17-21 April	Chehalis River	432,500	24.0
		18 April	Hoquium River	111,000	24.0
		18 April	Johns River	46,800	25.0
		18-22 April	Wishkah River	174,300	24.0
		18-24 April	Humptulips River	2,947,566	25.0
		25 April	Chehalis River	136,000	28.0
		30 April	Chehalis River	30,464	20.0
		15 May	Humptulips River	747,312	30.0
Total				7,704,230	

[1] Preliminary data provided by Mark Miller, Washington State Department of Fisheries, Harvest Management Division, Olympia

[2] Based on fish/pound data

[3] Egg box releases; survival rate unknown

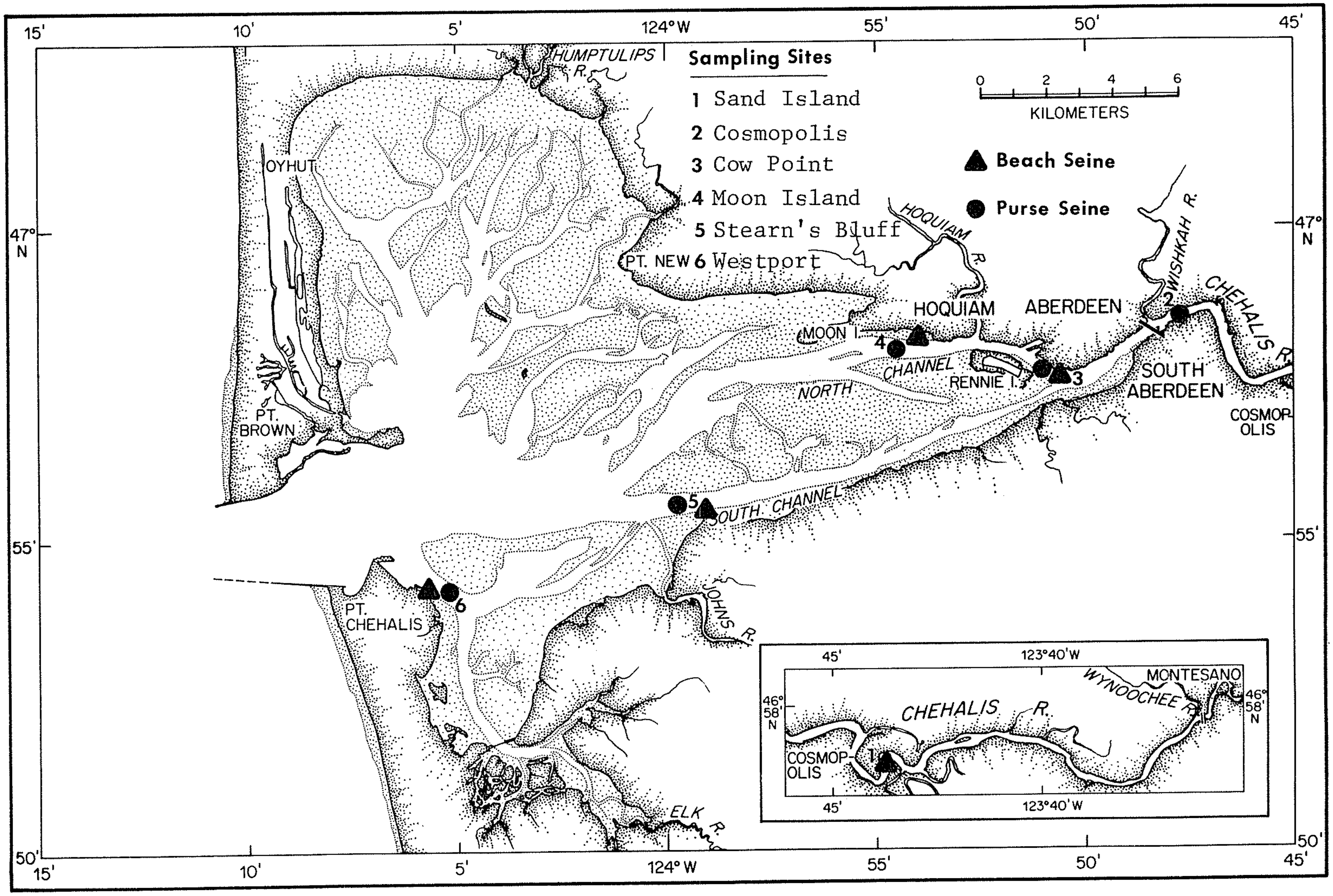

Fig. 3-1. Beach seine and purse seine sampling sites at Grays Harbor, March-October 1980.

the "upper" estuary while two (Stearn's Bluff and Westport) were located in the "lower estuary." Sand Island and Cosmopolis were tidally-influenced riverine sites characterized by steeply-banked, narrow channels greater than 10 m in depth. The Sand Island site was dominated by freshwater flow (Fig. 2-1), while the Cosmopolis sampling site was transitional between riverine and estuarine salinities (Figs. 2-5 to 2-8). The Cow Point sampling site was located at the head of the estuary four kilometers downriver from the Cosmopolis sampling site where the Chehalis River broadens and splits into two shallower (less than 10 m deep) channels bordered by extensive mud and sandflats (lightly stippled areas in Fig. 3-1) exposed at tide heights less than 0.5 m. The beach seine site, however, was characterized by a mud bottom and rock rip rap in the high littoral zone. The Moon Island sampling site was located six kilometers down the north channel from the Cow Point site. Consolidated mud composed the bottom at Moon Island and extended to the upper littoral zone. The Stearn's Bluff sampling site was located two kilometers above the western confluence of the north and south channels. This site was similar to the Moon Island site in terms of the consolidated mud habitat. The sampling site representative of the lower estuary was located at Westport, approximately two kilometers southeast of the navigation channel. The Westport sapling site had a sand bottom and littoral zone with shallow banks.

3.2.2 Sampling Techniques:

3.2.2.1 Fishing Methods: Fish in shallow sublittoral and lower littoral habitats at all sites except Cosmopolis were sampled with a 37- x 2-m floating beach seine set parallel to, and 30 m from, shore from an outboard-powered skiff (Fig. 3-2). The beach seine consisted of two 18-m wings of 3-cm mesh joined to a 2-m H x 2.4-m W x 2.3-m D bag of 6 mm mesh. Floats located along the floatline were sufficient to keep the net at the surface while solid core leadline prevented the net from rolling when on the bottom. Four people hand-hauled the net toward shore at a rate of approximately 15 m/min using lines attached to wooden poles at either end of the seine. For the first 20 m the two groups hauling the net were spaced 40 m apart, and 10 m apart for the final 10 m.

Sample area and volume were estimated to be 520 m^2 and 790 m^3, respectively.

Neritic waters at all sites except Sand Island were sampled with a 63- x 7-m purse seine set from a 7-m front-reel gillnetter using a "round haul" method whereby the seine skiff held position while the seine boat circled away from it (Fig. 3-3). Sample area and volume were estimated to be 300 m^2 and 2000 m^3, respectively. Currents greater than 1 m sec^{-1} were frequently encountered in the estuary, however, which often distorted the shape of the set net and lifted the leadline, thus affecting the actual area and volume sampled during these situations.

The purse seine was set and pursed within 10 min. The net was reeled aboard, and the catch was concentrated in the bunt section of the net within another five minutes.

The purse seine (Fig. 3-4), modelled after the one used Hood Canal and Columbia River juvenile salmonid studies (Prinslow et al. 1980; Johnsen and Sims 1973), measured 63 m long by 7 m deep, with a 25% hang-in (i.e., in the water the net hung to a depth 25% less [5.3 m] than that obtained if the net were stretched out flat). The tapered bunt end of the net consisted of panels of 6-mm and 13-mm mesh knotless nylon webbing which were sewn to 25-mm mesh panels comprising the body and wing end of the net. Along the bottom of the net ran a three-mesh-deep panel of 76-mm knotless nylon webbing to facilitate spilling of water when the net was pursed and hauled aboard the seine vessel (see Prinslow et al. 1980 for detailed drawings).

Shallow sublittoral and lower littoral habitats in the estuary typically had gradually sloping bottoms, and consequently were available to beach seining only at tide heights less than 0.5 m. Neritic areas were purse seined at tide heights greater than 0.5 m to allow the net to pass over bottom snags.

a.

b.

Fig. 3-2. Sampling of shallow sublittoral and lower littoral habitats using a 37-m x 2-m floating beach seine at Grays Harbor; (a) setting the net 30 m off the beach, and (b) hauling in the net.

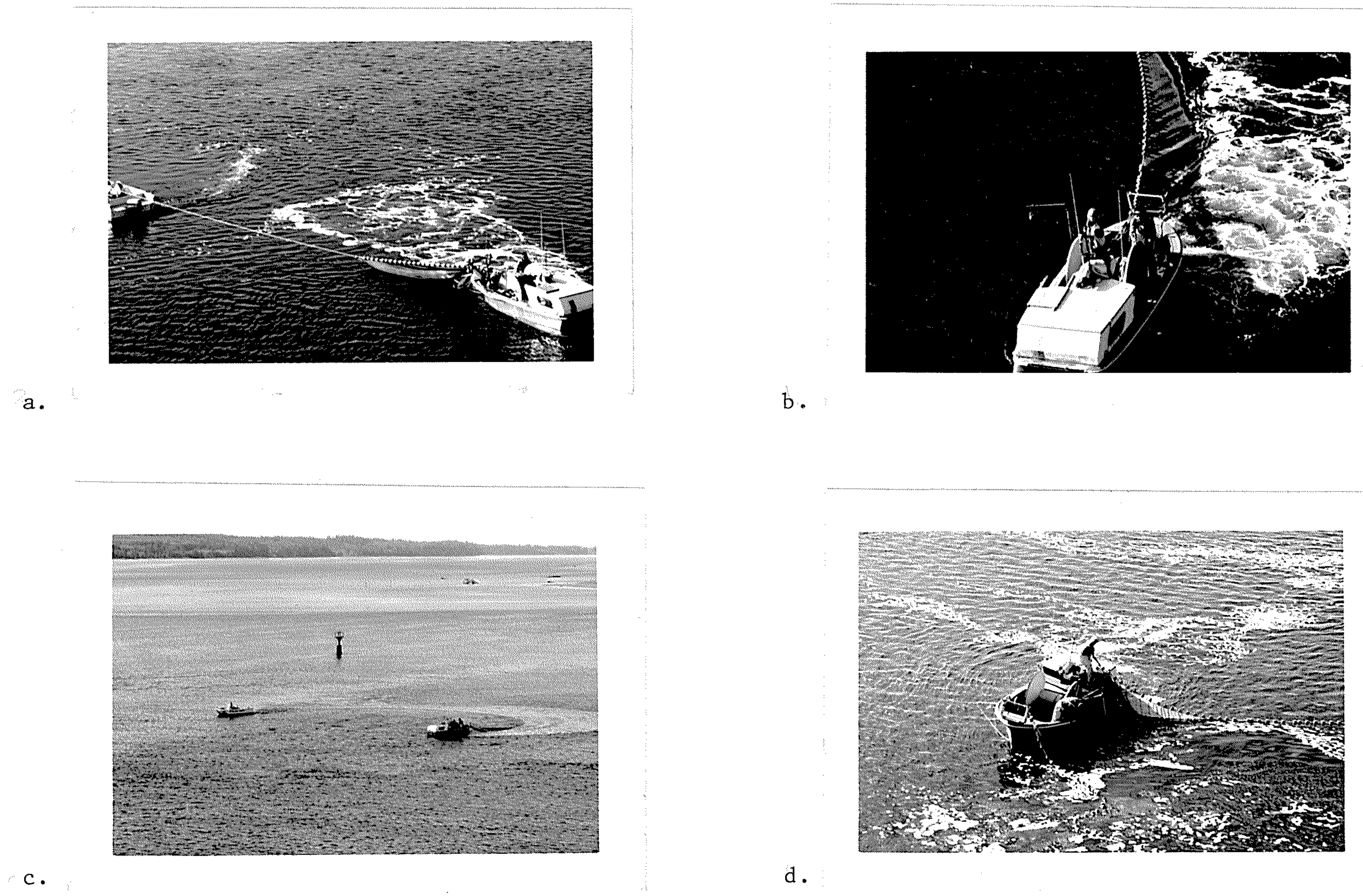

Fig. 3-3. Sampling neritic habitats using a 63-m x 7-m purse seine at Grays Harbor; (a) beginning the set, (b) laying out the net, (c) midway through the set, and (d) pursing the bag of the net.

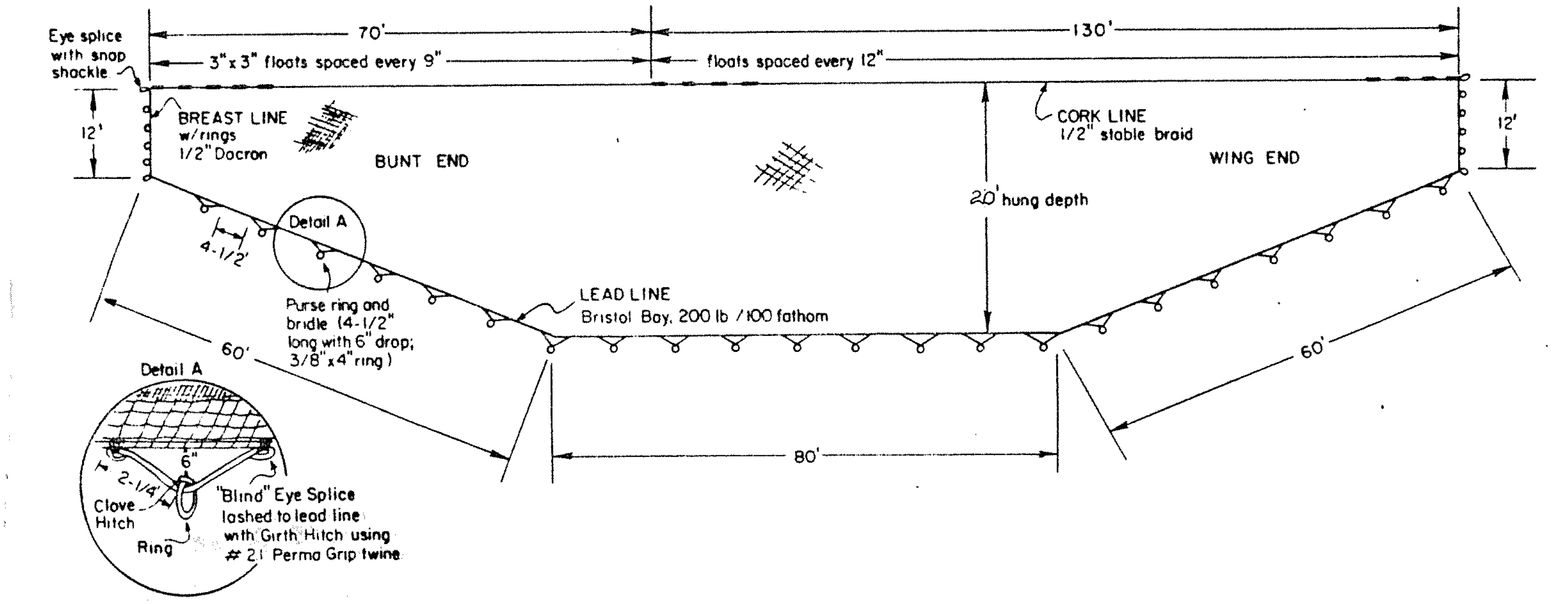

Fig. 3-4. Purse seine used during Grays Harbor study, March-October, 1980. Bunt end consisted of two panels, one of 0.64-cm (0.25-in.) mesh and one of 1.27-cm (0.50-in.) mesh; the body and wing end consisted of 2.54-cm (1.0-in.) mesh.

Two replicate sets were made at each beach seine or purse seine sampling site during each sampling trip, except when prohibited by storms or mechanical failure (see Section 3.2.3).

3.2.2.2 Fish Preservation and Processing: All fish were preserved in 10% buffered formalin immediately upon capture. After at least one week of preservation juvenile salmonids were identified and their fork lengths (FL) and blotted wet weights measured to the nearest mm and 0.01 g, respectively.

3.2.3 Sampling Schedule: Sampling began 3 March 1980 and continued biweekly until 24 October 1980, with the exception of one three-week interval in August to adjust for changing tide schedules. Tide stage and weather conditions determine the order in which sites were sampled and the type of net deployed and that order varied from week to week. All sampling occurred during daylight hours. During the 17 sampling trips, 164 beach seine sets and 148 purse seine sets were completed out of a possible 170 set per gear (2 replicates/site x 5 sites/trip x 17 trips). Mechanical problems during the first three trips accounted for 91% of the missed purse seine sets. Missed sets were noted as "no sampling" in the results and discussion following.

3.3 Results

3.3.1 Chum Salmon: The majority of juvenile chum salmon were caught during beach seine collections; less than 10 chums were caught in a total of 26 purse seine sets made during the chum salmon outmigration period. Apparently, few juvenile chum salmon were occupying neritic habitats in the estuary or those which did moved over the mud and sandflats at high tide and were unavailable to the purse seine collections. Therefore, the following results concern beach seine catches only.

The outmigration of juvenile chum had already begun by the initial sampling trip (March 3-7); the only chum caught upriver at Sand Island were caught during this trip and peak catch-per-unit-effort (CPUE = no. fish caught per set) at Cow Point and Moon Island also occurred at this time (Fig. 3-5). A high CPUE at Westport early in the spring and the similar size distribution of chum caught throughout the estuary during the first week (35-50 mm FL; see Fig. 3-6), suggest rapid movement through the estuary by these early outmigrating juvenile chum salmon. The CPUE at Stearn's Bluff reached a maximum during the sampling week of March 17-21 and was of a magnitude comparable to that documented at Moon Island, in a similar habitat (Fig. 3-5). The size distribution of the fish (Appendix Fig. 3-1) was comparable as well, suggesting that the same or similar cohort groups of outmigrating chum salmon utilized both the north and south channels during their movement through the estuary.

A secondary CPUE maximum observed at Cow Point and Moon Island during the sampling week of March 31-April 4 was followed by a similar maximum at Stearn's Bluff two weeks later (Fig. 3-5). The CPUE reached a maximum at Westport during the sampling week of April 28-May 2. Over this period of movement through the lower estuary the size distribution increased from 30-49 mm FL at Cow Point, Moon Island and Stearn's Bluff to 45-80 mm FL at Westport (Appendix Fig. 3-1).

The progressive movement in maximum CPUE and the change in size distribution between the upper and lower regions of the estuary suggest a two to four week residence in the lower estuary accompanied by an approximately 30-mm increase in the mean size (mm FL) of juvenile chums in the outmigrating population (see Section 3.4.3 for further discussion of this growth measurement).

No juvenile chum salmon were caught in the estuary after the sampling week of May 12-16.

3.3.2 Chinook Salmon

3.3.2.1 Distribution and Abundance: Juvenile fall chinook salmon (age 0+, size range 35-60 mm FL) were caught initially at Sand Island during the sampling week of March 31-April 4, and in the estuary

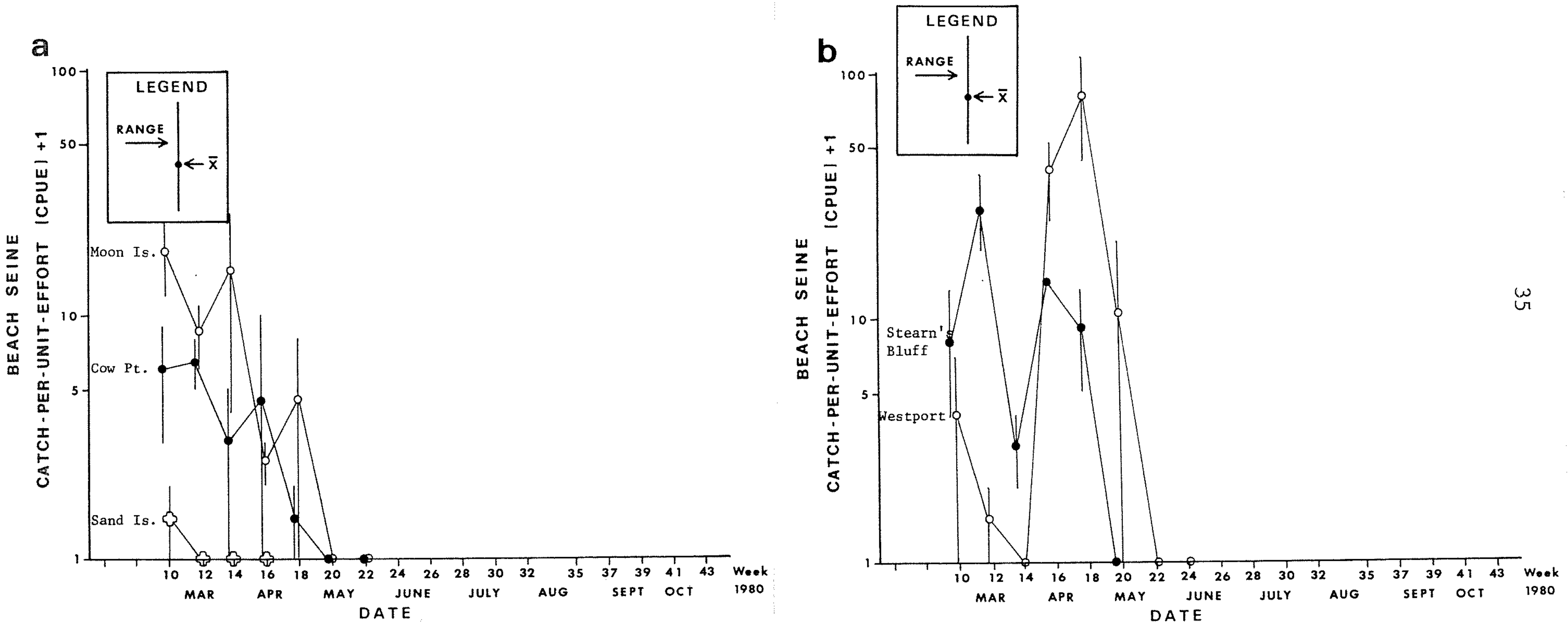

Fig. 3-5. Beach seine catch-per-unit-effort (CPUE) of juvenile chum salmon at five sites in Grays Harbor, Washington, March-October 1980; a) upper estuary sites at Sand Island, Cow Point, and Moon Island, and b) lower estuary sites at Stearn's Bluff and Westport.

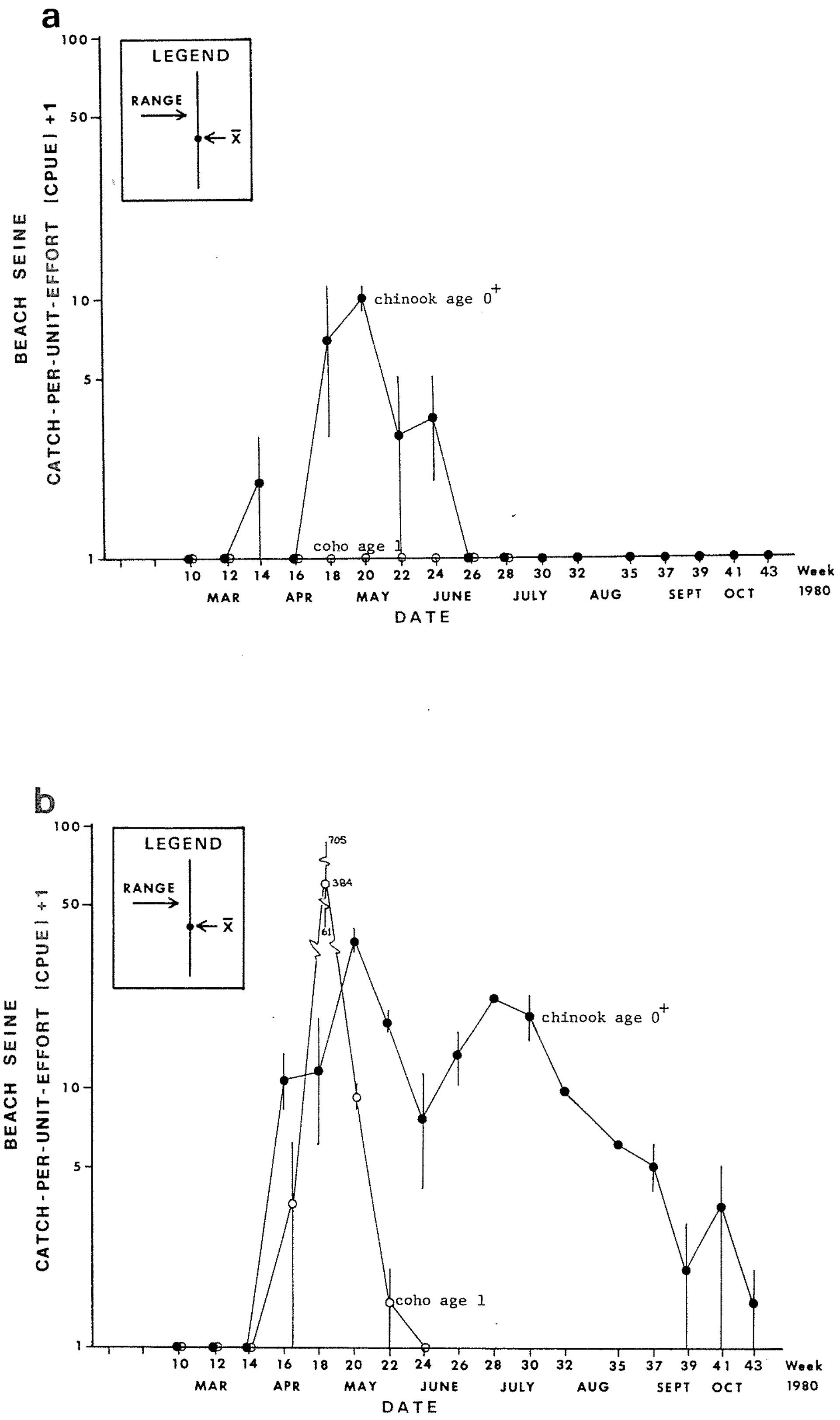

Fig. 3-6. Beach seine catch-per-unit-effort (CPUE) of juvenile chinook and coho salmon at Grays Harbor, Washington, March-October 1980; a) Sand Island, and b) Cow Point.

at Cow Point, Moon Island and Stearn's Bluff beach seine sites during the week of April 14-18 (Figs. 3-6 and 3-7). Beach seine CPUE at these sites indicated maxima between April 28 and May 30. Few juvenile chinook were caught in the purse seine collections during this period, with the largest catches occurring at Cow Point during May (Figs. 3-8 and 3-9). Only three fish were caught in the purse seine collections at Westport at this time and none were caught in the beach seine collections (Fig. 3-10), indicating residence in the upper estuary during this period of the outmigration.

Some juvenile chinook of a size distribution generally larger than those previously caught in the estuary (up to 125 mm FL) were captured at the Stearn's Bluff and Westport purse seine sites during the sampling week of June 9-13 (Appendix Figs. 3-2 and 3-3). These catches coincided with a release of approximately 15,500 age 0+ fall chinook juveniles (averaging 5 g/fish, 80-90 mm FL) into the Chehalis River watershed on June 3, suggesting that the fish captured in the lower estuary represented this group of hatchery fish, which had moved rapidly through the upper estuary. No fish of this size distribution were caught two weeks later (June 23-27), indicating that they had migrated out of the lower estuary.

The CPUE of the smaller, presumably naturally-spawned juvenile chinook at the Sand Island site declined to zero during the sampling week of June 23-27, indicating the end of the migration into the estuary (Fig. 3-6). CPUE maxima occurred in the estuary during late June and early July in the beach seine collection and during August in the purse seine collections (Figs. 3-6 to 3-10). Juvenile chinook salmon continued to be caught by both gears, but in diminishing numbers, through the end of the sampling period (October 24). The rapid decline in CPUE of chinook in the purse seine during early August suggested that a portion of the population of naturally-produced chinook left the estuary, leaving a residual populations which continued to grow and reside in the estuary through late summer and early fall. In addition, CPUE values from the purse

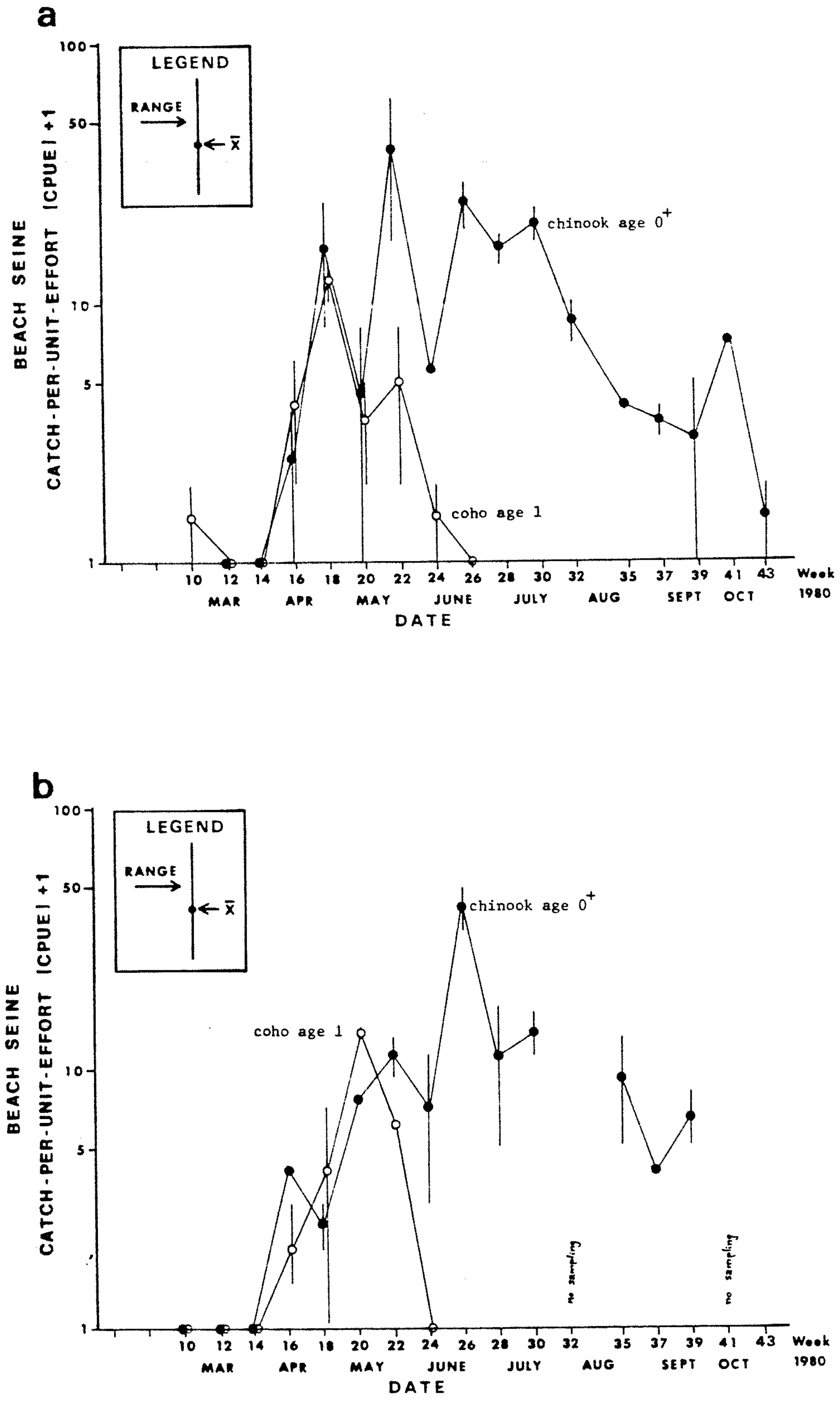

Fig. 3-7. Beach seine catch-per-unit-effort (CPUE) of juvenile chinook and coho salmon at Grays Harbor, Washington, March-October 1980; a) Moon Island and b) Stearn's Bluff.

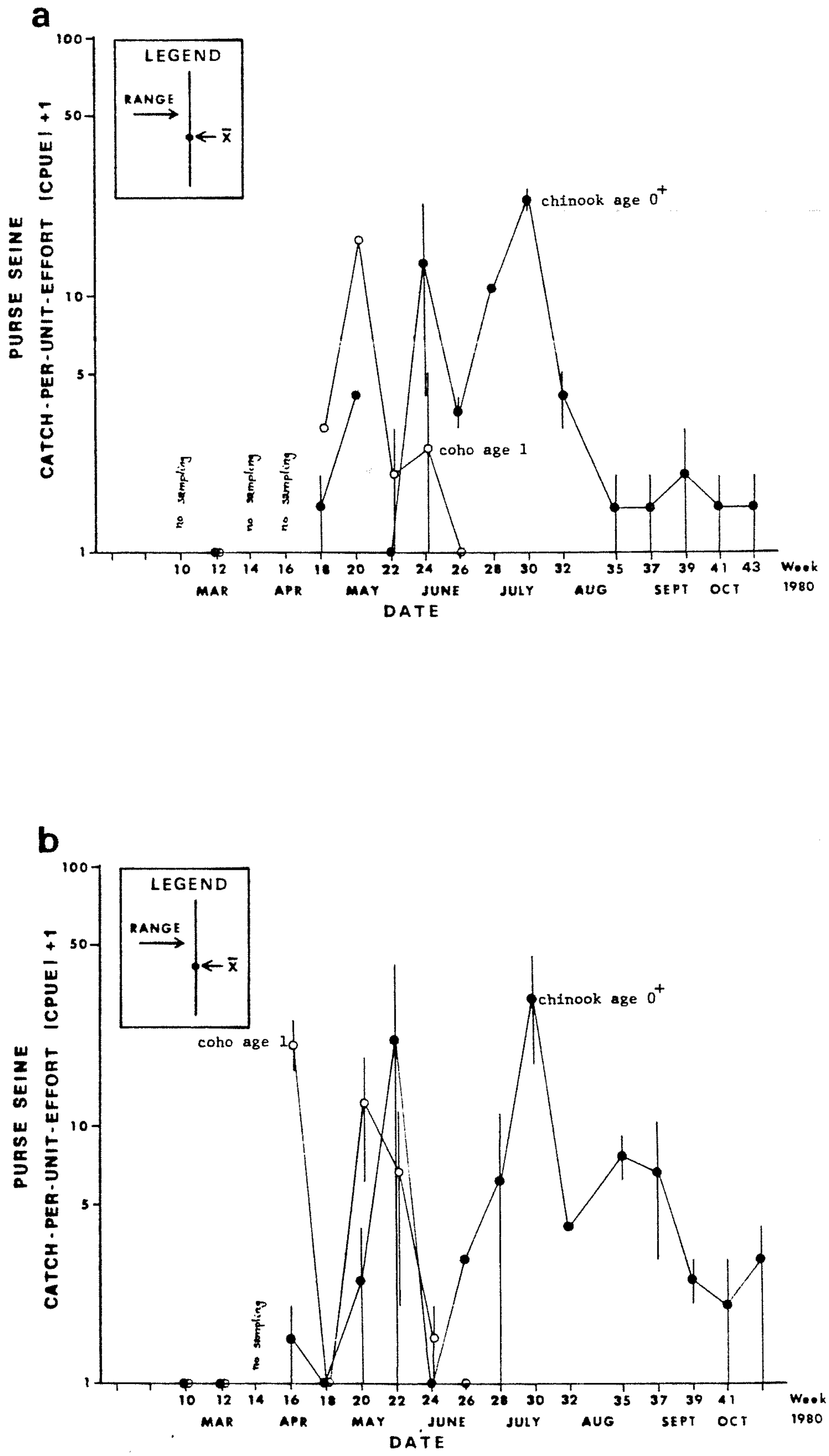

Fig. 3-8. Purse seine catch-per-unit-effort (CPUE) of juvenile chinook and coho salmon at Grays Harbor, Washington, March-October 1980; a) Cosmopolis and b) Cow Point.

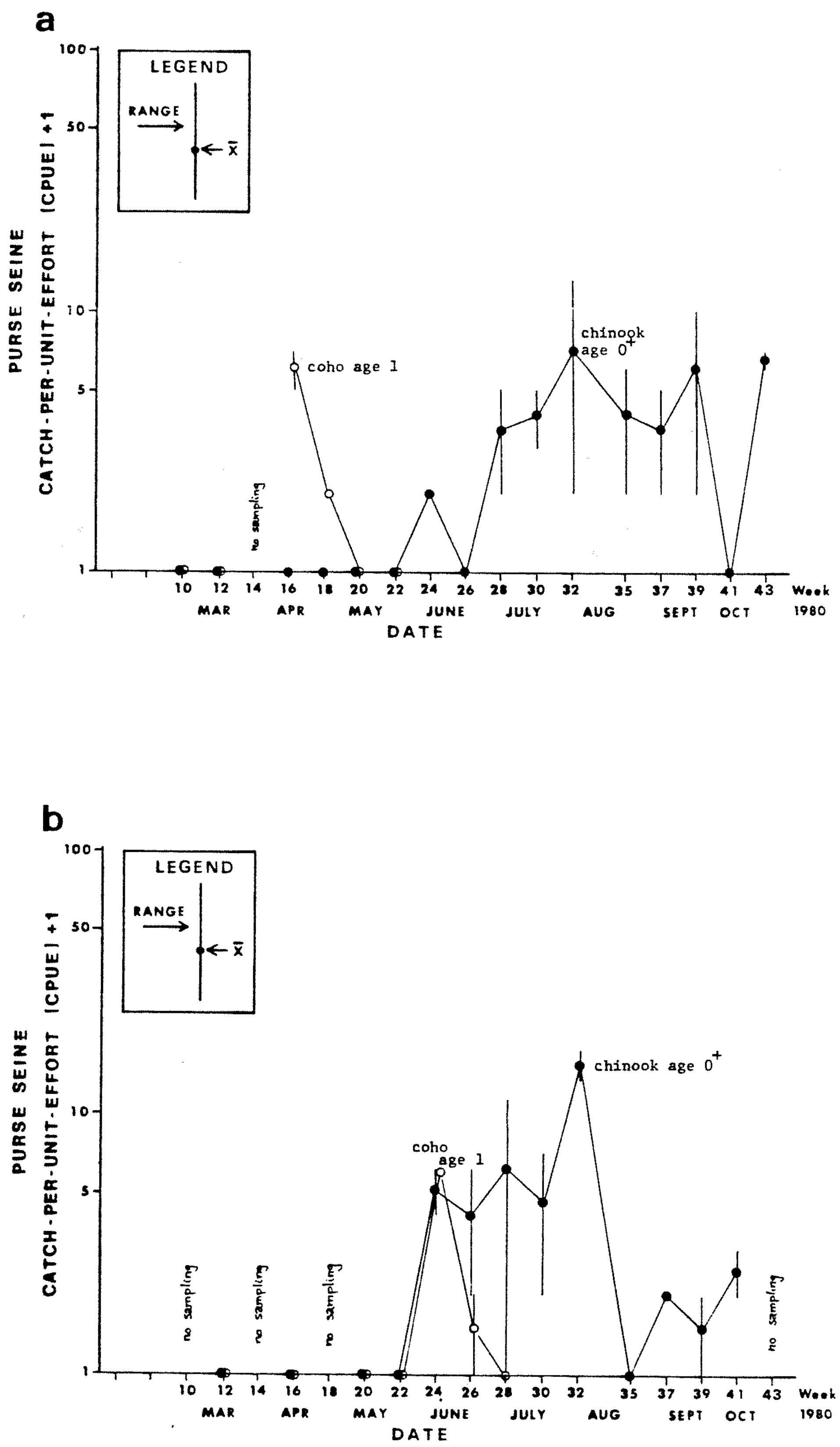

Fig. 3-9. Purse seine catch-per-unit-effort (CPUE) of juvenile chinook and and coho salmon at Grays Harbor, Washington, March-October 1980; a) Moon Island and b) Stearn's Bluff.

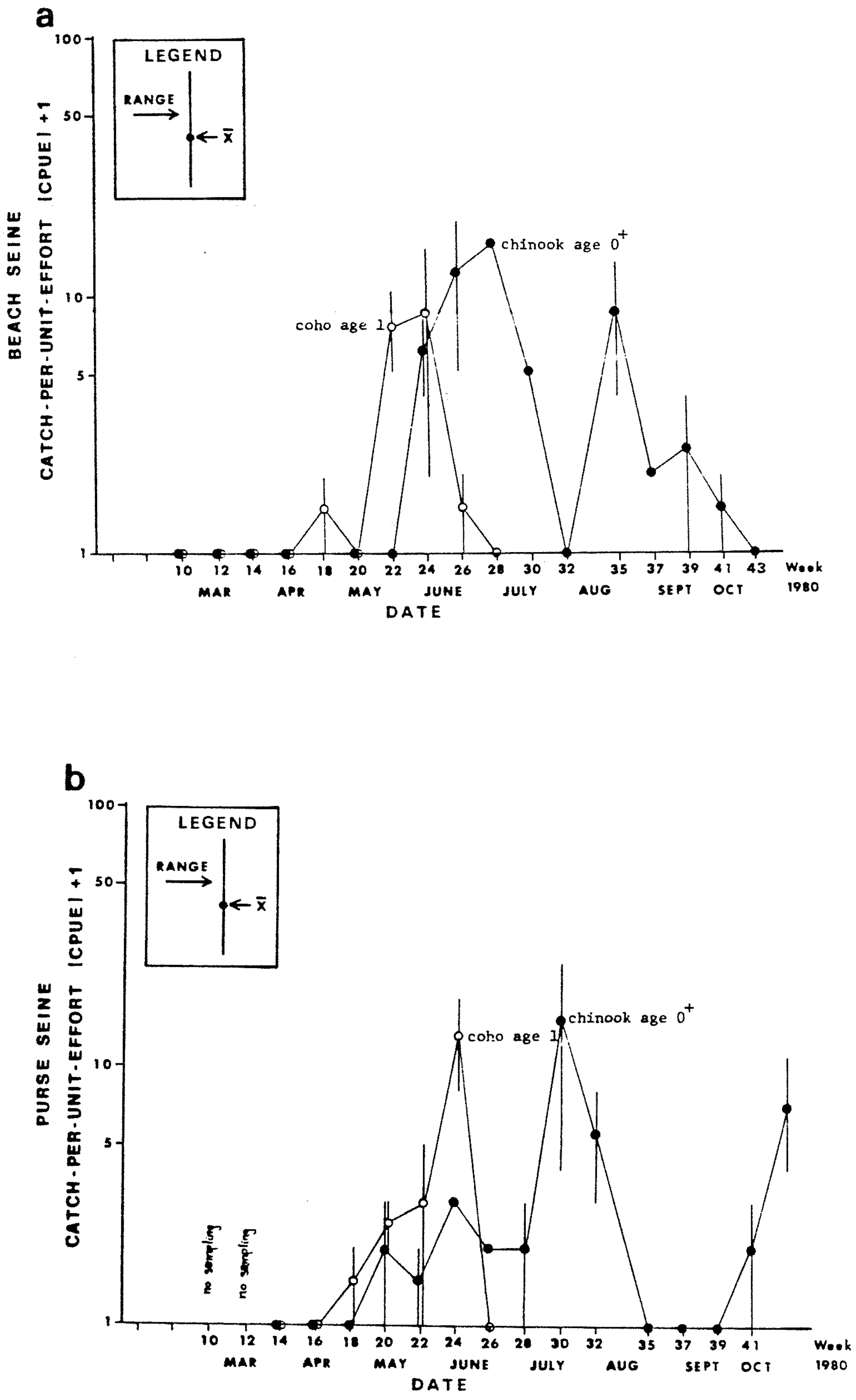

Fig. 3-10. Catch-per-unit-effort (CPUE) of juvenile chinook and coho salmon at Westport, Grays Harbor, Washington, March-October 1980; a) beach seine and b) purse seine.

seine collections were generally higher than the relative beach seine CPUE values during late September and October, indicating a possible transition from utilization of shallow sublittoral and lower littoral habitats to neritic habitats over this time period. Further discussion of this behavioral transition and possible explanations are provided in Section 3.4.

Large (greater than 100 mm FL) juvenile chinook occasionally appeared in July, August, and September purse seine collections, e.g., July 21-25 at Westport, August 4-8 at Westport and Stearn's Bluff, and September 8-12 at Cow Point and Moon Island (Figs. 3-8 to 3-10). Those caught during July and August apparently were naturally-spawned chinook, as the only hatchery release after the June 3rd release occurred on August 27 (Table 3-1). And, while those caught during September may have been from the August release, the hatchery fish were released into the Humptulips River watershed (which enters into the northwestern end of Grays Harbor) and would have had to travel 10 km up the estuary to be caught at Moon Island and Cow Point. The more probable explanation is that these fish represented a small population of residual chinook from naturally-spawned fish which had entered the estuary early in the outmigration and remained in the estuary through the summer. The size of this population of residual, natural chinook may be larger than indicated, however, because the fishes' capability to avoid the small purse seine may be significant by the time they have achieved sizes greater than 100 mm FL.

In Section 3.3.1 we noted that juvenile chum salmon utilized both the north and south channels during outmigration through Grays Harbor. The similar beach seine CPUE of juvenile chinook at Cow Point, Moon Island and Stearn's Bluff (Figs. 3-6 and 3-7) indicate that juvenile chinook also utilized the shallow sublittoral and lower littoral habitats of both the north and south channels during the peak of their migration into the estuary (mid-May to late June) and during estuarine residence (after early July). In terms of the abundance of juvenile chinook in neritic habitats, the relative abundance was greater at the Cow Point site than at either Moon Island or Stearn's Bluff (Figs. 3-9B and 3-10). This may be explained by the availability of neritic habitat at Cow Point, where it is restricted to the channel area. At Moon Island and Stearn's Bluff the neritic habitat extends over extensive mud and sandflat habitats but is not sampled at high tide when purse seining took place. This effect would not affect the estimate of relative abundance in shallow sublittoral and lower littoral habitats samples by beach seining, as these collections were made at low tide when the mud and sandflats were exposed.

Juvenile chinook were caught at Cow Point and Stearn's Bluff during April and May while none were caught at Westport during this period. This suggested that the naturally-spawned juvenile chinook entered the upper estuary from the Chehalis, Wishkah and/or Johns rivers watersheds and few entered the lower estuary directly from the Johns and Elk rivers.

3.3.2.2 Size Distribution: Juvenile chinook entering the estuary during the sampling week of April 14-18 ranged 35-59 mm FL; modal length at Cow Point and Moon Island measured 35-39 mm FL, while it was 40-44 mm FL at Stearn's Bluff (Appendix Fig. 3-2). This difference in size distribution may indicate different origins of these populations, e.g., a John's River population at Stearn's Bluff and a Chehalis River population at Cow Point. Although it is impossible to verify without mark-recapture experimentation, estuarine growth may be the more logical explanation. Juvenile chinook captured in shallow sublittoral and lower littoral habitats exhibited a steady increase in fork length during the 27-wk time period between initial capture and termination of the sampling (i.e., from 35-39 mm FL to 110-120 mm FL; Appendix Fig. 3-2, Cow Point and Moon Island). This probably represents not only growth of fish residing within the estuary but also the immigration of increasingly larger fish into the estuary and the movement of larger fish from the shallow sublittoral and lower littoral habitats into neritic habitats.

During any given sampling week, the modal length (FL) of juvenile chinook captured in neritic habitats exceeded that of fish captured in shallow sublittoral and lower littoral habitats by 10-15 mm (Appendix Figs. 3-2 and 3-3). While this could be an artifact of gear selectivity, the purse seine was capable of capturing juvenile chinook as small as those caught in the beach seine. Therefore, the difference in modal length (FL) is probably more a result of a transitional movement of juvenile chinook into neritic habitats as they grow longer.

The sizes of juvenile chinook caught either in shallow sublittoral and lower littoral habitats or neritic habitats during any sampling week were comparable among sites, however (Appendix Figs. 3-2 and 3-3), indicating that fish of all sizes utilize these aquatic habitats uniformly over the estuary as a whole.

3.3.2.3 Growth: Figure 3-11 is a semi-logrithmic plot illustrating the incremental change in the mean length (mm FL ± 1 s.d.) of juvenile chinook caught at Grays Harbor between March and Ocotober 1980. While incremental changes in mean length over time represents apparent growth of the mean size of the individuals in the estuary's population, it does not necessarily represent actual growth of the same cohort of fish from sampling week to sampling week since recruitment into and emigration out of the estuary may occur. It is not possible, given the available data in absence of mark-recapture experiments, to discern between these alternative explanations.

The length data from the beach seine (Fig. 3-11) showed that apparent growth rate (i.e., slope of semi-logarithmic plot of length versus time) of juvenile chinook is greater during the period from mid-April to mid-June than it was during the period mid-June to mid-August. A similar but less developed pattern holds for the length data from purse seine collections.

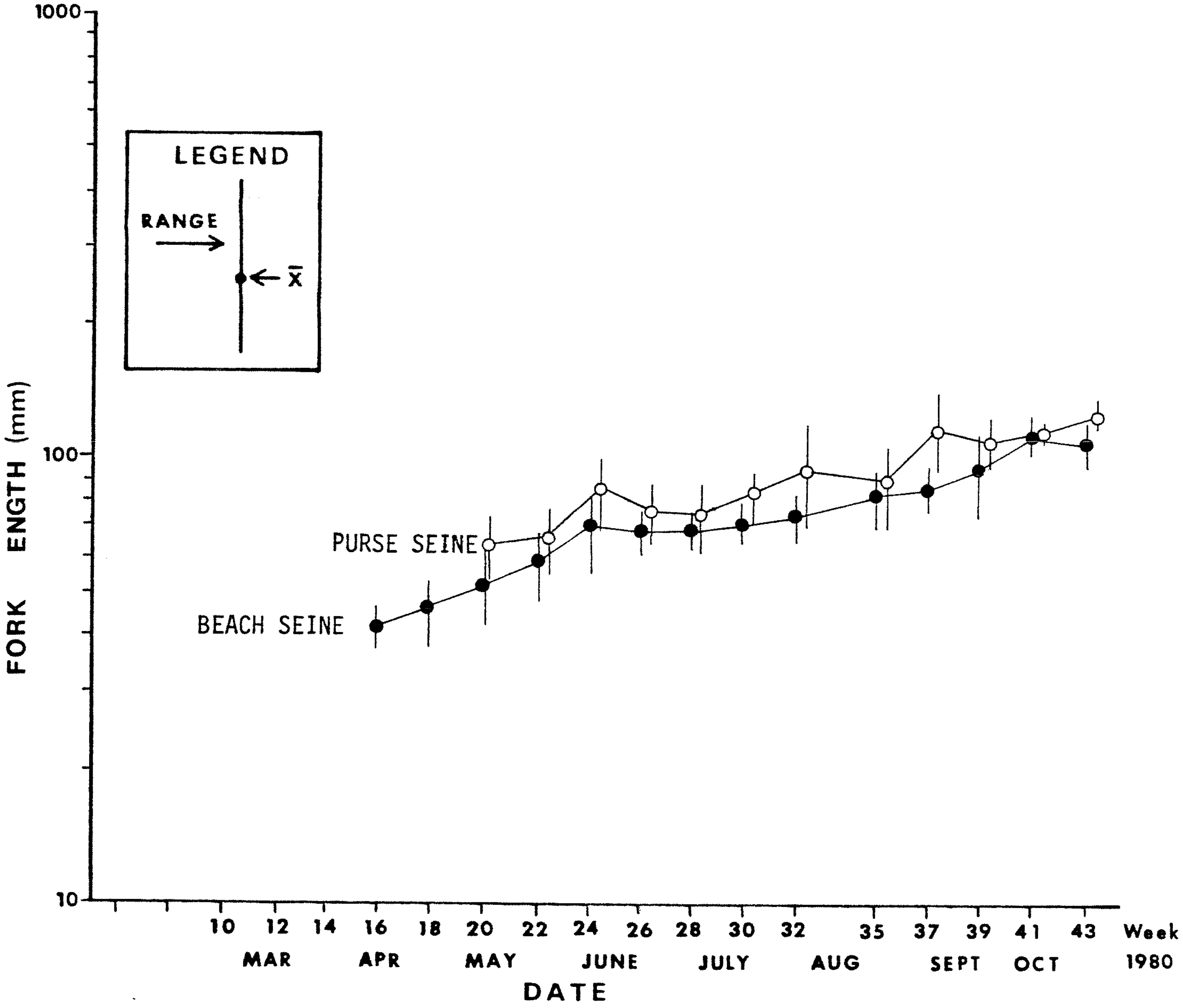

Fig. 3-11. Change in mean length (mm FL) of juvenile chinook salmon at Grays Harbor, Washington, March-October 1980.

3.3.3 Coho Salmon: Coho salmon were generally most abundant at the upper estuary beach seine and purse seine sites between April 14 and June 1 (Figs. 3-6 to 3-10). Catches were as high as 700 per set at the Cow Point beach seine site during the sampling week of April 28-May 2. The pattern of catches during this period was also similar among the Cow Point, Moon Island, and Stearn's Bluff beach seine and the Cosmopolis, Cow Point, and Moon Island purse seine sites. Catches of coho salmon at the Stearn's Bluff purse seine and both Westport sites were similar with peak catches occurring June 9-27, approximately one to 2 months later than the upper estuary sites.

Juvenile coho caught by both beach seine and purse seine in the upper estuary early in the outmigration were similar in size, ranging between 100 and 170 mm FL (Appendix Figs. 3-4 and 3-5).

The size frequency distributions of the coho caught in the lower estuary were similar to those caught in the upper estuary despite the differences in occurrence of maximum abundance (Appendix Figs. 3-4 and 3-5).

Juvenile coho were captured with both gears at the Westport site between April 18 and June 27, with maximum abundance occurring during the sampling week of June 9-13 (Fig. 3-10); size frequency distributions of these coho were similar to those captured at the other sites (Appendix Fig. 3-4 and 3-5).

These results would suggest that juvenile coho migrate rapidly through the estuary in a one to two month period. Further they utilized both shallow sublittoral and lower littoral habitats as well as neritic habitats of the north and south channels. There was no evidence of significant estuarine growth, and coho smolts had migrated out of Grays Harbor by mid-June.

3.3.4 Steelhead Trout: A total of 11 steelhead trout, ranging in size between 135 and 384 mm FL, were captured between May 12 and July 25 at the five sites from Cosmopolis to Westport (Table 3-2). Six of the 11 (55%) were captured during beach seine sampling. Those steelhead 135-227 mm FL were probably age 2+ outmigrant smolts, while the two larger fish (337 and 384 mm FL) were probably returning after a year in the ocean. No scales were read to verify this interpretation, however.

3.3.5 Cutthroat Trout: Two cutthroat trout, measuring 164 mm and 196 mm FL were caught during beach seine sampling at Cow Point and Moon Island during the sampling week of July 7-11. These apparently were age 1+ outmigrant smolts.

3.3.6 Dolly Varden: Two Dolly Varden, measuring 550 mm and 440 mm FL, were caught during beach seine sampling at Cow Point and Stearn's Bluff during March. These appeared to be "sea-run" adults.

3.4 Discussion

3.4.1 Patterns and Rates of Migration through Grays Harbor:

Figure 3-12 summarizes periods of outmigration of juvenile salmonids in Grays Harbor as documented during the March-October 1980 sampling and, although confirming mark-recapture data is not available, this best illustrates the availability of juvenile salmonids in Grays Harbor during this period. Juvenile chum salmon migrated first, probably beginning in January (Washington State Dep. Ecology 1971), reached greatest abundance in March and April and departed the estuary in early May. Juvenile coho and fall chinook both entered the estuary in mid-April. While the coho outmigration reached an abundance maximum in May and terminated in June, the chinook outmigration did not reach a maximum until June and a portion of the population ("Type III" fish; Reimers 1973) appeared to remain within the estuary through October while the remainder ("Type II" fish) migrated out of Grays Harbor. Steelhead

Table 3-2. Summary of steelhead trout caught at Grays Harbor, March-October 1980.

Sample Week	Date	Sampling Site	Gear[1]	Set #	Number	Length (mm FL)	Weight (g wet)
20	5/12-16	Cosmopolis	PS	1	1	152	32.2
"	"	Cow Point	BS	1	1	135	23.9
22	5/26-30	Stearn's Bluff	BS	1	1	199	84.6
"	"	Westport	PS	1	1	185	55.5
26	6/23-27	Moon Island	BS	1	1	175	40.3
28	7/7-11	Cosmopolis	PS	1	1	165	44.4
"	"	Cow Point	BS	1	1	196	84.3
"	"	Moon Island	BS	1	2	164 384	41.5 500.0
"	"	"	PS	1	1	337	340.0
30	7/21-25	Cosmopolis	PS	1	1	227	110.0

[1] PS = purse seine, BS = beach seine

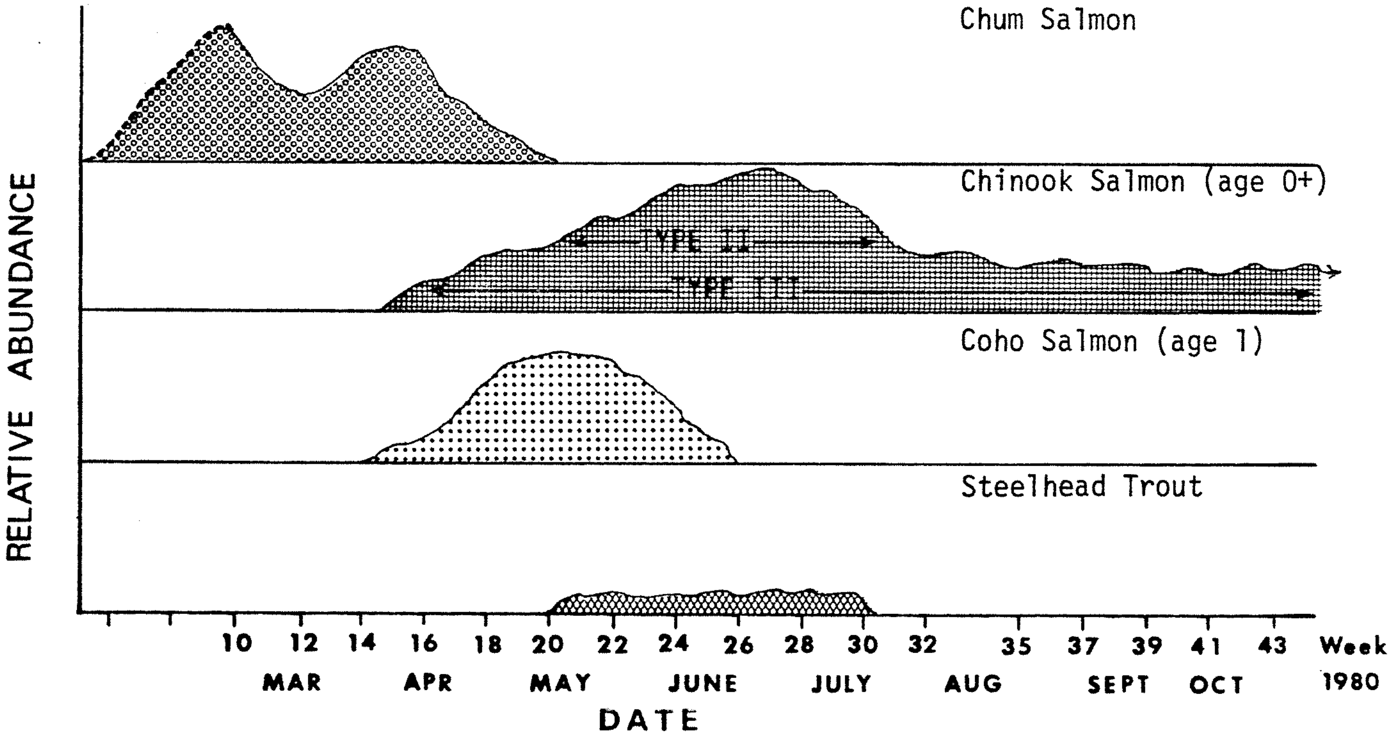

Fig. 3-12. Outmigration periods of chum, chinook (Types II and III; see text) and coho salmon, and steelhead trout in Grays Harbor, Washington, March-October 1980.

trout outmigrants entered the estuary in May and had completed their migration through the estuary during July.

Based upon temporal and spatial shifts in CPUE maxima, and on length frequency distribution, but in the absence of mark-recapture data, it can be hypothesized that juvenile chum and coho migrated quickly out of the estuary in 1980. In the case of juvenile chums, outmigrants entering the estuary in March probably passed through the estuary in less than two weeks while later groups of outmigrants remained for up to four weeks. Rapid movement of early chum outmigrants has been reported elsewhere, e.g., Hood Canal (Bax et al. 1979 and 1980; Whitmus and Olsen 1979; Salo et al 1980) and Nisqually Reach (Fresh et al. 1979) in Puget Sound. While the factors determining outmigration rate have not been identified or separated, food availability and anti-predation behavior may be partially responsible (Simenstad et al. 1980). Section 9.0 will examine the potential mechanisms and dynamics of estuarine residence further.

The abundance of juvenile chinook salmon in Grays Harbor decreased rapidly after a maximum in June, indicating departure from the estuary of the major component of the outmigrant population. Chinook continued to be caught at a reduced rate through October, however. Reimers (1973) described a similar pattern in the Sixes River estuary in Oregon. Healy (1980) reported that chinook smolts had departed the Nanaimo River estuary by the end of July, but sampling apparently was not continued into the fall months, so a small residual population may have been present. Those chinook remaining in the Sixes River estuary until fall comprised approximately 17% of the total number of fish emigrating that year, but represented approximately 90% of the returning spawners (Reimers 1973). The late-summer residual population at Grays Harbor may be of equal importance but verification will require detailed scale (age and stock) analysis.

The rapid migration of juvenile coho salmon through Grays Harbor is consistent with behavior reported by Hoar (1951) and with migration rates in Hood Canal (Bax et al. 1980).

There was no apparent selection of shallow sublittoral and lower littoral habitats or neritic habitats by fish of particular sizes. Neither was there distinct selection of migration routes between the north and south channels, although juvenile chinook occupying neritic habitats may have preferentially occupied the western region of the south channel during their latter residence in the estuary.

3.4.2 Importance of Sampling Sites and Habitats; Relationships to Communities: Based upon visual examination of CPUE and length frequency distribution data, shallow sublittoral and lower littoral habitats were of greater relative importance than neritic habitats to juvenile chum salmon and small chinook (see Section 3.3.2). Juvenile coho and larger chinook utilized both aquatic habitats equally. Juvenile chum, chinook and coho were captured in relatively equal abundances at all sampling sites in the estuary; more juvenile chinook, however, were caught at the riverine site at Sand Island than any other species. Steelhead trout appeared to utilize all estuarine habitats and sites, although this concluson is based upon CPUE values too low to be conclusive.

3.4.3 Growth of Juvenile Chinook within Grays Harbor: The period of apparent low growth of juvenile chinook between late June and late July coincided with the maximum abundance of chinook in the estuary. Reimers (1973) reported a similar growth pattern for the population of juvenile chinook residing in the Sixes River estuary. Reimers concluded that they reared in the estuary for a short period, evidencing decreased growth as the population increased, and then a major portion of the population left the estuary. Those remaining in the estuary until fall illustrated improved growth. He hypothesized that physiological changes associated with smoltification, changes in population abundance or availability of food resources, or interspecific competition could have depressed growth, but he was unable to offer direct evidence to support or refute any of these alternative hypotheses.

Emigration of larger chinook could also be responsible for depressing the apparent growth rate and this explanation cannot be rejected in the absence of mark-recapture data. The data from Grays Harbor illustrated that large juvenile chinook *did*, in fact, leave the estuary in mid- summer, indicated by the CPUE maximum between late July and early August and a rapid decline thereafter. The relatively larger chinook captured at Westport (Appendix Figs. 3-2 and 3-3), as compared to the upper estuary sites, suggests that the larger fish may have been emigrating at a higher rate.

Size-selective predation, by marine mammals, birds or larger neritic fishes, could also have the same effect of depressing the apparent growth rate as emigration. While this study did not attempt to document such predation, it is questionable that the rate of predation would be so concentrated during the one month period when chinook growth declined.

3.4.3.2 Chum Salmon: Juvenile chum salmon represented the only other population of juvenile salmonids showing increased fork length during residence in Grays Harbor; lengths increased from 30-50 mm FL to 45-80 mm FL during a four week period (see Section 3.3.1). The data are too few and fragmented to generate any estimate of growth rate, however.

3.4.4 Potential Effect of Dredging: Dredging may affect juvenile salmon by direct action of the suspended sediments, e.g., on gill or epithelial tissues; by decreasing dissolved oxygen; by release of toxic compounds contained in the dredged material; by altering their behavior, e.g., avoidance of turbid water masses; by destruction of habitat (see Salo et al. 1979 for review); or by direct uptake by the dredge.

Three types of dredging occurred at Grays Harbor in the vicinity of sampling during this study: pipeline, hopper and clamshell. The pipeline and hopper dredges maintained channel depth and width. The pipeline dredge was deployed from March through May between Cosmopolis and Moon Island, while the hopper dredge continuously operated in the main channel between Cow Point and Westport. The clamshell dredge began operations on September 22 about 100 m from the Moon Island sampling site and was used to remove sediments adjacent to a pier facility under construction.

The concentration of suspended sediments in the water column at our sampling sites in Grays Harbor, measured as TNFR (see Section 2.2), was highly variable (Fig. 2-11). While the greatest concentration recorded (~75 mg/l) occurred during pipeline dredging at Cow Point during the sampling week of May 26-30, dredging apparently was not associated with other high values of suspended sediment. During the beach seining at Moon Island in late September and October a fine soft layer of silt accumulated to a depth of 10 cm on the surface of the shallow sublittoral and lower littoral region, apparently as a result of the clamshell dredging operation adjacent to the sampling site. Yet the CPUE of juvenile chinook in the beach seine collections at Moon Island at this time were similar to that at Cow Point, a sampling site which was not affected by the dredging. This may suggest that in this instance the juvenile salmon did not overtly avoid the area of high turbidity and suspended sediments. Although this is a purely qualitative comparison, at no other time during the study did there occur decreased catches associated with dredging elsewhere in the estuary.

There was no apparent relationship between dredging activity and the concentration of dissolved oxygen in the water. However a period of high suspended sediment concentrations at Cow Point (sampling week of May 26-30) was associated with a low level of dissolved oxygen (Fig. 2-10). Nonetheless, dissolved oxygen supersaturation generally exceeded 80% throughout the study, suggesting that juvenile salmonids do not typically encounter excessively low dissolved oxygen levels during the migration past our sampling sites.

Dredging may disrupt the areal extent of shallow sublittoral and lower littoral habitat which provides epibenthic prey organisms to outmigrating juvenile chum and small juvenile chinook salmon and resident juvenile English sole. The magnitude of such an impact upon the total prey resources of these fish would depend upon the areal extent of habitat removed by dredging and the food requirements of the total population of juvenile salmon and other epibenthic-feeding fishes in the estuary. The proposed widening and deepening of the main channel would remove a significant percentage (1.1%) of epibenthic-feeding habitat available to fish during low tide (24% of the total 540.3 hectares of sublittoral habitat to be removed will be shallow sublittoral; U.S. Army Corps of Engineers, unpubl.) but a relatively low proportion (0.02-0.03%) of area at high tide (only 2.8 to 3.6 hectares of total littoral area to be removed), when the total area of littoral habitat and associated epibenthic organisms are available to foraging salmonids. This suggests that there would be a major difference in the proportion of this habitat removed in the upper estuary as compared to the lower estuary, where the ratio of mud- and sandflat habitat to channel habitat is orders of magnitude higher. Loehr and Collias (1981) suggested that 58% of the high tide surface area of Grays Harbor is attributed to mudflats, the majority of which exists west of Moon Island (Fig. 1-2). There is no indication of the potential magnitude and effect of siltation from dredging operations on adjacent mud-and sandflat habitats, although it should be relatively short-term if toxic components are not associated with the dredge sediments. Further discussion of the potential impacts of dredging and removal of habitat upon juvenile salmonids and English sole is presented in Section 9.0.

There may be some behavioral inhibition of migratory patterns of juvenile salmonids simply as a function of the dredging activities, e.g., noise, turbulence, obstructions. Dredging and shoreline construction activities in northern Hood Canal were associated with reduced abundances (CPUE) of outmigrating chum salmon; when construction ceased, the abundances returned to normal levels (Salo et al. 1980). Grays Harbor represents a different situation from Hood Canal, however, in that the water turbidity is typically much higher in Grays Harbor (making visual perception of such activities more restrictive than in the clear waters of Hood Canal) and dredging activity has been continuing in Grays Harbor for decades.

Entrainment of juvenile salmonids via uptake by the dredges has been shown to be insignificant, e.g., 0.1 fish per 100 m^3 of sediment removed (Stevens et al., in prep).

3.4.5 Sources of Migrant Salmonids: The two major salmon hatcheries producing juvenile salmonids for release into Grays Harbor tributaries, the Humptulips and Simpson hatcheries, generated over 75% of the total 1980 hatchery/egg box production of approximately 12.9 x 10^6 fish, of which potentially 5.9 to 7.7 x 10^6 survived to enter the estuary as juveniles (smolts) due to attrition or predation (M. Miller, WDF, personal communication) (Table 3-2). The majority of these fish (~4.9 x 10^6) entered from the Humptulips River system, while about 0.7 x 10^6 entered from the Chehalis River system. Juvenile coho and chinook from 1979 releases which had overwintered in tributaries to Grays Harbor as age 0+'s were released during June 2-3. A late summer group of 0.3 x 10^6 were released on August 27. Of these potential immigrants into Grays Harbor, the age 1+'s had probably left the estuary before sampling began as none were captured. Naturally spawned age 0+'s first appeared in our collections in mid-April and reached maximum abundance in mid-May. The second peak in abundance of age 0+'s in July probably comprised both hatchery and naturally-spawned fish, with the latter being the dominant fraction.

Approximately 3.9×10^6 coho age 1+'s were released between April 17 and 30, representing 83% of the total releases of this age group of juvenile chinook; an early release on March 4 and a late release on May 15 comprised the remainder. The maximum abundance of age 1+ coho in the estuary occurred between mid-April and mid-May and probably involved primarily the hatchery-released fish. Maximum abundances of coho 1+'s at Moon Island and Cow Point occurred prior to April releases and probably constituted overwintering fish from 1979.

The principal release of juvenile chum salmon occurred between March 15 and April 15, with the majority planted as eggs in streamside egg boxes. Maximum abundances of juvenile chum in our beach seine collection in the upper estuary during early March (Fig. 3-5) indicated that the majority of these fish resulted from natural spawning rather than from artificial propagation. The increased abundance at the two sites in the lower estuary between April 14/18 and May 12/15 may have included a larger contribution of egg box-reared juvenile chums, specifically from the April 15 release of 1.4×10^6 in the Wishkah River.

3.5 Summary

1. Six sites, representing shallow sublittoral and lower littoral or neritic habitats in riverine and estuarine regions of Grays Harbor, were sampled for juvenile salmonids between March 3 and October 24, 1980. A total of 164 beach seine and 148 purse seine collections were made over the course of 17 sampling trips to the estuary.

2. The migration of juvenile chum salmon through the estuary was underway by the initiation of sampling and continued through mid-May, suggesting a two to four week residence in the lower portion of the estuary accompanied by an approximately 3 cm increase in mean fork length.

3. Juvenile chinook salmon began entering the estuary in early April and, despite a general decline in population abundance after July, continued to be captured through the end of the sampling period in October; these data indicated that a residual population of chinook continued to grow and reside in the estuary through late summer and early fall. A transition in occupation of estuarine habitat was also evident, from shallow sublittoral and lower littoral habitats early in the outmigration to neritic habitats as the fish grew larger.

4. Juvenile coho salmon appeared in the estuary in mid-April, reached maxima in abundance over the next few sampling weeks (biweekly) and had emigrated from the estuary by late June.

5. Nine age 2+ steelhead smolts and two returning adults were captured in the estuary between mid-May and late July; cutthroat trout and dolly varden were even less numerous.

6. The pattern of apparent growth of juvenile chinook salmon during the period of their migration through and residence in Grays Harbor suggested that growth was low between late June and late July, coincident with the maximum population density in the estuary. After emigration of the majority of the juvenile chinook at this time, growth of the residual population appeared to increase dramatically.

7. Direct evidence of inhibition of salmonid migration rate and behavior by dredging activities in Grays Harbor was neither documented in the data nor observed. Therefore, inhibition was neither demonstrated nor disproved.

8. While the majority of the juvenile coho salmon outmigrating through Grays Harbor appeared to originate from hatchery releases into tributaries of the estuary, naturally spawned

juvenile chum were abundant between early March and mid-April, and naturally-produced juvenile chinook were caught between mid-April and mid-May, and probably were present through July.

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4.0 DISTRIBUTION AND ABUNDANCE OF ENGLISH SOLE

by K. Michael McDowell and Charles A. Simenstad

4.1 Introduction

Although quantitative information on the distribution and abundance of juvenile English sole in Grays Harbor is not available, there are indications that the estuary supports a large population of juveniles, which may utilize the extensive shallow sublittoral and lower littoral habitats as "rearing" habitat. Preliminary results from otter trawl sampling conducted prior to FRI's studies in Grays Harbor illustrated that juvenile English sole often comprised the dominant species in catches made in shallow, mud- and sandflat habitats (B. Stevens, College of Fisheries, Univ. Washington, personal communication).

Considering the apparent numerical importance of these flounders in the demersal fish community of the estuary and their prominant utilization of habitat which could be impacted by the proposed widening and deepening project, studies were conducted to document the distribution, abundance, growth, movement, and incidence of tumors and fin rot of this species. Catches originated from both FRI's sampling of juvenile salmonids in the estuary and from the studies of the distribution of Dungeness crab (*Cancer magister*) being conducted by Mr. Brad Stevens and Dr. David Armstrong, under the Seattle District, Corps of Engineers, Grays Harbor Environmental Studies program. While the two studies did not have identical experimental designs, overlap in several sampling sites, especially Moon Island, enabled comparison of samples made in shallow sublittoral and lower littoral habitats by FRI with those made in the demersal habitats of the deeper channels by the College of Fisheries investigators.

4.2 Materials and Methods

4.2.1 Beach Seine: The same 37-m x 2-m floating beach seine was used to sample all shallow sublittoral and lower littoral sites which were sampled for juvenile salmonids. Section 3.2.2.1 provides detailed descriptions of the beach seine and the sampling procedure. This was the most effective sampling gear for juvenile English sole, as the net was equipped with a solid core leadline that remained in close contact with the bottom except perhaps at Sand Island, where the bank dropped off at a very steep angle.

4.2.2 Purse Seine: The 61-m x 7-m purse seine which was utilized to sample juvenile salmonids in neritic habitats caught juvenile English sole on only four occasions during the entire sampling period. Section 3.2.2.1 also provides a detailed description of the purse seine and the sampling procedure. Three of the four occasions when English sole were caught during purse seining occurred at the deepest sampling sites, where the bottom of the net was at least 3 m above the bottom, indicating that the fish were quite a distance off the bottom. Water currents at these times of sampling were estimated to be greater than 5 km/hr; however, there were numerous occasions when currents of this magnitude or higher existed during purse seine sampling at these sites when no juvenile English sole were caught.

4.2.3 Otter Trawl: The otter trawl used in the College of Fisheries Crab Distribution Study in Grays Harbor was a 4.9-m trawl or "trynet." The net had a 4.9-m headrope, a 5.8-m footrope (with chain), 0.6-m leg extensions, and was constructed of #9, 1.9-cm mesh netting in the body and #15, 1.9-cm mesh netting in the codend; the codend was also lined with a 0.5-cm mesh woven nylon liner. The net was equipped with 15.3-m bridles and 35.6-cm x 50.8-cm wooden doors. In operation, however, the opening of the mouth of the net was approximately 3.1 m wide and 0.6 to 0.9 m high.

The net was deployed from a moving boat and held near the surface until the doors had spread the net open. The net was then lowered to the bottom and the length of the line out was measured to guarantee a minimum scope of 4:1. Towing speed was estimated to be 0.5 to 1.0 m $\sec^{-1}$. Typical tows were of 10 to 15 min duration and approximately 300 to 600 m long. All tows were made within 1.5 hr of low slack tide, in depths of 5 to 20 m, into the prevailing current. The net was hauled in by hand at the completion of each tow.

Tows were made from a 4.9-m Boston Whaler, equipped with an outboard motor, from May through September; all remaining tows were made from a 6.7-m vessel with an eight cylinder inboard engine.

4.2.4 Fish Preservation and Processing: All fish were preserved in 10% buffered formalin immediately after collection. Upon return of the samples to FRI's Seattle laboratories the English sole were measured for total length to the nearest millimeter and total wet weight to the nearest 0.01 g. When a sample contained 25 or fewer fish each fish was individually measured and weighed. When more than 25 fish were present the entire group was weighed as a whole, to the nearest 0.1 g; then a subsample of 25 fish were randomly chosen from the total sample and these wre individually measured and weighed. The length measurements were used in generating length frequency distributions (histograms). Presence or absence and type of skin tumors and fin rot were also noted and recorded at the time of fish examination.

4.3 Results

4.3.1 Abundance and Distribution: Juvenile English sole were included in the beach seine collections at Sand Island, the sampling site furthest up the estuary, on only two occasions, the sampling weeks of May 12-16 and May 26-30. A small catch of juvenile English sole was included in the beach seine colection at Cow Point during the sampling week of May 26-30 (Fig. 4-1); thereafter, they were caught only sporadically through the remainder of the sampling period. Juvenile English sole were caught during beach seining at the Moon Island sampling site during the initial sampling trip, the week of March 3-7 (Fig. 4-2); they were present in abundance at this site throughout the sampling period, except for brief declines in abundance during mid-April, late May and mid-September. They appeared in the beach seine collections at Stearn's Bluff and Westport

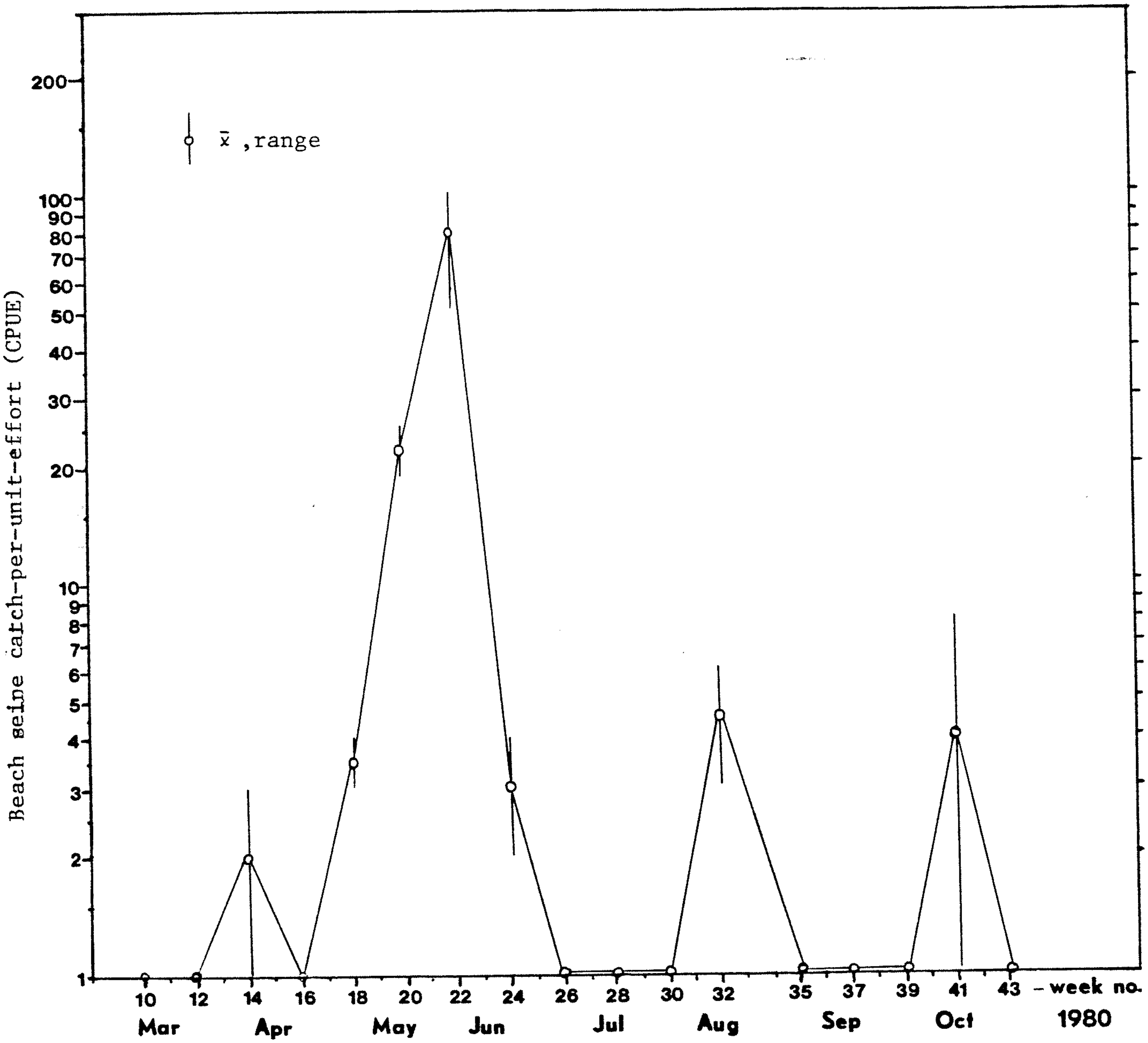

Fig. 4-1. Beach seine catch-per-unit-effort (CPUE) of juvenile English sole at Cow Point, Grays Harbor, Washington, March-October 1980.

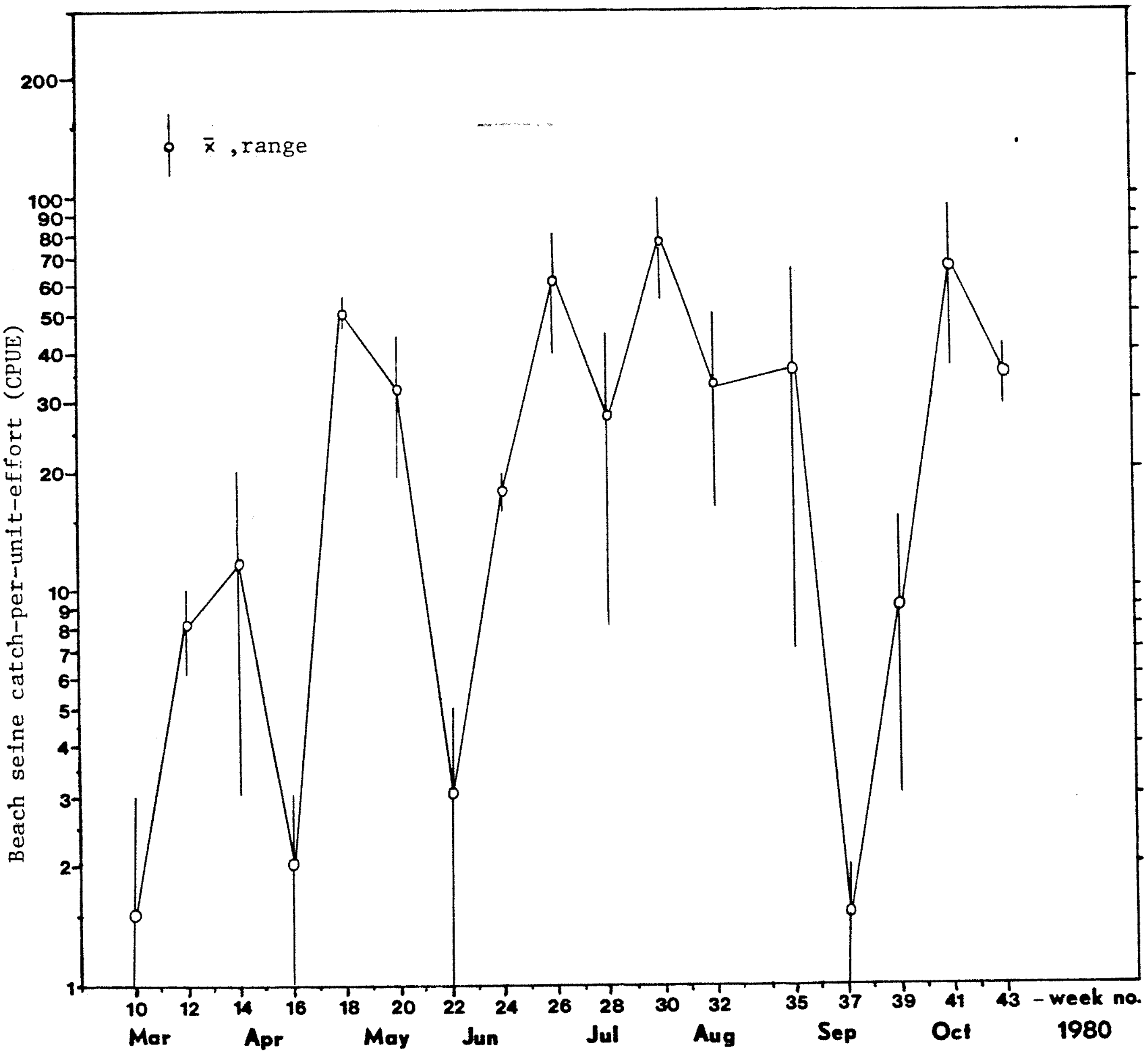

Fig. 4-2. Beach seine catch-per-unit-effort (CPUE) of juvenile English sole at Moon Island, Grays Harbor, Washington, March-October 1980.

during the subsequent sampling week, March 17-21, and were also present at both of these sites through the last sampling week, October 20-24 (Figs. 4-3 and 4-4). The abundance at the Westport sampling site, however, showed a marked depression during August which was not reflected in the Stearn's Bluff collections.

Juvenile English sole were relatively more abundant, as measured by catch-per-unit-effort, at sampling sites in the lower estuary (i.e., Stearn's Bluff and Westport) than those in the upper estuary (i.e., Sand Island, Cow Point and Moon Island), including the riverine site at Sand Island. The catches averaged higher at Stearn's Bluff, although the largest catch of 300 fish in one set occurred at Westport.

Recruitment of post-metamorphosis juveniles or settlement out of the water column by larvae in the lower estuary in the vicinity of Westport appeared to proceed over a ten week period after the initial sampling week, with the maximum abundance occurring around the week of May 26-30. A steady decline proceeded over the next ten weeks until the abundance was essentially zero during the sampling week of August 4-8, then increased slightly over the latter eight weeks of the sampling period (Fig. 4-3). The pattern of abundance of juvenile English sole at the Stearn's Bluff sampling site (Fig. 4-2) was similar to that of Westport, increasing steadily to a maximum during the sampling week of May 26-30. Although there were fluctuations in abundance thereafter, the average abundance remained relatively high throughout the remainder of the sampling period. Abundances at Moon Island (Fig. 4-1) were typically less than half those at Westport and Stearn's Bluff and fluctuated more over the sampling period; abundances at the Cow Point sampling site (Fig. 4-4), were even less and were only comparable to abundances during the sampling week of May 26-30, the same time of abundance maxima in the lower estuary. Only five fish were caught at Sand Island.

The abundance and occurrence of juvenile English sole in the purse seine collections were too low to provide any indications of relative

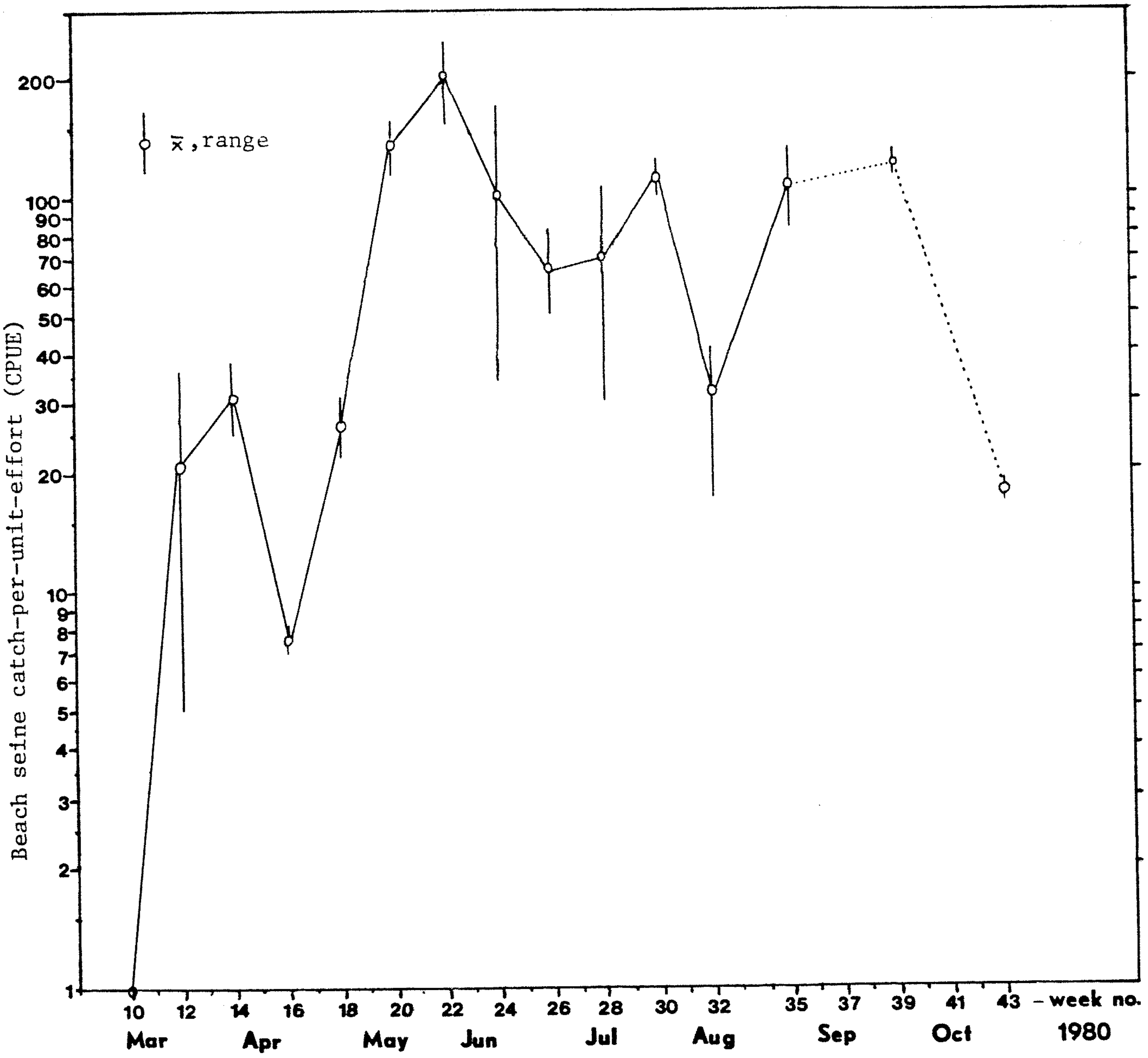

Fig. 4-3. Beach seine catch-per-unit-effort (CPUE) of juvenile English sole at Stearn's Bluff, Grays Harbor, Washington, March-October 1980.

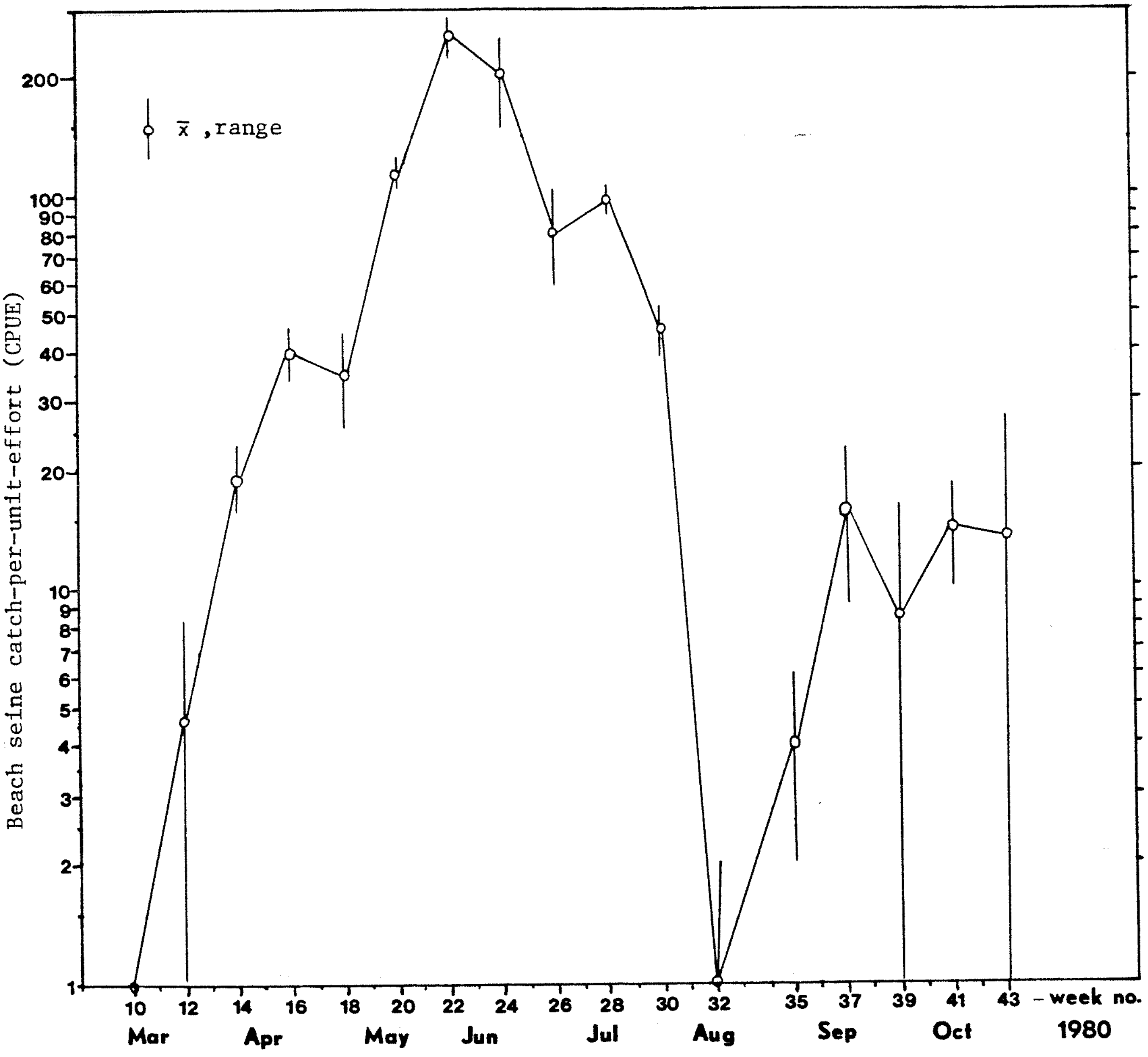

Fig. 4-4. Beach seine catch-per-unit-effort (CPUE) of juvenile English sole at Westport, Grays Harbor, Washington, March-October 1980.

abundance in channel areas in the vicinity of the neritic sampling sites.

4.3.2 Residence and Movement: Juvenile English sole appeared to exhibit two opposite patterns of movement during their early period of residence in the estuary. Two different size classes, probably representing young-of-the-year and yearlings, were observed in the beach seine and otter trawl collections between March and early July. The apparent 1979 age class was captured by the otter trawl in the deep sublittoral habitats of the channels, while recently settled, young-of-the-year juveniles of the 1980 cohort group were captured principally in the shallow sublittoral and lower littoral habitats with the beach seine. While the abundance of 1979 age class fish declined until early July, when these fish appeared to have emigrated out of the estuary, the young-of-the-year exhibited an increasing recruitment into the shallower habitats until late May, when the population appears to have stabilized.

The mean length and weight of juvenile English sole at the different shallow sublittoral and lower littoral (beach seine) sites also varied enough to suggest that distinct populations may have persisted in different regions of the estuary without a significant degree of mixing. The total length and wet weight of the young-of-the-year English sole at the time of the last sampling week of October 20-24 (Table 4-1) and the length frequency distributions over the 33 week sampling period (Appendix Figs. 4-1 A-D) indicate that growth rates were significantly different among relatively distinct populations.

4.3.3 Growth: Growth of young-of-the-year English sole in Grays Harbor was asymptotic, initially illustrating rapid, exponential growth which slowed dramatically by mid-summer (Fig. 4-5 A-D); although there was some variation, growth appeared to decline sometime between the sampling weeks of July 7-11 and August 4-8 at the four sites. There also was indication of differential growth between the upper and lower regions of the estuary, with fish at Cow Point and Moon Island showing

Table 4-1. Mean total length (mm, ± 1 s.d.) and wet weight (g) of young-of-the-year English sole at the time of recruitment and the end of sampling (October 20-24) at four shallow sublittoral and lower littoral sites at Grays Harbor, Washington. Sample sizes appear in parentheses.

	Site			
	Cow Point	Moon Island	Stearn's Bluff	Westport
Recruitment:				
Sampling Week	April 28- May 2	March 17-21	March 17-21	March 17-21
Total Length (mm, ± 1 s.d.)	36.28 ± 10.95 (7)	23.66 ± 4.25 (16)	29.99 ± 16.76 (41)	35.99 ± 12.24 (9)
Mean Wet Weight (g)	0.6 (7)	0.3 (16)	1.0 (41)	1.2 (9)
Final Sampling Week:				
Total Length (mm, ± 1 s.d.)	83.0 ± 0.0 (1)	101.27 ± 13.49 (50)	93.20 ± 11.56 (35)	80.55 ± 10.80 (25)
Mean Wet Weight (g)	4.8 (1)	7.07 (70)	6.52 (35)	4.51 (27)

A. Cow Point

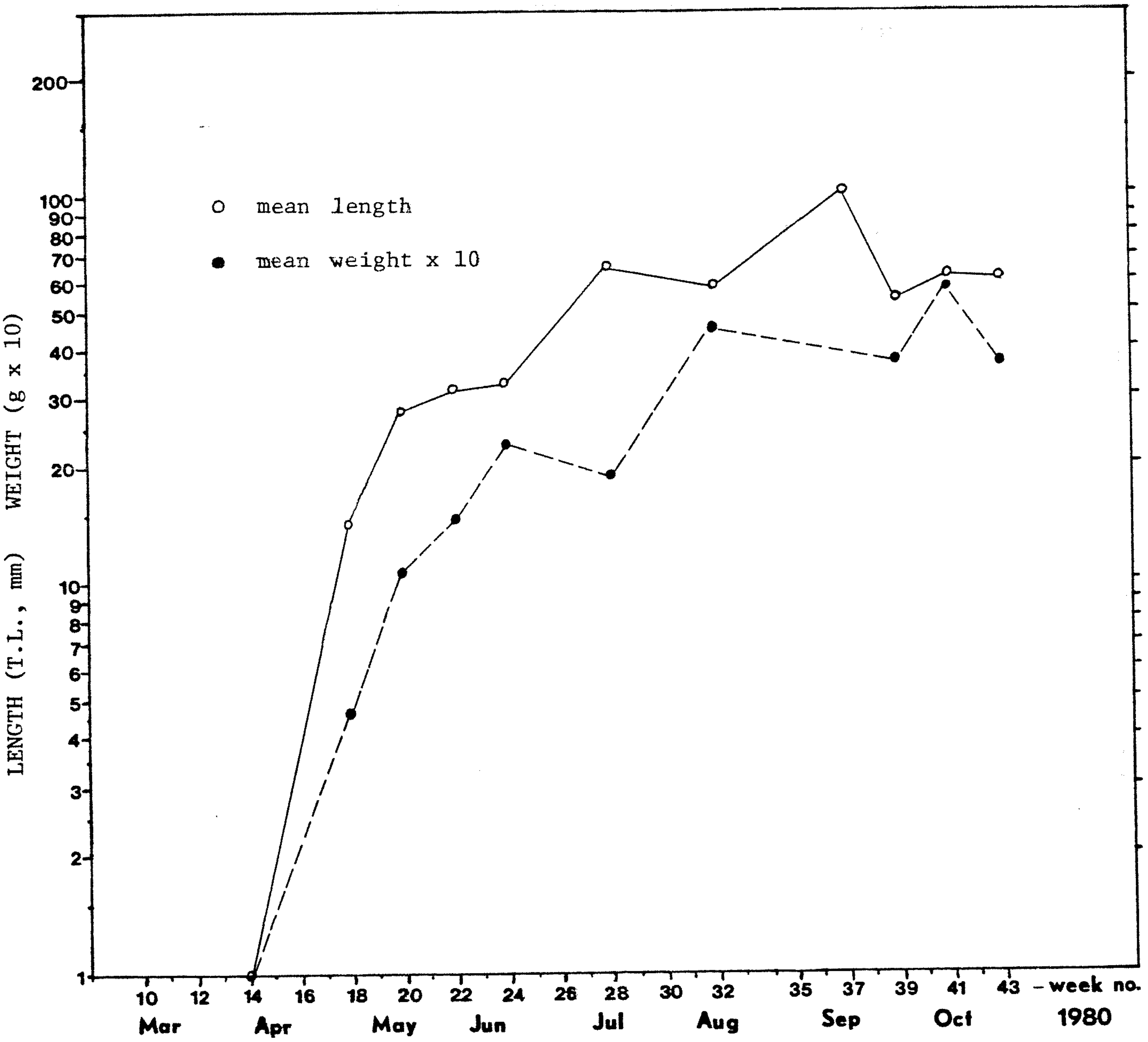

Fig. 4-5. Incremental growth (total length, mm; weight, g) of young-of-the-year English sole caught by beach seine at Grays Harbor, March-October 1980; A) Cow Point, B) Moon Island, C) Stearn's Bluff, and D) Westport.

B. Moon Island

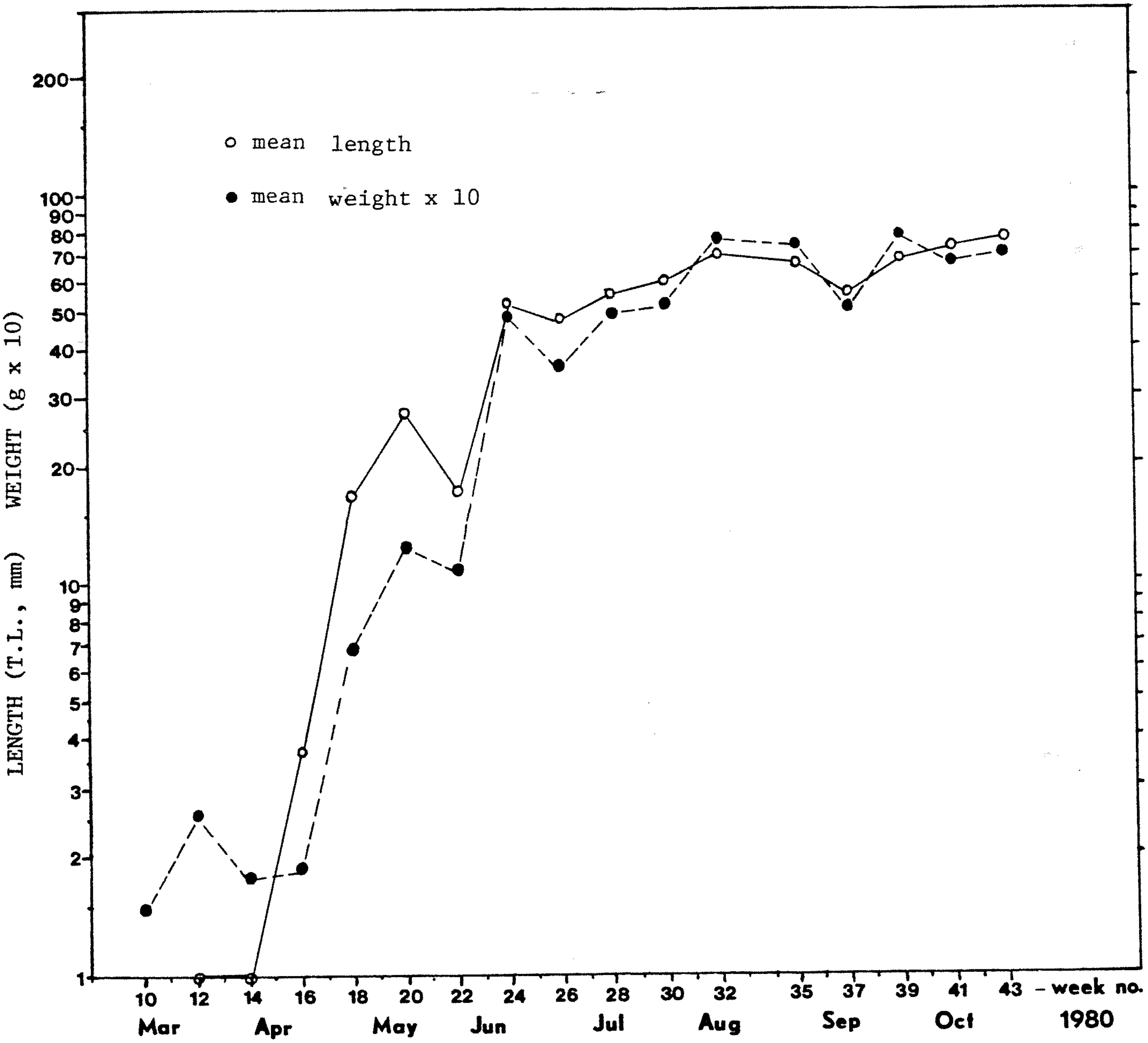

Fig. 4-5. Incremental growth (total length, mm; weight, g) of young-of-the-year English sole caught by beach seine at Grays Harbor, March-October 1980; A) Cow Point, B) Moon Island, C) Stearn's Bluff, and D) Westport - continued.

C. Stearn's Bluff

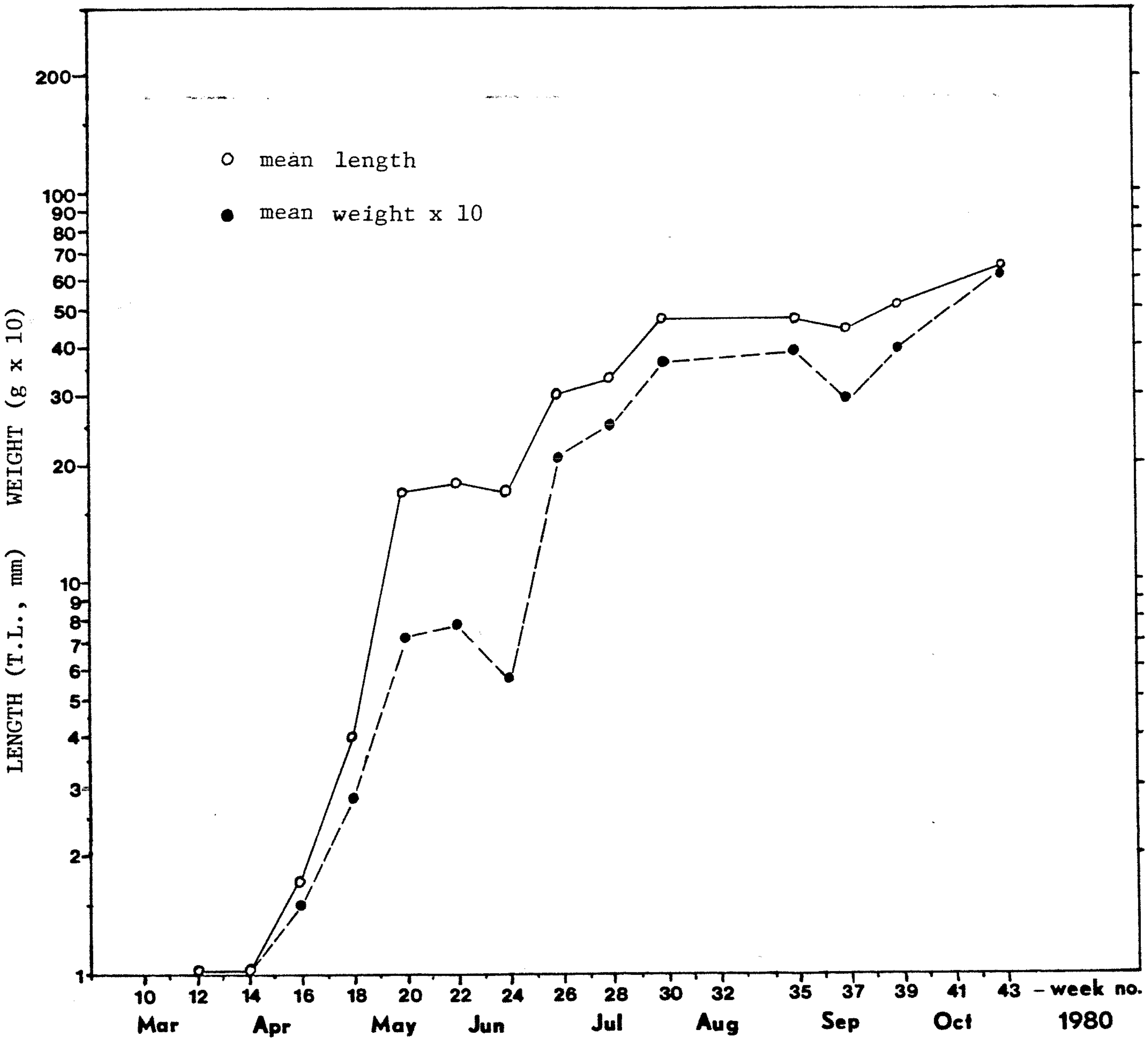

Fig. 4-5. Incremental growth (total length, mm; weight, g) of young-of-the-year English sole caught by beach seine at Grays Harbor, March-October 1980; A) Cow Point, B) Moon Island, C) Stearn's Bluff, and D) Westport - continued.

D. Westport

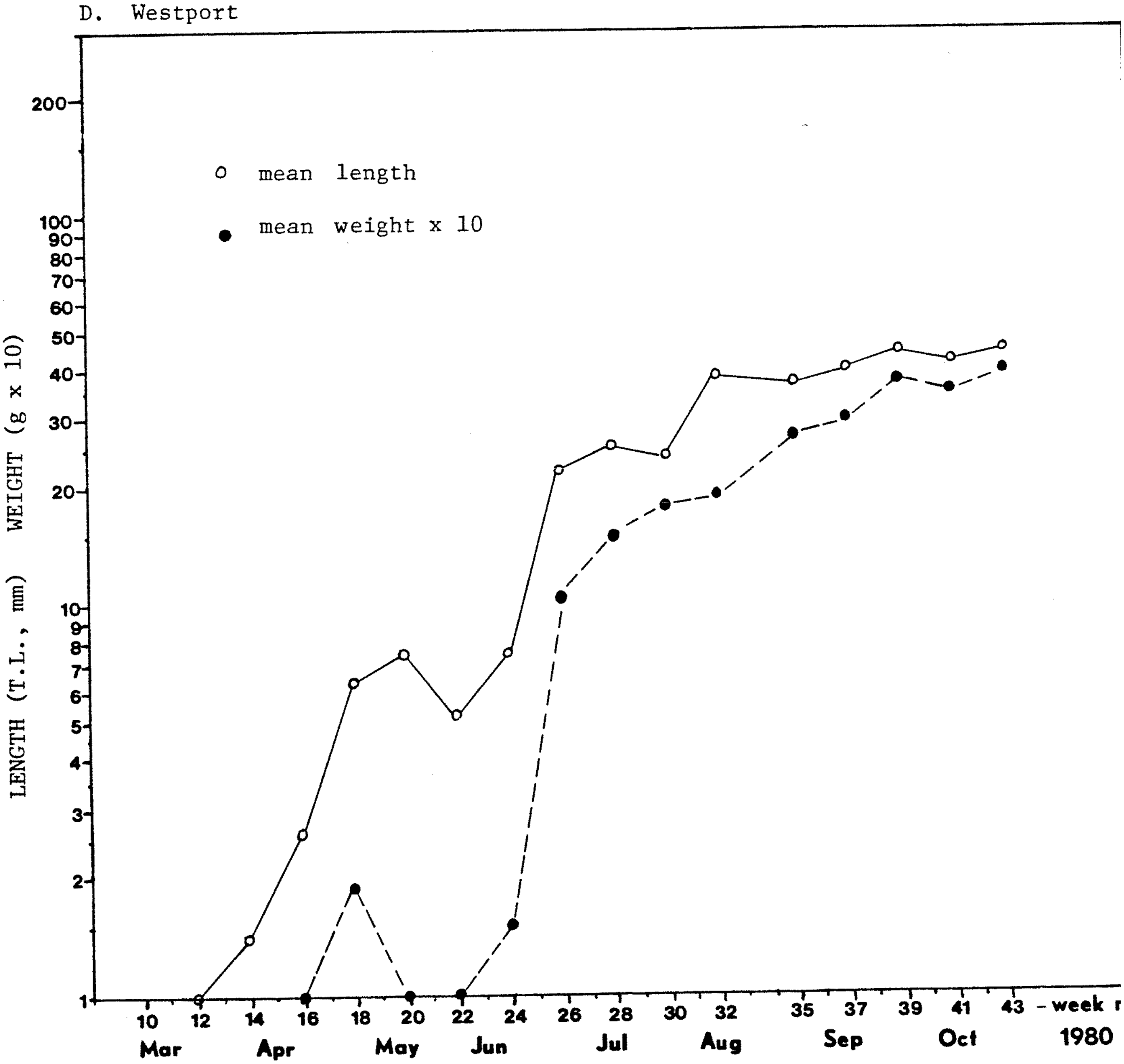

Fig. 4-5. Incremental growth (total length, mm; weight, g) of young-of-the-year English sole caught by beach seine at Grays Harbor, March-October 198(A) Cow Point, B) Moon Island, C) Stearn's Bluff, and D) Westport - continued.

higher rates of incremental growth during the early exponential growth period, as well as the lower asymptote already discussed. An apparent growth plateau or decline was evidenced for all populations between the sampling weeks of May 12-16 and June 9-13: in all probability this represents secondary recruitment of smaller fish although the length frequency distributions (Fig. 4-5 A-D) did not indicate a very significant influx. This period was, however, the time of maximum abundance of young-of-the-year English sole at most sites (Figs. 4-1 to 4-4) and may be related to this equilibration in the populations in the shallower habitats in the estuary. And, as suggested in the timing and distribution of young-of-the-year English sole at the five shallow sublittoral and lower littoral habitats over time, the more pronounced depressions in the growth rate at the two lower estuary sites indicate that recruitment is strongest in this region of Grays Harbor.

4.3.4 Incidence of Tumors and Fin Rot: Skin tumors (epidermal papillomas) were observed to occur, often in high incidence, in juvenile English sole at all sites in Grays Harbor (Fig. 4-6). The highest mean incidence (percent of total catch or subsample) occurred at Westport (15.7%) and Moon Island (14.1%), the lowest at Cow Point (3.8%). Disregarding a single incidence of tumors at Moon Island in early March, tumor-bearing English sole generally appeared at successively later dates between Westport and Cow Point with an approximate 10-wk lag between the occurrence of significant proportions of tumor-bearing fish at Westport and their appearance at Cow Point.

There was a trend, illustrated especially in the tumor-bearing English sole caught at Moon Island, for the mean length of the fish with tumors to be be somewhat longer than the normal fish (Fig. 4-7). Although there may be a sampling error involved (i.e., tumors on larger fish might be more noticeable than on smaller fish), this may also illustrate that distinct size classes or populations of English sole

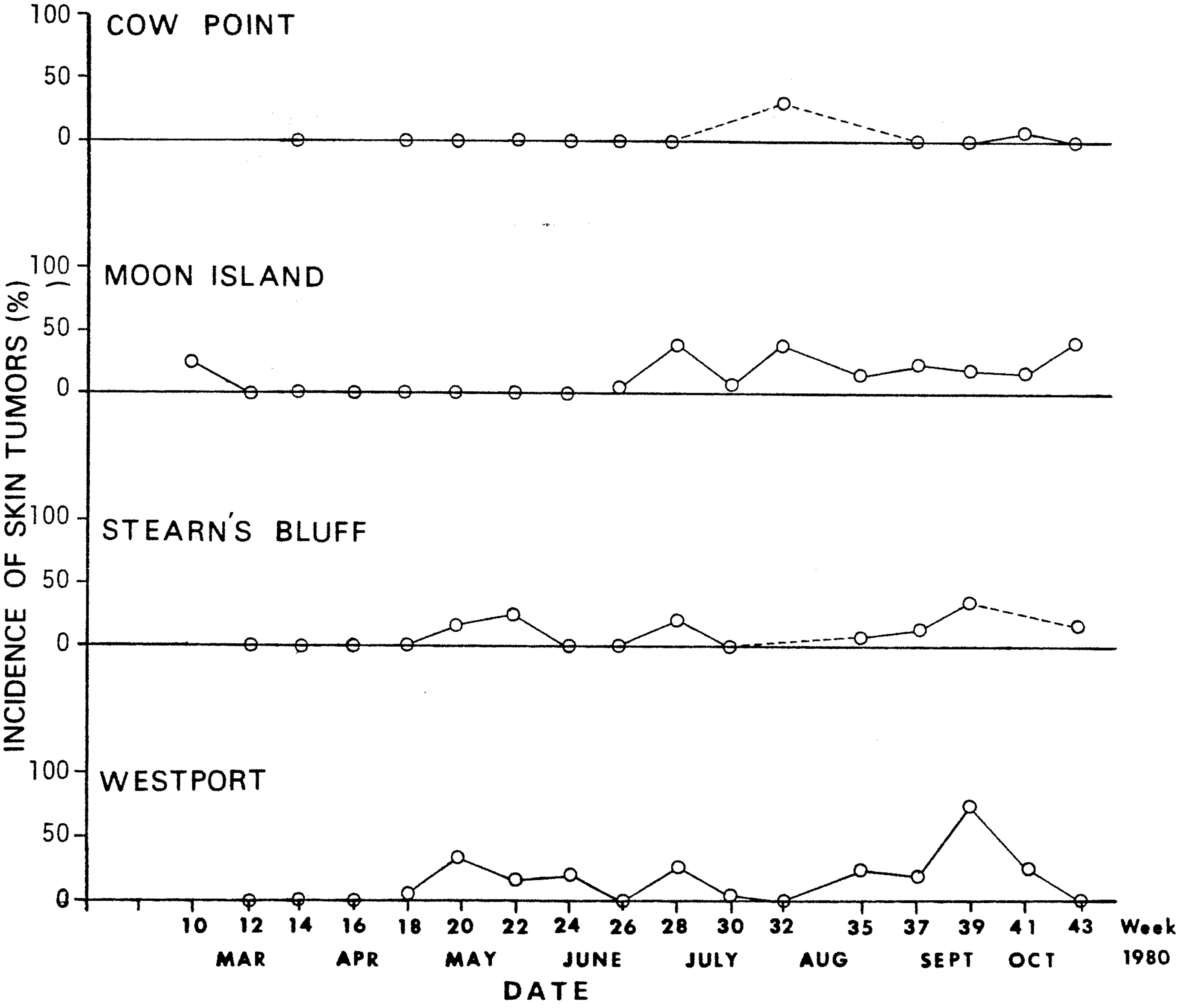

Fig. 4-6. Incidence (% of catch or subsample) of epidermal papilloma skin tumors on juvenile English sole in Grays Harbor, Washington, March-October 1980.

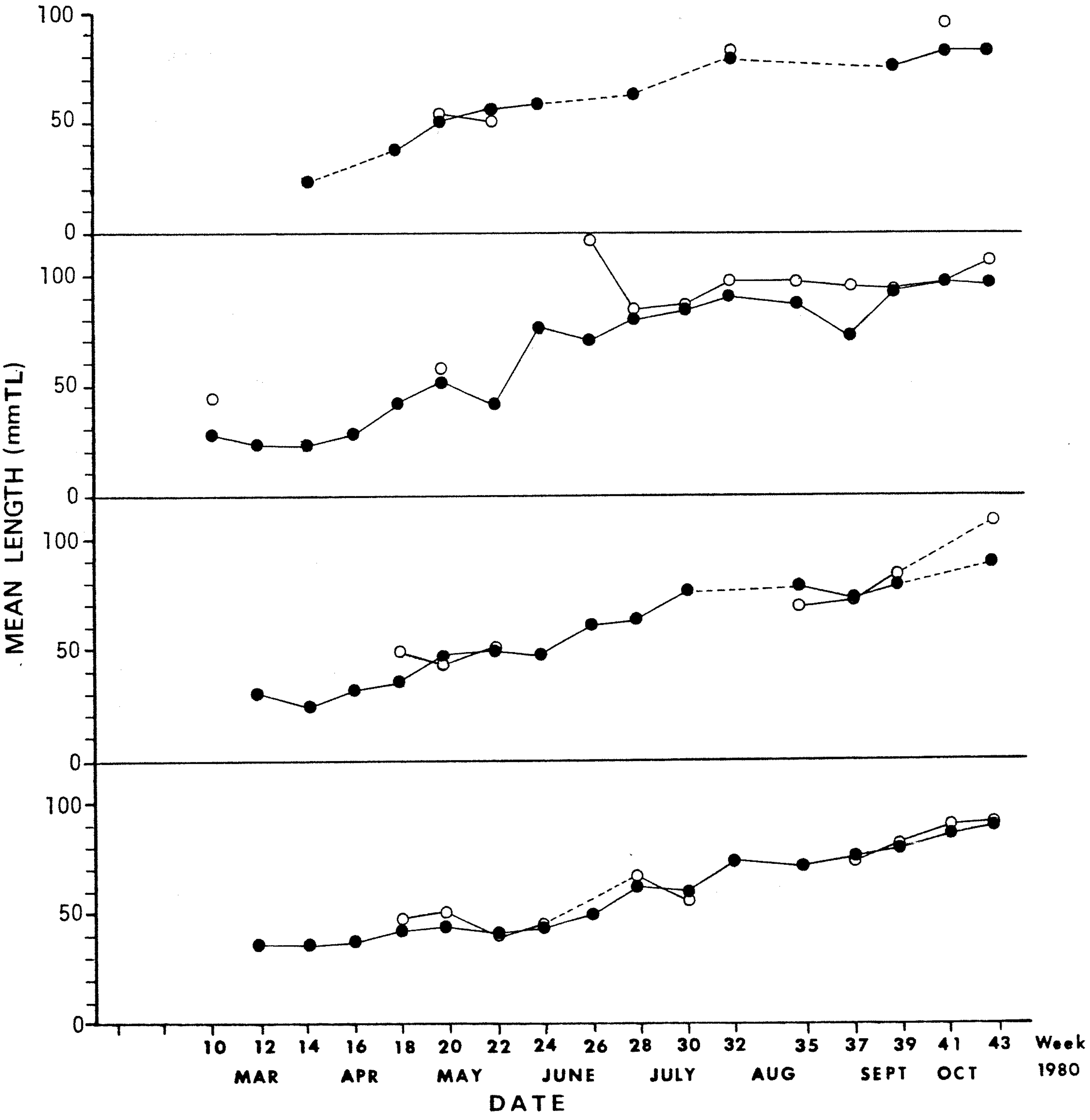

Fig. 4-7. Mean length (mm TL) of juvenile English sole with (open circles) and without epidermal papilloma skin tumors (closed circles) in Grays Harbor, Washington, March-October 1980.

maybe more prone to tumor incidence (i.e., the earlier spawning populations). A third explanation, that the tumor-bearing fish may actually grow faster than the normal juvenile English sole is also plausible.

Fin rot was not observed on any English sole captured in Grays Harbor.

4.4 Discussion

4.4.1 Importance of Estuarine Habitats to the Production of Juvenile English Sole--the "Nursery" Concept: Given the predominance of juvenile stages of English sole in Grays Harbor, the estuary would appear to represent exclusively a nursery or rearing environment for recently metamorphosed (settled) postlarvae which originated from spawning populations outside Grays Harbor. Only two yearclasses appeared to be present during the eight-month sampling period, the yearling English sole (130-150 mm TL) which occurred in the Dungeness crab trawl catches in the channels early in the sampling period, and the young-of-the-year English sole which occupied shallow sublittoral habitats in abundance after early March. Accordingly, Grays Harbor represents a transitional environment for the juvenile English sole during a critical period in their early life history when they are especially vulnerable to predation and require high densities of small epibenthic prey organisms. Once transported or immigrated into the estuary, they appear to distribute themselves throughout the extensive shallow sublittoral habitats well into the upper estuary. Except for short-term variability observed in the abundance of fish at several sites (especially Moon Island and Cow Point), which might represent local movement associated with salinity changes in the upper estuary, the young-of-the-year sole resided in these shallow habitats through October and apparently moved into the deeper channel habitats sometime during the early winter.

Without mark and recapture experiments, it is impossible to establish the extent of movement of young-of-the-year English sole through the estuary but patterns of abundance and size distribution in the catches at the lower and upper estuarine sites indicate that recruitment occurred earlier and more intensely in the lower estuary; recruitment into the upper estuary may therefore have involved both settlement of postlarvae from the water column and movement of settled juveniles from the lower estuary in association with the progressive intrusion of marine water up the estuary. Maximum population abundance appears to have been reached by June and maintained through the summer.

4.4.2 Sources of English Sole Recruitment: Data from both the FRI studies of shallow sublittoral and neritic fishes and the Dungeness crab trawl sampling in deeper habitats failed to indicate the presence of mature English sole. As illustrated by Hayman and Tyler (1980), among others, populations of adult sole in shelf habitats offshore Grays Harbor are probably the principal source of larval and juvenile sole recruited into inshore environments, including the estuarine environment of Grays Harbor. Unfortunately, there are no data which allow a quantitative comparison of the rates of recruitment or densities of juvenile English sole in nearshore oceanic habitats adjacent to Grays Harbor.

Laroche and Richardson (1979), Olson and Pratt (1973) and Hayman and Tyler (1980) indicated that variable spawning times, typically associated with coastal upwelling patterns, were generally responsible for differential strengths of English sole cohorts. Thus, the apparent heterogeneity of recruitment into Grays Harbor during 1980 may be attributed to either 1) different source populations of larvae and post-metamorphosis juveniles or 2) prolonged spawning of one population of mature English sole spawning in oceanic waters adjacent to Grays Harbor.

4.4.3 Relationship to Epibenthic/Benthic Fauna: As illustrated for some other marine species, the density and size composition of prey organisms available to fish larvae immediately after the absorption of their yolk sac ultimately determines the ability of the postlarvae and juveniles to catch food and avoid predators (Cushing 1974; Lasker 1975;

May 1974). For the case of juvenile English sole that had just settled out of the pelagic environment, the availability of small epibenthic organisms which are suitable as prey may be critical to the overall survival of that cohort or yearclass of sole. Sampling of the epibenthic community at Moon Island, albeit limited in scope, has shown that shallow sublittoral and lower littoral habitats with unconsolidated substrates (mud or sand) support high densities of epibenthic crustaceans (Section 7.0), which form the principal prey taxa of juvenile English sole in this habitat (Section 8.0). This is not unique to Grays Harbor, as illustrated by the stomach contents of juvenile English sole in the Columbia River estuary (Durkin and Lipovsky 1977; Durkin et al. 1979; Haertei and Osterberg 1967) and nearshore environs of Puget Sound and the Strait of Juan de Fuca (summarized in Simenstad et al. 1979), where epibenthic crustaceans similarly form the principal components of their diet. Thus, these shallow water epibenthic crustacean populations may form unique prey resources which are required by young-of-the-year English sole during the critical period after absorption of their yolk sac and settlement to the bottom.

4.4.4 Significance of Tumor Incidence: In summarizing the incidence of skin papillomas among young post-metamorphosed English sole along the Pacific coast, Stich et al. (1976) indicated that the frequency of affected fish can average as high as 58% but that tumor prevalence can differ considerably within a restricted geographic area; thus, incidence inside the Strait of Georgia varied between 0.4% and 58.6%. Stich et al. (1976) also suggested that there definitely was a higher incidence of skin tumors among English sole inhabiting areas of urban contamination than among English sole populations in relatively remote areas. Angell et al. (1975) documented the epizootiology of tumors in an English sole population in central Puget Sound and found tumor incidence in age-group 0 fish to range between 16.6% and 19.9% over three years. The English sole population they examined, however, did not illustrate an influx of tumorous fish until August, peaking in October.

They did, however, document a significantly higher incidence of tumors in the earliest recruits. The fact that tumorous fish in Grays Harbor began appearing consistently at Westport in early May would suggest that the recruitment pattern of these fish into the estuary was somewhat different than in Puget Sound or that the development of the tumors occurred earlier in the early life history of the English sole populations on the outer coast. The apparent progression of tumor incidence up the estuary through the summer would also suggest that the affected fish originated outside the urban environment of the upper estuary and moved into that region of the estuary with the summer intrusion of saline water masses. Unfortunately, there is no information available on the incidence of skin papillomas in populations of English sole immediately outside Grays Harbor.

4.5 Summary

1) Juvenile English sole were captured during both beach seine and purse seine collections for juvenile salmonids and during otter trawl sampling for Dungeness crab conducted by the College of Fisheries.

2) Larger English sole, presumably 1979 age class yearlings, were captured in deep sublittoral habitats by the otter trawl but appeared to have emigrated from the estuary by early July. Recruitment of post-metamorphosis juveniles or settlement out of the water column by larvae proceeded over a ten week period until the population stabilized in late May.

3) The relative abundance of juvenile (young-of-the-year) English sole was greater at the two sites in the lower estuary than at the four sites in the upper estuary. Length frequency distributions and growth rates suggested that distinct populations may have persisted in different regions of the estuary without significant mixing.

4) An apparent growth plateau or decline was evidenced for all populations between mid-May and mid-June, any may have involved a density-dependent depression associated with the period of maximum abundance at most sites.

5) Skin tumors (epidermal papillomas) were documented, often in high incidence, on juvenile English sole at all sites; the highest mean incidences (14-15%) occurred in the Westport and Moon Island collections, the lowest (4%) in fish captured at Cow Point. An apparent progression of tumor incidence up the estuary through the summer suggested that the affected fish originated outside the upper estuary and moved into that region of the estuary with the summer intrusion of saline water masses.

6) Recently metamorphosed and settled English sole may be highly dependent upon shallow sublittoral and lower littoral habitats in Grays Harbor for epibenthic crustacean populations which form important, perhaps critical, constituents of their diet at this time.

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5.0 DISTRIBUTION AND ABUNDANCE OF BAITFISH

by Charles A. Simenstad

5.1 Introduction

Estuaries along the Pacific Northwest coast appear to sustain high densities of schooling neritic fishes or "baitfish" during certain times of the year and are known to be the principal rearing or "nursery" areas for the larval and juvenile stages of many of these fishes (Haertel and Osterberg 1967; Pearcy and Meyers 1973). Due to their commercial importance, e.g., Pacific herring, or their ecological importance as prey for juvenile salmonids and resident fishes of the estuary, the distribution and relative abundance of baitfish was considered to be an important aspect of any evaluation of the effects of habitat removal and dredging in Grays Harbor.

The majority of these fishes are either anadromous marine species, i.e., they spend their adult lives in marine water but return to fresh or estuarine waters to spawn and the juveniles may remain in estuarine environments for some time, or are truly marine species which enter and reside within the estuary in the marine water masses. While the latter may constitute rather ephemeral populations within the estuary, due to variable transport into the estuary from offshore waters, the anadromous species may require the estuarine environs functionally as spawning and rearing habitats.

Therefore, in documenting the distribution and abundance of baitfish in several regions of Grays Harbor, we hoped to be able to identify those populations which were either 1) dependent upon particular estuarine habitats for a critical stage of their life history (e.g., spawning or rearing) or 2) provided a predictable source of prey for juvenile salmonids during their outmigration through the estuary.

5.2 Materials and Methods

5.2.1 Beach Seine: Baitfish were captured in shallow sublittoral and lower littoral habitats with the 37-m floating beach seine described in Section 3.2.1. The occurrence of baitfish in the beach seine samples, however, was inconsistent and, as compared to the purse seine collections, did not appear to be representative of the presence of abundance of baitfish species. We have not used beach seine data in the following sections.

5.2.2 Purse Seine: The systematic collections with the 61-m x 90-m purse seine described in Section 3.2.2 were found to effectively capture baitfish larger than late larvae/early postlarvae. This depended upon the species, as even adult Pacific sand lance, Ammodytes hexapterus, had cross-sectional areas small enough to pass through all but the 6-mm mesh netting forming the bunt of the seine; abundant catches of this and similar species were therefore assumed to indicate extremely high densities in that area.

5.2.3 Field Preservation: All fish were preserved in 10% buffered formalin immediately upon capture and placed in separate bags with appropriate labels for return processing at FRI's Seattle laboratories.

5.2.4 Laboratory Processing: In the laboratory all duplicate samples were sorted to species and life history stage (larvae, juvenile, adult) and their standard lengths and blotted wet weights measured to the nearest 1 mm and 0.01 g, respectively. Subsamples of 50 (25 from each duplicate sample) were taken randomly from excessively large catches of various life history stages.

5.2.5 Data Analysis: All data were recorded on MESA/NODC format type 100 data coding formats prior to keypunching and transfered to magnetic tape for computer storage. Basic statistical tabulation and analyses w ere performed on these data using FRI computer program packages specially designed for the MESA/NODC-formatted data and for plotting catch and length frequency data in this form.

5.3 Results

5.3.1 Species Composition:

Seven species of baitfish were captured in Grays Harbor, involving fifteen distinct life history groups. The unidentified osmerid larvae were probably one of the three species which were later identifiable as juveniles and adults (Table 5-1). Species were considered rare when they occurred in less than one third of the collections and had CPUE values less than one; common species occurred in more than one third of the collections and typically had CPUE values greater than one; and those species which occurred commonly in high abundance appeared in half or more of the collections and often had CPUE values greater than 100. Northern anchovy were the most ubiquitously distributed fish and were represented in all life history stages. Juvenile Pacific herring were also abundant at four of the five sampling sites. Surf smelt appeared to be most common in the lower estuary while longfin smelt appeared to be restricted to the sampling sites in the upper reaches of the estuary. Over the five sites, the Moon Island site illustrated the greatest diversity of species and life history stages, perhaps indicating its position in the estuary as a general mixing region and boundary area between the more saline waters of the lower estuary and the riverine waters of the Chehalis River.

5.3.2 Abundance of Principal Baitfish Species/Life History Stages:

Only four species or life history stages of baitfish (adult and juvenile northern anchovy, juvenile Pacific herring, and juvenile longfin smelt) were consistently abundant over the sampling period to indicate residence and actual utilization of the estuary. The other species and life history stages, especially larvae, were either rarely encountered in abundance or were never abundant, though often present; juvenile and adult American shad occurred often at sites in the inner estuary but were never abundant (CPUE usually less than 10 fish/set) and surf smelt

Table 5-1. Occurrence and relative abundance of baitfish species at five purse seine sampling sites in Grays Harbor, Washington, March-October 1980. Circles represent rare occurrences; +'s, common occurrences; and X's, commonly occurring in high abundances; see text for definition of these terms.

Species/Life History Stage	Sampling Site Cosmopolis	Cow Point	Moon Island	Stearn's Bluff	Westport
Alosa sapidissima, American shad					
juvenile		o	o	o	
adult	+	+	o		
Clupea harengus pallasi, Pacific herring					
juvenile	+	X	X	X	X
larvae	o	o	o		
Engraulis mordax, northern anchovy					
adult		+	X		X
juvenile	o	+	X	X	
larvae	o	+	X	o	
Osmeridae, smelts					
larvae	o	o	o		
Hypomesus pretiosus, surf smelt					
adult/juvenile	o	o	+	X	X
larvae	o	o	o		
Spirinchus thaleichthys, longfin smelt					
adult	o	+	+	o	
juvenile, larvae	+	+	+		
Allosmerus elongatus, whitebait smelt					
adult			o		
juvenile			o		
Ammodytes hexapterus, Pacific sand lance					
juvenile			o	X	o
larvae			o		

and Pacific sand lance were infrequently caught at the two sites in the lower estuary, though in abundance (CPUE greater than 50 fish/set) when captured.

Adult northern anchovy appeared in the estuary in three distinct influxes, the first (only detectable at Moon Island) in mid-May, a second in the lower estuary sites in July and the latter at these same sites in late August and September (Fig. 5-1). There was no obvious relationship between the occurrence of northern anchovy larvae and the adults to suggest that these influxes were associated with spawning in the estuary. Patterns of abundance of juvenile northern anchovy (Fig. 5-2) were not as uniform as with the adults. The abundances associated with periodic influxes generally increased from mid-May to late September and an extended, six-week period of residence between late August and most of September was indicated at Moon Island.

As in the case of northern anchovy adults and juveniles, juvenile Pacific herring appeared to begin entering Grays Harbor in mid-May (Fig. 5-3); herring larvae were seldom encountered,* implying that the source of these juveniles was from adjacent oceanic waters outside the estuary, despite the fact that Pacific herring spawning has been reported to occur within Grays Harbor and in similar, adjacent coastal estuaries, i.e., Willapa Bay and the Columbia River estuary (R. Trumble, Washington Dep. Fish., personal communication and J. Durkin, Natl. Mar. Fish. Serv., personal communication). Influxes of postlarvae and juveniles to our sampling sites were apparently of low magnitude between mid-May and early July except at Stearn's Bluff, which showed a four week period of abundant juvenile herring in mid-June. By late August, however, abundances began increasing at all sites and continued for approximately nine weeks until early October; an additional influx appeared to occur

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*Our sampling was not designed for fish larvae assessment, however, because the smallest mesh sizes of the purse and beach seines were too small to effectively capture larvae while the plankton nets had mesh sizes so small that fish larvae could actually detect and avoid the net.

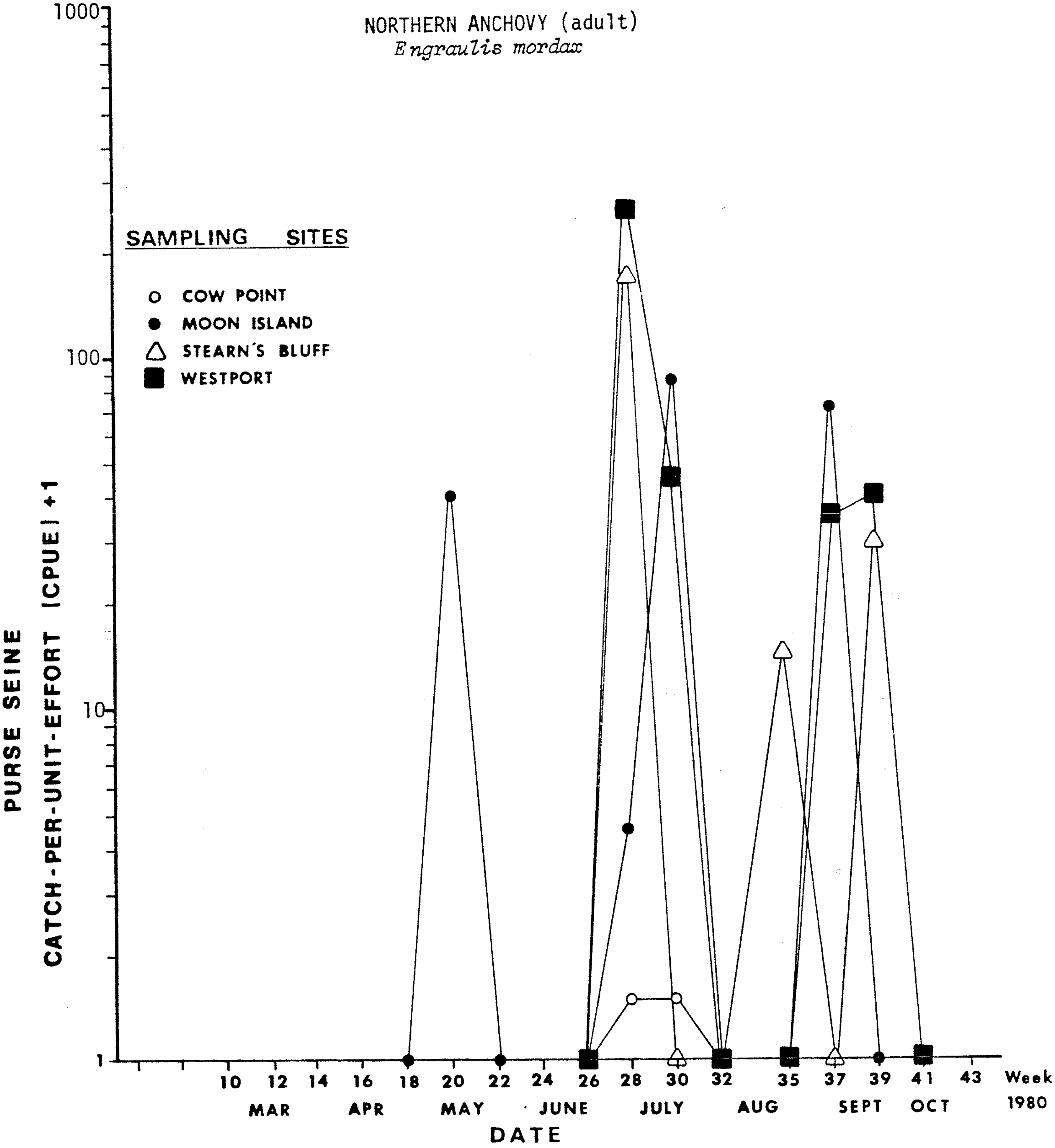

Fig. 5-1. Abundance (purse seine CPUE) of adult northern anchovy in neritic habitat at four sites in Grays Harbor, Washington, March-October 1980.

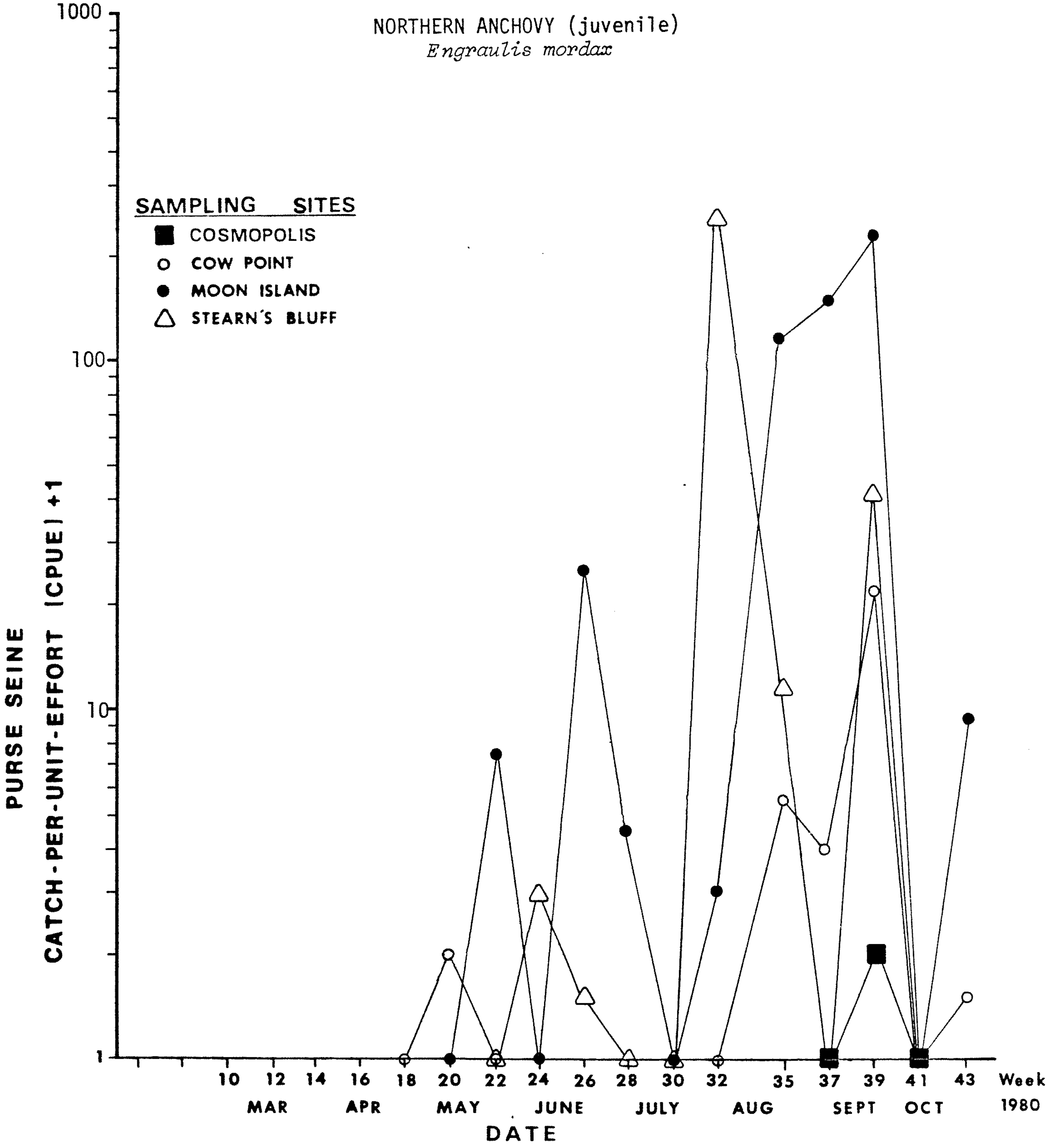

Fig 5-2. Abundance (purse seine CPUE) of juvenile northern anchovy in neritic habitat at four sites in Grays Harbor, Washingon, March-October 1980.

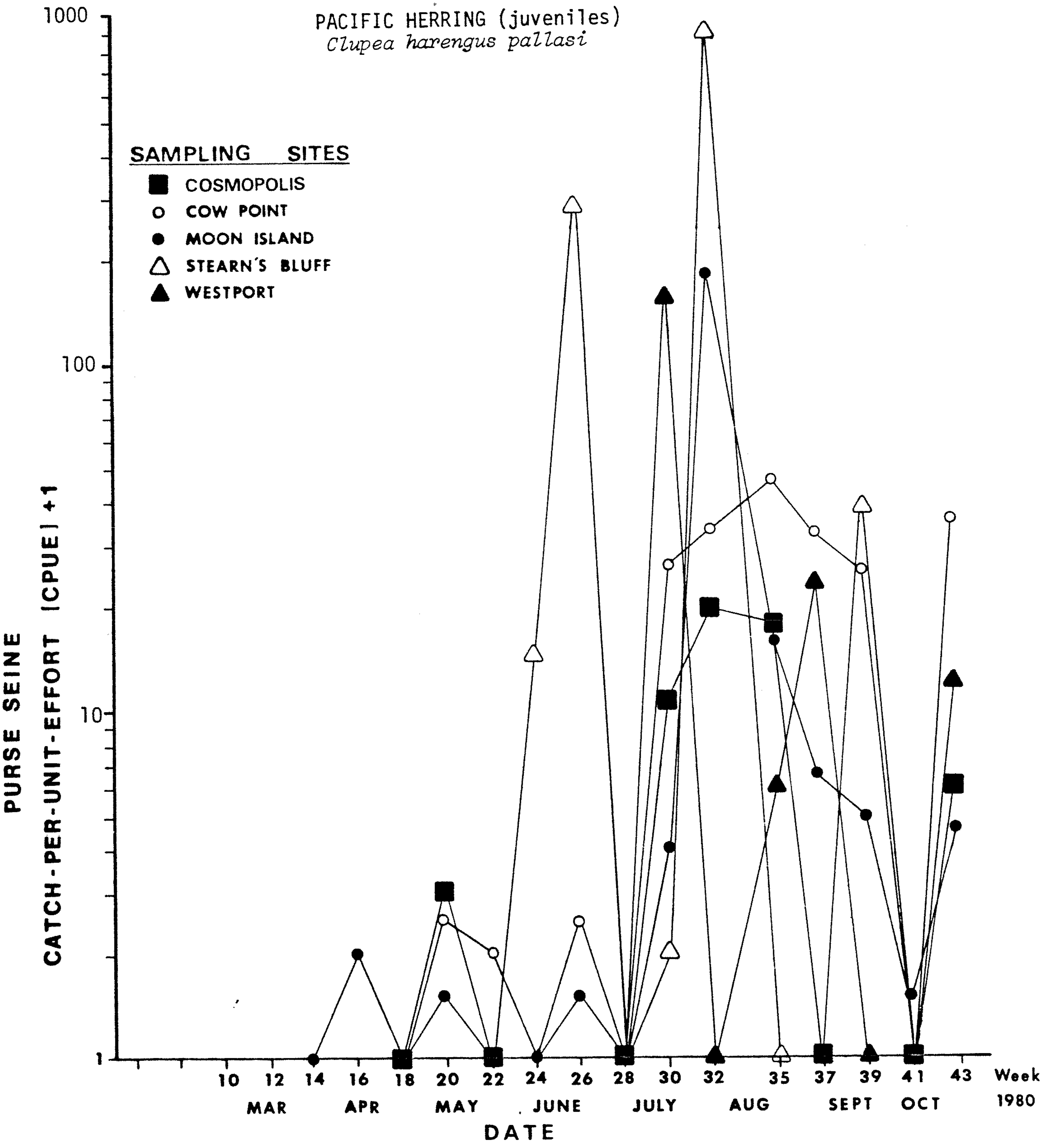

Fig. 5-3. Abundance (purse seine CPUE) of juvenile Pacific herring in neritic habitat at five sites in Grays Harbor, Washington, March-October 1980.

in mid-October but the termination of our sampling in the estuary does not permit us to determine whether that influx was sustained. The maxima in juvenile Pacific herring abundance occurred at Westport and Stearn's Bluff, the two sampling sites in the lower estuary. Abundances in the upper estuary sites were typically an order of magnitude lower at their maxima. And, while most influxes of juvenile herring seldom lasted more than six weeks at any one site, an extended period of residence was indicated at Cow Point which lasted for approximately nine weeks between late July and late September.

Only juvenile longfin smelt were captured in any abundance throughout the eight month sampling period (Fig. 5-4). Three influxes were evident, all occurring at the three sites in the upper estuary: a low abundance influx in March, a six or twelve week long (depending upon the cause of the low catches in late June) residence between mid-May and late July, and a seven week long influx between mid-August and late September. Each of the influxes appeared to be of greater magnitude than the previous one. There was no evidence that these influxes were correlated with any periodic phenomena such as tides. Coastal upwelling, however, does occur in the Grays Harbor region from June to September as a series of distinct events associated with winds having a strong northerly component (Loehr and Collias 1981) and may be an important mechanisms of larval fish transport into the estuary.

5.3.3 Spawning Ground Surveys: One of the major objectives of the FRI studies in Grays Harbor was to determine whether or not substantial Pacific herring spawning occurs in the vicinity of the navigation channel between Moon Island and Westport during the sampling period. In developing the sampling design for this aspect of the study we assumed that spawning, if its was to occur, would take place in the maximum concentration of eelgrass (Zostera marina, Z. noltii) in the vicinity of the navigation channel. Phipps (1977) had indicated dense beds of eelgrass, primarily Z. marina, in the shallow sandflat habitats west of Moon Island and his distributions maps were used for the initial survey

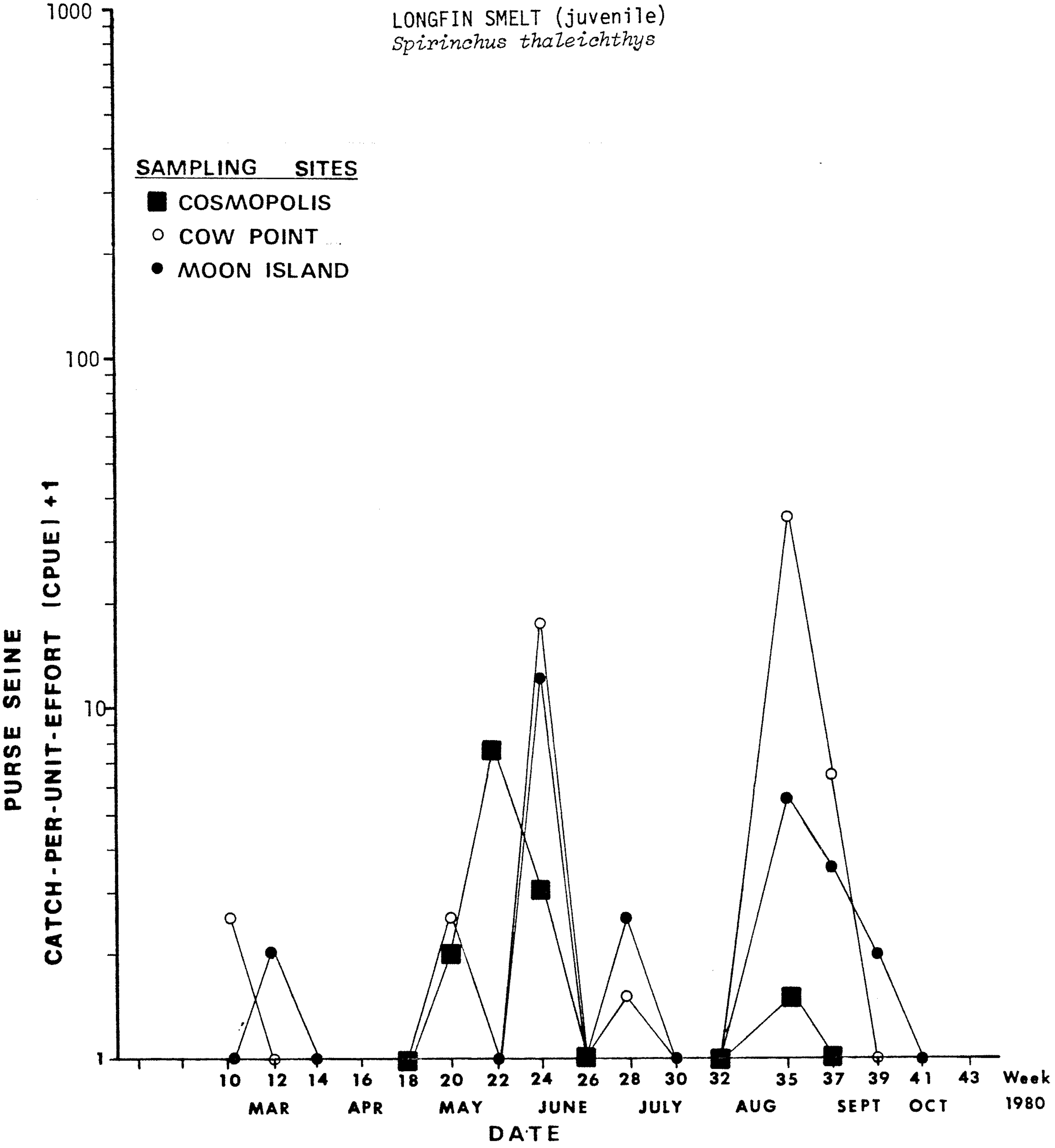

Fig. 5-4. Abundance (purse seine CPUE) of juvenile longfin smelt in neritic habitat at three sites in Grays Harbor, Washington, March-October 1980.

transects between Moon Island and Pt. Brown. In these surveys a rake (Fig. 5-5) was dragged along the bottom for a standard length of tow (five minutes) to procure eelgrass blades and plants for examination for attached hearing eggs. No eelgrass was found during these surveys between March and April, as well as supplemental surveys along the edge of the sandflats immediately west of Moon Island adjacent to the navigation channel. Waves breaking over the sandflats at high tide prevented raking on the top but no eelgrass was visually evident on these sandflats when they were exposed at low tide.

Considering the relative absence of dense eelgrass beds in these area, we modified our sampling design by locating dense eelgrass beds in the Elk River portion of the estuary, just southeast of Westport. Although this sampling site was not in the vicinity of the existing or proposed navigation channel, it was assumed that at least the timing of any herring spawning would be indicated by sampling eelgrass in this region. No herring eggs were found on any of the eelgrass raked from this latter area between mid-April and early June, when sampling terminated. This lack of significant herring spawning, at least in the southern and central reaches of the lower estuary during the sampling period, was corroborated by the general sparsity of larval and postlarval herring in either the purse seine catches or the bongo net plankton tows in the estuary during the course of the FRI sampling.

5.4 Discussion

5.4.1 Baitfish Utilization of the Estuary--the "Nursery" Concept:

In general, the occurrence of baitfish in Grays Harbor appears to be highly transitory and typically related to influxes of fish into the estuary from offshore sources, although there are two species which utilize the estuary extensively. Based upon evidence from Willapa Bay, our sampling for spawning herring may have occurred too late to actually document the timing, location, and density of spawning in Grays Harbor, although spawning of Pacific herring in the Columbia River estuary is

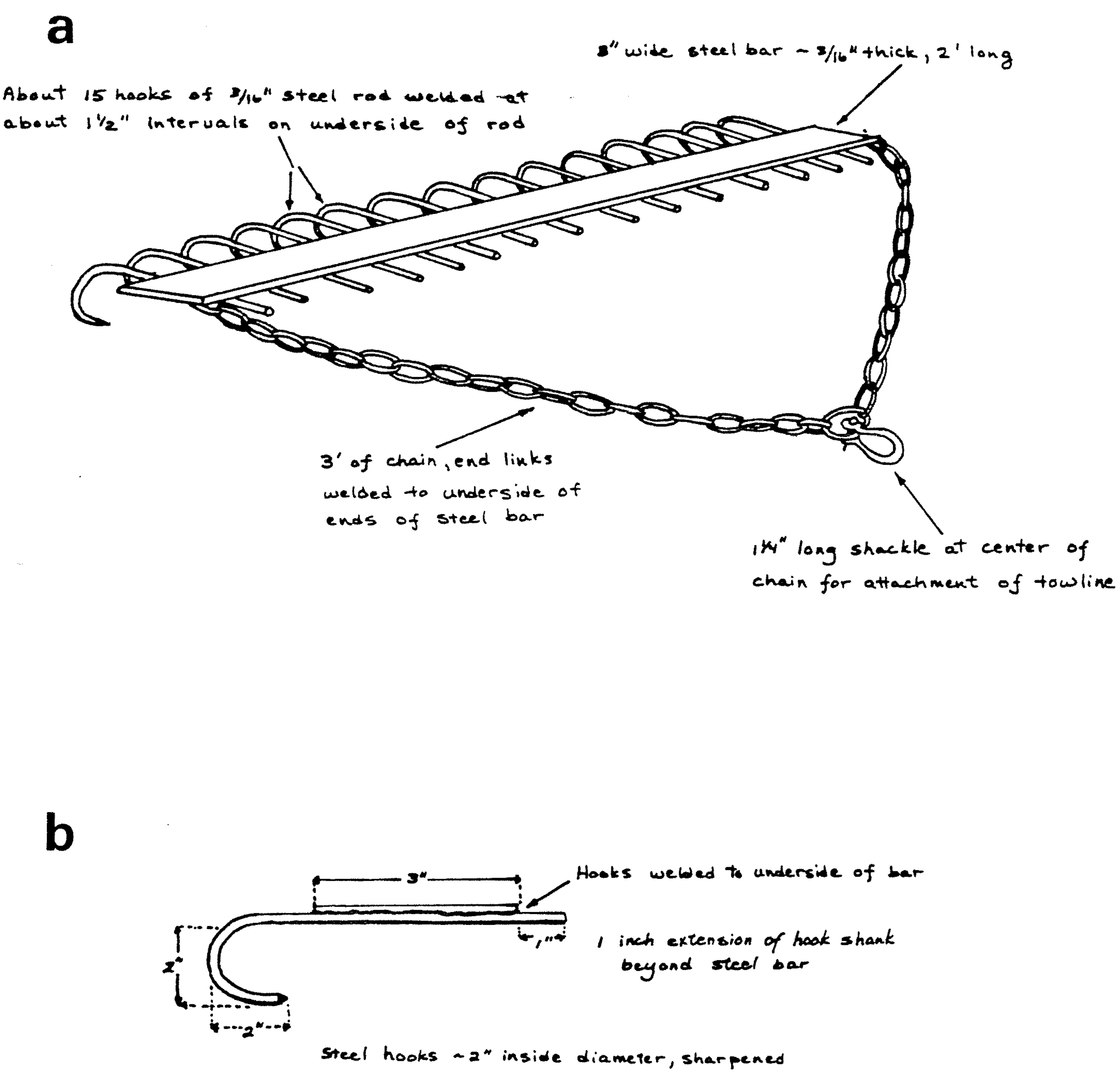

Fig. 5-5. Herring spawn-vegetation sampling rake (a) and detailed view of steel hooks (b) similar to the type utilized to sample for eggs of Pacific herring in Grays Harbor, Washington, March-June 1980. Design and drawing courtesy of Washington Department of Fisheries.

reported to be later, i.e., April-June (J. Durkin, Natl. Mar. Fish. Serv., personal communication). The high densities of postlarval and juvenile Pacific herring at our sampling sites do indicate extensive spawning occurs within or closely adjacent to the estuary and that estuarine residence is an important early life history characteristic of these populations. Longfin smelt, which are reported to spawn in the Chehalis River and other tributaries to Grays Harbor (Deschamps and Wright 1970; Smith et al. 1976), are also directly associated with the estuary during reproduction and subsequent early life history development. But even the abundance of these juvenile baitfish varied considerably during the eight-month sampling period, suggesting patchy distributions of low density of these pelagic stages. Juvenile northern anchovy, although apparently not associated with significant populations of adults spawning within the estuary, are certainly present in high numbers through the summer months. Whether this is the result of active movement of the larvae, postlarve and juveniles into Grays Harbor, or passive transport via oceanic water masses entering the estuary cannot be determined from existing information.

In all cases, however, certain survival advantages may be obtained by extended residence in the estuary, including reduction in mortality due to predation and the availability of high densities of preferred prey items. The highly turbid waters of the estuary may well protect these early life history stages from significant predation by visual predators such as coho and chinook salmon, spiny dogfish (_Squalus acanthias_), lingcod (_Ophiodon elongatus_), and various marine mammals. The densities of small zooplankton, especially calanoid copepods, which tend to be present within the productive regions of the estuary (_see_ Section 6.0) may also provide the critical concentrations of prey necessary for maximum growth and survival during this "critical" period in their total life history. This is especially true for the stage between larvae and postlarvae, when the fish must switch from utilization of yolk sac energy to feeding upon live prey organisms. Studies with similar species of neritic fishes have shown that the larvae require concentrations of prey between 6,000 and 20,000 individuals per m^3 in order to survive (Blaxter 1965). The mean densities of appropriately-sized zooplankters in Grays Harbor during the sampling period (see Section 6.0) were definitely lower than these values but do not take into consideration the typcially patchy distribution of neritic zooplankton and may underestimate the actual densities within patches.

5.4.2 Residence Time of Baitfish: While the residence time of juvenile salmonids in Grays Harbor appears to be a function of varying migration rates through the estuary, the apparent period of time that baitfish spend in the estuary was highly variable and may be a function of a number of factors, including: 1) passive transport via the intrusion of oceanic water masses into Grays Harbor due to coastal upwelling, 2) active migrations into or through the estuary for spawning or feeding purposes, 3) import into the estuary from freshwater or estuarine spawning populations, or 4) infrequent, low coverage sampling of extremely patchy concentrations of baitfish. Thus, unlike the juvenile salmonids passing through Grays Harbor, residence time of baitfish may be more dependent upon the physical processes, i.e., the hydrodynamics or water characteristics, of the estuary. Given the lack of detailed studies of water transport and characteristcs in Grays Harbor during our studies, it is difficult or impossible to separate behavioral from abiotic factors and the following data may not be representative of similar periods in other years.

Table 5-2 summarizes the maximum residence times of the prominent taxa and life history stages of baitfish in Grays Harbor during the eight months we sampled the estuary. However, considering the late initiation of sampling (early March), several species such as Pacific herring, probably reside in the estuary longer than indicated in Table 5-2. Juvenile Pacific herring illustrated the longest residence time, up to 15 weeks, and juvenile northern anchovy were similar, up to 11 weeks. Both maintained the longest residence at the upper estuary sites of Moon Island and Cow Point in summer and early fall. Adult northern anchovy

Table 5-2. Summary of residence times of prominent taxa and life history stages of baitfish in Grays Harbor, Washington, March-October 1980.

Species	Life History Stage	Maximum Residence Times (weeks)	Remarks
Northern anchovy, *Engraulis mordax*	adult	6	Maximum residence during two period (mid-June to early August, late Augu to early October); longest residence Westport
	juvenile	11	Maximum sustained residence from mi to early October; longest residence Moon Island
Pacific herring, *Clupea harengus pallasi*	juvenile	>15	Maximum sustained residence from ea July to early October; longest res at Cow Point and Moon Island
Longfin smelt, *Spirinchus thaleichthys*	juvenile	9	Maximum residence during two period (early May to mid-July, early Augus early October); longest residence Moon Island

and juvenile longfin smelt appeared to spend shorter times in the estuary (6-9 weeks) during two periods, punctuated by a gap between late July and early August.

Although they were not prominent in the estuary, juvenile shad did occur sporadically in the purse seine catches in the upper estuary, particularly at Cow Point. The longest sustained residence was at least ten weeks long, extending until our last sampling week (October 20-23).

5.5 Summary

1) Baitfish species occurred in the Grays Harbor fish collections, principally the purse seine samples, throughout the sampling period; seven species were documented, including American shad (juvenile, adult), Pacific herring (larvae, juvenile), northern anchovy (larvae, juvenile, adult), surf smelt (larvae, juvenile, adult), longfin smelt (larvae, juvenile, adult), whitebait smelt (juvenile, adult) and Pacific sand lance (larvae, juvenile).

2) Only four species or life history stages of baitfish—adult and northern anchovy, juvenile Pacific herring, and juvenile longfin smelt—were consistently abundant over the sampling period to indicate extended residence and utilization of the estuary; only Pacific herring and longfin smelt may be directly associated with the estuary during reproduction and subsequent early life history development.

3) Juvenile Pacific herring sustained the highest mean densities (CPUE) and illustrated the longest residence time (up to 15 weeks) of the prominent species; juveniles and adult northern anchovy were slightly less, both in abundance and residence time.

4) Although no evidence of spawning of adult Pacific herring was documented during these studies, spawning may have occurred prior to the initiation of sampling on March 3 or subsequent to the termination of sampling in early June.

5) Except for adult northern anchovy, the majority of the prominent species sustained the longest residence times in the upper estuary in the vicinity of Cow Point and Moon Island.

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6.0 COMMUNITY STRUCTURE AND STANDING STOCK OF NERITIC ZOOPLANKTON

by William J. Kinney, Jeffrey R. Cordell,
and Charles A. Simenstad

6.1 Introduction

Due to their entrainment in the estuary's water masses, neritic zooplankton provide important prey resources to secondary carnivores utilizing the estuary. In the case of Grays Harbor, juvenile salmonids and schooling neritic fishes migrating through or rearing in the estuary are suspected to be the principal predators upon neritic zooplankton. As such, these diverse, productive zooplankton resources may well constitute the limiting factor to the distribution, residence time, growth and population abundance of these zooplanktivorous fishes in Grays Harbor.

Until these studies, little research had been conducted on the trophic ecology of salmonids in Grays Harbor (see Section 1.4). However, recent studies in Puget Sound (Simenstad et al. 1979, 1980; Fresh et al. 1979; Miller et al. 1977, 1980), the Columbia River (Haertel and Osterberg 1967; Craddock 1976), and coastal British Columbia (Healey 1979; 1980) have indicated that neritic zooplankters often form the predominant component of the prey spectra of juvenile salmonids during their initial period of marine residence; baitfish have been found to be almost exclusively zooplanktivorous upon neritic zooplankton (Simenstad et al. 1979).

In order to best evaluate the potential effects of the proposed widening and deepening of the navigational channel in Grays Harbor upon juvenile salmonids and baitfish, it was considered important to document the temporal and spatial composition and standing stock of such a major fish prey resource as the estuary's assemblages of neritic zooplankton. Systematic sampling of these assemblages occurred in conjunction with the sampling of juvenile salmonids and baitfish, also conducted by Fisheries Research Institute, between March and October 1980.

The objectives of this part of the research program were to:

1) Document the community structure of zooplankton and ichthyoplankton in the neritic zone;

2) estimate density and standing crop of neritic zooplankton (including ichthyoplankton);

3) discuss the importance of Grays Harbor to the dominant taxa of the neritic zooplankton;

4) relate the neritic zooplankton abundance to the prey spectra of juvenile salmonids and English sole captured in the neritic zone; and,

5) examine the potential for impacts upon neritic zooplankton by the proposed dredging required for widening and deepening the navigational channel.

6.2 Materials and Methods

Neritic zooplankton was collected biweekly at Cow Point, Moon Island and Stearns Bluff, and monthly at Sand Island and Westport from March through October 1980. These sites and the respective sampling occasions corresponded to the purse seine collections for juvenile salmonids and baitfish (Fig. 3-1), with the exception that zooplankton was not collected at Cosmopolis.

Replicate oblique zooplankton net collections were made from the 6.4-m purse seine vessel or the 7.9-m whaleboat using a weighted 60-cm bongo net frame (Smith and Richardson 1979) equipped with Nitex nets of

0.333-mm mesh having an open area/aspect ratio of 8:1. Sample volume was estimated using a General Oceanics propeller flowmeter centered in one frame.

The net was set off of the port side of the vessel with the engine at idle and the transmission in gear in order to achieve a slow forward speed. The net frame was swung into position just above the water's surface, and the flowmeter was read. The nets were then lowered into the water and cable let out to a length approximately equal to the depth of the water in that location, as determined by fathometer. The line was immediately hauled back in. After recording the flowmeter reading, the nets were rinsed and samples were removed from the net cups. Labeled samples were preserved in PVC jars in a 50% buffered seawater formalin solution.

If necessary, samples were subsampled using a standard glass quartered petri dish or a Hensen-Stempel pipette, depending upon the densities and type of organisms in the sample. The samples were then sorted to major taxonomic group and subsequently identified to the lowest taxon possible using a dissecting microscope. All data were recorded directly onto MESA/NODC-type zooplankton analysis forms which utilize the NODC taxonomic code, a 10-digit code system which enables coding of aquatic organisms to most phylogenetic levels. The raw data was verified and stored on the University of Washington's CDC Cyber 170/750 computer system. Tabulation and basic statistical analyses of the data were performed using the FRI computer program package FR 363 (SUPERPLANKTON), specifically developed for the MESA/NODC-formatted zooplankton data. The program tabulates the plankton collections by various gear types, sites and collection periods. Given species, life history stage, number and wet weight, the program then adjusts the data to a standard sample volume and computes the abundance and biomass per cubic meter (density and standing crop, respectively) by taxon and life history stage. The program then calculates the percent composition by abundance and biomass, as well as standard diversity indices for the total composition.

The structure of the NODC taxonomic code enables the truncation of the code by 2, 4, and 6 digits to standardize the organisms by genus, family and class, respectively. The FRI program is also designed to operate at any one of these three truncation levels, and produce tables either on each life history stage or pooled life history stages (except eggs) per taxon.

An SPSS system file was created in order to perform additional statistical analyses of the data, and plotting was accomplished using the Tektronix Interactive Graphics Package.

Intrasite similarity was measured using the Pearson coefficient of community, CC, (Barbour et al. 1973) calculated from taxa occurrences (exclusive of unidentified organisms; see Table 6-2) at the five locations according to the formula:

$$CC_{A-B} = \frac{AB - (X_A \cdot X_B)/n}{\sqrt{(X_A{}^2 - (X_A)^2/n) \cdot (X_B)^2/n)}}$$

where X_A and X_B equal the sums of values (if a taxa is present, the community is given a value of two; if absent, a value of zero) in communities A and B, respectively; n is the total number of taxa at all sites; and AB is the sum of the product of each pair of taxa values in the two sites being compared. Pearson's coefficient ranges between + 1.00 (complete overlap in composition) and -1.00 (no species in common).

6.3 Results

6.3.1 Community Structure of Neritic Zooplankton: One hundred and ninety-one taxa were identified in the Grays Harbor collections between March 20 and October 22 (Table 6-1). The greatest numbers of taxa identified during one trip occurred early in the survey, e.g., 85 and 79 taxa in March and mid-May, respectively; only 31 taxa were collected in

Table 6-1. Species composition and relative abundance of neritic zooplankton in Grays Harbor, WA 1980. LHS = life history stages; egg = eggs; larv = larvae; juv = juvenile; adlt = adult.

+ = <5% Composition
• = 5 - 9.9%
● = 10 - 24.9%
⬤ = 25 - 100%

SPECIES	L.H.S.				STATION					SAMPLING TRIP															
	EGG	LARV	JUV	ADLT	SAND	COW	MOON	STRM	WEST	MR20	AP1	AP15	AP30	MY14	MY28	JN11	JN25	JY7	JY21	AU6	AU26	SE9	SE23	OC6	OC22
CNIDARIA			J	A			+		+		+	+		+											
HYDROZOA			J	A		+	+	+	+	+	+	+	+	+	+						+	+	+		+
HYDROIDA			J	A	+	+	+	+	+	+	●	+		+	+	+	+	+	+	+	+	+	+	+	+
CORDYLOPHORA SP.			J	A	●	+	+	+	+	+		+	+	+	+	+		+		+		+		+	
OBELIA SP.			J	A				+		+															
SIPHONOPHORA			J	A				+	+		+			+											
LENSIA CONOIDEA			J	A				+	+		+	+													
SCYPHOZOA		L						+	+		+														
CTENOPHORA			J-	A			+	+	+	+	+	+													
TURBELLARIA			J-	A	+	+															+			+	
NEMATODA			J	A	+		+	+	+	+						+	+	+				+			
POLYCHAETA		L	J	A	+	+	+	+	+	+	+	+	+	+	+						+	+	+		
POLYNOIDAE		L	J	A		+	+	+	+	+	+	+	+	+	+										+
PHYLLODOCIDAE			J-	A		+								+											
ETEONE SP.			J-	A	+																	+			
SYLLIDAE			J-	A		+										+									
AUTOLYTUS SP.			J	A			+	+			+					+									
SPIONIDAE		L	J	A	+	+	+	+	+		+	+	+	+		+	+	+	+	+	+	+	+	+	+
MAGELONA SP.			J-	A				+	+	+	+														
AMPHARETIDAE			J-	A	+					+															
OLIGOCHAETA			J	A	+	+				+				+		+				+	+	+		+	
GASTROPODA	E						+		+	+										+					
MESOGASTROPODA	E	L	J	A		+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+			
NEOGASTROPODA-STENOGLOSSA		L	J					+	+	+		+													
THECOSOMATA			J-	A				+	+	+	+	+													
OPISTHOBRANCHIA			J			+											+			+					
BIVALVIA			J	A	+	+	+	+	+	+				+			+			●	+	+	+	+	
MYTILIDAE			J				+	+	+		+					+				+					
VENEROIDA			J				+	+	+			+		+		+	+								
MACOMA SP.			J					+	+			+					+	+							
ARANEAE			J	A	+	+		+		+	+										+			+	
ACARINA				A					+													+			
HYDRACARINA PROSTIGMATA				A	+																	+			
HALACARIDAE			J	A			+	+	+	+		+		+		+							+		+
ARTHROPODA PYCNOGONIDA		L	J					+	+	+											+				
EUCLADOCERA			J	A	+					+															
DAPHNIA SP.			J-	A		+				+		+													
DAPHNIA GALEATA				A		+				+															
CERIODAPHNIA RETICULATA				A	+								+	+											
BOSMINA SP.				A	+								+												
EVADNE NORDMANNI			J	A		+	+	+	+					+	+	+	+	+	+	+	+	+	●	●	+
PODON SP.			J	A	+	+	+	+	●			+		+	+	+	+	+	●	+	+	+	+	●	+
CHYDORIDAE				A	+								+												
EURYCERCUS LAMELLATUS				A	+													+							
PODOCOPA			J-	A	+											+									
COPEPODA	E	L				+	+	+	+					+		+			+	+	+	+	+		
CALANOIDA		L	J	A	+	+	+	+	+	+		+	+	+						+	+	+	+	+	+
CALANUS SP.		L	J	A		+	+	+	●	+	+	●	+	+	+	+	+	+	+		+	+	+	+	+
CALANUS PLUMCHRUS		L					+			+															
EUCALANUS SP.			J	A				+	+	+															
EUCALANUS BUNGII		L	J	A				+	+	+	+	+		+											
PARACALANUS SP.		L	J	A		+	+	+	+	+	+	+	+	+	+	+						+	+	+	+
PSEUDOCALANIDAE		L						+	+		+													+	
CLAUSOCALANUS PARAPERGENS			J	A			+	+	+	+	+	+	+	+										+	
PSEUDOCALANUS SP.		L	J	A	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	●	+	+
AETIDIUS ARMATUS			J	A	+					+															
EUCHAETA SP.		L						+														+			
SCOLECITHRICELLA MINOR				A				+							+										
METRIDIA SP.		L	J	A			+	+	+	●				+	+										
METRIDIA LUCENS			J	A				+	+	+	+	+													
CENTROPAGES ABDOMINALIS		L	J	A	+	+	+	●	●	+	+	●	+	●	+	●	●	+	+	+	+	+	+	+	+
DIAPTOMUS SP.			J-	A	+	+								+				+	+						
EURYTEMORA AMERICANA		L	J	A	●	⬤	⬤	•	+	+	+	+	⬤	⬤	⬤	●	•	+	+	●	•	●	•	●	•
EPILABIDOCERA AMPHITRITES		L	J	A	+	+	+	+	+		+			+	+	+	+	+	+	+	+	+	+	+	+
ACARTIA SP.		L	J				+	+					+								+	+	+	+	
ACARTIA CLAUSI			J	A	+	●	●	⬤	•	●	●	•	⬤	●	•	•	+	+	+	+	+	+	+	+	⬤
ACARTIA DANAE				A				+	+					+										+	
ACARTIA LONGIREMIS			J	A		+	+	+	+	+		+		+		+	+	+		+	+	+	●	+	+
ACARTIA TONSA			J	A	+	+	+	+	+		+		+	+	+	+	+	+	●	+	+	+	+	+	+
TORTANUS DISCAUDATUS			J	A	+			+		+		+													

Table 6-1, continued

+ = <5% Composition
• = 5 - 9.9%
● = 10 - 24.9%
⬤ = 25 - 100%

SPECIES	L.N.S.				STATION					SAMPLING TRIP															
	EGG	LARV	JUV	ADLT	SAND	COU	MOON	STRM	WEST	MR20	AP1	AP15	AP30	MY14	MY28	JN11	JN25	JY7	JY21	AU6	AU26	SE9	SE23	OC6	OC22
HARPACTICOIDA		L	J	A	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+
SCOTTOLANA CANADENSIS		L	J	A	+	+	+	+	+				+	+				+				+	+		+
HARPACTICUS SP.			J	A		+		+	+					+	+	+		+			+				
ZAUS SP.		L		A		+	+	+							+		+	+		+	+	+			+
ALTEUTHA SP.			J	A			+		+		+		+												
TISBE SP.			J	A		+		+	+						+							+			+
TACHIDIUS TRIANGULARIS				A		+																	+		
NITOCRA SP.				A			+							+											
CLETODIDAE		L	J-	A	+	+														+			+		
HUNTEMANNIA JADENSIS				A	+	+	+						+	+	+	+	+	+							+
BRYOCAMPTUS SP.			J	A	+	+	+	+					+	+		+	+								
THALESTRIDAE			J	A		+	+	+	+										+	+	+	+	+		
CORYCAEUS ANGLICUS				A			+	+	+	+	+	+	+	+	+	+	+					+		+	
HALICYCLOPS SP.			J	A		+	+	+	+						+	+					+	+		+	+
CYCLOPS SP.			J	A	+	+	+			+		+	+												
CYCLOPS VERNALIS			J	A	+	+	+			+			+	+	+	+									
CYCLOPS BICUSPIDATUS		L		A	+	+							+	+		+									
EUCYCLOPS AGILIS				A	+									+		+									
EUCYCLOPS PHALERATUS				A	+									+											
MACROCYCLOPS SP.				A	+									+				+							
OITHONA SP.		L	J	A		+	+	+	+		+				+						+	+		+	
OITHONA SIMILIS				A					+															+	
CALIGOIDA			J	A	+				+							+				+					
BALANOMORPHA		L	J		+	⬤	⬤	⬤	●	+	+	⬤	+	●	●	⬤	⬤	⬤	⬤	⬤	⬤	⬤	⬤	●	+
MYSIDACEA-MYSIDA			J		●	+	+	+					+	+	+	+	+	+	+	+	+	+	+	+	+
ACANTHOMYSIS SP.			J				+	+	+		+	+		+											
ACANTHOMYSIS MACROPSIS			J	A		+	+	+		●	●	+	+					+	+		+	+		+	+
ACANTHOMYSIS SCULPTA			J				+											+							
ARCHAEOMYSIS GREBNITSKII			J-	A		+	+	+		+	+	+													
NEOMYSIS SP.			J				+														+				
NEOMYSIS MERCEDIS		L	J	A	●	+	+			+		+	+	+	+	+	+	+		+	+	+	+	+	+
NEOMYSIS RAYII			J-	A		+									+										
NEOMYSIS INTEGER			J	A		+	+	+		+				+				+	+	+		+	+	+	+
LAMPROPIDAE			J				+	+	+	+	+	+		+	+	+	+	+	+						
LAMPROPS SP.			J	A	+	+	+	+		+	+				+					+	+	+	+	+	+
LEUCONIDAE			J					+				+													
LEUCON SP.			J	A	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+
CUMELLA SP.			J	A	+	+	+	+	+	+	+	●	+	+	+	+	●	+	+	+	+	+	+	+	+
PANCOLUS CALIFORNIENSIS				A		+	+	+										+			+				
ISOPODA		L	J	A		+	+	+			+														+
GNORIMOSPHAEROMA OREGONENSIS			J	A	+				+	+		+		+				+							
BOPYRIDAE			J	A		+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+		
GAMMARIDEA			J	A		+	+	+	+	+	+			+		+				+		+	+	+	
AMPITHOE SP.				A				+																	+
AYTLUS TRIDENS			J						+			+													
COROPHIUM SP.			J	A	⬤	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+
COROPHIUM BREVIS			J				+					+													
COROPHIUM SALMONIS			J	A	+	+	+			+		+								+					
COROPHIUM SPINICORNE			J	A	+	+	+			+		+	+	+											
PONTOGENEIA SP.			J			+																	+		
ANISOGAMMARUS SP.			J		+	+	+							+	+	+	+	+	+						
EOGAMMARUS CONFERVICOLUS			J	A	+	+	+	+		+		+	+	+	+						+	+			
MEGALUROPUS SP.			J		+											+									
EOGAMMARUS SP.			J		+	+	+	+												+	+	+	+	+	+
EOGAMMARUS OCLAIRI			J	A		+	+														+	+			
PARATHEMISTO PACIFICUS			J-	A					+	+															
CAPRELLIDAE		L	J-	A			+	+	+		+										+	+			
CAPRELLA SP.			J	A				+	+															+	
CAPRELLA ALASKANA			J-	A	+															+					
CAPRELLA CALIFORNICA				A		+																		+	
EUPHAUSIACEA		L	J		+	+	+	+	+	+	+	+		+							+		+	+	+
HIPPOLYTIDAE		L					+	+	+	+	+														
PANDALIDAE		L					+								+										
CRANGONIDAE		L	J		+	+	+	+	●	●	●	+	+	+	+	+	+	+	+	●		+	+	+	+
CRANGON SP.		L	J			+	+	+	+			+		+	+	+								+	
CRANGON FRANCISCORUM			J	A		+	+								+				+	+	+	+			

Table 6-1, continued

+ = <5% Composition
• = 5 - 9.9%
● = 10 - 24.9%
⬤ = 25 - 100%

SPECIES	L.H.S.				STATION					SAMPLING TRIP															
	EGG	LARV	JUV	ADLT	SAND	COU	MOON	STRN	WEST	MR20	AP1	AP15	AP30	MY14	MY28	JN11	JN25	JY7	JY21	AU6	AU26	SE9	SE23	OC6	OC22
CALLIANASSIDAE		L					+					+													
UPOGEBIA PUGETTENSIS		L	J				+	+	+	+	+	+													
CALLIANASSA SP.		L							+			+													
PAGURIDAE		L							+		+					+				+					
PORCELLANIDAE		L						+			+														
PETROLISTHES SP.		L							+			+													
PUGETTIA SP.		L						+	+	+								+							
CANCER SP.		L					+	+	+		+	+												+	
CANCER MAGISTER		L						+				+													
PINNOTHERIDAE		L				+	+	+	+	+	●	+		+	+	+		+	+	+		+	+	+	
HEMIGRAPSUS SP.		L						+	+		+									+				+	
COLLEMBOLA				A		+		+		+														+	
SMINTHURIDAE			J-A		+					+															
HYPOGASTRURIDAE(=PODURIDAE)			J-A		+					+															
ISOTOMIDAE			J-A		+					+															
EPHEMEROPTERA		L					+					+													
PLECOPTERA		L			+								+												
HOMOPTERA		L							+			+													
HOMOPTERA-APHIDOIDEA				A			+														+				
POLYCENTROPODIDAE		L			+					+															
CERATOPOGONIDAE		L			+					+															
NEMATOCERA		L		A		+			+	+										+					
DIPTERA-CHIRONOMIDAE		L		A	+	+	+	+	+	+		+	+	+		+						+	+		
DIPTERA-BRACHYCERA		L		A		+	+		+					+		+							+		
EPHYDRIDAE				A		+															+				
MUSCOIDEA				A					+					+											
HYMENOPTERA				A		+		+	+					+								+			
GYMNOLAEMATA		L						+	+					+								+			
CHAETOGNATHA			J	A		+	+				+			+		+									
SAGITTA SP.			J	A		+	+	+	+	+	+	+	+	+	+	+	+								+
SAGITTA ELEGANS			J	A			+			+											+	+	+	●	+
OIKOPLEURA SP.			J	A		+	+	+	+	+	+	+	+	+		+									
TELEOSTEI	E	L			+	+	+	+	+	+	+	+		+	+	+	+	+	+	+		+	+		
ENGRAULIS MORDAX	E	L				+	+	+									+	+	+	+	+	+	+	+	
OSMERIDAE		L			+	+	+	+	+	+	+	+	+			+								+	
SPIRINCHUS THALEICHTHYS				A		+													+						
GADIDAE		L						+	+	+		+		+										+	
GASTEROSTEUS ACULEATUS			J				+														+				
COTTUS SP.		L				+				+															
COTTUS ASPER		L			+	+	+	+	+	+	+	+	+	+	+										
PHOLIS SP.		L					+					+													
AMMODYTES HEXAPTERUS		L						+		+	+														
GOBIIDAE		L			+	+	+	+	+					+	+	+	+	+	+	+	+	+		+	
UNIDENTIFIED EGG	E				+	+	+	+	+	+	+	+	+	+	+	+						+			
UNIDENTIFIED		L	J	A	+			+	+	+	+														

(DASH BETWEEN LIFE HISTORY STAGES DENOTES QUESTIONABLE DEMARKATION BETWEEN STAGES) late July (Table 6-2). Similarly, numerical diversity (Shannon-Wiener and Brillouin's indices based upon numbers) tended to be highest in the early sampling weeks, i.e., mid-March through late May.

Based upon frequency of occurrence in the collections, the most prominent taxa of neritic zooplankton included barnacle nauplii and cypris larvae and the calanoid copepods *Eurytemora americana* and *Acartia clausi*; other species which stand out because of their sustained presence in the estuary throughout the study were crangonid shrimp larvae, *Centropages abdominalis*, *Pseudocalanus* sp., and the cumacean *Cumella* sp. Hydrozoa, Spionidiae (polychaetes), *Calanus* spp., *Epilabidocera amphitrites*, *Acartia tonsa*, Harpacticoida (copepods), *Neomysis mercedis*, *Leucon* sp., Bopyridae (isopods), *Corophium* sp. and fish larvae also occurred frequently.

Pinnotheridae larvae occurred in four separate six week series of collections. Species associated primarily with collections in the spring months were hydrozoans, polychaete and polynoid worms, the calanoid copepods *Paracalanus* sp., *Clausocalanus parapergens*, and *Metridia lucens*, the cyclopoid copepod *Corycaeus anglicus*, the mysids *Acanthomysis macropsis*, and *A. grebnitskii*, the gammarid amphipods *Corophium spinicorne*, and *Eogammarus confervicolus*, euphausiids, hippolytid shrimp larvae, *Upogebia pugettensis*, chironomid larvae, the arrowworm, *Sagitta* sp., the larvacean, *Oikopleura* sp., the larvae of osmerid, gadid, cottid, and Pacific sand lance (*Ammodytes hexapterus*) fishes, and unidentified eggs. Cancrid crab (probably Dungeness crab, *Cancer magister*) larvae were found only at Moon Island Stearn's Bluff and Westport during early to mid-April and early October and were never abundant.

Epibenthic zooplankton taxa occurring in the samples primarily during the summer months, were nematodes, the harpacticoids *Harpacticus* sp., *Zaus* sp., *Huntemania jadensis* and *Bryocamptus* sp., the gammarid amphipod *Anisogammarus* sp. and gobid fish larvae.

Table 6-2. Taxa richness (total number of zooplankton categories) and numerical diversity of biweekly neritic zooplankton samples from Grays Harbor, Washington, 1980 (without regard to life history stages).

	Mr	Ap	Ap	Ap	My	My	Jn	Jn	Jy	Jy	Au	Au	Se	Se	Oc	Oc
Site	20	1	15	30	14	28	11	25	7	21	6	26	9	23	6	22
Taxa Richness																
Sand Is.	24			21	28		12		12		20		12		17	
Cow Point	16		10	22	31	29	24	19	19	22	26	42	25	26	21	27
Moon Is.	31	29	32	30	30	33	17	23	24	22	19	25	29	22	23	23
Stearns	42	45	36		30	27	26	22	17	11	24	31	38	23	30	25
Westport	31	37	39		37		31		17		29		27		27	
Overall	85	63	71	46	79	50	59	38	43	31	49	52	61	46	54	40
Shannon-Wiener Diversity Index, numbers																
Sand Is.	4.02			3.41	2.94		1.84		2.89		2.51		1.53		2.83	
Cow Point	2.99		2.28	2.11	2.97	2.61	3.24	2.32	1.30	1.78	2.53	1.72	1.59	2.43	2.03	1.84
Moon Is.	3.30	3.08	2.77	1.91	1.88	2.56	1.80	1.26	0.97	1.64	2.14	2.89	1.88	1.20	2.35	1.90
Stearns	4.19	4.13	3.22		3.49	3.23	2.64	3.06	1.21	2.67	2.01	1.78	2.55	2.27	3.38	1.14
Westport	3.87	4.04	3.21		3.63		3.32		2.55		3.06		3.32		3.07	
Overall	4.50	4.44	3.78	2.07	3.12	3.14	2.89	2.49	1.35	1.92	2.71	2.06	2.62	2.59	3.68	1.39
Brillouins Diversity Index, numbers																
Sand Is.	5.18			2.92	2.55		1.70		2.47		2.24		1.38		2.44	
Cow Point	2.65		1.76	2.07	2.64	2.44	3.04	2.20	1.18	1.59	2.31	1.60	1.53	2.24	1.93	1.76
Moon Is.	3.06	2.84	2.63	1.89	1.85	2.45	1.77	1.20	0.91	1.52	2.00	2.65	1.83	1.13	2.06	1.83
Stearns	3.78	3.64	3.10		3.35	3.08	2.62	2.98	1.15	2.04	1.93	1.69	2.31	2.16	3.17	1.12
Westport	3.48	3.66	3.15		3.51		3.16		2.29		2.70		3.18		2.93	
Overall	4.27	4.19	3.71	2.05	3.07	3.05	2.86	2.44	1.30	1.79	2.63	1.98	2.57	2.51	3.58	1.37

Juvenile bivalves, Paracalanus sp., Halicyclops sp., Oithona sp., Neomysis integer, Lamprops sp., and Eogammarus sp. juveniles were all captured predominantly in the early autumn months.

Mean taxa richness, although encompassing variable sample sizes, increased progressively from the riverine to the lower estuarine site closest to the mouth of Grays Harbor (Table 6-3). Numerical diversity, on the other hand, illustrated a general decline in the middle of the estuary, i.e., at the sites in the upper estuary, between the riverine site at Sand Island and the more marine sites of Westport and Stearns Bluff.

The similarity of community (taxonomic) structure among all five collection sites (Table 6-4) was greatest between Westport and Stearns Bluff (+0.57). Cow Point-Moon Island and Stearns Bluff-Moon Island comparisons showed similar positive coefficients of community, +0.39 and +0.35, respectively. Comparisons of the neritic zooplankton assemblages at Sand Island with those at Westport and Stearns Bluff showed, not surprisingly, negative coefficients of similarity.

6.3.2 Density of Neritic Zooplankton: The mean density (± 1 standard deviation) of all neritic zooplankton samples pooled by trip ranged from minima of 51.4 ± 47.1 and 42.7 ± 32.3 animals m^{-3} in late March and late July, respectively, to maxima of 903.6 ± 1007.2 and 854.0 ± 869.7 m^{-3} in late April and late October, respectively. Three sustained declines in density were evident, between April 30-May 28, June 1-July 21, and September 9-October 6 (Fig. 6-1).

Sand Island, the riverine site within the tidally-influenced stretches of the Chehalis River, showed the lowest density of neritic zooplankton during most sampling dates (Fig. 6-2, Table 6-5), with highest densities occurring in late April (30.8 ± 13.0 m^{-3}), early June (56.6 ± 1.2 m^{-3}) and early September (48.4 ± 1.6 m^{-3}). As at Sand Island, the lower estuary site at Westport was sampled monthly. Samples

Table 6-3. Mean total density, standing crop, total taxa richness, and numerical diversity of neritic zooplankton from Grays Harbor, Washington, 1980 (life history stages pooled).

Site	Density	Standing crop	Total taxa richness	Diversity Indices	
	($\bar{x}$ m^{-3} ± 1 S.D.)	(mg m^{-3} ± 1 S.D.)		Shannon-Wiener	Brillouin's
Sand Island	25.08 ± 19.25	9 ± 11	71	3.31	3.14
Cow Point	162.85 ± 195.27	111 ± 160	92	2.81	2.78
Moon Island	410.45 ± 540.04	66 ± 82	104	2.76	2.74
Stearns Bluff	391.68 ± 563.73	31 ± 44	110	3.28	3.25
Westport	214.41 ± 251.34	35 ± 61	98	4.30	4.23
$\bar{X}$	270.09 ± 427.81	55 ± 98	191	3.47	3.46

Table 6-4. Similarity of zooplankton communities, ranked by Pearson's coefficient of community, among five sampling sites in Grays Harbor, Washington, March - October 1980.

Site Pair	Coefficient of Community
Stearns Bluff - Westport	+ 0.57
Cow Point - Moon Island	+ 0.39
Stearns Bluff - Moon Island	+ 0.35
Westport - Moon Island	+ 0.21
Sand Island - Cow Point	+ 0.21
Stearns Bluff - Cow Point	+ 0.19
Sand Island - Moon Island	+ 0.06
Cow Point - Westport	+ 0.02
Sand Island - Stearns Bluff	- 0.16
Sand Island - Westport	- 0.17

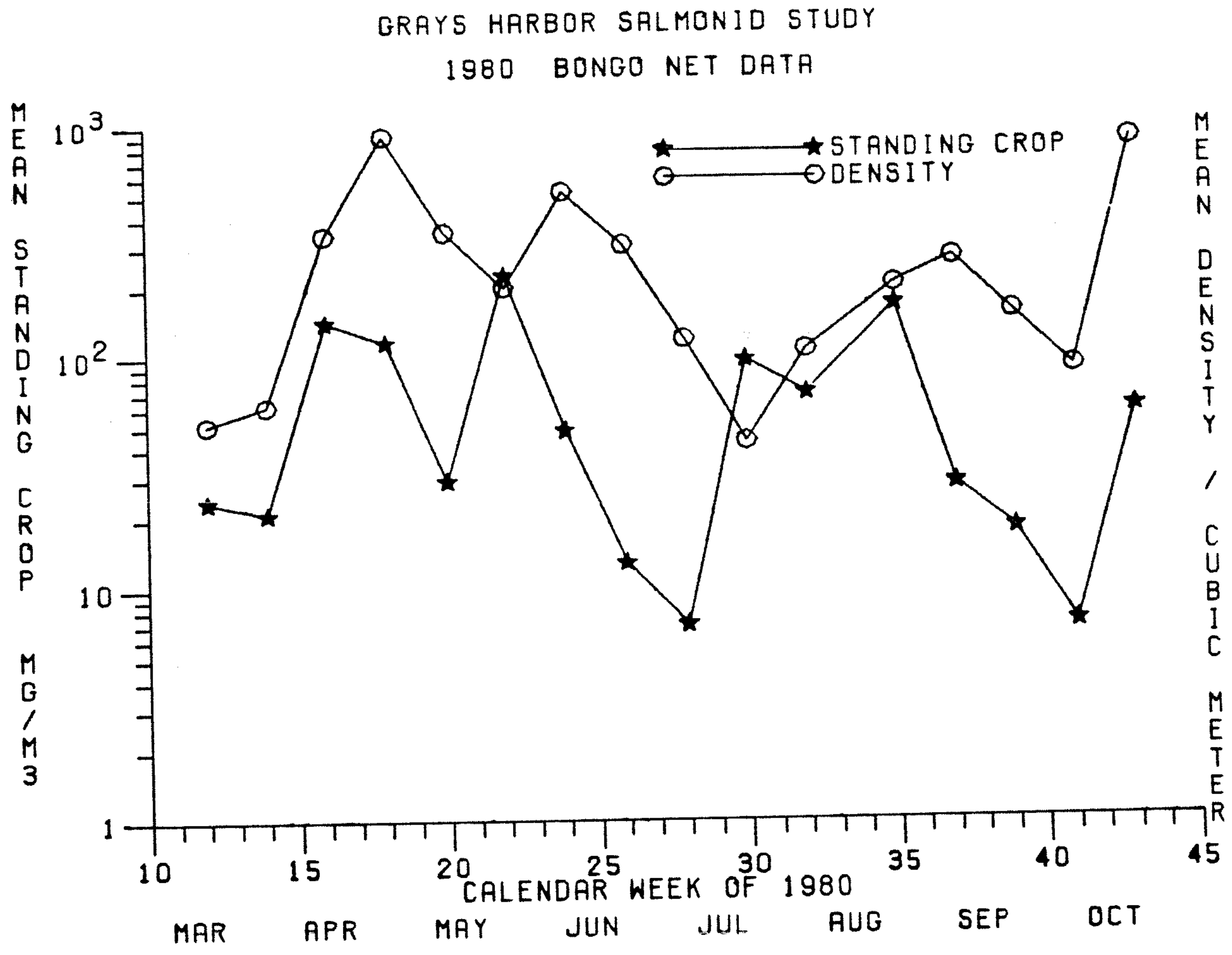

Fig. 6-1. Mean total density and standing crop of neritic zooplankton pooled over five sampling sites in Grays Harbor, Washington, March - October 1980.

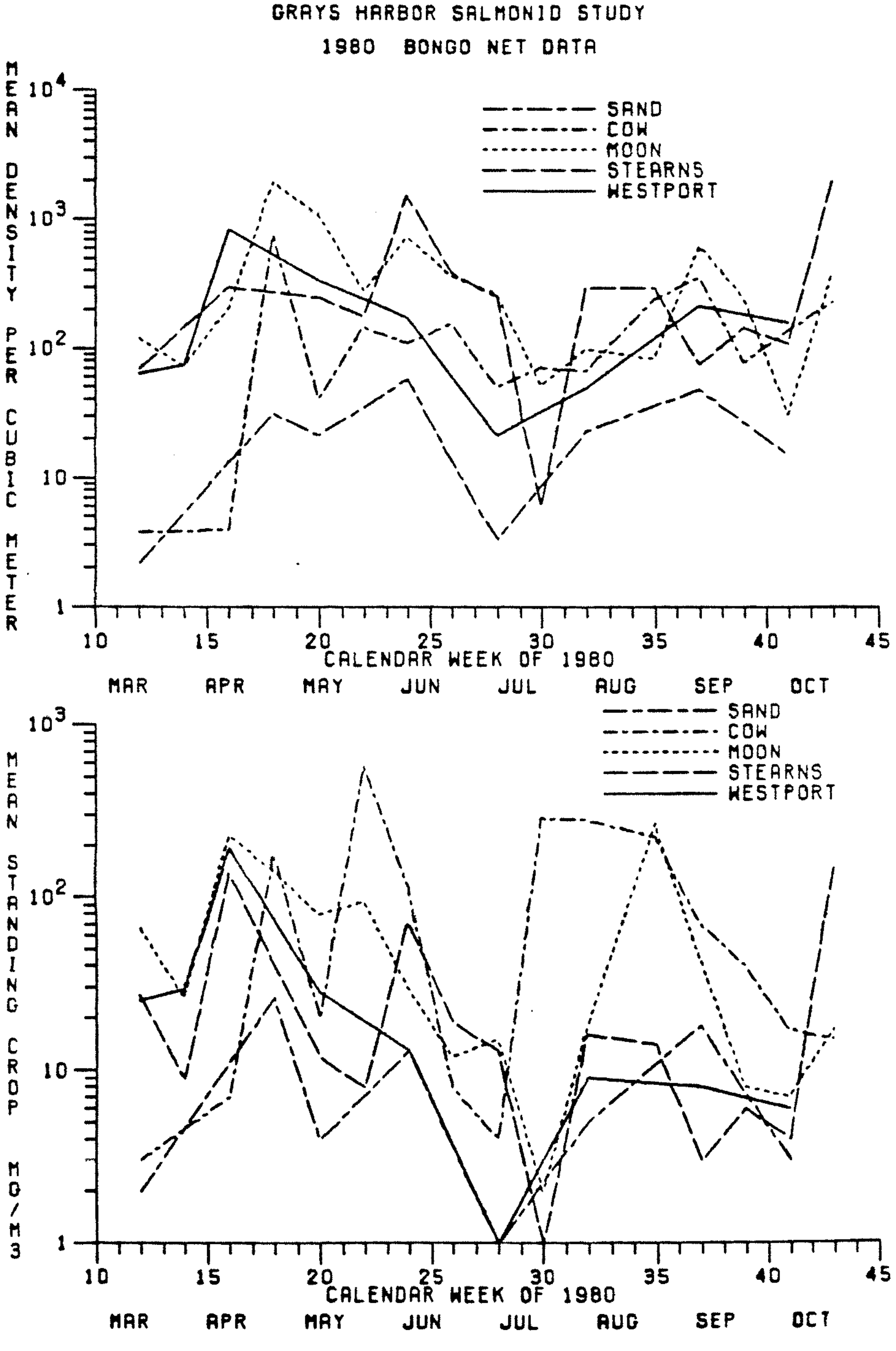

Fig. 6-2. Mean total density and standing crop of neritic zooplankton in Grays Harbor, Washington, March - October 1980.

Table 6-5. Mean total density ($\bar{x}$ No. animals m^{-3} $\pm$ 1 s.d.) of biweekly neritic zooplankton samples from Grays Harbor, Washington, 1980.

Site	Mar 19-20	April 1	April 15	Apr 29-30	May 13-15	May 28-29	Jun 10-12	Jun 25-26
Sand Is.	2.2±0.4			30.8±13.0	20.9±1.7		56.6±1.2	
Cow Point	3.8±2.9		3.9 ±3.9	760.0±124.5	40.8±27.4	145.2±44.9	109.9±28.8	154.9±6.5
Moon Is.	119.4±17.7	72.1±1.7	203.4 ±1.6	1920.0±1194.0	1089.2±446.8	276.7±18.5	727.1±80.7	370.0±31.6
Stearns	68.9±4.0	40.3±6.4	297.1 ±94.1		248.2±43.3	179.2±0.4	1525.8±417.6	391.5±264.8
Westport	62.8±12.0	74.1±1.9	843.3 ±66.0		336.3±53.2		172.1±3.7	
$\bar{x}$	51.4±47.1	62.2±17.3	336.95±335.3	903.6±1007.2	347.1±438.0	200.4±64.8	518.3±605.4	305.5±167.1

Site	July 7-8	Jul 21-22	August 6	August 26	Sept. 9	Sept. 23	Oct 6-7	Oct 21-23
Sand Is.	3.3±0.8		23.3 ±2.8		48.4±1.6		15.2±2.2	
Cow Point	50.3±10.4	71.1±19.8	65.8 ±0.4	237.7±13.9	360.0±53.0	76.9±8.9	134.7±82.9	227.8±225.8
Moon Is.	265.4±31.2	51.4±17.7	98.9 ±34.0	82.2±2.5	627.5±96.5	249.1±53.0	31.4±1.6	383.3±213.8
Stearns	252.5±82.7	5.6±1.8	298.5 ±1.1	292.3±44.2	75.0±2.8	142.2±6.0	107.5±31.6	1950.6±229.6
Westport	21.0±3.1		49.2 ±3.9		213.3±1.5		157.5±145.0	
$\bar{x}$	118.5±125.5	42.7±32.3	107.1 ±104.7	204.1±99.7	264.9±227.2	156.1±81.4	89.3±82.1	853.9±869.7

from that site displayed an earlier peak in mean total density (843.3 ± 66.0 m^{-3}) in mid-April; total density fell to 21.0 ± 3.1 m^{-3} in early July and increased again to 213.3 ± 1.5 m^{-3} by early September.

Among the biweekly-sampled, central estuary sites, temporal patterns in total density of neritic zooplankton at Moon Island and Stearns Bluff were more similar to each other than to Cow Point, which had the lowest total mean density of the three (Fig. 6-3). Neritic zooplankton density at Moon Island reached an early maximum in late April (1920.0 ± 1194.0 m^{-3}) and again in early June (727.1 ± 80.7 m^{-3}), then declined to only 51.4 ± 17.7 m^{-3} in late July; densities increased to 627.5 ± 96.5 m^{-3} in early September, but bounced from 31.4 ± 1.6 m^{-3} to 383.3 ± 213.8 m^{-3} between early and late October. The density of neritic zooplankton at Stearns Bluff followed the same trend as at Moon Island through August, with peak density appearing in early June (1525.8 ± 417.6 m^{-3}), the late July minimum of only 5.6 ± 1.7 $^{-3}$, and then maintenance of approximately 295 m^{-3} throughout August until a slow decline which continued until a late maximum of 1950.6 ± 229.6 m^{-3} on the last sampling trip. Neritic zooplankton densities at Cow Point were relatively low, however, until the end of April (760.0 ± 124.5 m^{-3}), declined until late August (237.7 ± 13.9 m^{-3}), then increased sharply to 360.0 ± 53.0 m^{-3} two weeks later.

Barnacle nauplii and cypris larvae accounted for 28.1% of the total density of neritic zooplankton. Calanoid copepods comprised the majority of the other abundant taxa--*Acartia clausi* (22.1%), *Eurytemora americana* (19.5%), *Centropages abdominalis* (6.2%) and *Calanus* spp. (2.9%); pooled Calanoida, however, constituted 55.5% of the total density. The cumaceans *Cumella* sp. and *Leucon* sp. accounted for 1.8 and 1.5% of the total density, respectively.

The epibenthic gammarid amphipod *Corophium* sp. dominated the numerical composition (34.0%) at Sand Island over the eight month study period, with a mean total density of 8.5 m^{-3}. The estuarine mysid, *Neomysis*

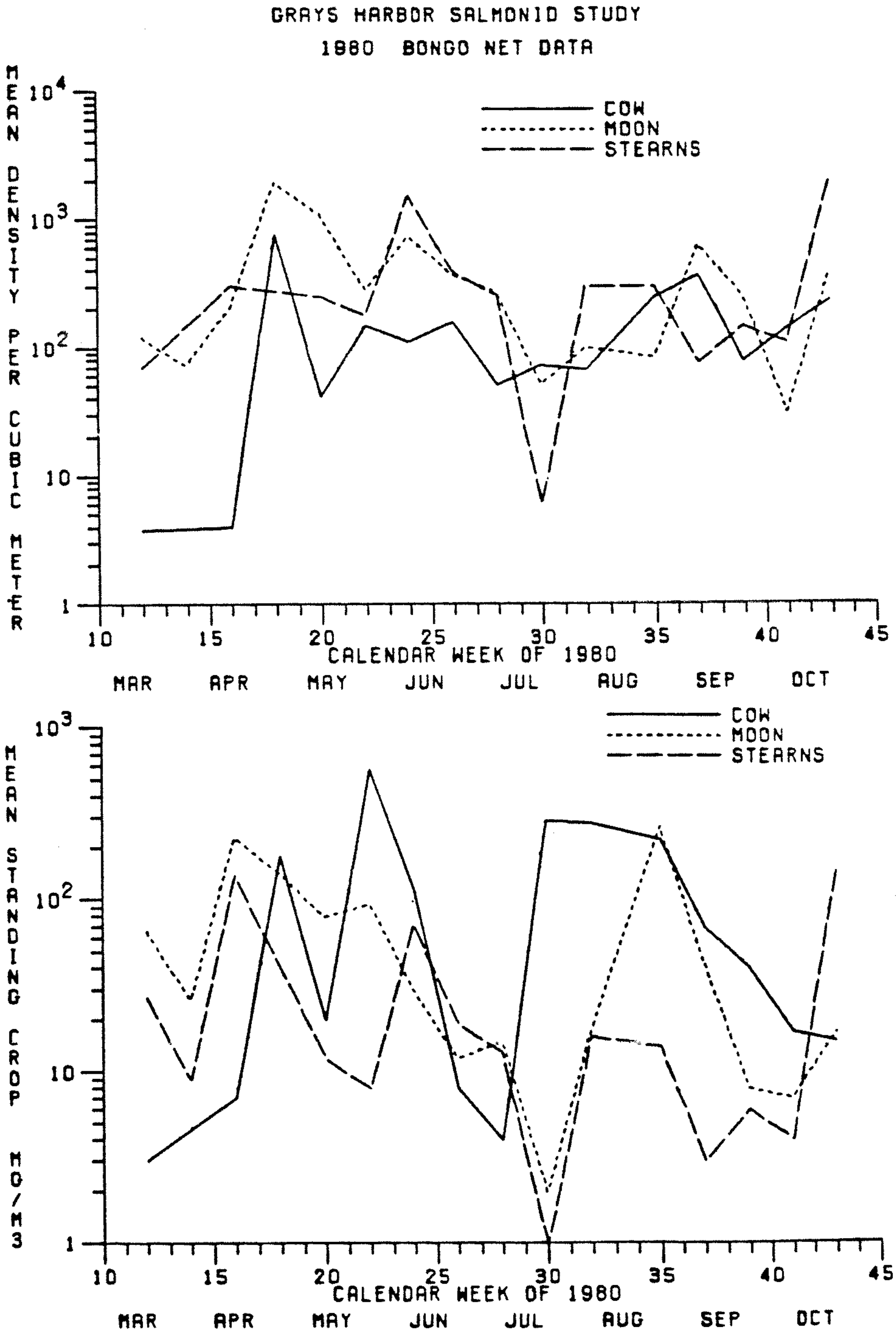

Fig. 6-3. Mean total density and standing crop of neritic zooplankton at three mid-estuary sites in Grays Harbor, Washington, March - October 1980.

mercedis, was slightly less abundant, with 30.0% of the total density and a mean total density of 7.5 m^{-3}. Eurytemora americana composed 10.1% of the total mean density (2.5 m^{-3}); the coelenterate Cordylophora sp., comprised 6.9 (1.7 m^{-3}).

Barnacle nauplii and cypris larvae were the most abundant zooplankters at Cow Point, comprising 31.8% of the mean total density 51.7 m^{-3}. Eurytemora americana (28.2%, 45.8 m^{-3}) and Acartia clausi (22.4%, 36.4 m^{-3}), were also numerically prominent.

The most abundant zooplankton taxa at Moon Island was Eurytemora americana (34.2%, 140.2 m^{-3}) and Acartia clausi (18.5%, 76.0 m^{-3}).

Neritic zooplankton at Stearn's Bluff was numerically dominated by Acartia clausi (32.1%), with a mean total density of 125.7 m^{-3}, barnacle nauplii and cypris larvae (27.1%, 106.2 m^{-3}), Centropages abdominalis (11.4%, 44.6 m^{-3}) and Eurytemora americana (6.0%, 23.4 m^{-3}).

Numerically predominant zooplankton taxa at Westport were barnacle nauplii and cypris larvae (22.9%, 49.0 m^{-3}), Calanus sp. (11.9%, 25.4 m^{-3}) Centropages abdominalis (9.9%, 21.3 m^{-3}), the cladoceran Podon leuckarti (6.6%, 14.2 m^{-3}), crangonid shrimp zoea (6.6%, 14.2 m^{-3}), Acartia clausi (5.9%, 12.7 m^{-3}), and Psuedocalanus sp. (4.1%, 8.9 m^{-3}).

Appendix Tables 6-1 to 6-5 provide the detailed numerical description of the density of specific taxa and life history stages over the course of the studies in Grays Harbor. Barnacle larvae were prominent during each sampling trip and accounted for over 25% of the numerical composition of the zooplankton on eight consecutive trips between May and September with maximum mean density of 200.8 m^{-3} occurring on June 11. Eurytemora americana illustrated an initial increase in density (to a peak of 408.3 m^{-3} in late April) through June, and then another significant level of abundance from August through the end of October (maximum of 83.3 m^{-3}). Acartia clausi was the numerically dominant taxa during the initial two months of the study and again in late October, when it comprised 78.3% of the mean total density (668.8 m^{-3}).

Other taxa which were numerically important throughout the sampling period include crangonid shrimp larvae, Centropages abdominalis, Pseudocalanus sp., and Cumella sp.

6.3.3 Standing Crop of Neritic Zooplankton: The mean total standing crop of neritic zooplankton ranged from minima of 7 ± 6 mg m^{-3} in early July and in early October to maxima of 225 ± 353 and 167 ± 176 mg m^{-3} in late May and late August, respectively (Table 6-6). As with density, standing crop displayed spring and early autumn increases, associated with mid-summer and late autumn declines.

A single adult medusae, weighing 26 g, which was caught in the bongo nets in late September accounted for 46.6% of the total mean standing crop; removal of the medusae and a single adult smelt (captured in late July) from the data set, however, was justified on the basis of their low occurrence and excessive biomass. Based upon the revised data set, juvenile and adult Crangon franciscorum dominated the mean total standing crop (39.3%, 22 mg m^{-3}); juvenile and adult Neomysis mercedis (5.3%, 3 mg m^{-3}) and Eurytemora americana (4.7%, 3 mg m^{-3}) were of secondary importance.

The standing crop at Sand Island was dominated by Neomysis mercedis (70.7% of mean total standing crop, 6 mg m^{-3}), followed by Corophium sp. (7.7%, 1 mg m^{-3}), Eogammarus confervicolus (5.7%) and larval cottids (5.9%).

Crangon franciscorum predominated at Cow Point, comprising 70.9%, 79 mg m^{-3} of the mean total standing crop; larval osmerids (6.4%, 7 mg m^{-3}) and Neomysis mercedis (5.4%, 6 mg m^{-3}) were also prevalent.

Table 6-6. Mean total standing crop (mg m^{-3} $\pm$ 1 s.d.) of neritic zooplankton at five locations in Grays Harbor, WA, March-October 1980.

Site	Mar 19-20	April 1	April 15	Apr 29-30	May 13-15	May 28-29	Jun 10-12	Jun 25-26
Sand Is.	2 ± 1			26 ± 27	4 ± 2		13 ± 1	
Cow Point	3 ± 2		7 ± 7	178 ± 161	20 ± 5	571 ± 502	114 ± 144	8 ± 0
Moon Is.	66 ± 42	26 ± 1	228 ± 10	143 ± 67	79 ± 19	95 ± 54	29 ± 2	12 ± 1
Stearns	27 ± 2	9 ± 2	139 ± 22		12 ± 3	8 ± 0	73 ± 8	19 ± 7
Westport	25 ± 6	29 ± 3	193 ± 66		28 ± 3		13 ± 0	
$\bar{x}$	24 ± 28	21 ± 10	142 ± 94	116 ± 106	29 ± 29	225 ± 353	48 ± 64	13 ± 6

Site	Jul 7-8	Jul 21-22	August 6	August 25	Sept. 9	Sept. 23	Oct. 6-7	Oct 21-23
Sand Is.	0 ± 0		5 ± 2		18 ± 3		3 ± 1	
Cow Point	4 ± 1	288 ± 112	297 ± 221	222 ± 279	69 ± 65	40 ± 31	17 ± 1	15 ± 10
Moon Is.	15 ± 3	2 ± 0	18 ± 22	265 ± 63	42 ± 2	8 ± 2	7 ± 4	17 ± 2
Stearns	13 ± 5	0 ± 0	16 ± 7	14 ± 5	3 ± 0	6 ± 1	4 ± 1	146 ± 27
Westport	1 ± 0		9 ± 5		8 ± 1		6 ± 5	
$\bar{x}$	7 ± 7	97 ± 156	69 ± 141	167 ± 176	28 ± 34	18 ± 22	7 ± 6	59 ± 68

Crangon franciscorum were also responsible for the greatest proportion of the mean total standing crop at Moon Island (19.2%, 12 mg m^{-3}), although other taxa, including Eurytemora americana (11.9%, 8 mg m^{-3}), juvenile threespine stickleback (Gasterosteus aculeatus) (10.9%, 7 mg m^{-3} Cancer sp. megalops larvae (7.2%, 5 mg m^{-3}), Acanthomysis macropsis (6.8%, 4 mg m^{-3}), gunnel larvae (Pholis sp.) (5.6%, 4 mg m^{-3}), Acartia clausi (5.2%, 3 mg m^{-3}), and Neomysis mercedis (5.2%, 3 mg m^{-3}), also constituted significant proportions of the total mean standing crop.

Cancer magister megalops larvae dominated the mean total standing crop at Stearns Bluff (15.3%, 5 mg m^{-3}), followed by Acartia clausi (10.8%, 3 mg m^{-3}), Centropages abdominalis (9.9%, 3 mg m^{-3}), barnacle nauplii and cypris larvae (8.9%, 3 mg m^{-3}), Acanthomysis macropsis (7.9%, 2 mg m^{-3}), Calanus spp. (7.8%, 2 mg m^{-3}) and Neomysis integer (7.6%, 2 mg m^{-3}).

Calanus spp. contributed (20.5%, 6 mg m^{-3}) to the mean total standing crop at Westport; other gravimetrically important species included Gnorimosphaeroma oregonensis (12.6%, 4 mg m^{-3}), Sagitta sp. (10.2%, 2 mg m^{-3}), crangonid shrimp zoea (7.5%, 2 mg m^{-3}), barnacle larvae (7.3%, 2 mg m^{-3}), Centropages abdominalis (5.6%, 2 mg m^{-3}), and ctenophores (5.2%, 2 mg m^{-3}).

6.4 Discussion

6.4.1 Probable Sources of Dominant Neritic Zooplankton Populations: All neritic zooplankton sampling stations included samples with marine organisms, including Sand Island in the lower Chehalis River. Yet no riverine zooplankters, as defined by Haertel and Osterberg (1967), occurred in the samples from the lower estuary sites, e.g., Westport and Stearns Bluff. At Sand Island and Cow Point, neritic zooplankters representing the riverine assemblage included Ceriodaphnia reticulata, Daphnia galeata, Bosmina sp., Chydoridae, Diaptomus sp., Cyclops sp., Eucyclops sp., and Macrocyclops sp. Evidence of saltwater intrusion at these sites is indicated by taxa representative of marine assemblages, including *Podon* sp., *Pseudocalanus* sp., *Aetidius armatus*, *Centropages abdominalis*, *Epilabidocera amphitrites*, *Acartia tonsa*, *Tortanus discaudatus*, and euphausiid larvae.

True estuarine zooplankters, including *Neomysis mercedis*, *Eurytemora americana*, the harpacticoids *Huntemmania jadensis*, *Bryocamptus* sp. and *Scottolana canadensis*, *Cordylophora* sp., and *Gnorimosphaeroma oregonensis*, were also found at the upper estuary sites, but were most abundant at Moon Island and Cow Point.

The vertical salinity distribution (Fig. 2-6) shows that a "saltwater wedge" and a lighter, less saline lens of river water typical at the mouth of the Chehalis River (Cosmopolis, Fig. 2-6-A) was only regularly measured at one other site, Stearns Bluff (Fig. 2-6-D). This would suggest that the predominant river flow directed through the north channel is well mixed while the riverine and marine waters in the south channel are typically well stratified. Superimposed upon the tidal currents, contour profiles, and river flow levels in an estuary of this size are mixing processes due to the Coriolis effect, which tends to deflect the outflowing freshwater toward the right of an observer looking seaward in the northern hemisphere (Barnes 1974). While the zooplankton diversity at the north channel sites (which showed less salinity stratification than other sites) was the lowest of all sites, estuarine organisms such as barnacle larvae occurred there in the greatest densities—e.g., 123.3 m^{-3} over the entire study at Moon Island. Since the entire planktonic life history of barnacle larvae is less than 14 days (Kaestner 1970), the continuous abundance of nauplii in the estuary indicates a constant production of successive cohorts throughout the study period.

6.4.2 *Importance of Neritic Zooplankton as Prey of Juvenile Salmonids and English Sole*: While chum salmon captured at Moon Island and Stearn's Bluff during their outmigration between March and June had preyed predominately upon epibenthic organisms (Section 8.3.1), many of these prey were found consistently in the neritic zooplankton collections, e.g., harpacticoid copepods, and cumaceans (*Cumella* sp. and *Leucon* sp.). Typically neritic zooplankters such as larval fish, crangonid shrimp larvae, calanoid copepods and cyclopoid copepods were also important prey for juvenile chum, especially for the chum caught in the purse seine. While all of these groups occurred consistently in the water column, only the crangonid shrimp larvae comprised more than 5% of the neritic zooplankton abundance (mean total densities of 12.1%, 6.2 ± 8.5 m^{-3} and 12.5%, 7.8 ± 5.5 m^{-3} on March 20 and April 1, respectively).

The diet of beach seine-caught chinook salmon was also dominated by epibenthic organisms at both Moon Island and Stearns Bluff, i.e., *Cumella* sp. (83% and 93% of the total IRI, respectively). Frequent occurrence of drift insects in the diet of all chinook, and fish larvae (e.g., *Engraulis mordax* 48.8% of total IRI) in the purse seine-caught fish, suggest that juvenile chinook salmon feed throughout the water column.

The prey of juvenile coho salmon from both beach seine and purse seine collections were predominantly neritic zoea and megalop larvae of *Cancer* sp. These crab larvae were only found in the neritic zooplankton in early and mid-April, with maximum densities found on April 15 at Westport (1.7 ± 2.4 m^{-3}). A few *Cancer* sp. larvae were also found at Westport on October 6 (0.2 ± 0.3 m^{-3}).

Cancer sp. larvae also predominated the diet of a small sample size of cutthroat trout (44% of total IRI). Juvenile smelt were secondary prey (34.4%), and they were found in the total neritic zooplankton at a density of 0.5 - 0.6 m^{-3} between March 20 and April 15.

English sole were found to feed almost exclusively on epibenthic organisms.

Thus, juvenile salmon are preying upon only a small fraction of the neritic zooplankton produced or transported into Grays Harbor. Those organisms which were fed upon tended to be rare and large, although avoidance of the bongo nets by these large zooplankters may have biased (negatively) their actual abundance and availability to foraging salmon.

6.5 Summary

1. The community structure, density and standing crop of neritic zooplankton was examined at five sites in Grays Harbor between March and October 1980.

2. The prominent taxa, based on frequency of occurrence in the collections, included barnacle larvae (nauplii and cyprides) and the calanoid copepods *Eurytemora americana* and *Acartia clausi*; these taxa also dominated the numerical composition, in addition to *Centropages abdominalis* and *Calanus* spp. Juvenile and adult *Crangon franciscorum*, juvenile and adult *Neomysis mercedis* and *Eurytemora americana* composed the majority of the total standing crop.

3. The mean density of all neritic zooplankton (pooled) ranged between 43 and 904 animals m^{-3} and illustrated three sustained declines, between April 30 - May 28, June 1 - July 21, and September 9 - October 6; mean standing crop ranged between 7 and 225 mg m^{-3} and displayed similar spring and early autumn increases, associated with mid-summer and late fall declines.

4. Three sources—riverine, estuarine, and marine—of neritic zooplankters were identified. True estuarine assemblages were most abundant at Moon Island and Cow Point, where the water column was well mixed between freshwater and marine water masses.

5. Juvenile salmonids appear to feed upon only a small fraction of the neritic zooplankton in Grays Harbor, and even less upon the taxa which are actually produced within the estuary; English sole utilize very little neritic zooplankton.

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7.0 COMMUNITY STRUCTURE AND STANDING STOCK OF EPIBENTHIC ZOOPLANKTON AT MOON ISLAND

by Jeffery R. Cordell and Charles A. Simenstad

7.1 Introduction

Recent studies of the feeding ecology of juvenile salmonids and other nearshore marine and estuarine fish have documented the importance of epibenthic organisms as prey (Sibert and Kask 1978; Levy et al. 1979; Simenstad and Kinney 1978, 1979; Simenstad et al. 1979, 1980). Epibenthic and meiobenthic crustaceans, especially gammarid amphipods and harpacticoid copepods, are particularly important in estuarine habitats (Mason 1974; Sibert et al. 1979; Healey 1979, in addition to the previous citations).

Considering the diversity and magnitude of juvenile salmonids passing through and residing within Grays Harbor, the proportional representation of shallow sublittoral and lower littoral habitat in the estuary and the potential for removal of a signifianct areal portion of this habitat in the widening and deepening project, it was considered desirable to obtain some documentation of the composition and standing stock of epibenthic animals which were prey of outmigrating juvenile salmonids or other important epibenthic-feeding fishes, i.e., juvenile English sole.

The objectives of this study were to systematically sample the shallow sublittoral and lower littoral epibenthic habitat of Moon Island in order to:

1. Document the community structure of the epibenthos;
2. estimate the density and standing stock of these animals;
3. determine the differences, if any, in community structure and standing stock over diel and tidal regimes; and

4. relate the standing stock and availability of these animals to nearshore fish which were sampled at this site.

The sampling site at Moon Island was chosen due to its relationship to the projected impact upon the shallow sublittoral habitat in that vicinity during the widening and deepening dredging. As the process of detailed quantitative sampling and examination of epibenthic animals is very time-consuming and expensive only one sampling trip, covering an 18-hour sampling period, was feasible given the budget constraints.

7.2 Materials and Methods

Shallow sublittoral and lower littoral epibenthic zooplankton at Moon Island was sampled using a modified suction pump and technique designed for the quantitative sampling of epibenthic prey of juvenile salmonids in Hood Canal (Simenstad 1977; Simenstad and Kinney 1978; Simenstad et al. 1980). The pump system consisted of a self-priming, gasoline-powered 5.1-cm centrifical pump which drew water and associated plankters through a ported cylinder which sampled 0.1 m^2 of bottom surface area to a height of 25 cm; as such, this typified the epibenthic community in 0.025 m^3 within that distance of the bottom (Fig. 7-1). Once through the pump, the sample passed through a totalizing flowmeter into a double stainless steel cylinder in which three nested conical nets were suspended; the mesh sizes were 0.500 mm, 0.253 mm and 0.130 mm. The epibenthic animals were retained in net buckets with windows of respective mesh size.

Sampling commenced at 1830 PST on May 27 and terminated at 1230 PST on May 28. Samples were obtained at slack, flood, and ebb tide stages, approximately six hours apart. Duplicate samples, comprising pumping of 500 liters or until the ports on the sampling cylinder became clogged and sediment started entering the system, were obtained at approximately the 0.0-m tide level as determined by orientation to identifiable pilings located at the Moon Island sampling site; one additional replicated sample was obtained at the 0.3-m tide level at 1215 PST on May 28.

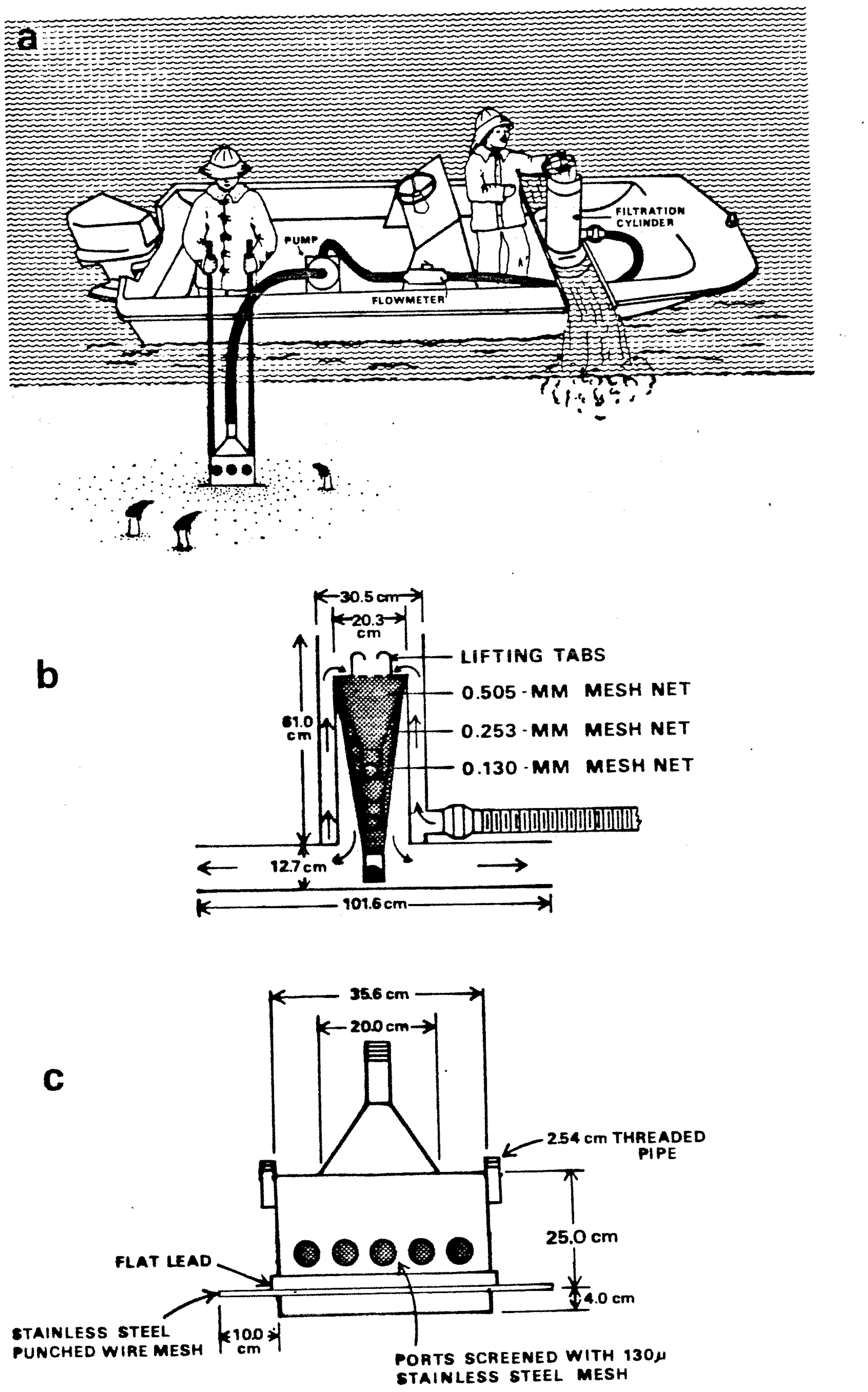

Fig. 7-1. Suction pump system utilized to quantitatively sample epibenthic zooplankton in shallow sublittoral and lower littoral habitats at Moon Island, Grays Harbor, Washington, May 27-28 1980; (a) system components in use, (b) filtration cylinder, and (c) sampling cylinder.

In the laboratory samples were subsampled if necessary using a standard glass quartered petri dish or a Hensen-Stempel pipette, depending upon the densities of organisms in the sample. They were then sorted to major taxonomic group and subsequently identified as specifically as possible.

Data was encoded and tabulated using the same methods and computer systems described for neritic zooplankton analyses (Section 6.2).

7.3 Results

7.3.1 Community Structure: Approximately 45 taxa of epibenthic organisms were identified from the samples (Table 7-1). Copepods of various life history stages and meroplanktonic larvae were the primary constituents of the epibenthic zooplankton at Moon Island (Fig. 7-2). In the shallow sublittoral samples, for all sampling times combined, numerically dominant organisms included harpacticoid copepod copepodite larvae (28.8%), calanoid copepod nauplii (27.6%) and copepodites (12.2%), the harpacticoid copepod *Microarthridion littorale* (10.5%), other harpacticoids (8.8%) and balanoid barnacle larvae (3.6%). Benthic infaunal organisms such as bivalves, oligochaetes, and nematodes were present at all sampling times but in lower abundances (*see* Appendix 7-1).

Gravimetrically, the dominant taxa were the larvae and adults of harpacticoids (40.8%), adult and larval calanoid copepods (19.6%), polychaetes (mostly juveniles and larvae, 11.2%), and balanoid barnacle larvae (6.9%).

The percent composition by density and standing crop of the numerically and gravimetrically dominant organisms showed an increase in the proportion of planktonic calanoid copepod adults and larvae and polychaete larvae with rising tide, and a concordant decrease of overall proportion of epibenthic or benthic organisms such as harpacticoid copepods and cumeaceans (Fig. 7-2). The opposite pattern was observed

Table 7-1. Taxonomic, numerical and gravimetric diversity and mean density and standing crop of epibenthic zooplankton among five samples obtained from shallow sublittoral and lower littoral habitats at Moon Island, May 27-28, 1980.

Time	Habitat	Tide stage	Number of taxa	Shannon-Wiener Diversity, H'		Density ($\bar{x}$ no. m^{-3} ± 1 s.d.)	Standing crop ($\bar{x}$ g m^{-3} ± 1 s.d.)
				density	standing crop		
1840	shallow sublittoral	ebb	30	3.04	4.89	27,860 ±	0.160 ±
		slack				1,725	0.113
2340	" "	flood	30	2.89	4.86	132,725 ±	0.545 ±
		slack				94,590	0.403
0540	" "	ebb	18	3.14	0.11[1]	6,800 ±	0.080 ±
		slack				6,279	0.040[2]
1140	" "	flood	21	2.50	4.39	88,660 ±	0.360 ±
		slack				81,713	0.170
1215	lower littoral	flood	16	3.40	4.51	166,213 ±	1.120 ±
		slack				8,730	0.358

[1] Biased by weight of one juvenile English sole (17.6 g).

[2] Excluding weight of one juvenile English sole (17.6 g).

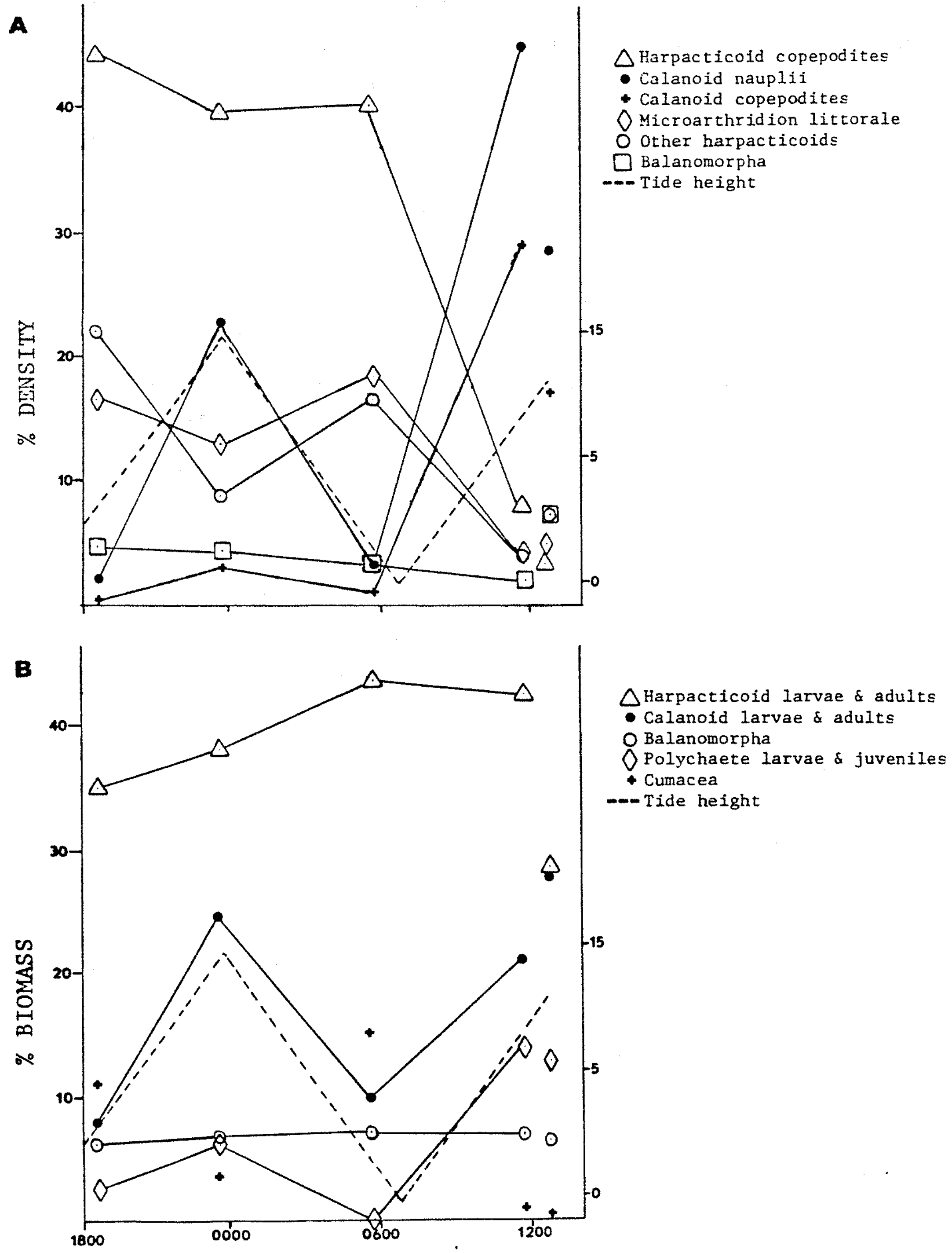

Fig. 7-2. Percent cumulative composition by density (A) and biomass (B) of zooplankton in epibenthic collections in shallow sublittoral and lower littoral (unconnected points) habitats at Moon Island, Grays Harbor, Washington, May 27-28, 1980. Tide height at time of collection is also denoted.

during the ebb tide, with proportions of planktonic organisms declining and epibenthic and benthic organisms increasing. Exceptions were the contribution of harpacticoids to the total standing crop, which showed no such correlation with tide stage, and in the proportion of both density and standing crop contributed by balanoid barnacle larvae, which was relatively constant.

In the single (replicated) samples obtained in the lower littoral zone at approximately 1215 PST on May 28 the numerically dominant animals included calanoid copepod nauplii (28.1%) and copepodites (17.3%), nematodes (13.0%), and harpacticoid copepods (13.0%). Based upon gravimetric composition, the predominant taxa were harpacticoid copepodids and adult (28.8%), calanoid copepod larvae and adults (primarily *Acartia* sp., 28.0%), balanoid barnacle larvae (6.7%), polychaete larvae and juveniles (6.7%) and nematodes (6.6%).

Taxonomic composition and statistical diversity based upon density and standing crop did not change dramatically among the five samples (Table 7-1), except for the drop in the number of taxa after the first two (flood tide) samples.

7.3.2 Density and Standing Crop: Mean total density of epibenthic zooplankton in the shallow sublittoral habitat at Moon Island varied dramatically among the four sampling times and tide periods, with a maximum of 132,726 individuals m^{-3} at 2340 PST on May 27 to a minimum of 6,800 m^{-3} at 0540 PST on May 28 (Fig. 7-3, Table 7-1). Much of the variation in total density over time was correlated with tide stage (Fig. 7-3), due principally to the increased representation by calanoid copepod nauplii (Fig. 7-2, Table 7-1).

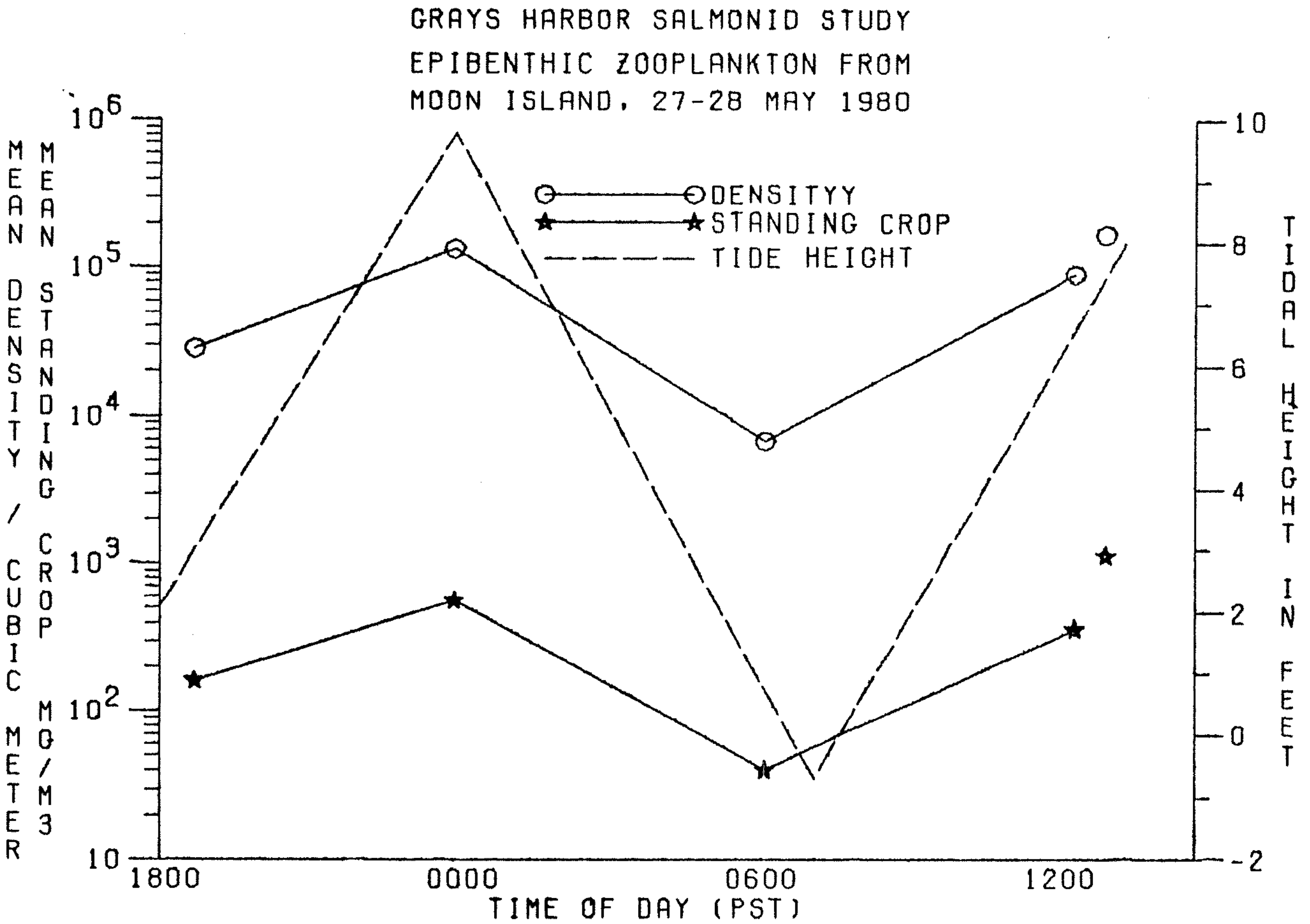

Fig. 7-3. Mean density (individuals m^{-3}) and standing crop (g m^{-3}) of zooplankton in epibenthic collections in shallow sublittoral and lower littoral (unconnected points) habitats at Moon Island, Grays Harbor, Washington, May 27-28, 1980. Tide height, relative to MLLW, at time of collection is also denoted.

The mean standing crop of the four shallow sublittoral samples was 0.281 g m^{-3}, ranging from a maximum of 0.565 g m^{-3} at 2340 PST on May 27 to a minimum of 0.040 g m^{-3} at 0540 PST on May 28.[1] As with density, the mean standing crop of epibenthic zooplankton appeared to be correlated with tide height (Fig. 7-3).

The mean density of epibenthic zooplankton in the lower littoral habitat at 1215 PST on May 28 was 166,213 individuals m^{-3} and the standing crop was 1.12 g m^{-3}. These values were the highest values obtained for the shallow sublittoral habitat.

This correlation of density and standing crop with tide stage held true for all major taxa, excluding cumacean density, which generally declined throughout the sampling period (Fig. 7-4).

7.4 Discussion

7.4.1 Comparison of Moon Island Epibenthic Zooplankton with Other Published Descriptions of Epibenthic Zooplankton Communities in Similar Habitats: The total mean density (± one standard deviation) of 84,452 ±67,575 organisms m^{-3} found at Moon Island is comparable to the higher density values found in comparable quantitative studies of shallow sublittoral epibenthic communities where pump sampling or similar techniques were utilized. Studies of Hood Canal (Simenstad et al. 1980) and the Straits of Juan de Fuca (Simenstad et al. 1980a) have documented mean density estimates of 25,895 ± 3,537 animals m^{-3} and 51,039 ± 75,841 m^{-3}, respectively, for epibenthic communities in nearshore marine habitats.

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[1] One juvenile English sole, weighing 17.6 g, was omitted from the standing crop estimates for this collection.

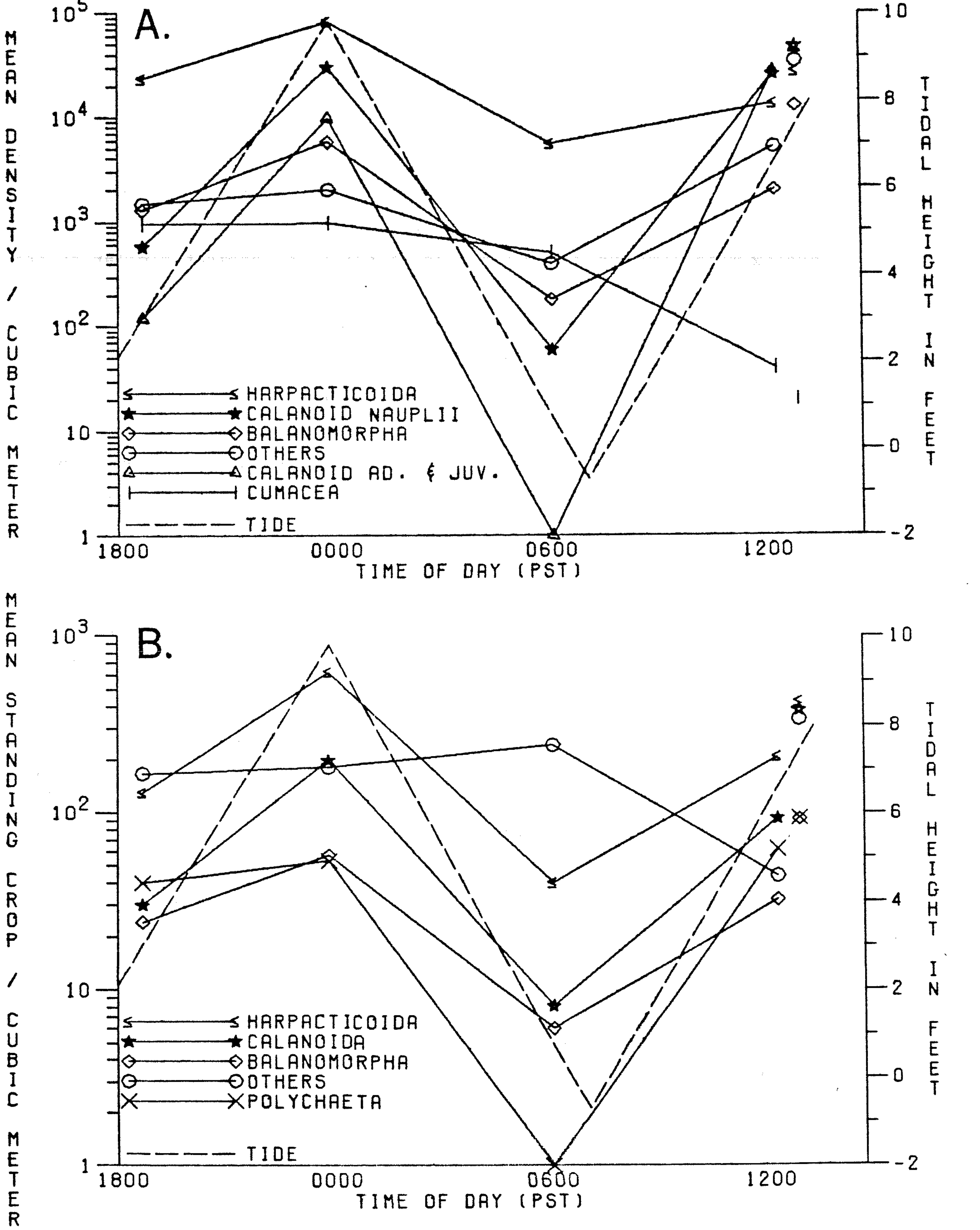

Fig. 7-4. Mean density (individuals m^{-3};A) and standing crop (g m^{-3};B) of principal taxa groups of zooplankton in epibenthic collections in shallow sublittoral and lower littoral (unconnected points) habitats at Moon Island, Grays Harbor, Washington, May 27-28, 1980. Tide height at time of collection is also noted.

The sampling apparatus used in the present study is presently being used in an extensive study of the epibenthic community in the Columbia River estuary, where preliminary data indicates an upper density value of approximately 98,500 animals m^{-3} in an estuarine habitat similar to the Moon Island site in Grays Harbor (second author, unpublished data). Epibenthic pump samples taken 5 cm from the bottom in the Nanaimo River estuary provided mean density estimates of approximately 8,567 animals m^{-3} (Sibert submitted). Thus, from the standpoint of the total density of epibenthic organisms, the shallow sublittoral habitat at Moon Island would appear to have a well developed epibenthic community comparable to or richer than other estuarine or nearshore marine habitats which have been similarly sampled in this region.

Densities of epibenthic harpacticoid copepods, the dominant taxa, averaged 28,368 individuals m^{-3}. Since our epibenthic pump sampling cylinder encompassed a volume of 0.025 m^{-3} over a bottom area of 0.1 m^{-2}, estimates of density and standing crop m^{-3} can be divided by four to arrive at an equivalent m^{-2} estimate for comparison with similar areal estimates, i.e., raw data expanded by a factor of 10 rather than 40. Thus, the equivalent mean density of epibenthic harpacticoids (within 25 cm of the bottom) at Moon Island is 7,096 m^{-2} and is considerably lower than maxima reported for infaunal harpacticoids in this area: 285,800 m^{-2} in the Nanaimo River estuary (Kask and Sibert 1976), 272,200 m^{-2} on Puget Sound beaches (Feller 1977) and 86,000 m^{-2} in Yaquina Bay, Oregon (Crandell 1967). It is also considerably lower than mean harpacticoid densities documented for similar epibenthic communities: 38,795 m^{-2} along the Straits of Juan de Fuca (Simenstad et al. 1980a) and Hood Canal, 39,500 m^{-2} (Simenstad et al. 1980b), but is similar to epibenthic harpacticoid density estimates of 9,500 m^{-2} in the Nanaimo River estuary (Sibert et al. 1977).

7.4.2 Relationship between Standing Stock of Epibenthic Animals and Tidal Rhythms: The observed increase in density and standing crop with increasing tide height could be explained as an influx of planktonic animals with the flooding tide into an existing epibenthic community; this appears at least partially true, as indicated by the high proportion of density and standing crop of planktonic animals at these times. However, the data indicated an increase in not only planktonic animals such as calanoid copepods, but epibenthic animals such as harpacticoids as well. Results similar to these have recently been implied in an investigation of a Spartina marsh, in which it was found that meiobenthic harpacticoids on a creek slope increased in density in the sediment during low and ebb tides, and decreased (presumably through entering the water column) during flood and high tides (Palmer and Brandt 1981). This effect is also consistent with the documentation of regular occurrence of meiofauna in the water column (Bell and Sherman 1980) and of reports of unique populations of "hyperbenthic" zooplankton which contain both benthic and planktonic elements and which are maintained by the continuous sinking of pelagic zooplankton and suspension of benthic meiofauna by scouring (Sibert submitted); Sibert has hypothesized that this hyperbenthic community is maintained by current-induced turbulence and that the fluctuations in the density of such populations could be attributed principally to tidal rhythms, as was also observed in this study.

7.4.3 Epibenthic Community Structure Relative to Location of Moon Island in Grays Harbor Estuary: The brackish shallow sublittoral habitat (salinity averaged approximately 14 ppt, Fig. 2-6) at Moon Island was characterized by a number of typically estuarine and euryhaline species mixed with marine species. The euryhaline harpacticoid copepods Microarthridon littorale, Bryocamptus sp., Attheyella sp., Huntamannia jadensis, Scottolana canadensis and species of the family Ectinosomidae and the calanoid copepods Eurytemora spp. have been documented from the epibenthos of similar estuarine habitats (Sibert et al. 1977; Haertel and Osterberg 1966; Lang 1948). Typically marine animals found in the epibenthos at Moon Island, which have been characterized as part of the "salt intrusion" group in the Columbia River estuary by Haertel and Osterberg (1966), included the calanoid Acartia sp., calanoid larvae and the meroplanktonic larvae of balanoid barnacles. The interesting aspect of the diel/tidal series of samples examined during this study was that the relative proportions of these different zooplankton assemblages changed somewhat during different tide stages. The density and standing crop of most organisms sampled, including characteristically epibenthic groups such as harpacticoid copepods, increased during the flood tide and decreased during the ebb tide. This implies that, in addition to the periodic influx of marine zooplankton with the flood tide, increased immigration of truly epibenthic and meiofaunal organisms into the water column at the flood tide tends to maintain the two assemblages in the epibenthic community. Whether this is an actual behavioral response by the epibenthic assemblage or, as Sibert's model suggests, a function of boundary layer turbulence, cannot be determined from our data.

7.4.4 Relationship between Epibenthic Zooplankton and Diets of Juvenile Salmonids and English Sole at Moon Island: The presence of significant proportions of epibenthic organisms (i.e., harpacticoid copepods, cumaceans) in the stomach contents of juvenile chum salmon, small juvenile chinook salmon and juvenile English sole captured at Moon Island (*see* Section 9.0) indicates that the epibenthos of shallow sublittoral and lower littoral habitats in Grays Harbor provide important prey resources for these fishes. While juvenile English sole fed primarily on the more common constituents of the epibenthic community (i.e., harpacticoids), juvenile chum and chinook salmon were often found to feed extensively upon prey organisms which were relatively rare components of the epibenthos (i.e., cumaceans). The fact that the epibenthic-feeding juvenile salmonids appeared to be selecting sparsely distributed prey suggests that the total area of shallow sublittoral habitat may be important in determing the number of juvenile salmonids which can efficiently obtain enough food in the upper estuary, where the extent of this habitat is small relative to the lower estuary.

7.4.5 Effect of Predation of Epibenthic-feeding Fishes upon the Community Structure and Standing Stock of Epibenthic Organisms: Although it is impossible to speculate upon the effect of predation by epibenthic-feeding fishes upon the community structure and standing stock of epibenthic organisms, due to the lack of a time series of samples, investigations in Hood Canal suggest that the epibenthic community is structured by the predation on outmigrating juvenile chum salmon (Simenstad et al. 1980b). In that the outmigration of juvenile chum salmon had already terminated by late May, when the epibenthic samples were collected, the structure and standing stock of the epibenthic community may have been dramatically different prior to May and could have been significantly more diverse and abundant if the intensity of chum salmon feeding in the shallow sublittoral habitat at Moon Island was high. The presence of small juvenile chinook at this time and their predominant consumption of cumaceans (Fig. 8-5) suggests that the epibenthic community at Moon Island may well have been under the selective influences of significant fish predation at the time of sampling. Similarly, the abundance of juvenile English sole was generally increasing at this time, although the catch rate at Moon Island was quite variable between March and late June (Fig. 4-1). It is interesting to note, however, that the state of the epibenthic community documented in late May coincided with the leveling off of incremental growth of the young-of-the-year English sole (Fig. 4-6 A), indicating that the prey resources may have become more limited at this point in the residence of English sole in shallow sublittoral habitats in the upper estuary.

7.5 Summary

1. The shallow sublittoral and lower littoral habitat at Moon Island was quantitatively sampled for epibenthic zooplankton over diel and tidal regimes in late May 1980 using an epibenthic suction pump.

2. Numerically, the prominent animals in the collections were harpacticoid and calanoid copepod larvae, adult harpacticoid copepods (primarily Microarthridion littorale), and barnacle larvae; gravimetrically, the dominant taxa were larval and adult harpacticoids and calanoids, polychaete and barnacle larvae.

3. The mean total density of epibenthic zooplankton varied as a direct, positive function of tide height, reaching a maximum of 132,725 ± 94,590 individuals m^{-3} at 2340 PST when flood slack occurred and a minimum of 6,800 ± 6,279 m^{-3} at 0540 PST during ebb slack; the standing crop reflected a similar relationship, ranging from 0.565 ± 0.403 g m^{-3} at 2340 PST to a minimum of 0.080 ± 0.040 g m^{-3} at 0540 PST.

4. The changes in standing stock of zooplankton in the epibenthic environs in association with tidal stage could in most respects be explained by the influx of planktonic animals into the shallow sublittoral zone; but there also was a corresponding increase in the standing stock of some epibenthic animals, notably harpacticoid copepods, which suggested that the epibenthic community is also accommodated to tidal influences.

5. The standing stock of epibenthic zooplankton in the lower littoral habitat, sampled at 1115 PST, was higher than any of the collections made in the shallow sublittoral habitat, averaging 166,213 individuals and 1.12 g m^{-3}.

6. The structure and standing stock of epibenthic zooplankton was found to be comparable with published reports of similarly-sampled communities in other shallow sublittoral and lower littoral estuarine and marine habitats in the region, although the standing stock of harpacticoid copepods was generally lower than has been found in other estuarine studies.

7. It was suggested that the structure and standing stock of the epibenthic zooplankton community sampled at Moon Island may be indicative of a limited prey resource for epibenthic-feeding fishes in the upper estuary, where shallow sublittoral and lower littoral mud- and sandflat habitat is not extensive; indications of predation effects upon the community, however, cannot be examined in the absence of a time series of data through the period of residence of juvenile salmonids and other epibenthic predators.

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8.0 FOOD WEB RELATIONSHIPS OF JUVENILE SALMONIDS AND ENGLISH SOLE

by Hannele Buechner, Linda Matheson, and Charles A. Simenstad

8.1 Introduction

Estuaries and nearshore marine environments of the Pacific Northwest appear to provide important rearing habitat for juvenile salmonids and English sole (Congleton and Smith 1977; Congleton 1979; Fresh et al. 1979; Healey 1979, 1980; Johnsen and Sims 1973; Levy and Levings 1978; Levy et al. 1979; Pearcy and Myers 1973; Reimers 1970; Royal 1962; Sibert and Parker 1972; Sibert 1974, 1979; Sibert et al. 1977; Simenstad et al. 1979, 1980). Smith (1976) and this report (see Section 4.0) state that Grays Harbor provides suitable nursery grounds for small, post-larval English sole and Herrmann (1971) and this report (see Section 3.0) indicate that juvenile salmonids also utilize the estuary as a rearing area.

In order to evaluate the potential impact of any perturbation in these rearing habitats in the estuary, such as that caused by the dredging operation or the eventual modification of habitat, during the outmigration and residence of these juvenile fishes it is imperative to consider the trophic or food web relationships between the fishes and the prey animals associated with representative estuarine habitats.

Our objective was to establish the prey spectra of the principal commercially-important fish, specifically juvenile chum and chinook salmon, steelhead trout and English sole, through quantitative analyses of their stomach contents. Within this objective we intended to examine:

1) interspecific diet overlap and intraspecific prey selectivity;
2) temporal and spatial differences in diet as compared to relative prey availability; and

3) inter- and intraspecific variations in diet with respect to size of predator.

8.2 Materials and Methods

8.2.1 Collection of Fish Stomachs:

Juvenile salmonids, English sole, associated baitfish and other fishes were collected in shallow sublittoral and lower littoral habitats using a 37-m floating beach seine and in neritic habitats using a 61-m x 90-m purse seine. A complete description of these sampling gears and the associated techniques is included in Section 3.2.

8.2.2 Field Preservation of Samples:

Upon collection, smaller fish (<200 mm in length) were immediately preserved whole in 10% buffered formalin; stomach samples from larger fish (>200 mm in length) were dissected from the fish and preserved separately.

8.2.3 Laboratory Processing:

Stomach samples were individually examined in the laboratory according to a systematic, standard procedure (Terry 1977) which identifies the numerical and gravimetric composition of prey organisms in the stomach contents, the stage of digestion and the degree of stomach fullness.

From each collection of fish, subsamples of five fish per size category (40-59, 60-79, 80+ mm) of each species (when available) were measured for length (FL for salmonids, TL for English sole) in millimeters and damp weight to the nearest 0.1 g. Fish from which stomachs had been dissected in the field had been measured and weighed at the time of stomach removal. When the stomach was removed from the fish, either in the field or laboratory, it was cut at points at the anterior end of the esophagus and posterior to the pylorus. The stomach contents were then removed to a petri dish and the stomach lining immediately blotted on paper toweling and reweighed to derive the total contents weight by subtraction. Stomach fullness was qualitatively evaluated and coded from 1 (empty) to 7 (distended) and the stage of digestion determined and coded from 1 (all unidentifiable) to 6 (no digestion evident). Prey items were then sorted under an illuminated dissecting microscope, enumerated, and identified as specifically as the state of digestion allowed. Life history stage of the prey and the blotted wet weight of each taxon to the nearest 0.001 g were also recorded.

8.2.4 Data Management and Analysis: All stomach analysis data were directly recorded onto MESA/NODC Format No. 100, record type 6 computer forms which utilize the NODC taxonomic code.

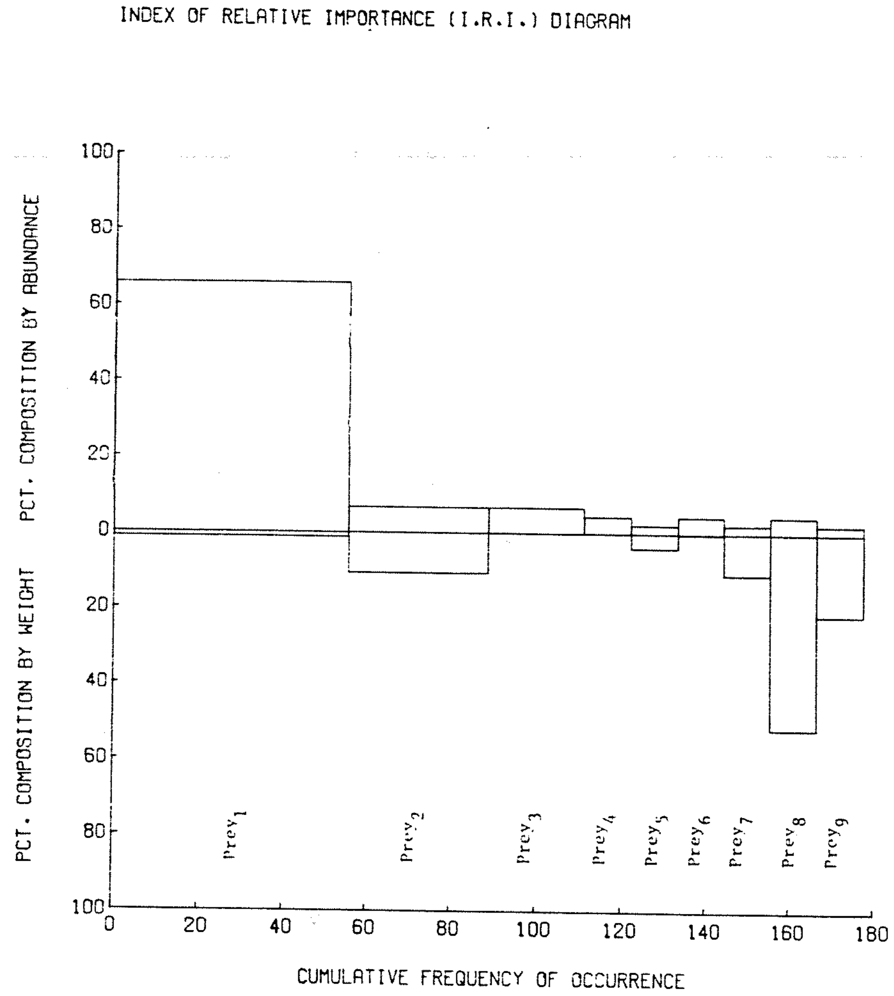
Tabulation and basic statistical analyses of the data were performed using an FRI computer program package, GUTBUGS, specifically developed for the MESA/NODC-format stomach analysis data. The program tabulates the sources (identification numbers, sample numbers, location numbers), numbers of specimens from each sample, and the collection time of each. The total number of stomach samples were itemized according to life history stage, and subsequently the number of empty stomachs was listed, the percentage of empty stomachs calculated, and the adjusted (stomachs containing prey) sample size was determined. Only stomachs containing prey were utilized in the subsequent statistical calculations. The mean, range and standard deviation of the fullness and digestion indices, total contents weight, total contents abundance, predator length and weight, and percent ratio of contents weight to predator weight were listed. For each prey taxon and life history stage identified from the combined stomach sample, the frequency of occurrence, mean, range, and standard deviation of the number and biomass, mean and standard deviation of the average biomass per individual, and the percentage composition by abundance, total biomass, and biomass adjusted by subtracting the unidentifiable material were listed. The total number of prey categories and standard diversity indices (Shannon-Wiener and Brillouin) were also computed. The stomach analysis program was designed to operate at any one of the three truncation levels of the taxonomic code, facilitating comparisons between stomach sample sets with differing stages of contents digestion.

A modification of Pinkas et al. (1971) Index of Relative Importance (IRI) was used to rank the importance of prey taxa. The IRI values for prey taxa were displayed both graphically and in tabular form where justified by sample size (n >25). The three-axis IRI graphs illustrated frequency of occurrence (the proportion of stomachs containing a specific prey taxa) plotted sequentially on the horizontal axis, and the percentage of total abundance and percentage of total biomass plotted above and below the horizontal axis, respectively (Fig. 8-1). All prey taxa, including those assigned to a broad taxonomic level (family, order, class) because of inability to assign a more specific identification, have been arranged from left to right by decreasing frequency of occurrence. Prey taxa in differing stages of digestion (e.g., partly digested shrimp, "Natantia-unidentified," as opposed to family, "Pandalidae," or species, "Pandalus borealis" were graphed separately).

The IRI value was computed as follows:

$$\mathrm{IRI} = \%\ \text{Frequency of occurrence}_i \left[\%\ \text{Numerical composition}_i \times \%\ \text{Gravimetric composition}_i\right]$$

and is equivalent to the area encompassed by the bar for each prey taxa i composing the IRI diagrams. In order to compare the IRI values between prey spectra of different sample sizes, the overall importance of general prey taxa (e.g., all shrimp, including "unidentified Natantia" and those identified to family and species, added together) has been discussed as a percentage of the total combined IRI (areas) of the different prey taxa. The advantage of the IRI value is that the more representative prey are not dominated by numerically rare but high biomass prey (e.g., prey_8, Fig. 8-1), by infrequently occurring but abundant or high biomass (when eaten) taxa, or by numerically abundant or frequently



Prey Category	% Freq. of occurrence	% Numerical composition	% Gravimetric composition	Prey IRI	% Total IRI
1	55.56	65.91	1.22	3729.5	65.76
2	33.33	6.82	10.69	583.7	10.29
3	22.22	6.82	0.04	152.5	2.69
4	11.11	4.55	< 0.01	50.5	0.89
5	11.11	2.27	3.84	67.9	1.20
6	11.11	4.55	0.12	51.8	0.91
7	11.11	2.27	10.89	146.3	2.58
8	11.11	4.55	51.67	624.6	11.01
9	11.11	2.27	21.52	264.4	4.66

Fig. 8-1. Illustration of Index of Relative Importance (IRI) plot and table utilized to describe prey spectra of juvenile salmonids and English sole in Grays Harbor, Washington, 1980.

occurring taxa which contribute little in the way of biomass (e.g., $prey_1$, Fig. 8-1).

8.3 Results

A total of 406 stomachs from juvenile salmonids and English sole and other salmonids were examined in the course of FRI's Grays Harbor studies (Table 8-1). Over 48% (200) of these were from juvenile chinook salmon, 34% (140) from juvenile English sole, 11% (45) and 8% (32) by juvenile coho and chum, respectively, and only a few (7) steelhead and (6) cutthroat trout and (1) dolly varden. Empty stomachs were relatively rare and varied according to species: highest (18%) in coho and cutthroat (20%); low in steelhead, English sole and chinook (12.5%, 8% and 4%, respectively); and absent in chum salmon, and dolly varden.

The life history and ecological characteristics of the more common prey taxa are outlined in Table 8-2, based upon Kozlof (1973), Borret et al. (1976), Merrit and Cummins (1978), Simenstad et al. (1980), Lasker (1975) and Hunter (1977).

8.3.1 Chum Salmon: Juvenile chum salmon preyed predominantly upon epibenthic organisms, especially harpacticoid copepods, during their residency in shallow sublittoral and lower littoral habitats in Grays Harbor (Fig. 8-2). Harpacticoids comprised over 80% of the total IRI prey spectrum while the cumaceans *Cumella* sp. and *Leucon* sp. (8.5% of total IRI), chironomid larvae (2.3%) and juvenile caridean shrimp (1.1%) were secondary. Fish larvae, which constituted 42% of the total prey biomass, were relatively unimportant (3.9% of total IRI) due to their infrequent occurrence (7.4%) in the stomach samples. The primary importance of harpacticoid copepods in the diet was maintained from early March through mid-April and did not shift (to cumaceans) until late April (Table 8-3); although cumaceans were also consumed in significant abundance in mid-March and early April. Gammarid amphipods, including *Corophium spinicorne* and *Eogammarus confervicolus*, began to appear in

Table 8-1. Description of stomach samples and characteristics of contents from juvenile salmonids and English sole caught in Grays Harbor, Washington, March–October 1980.

Species	Site	Sampling Gear	Total Sample Size, n	Number and % Empty	Length FL,TL mm x̄ ± 1s.d.	Weight g x̄ ± 1s.d.	Stomach Condition Factor x̄ ± 1s.d.	Contents Digestion Factor x̄ ± 1s.d.	Total Contents Abundance x̄ ± 1s.d.	Total Contents Weight g, x̄ ± 1s.d.	Total Number Prey Taxa x̄ ± 1s.d.	Ratio of Stomach Cont Weight to Body Wt., x̄ ± 1s.d.
Parophrys vetulus, juvenile English sole	Moon Is.	beach seine	130	10 (7.7)	76.0 ± 23.22	4.92 ± 3.86	2.8 ± 1.1	3.3 ± 1.3	27.7 ± 47.5	0.02 ± 0.02	3.6 ± 2.2	0.44 ± 0.48
Oncorhynchus keta, juvenile chum salmon	Moon Is.	beach seine	18	0 (0)	41.7 ± 5.01	0.74 ± 0.33	4.6 ± 1.4	4.8 ± 0.4	65.7 ± 84.6	0.01 ± 0.01	4.8 ± 2.9	1.72 ± 0.80
"	"	purse seine	4	0 (0)	69.5 ± 34.78	6.23 ± 7.88	5.8 ± 0.5	4.3 ± 0.5	61.3 ± 64.4	0.25 ± 0.40	7.3 ± 4.5	2.68 ± 1.51
"	Stearn's Bluff	beach seine	10	0 (0)	38.7 ± 2.45	0.52 ± 0.13	4.8 ± 1.2	4.2 ± 0.6	124.3 ± 137.3	0.01 ± 0.01	7.4 ± 5.2	2.12 ± 1.91
O. kisutch, juvenile coho salmon	Moon Is.	beach seine	17	2 (11.8)	126.9 ± 9.48	22.48 ± 5.30	4.7 ± 1.5	3.9 ± 1.0	5.9 ± 3.7	0.19 ± 0.22	3.0 ± 1.4	0.93 ± 1.16
"	"	purse seine	8	2 (25.0)	124.7 ± 2.88	20.82 ± 1.72	4.5 ± 2.0	4.2 ± 1.6	19.2 ± 34.4	0.16 ± 0.11	2.0 ± 1.5	0.77 ± 0.53
"	Stearn's Bluff	beach seine	13	3 (23.1)	125.4 ± 9.71	20.75 ± 4.59	4.8 ± 1.5	4.1 ± 1.2	14.9 ± 17.8	0.31 ± 0.22	3.5 ± 2.2	1.61 ± 1.28
O. tshawytscha	Moon Is.	beach seine	101	3 (3.0)	72.9 ± 18.13	5.36 ± 4.45	5.2 ± 1.5	3.5 ± 1.0	118.2 ± 189.2	0.11 ± 0.11	5.5 ± 4.0	2.24 ± 1.69
"	"	purse seine	44	2 (4.6)	97.4 ± 24.53	12.33 ± 10.69	5.5 ± 1.5	3.6 ± 1.0	18.7 ± 33.3	0.29 ± 0.33	3.7 ± 2.7	2.78 ± 2.00
"	Stearn's Bluff	beach seine	47	3 (6.4)	75.1 ± 17.62	5.63 ± 4.96	4.8 ± 1.3	3.9 ± 1.0	176.5 ± 301.0	0.07 ± 0.05	5.2 ± 3.5	1.59 ± 1.10

Table 8-1. Description of stomach samples and characteristics of contents from juvenile salmonids and English sole caught in Grays Harbor, Washington, March through October 1980 - continued.

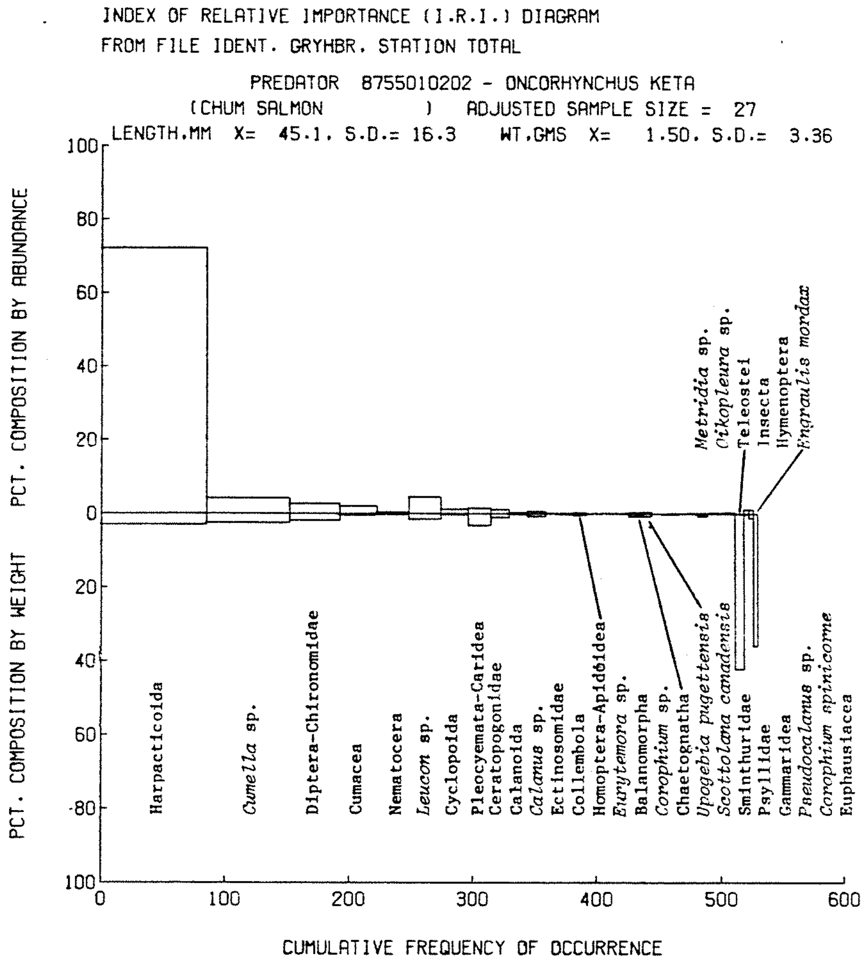
Species	Site	Sampling Gear	Total Sample Size, n	Number and % Empty	Length FL,TL mm $\bar{x}\pm1$ s.d.	Weight g $\bar{x}\pm1$ s.d.	Stomach Condition Factor $\bar{x}\pm1$ s.d.	Contents Digestion Factor $\bar{x}\pm1$ s.d.	Total Contents Abundance $\bar{x}\pm1$ s.d.	Total Contents Weight $\bar{x}\pm1$ s.d.	Total Number Prey Taxa $\bar{x}\pm1$ s.d.	Ratio of Stomach Content Wt to Body Wt $\bar{x}\pm1$ s.d.
Salmo clarki	Moon Is.	beach seine	2									
"	"	purse seine	1	1	260.0 ± 116.42	41.1 ± 16.55	6.5 ± 1.0	4.3 ± 1.0	5.0 ± 4.0	9.11 ± 9.88	1.5 ± 0.6	6.64 ± 0.57
"	Cosmo	purse seine	1	(20.0)								
"	Westport	purse seine	1									
S. gairdneri	Cosmo	purse seine	3									
"	Cow Point	beach seine	1									
"	" "	purse seine	1	1	181.9 ±	63.66 ±	3.7 ±	3.3 ±	3.7 ±	0.56 ±	1.4 ±	0.85 ±
"	Moon Is.	beach seine	1	(12.50)	34.94	33.87	1.5	1.1	4.2	0.51	0.5	0.74
"	Stearn's Bluff	beach seine	1									
"	Westport	beach seine	1									
Salvelinus malma	Cow Point	beach seine	1	0 (0.00)	--	--	6.0 ± 0.0	5.0 ± 0.0	1.0 ± 0.0	38.25 ± 0.0	1.0 ± 0.0	--

Table 8-2. Characteristic habitats, habits and feeding modes of major prey organisms of juvenile salmonids and English sole in Grays Harbor, Washington, March-October 1980

Taxon	Life History Stage	Habitat	Habits	Feeding Mode
Phylum Arthropoda Class Insecta Order Diptera (true flies) Superorder Nematocera Superfamily Culicoidea (mosquito-like flies) Family Chironomidae (midges)	Adult	Riverine/estuarine	Mating occurs in aerial swarms, surface swarms or on solid substrates-eggs are scattered on water surface or deposited in gelatinous masses on surface, emergent substrates or vegetation	Food not required
Family Ceratopogonidae (biting midges)	Larvae	Riverine/estuarine	Aquatic or semi-aquatic-occurring in sand, mud, decaying vegetation, temporary ponds and pools, shallow shore areas; may be planktonic, tubicolus burrowers or inhabit surfaces of floating vegetation or fine sediments	Detritivores-deposit and surface film feeders
	Adults	Riverine/estuarine	Shallow shore areas-running water pools and margins; may breed in the littoral zone	Predators-biting, sucking mouthparts are used to attack other insects and suck blood from host as an ectoparasite

Class Crustacea Subclass Copepoda Order Harpacticoida	Juvenile-adult	Marine/estuarine/riverine	Infaunal or epibenthic-crawling on substrate in sand, mud, or among algae, eelgrass or sphagnum; some may swim short distances	Little known-some may be raptoral feeders, grasping particles to graze on microflora; some may be herbivorous
Family Canuellidae (*Scottolana canadensis*)	Juvenile-adult	Estuarine	Epibenthic	Unknown
Order Cumacea Family Nannastacidae (*Cumella* sp.)	Adult	Marine	Burrowers in fine sand or mud substrates-may perform nocturnal vertical migrations	Grazers-chewing algae and detritus off fine sand grains 0.15-0.50 mm in diameter
Family Leuconidae (*Leucon* sp.)	Juvenile-adult	Marine/estuarine	"	Detritivores, mud deposit feeders
Order Amphipoda Superorder Gammaridea Family Corophiidae (*Corophium* sp.)	Juvenile-adult	Estuarine	Tubicolus, burrowing in sand or mud substrates	Detritivores
Family Gammaridae (*Eogammarus* sp.)	Juvenile-adult	Estuarine/marine	Some free swimming and phytophagus or omnivorous; some nestle in algae	Detritivores and herbivores
Phylum Chordata Class Osteichthys Order Clupeiformes Family Engraulidae (*Engraulis mordax*)	Larvae	Marine	Schooling begins when larvae reach 18-20 mm; feed during day esp. in inshore chlorophyll maximum layer	Planktivorous upon copepods and dinoflagellates

Order Hymenoptera Superfamily Scolioidea Family Formicidae (ants)	Winged adults	Terrestrial	Social insects nesting in the ground, wood or plants; engage in mating flights	Variable-feed on both living and dead animal matter, plants, fungi, sap and nectar
Order Psocoptera (psodid or bark lice)	Adults	Terrestrial	Occur on bark or foliage of trees and shrubs; also under bark and stones	Feed on molds, fungi, cereals, pollen, fragments of dead insects



PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
HARPACTICOIDA	85.19	72.21	2.97	6403.8	80.04
CUMELLA SP.	66.67	4.25	2.44	446.4	5.58
DIPTERA-CHIRONOMIDAE	40.74	2.66	1.76	180.3	2.25
CUMACEA	29.63	2.10	.52	77.9	.97
NEMATOCERA	25.93	.34	.28	16.3	.20
LEUCON SP.	25.93	4.51	1.49	155.5	1.94
CYCLOPOIDA	22.22	1.29	.27	34.7	.43
PLEOCYEMATA-CARIDEA	18.52	1.55	3.18	87.6	1.09
CERATOPOGONIDAE	14.81	1.12	.92	30.2	.38
CALANOIDA	14.81	.43	.15	8.6	.11
CALANUS SP.	14.81	.73	.58	19.4	.24
ECTINOSOMIDAE	11.11	.21	.03	2.8	.03
COLLEMBOLA	11.11	.13	.14	2.9	.04
HOMOPTERA-APHIDOIDEA	11.11	.43	.25	7.6	.09
EURYTEMORA SP.	11.11	.13	.03	1.8	.02
BALANOMORPHA	11.11	.17	.03	2.3	.03
COROPHIUM SP.	11.11	.21	.03	2.8	.03
CHAETOGNATHA	11.11	.39	.68	11.9	.15
UPOGEBIA PUGETTENSIS	7.41	.60	.57	8.7	.11
SCOTTOLANA CANADENSIS	7.41	.09	.02	.8	.01
SMINTHURIDAE	7.41	.09	.13	1.6	.02
PSYLLIDAE	7.41	.13	.23	2.6	.03
GAMMARIDEA	7.41	.09	.02	.8	.01
PSEUDOCALANUS SP.	7.41	.13	.02	1.1	.01
COROPHIUM SPINICORNE	7.41	.30	.68	7.3	.09
EUPHAUSIACEA	7.41	.13	.02	1.1	.01
METRIDIA SP.	7.41	.13	.02	1.1	.01
OIKOPLEURA SP.	7.41	.39	.02	3.0	.04
TELEOSTEI	7.41	.09	42.07	312.3	3.90
INSECTA	3.70	1.16	.23	5.1	.06
HYMENOPTERA	3.70	1.12	1.14	8.3	.10
ENGRAULIS MORDAX	3.70	.04	35.81	132.8	1.66

Fig. 8-2. Index of Relative Importance (IRI) plot and table for juvenile chum salmon captured in shallow sublittoral and lower littoral habitats at Grays Harbor, Washington, March-June 1980.

Table 8-3. Relative importance of prey (% of total IRI) of juvenile chum salmon in Grays Harbor, by sampling week, between 6 March and 27 April 1980. (Samples pooled for Moon Island and Stearn's Bluff sites).

Week	Date	Sample Size n	% of Total IRI Prey Harpacticoid Copepods	Cumaceans	Chironomid Larvae	Juvenile Shrimp	Cyclopoid Copepods	Gammarid Amphipods
1	6 March	5	90.8	5.0	1.3	0.0	0.0	0.1
2	17-19 March	11	66.2	20.3	3.8	3.3	0.5	0.1
3	2 April	5	64.4	25.3	7.1	0.0	0.0	1.03
4	15-16 April	4	84.3	1.99	0.14	0.0	5.44	0.28
5	20 April	5	9.2	69.5	1.3	9.6	0.00	10.46

the prey spectra late in the outmigration. Two larger specimens of juvenile chum collected later (29 May and 10 June), after the chum outmigration had declined, had fed differentially upon fish larvae (northern anchovy) and insects.

The few (four) juvenile chum salmon captured in the purse seine at the Moon Island sampling site tended to be larger than those captured in the beach seine and had consumed, on the average, more and different prey taxa and a larger proportion of their total body weight instantaneous ration) (Table 8-1). While chums captured in the shallow sublittoral and lower littoral habitat by the beach seine (Fig. 8-3) had consumed principally harpacticoid copepods (68.0% of the total IRI), <u>Cumella</u> sp. (16.2%) and chironomid larvae (4.4%), the fish captured in neritic waters by the purse seine had consumed predominately pelagic organisms, including unidentifiable larval fish (20.2% of total IRI), larval northern anchovies (17.2%) and adult (drift) insects (13.7%). Epibenthic harpacticoids were also prevalent (17.8%) in the prey spectra of the neritic chums, indicating that some foraging was occurring in the shallower habitats.

Juvenile chum salmon captured in the shallow sublittoral and lower littoral habitat at Stearn's Bluff in the beach seine collections were comparable in size to those captured in the same habitat at Moon Island (Table 8-1) but had consumed almost twice as many prey organisms per fish (stomach) and indicated a higher instantaneous ration.[1] These fish were only caught on March 6 and March 17. The prey spectra (Fig. 8.4) of the fish caught in the lower estuary (Stearn's Bluff) was also focused upon epibenthic crustaceans, those being primarily harpacticoid

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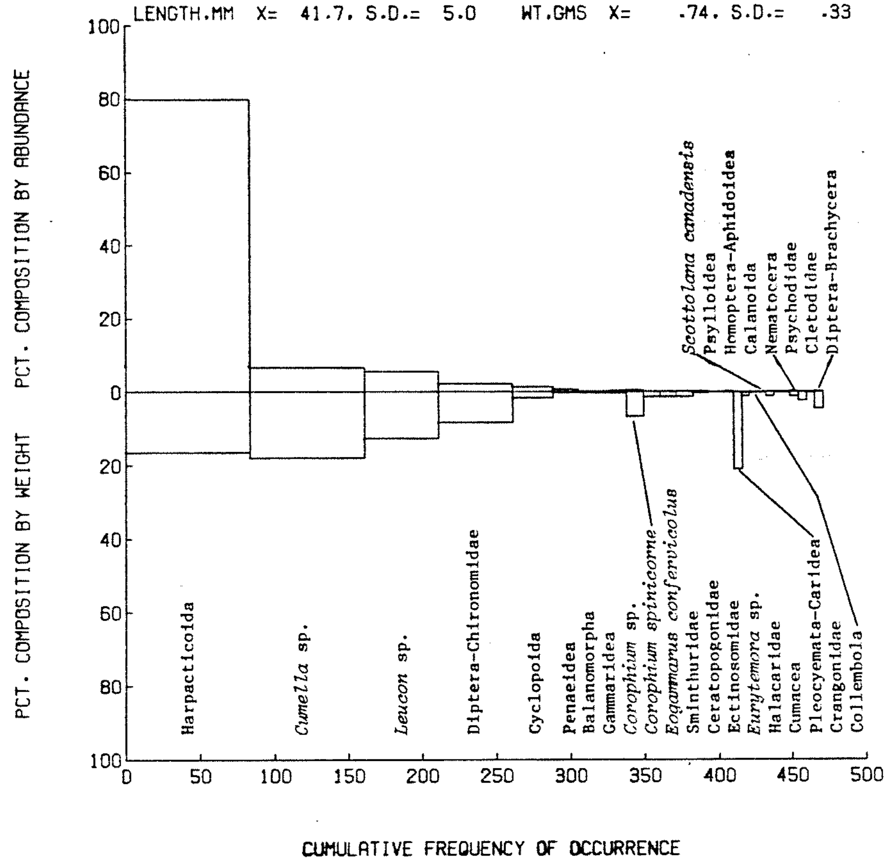
[1] Instantaneous ration here refers to the ratio of the mean stomach contents biomass to the mean fish biomass; it is less than the actual daily ration because it does not include the biomass of food consumed in a 24-hr period.

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. ALLBS , STATION MOON

PREDATOR 8755010202 - ONCORHYNCHUS KETA
(CHUM SALMON) ADJUSTED SAMPLE SIZE = 18
LENGTH,MM X= 41.7, S.D.= 5.0 WT,GMS X= .74, S.D.= .33



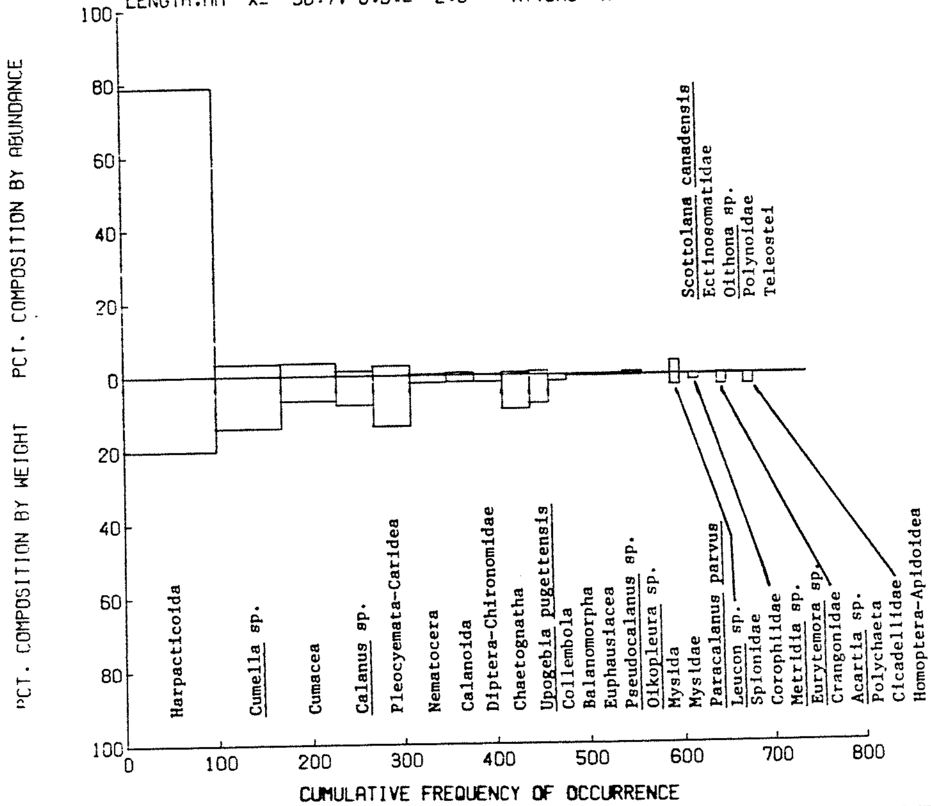
PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
HARPACTICOIDA	83.33	79.70	16.45	8010.8	67.99
CUMELLA SP.	77.78	6.60	17.99	1912.6	16.22
LEUCON SP.	50.00	5.56	12.56	906.3	7.70
DIPTERA-CHIRONOMIDAE	50.00	2.26	8.17	522.6	4.43
CYCLOPOIDA	27.78	1.44	1.55	82.9	.70
PENAEIDEA	16.67	.65	.33	16.3	.14
BALANOMORPHA	11.11	.17	.22	4.3	.04
GAMMARIDEA	11.11	.17	.22	4.3	.04
COROPHIUM SP.	11.11	.34	.22	6.2	.05
COROPHIUM SPINICORNE	11.11	.59	6.62	80.2	.68
EOGAMMARUS CONFERVICOLUS	11.11	.17	1.22	15.4	.13
SMINTHURIDAE	11.11	.17	1.22	15.4	.13
CERATOPOGONIDAE	11.11	.25	1.21	16.3	.14
ECTINOSOMIDAE	11.11	.25	.22	5.3	.04
EURYTEMORA SP.	5.56	.08	.11	1.1	.01
HALACARIDAE	5.56	.08	.11	1.1	.01
CUMACEA	5.56	.17	.11	1.6	.01
PLEOCYEMATA-CARIDEA	5.56	.08	20.97	117.0	.99
CRANGONIDAE	5.56	.08	1.10	6.6	.06
COLLEMBOLA	5.56	.08	.11	1.1	.01
SCOTTOLANA CANADENSIS	5.56	.08	.11	1.1	.01
PSYLLOIDEA	5.56	.08	1.10	6.6	.06
HOMOPTERA-APHIDOIDEA	5.56	.08	.11	1.1	.01
CALANOIDA	5.56	.08	.11	1.1	.01
NEMATOCERA	5.56	.17	1.10	7.1	.06
PSYCHODIDAE	5.56	.08	2.21	12.7	.11
CLETODIDAE	5.56	.08	.11	1.1	.01
DIPTERA-BRACHYCERA	5.56	.25	4.42	25.9	.22

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX		.64	.15		.50
SHANNON-WEINER DIVERSITY		1.34	3.33		1.58
EVENNESS INDEX		.26	.64		.33

Fig. 8-3. Index of Relative Importance (IRI) plot and table for juvenile chum salmon captured in the shallow sublittoral and lower littoral habitat at Moon Island, Grays Harbor, Washington, March-June 1980.

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. SEINE . STATION STRNS
PREDATOR 8755010202 - ONCORHYNCHUS KETA
(CHUM SALMON) ADJUSTED SAMPLE SIZE = 10
LENGTH.MM X= 38.7. S.D.= 2.5 WT.GMS X= .52. S.D.= .13



PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
HARPACTICOIDA	100.00	78.76	20.15	9891.3	72.14
CUMELLA SP.	70.00	3.38	13.94	1212.3	8.84
CUMACEA	60.00	3.62	6.67	617.2	4.50
CALANUS SP.	40.00	1.37	7.73	363.8	2.65
PLEOCYEMATA-CARIDEA	40.00	2.82	13.64	658.1	4.80
NEMATOCERA	40.00	.32	1.97	91.7	.67
CALANOIDA	30.00	.72	1.82	76.3	.56
DIPTERA-CHIRONOMIDAE	30.00	.24	1.82	61.8	.45
CHAETOGNATHA	30.00	.72	9.09	294.4	2.15
UPOGEBIA PUGETTENSIS	20.00	1.13	7.58	174.0	1.27
COLLEMBOLA	20.00	.16	1.67	36.6	.27
BALANOMORPHA	20.00	.24	.30	10.9	.08
EUPHAUSIACEA	20.00	.24	.30	10.9	.08
PSEUDOCALANUS SP.	20.00	.24	.30	10.9	.08
OIKOPLEURA SP.	20.00	.72	.30	20.5	.15
MYSIDA	10.00	.08	.15	2.3	.02
MYSIDAE	10.00	.08	.15	2.3	.02
PARACALANUS PARVUS	10.00	.08	.15	2.3	.02
LEUCON SP.	10.00	3.54	3.03	65.7	.48
SPIONIDAE	10.00	.08	.15	2.3	.02
COROPHIIDAE	10.00	.08	1.52	16.0	.12
METRIDIA SP.	10.00	.16	.15	3.1	.02
EURYTEMORA SP.	10.00	.08	.15	2.3	.02
CRANGONIDAE	10.00	.24	3.03	32.7	.24
ACARTIA SP.	10.00	.24	.15	3.9	.03
POLYCHAETA	10.00	.08	.15	2.3	.02
CICADELLIDAE	10.00	.08	3.03	31.1	.23
HOMOPTERA-APHIDOIDEA	10.00	.08	.15	2.3	.02
SCOTTOLANA CANADENSIS	10.00	.08	.15	2.3	.02
ECTINOSOMIDAE	10.00	.08	.15	2.3	.02
OITHONA SP.	10.00	.08	.15	2.3	.02
POLYNOIDAE	10.00	.08	.15	2.3	.02
TELEOSTEI	10.00	.08	.15	2.3	.02

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

	NUM. COMP.	GRAV. COMP.	PERCENT TOTAL IRI
PERCENT DOMINANCE INDEX	.63	.11	.53
SHANNON-WEINER DIVERSITY	1.54	3.67	1.71
EVENNESS INDEX	.30	.73	.34

Fig. 8-4. Index of Relative Importance (IRI) plot and table for juvenile chum salmon captured in the shallow sublittoral and lower littoral habitat at Stearn's Bluff, Grays Harbor, Washington, March 1980.

copepods (90.8% of total IRI on March 6, 56.4% on March 17), Cumella sp. (11.4% of the total IRI on March 17) and juvenile caridean shrimp (9.7% of the total IRI on March 17).

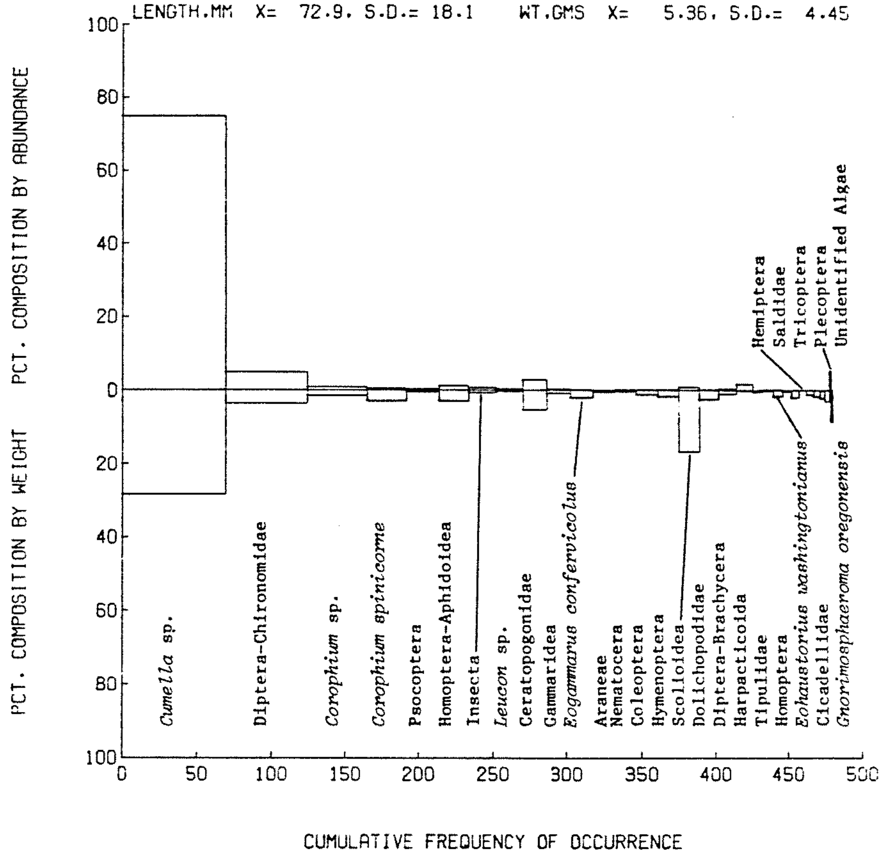
8.3.2 Chinook Salmon: Juvenile chinook salmon captured in the shallow sublittoral and lower littoral habitat at Moon Island, the primary sampling site in Grays Harbor, fed predominately upon epibenthic crustaceans with minor emphasis upon adult (drift) insects. The cumacean Cumella sp. was singularly important, comprising over 83% of the total IRI while adult chironomids (5.4%) and ants (2.9%) were of secondary importance (Fig. 8-5). Cumella sp. is usually considered an infaunal organism but adult males characteristically leave the substrate and become epibenthic.

Larger juvenile chinook (smolts) captured in neritic waters during the purse seine collections illustrated dramatically different prey spectra than did the fish caught in shallower habitats with the beach seine. Drift insects were the prevalent prey taxa (Fig. 8-6) and included adult chironomids (7.3% of the total IRI), psocopterans (barklice, 3.5%), aphids (4.0%), and ants (20.0%); overall, however, larval northern anchovies were the singularly most important prey, comprising 48.8% of the total IRI.

Differences in prey spectra of the juvenile chinook captured in the two different habitats may be, in part, related to the size of fish, as the beach seine-caught fish were some 20-mm FL smaller than those captured by the purse seine (Table 8-1). This indicates that the habitat preferences (small chinook in shallow sublittoral and lower littoral habitats, larger chinook in neritic habitats) hypothesized in Section 3.4 is reflected in or perhaps explained by differential prey requirements (size and density) or feeding behavior. It is also important to consider that beach seine collections were performed at low tide and purse seine collections were performed at high tide, thus the relative

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. ALLBS, STATION MOON

PREDATOR 8755010206 - ONCORHYNCHUS TSHAWYTSCHA
(CHINOOK SALMON) ADJUSTED SAMPLE SIZE = 98
LENGTH.MM X= 72.9, S.D.= 18.1 WT.GMS X= 5.36, S.D.= 4.45

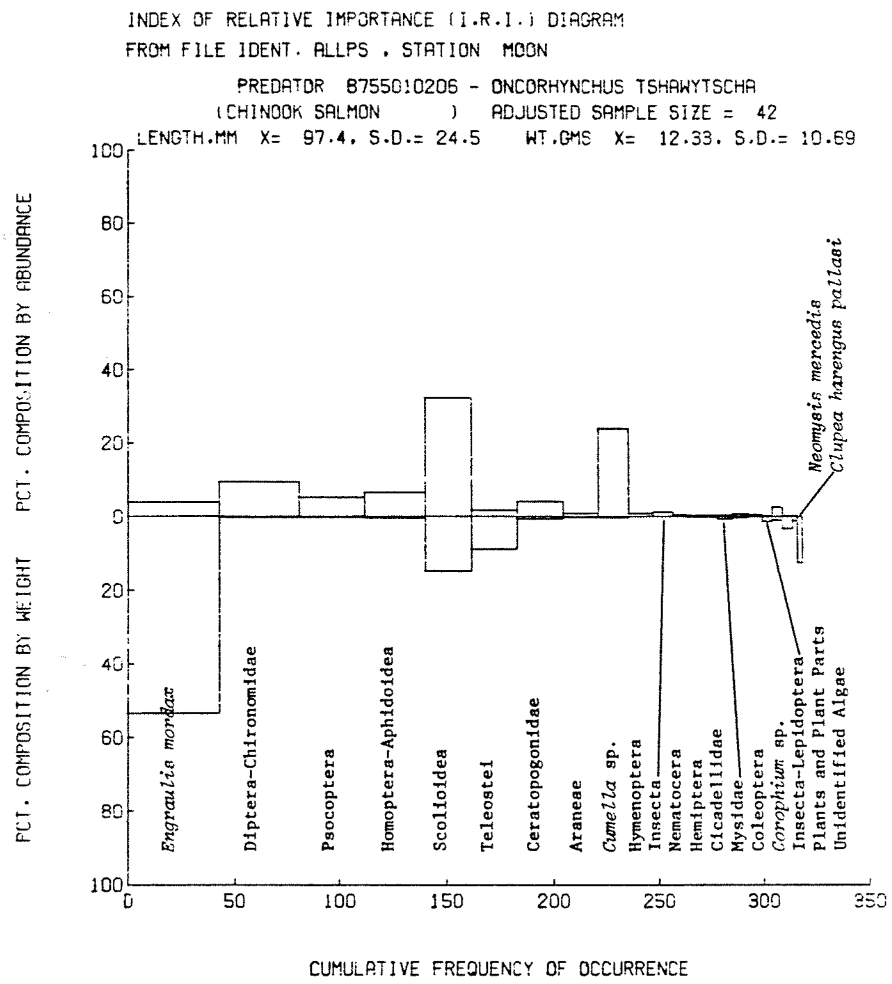


PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
CUMELLA SP.	69.39	74.76	26.20	7149.6	83.13
DIPTERA-CHIRONOMIDAE	25.10	4.94	3.55	466.5	5.42
COROPHIUM SP.	40.82	.96	1.46	99.4	1.16
COROPHIUM SPINICORNE	26.53	.24	2.87	90.4	1.05
PSOCOPTERA	22.45	.31	.42	16.5	.19
HOMOPTERA-APHIDOIDEA	19.39	1.16	2.91	79.4	.92
INSECTA	19.39	.82	.65	28.4	.33
LEUCON SP.	17.35	.33	.27	10.4	.12
CERATOPOGONIDAE	16.33	2.97	5.34	135.6	1.58
GAMMARIDEA	16.33	.33	.79	18.3	.21
EOGAMMARUS CONFERVICOLUS	15.31	.23	1.85	31.9	.37
ARANEAE	14.29	.15	.39	7.7	.09
NEMATOCERA	14.29	.26	.33	8.5	.10
COLEOPTERA	14.29	.17	1.11	18.3	.21
HYMENOPTERA	14.29	.20	1.51	24.4	.28
SCOLIOIDEA	14.29	1.02	16.66	252.6	2.94
DOLICHOPODIDAE	13.27	.29	2.37	35.4	.41
DIPTERA-BRACHYCERA	12.24	.47	.90	16.7	.19
HARPACTICOIDA	11.22	1.79	.07	20.9	.24
TIPULIDAE	7.14	.14	.37	3.7	.04
HOMOPTERA	7.14	.23	.09	2.3	.03
EOHAUSTORIUS WASHINGTONIANUS	6.12	.26	1.57	11.4	.13
CICADELLIDAE	6.12	.08	.16	1.6	.02
GNORIMOSPHAEROMA OREGONENSIS	5.10	.08	1.95	10.3	.12
HEMIPTERA	5.10	.04	.05	.4	.00
SALDIDAE	5.10	.09	1.07	5.9	.07
TRICOPTERA	4.08	.09	1.58	6.8	.06
PLECOPTERA	3.06	.03	2.15	6.7	.08
UNIDENTIFIED ALGAE	3.06	.08	2.92	9.1	.11
SIMULIIDAE	1.02	5.39	2.20	7.7	.09
TELEOSTEI	1.02	.01	8.37	8.5	.10

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX		.57	.13		.70
SHANNON-WEINER DIVERSITY		1.61	4.00		1.25
EVENNESS INDEX		.29	.65		.20

Fig. 8-5. Index of Relative Importance (IRI) plot and table for juvenile chinook salmon captured in the shallow sublittoral and lower littoral habitat at Moon Island, Grays Harbor, Washington, March-June 1980.


INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. ALLPS . STATION MOON
PREDATOR 8755010206 - ONCORHYNCHUS TSHAWYTSCHA
(CHINOOK SALMON) ADJUSTED SAMPLE SIZE = 42
LENGTH.MM X= 97.4. S.D.= 24.5 WT.GMS X= 12.33. S.D.= 10.69

PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
ENGRAULIS MORDAX	42.86	3.95	53.46	2460.8	48.80
DIPTERA-CHIRONOMIDAE	38.10	9.44	.23	368.3	7.30
PSOCOPTERA	30.95	5.36	.31	175.3	3.48
HOMOPTERA-APHIDOIDEA	28.57	6.51	.49	200.0	3.97
SCOLIOIDEA	21.43	32.40	14.72	1009.7	20.02
TELEOSTEI	21.43	1.79	8.75	225.9	4.49
CERATOPOGONIDAE	21.43	4.08	.51	98.5	1.95
ARANEAE	16.67	.89	.18	17.6	.35
CUMELLA SP.	14.29	23.98	.25	346.1	6.86
HYMENOPTERA	11.90	1.02	.03	12.5	.25
INSECTA	9.52	1.28	.03	12.5	.25
NEMATOCERA	7.14	.51	.00	3.7	.07
HEMIPTERA	7.14	.38	.06	3.2	.06
CICADELLIDAE	7.14	.38	.04	3.0	.06
MYSIDAE	7.14	.38	.51	7.1	.14
COLEOPTERA	7.14	.64	.32	6.8	.14
COROPHIUM SP.	7.14	.51	.03	3.9	.08
INSECTA-LEPIDOPTERA	4.76	.26	1.20	6.9	.14
PLANTS AND PLANT PARTS	4.76	2.68	.88	17.0	.34
UNIDENTIFIED ALGAE	4.76	.26	3.26	16.8	.33
NEOMYSIS MERCEDIS	2.38	.26	1.10	3.2	.06
CLUPEA HARENGUS PALLASI	2.38	.13	12.52	30.1	.60

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

	NUM.	GRAV.	IRI
PERCENT DOMINANCE INDEX	.18	.33	.29
SHANNON-WEINER DIVERSITY	3.20	2.29	2.45
EVENNESS INDEX	.62	.44	.47

Fig. 8-6. Index of Relative Importance (IRI) plot and table for juvenile chinook salmon caught in the neritic habitat at Moon Island, Grays Harbor, Washington, March-June 1980.

prey availability (composition and relative density) cannot be considered exactly comparable between stomach samples collected with the two gears. The probable time required for gastric evacuation (~8 hr) of the stomach contents (Healey 1979), however, is longer than the period of one tide stage (~6 hr), implying that the occurrence of significant feeding in neritic habitats by small chinook and vice versa should be evident in the prey spectra.

The ranking of important (based upon the percentage of total IRI) prey taxa of juvenile chinook captured in shallow sublittoral and lower littoral habitats changed dramatically over the period of sampling in the estuary (Fig. 8-7), perhaps reflecting fluctuations in prey availability. Feeding between early and mid-April emphasized drift insects and cumaceans (*Leucon* sp.); gammarid amphipods (*Corophium salmonis* and *C. spinicorne*) and mysids (*Neomysis* sp.) were prominent in late April; and drift insects and harpacticoid copepods dominated the prey spectra in mid-May. Between late May and mid-August, however, feeding became more specific as the cumacean *Cumella* sp. became the singularly most important prey taxa. After mid-August the predominant prey taxa in the spectra shifts with time from *Corophium* sp., *Cumella* sp. and aphids in late August to adult insects and ants in early September and to *Cumella* sp., unidentified insects and algae in late September. During early October juvenile chinook preyed upon unidentifiable fish (due to advanced stage of digestion) and sphaeromatid isopods. During the final sampling week (October 20-24) one chinook which had fed upon the isopod *Gnorimosphaeroma oregonenesis* and *C. spinicorne* was captured in the beach seine collections at Moon Island.

The biweekly sample sizes for juvenile chinook salmon captured in the neritic habitat at Moon Island by purse seine were not sufficient to provide a quantitative analysis of the changes in prey spectra over the sampling period.

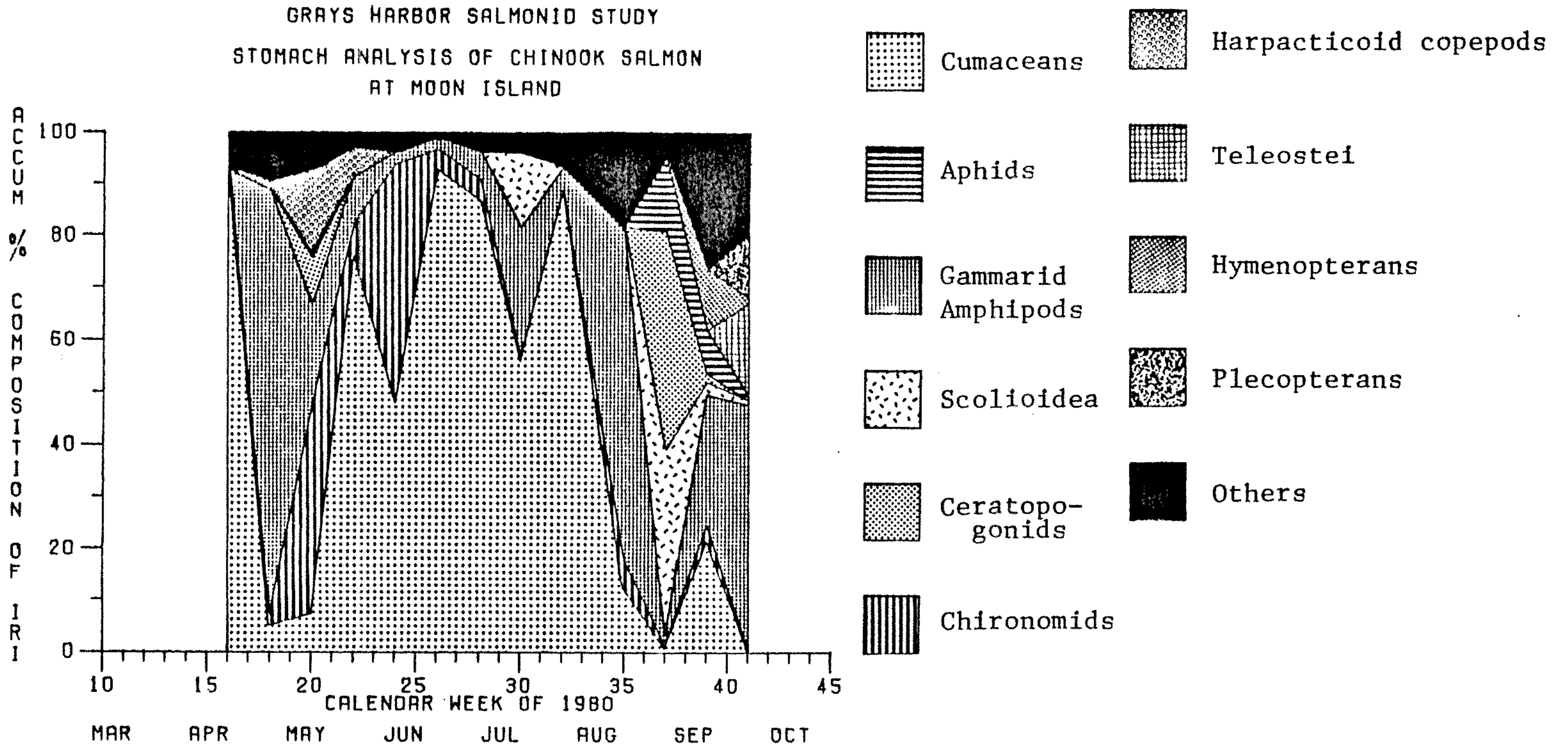


Fig. 8-7. Temporal composition (percent of total IRI) of diet spectra of juvenile chinook salmon captured in shallow sublittoral and lower littoral habitat at Moon Island, Grays Harbor, Washington, March-October, 1980.

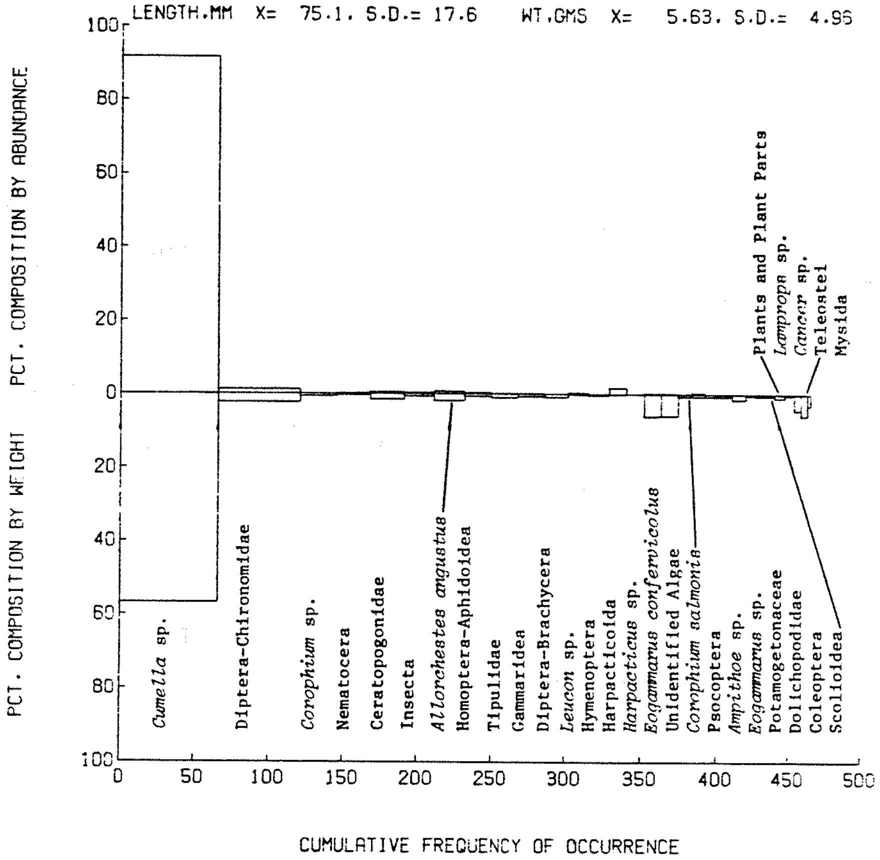
Juvenile chinook captured in the beach seine at Stearn's Bluff were comparable in size to those at Moon Island (Table 8-1) where the overall prey spectrum was similarly predominated by *Cumella* sp. (Fig. 8-8) (93.3% of the total IRI, as compared to 83.1% at Moon Island). Adult (drift) insects were fed upon less at Stearn's Bluff (ants, 0.03%; chironomids, 1.9%) than at Moon Island, where *Corophium* spp. (1.2%, including 1.1% *C. spinicorne*) and ceratopogonids (biting midges, 1.6%) were somewhat more important.

8.3.3 *Coho Salmon*: Unlike juvenile chinook, there appeared to be no separation in either size composition or prey spectra of juvenile coho salmon in Grays Harbor. Coho of uniform sizes were caught in shallow sublittoral and lower littoral as well as neritic habitats (Table 8-1). Their respective prey spectra (Figs. 8-9 to 8-11) were also similar among sites and between habitats (littoral vs shallow sublittoral). In all cases, neritic larvae of *Cancer* sp. crabs formed approximately half (51.8% in Moon Island beach seine catches; 54.5% in Moon Island purse seine catches; 49.5% in Stearn's Bluff beach seine catches) of the total IRI spectra. Epibenthic gammarid amphipods typically formed the remaining half of the prey spectra, although the proportional representations of the different species varied by site. *Corophium salmonis* and *C. spinicorne* were prominent at Moon Island, with *Eogammarus confervicolus* and the isopod *Gnorimosphaeroma oregonensis* (in beach seine-caught fish) being of secondary importance. Gammarid amphipod species which are typically more marine species, however, had functionally replaced the *Corophium* spp. in the prey spectra of coho collected at Stearn's Bluff. These included *Eogammarus oclairi*, *E. confervicolus*, *Eohaustorius washingtonianus* and *Allorchestes angustus*, which together composed over 35% of the total IRI.

The comparability of the prey spectra in the different habitats and the different sites in the estuary suggest that juvenile coho (at least of that limited size range) prey selectively upon the larger component of the prey available in the habitat in which they occur. Coho appear

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. ALLBS. STATION STRNS

PREDATOR 8755010206 - ONCORHYNCHUS TSHAWYTSCHA
(CHINOOK SALMON) ADJUSTED SAMPLE SIZE = 44
LENGTH.MM X= 75.1. S.D.= 17.6 WT.GMS X= 5.63. S.D.= 4.95

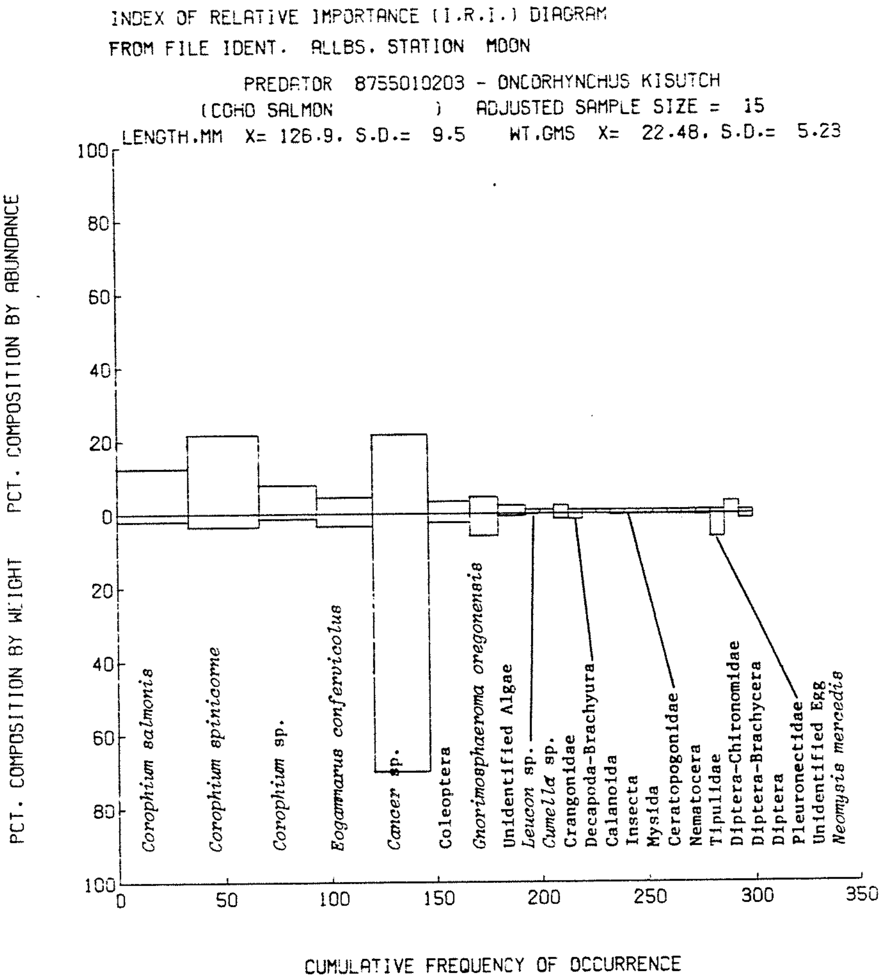


PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
CUMELLA SP.	65.91	91.67	56.70	9776.8	93.34
DIPTERA-CHIRONOMIDAE	29.55	1.24	2.26	190.6	1.82
COROPHIUM SP.	25.00	.15	.65	20.0	.19
NEMATOCERA	22.73	.22	.23	10.1	.10
CERATOPOGONIDAE	22.73	.58	1.47	46.6	.44
INSECTA	20.45	.33	.65	20.1	.19
ALLORCHESTES ANGUSTUS	20.45	.66	1.78	50.4	.48
HOMOPTERA-APHIDOIDEA	18.18	.41	.69	20.0	.19
TIPULIDAE	18.18	.19	.93	20.4	.19
GAMMARIDEA	18.18	.21	.51	13.0	.12
DIPTERA-BRACHYCERA	15.91	.10	.80	14.4	.14
LEUCON SP.	13.64	.40	.15	7.4	.07
HYMENOPTERA	13.64	.09	.32	5.6	.05
HARPACTICOIDA	11.36	1.82	.09	21.6	.21
HARPACTICUS SP.	11.36	.09	.03	1.4	.01
EOGAMMARUS CONFERVICOLUS	11.36	.21	5.06	60.9	.66
UNIDENTIFIED ALGAE	11.36	.22	5.80	68.4	.65
COROPHIUM SALMONIS	9.09	.06	.61	6.1	.06
PSOCOPTERA	9.09	.32	.56	8.0	.08
AMPITHOE SP.	9.09	.09	.67	6.9	.07
EOGAMMARUS SP.	9.09	.08	.56	5.8	.06
POTAMOGETONACEAE	9.09	.09	1.40	13.6	.13
DOLICHOPODIDAE	6.82	.04	.24	1.9	.02
COLEOPTERA	6.82	.04	.43	3.2	.03
SCOLIOIDEA	6.82	.04	.45	3.2	.03
PLANTS AND PLANT PARTS	6.82	.12	.92	7.0	.07
LAMPROPS SP.	6.82	.12	.19	2.1	.02
CANCER SP.	4.55	.03	4.33	19.8	.19
TELEOSTEI	4.55	.03	5.00	20.5	.25
MYSIDA	2.27	.02	3.11	7.1	.07

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX		.84	.34		.67
SHANNON-WEINER DIVERSITY		.76	2.61		.62
EVENNESS INDEX		.14	.20		.11

Fig. 8-8. Index of Relative Importance (IRI) plot and table for juvenile chinook salmon captured in the shallow sublittoral and lower littoral habitat at Stearn's Bluff, Grays Harbor, Washington, March-October 1980.



PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
COROPHIUM SALMONIS	33.33	12.50	1.85	476.2	10.14
COROPHIUM SPINICORNE	33.33	21.59	3.47	832.0	17.64
COROPHIUM SP.	26.67	7.95	1.29	246.6	5.23
EOGAMMARUS CONFERVICOLUS	26.67	4.55	3.21	206.8	4.36
CANCER SP.	26.67	21.59	69.96	2441.2	51.76
COLEOPTERA	20.00	3.41	2.17	111.5	2.36
GNORIMOSPHAEROMA OREGONENSIS	13.33	4.55	6.02	140.8	2.99
UNIDENTIFIED ALGAE	13.33	2.27	.64	38.9	.82
LEUCON SP.	6.67	1.14	.06	8.1	.17
CUMELLA SP.	6.67	1.14	.01	7.6	.16
CRANGONIDAE	6.67	2.27	1.26	23.7	.50
DECAPODA-BRACHYURA	6.67	1.14	1.44	17.2	.36
CALANOIDA	6.67	1.14	.01	7.6	.16
INSECTA	6.67	1.14	.01	7.6	.16
MYSIDA	6.67	1.14	.32	9.7	.21
CERATOPOGONIDAE	6.67	1.14	.06	8.1	.17
NEMATOCERA	6.67	1.14	.06	8.1	.17
TIPULIDAE	6.67	1.14	.16	8.6	.18
DIPTERA-CHIRONOMIDAE	6.67	1.14	.06	8.1	.17
DIPTERA-BRACHYCERA	6.67	1.14	.16	8.6	.18
DIPTERA	6.67	1.14	.32	9.7	.21
PLEURONECTIDAE	6.67	1.14	6.26	49.3	1.05
UNIDENTIFIED EGG	6.67	3.41	.01	22.8	.48
NEOMYSIS MERCEDIS	6.67	1.14	1.20	15.6	.33

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX	.12	.50		.32
SHANNON-WEINER DIVERSITY	3.63	1.90		2.40
EVENNESS INDEX	.79	.41		.52

Fig. 8-9. Index of Relative Importance (IRI) plot and table for juvenile coho salmon captured in the shallow sublittoral and littoral habitat at Moon Island, Grays Harbor, Washington, March-October 1980.

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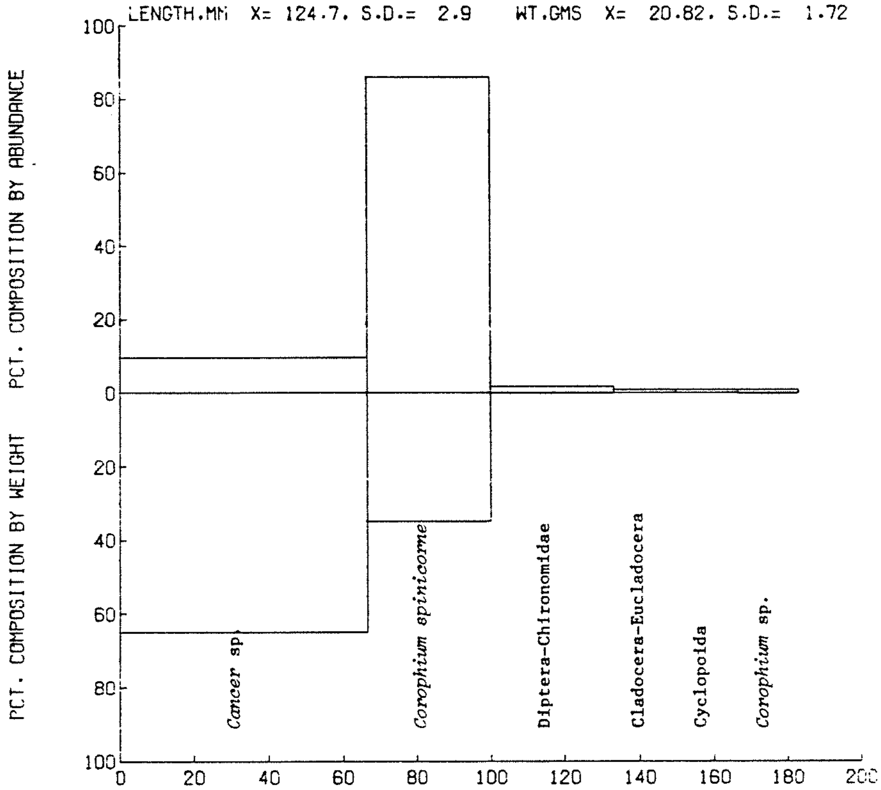
INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. ALLPS. STATION MOON
            PREDATOR 8755010203 - ONCORHYNCHUS KISUTCH
          (COHO SALMON          ) ADJUSTED SAMPLE SIZE =  6
LENGTH.MM  X= 124.7. S.D.= 2.9    WT.GMS  X= 20.82. S.D.= 1.72
```



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                        CUMULATIVE FREQUENCY OF OCCURRENCE

                                   FREQ    NUM.   GRAV.   PREY     PERCENT
        PREY ITEM                  OCCUR   COMP.  COMP.   I.R.I.   TOTAL IRI
  ---------------------------      -----   -----  -----   ------   ---------

 CANCER SP.                        66.67    9.57  64.84   4960.2     54.50
 COROPHIUM SPINICORNE              33.33   86.09  34.84   4030.8     44.29
 DIPTERA-CHIRONOMIDAE              33.33    1.74    .16     63.2       .69
 CLADOCERA-EUCLADOCERA             16.67     .87    .01     14.7       .16
 CYCLOPOIDA                        16.67     .87    .01     14.7       .16
 COROPHIUM SP.                     16.67     .87    .14     16.9       .19

   PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
   COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
   (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

      PERCENT DOMINANCE INDEX              .75    .54                .49
      SHANNON-WEINER DIVERSITY             .79    .97               1.09
      EVENNESS INDEX                       .31    .37                .42
```
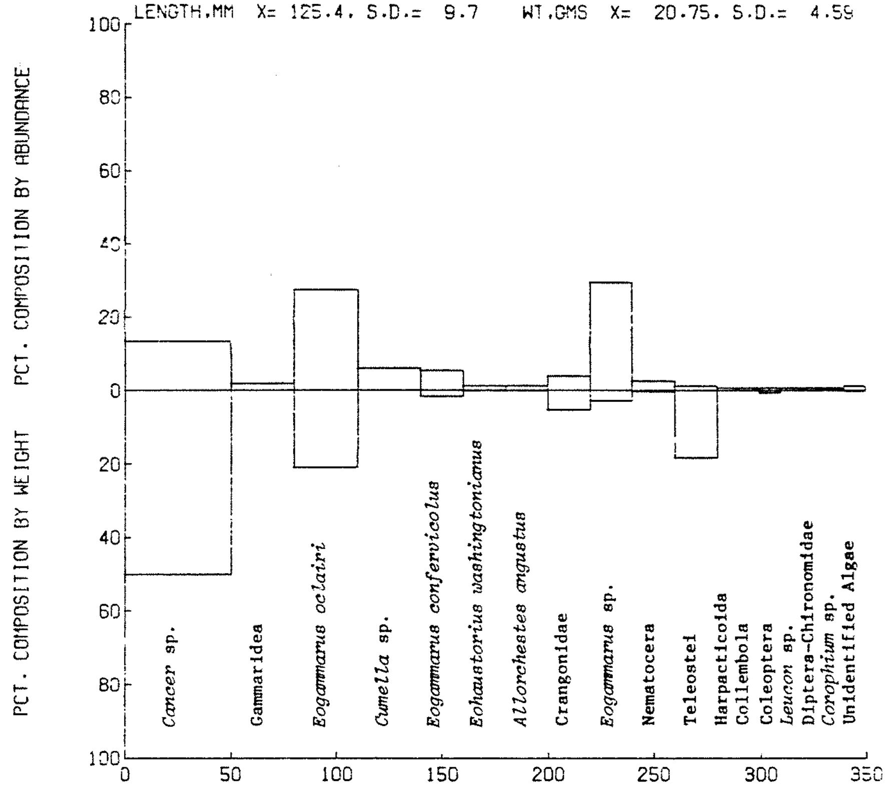

Fig. 8-10. Index of Relative Importance (IRI) plot and table for juvenile coho salmon captured in the neritic habitat at Moon Island, Grays Harbor, Washington, March-October 1980.

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. ALLBS, STATION STRNS

PREDATOR 8755010203 - ONCORHYNCHUS KISUTCH
(COHO SALMON) ADJUSTED SAMPLE SIZE = 10
LENGTH,MM X= 125.4, S.D.= 9.7 WT,GMS X= 20.75, S.D.= 4.59



CUMULATIVE FREQUENCY OF OCCURRENCE

PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
CANCER SP.	50.00	13.42	49.99	3170.8	49.48
GAMMARIDEA	30.00	2.01	.02	61.0	.95
EOGAMMARUS OCLAIRI	30.00	27.52	20.91	1452.7	22.67
CUMELLA SP.	30.00	6.04	.02	181.8	2.84
EOGAMMARUS CONFERVICOLUS	20.00	5.37	1.52	137.7	2.15
EOHAUSTORIUS WASHINGTONIANUS	20.00	1.34	.13	29.5	.46
ALLORCHESTES ANGUSTUS	20.00	1.34	.14	29.6	.46
CRANGONIDAE	20.00	4.03	5.34	187.4	2.92
EOGAMMARUS SP.	20.00	29.53	2.70	644.7	10.06
NEMATOCERA	20.00	2.68	.33	60.3	.94
TELEOSTEI	20.00	1.34	16.27	392.2	6.12
HARPACTICOIDA	10.00	.67	.01	6.8	.11
COLLEMBOLA	10.00	.67	.01	6.8	.11
COLEOPTERA	10.00	.67	.53	12.0	.19
LEUCON SP.	10.00	.67	.01	6.8	.11
DIPTERA-CHIRONOMIDAE	10.00	.67	.01	6.8	.11
COROPHIUM SP.	10.00	.67	.01	6.8	.11
UNIDENTIFIED ALGAE	10.00	1.34	.07	14.1	.22

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

	NUM. COMP.	GRAV. COMP.	PERCENT TOTAL IRI
PERCENT DOMINANCE INDEX	.19	.33	.31
SHANNON-WEINER DIVERSITY	2.96	1.99	2.27
EVENNESS INDEX	.71	.48	.54

Fig. 8-11. Index of Relative Importance (IRI) plot and table for juvenile coho salmon captured in the shallow sublittoral and lower littoral habitat at Stearn's Bluff, Grays Harbor, Washington, March-October 1980.

to forage in both neritic as well as shallow sublittoral and lower littoral habitats, perhaps in association with tidal rhythms.

8.3.4 English Sole: Overall, juvenile English sole occupying the shallow sublittoral and lower littoral habitat at Moon Island appeared to have relatively less food in their stomachs than did the juvenile salmonids; the stomachs were, on the average, only 25% full and less than 50% of the contents was identifiable (Table 8-1). The mean ratio of contents weight to total body weight was similarly lower than was documented for the juvenile salmonids. Unfortunately, the sampling design did not allow the examination of the possible factors attributing to this value, e.g. tidal stage (beach seining was always conducted at low tide) or time of day, or if it was representative of the actual foraging period.

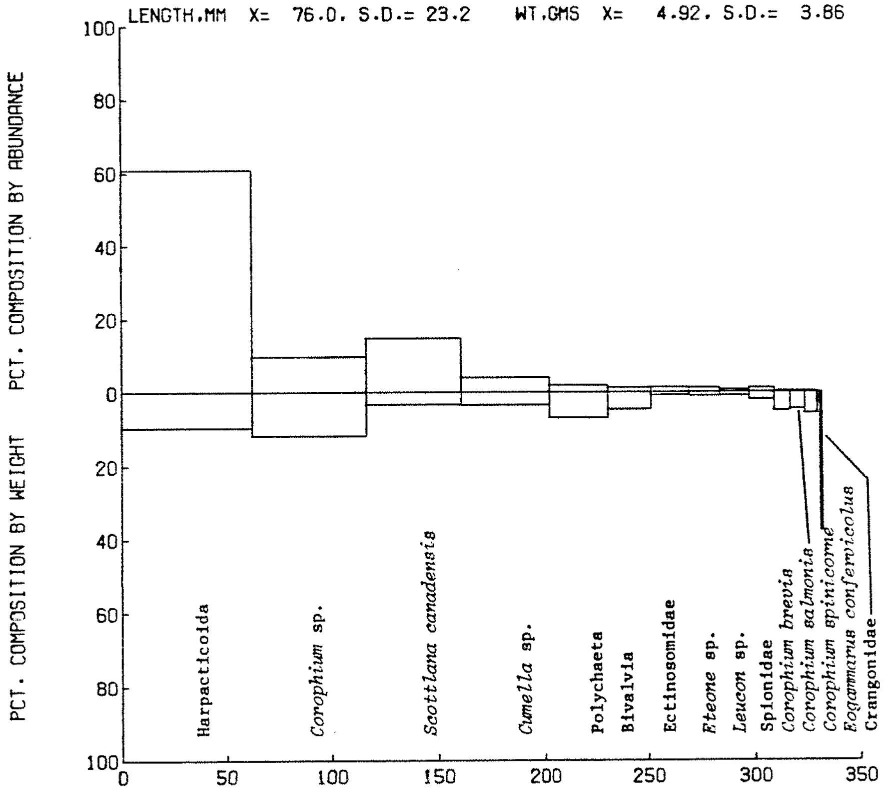
Harpacticoid copepods, especially the large harpacticoid Scottolana canadensis, were the primary prey taxa, composing 59.9% of the total IRI; Corophium spp. amphipods (10.9%) and Cumella sp. cumaceans (4.3%) were of secondary importance (Fig. 8-12).

Changes in the composition of the prey spectra with time of the sampling period appeared to illustrate diversification in foraging behavior with increasing size of fish, although prey availability cannot be excluded as an additional factor. The prominent prey taxa in early April through late May were harpacticoid copepods, with the exception of late April, when Corophium spp. amphipods appeared prominently in the prey spectrum (Fig. 8-13). Over this time period the total length of the English sole ranged from 19 mm to 65 mm.

Between mid-June and mid-July, when the size of the English sole was between 53 mm and 100 mm, harpacticoids were slightly less prominent components of the prey spectrum while Corophium spp. and Cumella sp. were conspicuous in mid-June, Scottolana canadensis in late June, and both S. canadensis and Corophium spp. in early July. As the juvenile

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. ALLBS . STATION MOON

PREDATOR 8857041301 - PAROPHRYS VETULUS
(ENGLISH SOLE) ADJUSTED SAMPLE SIZE = 120
LENGTH,MM X= 76.0, S.D.= 23.2 WT,GMS X= 4.92, S.D.= 3.86



CUMULATIVE FREQUENCY OF OCCURRENCE

PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
HARPACTICOIDA	62.50	60.79	9.57	4397.6	59.94
COROPHIUM SP.	54.17	9.74	11.84	1168.4	15.93
SCOTTOLANA CANADENSIS	44.17	14.81	3.29	799.6	10.90
CUMELLA SP.	41.67	4.15	3.49	318.2	4.34
POLYCHAETA	28.33	1.89	7.01	252.4	3.44
BIVALVIA	20.83	1.23	4.55	120.6	1.64
ECTINOSOMIDAE	18.33	1.41	.73	39.3	.54
ETEONE SP.	14.17	1.26	.86	30.1	.41
LEUCON SP.	14.17	.69	.85	22.0	.30
SPIONIDAE	11.67	1.35	1.99	39.0	.53
COROPHIUM BREVIS	7.50	.46	4.99	41.0	.56
COROPHIUM SALMONIS	6.67	.33	4.45	31.9	.43
COROPHIUM SPINICORNE	5.83	.39	5.65	35.2	.48
EOGAMMARUS CONFERVICOLUS	1.67	.05	1.35	2.4	.03
CRANGONIDAE	.83	.03	37.57	31.3	.43

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

	NUM. COMP.	GRAV. COMP.	PERCENT TOTAL IRI
PERCENT DOMINANCE INDEX	.40	.16	.40
SHANNON-WEINER DIVERSITY	2.06	3.20	1.98
EVENNESS INDEX	.43	.66	.41

Fig. 8-12. Index of Relative Importance (IRI) plot and table for juvenile English sole captured in the shallow sublittoral and lower littoral habitat at Moon Island, Grays Harbor, Washington,

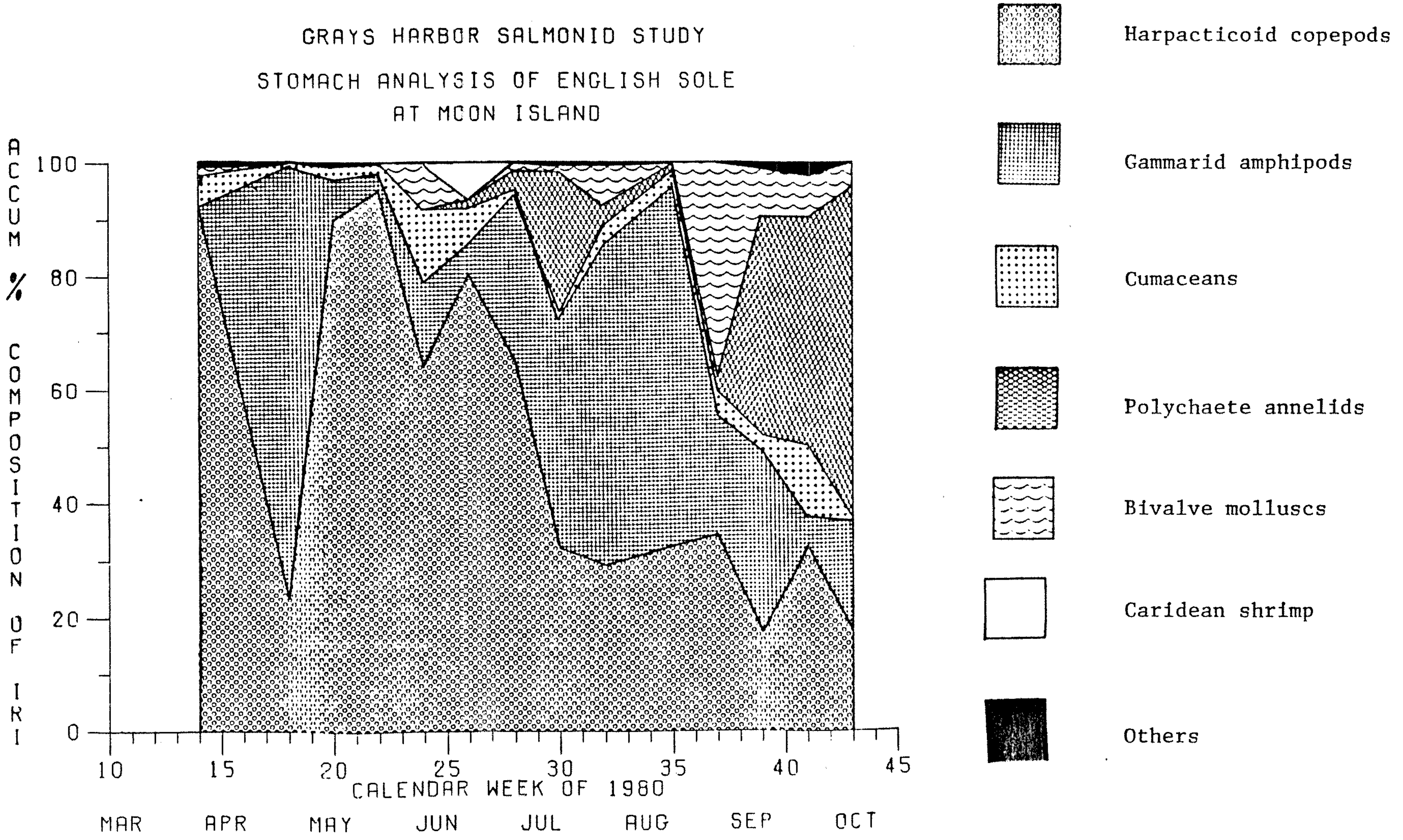


Fig. 8-13. Temporal composition (percent of total IRI) of diet spectra of juvenile English sole captured in shallow sublittoral and lower littoral habitat at Moon Island, Grays Harbor, Washington, March-October 1980.

sole grew greater than 60 mm total length, the proportional contribution by harpacticoids declined further (except for the large Scottolana canadensis) and the diet began to include more secondary prey taxa such as Corophium spp., polychaetes, and bivalves. Juvenile English sole collected from late September through late October, including fish as large as 120 mm total length, indicated the greatest diversity in prey spectra. Polychaetes had, by this time, superceded harpacticoids in importance and bivalves, polychaetes, and cumaceans appeared as important components of the prey spectra at various times.

8.3.5 Cutthroat Trout: Juvenile cutthroat trout were caught in both shallow sublittoral and lower littoral and neritic habitats (Table 8-1). Speciments were on the whole larger than other salmonids, including a wide range in fish sizes. Although the sample size (five) was insufficient to make generalizations concerning the diet, the principal prey of the four fish with analyzable stomach contents included pelagic larvae of Cancer sp. crabs (44% of the total IRI), and juvenile osmerids (smelt, 34.4%). The secondary prey were fish and included juvenile salmonids (8.3%), unidentifiable fish (7.9%) and hexagrammids (greenlings, 5.1%).

8.3.6 Steelhead Trout: Juvenile steelhead (also including a low sample size) had primarily consumed fish (67.9% of total IRI). Most of these were unidentifiable due to the advanced stage of digestion. Crustacean prey organisms included Crangon sp. shrimp (7.9%) and Cancer sp. larvae (1.3%); the epibenthic and infaunal amphipod Corophium sp. was also present in the stomach contents to a lesser degree (2.2%). Adult (drift) insects were also found in the stomach contents and included tricopterans (caddis flies, 3.3%), hemipterans (true bugs, 1.2%) and brachyceran diptera (true flies, 1.2%).

8.3.7 Dolly Varden: One dolly varden was captured in a beach seine sample at Cow Point (Table 8-1); it had consumed only fish, which were unidentifiable due to the advanced stage of digestion.

8.4 Discussion

8.4.1 Prominent Prey Resources of Juvenile Salmonids and English Sole:

Prey spectra of juvenile salmonids in Grays Harbor indicated the same general patterns in feeding ecology exhibited in estuaries and nearshore marine habitats in Puget Sound (Congleton 1979; Fresh et al. 1979; Meyer et al. 1981; Simenstad et al. 1979, 1980; Stober and Salo 1973), British Columbia (Anderson et al. 1980; Healey 1979, 1980; Levy et al. 1979; Levy and Levings 1978; Levy and Northcote 1981; Mason 1974; Sibert et al. 1977), the Columbia River (Sims 1974; Durkin et al. 1979; Durkin and Lipovsky 1977) and coastal Oregon (Reimers 1970). As a general rule, juvenile salmonids feed upon epibenthic crustaceans upon their initial entry into estuaries and, with growth or larger initial size, convert to neritic zooplankton during their residency in the estuary. Some species, such as chum salmon, may never leave the shallow sublittoral habitats while they are less than approximately 55-60 mm FL in size and are completely dependent upon epibenthic crustaceans. And, while they may be much larger, some species such as chinook salmon may forage on both epibenthic fauna in shallow sublittoral habitats and pelagic or drift animals in neritic habitats. In most estuarine systems, however, the juvenile salmonids illustrate relatively divergent prey spectra; only in the case of juvenile pink and chum salmon feeding in neritic habitats has there been indications of high prey overlap (Simenstad et al. 1980).

The specific prey animals within the general epibenthic and neritic zooplankton prey categories do vary, principally as a function of variations in the respective zooplankton communities common to each estuary. One of the obvious contrasts of juvenile salmonid prey spectra in Grays Harbor as compared to other systems was the prominence of the cumacean *Cumella* sp., whereas epibenthic-feeding chum and chinook salmon in the Columbia, Sixes, Fraser, and Skagit Rivers estuaries were more dependent upon epibenthic gammarid amphipods such as *Corophium* spp., *Anisogammarus pugettensis*, and *Eogammarus confervicolus*.

Similarly, while harpacticoid copepods are the predominant prey of juvenile chum salmon <55-60 mm FL in almost all estuaries throughout the region, the specific harpacticoids fed upon tend to vary between systems; Harpacticus uniremis was the principal prey of chums feeding in the Nanaimo River estuary (Sibert 1979); Harpacticus sp. appeared to be prominent in the stomach contents of outmigrating chums in Hood Canal; and Scottolana canadensis may be the principal harpacticoid prey species of chums in the Columbia River estuary (Simenstad, unpubl.). In all cases, however, these harpacticoids tend to be the largest, most conspicuous epibenthic species in the community the fish are feeding upon.

Thus, the feeding behavior of the juvenile salmonids would appear to be regulated in part by the size distributions of prey required by particular size stanzas of the fish. This appears to be accommodated, however, by certain habitat requirements. Although we have no information on the causal mechanisms, the fishes' foraging may be constrained to a particular habitat, i.e., shallow sublittoral and lower littoral habitats for juvenile chum salmon greater than 50 mm FL in size. Protection from predation is one of the factors which has been postulated for the early occupation of shallow habitats. Given the apparent requirement for abundant, small zooplanktonic prey, small juvenile salmonids may preferentially exploit shallow sublittoral environments because of the high densities of epibenthic zooplankton available there (Simenstad et al. 1980; Section 7.0, this report). It remains to be illustrated, on the other hand, why the often dense communities of neritic zooplankton are not suitable prey.

8.4.2 Significance of Spatial (by Site) or Temporal Shifts in Dominant Prey Taxa: It is apparent that shallow sublittoral habitats provide (apparent) requisite feeding habitat for several species and size stanzas of juvenile salmonids migrating through or residing in Grays Harbor. Comparisons of the relative importance of different habitats in the different estuarine zones of Grays Harbor are difficult, as food habits data are available only for Moon Island and, to a lesser extent, Stearn's Bluff. The shallow sublittoral and lower littoral habitat at Moon Island is relatively narrow and of steeper gradient and current exposure than that at Stearn's Bluff and much of the similar habitat in the estuary, i.e., the South Channel area. Despite these differences, the prey spectra of juvenile salmonids feeding at the two sites were remarkably similar. Thus, the Moon Island area probably represents the first extensive epibenthic-feeding habitat which the migrating juvenile salmonids encounter as they move into the estuary and that this habitat forms a continuum into the lower estuary, where the total area of shallow sublittoral habitat of that type is much more expansive. The size frequency distributions of most of the juvenile salmonids except chinook (Section 3) implied that the majority of residency and feeding was occurring in the lower estuary; chinook salmon, however, illustrated growth over time at Moon Island, some of which could be accounted for by residency within that area. It may be that the availability of epibenthic-feeding habitat at Moon Island is sufficient to maintain a "resident" population of juvenile chinook, although the proximity to terrestrial sources of drift insects, also important prey organisms, may also account for the occupation of the upper estuarine habitats by juvenile chinook salmon through the sampling period. The lack of comparable data from the stomach contents of chinook feeding in other areas of the estuary prevents us from further evaluating the overall importance of these habitats or zones of the estuary.

8.5 Summary

1. Quantitative analyses of stomach contents were performed upon selected subsamples of juvenile salmonids and English sole captured in shallow sublittoral and lower littoral habitats using a 37-m floating beach seine and in neritic habitats using a 7-m x 63-m purse seine in Grays Harbor over the eight-month period from March through October 1980.

2. The fish illustrated distinctly divergent prey spectra in most cases and their diets were typically associated with the predominant epibenthic or neritic habitats in which they were caught. Fishes occupying nearshore habitats fed predominantly upon epibenthic crustaceans, primarily harpacticoid copepods, cumaceans and various species of gammarid amphipods. Salmonids captured in neritic habitats tended to be somewhat larger and fed upon more pelagic prey such as larval fish (particularly the larvae of northern anchovy) and adult (drift) insects.

3. Chum salmon: Juvenile chum salmon captured in shallow sublittoral and lower littoral habitats preyed predominantly upon harpacticoid copepods between early March and mid-April and cumaceans in late April. Larger chum fed upon fish larvae and insects. When captured in neritic habitats the larger chum consumed larval anchovies and drift insects, although harpacticoid copepods persisted to some degree in their prey spectra. Chum captured at Stearn's Bluff with the beach seine were comparable in size to those captured in similar collections at Moon Island, but had consumed almost twice as many prey items per fish; the prey spectra were very similar, however.

4. Chinook salmon: At the Moon Island site juvenile chinook salmon captured in the shallow sublittoral and lower littoral habitat fed upon epibenthic crustaceans, particularly the cumacean <u>Cumella</u> sp., with minor emphasis upon adult (drift) insects such a chironomids (midges) and ants. The rank importances (based upon the percentage of the total IRI) of different prey taxa changed dramatically with time, suggesting fluctuations in prey availability; <u>Cumella</u> sp., however, dominated the prey spectra between late May and mid-August. Chinook salmon smolts captured in neritic habitats tended to be some 20 mm FL larger than those captured in the shallower habitats and fed primarily upon larval anchovies and drift insects such as adult

chironomids, psocids, aphids and ants. This dramatic difference in prey composition of these fish found in the two different habitats may be related to their difference in size and consequent differential prey requirements or feeding behavior.

5. Coho salmon: Specimens of coho salmon smolts were somewhat unique in that they were of uniform size ranges in both habitats. Prey composition was correspondingly similar in fish collected in both habitats. Cancer sp. crab larvae composed approximately half of the total IRI spectra and gammarids the remaining half. This indicates coincident utilization of both shallow sublittoral and lower littoral and neritic habitats, perhaps simply as a function of tidal stage.

6. English sole: Juvenile English sole captured in the shallow sublittoral and lower littoral habitat at Moon Island typically contained less food (based on percent of total body weight) in their stomachs than did juvenile salmonids. Harpacticoid copepods were the major prey taxa, followed by Corophium sp. amphipods and Cumella sp. The change in prey composition with time over the eight-month sampling period indicated an increasing diversification of foraging behavior due possibly to increased size and/or prey availability. As the English sole grew larger the predominant prey taxa fluctuated among harpacticoids, Corophium spp., polychaetes and bivalves, with the latter becoming more important with time.

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9.0 SUMMARY OF THE DYNAMICS OF JUVENILE SALMON OUTMIGRATION, ENGLISH SOLE AND BAITFISH UTILIZATION OF GRAYS HARBOR AND PREY RESOURCE DISTRIBUTION AND STANDING STOCK

By Charles A. Simenstad and Douglas M. Eggers

9.1 Introduction

As described in Section 1.2, the objective of the FRI studies in Grays Harbor was to examine factors affecting migration rate, residence time, behavior and feeding ecology of juvenile salmonids, English sole and baitfish in the estuary and postulate the impact of dredging and habitat removal or modification upon these relationships. The following discussion addresses the principal mechanisms that account for deleterious impacts upon these marine and estuarine fish resources.

9.2 Outmigration of Juvenile Salmonids through Grays Harbor

9.2.1 Rates and Patterns of Outmigration--Relationships to Environmental and Trophic Conditions in the Estuary: The timing of juvenile salmonid entry into Grays Harbor was variable according to species. Juvenile chums entered in mid- to late January, juvenile coho and fall chinook entered in mid-April and steelhead trout entered the estuary in May. The pattern of habitat utilization and residence time within the estuary was similarly variable. Chum and coho outmigrants showed rather short- term residency. Chum resided principally in shallow sublittoral (i.e., nearshore less than 2 m deep) habitats for two to four weeks while coho had a relatively ubiquitous distribution in both shallow sublittoral and neritic (i.e., open water) habitats during their four to eight week residency. Juvenile steelhead occupied the estuary for a slightly longer period, on the order of three months. Juvenile chinook showed two patterns of estuarine utilization. Like chum salmon, the greatest proportion of the population migrated out of the estuary within 3 months. The remainder continued to reside within the estuary through the end of the sampling period in mid-October. Chinook occupied shallow sublittoral habitats to some extent throughout their residency, but tended to be found in the estuary's neritic habitats later in the periods of residence. The size of the fish occupying shallow habitats was less than the size of fish occupying neritic habitats.

Entry of these different species and populations into the estuary could be related to any one or more of the following factors:

1) spawning time of adults; life history patterns of species,
2) waterflow and temperature regimes in natal rivers,
3) densities of cohorts and other salmonids in rivers,
4) availability of food resources in rivers, and
5) hatchery releases of juvenile salmonids.

Chum salmon emigrate out of riverine systems almost immediately after emergence from spawning beds. The other species, however, have some degree of riverine residence. Wright (1973), Brix (1974) and Brix et al. (1974) have shown that chinook (0+) and coho salmon (0+,1+) and steelhead trout juveniles (0+,1+,2+) all rear in the Chehalis, Wynoochee, Satsop, and Humptulips Rivers for varying periods of time. Chinook are generally present from mid-March through late July, and even through August in the Humptulips River; underyearling (i.e., 0+) coho reside in the Satsop River between April and July but have been caught in the Humptulips River into October. It would appear, therefore, that high riverflows typically present in March and April (Fig. 2-1) do not have the effect of flushing juvenile chinook and coho out of the river systems. Coho and chinook juveniles appeared to emigrate during periods of low flow and increasing temperature during July and August, although they may also be less susceptible to capture by beach seine at this time. Emigration may be in response to declining amounts of available rearing habitat, depending upon the size of initial fry populations, or a physiological response to higher temperature or increasing body size.

The density-size distributions of the two species in freshwater also affect the degree of interspecific competition and pressure for emigration. Brix (1974) noted that newly emergent chinook fry were typically associated with slow to moderate flows at the base of riffle sections or on the edges of gravel bars but moved into riffle areas with higher flow rates as the fish grew larger; underyearling coho, on the other hand, tended to be associated with slow flows and the edges of gravel bars as fry and long, slow, deep stretches with increased size. The introduction and size composition of hatchery-reared fish also will influence the emigration timing, as larger chinook have been shown to emigrate much more rapidly than smaller fish. There is no information available regarding the production and availability of freshwater prey resources during these periods of residence in the rivers. We therefore do not know if declining prey and spatial resources resulting from hatchery releases are affecting the rate and timing of emigration of chinook and coho juveniles into Grays Harbor.

Residence in Grays Harbor, however, may be related more to biotic conditions than physical parameters such as space and temperature. Grays Harbor represents prime rearing habitat for juvenile salmonids because of the abundance of small zooplanktonic prey suitable for ingestion by small fish and the refuge from predators. Juvenile salmonids are extremely vulnerable to predation in view of the large number and variety of fish, birds and marine mammals that can potentially consume small fish. Grays Harbor is a highly turbid environment, resulting from great influx of sediment-bearing freshwater and turbulence at the sediment-water interface, particularly in the outer harbor where waves from the open ocean penetrate the estuary. The distance at which visually feeding predators can see prey is greatly reduced in such turbid situations (Vinyard and O'Brien 1976), therefore small fish are less vulnerable in the turbid estuary than in the open ocean or coastal waters.

The results of the food habits portion of this study (Section 8.0) illustrated that epibenthic zooplankton, allochthonous terrestrial insects and only the largest neritic prey (decapod larvae and northern anchovy larvae) were consumed by the juvenile salmonids (i.e., chum, chinook, and coho). Such turbid environments, while offering refuge from piscivore predation, require higher ambient concentrations, or larger sizes or prey relative to less turbid environment to maintain comparable rates of prey ingestion. The range of density and standing crop of epibenthic zooplankton at Moon Island was 6,800 to 132,000 organisms m^{-3} and 281 to 565 mg m^{-3}, respectively; the range in mean density and standing crop of neritic zooplankton, in comparison, was 43 to 904 organisms m^{-3} and 7 to 225 mg m^{-3}, respectively. This illustrates that during the limited period of sampling the numerical availability of epibenthic prey was greater than neritic prey, although the generally larger biomass of the neritic zooplankters accounted for the similar magnitude in standing crop. This density-size contrast is reflected in the prey spectra for those salmonids, especially juvenile chinook, that grow during their period of residence in the estuary. As small individuals the salmonids tended to reside in shallow sublittoral habitats feeding upon epibenthic zooplankton which are of appropriate sizes for consumption and in high densities. As they grew they began to utilize neritic habitats and their associated pelagic zooplanktonic prey which, as we have documented, were of larger size than the normal size distribution of neritic zooplankton.

In the case of juvenile chum salmon, however, residence time was relatively brief, especially for early outmigrating fish. As we only have prey community structure and standing stock data for May at Moon Island for this period, we cannot determine whether this brief residence time was associated with the availability of epibenthic zooplankton or an unaccountable behavioral response. Chum salmon are not generally known, however, to reside in estuaries, even nonturbid ones, for periods longer than two to four weeks (Mason 1974; Healey et al. 1976; Manzer 1956; Healey 1979; Levy et al. 1979; Levy and Northcote 1981; Salo et al. 1980) and are seldom caught at greater than 75-80 mm FL, comparable to their maximum sizes when emigrating Grays Harbor. Given the high potential rate of migration documented for juvenile chum salmon in Hood Canal (up to 14 km day^{-1}; Salo et al. 1980), it is apparent that juvenile chum migrating through Grays Harbor are foraging and rearing in shallow sublittoral habitats for as long a period as has been reported elsewhere.

Juvenile coho salmon had apparent residence times comparable to or slightly longer than chums, i.e., on the order of four to eight weeks. This is equivalent or longer than most reported residence times (Simms 1970; Sjolseth 1969) but may be less than in nearshore marine areas such as Puget Sound. Although epibenthic organisms were found in the prey spectra, neritic decapod larvae were the predominant prey of coho in the estuary. The results of the neritic zooplankton sampling suggest that these crab larvae are either not numerically abundant or are extremely patchy in their distribution, thus limiting the relative availability of such food resources to coho in the turbid waters of Grays Harbor. The general lack of growth of coho captured in Grays Harbor in our studies suggest that residence is brief and may be a result of these unpredictable prey resources.

Juvenile chinook migrating through and rearing in Grays Harbor illustrated variable periods of residence, with early migrants apparently migrating rapidly through the estuary and later migrants residing for longer periods, a small fraction remaining through October. Thus, residence times varied from just a few weeks to over four months. This variability is also evident in other studies. Simms (1970) reported relatively short residence times for chinook in the Columbia River estuary, i.e., 10-15 days in the spring and summer and 7-10 days later in the year. Miller et al. (1967) and Salo (1969) found that juvenile chinook released from the Soos Creek Hatchery spent at least two months in Elliott Bay but Sjolseth (1969) documented that similar hatchery-reared chinook resided in Bellingham Bay for only two weeks or less. Sibert (1975) and Healey (1980) described residence times of chinook in the Nanaimo River estuary as up to two months and 25 days, respectively.

Despite this apparent variability in residence time with estuary, the migration pattern of juvenile chinook in Grays Harbor is markedly similar to that found in the Sixes River estuary by Reimers (1973). In both systems the major component of the population leaves the estuary during the summer, with a smaller residual population staying until fall. In the Sixes River estuary, the first period of outmigration occurred in June rather than in August as it did in Grays Harbor.

The prey resources of juvenile chinook through the period of outmigration and residence until the late August decline were predominantly epibenthic organisms such as cumaceans, gammarid amphipods and chironomid larvae. Coincident with the decline in the estuarine chinook population was a shift in the prey spectra of the remaining fish from epibenthic organisms to neritic and drift organisms such as fish larvae, ants, aphids, and biting midges (Fig. 8-7). This may be the result of an innate preference for drift insects since drift insects have been reported to be prominent prey of juvenile chinook in other, more productive and less turbid regions in Puget Sound (Fresh et al. 1979; Simenstad et al. 1979). Alternatively, this shift from epibenthic to neritic (surface) may be in response to declining abundance of epibenthic prey. Unfortunately, we have only one sample of epibenthic organisms, at Moon Island in May, and have no indication of relative availability of prey to salmon, leading up to the emigration of the majority of the chinook out of Grays Harbor. The initiation of declining beach seine catches in July generally coincided with increasing purse seine catches, however. This suggests that there was a behavioral shift from shallow sublittoral habitats to neritic habitats prior to the major emigration of chinook from the estuary. This sequence of events infers that while epibenthic production of prey organisms was capable of sustaining a relatively high density of juvenile chinook in the estuary, once they had made a natural transition to neritic habitats the availability of prey organisms became limiting and emigration of the majority of the chinook was induced.

9.2.2 Possible Adverse Effects of Dredging and Adverse Water Quality: Dredging and the associated activities can potentially alter the production of juvenile salmonids in Grays Harbor through either direct reduction in the population (direct mortality) or indirectly through reduction of the carrying capacity (i.e., the amount of prey resource available to juvenile salmonids) of the estuary. The latter may evoke either a behavioral change in the outmigration or residence patterns of fish or in reduction or modification of the preferred habitat. Direct mortality of the salmonids as a result of dredging operations, either by intake into the dredge or release of toxic components into the water column (Sec. 3.3.4) has been discussed previously.

Avoidance of dredging activity or dredging water plumes was not documented in the course of these studies. Considering the high turbidities occurring naturally in the estuary, it is unlikely that additional loadings of suspended solids would alter salmonid behavior except in extreme cases, e.g., in the upper estuary during summer low flow periods (July-September). However, data in Loehr and Collias (1981, Fig. 3-29) indicated that turbidity in the upper estuary may be lowest during January-March, although river flow during that year (1976) was unusually low. Substantial concentrations of toxic or noxious compounds within the resuspended sediments could have the effect of altering the migration behavior within the local area of the plume with the likely response being avoidance of the contaminated area. If prolonged, this could effectively eliminate a portion of shallow sublittoral or neritic rearing habitat for utilization by juvenile salmonids. Barring contamination of the surface sediments and associated epibenthic zooplankton communities by toxic compounds, such an effect would theoretically last only as long as the dredging plume encompassed that area.

It is possible that dredging could alter the physical characteristics of the sediment. Dramatic changes in the sediment quality (size, texture, percentage of dissolved organics) could change the community structure of the original epibenthic zooplankton because of the specific sediment requirements of the various organisms. Deposition of fine silt, for example, would probably result in an eventual shift toward epibenthic crustacean communities better adapted to a burrowing and tube formation, e.g., Corophium amphipods. It is not clear as to whether altering the epibenthic zooplankton community in this manner would reduce the carrying capacity of the habitat since many of the prey found in fine silt communities are utilized by juvenile salmonids.

Direct removal of the shallow sublittoral habitat would, of course, have an absolute, long-term effect upon the ability of that area of the estuary to support epibenthic-feeding juvenile salmonids. Based upon information on the depth distribution of epibenthic crustaceans in areas other than Grays Harbor, it would appear that maximum concentrations of organisms such as harpacticoid copepods occur within ± 1 m of the MLLW tide level, although important prey taxa such as Corophium amphipods (C. salmonis, C. spinicorne, C. brevis) may occur in abundance at high tidal heights (Rick Albright, College of Fisheries, unpublished data). Thus, removal of shallow sand and mudflat habitat higher than the -1 m tide level would effectively remove that area from production of salmonid prey organisms. This could probably have the greatest impact upon juvenile chum and small chinook salmon, which tend to utilize epibenthic organisms to a greater extent than other salmonids.

The proportion of rearing habitat (i.e., habitat utilized by juvenile salmonids) removed will be the ultimate determinant of the impact upon the ability of juvenile salmonids to reside and grow in the estuary. Juvenile chums and a portion of the early chinook outmigrant population move rapidly through the estuary in May. This may be in response to declining epibenthic prey resources in shallow sublittoral and littoral habitats. Unfortunately, there are no data on the structure or standing stock of epibenthic organisms during this period of the outmigration, other than the unpublished information on Corophium amphipods. If epibenthic resources were limiting, removal of a significant area of epibenthic-feeding habitat could increase the migration rate and reduce residence time of juvenile chinook and chums in the impacted area. The consequence of this would be premature entry to neritic habitat which would presumably result in greater mortality of the juvenile salmonids.

It is possible that juvenile salmonids would move into other underutilized sublittoral and littoral habitats that may be available in Grays Harbor. If, as in the Corps of Engineers plan, dredging is confined to the Moon Island region of the upper estuary, the extensive shallow sublittoral and littoral sand- and mudflat habitats in the lower estuary should offer equivalent epibenthic prey resources. Similarly, the shallow sublittoral and littoral habitats along the South Channel of the upper estuary may offer comparable, though not necessarily alternative (since the fish at low tide must reverse normal migratory directions to utilize those habitats) foraging habitats. Unfortunately, without extensive mark-and-recapture studies, we have no indication of the mobility of juvenile salmonids within the estuary, including their distribution across the sand- and mudflat habitats at high tide.

The most serious potential impact of dredging the upper estuary would be the permanent loss of shallow sublittoral and lower littoral rearing habitat for juvenile salmonids; as described in section 3.4.4, this is only significant in the case of the shallow sublittoral where an estimated 104.5 hectares (1.1% of total sublittoral*) will be removed. The magnitude of this loss cannot be ascertained without further information on the extent of juvenile salmonid utilization of shallow sublittoral prey in these habitats (i.e., are they limiting) and whether juvenile salmonids would utilize alterative rearing habitats in the estuary.

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*Based upon an estimated 38.0 square miles (9,842 hectares) of area below MLLW between Montesano to the jetties and excluding South Bay (U.S. Army Corps of Engineers 1976).

9.3 Dynamics of Emigration of Juvenile English Sole into Shallow Sublittoral Habitats

9.3.1 Mechanisms of Utilization or Selective Forces Determining Nursery Role of Shallow Sublittoral Habitat: As discussed in Section 4.4, juvenile English sole appear to be transported into Grays Harbor as larvae or recently metamorphosed postlarvae which were the result of spawning in nearshore waters outside the mouth of the estuary. Although we have no information on the abundance or survival of juvenile English sole outside Grays Harbor, it is suggested that there is a selective advantage to spawning at a time and place that results in the developing and hatching eggs being passively transported into Grays Harbor (Pearcy and Meyers 1973). Survival through metamorphosis and the initial few months of demersal life is probably much higher in the turbid waters and the productive shallow sublittoral habitats, respectively, of Grays Harbor. Water turbidity will reduce the effectiveness of visual predators and high densities of small epibentic crustaceans provide the requisite abundances of appropriately-sized food particles during the critical period in the early life history of English sole.

The suitability of Grays Harbor as a nursery area for English sole is illustrated by the concentration of age 0+ sole in the shallow sublittoral habitats. Emigration into deeper channel habitats occurs during the winter and is complete by the time the fish have reached 130-150 mm TL as yearlings. Emigration out of the estuary appears to take place during the second summer.

9.3.2 Optimal Prey Resource Utilization of Epibenthic Zooplankton: The extremely selective nature of juvenile English sole foraging upon epibenthic zooplankton of shallow sublittoral and littoral habitats of the upper estuary (as represented by the stomach samples examined from Moon Island collections) further substantiates the role of these habitats as nursery areas. The principal taxa and species of prey, including harpacticoid copepods such as *Scottolana canadensis*, gammarid amphipods such as Corophium spp. and cumaceans such as Cumella sp., are characteristic of coarse mud-sand habitats above -1 m tide levels. The high densities of harpacticoid copepods ($\bar{x} = 28,368\ m^{-3}$) found at Moon Island in May illustrates the standing stock of prey available in these habitats, although their densities may be appreciably higher earlier in the spring, when the juvenile English sole have first settled or recruited into the shallow sublittoral habitats. Natural selection appears to have structured the early life history of English sole to coincide with the maximum production rate of epibenthic crustaceans, e.g., the population increase of detritivores which occurs as a result of the springtime increase in temperatures and the concurrent distribution of fine particulate organic carbon (FPOC) over the shallow sublittoral (see Section 9.3.2).

The gradual transition from diet composed principally of harpacticoid copepods early in the residence of juvenile English sole in the estuary to a diet composed of larger epibenthic prey such as gammarid amphipods in late summer and eventually to larger infaunal macroinvertebrates in the fall probably indicates changes in the morphological and bioenergetic constraints upon the fish's foraging ability, although changes in prey availability cannot be discounted.

9.3.3 Potential Adverse Effects of Dredging, Adverse Water Quality or other Perturbations upon Utilization of Shallow Sublittoral Habitats by Juvenile English Sole: As discussed in Section 9.2.2, dredging could have the highest impact within the shallow sublittoral and littoral zones. The permanent loss of habitat due to dredging may be more deleterious to juvenile English sole than to epibenthic feeding juvenile salmonids, since their utilization of these habitats is more specialized. All the potential deleterious effects of dredging on juvenile salmon would apply to English sole since the shallow sublittoral and littoral habitat is utilized as a nursery area by English sole. While juvenile salmonids are adapted to a transitory, migratory passage through these habits, juvenile English sole reside in the shallow sublittoral habitats until movement into channel habitats in the late fall and winter.

The significance of the rearing habitat lost to dredging depends on whether the magnitude of metamorphosed larvae coming into Grays Harbor reaches the carrying capacity of the available habitat. If this is the case then loss of English sole production from Grays Harbor is equal to the relative loss of habitat due to dredging.

9.4 Baitfish Utilization of Grays Harbor

9.4.1 Importance of Grays Harbor as a Spawning Habitat: While the longfin smelt and American shad utilize the tributaries of Grays Harbor for spawning, the FRI studies between March and mid-October 1980 imply that the estuary is not a major spawning habitat of "baitfish" or schooling neritic fishes. This result generally corroborates the conclusions of Smith (1976) that herring in the estuary in 1974 and 1975 were part of a larger population which existed largely outside Grays Harbor. Recent observations in similar coastal estuaries, Willapa Bay and the Columbia River estuary, have suggested that spawning of Pacific herring could be occurring in Grays Harbor both earlier (before March) or later (June-July) than our sampling indicated. Similarly, northern anchovy did not appear to be spawning within the estuary, as evidenced by the lack of any relationship between adults in spawning condition and the occurrence and abundance of larvae. While both clupeids and osmerids are known to spawn in inland estuaries such as Puget Sound (Bruce Miller, College of Fisheries, personal communication), spawning in the large coastal estuaries may not be a predominant phenomenon. There are a number of potential explanations for this including the lack of suitable spawning substrate for Pacific herring and the high turbidity levels in the estuaries during the period of spawning. Eelgrass, which is a major spawning substrate for Pacific herring, was located in areas of the lower estuary, although not in the broad distribution and densities defined by Smith (1976). The turbidity and lack of visual clarity in the highly turbid Grays Harbor may limit the feeding success of Pacific herring and northern anchovy larvae.

9.4.2 The Survival Advantage of Transport of Larval and Juvenile Baitfish into Grays Harbor and Extended Residence within the Estuary: Baitfish larvae, postlarvae and juveniles are transported into Grays Harbor, often in high densities. For some fish such as larval English sole, extended residence (e.g., at least through the "critical" period of first feeding) in the estuary may provide distinct survival advantages. Predation by visually feeding piscivores is limited in the turbid waters of Grays Harbor while small, neritic zooplankton important as prey during the early life history of the baitfish (e.g., Acartia clausi, Centropages abdominalis, Pseudocalalnus sp., Eurytemora americana) often occur in the high densities necessary for adequate growth. Growth for most fish provides the ultimate refuge from predation and the turbid waters of Grays Harbor may well function as an opportune sanctuary for baitfish, allowing them to acquire sufficient growth to reduce predation in the more clear coastal waters where they mature. Unfortunately, we have no data to compare the relative survival rates of baitfish larvae within and without Grays Harbor.

Although there is considerable variability in the relative abundances (CPUE) of juvenile baitfish (Figs. 5-2 to 5-4) between March and October in Grays Harbor, there were numerous cases where catches in the purse seine were sustained at a relatively constant level over six to ten weeks. This is particularly true in the case of northern anchovy at Cow Point and Pacific herring at Cosmopolis and Cow Point between late July and late September. Considering the mobility of these schooling fishes, these catches suggest sustained residence in the upper estuary during this period, rather than passive transport via the various marine water masses which surge into this area on the flood tide. The interesting association with the high standing crop of neritic zooplankton at Cow Point and Moon Island during this same period (Fig. 6-2) suggests that the baitfish were residing in this region in response to high prey densities. However, Crangon franciscorum, a large epibenthic shrimp and unlikely baitfish prey organism, often accounted for these high zooplankton standing crop estimates and this association is not substantial.

9.4.3 Baitfish as Prey Resources of Juvenile Salmonids: Juvenile baitfish were generally not important components in the prey spectra of juvenile salmonids in Grays Harbor, with the prominent exception of juvenile chinook at Moon Island. At this site, juvenile northern anchovy were the most frequently consumed organism and composed over 50% of the prey composition by weight (Fig. 8-6). As such, these juvenile baitfish represent the most prominent neritic organism consumed by juvenile chinook migrating through the estuary.

9.4.4 Potential Adverse Effects of Dredging or Adverse Water Quality upon Baitfish Utilization in Grays Harbor: As described for juvenile salmonids, the effects of dredging upon baitfish utilization of Grays Harbor may be short-term and restricted to behavioral modification, rather than long-term reduction in carrying capacity. The prominent baitfish utilization of the upper estuary in the vicinity of Moon Island and Cow Point during the summer months (July-September) of 1980 may have resulted from low freshwater flows (Fig. 2-1) allowing intrution of relatively clear marine water masses, in which case the high turbidities associated with dredging operations in the upper estuary could reduce the baitfish utilization of the upper estuary during late summer.

9.5 Structure and Standing Stock of Neritic and Epibenthic Zooplankton Communities

9.5.1 Role of Grays Harbor in Production of Two Zooplankton Communities: The standing stock and much of the structure of the neritic and epibenthic zooplankton communities described in our studies of Grays Harbor are directly related to their different carbon sources.

The neritic zooplankton production is based both on autotrophic production in the water column and suspended detrital material. The epibenthic zooplankton production is based on detrital material and epiphytic diatom production associated with the sediment water interface in the extensive littoral and sublittoral zones of Grays Harbor.

Grays Harbor receives high inputs (ca 900 x 10^6 kg C/yr) of both particulate and dissolved organic carbon through the six major rivers and many small tributaries which enter it (R. Thom, U.S. Army Corps of Engineers, Unpubl.). The terrestrial "wetland" habitats surrounding the estuary also contribute extensively (ca 200 x 10^6 kg C/yr) to the detritus pool. Eelgrass beds also appear to be a source of particulate and dissolved organic matter to the estuary.

Because of high turbidity the water column autotrophic production is low. Detrital material could be an important source of the neritic zooplankton production. Estuarine frontal zones are regions of high bottom turbulence and high stream velocities (Bowman and Iverson 1978). These facilitate suspension and accumulation of detrital material. The location and duration of these estuarine frontal zones are quite variable in a complex system such as Grays Harbor, and would depend on river flow, tidal stage, and wind conditions. Nevertheless, they provide a mechanism for transport of detrital material to the neritic community. In view of this, the most important sources of the Grays Harbor epibenthic and neritic zooplankton production are allochthonous detrital material, eelgrass and epiphytic algae.

9.5.2 <u>Possible Sources of Detrital Carbon to Important Detritivorous Zooplankton with Trophic Linkages to Juvenile Salmonids and English Sole</u>: A large component of the neritic zooplankton community standing stock consists of organisms that are exogenous (i.e., produced outside) to Grays Harbor. Freshwater organisms enter from the tributaries to the estuary or purely marine forms are swept in with tidal fluxes. The production of the epibenthic zooplankton community, on the other hand, is endogenous (produced within) Grays Harbor. That production is fueled in part by the influx of detrital material from terrestrial sources via the rivers; thus, most of this detritus input occurs during the high flow period, during the winter and spring. Accumulation zones, where both terrestiral and estuarine detritus are deposited by the action of currents, wind and tides, play an important role in the biochemical decomposition of the detritus, for it appears that the microflora which colonize detritus particles form the principle food source for detritivorous crustaceans. Thus, the most rapid conditioning of the refractory (biologically inert) component of detritus take place in the accumulation zones where the essential requirements of bacterial and fungal growth--nutrients, temperature, physical stability--are optimum. Although there have been no studies of detritus accumulation or processing in Grays Harbor, studies in other regions would suggest that the high littoral region of fine, unconsolidated sediment habitats, e.g., channels in saltmarshes and mudflats, meet these criteria. Detritus from both terrestrial and estuarine sources accumulates in these regions and is physically degraded during the fall and winter, biochemically decomposed in the spring, and distributed as fine particulate organic matter (FPOC), heavily colonized by microflora, throughout the shallow sublittoral habitats by spring tides. This FPOC, with its associated microflora is grazed upon by epibenthic and infaunal detritivores.

The other important base of epibenthic zooplankton production is benthic diatoms and macroalgae produced within the estuary. The great expanse of mud- and sandflats are exposed to high solar radiation, particularly during the spring, and nutrients are continually replaced by tidal inundation. The epibenthic zooplankton can graze the epiphytic algae directly or indirectly with the epiphytic algae entering the detrital pool.

9.5.3 Possible Effects of Dredging and Adverse Water Quality on Epibenthic and Neritic Zooplankton: Not considering the potential effects of toxic compounds which may be released or resuspended in dredging plumes, the dredging process should not impact neritic zooplankton communities dramatically. The dominant neritic zooplankton communities characterizing Grays Harbor are adapted to the high turbidity and mixing which occur during all but a few months of the year. Photosynthesis may be depressed by dredging during this period in the vicinity of the dredging plume but potential introduction of nutrients from dredge sediments may actually enhance primary production.

Epibenthic zooplankton production, on the other hand, will be affected by the dredging in proportion to the area of shallow sublittoral and lower littoral zone that is permanently removed. Further impact may result from sedimentation and reduction in water quality beyond the area actually dredged; however, considering the high turnover rate and mobility of epibenthic zooplankton, recovery of sublittoral and littoral habitat would be expected to be relatively rapid, e.g., within three months (Rhoads et al. 1977).

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