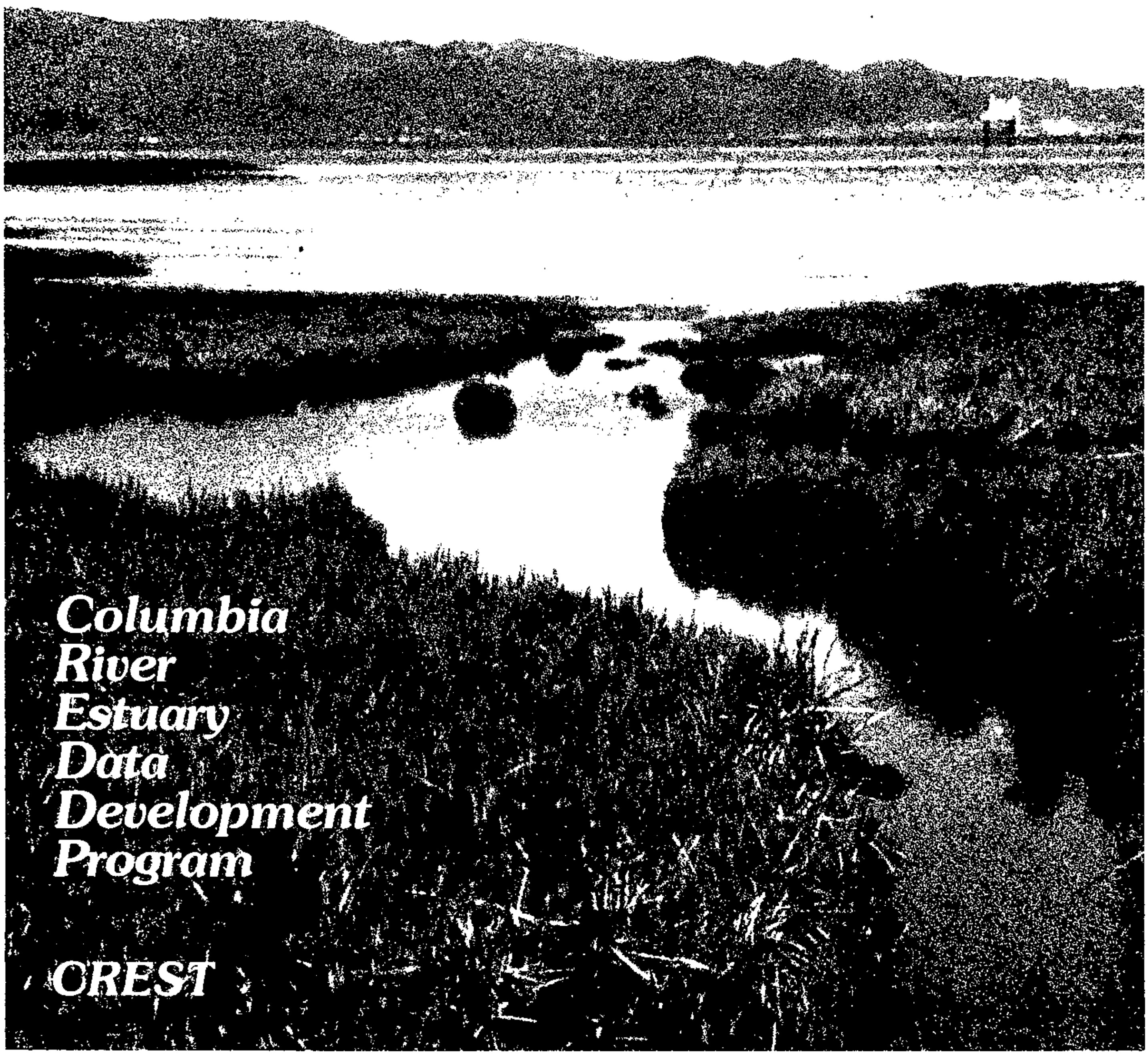
FISHES OF THE COLUMBIA RIVER ESTUARY



Final Report on the Fish Work Unit
of the Columbia River Estuary Data Development Program

FISHES OF THE COLUMBIA RIVER ESTUARY

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PREFACE

The Columbia River Estuary Data Development Program

This document is one of a set of publications and other materials produced by the Columbia River Estuary Data Development Program (CREDDP). CREDDP has two purposes: to increase understanding of the ecology of the Columbia River Estuary and to provide information useful in making land and water use decisions. The program was initiated by local governments and citizens who saw a need for a better information base for use in managing natural resources and in planning for development. In response to these concerns, the Governors of the states of Oregon and Washington requested in 1974 that the Pacific Northwest River Basins Commission (PNRBC) undertake an interdisciplinary ecological study of the estuary. At approximately the same time, local governments and port districts formed the Columbia River Estuary Study Taskforce (CREST) to develop a regional management plan for the estuary.

PNRBC produced a Plan of Study for a six-year, $6.2 million program which was authorized by the U.S. Congress in October 1978. For the next three years PNRBC administered CREDDP and $3.3 million was appropriated for the program. However, PNRBC was abolished as of October 1981, leaving CREDDP in abeyance. At that point, much of the field work had been carried out, but most of the data were not yet analyzed and few of the planned publications had been completed. To avoid wasting the effort that had already been expended, in December 1981 Congress included $1.5 million in the U.S. Water Resources Council (WRC) budget for the orderly completion of CREDDP. The WRC contracted with CREST to evaluate the status of the program and prepare a revised Plan of Study, which was submitted to the WRC in July 1982. In September, after a hiatus of almost one year, CREDDP work was resumed when a cooperative agreement was signed by CREST and the WRC to administer the restructured program and oversee its completion by June 1984. With the dissolution of the WRC in October 1982, the National Oceanic and Atmospheric Administration (NOAA) assumed the role of the WRC as the federal representative in this cooperative agreement.

CREDDP was designed to meet the needs of those groups who were expected to be the principal users of the information being developed. One such group consists of local government officials, planning commissions, CREST, state and federal agencies, permit applicants, and others involved in planning and permitting activities. The other major anticipated user group includes research scientists and educational institutions. For planning purposes, an understanding of the ecology of the estuary is particularly important, and CREDDP has been designed with this in mind. Ecological research focuses on the linkages among different elements in the food web and the influence on the food web of such physical processes as currents, sediment transport and salinity intrusion. Such an ecosystem view of the estuary is necessary to predict the effects of estuarine alterations on natural resources.

Research was divided into thirteen projects, called work units. Three work units, Emergent Plant Primary Production, Benthic Primary Production, and Water Column Primary Production, dealt with the plant life which, through photosynthesis and uptake of chemical nutrients, forms the base of the estuarine food web. The goals of these work units were to describe and map the productivity and biomass patterns of the estuary's primary producers and to describe the relationship of physical factors to primary producers and their productivity levels.

The higher trophic levels in the estuarine food web were the focus of seven CREDDP work units: Zooplankton and Larval Fish, Benthic Infauna, Epibenthic Organisms, Fish, Avifauna, Wildlife, and Marine Mammals. The goals of these work units were to describe and map the abundance patterns of the invertebrate and vertebrate species and to describe these species' relationships to relevant physical factors.

The other three work units, Sedimentation and Shoaling, Currents, and Simulation, dealt with physical processes. The work unit goals were to characterize and map bottom sediment distribution, to characterize sediment transport, to determine the causes of bathymetric change, and to determine and model circulation patterns, vertical mixing and salinity patterns.

Final reports on all of these thirteen work units have been published. In addition, these results are integrated in a comprehensive synthesis entitled The Dynamics of the Columbia River Estuarine Ecosystem, the purpose of which is to develop a description of the estuary at the ecosystem level of organization. In this document, the physical setting and processes of the estuary are described first. Next, a conceptual model of biological processes is presented, with particular attention to the connections among the components represented by the work unit categories. This model provides the basis for a discussion of relationships between physical and biological processes and among the functional groups of organisms in the estuary. Finally, the estuary is divided into regions according to physical criteria, and selected biological and physical characteristics of the habitat types within each region are described. Historical changes in physical processes are also discussed, as are the ecological consequences of such changes.

Much of the raw data developed by the work unit researchers is collected in a magnetic tape archive established by CREDDP at the U.S. Army Corps of Engineers North Pacific Division Data Processing Center in Portland, Oregon. These data files, which are structured for convenient user access, are described in an Index to CREDDP Data. The index also describes and locates several data sets which were not adaptable to computer storage.

The work unit reports, the synthesis, and the data archive are intended primarily for scientists and for resource managers with a scientific background. However, to fulfill its purposes, CREDDP has developed a set of related materials designed to be useful to a wide range of people.

Guide to the Use of CREDDP Information highlights the principal findings of the program and demonstrates how this information can be used to assess the consequences of alterations in the estuary. It is intended for citizens, local government officials, and those planners and other professionals whose training is in fields other than the estuary-related sciences. Its purpose is to help nonspecialists use CREDDP information in the planning and permitting processes.

A detailed portrait of the estuary, but one still oriented toward a general readership, is presented in The Columbia River Estuary: Atlas of Physical and Biological Characteristics, about half of which consists of text and illustrations. The other half contains color maps of the estuary interpreting the results of the work units and the ecological synthesis. A separate Bathymetric Atlas of the Columbia River Estuary contains color bathymetric contour maps of three surveys dating from 1935 to 1982 and includes differencing maps illustrating the changes between surveys. CREDDP has also produced unbound maps of the estuary designed to be useful to resource managers, planners and citizens. These black-and-white maps illustrate the most recent (1982) bathymetric data as contours and show intertidal vegetation types as well as important cultural features. They are available in two segments at a scale of 1:50,000 and in nine segments at 1:12,000.

Two historical analyses have been produced. Changes in Columbia River Estuary Habitat Types over the Past Century compares information on the extent and distribution of swamps, marshes, flats, and various water depth regimes a hundred years ago with corresponding recent information and discusses the causes and significance of the changes measured. Columbia's Gateway is a two-volume set of which the first volume is a cultural history of the estuary to 1920 in narrative form with accompanying photographs. The second volume is an unbound, boxed set of maps including 39 reproductions of maps originally published between 1792 and 1915 and six original maps illustrating aspects of the estuary's cultural history.

A two-volume Literature Survey of the Columbia River Estuary (1980) is also available. Organized according to the same categories as the work units, Volume I provides a summary overview of the literature available before CREDDP while Volume II is a complete annotated bibliography.

All of these materials are described more completely in Abstracts of Major CREDDP Publications. This document serves as a quick reference for determining whether and where any particular kind of information can be located among the program's publications and archives. In addition to the abstracts, it includes an annotated bibliography of all annual and interim CREDDP reports, certain CREST documents and maps, and other related materials.

To order any of the above documents or to obtain further information about CREDDP, its publications or its archives, write to CREST, P.O. Box 175, Astoria, Oregon 97103, or call (503) 325-0435.

FOREWORD

The Columbia River Estuary Study Taskforce contracted with the Oregon Department of Fish and Wildlife to prepare an interpretive report on the fish community of the Columbia River Estuary. Most of the data contained in this report were collected for the Columbia River Estuary Data Development Program (CREDDP) by the National Marine Fisheries Service (NMFS), National Oceanic and Atmospheric Administration during an estuarine finfish survey, February 1980 - July 1981. A description of all NMFS data collected and summarized for CREDDP is contained in Appendix A. A discussion of NMFS survey and analytical methods is given in Appendix B.

We gratefully acknowledge the cooperation and assistance provided by Ted Blahm and his staff at NMFS, Northwest and Alaska Fisheries Center, while we prepared this report. We especially wish to thank Teresa Clocksin for computer processing of the NMFS data. Our thanks to Bob Emmett for information about survey methods and interpretation of survey results. Earl Dawley provided much of the data needed for our analysis of salmonid migration rates through the estuary.

We received a lot of moral and administrative support from CREDDP staff during the project. We are particularly grateful to Jack Damron for his attention to our every administrative need and to David Fox for his advice on technical aspects of the report.

We thank Charles Simenstad of the University of Washington for his helpful suggestions on data analysis, his interpretations of survey results, and his review of this manuscript. Also thanks to Duane Higley from Oregon State University for his assistance with several computer programs. Bill Pearcy of Oregon State provided helpful comments for revision of our draft report.

This report was prepared by the Research and Development Section of the Oregon Department of Fish and Wildlife (ODFW). Dan Bottom was project leader under the direction of Jim Lichatowich. Kim Jones was responsible for all computer analyses and the description of fish community structure and distribution. Peggy Herring summarized the salmonid migration and hatchery release data. We also received help from Bob Mullen of ODFW, who prepared several computer programs to summarize food habit and feeding intensity data. Graphics were prepared by Debbie Santiago and Kathryn Torvik. Lori Turner and Jan Ehmke were responsible for typing several drafts of the report.

TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

EXECUTIVE SUMMARY

The Oregon Department of Fish and Wildlife analyzed finfish data from a survey of the Columbia River Estuary. The survey was conducted by National Marine Fisheries Service (NMFS) from February 1980 through July 1981. NMFS collected more than 148,000 individuals of 75 fish species at 49 estuarine locations using bottom trawl, beach seine, and purse seine.

Seasonal cycles in the life history and migration of fishes influence the composition of species assemblages in the Columbia River Estuary. As the number of species and life history stages in the estuary increases from winter to summer, the composition and distribution of assemblages become more complex.

Superimposed over natural reproductive cycles are seasonal changes in river flow and salinity patterns that affect fish distribution in the estuary. We used cluster analysis to group survey stations with similar species composition for each of three hydrologic seasons in the Columbia River: winter fluctuating (November-March), spring high (April-June), and summer low (July-October) flows. In each season we found three major divisions among estuarine sampling sites. These corresponded to marine, estuarine mixing, and freshwater salinity zones. In winter and summer the marine-estuarine mixing boundary was located near the mouth at approximately River Mile 7 (RM-7); the freshwater-estuarine mixing boundary was located near Tongue Point at approximately RM-18. During spring maximum flows, station groups reflected increased water column stratification as the boundaries between salinity zones shifted downstream for nearshore and pelagic sampling locations. Freshwater species were captured further downstream in shallow beach seine sites than in deeper trawl sites.

Within each salinity zone the distribution of fishes was influenced by habitat type. We found evidence for slightly different fish assemblages associated with nearshore, bay, shoal, water column, and channel bottom habitats.

A few species and assemblages were represented consistently and distributed similarly during spring high and summer low flow periods. Longfin smelt, northern anchovy, Pacific herring,and surf smelt, for example, were among pelagic assemblages that occurred most frequently in the marine and estuarine mixing zones. Shiner perch, Pacific staghorn sculpin, and starry flounder were part of a demersal assemblage that commonly occurred between RM-7 and RM-29 and in protected habitats of Baker Bay and Youngs Bay. Pacific tomcod, English sole, and snake prickleback were among demersal fishes most often present between RM-2 and RM-19 throughout the year.

Results of discriminant analysis and reciprocal averaging of fish density data indicate that species assemblages are not discrete groups. Most of the fishes in the estuary are euryhaline species that can be found throughout most salinity zones and habitats. Distribution is defined along a continuum of stations that represents salinity and depth-habitat gradients. Distribution of the most common fishes in the Columbia River Estuary is governed by salinity and habitat preferences rather than by absolute limits of environmental tolerance.

The distribution and abundance of fishes in the Columbia River Estuary reflect the distribution and standing crop of invertebrate prey. During the 1980-81 survey the greatest number of fish species and individuals occurred in the estuarine mixing zone and in shallow bays. These were also regions of maximum standing crop during a concurrent survey of epibenthic invertebrates by University of Washington researchers (Simenstad 1984). Pelagic zooplankton densities were also consistently higher in the estuarine mixing zone (Jones and Bottom 1984).

The mean weight of stomach contents for fishes (Index of Feeding Intensity) also reflects the distribution of invertebrate prey. Average "feeding intensity" for the entire survey was generally higher among channel bottom and nearshore habitats between RM-6 and RM-19 and in Youngs Bay and Baker Bay. Other CREDDP researchers found epibenthic and zooplankton densities were maximum between RM-6 and RM-16 during high flows and between RM-16 and RM-23 during low flows. High concentration of fishes in the central estuary and protected bays is probably a response to higher food densities.

Columbia River fishes may consume few prey taxa. Corophium salmonis, Daphnia spp., and calanoid copepods were among the most important prey items for a variety of fishes. However, the apparent overlap in the diet of many fishes may be exaggerated since copepods in fish stomachs were not identified to the species level. We were able to discern several pelagic and several demersal feeding groups each season. Species we classified into feeding groups (based on similar food habits) frequently were distributed among similar regions and habitats of the estuary.

During 1980, mean weights of stomach contents for most fishes in the Columbia were low compared with limited data from other estuaries in the Northwest. There was a relatively large proportion of empty stomachs among all individuals for several species. Total annual growth for subyearling English sole and starry flounder was low relative to reported values for several other estuaries. The Columbia River Estuary may offer a poor feeding environment relative to some other estuarine systems in the region; however, diel consumption studies are needed to test this hypothesis.

The Columbia River basin has been modified from a wild to a hatchery production system for salmonids. More than 172 million juvenile salmonids were released into the Columbia River in 1981. The timing and residence period of salmonids in the estuary are influenced by the rearing and release strategies of hatcheries upriver and may not reflect historical patterns of estuarine rearing. Migration rates for hatchery salmonids to the lower estuary generally increase with distance of release location from the river mouth.

Hatchery yearling chinook, coho, and steelhead move more rapidly through the estuary than subyearling chinook salmon. Yearling chinook, coho, and steelhead primarily use deeper channel habitats en route to the ocean. Subyearling chinook use a greater diversity of habitats as they linger in the estuary. Our estimates of migration rates based on tag recoveries from hatchery releases suggest that the Columbia, like other estuaries in the Northwest, is used as a rearing area for subyearling chinook salmon.

1. INTRODUCTION

The Columbia River flows more than 1920 kilometers (km) before it reaches the Pacific Ocean. In the lower 75 km the river forms an estuary (Figure 1) that serves as both harbor and fishing ground for a large commercial fleet. Since the late 1800's fishing and seafood processing industries have depended on the constant migrations of salmon produced in the Columbia River watershed and caught in ocean and estuarine fisheries. Other commercial finfish--shad, smelt, and herring--are nurtured and harvested in the estuary.

Despite its size and importance to commercial fisheries there is little published information on fish assemblages in the Columbia River Estuary. Most research has focused on single species of interest, particularly salmonids (Sims 1972;1975; Johnsen and Sims 1973; Dawley et al. 1978). Other surveys have had a broader focus but have been confined to one or a few specific sites of interest (Higley and Holton 1975; Durkin 1974; Durkin and Lipovsky 1977; Durkin et al. 1977a; 1977b; 1979). Much of this work was designed to assess the impacts associated with proposed developments at these particular locations.

Haertel and Osterberg (1967) presented results of the first ecological study of fishes throughout the Columbia River Estuary. Their research described trophic relationships among demersal fishes and the effects of salinity on distribution of fish and invertebrate prey species. Since their report, Misitano (1977) also completed a broad survey of larval and postlarval fishes in the lower 18 miles of the Columbia River.

In 1980 the National Marine Fisheries Service (NMFS) began an 18-month survey of fishes in the Columbia River Estuary as part of the Columbia River Estuary Data Development Program (CREDDP) (described in the Preface). In their survey NMFS sampled a variety of habitats using several types of gear to better define pelagic as well as demersal components of the fish community. Brief summaries of survey results are given in NMFS (1981 and 1983a). A list of NMFS data collected for CREDDP and a description of their survey methods and analytical methods are provided in Appendix A and Appendix B, respectively.

In August 1983 the Oregon Department of Fish and Wildlife received funds from CREDDP to complete additional analyses of the NMFS data in order to describe community level interactions among fishes in the estuary. The primary objectives of our analyses were:

(1) To identify species assemblages in the estuary and to describe their spatial distribution during each season;

(2) To determine the primary physical factors that influence the composition and distribution of these species assemblages; and

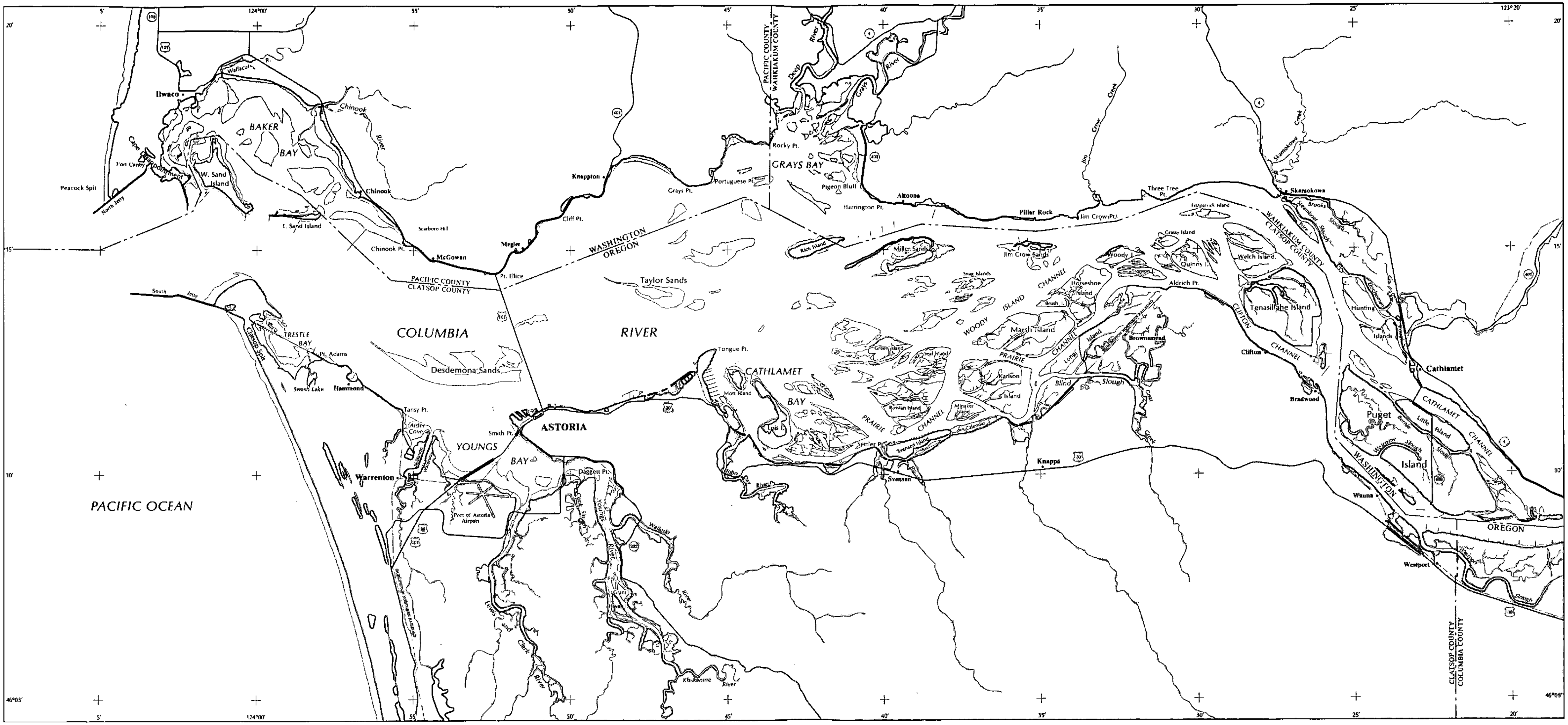
(3) To describe trophic interactions among fish species and the relationship between predator and prey distributions.

To fulfill these objectives we also analyzed additional fish data collected by University of Washington during a concurrent macro-invertebrate survey for CREDDP (Simenstad 1984).

Salmonids have been and will continue to be the primary fisheries concern in the Columbia River basin. In this light we also analyzed migration and distribution information for salmonids as a fourth objective:

(4) To evaluate the importance of the Columbia River Estuary as a rearing environment for juvenile salmon.

This report describes fish assemblages in the Columbia River Estuary and provides data needed to integrate the fish survey results with other research elements in CREDDP. We have not described the life history of individual species in the estuary. Additional data for key species are available in NMFS (1981).



Columbia River Estuary

Scale 1:160,000

0 1 2 3 4 5 6 7 8 9 10 Kilometers

0 1 2 3 4 5 6 Miles

Map produced in 1983 by Northwest Cartography, Inc.
for the Columbia River Estuary Data Development Program

- Shoreline (limit of non-aquatic vegetation)
- Intertidal vegetation
- Shoals and flats
- Lakes, rivers, other non-tidal water features
- Major highways
- Cities, towns
- Railroads
- Other cultural features

Figure 1. Columbia River Estuary

2. METHODS AND MATERIALS

2.1 DISTRIBUTION AND ABUNDANCE

2.1.1 Gear and Methods

Fishes were collected monthly in the Columbia River Estuary from February 1980 through July 1981 by NMFS. NMFS made a single haul at each of 22 trawl, 16 purse seine, and 11 beach seine sites (Figure 2). It required approximately 4 weeks from the first date of each monthly survey to sample all stations. Sampling effort was equal for all stations during all months.

NMFS sampled with an 8 m (head rope) semi-balloon shrimp trawl containing 38.1 mm mesh (stretched) with a knotless 12.7 mm liner in the cod end. The trawl was towed upstream during flood tide for 5 minutes. A 200 m by 9.8 m purse seine with variable knotless mesh (19.0 mm and 12.7 mm) was used to sample deeper channels. The purse seine was set upstream for 5 minutes at various tide stages. Two 50 m beach seines of variable knotless mesh (19.0 mm, 12.7 mm, and 9.5 mm), one 4.0 m deep and the other 3.4 m deep, were used to sample intertidal habitat and the adjoining subtidal habitat.

Also during 1980 and 1981, the Fisheries Research Institute (FRI) of the University of Washington collected fish at additional survey sites while sampling large invertebrates for CREDDP (Simenstad 1984). FRI sampled 10 trawl sites and 4 beach seine sites (Figure 2) during the survey period. Replicate 5-minute trawl and replicate beach seine hauls were made at each site. FRI sampled with a 4.9 m (foot rope) semi-balloon trawl with a 6 mm mesh cod end and a 37 m by 2 m sinking beach seine with a 6 mm mesh bag.

To standardize catch among stations sampled with different types of gear, we converted catch data to densities (fish per square meter). Only very approximate conversions were available from NMFS (1983a) based on estimates of mean area covered by each gear type for the entire survey as follows:

	Area sampled
Trawl	2944 m^2
Purse Seine	7959 m^2
Beach Seine	2713 m^2

FRI trawl data were standardized to density based on tidal stage. A single conversion factor was used for beach seine collections (PNRBC 1981) as follows:

	Slack Tide	Against Tide	With Tide
Trawl	750 m^2	375 m^2	1125 m^2
Beach Seine	520 m^2	--	--

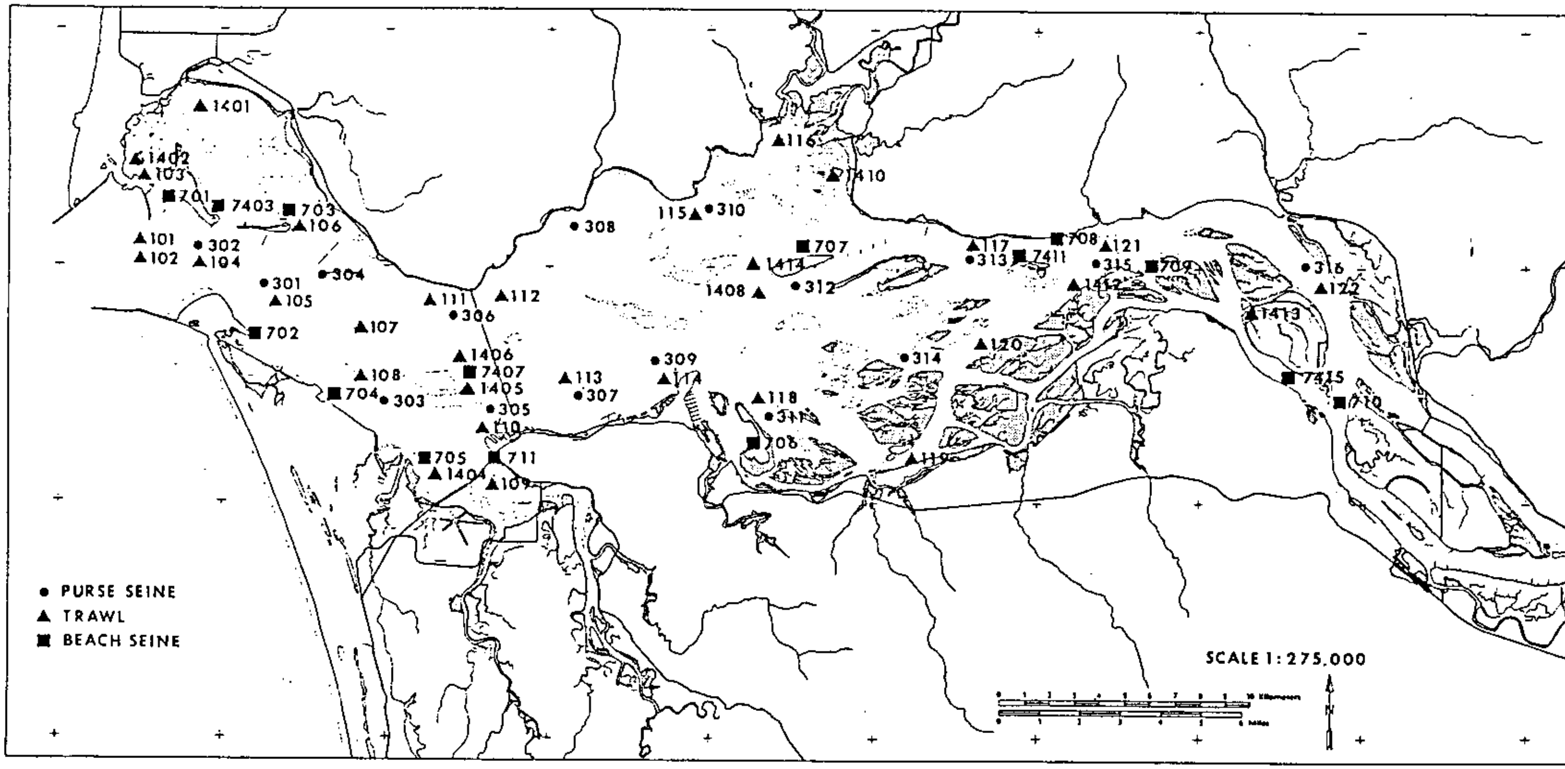


Figure 2. Fish sampling stations during 1980-81 NMFS and FRI surveys.

Fish density values were used in several multivariate analyses to compare species composition and abundance for habitats sampled with different types of gear.

2.1.2 Study Locations

Sampling sites extended from marine stations close to the mouth of the river up to River Mile 38 (RM-38) in the freshwater region of the Columbia River Estuary (Figure 2). In addition, stations were chosen to represent a diversity of habitats within the estuary (Table 1). These included water column (sampled primarily with purse seines), channel bottom (sampled with trawls), nearshore (sampled with beach seines), shoals (sampled with trawls and beach seines), and bay habitats (sampled with trawls and beach seines).

2.1.3 Analysis

Several multivariate analyses were performed with the fish density data supplied by NMFS and FRI.

Cluster Analysis

Cluster analysis was used to classify stations and species into discrete groups based on the Bray-Curtis dissimilarity measure and group averaging method (Boesch 1977). All analyses used the computer program CLUSTER from Oregon State University (Keniston 1978).

Results of two separate analyses are presented in this report. First, NMFS combined 18 months of collection data into 4 calendar seasons: winter (January-March), spring (April-June), summer (July-September), and fall (October-December). For each of these seasons NMFS produced dendograms grouping species and stations. Their analysis used a root-root transformation of the average species density for each season. Data from June 1980 were not included in the spring average because of potential effects of the eruption of Mt. St. Helens on fish distribution. If 10 or fewer of a species were caught for the entire study (or 15 or fewer of a life history stage for key taxa), these species (or life history stages) were excluded from the analysis. NMFS also excluded from analyses all chinook and coho salmon captured in trawls; English sole, Pacific staghorn sculpin, and starry flounder captured in purse seines; and northern anchovy captured in beach seines. The apparent distribution of some fishes may have been affected by the selective removal of these species from these gear types.

We completed a second series of cluster analyses at Oregon State University's computer center to combine species data collected by FRI with the data collected by NMFS. These analyses were identical to NMFS methods except that we excluded additional rare species and life history stages (fewer than 5 captured in a particular month), and we used a $\log_{10}$ (X+1) transformation for all species densities. In addition, only data collected in January 1981, May 1980, and August

Table 1. List of habitat types represented by each sampling station. Stations with a four-digit code were sampled by FRI. All others were sampled by NMFS.

Habitat	Gear	Station	RM
Water Column	Purse Seine	301	5.7
		302	4.0
		303	9.8
		304	7.1
		305	13.3
		306	10.9
		307	15.2
		308	14.1
		309	18.4
		310	16.6
		311	20.5
		312	21.6
		313	24.9
		314	25.0
		315	29.0
		316	34.9
Channel Bottom	Trawl	101	2.3
		102	2.3
		104	4.0
		105	5.8
		107	7.8
		108	9.5
		110	12.9
		111	10.3
		112	11.7
		113	15.2
		114	17.7
		115	16.4
		117	25.0
		118	20.5
		119	24.3
		120	26.5
		121	29.0
		122	34.8
		1405	11.8
		1408	19.7
Shoals	Trawl	1406	11.2
		1414	19.1
		1413	31.1
	Beach Seine	7407	11.2
		7411	25.6
Nearshore	Trawl	1412	27.1
	Beach Seine	702	6.3
		704	8.9
		706	21.0
		707	21.8
		708	28.3
		709	29.5
		710	38.4
		7415	34.0
Bay	Trawl	103	4.5
		106	6.5
		109	14.0
		116	19.4
		1401	5.7
		1402	4.7
		1404	11.5
		1410	21.0
		701	4.0
		703	7.0
		705	11.4
		711	12.7
		7403	5.0

1980 were analyzed. These months were chosen to contrast species distributions for three typical flow conditions in the Columbia River Estuary (Simenstad et al. 1984): winter fluctuating flow (November to March), spring high flow (April to June), and summer-fall low flow (July to October). These periods will be referred to as "hydrologic seasons" (as opposed to the NMFS calendar seasons), and each of the three months will be referred to as a "representative month."

We used a nodal analysis of constancy (Boesch 1977) to compare the distribution of species with the station clusters for each representative month. Constancy values represent the percentage of co-occurrence between each species assemblage and each station cluster.

Discriminant Analysis

Species data for each station were compared using discriminant analysis (Gauch 1982) to 1) determine whether the cluster analyses accurately predicted group membership, and 2) test the degree of overlap between station clusters and the homogeneity of stations within each group. Discriminant analysis reduces density data for all species at a station into several linear functions. These functions maximize the variation between *a priori* designated station groups and minimize the variation within these groups. The degree of overlap or separation between cluster groups is depicted in this report by scatter plots of the discriminant scores for each station. The first function (graphically presented as axis 1 on scatter plots) accounts for the greatest separation between station groups. The second function accounts for slightly less, and so on. Discriminant analyses were performed with the Statistical Package for Social Sciences (SPSS) on the Oregon State University CDC Cyber computer.

Reciprocal Averaging

We used a reciprocal averaging technique (Gauch 1982) to describe the similarities or differences between stations or species based on their ordination along several axes. Like discriminant analyses, reciprocal averaging uses species density data to compare between stations. However, each station is treated separately in the analysis. The technique can be useful to describe environmental gradients based on scatterplots of the station scores. Reciprocal averaging also ordinates species along the same axes as stations according to the densities of a species among all stations. The reciprocal averaging method used in this study was the DECORANA Program (Hill 1979), which prevented the second axis from being a quadratic distortion of the first axis.

2.2 GROWTH AND LIFE HISTORY

NMFS (1981) measured length and weight of selected fish species to estimate growth, separate age classes, and determine periods of estuarine residence for different life history stages. A subsample of no more than 50 of a single species were measured to the nearest millimeter total length and weighed to the nearest gram. When more than 50 of a species were caught in a set, additional fish were counted and were weighed as a group. American shad, Pacific herring, longfin smelt, English sole, and starry flounder were among key species that were measured and weighed. Life history stages of these and several other species are designated in the text as subyearlings (0), yearlings (1), and 2-year olds and above (2). No differentiation between age classes was made for species with no life history designation.

Instantaneous growth rates (G_w) were estimated from the monthly change in average weight of a single age class and species of fish sampled from the estuarine population:

$$G_w = \frac{\ln \bar{w}_2 - \ln \bar{w}_1}{\Delta t}$$

where: $\bar{w}_1, \bar{w}_2$ = mean wet weights of fish at times t_1 and t_2 (in days), respectively.

Growth rate estimates assume that the mean weight of fish sampled from a population is unbiased by size selectivity of the sampling gear. Size related differences in mortality rate, migration of small fish in, or migration of large fish out will bias growth estimates that are based on mean size of the sample population. We have no independent measures of growth from tagging, scale, or otolith studies to validate growth estimates.

2.3 FOOD HABITS AND FEEDING INTENSITY

2.3.1 Field and Laboratory Methods

NMFS selected five individuals of each species from each sample set for stomach analysis. Each fish was injected with 20% buffered formalin solution in the field, then weighed and measured in the laboratory. The stomachs were stored in 70% ethyl alcohol until examination. Stomach contents were identified to the lowest possible taxon. Copepods were classified among three taxonomic orders (Calanoida, Cyclopoida, Harpacticoida) and were not identified to generic or species levels. Each taxa from stomach samples was blotted and air-dried for 10 minutes then weighed to the nearest 0.0001 g.

2.3.2 Analysis

The relative significance of a prey species can be expressed as a function of its numerical abundance, biomass or volume, or frequency of occurrence in fish stomachs. For each prey taxon consumed by each predator species we calculated an Index of Relative Importance (IRI) (Pinkas et al. 1971),

IRI = (% prey abundance + % prey biomass) X % freq of occurrence.

The IRI value tends to minimize bias for uncommon prey species or those with a high biomass and very low abundance or visa versa. A single IRI value was calculated by prey and predator species for all stations combined during each of the three hydrologic seasons. In order to compare stomach contents for different fish predators, each prey IRI value was expressed as a percentage of the total of all prey values calculated for each predator species,

$$\% \text{ TOTAL IRI}_i = \frac{\sum_{j=1}^{n} \text{IRI}_{ij}}{\sum_{j=1}^{n} \sum_{i=1}^{m} \text{IRI}_{ij}} \times 100$$

where: IRI_{ij} = Index of Relative Importance for prey taxa i in fish j
n = total number of fish sampled of a single taxa
m = Total number of all prey taxa.

We used total wet weight of stomach contents as a relative index of the amount of food consumed for a particular area or sample date. The Index of Feeding Intensity was expressed as a percentage of the total wet body weight of the predator:

$$\text{IFI} = \frac{\text{Total weight of prey}}{\text{Total weight of predator}} \times 100.$$

2.4 SALMONID MIGRATION RATES

We used records from the Washington Department of Fisheries (WDF), and Washington Department of Game (WDG), Oregon Department of Fish and Wildlife (ODFW), Idaho Department of Fish and Game (IFG), and the U.S. Fish and Wildlife Service (USFWS) to calculate numbers of juvenile salmonids released from hatcheries into the Columbia River.

Migration rates were calculated from release sites to recapture sites using data provided by NMFS and Dawley et al. (1982). Comparisons were made among groups with the largest number of tagged fish released each year. Hatchery groups with fewer than 5,000 marked fish were not compared nor were tagged groups of fish trucked for release below Bonneville Dam. We compared migration rates for groups that were recaptured at both RM-45 (Jones Beach) and in the north channel at RM-10 (near McGowan). Hatcheries below RM-45 were not included in the comparison.

3. RESULTS

3.1 ESTUARINE FISH COMMUNITY

During the 18-month NMFS survey, 75 fish species were collected (Table 2). Mean catches of 49 species and life history stages are listed in Table 3. These results represent the average catch for all three gear types combined for each calendar season and the entire survey. Mean abundance was greatest in the summer. Subyearlings of starry flounder, shiner perch, Pacific herring, longfin smelt, English sole, and chinook salmon accounted for a large portion of the summer catch. Of the species collected in the estuary all year, the most abundant included subyearling chinook salmon, yearling and older longfin smelt, starry flounder, Pacific tomcod, yearling and older shiner perch, yearling and older Pacific herring , Pacific staghorn sculpin, surf smelt, and threespine stickleback. Some species (e.g., yearling American shad, yearling lonfin smelt, and staghorn sculpin) were captured all year in all areas of the estuary with all gear types. A more detailed summary of the seasonal and areal residence of each fish species in the estuary is presented in Appendix C.

Table 4 lists average seasonal abundance (catch-per-unit effort) and densities for all species of fish at each station. Average catch for all species combined was usually greatest in shallow bays and in a broad mid-estuary region between RM-7 and RM-21. Large numbers of fish were frequently caught in Baker Bay, Youngs Bay, and Grays Bay at trawl stations 3,6,9, and 16 and at beach seine sites 5 and 11. Relatively high mid-estuary catches occurred during most months at trawl stations 6,7,9, and 13; purse seine stations 6 and 8-10; and beach seine stations 4-6. Estimated densities of fish were frequently high at these same stations. Seasonal mean catch of fish was relatively low throughout the year at purse seine stations above RM-20 (11-16) and at trawl sites above RM-18 (14,15 and 17-22). Seasonal average catches in the beach seine were lowest near the estuary mouth at stations 1 and 3 except during spring.

3.2 SPECIES ASSEMBLAGES

Results of cluster analysis by NMFS using average density data for each species during each calendar season are shown in Figure 3. We arbitrarily divided clusters at the 0.7 level of dissimilarity to identify major species assemblages.

For all seasons cluster analysis grouped the most abundant demersal fishes into a single euryhaline assemblage. Pacific tomcod, Pacific staghorn sculpin, starry flounder, shiner perch, and a pelagic species--longfin smelt--were classified in the same assemblage during at least three of the four calendar seasons. A second demersal assemblage comprised of marine species could be identified during most time periods, although abundance of these fishes was low relative to the euryhaline demersal group. Butter sole, sand sole, English sole, and speckled sanddab were consistently represented in the marine

Table 2. Species of fish taken in the Columbia River Estuary between February 1980 and July 1981 (from NMFS 1981).*

Common Name	Scientific Name
Pacific lamprey	Lampetra tridentata
River lamprey	Lampetra ayresi
Spiny dogfish	Squalus acanthias
Big skate	Raja binoculata
Green sturgeon	Acipenser medirostris
White sturgeon	Acipenser transmontanus
American shad	Alosa sapidissima
Pacific herring	Clupea harengus pallasi
Northern anchovy	Engraulis mordax
Chum salmon	Oncorhynchus keta
Coho salmon	Oncorhynchus kisutch
Sockeye salmon	Oncorhynchus nerka
Chinook salmon	Oncorhynchus tshawytscha
Mountain whitefish	Prosopium williamsoni
Cutthroat trout	Salmo clarki
Steelhead	Salmo gairdneri
Whitebait smelt	Allosmerus elongatus
Surf smelt	Hypomesus pretiosus
Night smelt	Spirinchus starksi
Longfin smelt	Spirinchus thaleichthys
Eulachon	Thaleichthys pacificus
Common carp	Cyprinus carpio
Peamouth	Mylocheilus caurinus
Northern squawfish	Ptychocheilus oregonensis
Largescale sucker	Catostomus macrocheilus
Yellow bullhead	Ictalurus natalis
Brown bullhead	Ictalurus nebulosus
Pacific hake	Merluccius productus
Pacific tomcod	Microgadus proximus
Walleye pollock	Theragra chalcogramma
Threespine stickleback	Gasterosteus aculeatus
Bay pipefish	Syngnathus leptorhynchus
Pumpkinseed	Lepomis gibbosus
Warmouth	Lepomis gulosus
Bluegill	Lepomis macrochirus
Largemouth bass	Micropterus salmoides
White crappie	Pomoxis annularis
Black crappie	Pomoxis nigromaculatus
Yellow perch	Perca flavescens
Redtail surfperch	Amphistichus rhodoterus
Shiner perch	Cymatogaster aggregata
Striped seaperch	Embiotoca lateralis
Spotfin surfperch	Hyperprosopon anale
Walleye surfperch	Hyperprosopon argenteum
Silver surfperch	Hyperprosopon ellipticum

Table 2 (continued)

Common Name	Scientific Name
White seaperch	Phanerodon furcatus
Pile perch	Rhacochilus vacca
Pacific sandfish	Trichodon trichodon
Snake prickleback	Lumpenus sagitta
Saddleback gunnel	Pholis ornata
Pacific sand lance	Ammodytes hexapterus
Bay goby	Lepidogobius lepidus
Black rockfish	Sebastes melanops
Kelp greenling	Hexagrammos decagrammus
Lingcod	Ophiodon elongatus
Padded sculpin	Artedius fenestralis
Coastrange sculpin	Cottus aleuticus
Prickly sculpin	Cottus asper
Buffalo sculpin	Enophyrs bison
Red Irish lord	Hemilepidotus hemilepidotus
Pacific staghorn sculpin	Leptocottus armatus
Cabezon	Scorpaenichthys marmoratus
Warty poacher	Ocella verrucosa
Tubenose poacher	Pallasina barbata
Pricklebreast poacher	Stellerina xyosterna
Slipskin snailfish	Liparis fucensis
Showy snailfish	Liparis pulchellus
Ringtail snailfish	Liparis rutteri
Pacific sanddab	Citharichthys sordidus
Speckled sanddab	Citharichthys stigmaeus
Butter sole	Isopsetta isolepis
English sole	Parophrys vetulus
Starry flounder	Platichthys stellatus
C-O sole	Pleuronichthys coenosus
Sand sole	Psettichthys melanostictus
Larval smelt	
Larval flatfish	
Other larval fish	
Adult coho	Oncorhynchus kisutch
Adult chinook	Oncorhynchus tshawytscha
Adult steelhead	Salmo gairdneri
Totals	

* Species list includes results of 14 trapnet surveys in tributaries, coves, and sloughs of the estuary (NMFS 1981). Trapnet counts are not included among analyses for this report.

Table 3. Mean catch for 49 species and life history stages of fish during NMFS survey of Columbia River Estuary. Results combine catches for all gear types during four calendar seasons, February 1980 through July 1981. See METHODS for definition of calendar seasons.

Species	Winter (5 Months)	Spring (6 Months)	Summer (4 Months)	Autumn (3 Months)	Entire Survey (18 Months)
American shad (0)	0	0.2	112.8	1503.3	275.7
American shad (1)	266	150	410.8	19	218.3
American shad (2)	3.4	25	28	2.7	15.9
Big skate	0.6	0.3	0.8	1	0.6
Butter sole	16.4	25.3	3.3	5.3	14.6
Carp	123	2.3	1.5		1.1
Chinook salmon (0)	63	930.5	1062.5	39	570.3
Chinook salmon (1)	14.2	178.2	0.8	10.7	65.3
Chum salmon	0.2	5.0	0	0	1.7
Coho salmon	0.4	441	15.3	15.3	150.5
Cutthroat trout	0	5.3	6.3	0.7	3.3
English sole (0)	6.2	36.3	397.8	126.7	123.3
English sole (1 and 2)	18.4	8.5	13.0	2.7	11.3
Eulachon	385.2	2.7	0	1	108.1
Largescale sucker	4.4	12.7	33.5	24.7	17
Lingcod	0	0.5	1.5	0.7	0.6
Longfin smelt (0)	0.2	0	1075.5	428.3	310.4
Longfin smelt (1 and 2)	934.2	337.7	1273.5	518.3	741.4
Northern anchovy (0)	0	0	0	303	50.5
Northern anchovy (1 and 2)	224.4	56.7	1130	5.3	333.2
Northern squawfish	0	0.2	2	1	0.7
Pacific herring (0)	0	12.2	2492.5	320.7	611.4
Pacific herring (1 and 2)	7.8	750.7	700.3	46.7	415.8
Pacific lamprey	3.0	0.3	0	6.3	2
Pacific sand lance	179.6	25.7	274.3	47.0	127.2
Pacific staghorn sculpin	444.4	390	299.8	408.3	388.1
Pacific tomcod	322.8	213.5	934.5	635.7	474.4
Peamouth	9.4	48.2	285	77.3	94.9
Prickly sculpin	131.4	89	296.5	247	173.2
Redtail surfperch	0.6	1.8	3.8	3.3	2.2
River lamprey	0	2	7.3	0	2.3
Saddleback gunnel	2.4	3.3	0.8	2.3	2.3
Sand sole	28.8	10.5	17	11.7	17.2
Shiner perch (0)	0	2.2	2174.8	358.7	543.8
Shiner perch (1 and 2)	3.0	234.2	1419.3	165	421.8
Showy snailfish	0.2	1.5	0.3	0.7	0.7
Snake prickleback	70.4	118.2	215.3	55.3	116
Sockeye salmon	0.2	8.3	2.3	0	3.3
Speckled sanddab	2.2	2.2	2.5	3.7	2.5
Spiny Doofish	0	0.2	5.3	4.7	2
Spotfin surfperch	0.8	1.2	1.5	8	2.3
Starry flounder (0)	0	23.3	380.3	293	141
Starry flounder (1)	391.2	370.5	819.8	603	514.8
Starry flounder (2)	393.8	228.3	268.8	73.3	257.4
Steelhead (Rainbow trout)	1.8	146.3	1.5	0.3	49.7
Surf smelt	78.0	215.2	1169.5	13.7	355.6
Threespine stickleback	725.6	144.8	253.5	161.3	305.2
White sturgeon	3.2	2.7	7.8	3.7	4.1
Whitebait smelt	12.6	2.7	724.8	44	172.8

Table 4. Catch per unit effort and mean density for four calendar seasons for all fish captured at each station, February 1980 through July 1981. See METHODS for definition of calendar seasons.

	Winter (5 Months)		Spring (6 Months)		Summer (4 Months)		Autumn (3 Months)	
Station	CPUE	Mean Density ($x 10^{-4}$)	CPUE	Mean Density ($x 10^{-4}$)	CPUE	Mean Density ($x 10^{-4}$)	CPUE	Mean Density ($x 10^{-4}$)
101	49.4	168	6.7	23	58.5	199	13	44
102	6.8	23	6.5	22	72.3	246	12.3	42
103	38.4	130	55.7	189	147.5	501	183	622
104	6.6	22	9.7	33	57	194	13.7	47
105	15	51	15.3	52	57.5	195	25.3	86
106	38.6	131	63.3	215	737	2503	208	707
107	43.2	147	11.2	38	155.8	529	63.7	216
108	19.4	66	17.2	58	51	173	29.7	101
109	39.8	135	50.7	172	62	211	148.7	505
110	37.2	126	26.3	89	26.8	91	38	129
111	42.2	143	13.0	44	29	99	18.7	64
112	37.4	127	25.5	87	29.8	101	28	95
113	47.2	160	26.3	89	35.8	122	69.3	235
114	23.6	80	10	34	17.8	60	27	92
115	8.8	30	11.5	39	6.3	21	11	37
116	35.4	120	20	68	73.5	250	102.3	347
117	3.6	12	2.2	7	2	7	6.3	21
118	25.8	88	2.5	8	1.8	6	18.7	64
119	15.6	53	2.2	7	2	7	14	48
120	7.8	26	3	10	14	48	22.3	76
121	14.8	50	2.3	8	22.5	76	45.3	154
122	4.8	16	0.7	2	2.3	8	1.3	4
301	1.6	2	25.5	32	307.5	386	20	25
302	2.8	4	76.3	96	547	687	6.7	8
303	18.6	23	19.7	25	171.5	215	90	113
304	15	19	20.2	25	52.8	66	19	24
305	24.2	30	25.2	32	100.5	126	25	31
306	47.4	60	62.3	78	166.3	209	32.7	41
307	12.4	16	16.2	20	72.8	91	20.3	26
308	30.4	38	29.7	37	392	493	45.3	57
309	32.6	41	12.3	15	119.8	151	173.3	218
310	132	31	20	25	116	146	127.3	160
311	24.4	14	14	18	39.8	50	87	109
312	4.2	15	10.7	13	36.3	46	118.7	149
313	4.2	16	25.7	32	6.3	8	20	25
314	7.8	18	15.7	20	41.8	53	78.7	99
315	3.6	19	17.2	22	10.3	13	24.7	31
316	7.4	20	42.3	53	17.3	22	32	40
701	0.6	2	15	55	23	85	2.7	10
702	4.6	17	22.5	83	86	317	2.7	10
703	1.8	7	31	114	16	59	1	4
704	3.4	13	23	85	70.3	259	21.3	79
705	10.2	38	32.3	119	125.3	462	38	140
706	9.2	34	40	147	77.3	285	15.7	58
707	2.4	9	18.2	67	64.5	238	4.7	17
708	5.8	21	19.7	73	38.5	142	31.7	117
709	7.4	27	13.8	51	41.8	154	32.3	119
710	7.6	28	15.2	56	35.3	130	41.3	152
711	9	33	21.7	80	189.5	698	8.7	32

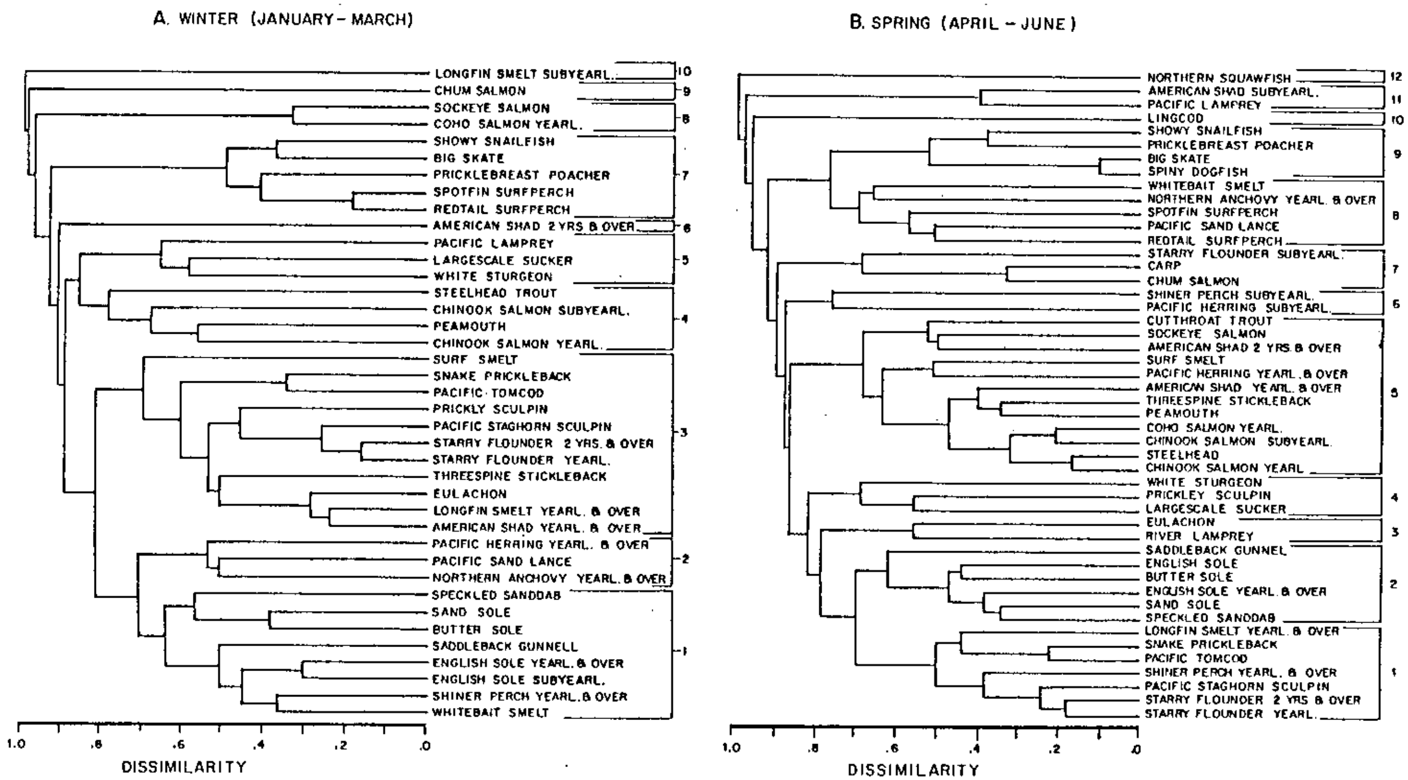


Figure 3 (A-B). Fish taxa-life history assemblages from NMFS average density data for winter (A) and spring (B) calendar seasons.

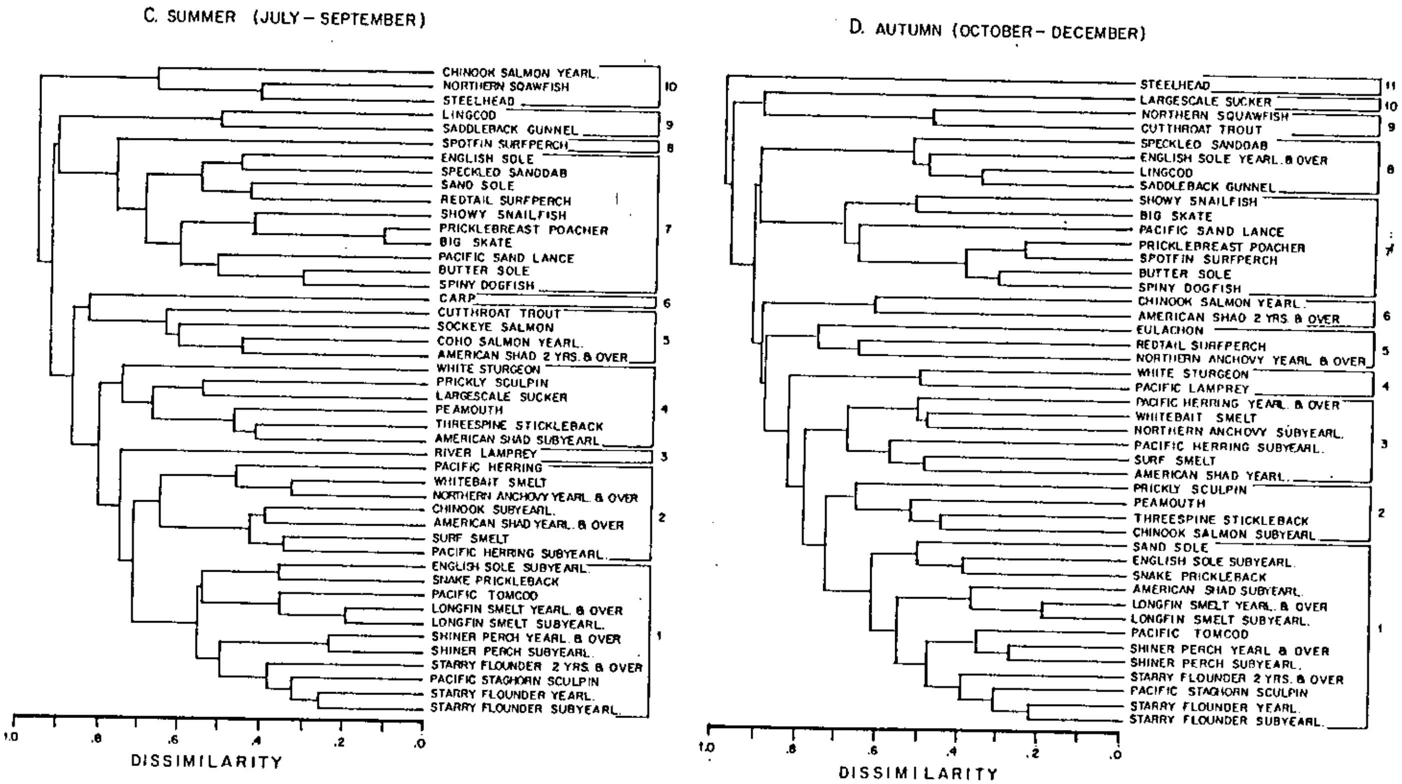


Figure 3 (C-D). Fish taxa-life history assemblages from NMFS average density data for summer (C) and autumn (D) calendar seasons.

demersal group.

One or two predominant pelagic assemblages were identified for each calendar season. Northern anchovy, Pacific herring, and Pacific sand lance were associated during winter (Figure 3A). A large Pacific herring, American shad, and salmonid asssemblage occurred during spring (Figure 3B). Subyearling chinook salmon were associated with a large summer pelagic assemblage that also included Pacific herring, whitebait smelt, Northern anchovy, American shad, and surf smelt (Figure 3C). Most of these same species were also grouped in a single assemblage during autumn (Figure 3D).

Changes in species composition of fish assemblages coincided with the seasonal migration and life cycles of individual taxa. Subyearlings of starry flounder, shiner perch, and Pacific herring appeared in samples during the spring and were collected in greatest number during summer. A large salmonid assemblage in spring was comprised of juveniles that migrated into the estuary from freshwater. Abundance of steelhead trout and coho, sockeye, and chum salmon declined in the summer as juveniles migrated out of the estuary. Chinook salmon was the only salmonid species captured in significant numbers during the winter.

3.3 STATION CLUSTERS

In Figure 4 we have grouped stations in the Columbia River Estuary that had a similar species composition and density based on NMFS cluster analysis (Appendix D). Station groups were discriminated at the 0.5 level of dissimilarity when divisions were unclear.

For all calendar seasons cluster analyses segregated sampling stations into two to four zones along a salinity gradient from lower to upper estuary. In nearly all cases purse seine, beach seine, and bottom trawl stations were placed in separate cluster groups. Winter fish assemblages were divided into three trawl, three purse seine, and two beach seine groups (Figure 4A). Cluster groups for autumn (Figure 4D) were similar to winter except the freshwater purse seine stations were also divided into upper and lower subgroups near RM-22. Spring trawl stations were split into two freshwater zones--a large mid-estuary region, and a small marine zone near the month (Figure 4B). Purse seine stations were divided into upper and lower estuary groups, and beach seine stations were segregated into three zones. River flows decreased and the boundaries for each zone extended upriver in summer (Figure 4C) relative to other calendar seasons. Summer station groups were divided among three major zones of the estuary that were similar to the zones defined for other seasonal periods.

Results of cluster analyses that combined FRI surveys with NMFS surveys for three representative months are shown in Figure 5 and summarized in Figure 6. Station clusters for January 1981 (Figure 6A) divided the estuary into three zones that were almost identical to NMFS results for winter and autumn calendar seasons (Figure 4A,D). In

May the additional FRI survey sites produced distinct beach seine and trawl station clusters for Baker and Youngs Bay (Figure 6B) that were not represented in results for any of the calendar seasons. Three major zones were defined for May. The divisions between trawl zones was located further upriver than for the spring seasonal average (Figure 4B). This suggested a sharper salinity stratification in the estuary during May compared with the spring average. The channel bottom marine zone (trawl stations) shifted upriver in May compared with January. However, water column (purse seine) and nearshore (beach seine) freshwater regions were located downriver relative to January. In August 1980 (Figure 6C) FRI stations again were grouped in a distinct bay assemblage that was not apparent for any of the NMFS calendar seasons. As in May, the bay group included trawl and beach seine stations in Youngs and Baker Bay plus an additional group of two shoal stations on Desdemona Sands. Three zones in August extended further upriver compared with results for winter or spring calendar seasons (Figure 4A,B).

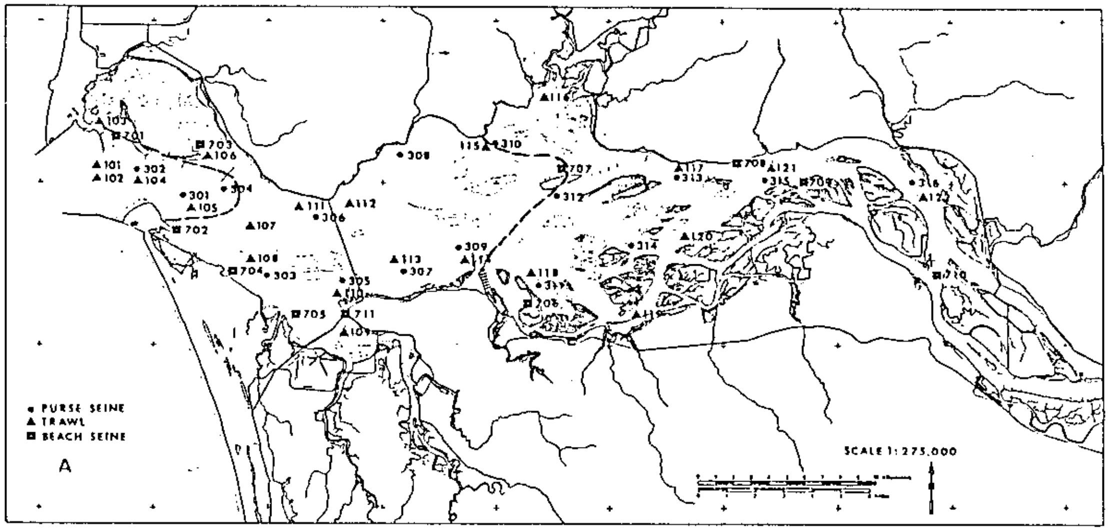
The results of cluster analyses for all calendar seasons and representative months are generalized for the entire year in Figure 7. Fishes were usually distributed among three major salinity zones, although the location of these zones varied with depth and seasonal river flow conditions. There was usually a lower boundary near RM-7 that segregated the lower estuary ("marine") and mid-estuary ("estuarine-mixing") zones. The upper boundary between estuarine mixing and freshwater zones was located near RM-18. Within each of these zones fishes were distributed among five major habitats. One of these--lower and mid-estuary bay habitat--is identified in Figure 7. Although not segregated in Figure 7, fish composition and densities also were divided among water column (purse seine), channel bottom (trawl), shoal (beach seine and trawl), and nearshore (beach seine) habitats.

3.4 DISTRIBUTION OF SPECIES ASSEMBLAGES

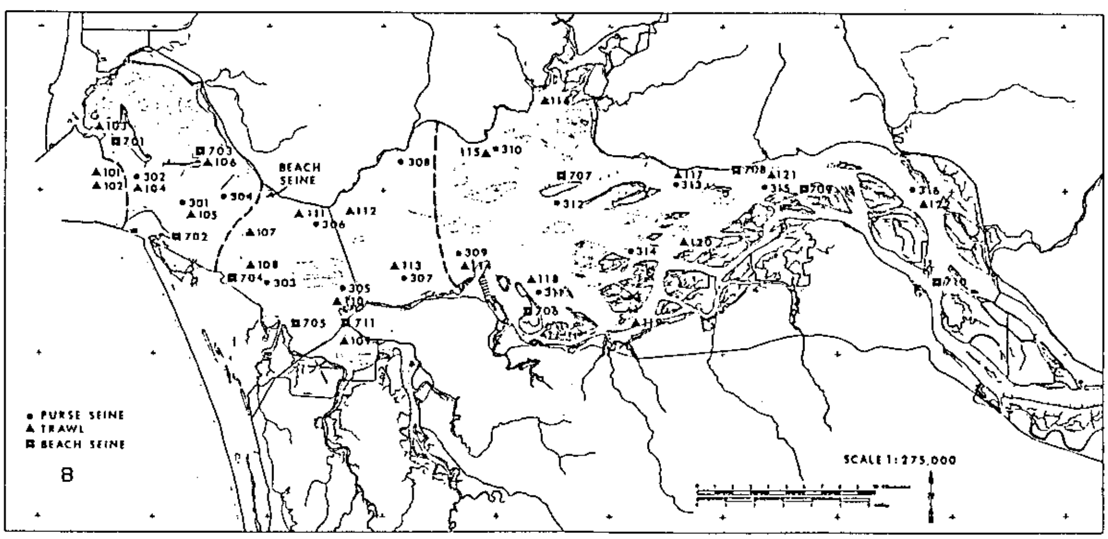
The nodal analysis of constancy compared species with station clusters (Figure 5) for the three representative months to describe the distribution of fish assemblages in the estuary (Figures 8, 10, and 12). From this analysis we arbitrarily defined a 0.5 or greater level of constancy as the primary distribution of each assemblage and summarized these distributions in Figures 9, 11, and 13. Our descriptions of fish distributions relative to marine, estuarine-mixing, and freshwater zones refers to the general regions of the estuary defined for the entire year (Figure 7). The actual location of these zones changed seasonally and with depth in the estuary.

3.4.1 January

In January 1981 (Figures 8 and 9) two groups of pelagic fish were captured. An assemblage composed of yearling shad, yearling longfin smelt, eulachon, and threespine stickleback occurred most frequently in purse seines in the estuarine mixing and freshwater zones and in



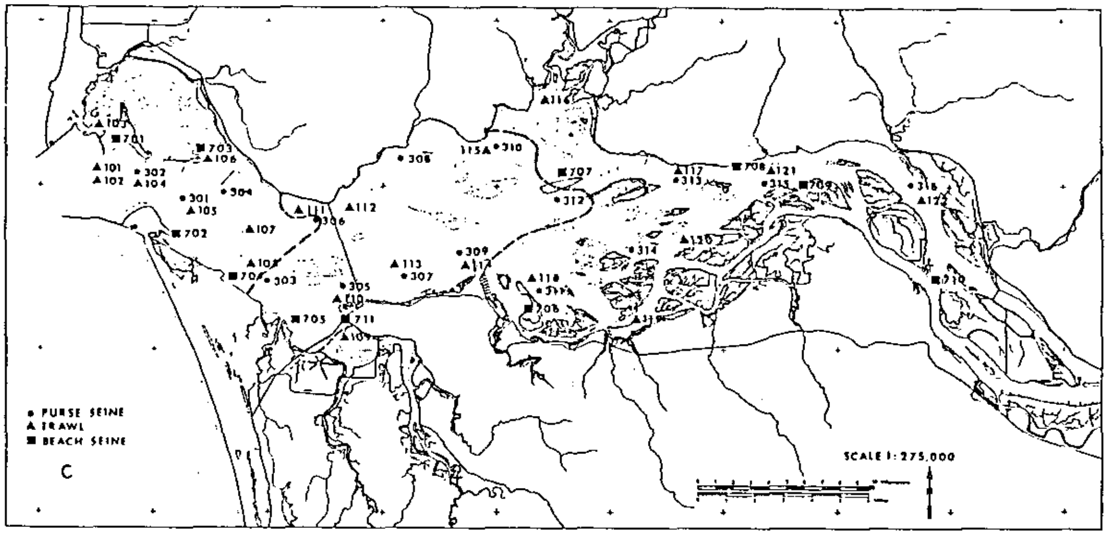
WINTER



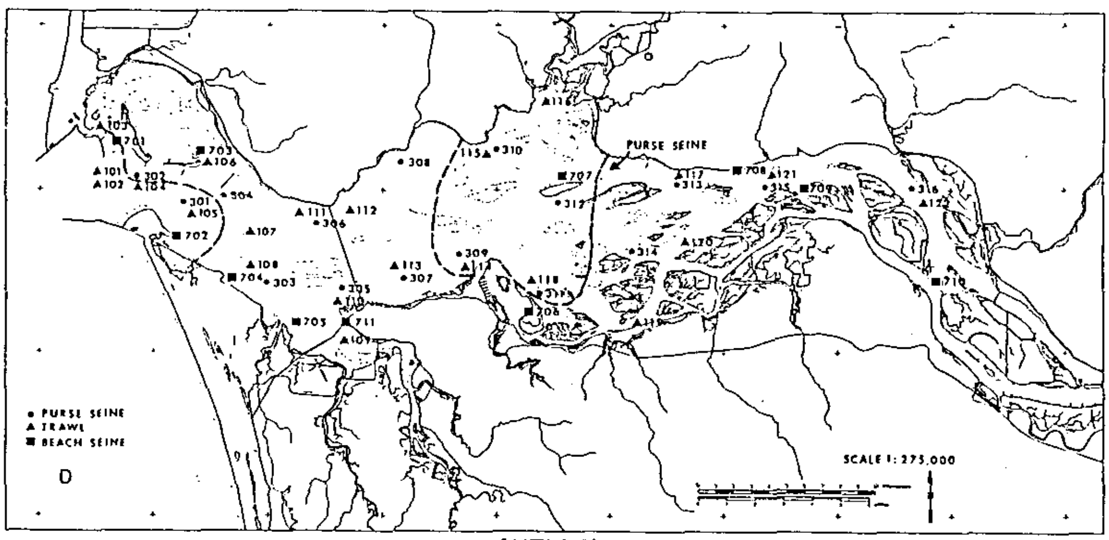
SPRING

Figure 4 (A-B). Distribution of station clusters from NMFS average density data for winter (A) and spring (B) calendar seasons. See METHODS for definition of calendar seasons.*

* Marine - estuarine mixing zone boundary further upstream for beach seine than trawl sites during spring.



SUMMER



AUTUMN

Figure 4 (C-D). Distribution of station clusters from NMFS average density data for summer (C) and autumn (D) calendar seasons. See METHODS for definition of calendar seasons.*

* Divisions between stations in autumn include a separate purse seine group in the upper freshwater zone as labeled. All other divisions apply to all three gear types.

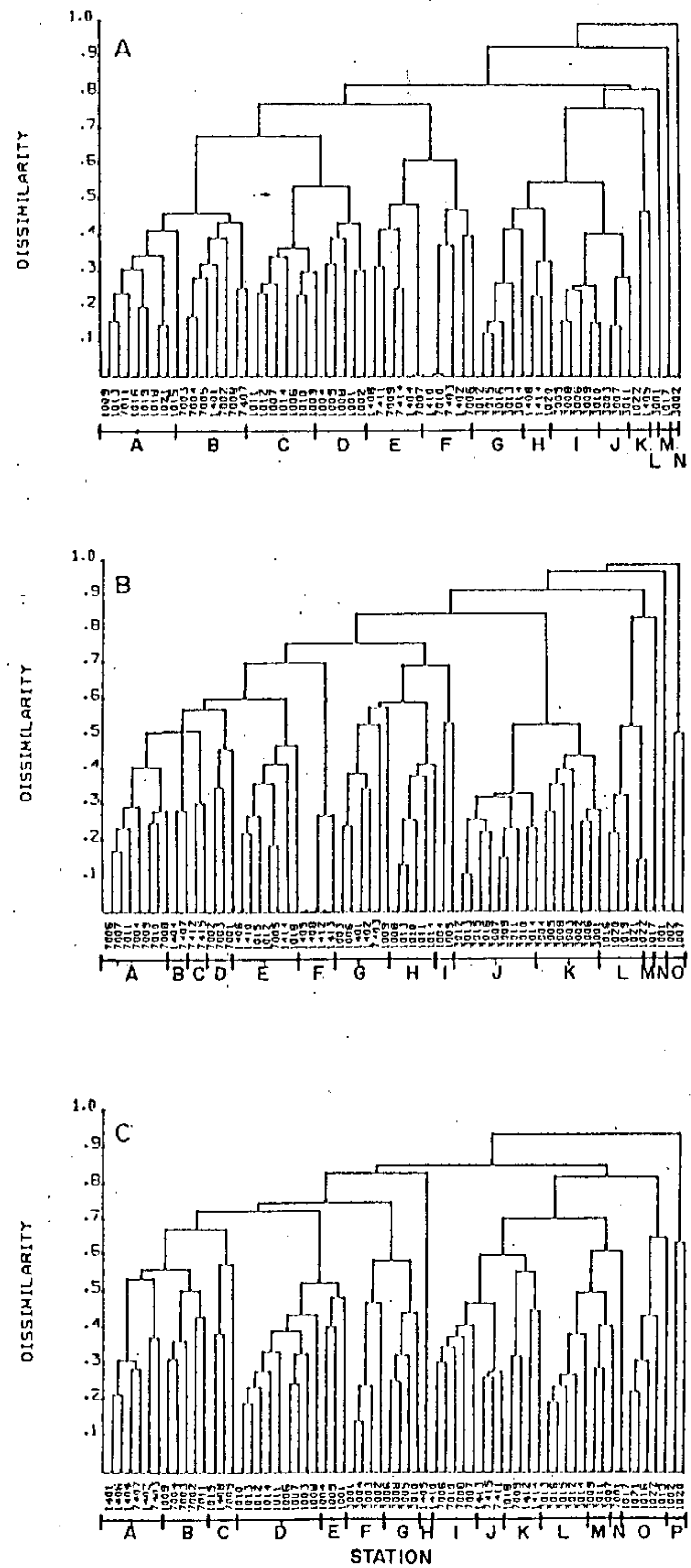


Figure 5. Station clusters from NMFS and FRI species density data for January 1981 (A), May 1980 (B), and August 1980 (C) representative months. See METHODS for description of representative months.

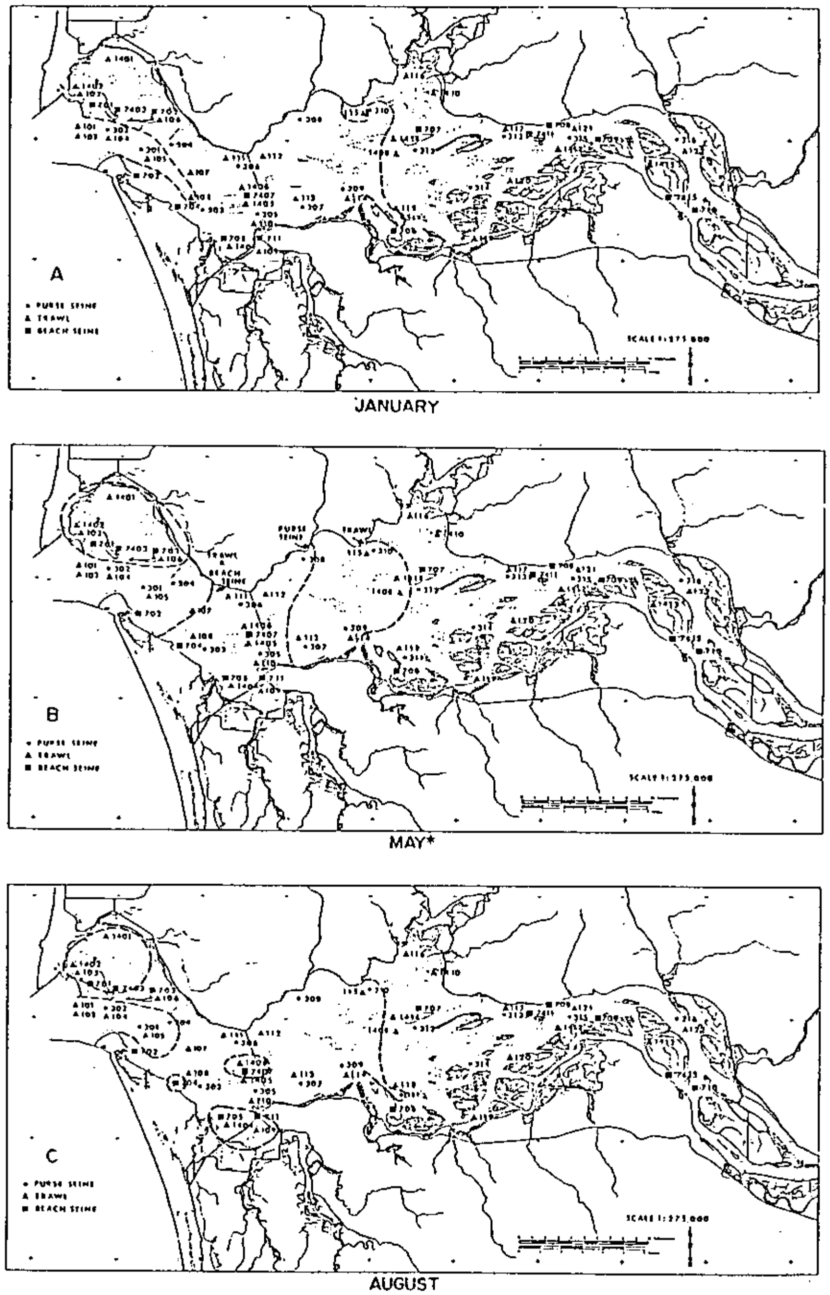


Figure 6. Distribution of station clusters from NMFS and FRI species density data for January (A), May (B), and August (C) representative months. See METHODS for description of representative months.*

*Divisions between stations in May varied with gear type as labeled. All other divisions apply to all three gear types.

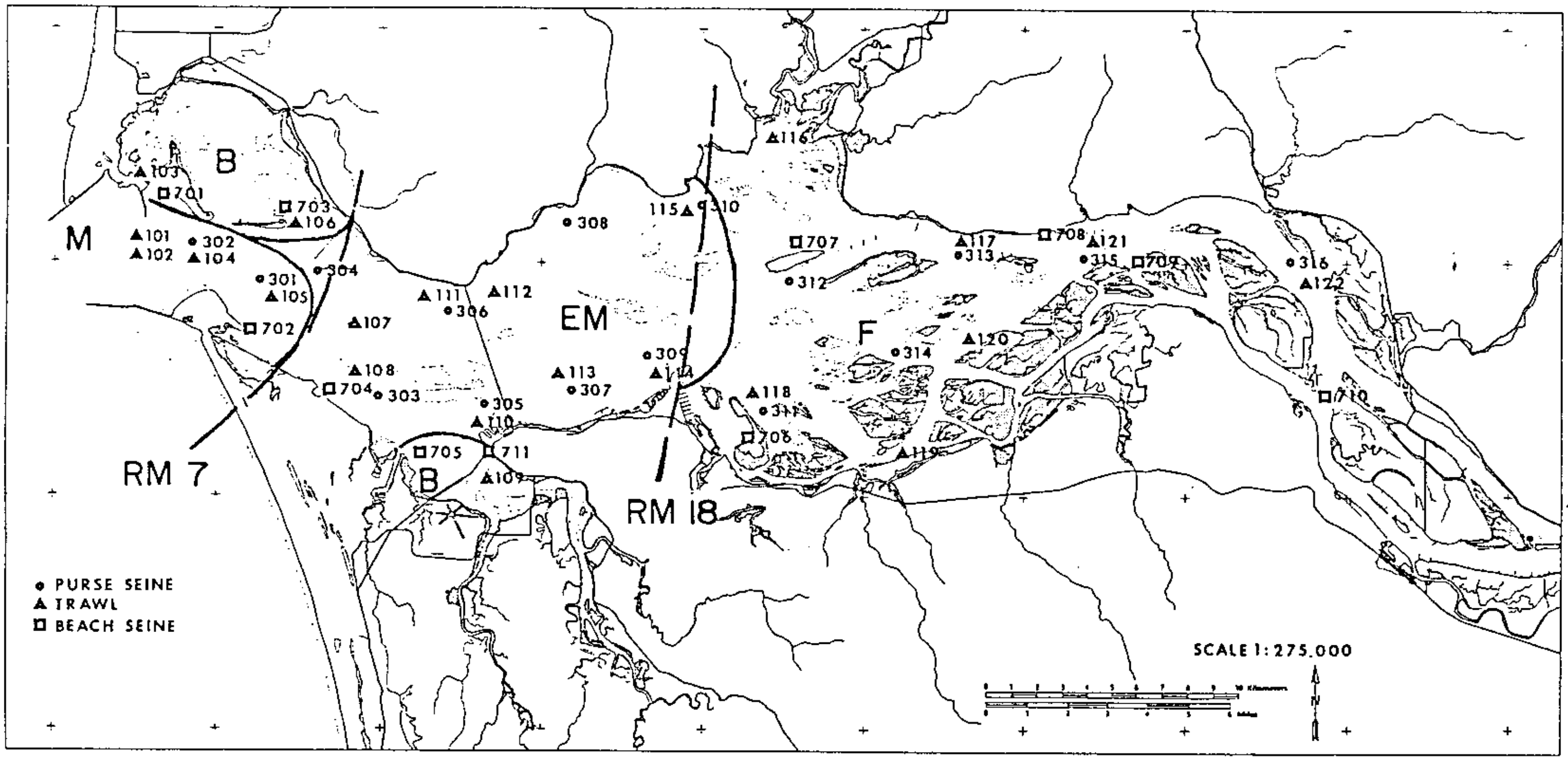


Figure 7. Summary of average distribution of station groups for the entire year. Divisions between marine (M), estuarine mixing (EM), and freshwater (F) zones and bay (B) habitats are indicated.

trawls in the marine and freshwater areas. A second group of pelagic fish consisted of two-year-old shad and surf smelt. This assemblage was sampled most frequently in the estuarine mixing zone. Anchovy, sand sole, and whitebait smelt were captured most often in trawls in the lower 11 km of the estuary.

Two major groups of demersal and epibenthic fish were present in January. Staghorn sculpin, yearling and older starry flounder, and prickly sculpin were frequently found in the estuarine mixing and freshwater zones in beach seines and trawls. These stations represented nearshore, shoal, and channel bottom habitats. Pacific tomcod, snake prickleback, yearling English sole, and butter sole were most commonly captured in trawls in the estuarine mixing zone.

3.4.2 May

Several pelagic assemblages occurred during May (Figures 10 and 11). A separate salmonid assemblage appeared in purse seine and in beach seine (nearshore) stations throughout the estuary. Yearling and older shad were captured in purse seines throughout the estuary and occasionally in trawls in the estuarine mixing zone. An assemblage of yearling longfin smelt, yearling Pacific herring, and surf smelt was commonly sampled in the marine zone in purse seines and nearshore beach seines and in the estuarine mixing zone in trawls. Northern anchovy were also caught in low numbers in purse seines at stations in the estuarine mixing and freshwater regions.

Three major fish assemblages were captured in May primarily with bottom trawls (Figures 10 and 11). In Baker and Youngs Bays and channel bottom habitats in the estuarine mixing zone, staghorn sculpin, yearling and older starry flounder, yearling shiner perch, and subyearling English sole composed a common and abundant assemblage. Prickly sculpin and peamouth represented a small freshwater group that also was caught occassionally in the estuarine mixng zone. A large group of demersal fish inhabited the marine region, and were caught less frequently in the estuarine mixing zone. The most abundant species of this group were Pacific tomcod, snake prickleback, butter sole, and yearling English sole.

3.4.3 August

There were two pelagic species groups captured during the August 1980 surveys (Figures 12 and 13). Yearling and older American shad, subyearling and yearling Pacific herring, and surf smelt were frequently caught at purse seine sites in the marine and estuarine mixing regions. An assemblage of subyearling chinook, peamouth, and three spine stickleback was common at most locations except stations sampled with the bottom trawl in the marine and estuarine mixing zones.

The most common assemblage caught throughout the estuary in August was composed of demersal species--subyearling and yearling shiner perch, subyearling starry flounder, and staghorn sculpin

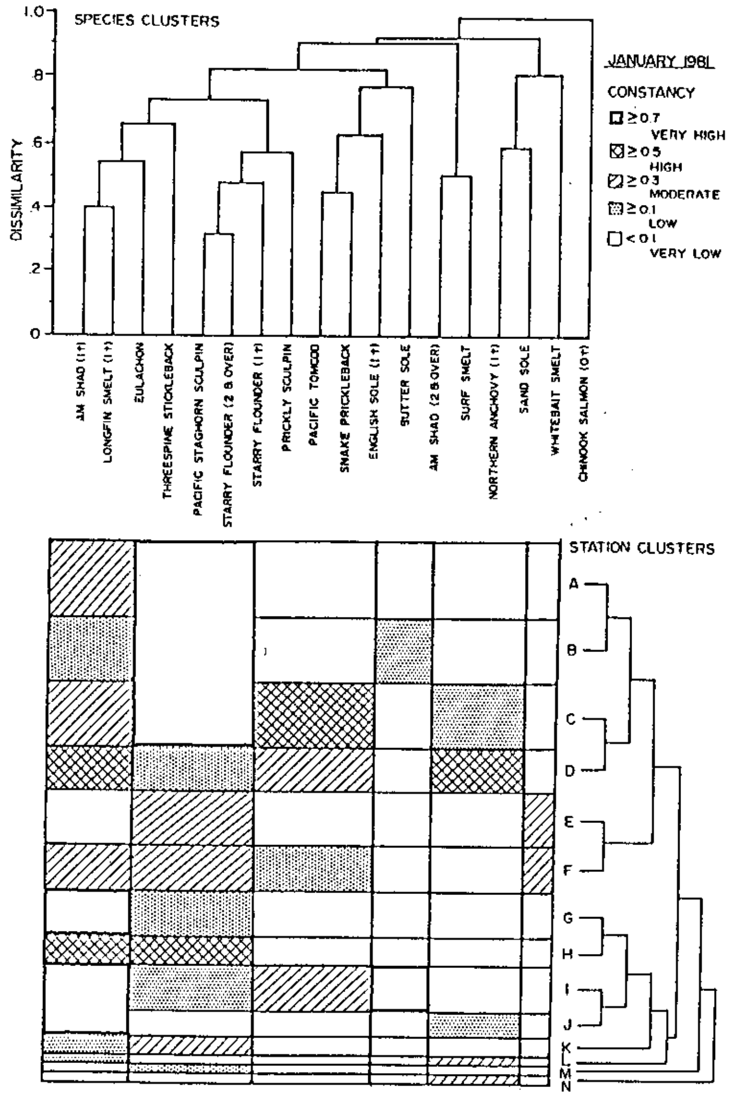


Figure 8. Nodal constancy to compare species and station clusters for January 1981. Constancy scale represents frequency of co-occurrence between each species and station cluster group. Letter designations for station clusters refer to groups listed in Figure 5 for January.

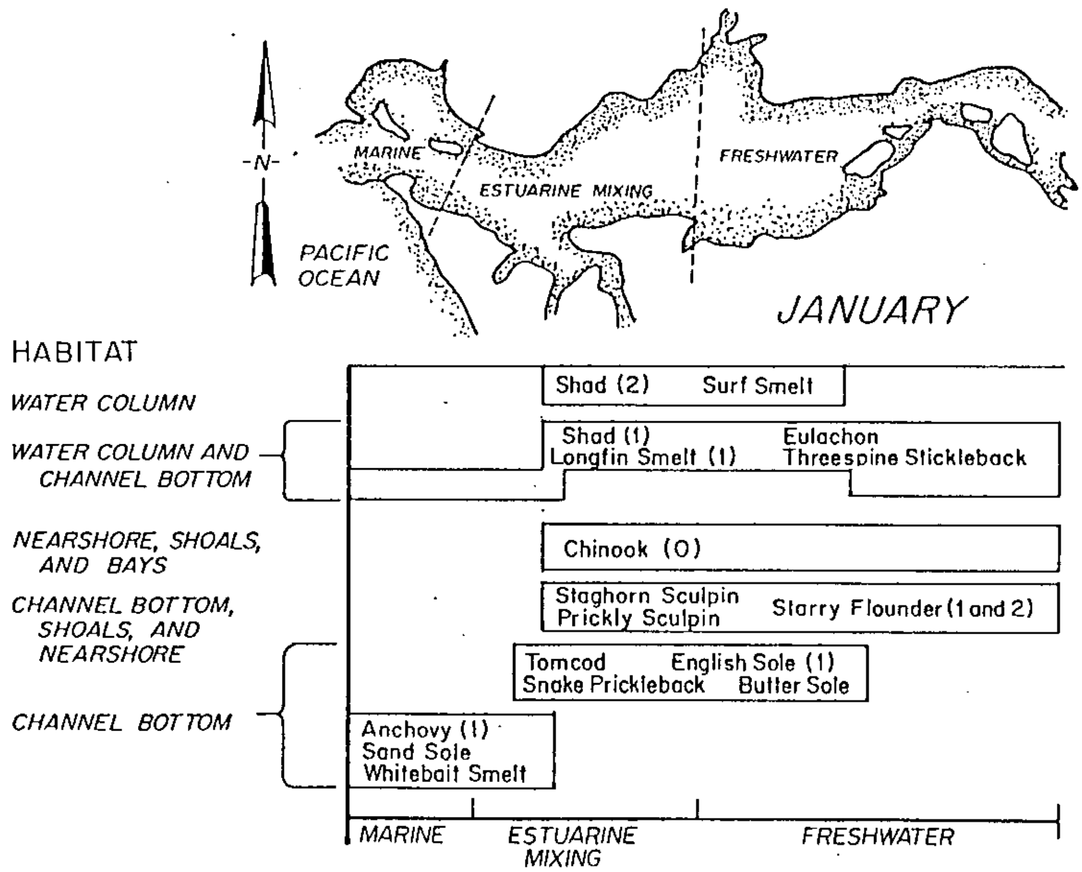


Figure 9. Summary of species assemblages and their most frequent habitats and distribution during January 1981. Distribution of assemblages depict general location of station groups where nodal constancy values (Figure 8) were ≥ .50. Boundaries of estuarine zones are an average for the entire year for comparison. See text for description of estuarine zones for each gear type for January.

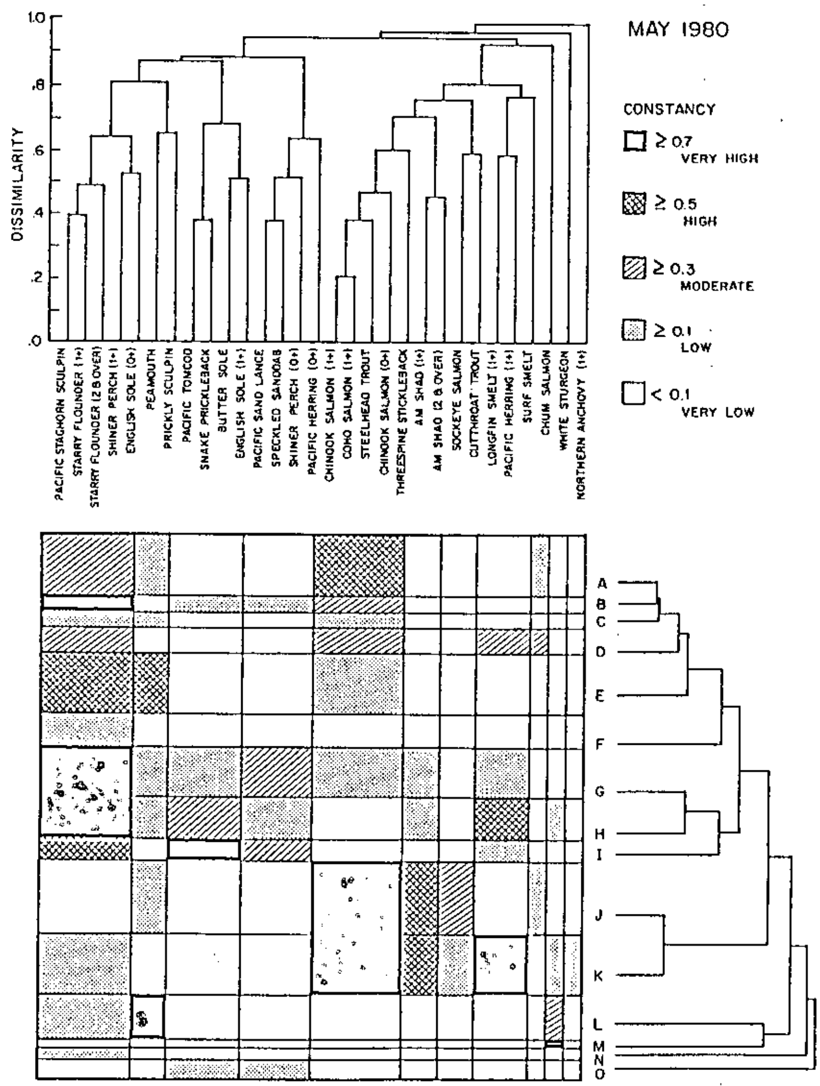


Figure 10. Nodal constancy to compare species and station clusters for May 1980. Constancy scale represents frequency of co-occurrence between each species and station cluster group. Letter descriptions for station clusters refer to groups listed in Figure 5 for May.

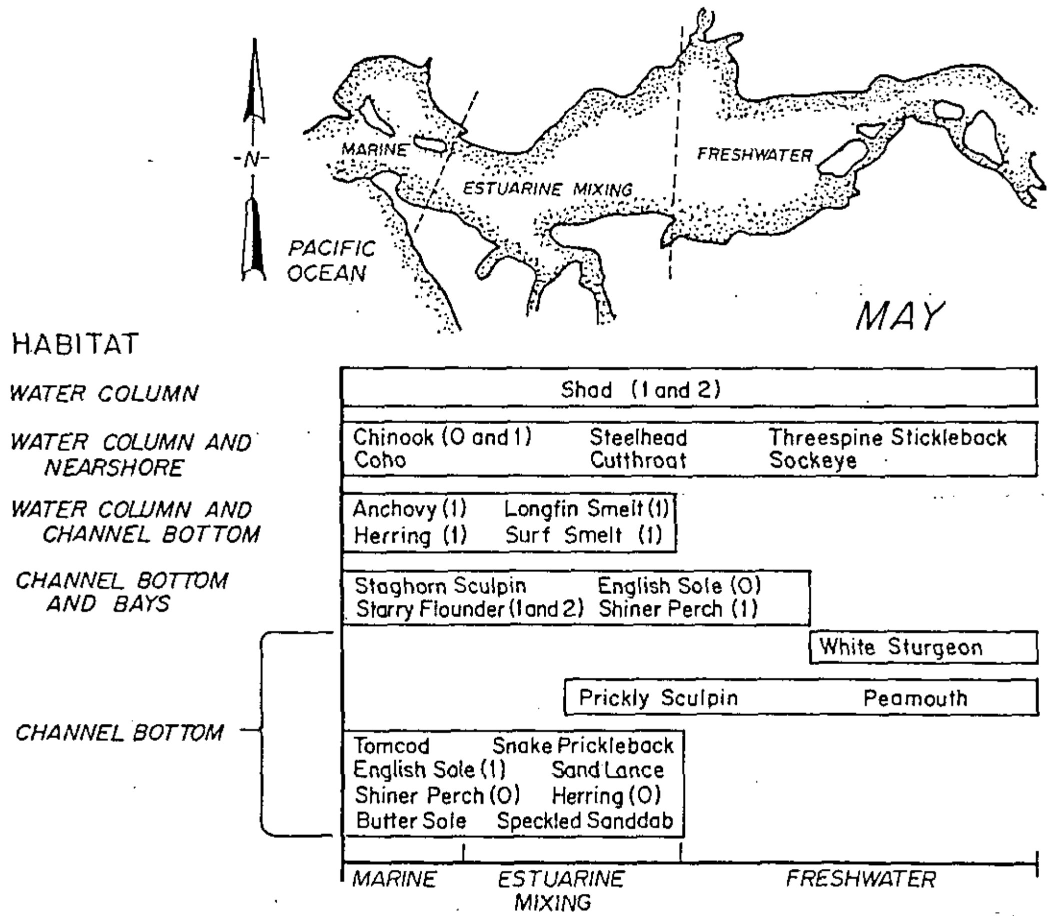


Figure 11. Summary of species assemblages and their most frequent habitats and distribution during May 1980. Distribution of assemblages depict general location of station groups where nodal constancy values (Figure 10) were $\geq$ .50. Boundaries of estuarine zones are an average for the entire year for comparison. See text for description of estuarine zones for each gear type for May.

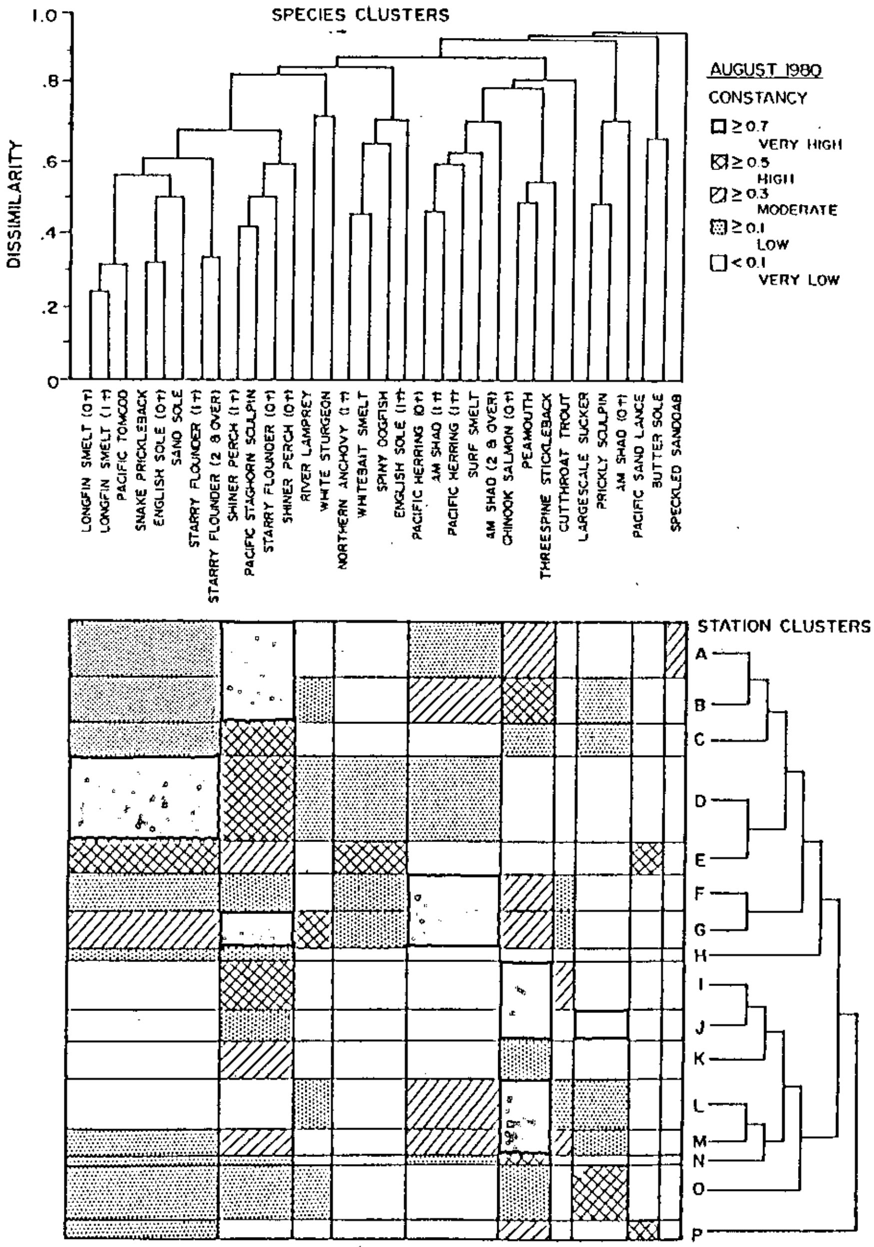


Figure 12. Nodal constancy to compare species and station clusters for August 1980. Constancy scale represents frequency of co-occurrence between each species and station cluster group. Letter designation for station clusters refer to groups listed in Figure 5 for August.

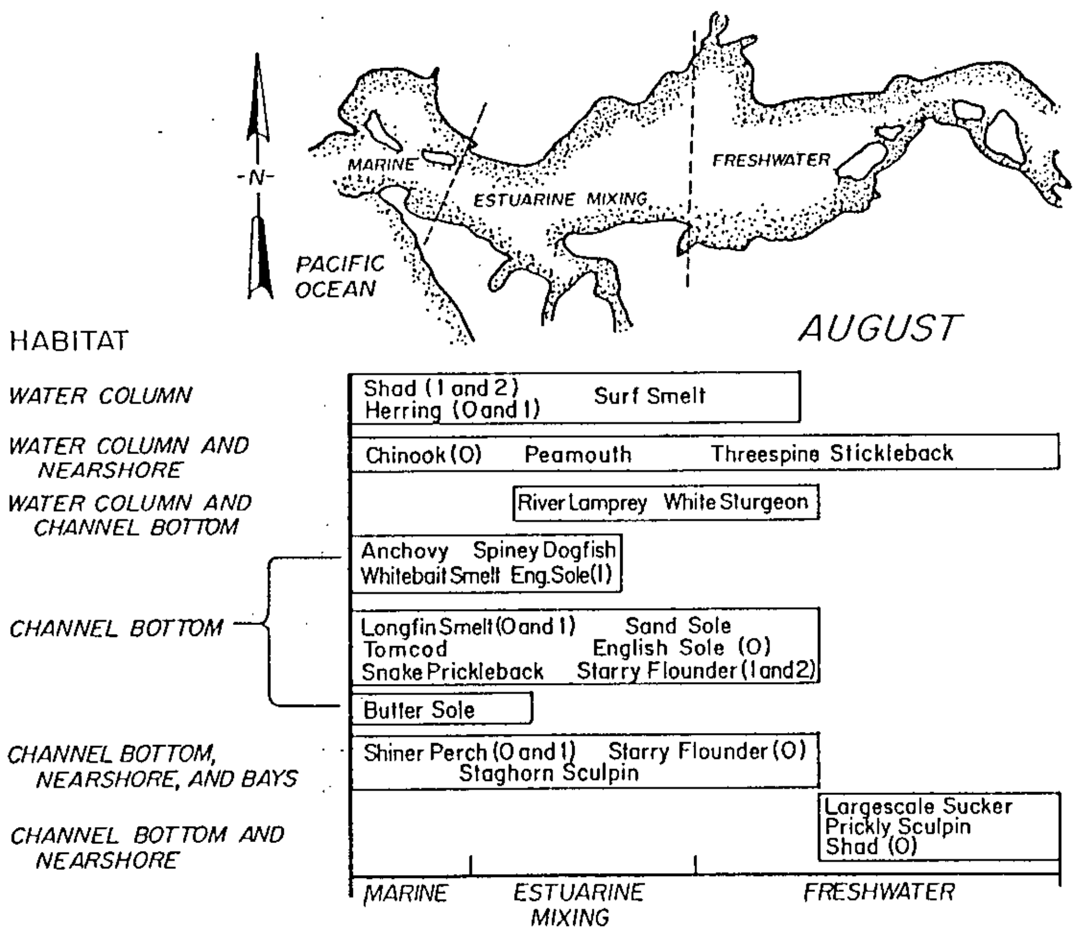


Figure 13. Summary of species assemblages and their most frequent habitats and distribution during August 1980. Distributions of assemblages depict general location of station groups where nodal constancy values (Figure 12) were $\geq .50$. Boundaries of estuarine zones are an average for the entire year for comparison. See text for description of estuarine zones for each gear type for August.

(Figures 12 and 13). These fish were extremely common in Baker Bay and Youngs Bay and throughout the estuarine mixing zone in beach seines and trawls. The only habitat in which these fish were not found was the freshwater pelagic zone.

Several additional demersal groups were identified in August (Figures 12 and 13). Subyearling and yearling longfin smelt, Pacific tomcod, snake prickleback, subyearling English sole, sand sole, and yearling starry flounder were associated throughout the estuary except in beach seines or freshwater purse seines. These fish were extremely abundant at trawl stations in the marine and estuarine mixing zones. Northern anchovy, whitebait smelt, spiny dogfish, and yearling English sole composed an uncommon demersal group captured primarily in the marine zone and occasionally in purse seines and trawls in the estuarine mixing region. Another demersal group--largescale sucker, prickly sculpin, and subyearling American shad--was usually caught in freshwater trawls and beach seines.

3.5 PHYSICAL FACTORS AND FISH DISTRIBUTION

In Figure 14 results of discriminant analyses are plotted on two axes, which represent the similarities and differences between stations. These two axes explained most of the variation in the data. For each representative month the discriminant analysis estimated that stations were correctly grouped into clusters 100% of the time.

Although the cluster technique created the impression of discrete zones in the estuary, discriminant plots show substantial overlap among some of the station clusters for each representative month. For January 1981, for example, only the channel bottom habitat in the lower estuary had a distinct fish assemblage as shown by station group 4. The first two axes accounted for 92% of the variation in the data.

For May 1980, the first two discriminant axes accounted for 74% of the variation; the first axis explained 61% of that variation. Upper (station group 9) and lower (station group 8) estuary purse seine groups separated along the first axis (Figure 14). Mid-estuary trawls (station group 6), Baker Bay and Youngs Bay stations (station group 5); upper estuary beach seines (station group 1); and two lower estary trawl stations (station group 7) also appeared as separate groups.

The discriminant analysis for August 1980 accounted for 76% of the variation in the data in the first two axes. Only the lower estuary (station group 5) and mid-estuary trawls (station group 4) were plotted as discrete station groups (Figure 14). Stations in group B were separated widely from other groups because these were the only stations where Pacific sand lance were captured (stations 102 and 120).

In contrast to discriminant analysis, reciprocal averaging considers all stations or species as members of one group. The

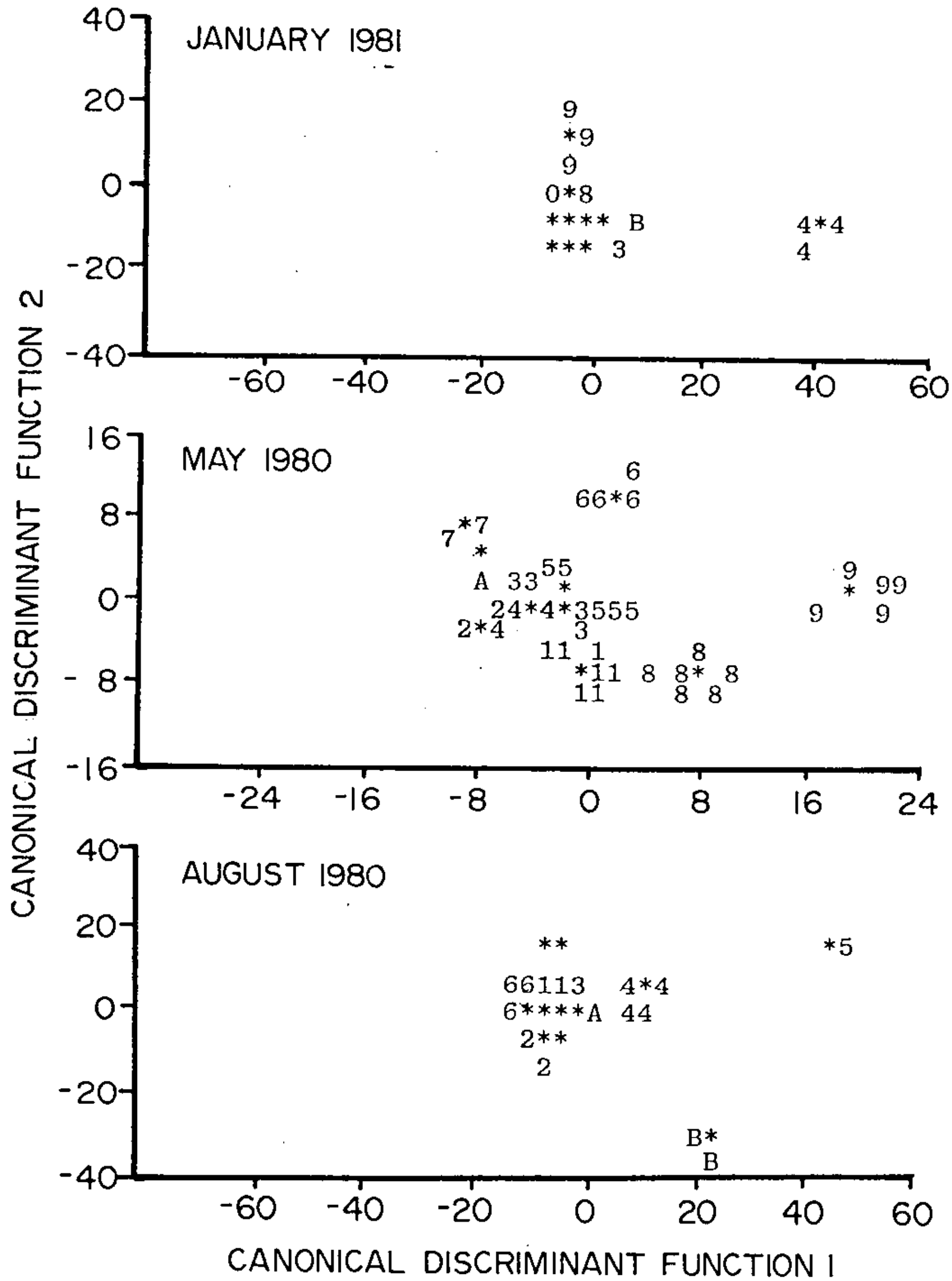


Figure 14. Discriminant analysis of station clusters for January (1981), May (1980), and August (1980). Selected cluster groups are described in text. Centroids for each cluster group are plotted as an asterisk (*).

scatter plots in Figures 15-17 describe the maximum differences between each individual station or species for each representative month without consideration of a priori groupings. Plots of individual stations indicated that fish species and life history stages were not confined to discrete zones of the estuary but were distributed along a continuum of stations that corresponded to environmental gradients. We have subjectively grouped stations to describe their arrangement along these gradients. In some cases the division between groups was clearly defined; in other cases the separation was arbitrary. For each representative month the first two axes accounted for the greatest differences among stations or species.

Reciprocal averaging plots for January 1981 data (Figure 15) arranged stations along two gradients--salinity (river mile) and habitat (gear type and depth). The purse seine stations (water column habitat) were subdivided into three salinity groups (station groups A_1, A_2, A_3). However, only the marine group was widely separated from other stations. Trawl stations also were subdivided into three salinity groups (station groups B_1, B_2, B_3). Five trawl stations (station group B_4) had a species composition similar to that of the freshwater purse seine stations (station group A_3). The beach seines also were spread along a salinity gradient (station groups C_1, D_1, C_2, D_2). Trawl and seine stations in Baker Bay and Youngs Bay were grouped as separate habitats (station groups D_1, D_2).

Results of reciprocal averaging for individual species and life history stages also reflected salinity and habitat gradients for the January catches (Figure 15). For example, eulachon was caught most often in fresh water purse seines. Subyearling chinook were caught in nearshore freshwater habitats. Pacific tomcod, snake prickleback, butter sole, sand sole, and yearling English sole were common in marine channel bottom habitats.

Results for May 1980 (Figure 16) were similar to results for January 1980. Stations distributed along the first axis suggested a habitat gradient. The spread of stations on the second axis approximated the salinity changes from lower to upper estuary. Purse seines were subdivided into upper and lower estuary zones (station groups A_1 and A_2). Nearshore stations sampled with beach seines were spread along a salinity gradient with a slight separation between upper (station group C_1) and lower estuary (station group C_2) groups. The trawl stations (channel bottoms) demonstrated the greatest variability ranging from the marine group at the bottom of Figure 16 to a freshwater group of stations at the top (station groups B_1, B_2, B_3, B_4). In the center was a group of stations in Baker Bay and Youngs Bay and a tight group of trawl sites (B_2) in the estuarine mixing zone. Included in station group D_1 were shoal habitats that are similar to the nearshore stations in the freshwater region of the estuary.

The fish species present in May 1980 were also related to environmental gradients (Figure 16). For example, sockeye salmon and

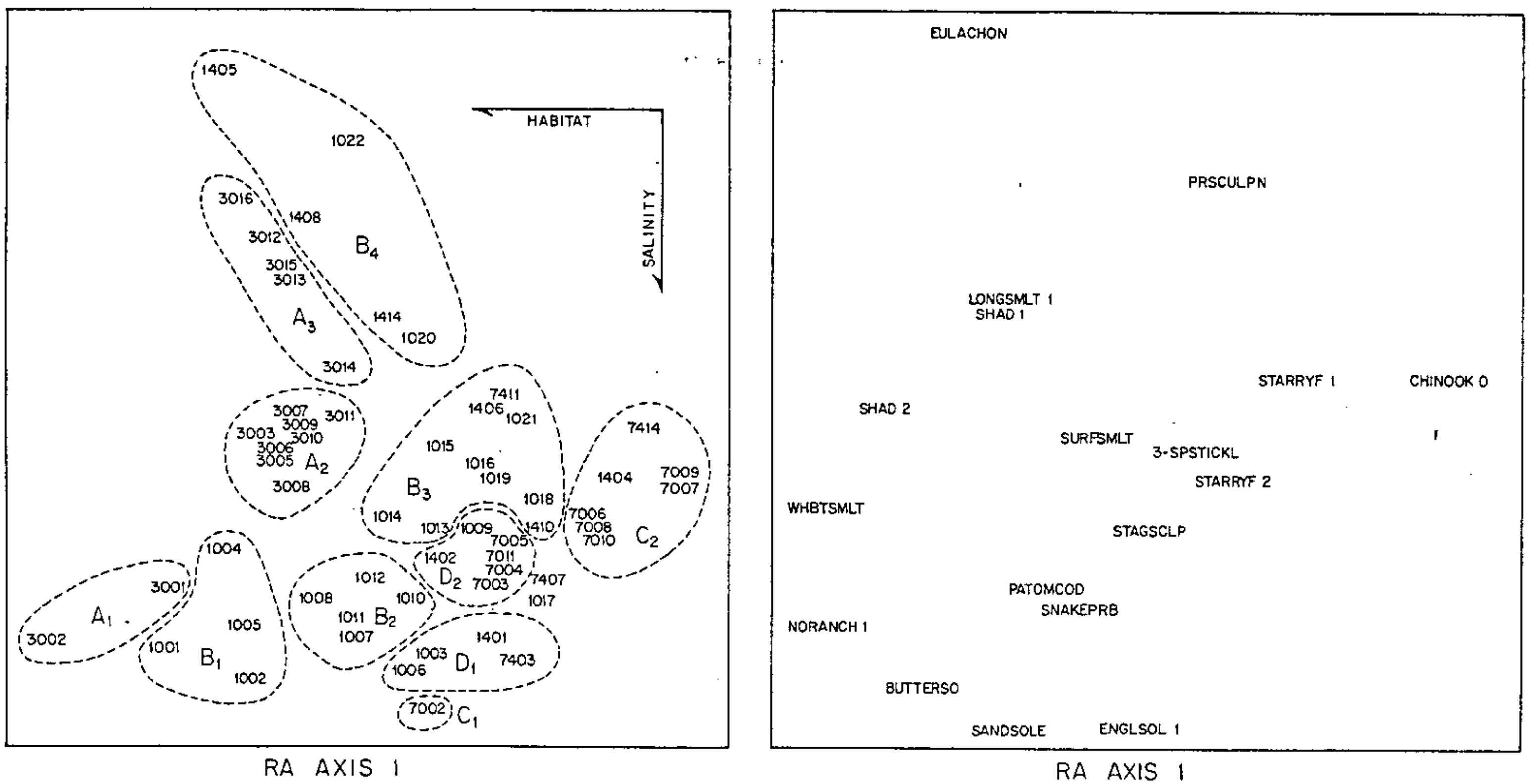


Figure 15. Reciprocal averaging plots for stations and species for January 1981. Stations are grouped for water column (A), channel bottom (B), nearshore (C), and bay (D) habitats.*

*NMFS stations are plotted as four-digit (rather than three-digit) codes with a zero inserted after the first digit. FRI stations are as listed in Table 1.

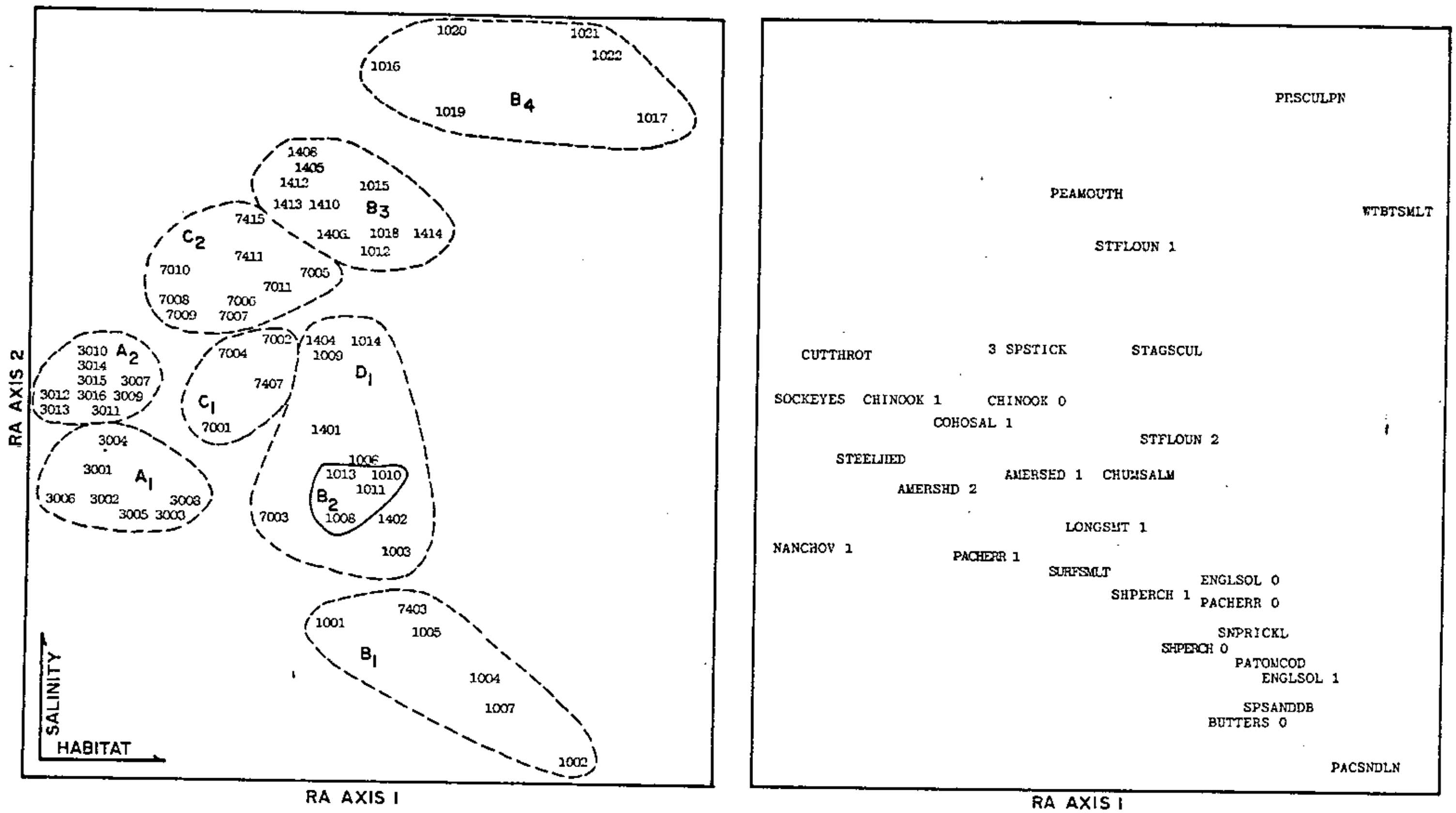


Figure 16. Reciprocal averaging plots for stations and species for May 1980. Stations are grouped for water column (A), channel bottom (B), nearshore (C), and bay (D) habitats.*

*NMFS stations are plotted as four-digit (rather than three-digit) codes with a zero inserted after the first digit. FRI stations are as shown in Table 1.

cutthroat trout were caught only in purse seines, peamouth and prickly sculpin were most abundant in upriver trawls, and speckled sanddab and butter sole were caught only in marine trawls.

The station ordination for August 1980 reflected trends similar to trends for January and May (Figure 17). The first two axes also suggested salinity and habitat gradients. The water column sampled by purse seines was subdivided into three zones (station groups A_1, A_2, A_3). Three north channel stations from the estuarine mixing zone were grouped closely. The nearshore beach seines were subdivided into two groups (station groups C_1, C_2), and the channel bottom habitat was split into three groups (station groups B_1, B_2, B_3). A group of bay stations (trawl and beach seines) was placed midway between the estuarine mixing and freshwater trawl stations (station group D_1).

The fish species (Figure 17) followed these general gradients. Most demersal species were segregated from pelagic groups. A general gradient from marine species--English sole, butter sole--to freshwater groups--starry flounder, prickly sculpin--was shown in the arrangement of species in the reciprocal averaging plot.

3.6 FOOD HABITS OF FISHES

Stomach contents of more than 4,000 fish from 13 key species in the Columbia River Estuary are shown in Figures 18-24. Each plot represents a grand total for each species collected at all stations (by all gear types). Only the data for salmonids include stomachs collected February 1980 through January 1981. All others were sampled through October 1980. The species and life history stages shown here can be classified into seven general habitat-feeding categories:

3.6.1 Pelagic Planktivores (micro- and macrozooplankton)

Yearling longfin smelt (1) and yearling and older American shad (1 and 2) most frequently preyed on calanoid copepods, *Corophium salmonis*, and harpacticoid copepods (Figure 18). Other common prey included mysid shrimp in longfin smelt and cyclopoid copepods in American shad. Shad also consumed the bivalve *Corbicula manilensis*.

3.6.2 Pelagic Planktivores (microzooplankton)

Young-of-the-year longfin smelt (0) and American shad (0), Pacific herring (0 and 1), and surf smelt also frequently ate calanoid copepods (Figure 19). However, larger zooplankton such as *Corophium salmonis* were not common among this group of pelagic feeders. *Daphnia* spp. and cyclopoid and harpacticoid copepods also were among the top four most frequently consumed prey.

3.6.3 Epibenthic-Surface (neuston) Feeders (amphipods-insects)

Juvenile chinook (0 and 1) and coho (Figure 20) comprised a group of epibenthic and surface feeding fish that ate crustaceans and

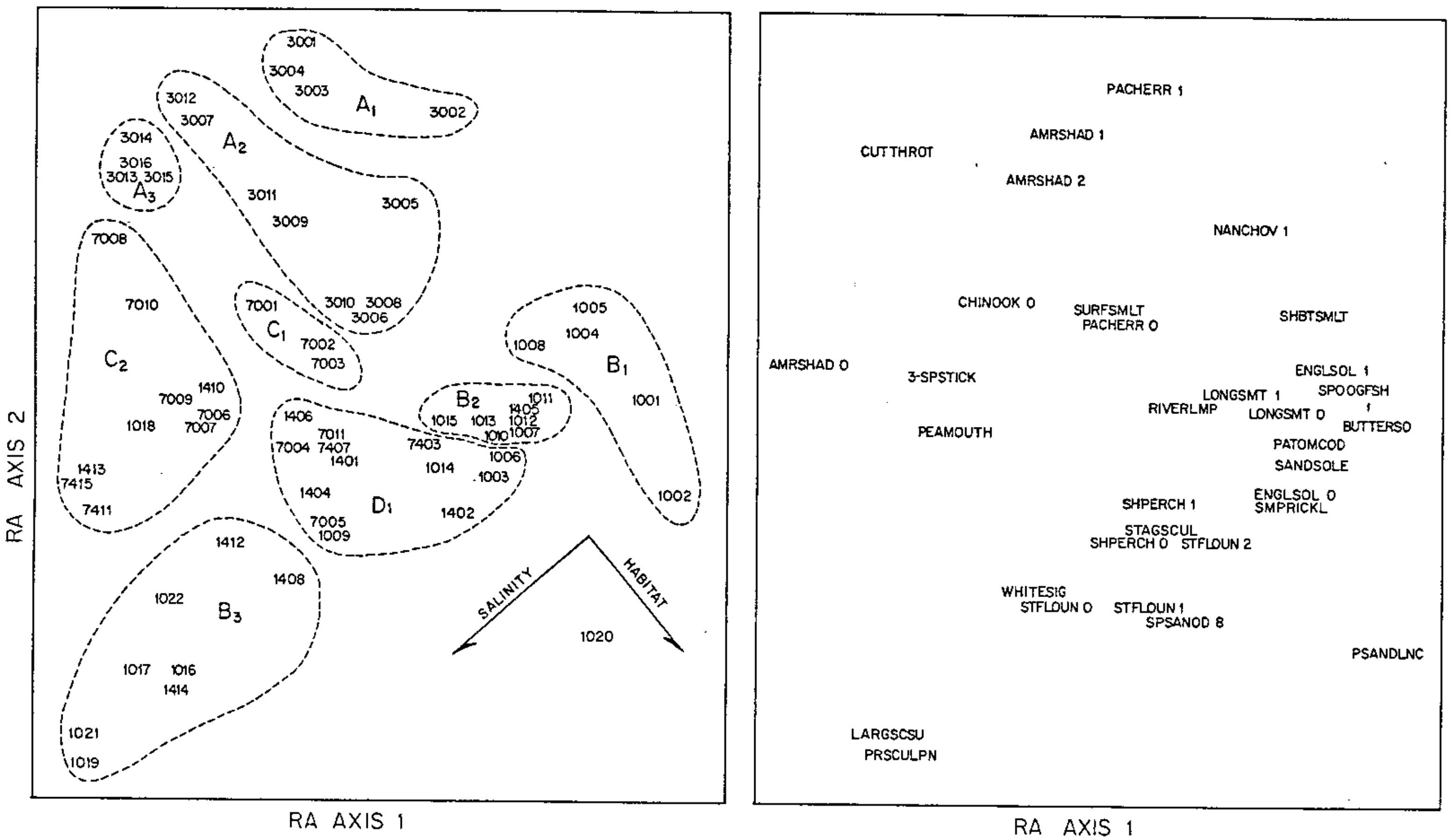


Figure 17. Reciprocal averaging plots for stations and species for August 1980. Stations are grouped for water column (A), channel bottom (B), nearshore (C), and bay (D) habitats.*

*NMFS stations are plotted as four-digit (rather than three-digit) codes with a zero inserted after the first digit. FRI stations are as shown in Table 1.

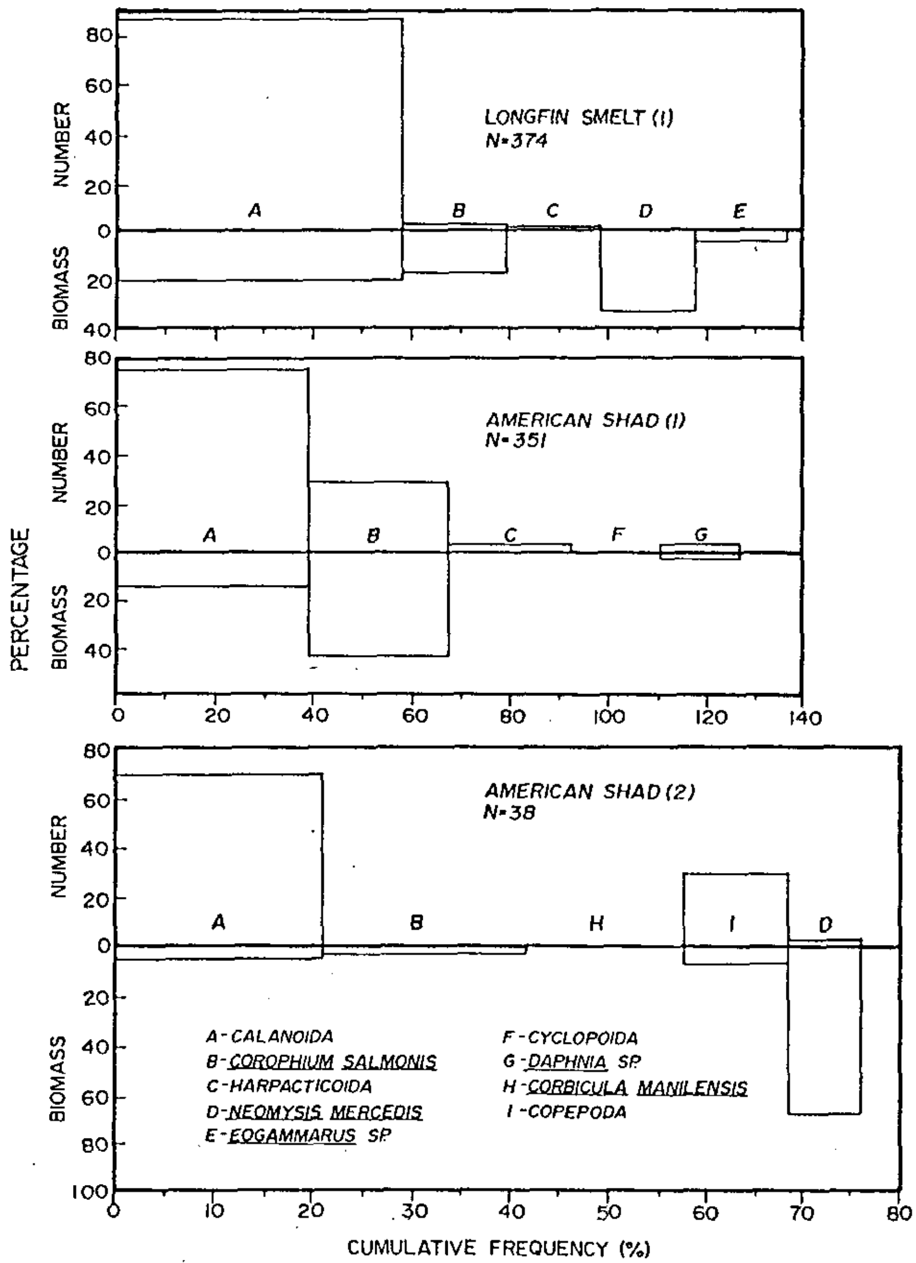


Figure 18. IRI plot for major prey taxa consumed by pelagic planktivore (macro and microzooplankton) group.

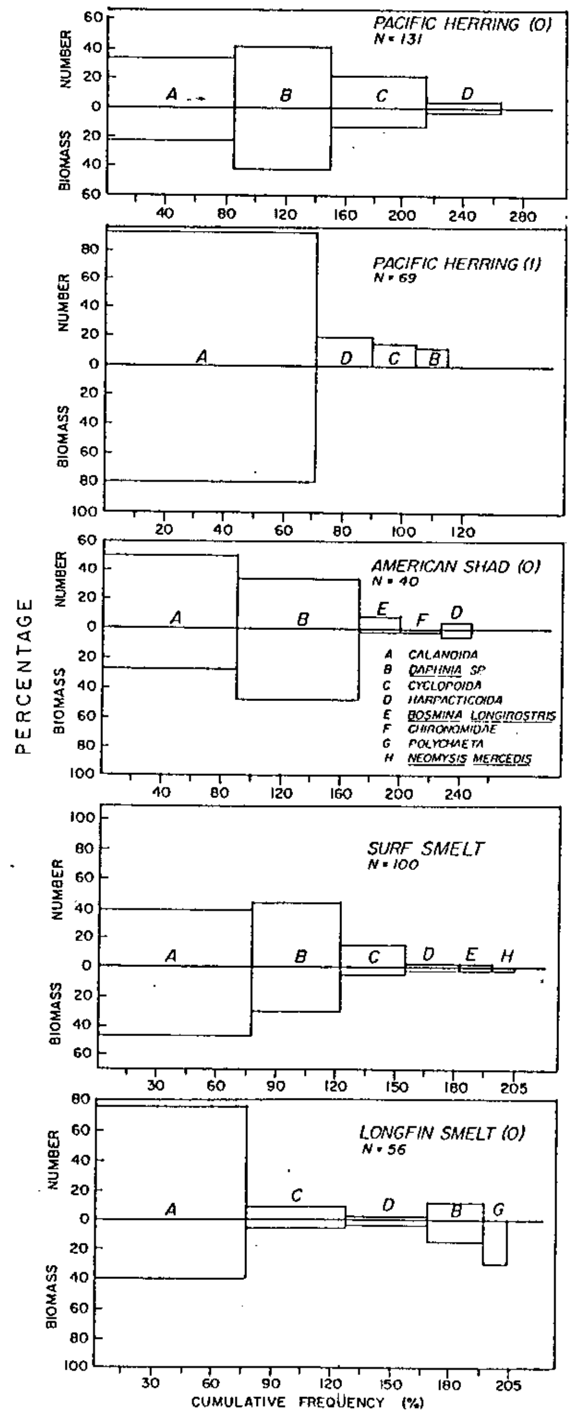


Figure 19. IRI plot for major prey taxa consumed by pelagic planktivore (microzooplankton) group.

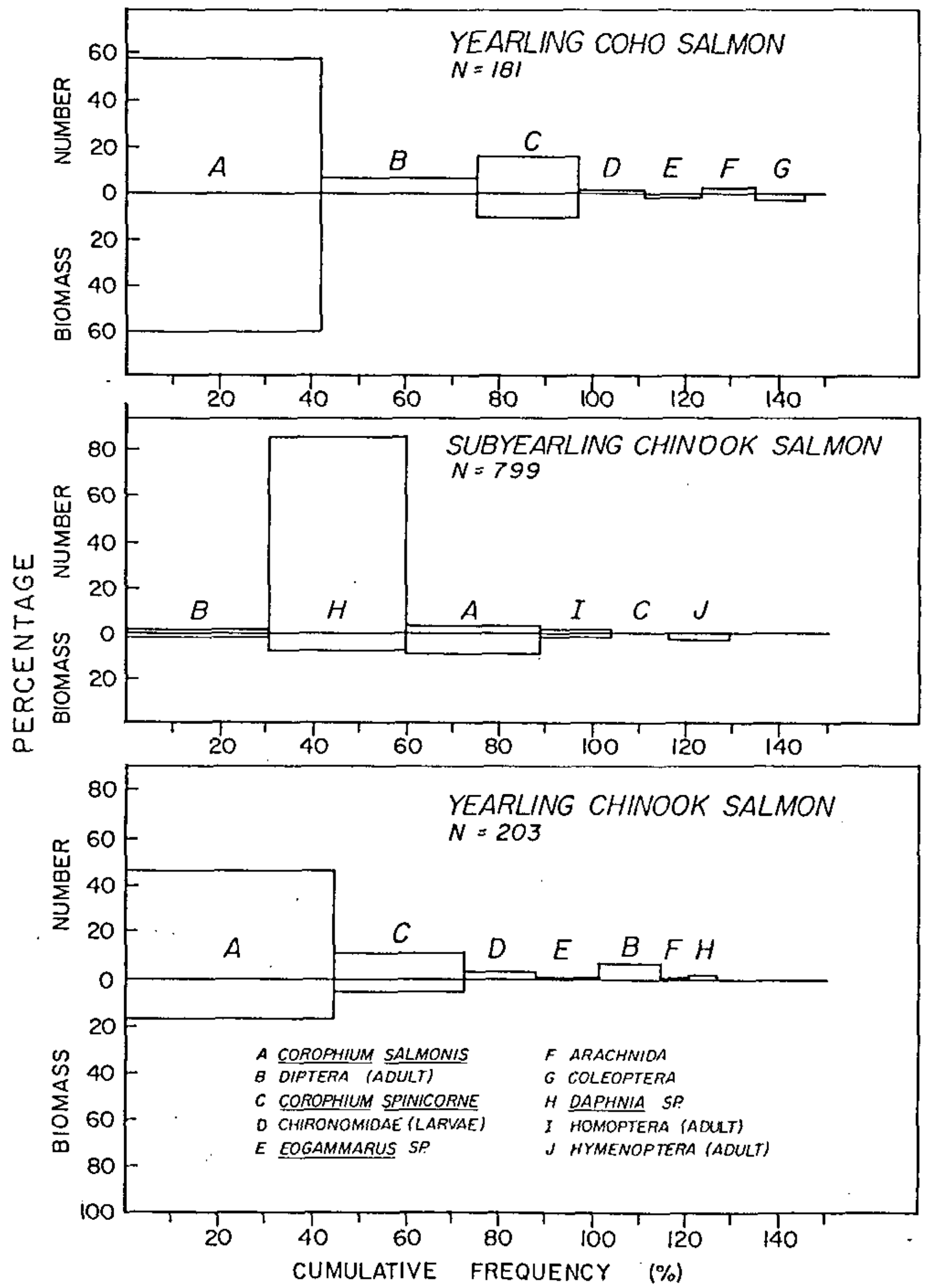


Figure 20. IRI plot for major prey taxa consumed by epibenthic-surface (neuston) feeders.

insects. Adult dipterans, Corophium salmonis, and Corophium spinicorne were the most common prey items in this feeding group. Daphnia spp. was a major prey item for young-of-the-year chinook during the summer months only. The total of all adult and larval insect taxa constituted approximately 8%, 55%, and 20% of the total number of prey consumed by 0-age chinook, yearling chinook, and coho, respectively.

3.6.4 Pelagic-Epibenthic Planktivores (amphipod-copepod)

Threespine stickleback and 0-age and yearling shiner perch (Figure 21) composed a group of pelagic and epibenthic planktivores. Corophium salmonis was a common prey item for this group. As with 0-age chinook (Figure 20) and the microzooplankton pelagic feeders (Figure 19), Daphnia spp., and calanoid and other copepods were important in the diet of threespine stickleback and shiner perch (0). When shiner perch reached a year of age, their diet (as with yearling chinook and coho) shifted to larger epibenthic crustaceans including the amphipod, Eogammarus spp. and the isopod, Gnorimosphaeroma oregonensis.

3.6.5 Demersal-Epibenthic Planktivores (amphipod-copepod)

As with shiner perch (0 and 1) and threespine stickleback (Figure 21), several 0-age flatfish species also consumed copepods and amphipods (Figure 22). We have grouped young-of-the-year starry flounder and English sole separately because they did not consume Daphnia spp., and they occupied a demersal habitat distinct from the other epibenthic feeders. Juvenile starry flounder consumed large numbers of Corophium salmonis and cyclopoid copepods. English sole (0) ate harpactacoid copepods, Eogammarus spp., and cumaceans.

3.6.6 Demersal Opportunists (crustacean, clam, polychaete)

Yearling and older flatfish ate a variety of benthic invertebrates that included mysid shrimp, Corophium salmonis, polychaetes, and clams (Figure 23). Eogammarus spp. was among the three most frequently consumed prey by yearling English sole and yearling and older starry flounder.

3.6.7 Demersal Predators (crustacean-fish)

Pacific tomcod, prickly sculpin, and Pacific staghorn sculpin composed a group of benthic predators that fed on amphipods (Corophium salmonis and Eogammarus spp.), decapods (Crangon spp.), and mysids (Neomysis mercedis) (Figure 24). Although fish were eaten by all three species in this group, Pacific staghorn sculpin was the most piscivorous. Pacific tomcod, northern anchovy, and other unidentifiable fish were consumed by staghorn sculpin.

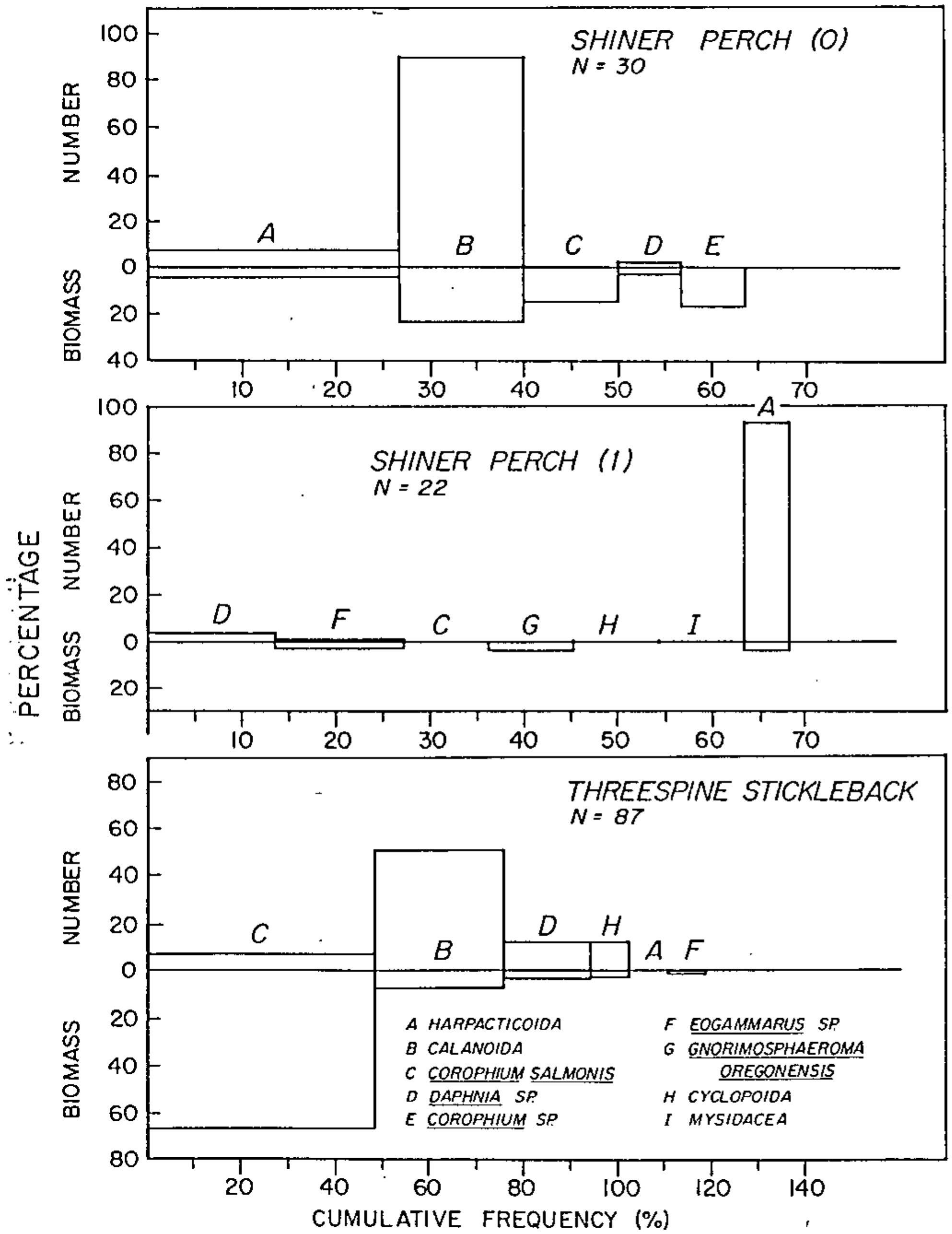


Figure 21. IRI plot for major prey taxa consumed by pelagic - epibenthic planktivores.

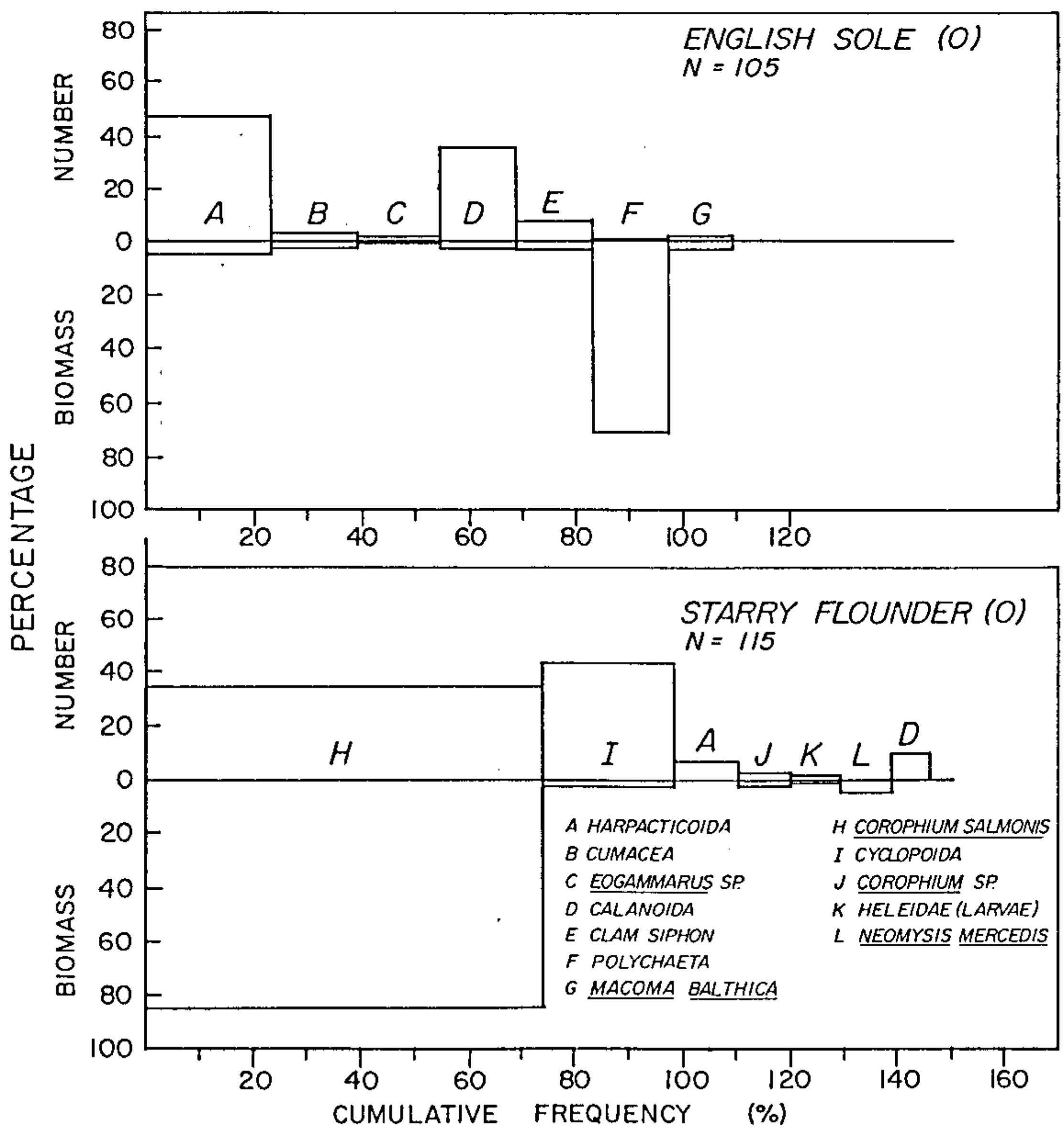


Figure 22. IRI plot for major prey taxa consumed by demersal-epibenthic planktivores.

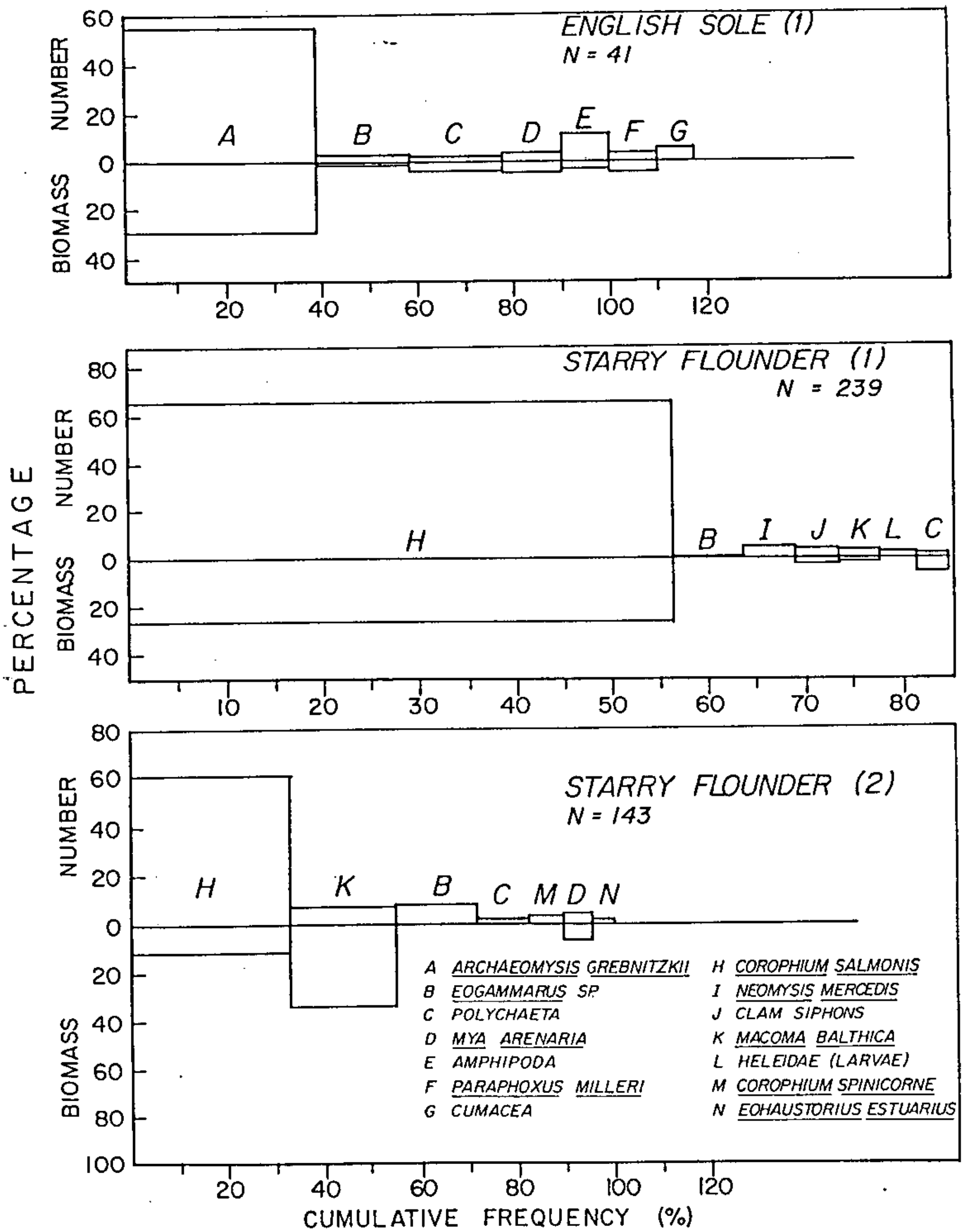


Figure 23. IRI plot for major prey taxa consumed by demersal opportunists.

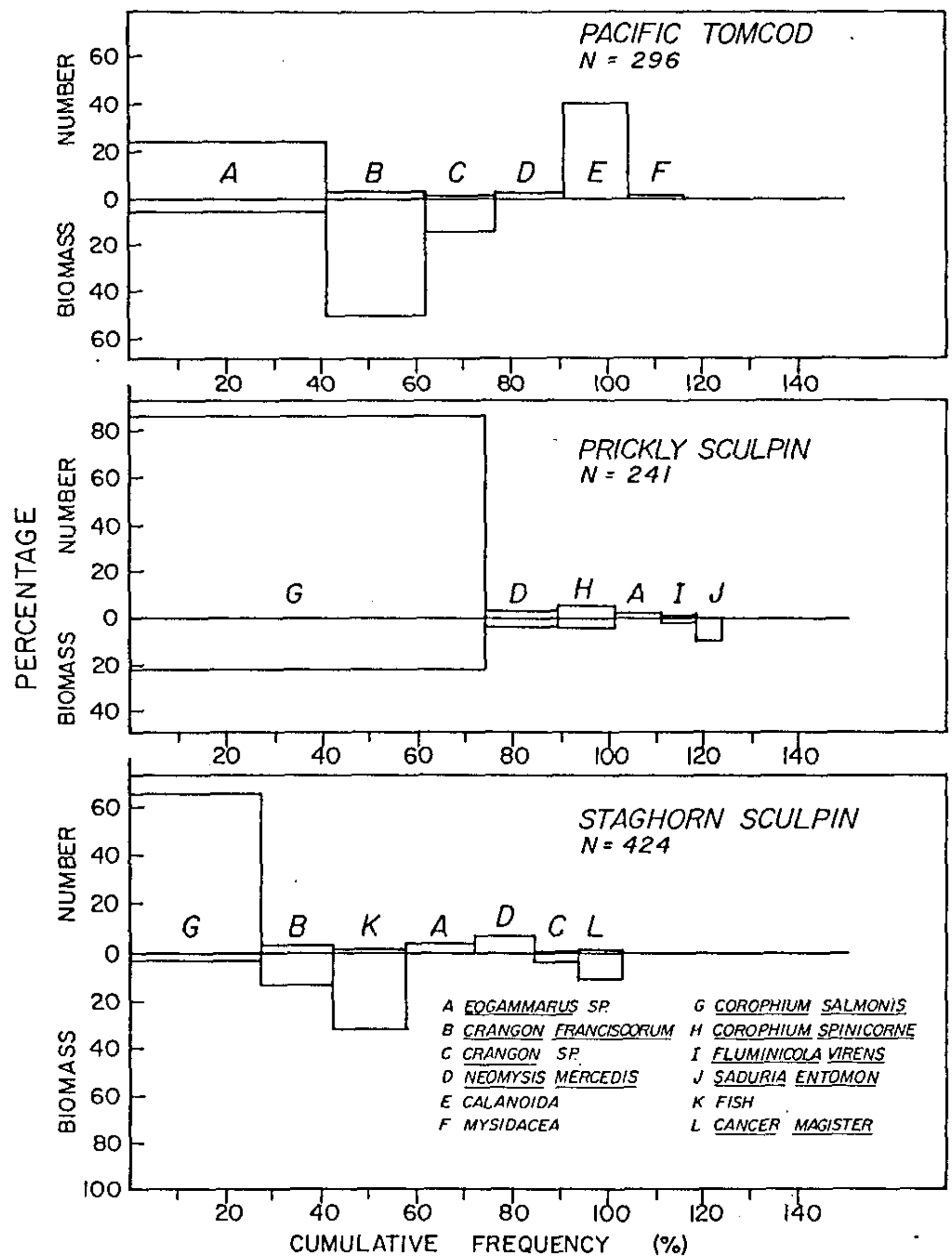


Figure 24. IRI plot for major prey items consumed by demersal predators.

3.7 FEEDING GROUPS

Discrete feeding groups were apparent in the Columbia River Estuary, which corresponded generally to the seasonal species clusters. This is shown in Figures 25-27, where the top three prey taxa (according to percentage IRI) are compared among all fish species in each cluster group. The ranges in IRI values represent the total for all fish collected throughout each of the three hydrologic seasons--winter (November-March), spring (April-June), and summer (July-October). Within each season fish are grouped according to the representative species clusters for January 1981, May 1980, and August 1980 (Figures 8, 10, and 12), respectively. All cluster groups for each representative month are numbered for reference.

3.7.1 Winter Hydrologic Season

During the winter hydrologic season two pelagic feeding assemblages were evident (Figure 25). Cluster group 1 comprised pelagic species from the estuarine mixing zone and bays (Figures 8-9) that consumed calanoid copepods, Corophium salmonis, and Neomysis mercedis. Cluster group 4 (American shad and surf smelt) comprised a second pelagic group that occurred primarily in the estuarine mixing zone. In this group surf smelt ate calanoid copepods, Daphnia spp., and polychaetes.

Two demersal feeding groups were also identified for the winter hydrologic season. Cluster group 2 consisted of demersal species (sculpins and starry flounder) that preyed heavily on Corophium salmonis. The diet of Pacific tomcod, snake prickleback, and sand sole from cluster groups 3 and 5 indicated a demersal assemblage that consumed calanoid and other copepods and Eogammarus spp.. Species in cluster group 2 were most common in nearshore beach seine sites in the estuarine mixing and freshwater zones of the estuary. Species in cluster groups 3 and 5 occurred primarily in the estuarine mixing and marine zones.

3.7.2 Spring Hydrologic Season

One or possibly two pelagic feeding assemblages represented by four cluster groups were present during the spring hydrologic season (Figure 26). Pelagic species from cluster groups 4 and 8 primarily consumed calanoid and harpacticoid copepods. Yearling and older American shad (cluster group 6) and sockeye salmon (cluster group 7) also consumed calanoids. Fish from cluster groups 6 and 7 consumed unidentified copepods that may or may not distinguish this assemblage from the other pelagic feeders during the spring hydrologic season. Fish from cluster groups 4 and 8 were captured in the water column in the estuarine mixing and marine zones and in channel bottom habitats in the freshwater zone (Figures 10-11). Fish from cluster group 6 occurred throughout the estuary, but sockeye (cluster group 7) were captured primarily in the freshwater zone.

IRI (PERCENT)

- 0.5 – 25
- 26 – 50
- 51 – 75
- > 75

PREDATOR	CLUSTER GROUP	N	Polychaeta	Calanoida	Harpacticoida	*Daphnia* sp.	*Corophium salmonis*	*Eogammarus* sp.	Cumacea	*Neomysis mercedis*	*Crangon franciscorum*	Diptera (adult)	Oligochaeta	*Mya arenaria*	*Macoma balthica*	Fish	DIGESTED (%)	OTHER (%)
American shad (1)	I	119		26 – 50			0.5 – 25			0.5 – 25							49.3	4.7
Longfin smelt (1)	I	108		26 – 50			26 – 50			0.5 – 25							0.1	9.7
Eulachon	I	4	0.5 – 25							0.5 – 25							47.8	17.2
Threespine stickleback	I	75		0.5 – 25			51 – 75										18.9	2.0
Staghorn sculpin	II	87					51 – 75	0.5 – 25								0.5 – 25	2.3	5.3
Starry flounder (2)	II	49					51 – 75							0.5 – 25	0.5 – 25		7.6	4.8
Starry flounder (1)	II	44					> 75						0.5 – 25				5.0	0.5
Prickly sculpin	II	56					> 75									0.5 – 25	2.1	1.0
Pacific tomcod	III	50		0.5 – 25				51 – 75			0.5 – 25						1.7	8.3
Snake prickleback	III	21		0.5 – 25	51 – 75			0.5 – 25									12.4	0.2
English sole (1)	III	17	0.5 – 25					0.5 – 25	0.5 – 25					0.5 – 25			35.7	15.1
Butter sole	III	–															—	—
American shad (2)	IV	–															—	—
Surf smelt	IV	14	0.5 – 25	0.5 – 25		0.5 – 25											58.2	0.9
Northern anchovy (1)	V	–															—	—
Sand sole	V	20		0.5 – 25				0.5 – 25		0.5 – 25						0.5 – 25	2.4	23.7
Whitebait smelt	V	–															—	—
Chinook salmon (0)	VI	92					51 – 75			0.5 – 25		0.5 – 25					2.2	22.6

Figure 25. Major prey taxa consumed by fish species in each cluster group during the winter hydrologic season. Species clusters are the same as listed for January 1981 in Figure 5.

IRI (PERCENT)

- 0.5 – 25
- 26 – 50
- 51 – 75
- >75

PREDATOR	CLUSTER GROUP	N	Copepoda	Calanoida	Harpacticoida	Cyclopoida	*Bosmina longirostris*	Amphipoda	*Corophium salmonis*	*Corophium spinicorne*	*Eogammarus* sp.	*Saduria entomon*	Cumacea	Mysidacea	*Archaeomysis grebnitzkii*	*Neomysis mercedis*	*Crangon franciscorum*	Insect adults	*Corbicula manilensis*	*Macoma balthica*	Fish	DIGESTED (%)	OTHER (%)
Staghorn sculpin	I	120							51 – 75							0.5 – 25					0.5 – 25	13.8	9.6
Starry flounder (1)	I	98		0.5 – 25					>75													11.3	1.2
Starry flounder (2)	I	55							51 – 75		0.5 – 25									0.5 – 25		21.2	3.6
Shiner perch (1)	I	6									>75			0.5 – 25								0.9	0
English sole (0)	I	29		26 – 50	0.5 – 25								0.5 – 25									6.3	17.8
Peamouth	II	–																				–	–
Prickly sculpin	II	82							>75	0.5 – 25		0.5 – 25										10.4	2.1
Pacific tomcod	III	66									>75				0.5 – 25		0.5 – 25					5.7	11.2
Snake prickleback	III	8		51 – 75											0.5 – 25							19.9	9.5
Butter sole	III	13													>75						0.5 – 25	11.7	0.6
English sole (1)	III	15						0.5 – 25							>75					0.5 – 25		4.9	1.0
Pacific sand lance	IV	8		>75			0.5 – 25															5.5	1.6
Speckled sanddab	IV	–																				–	–
Shiner perch (0)	IV	–																				–	–
Pacific herring (0)	IV	12		>75	0.5 – 25													0.5 – 25				11.3	2.6
Chinook salmon (1)	V	160							51 – 75	0.5 – 25								0.5 – 25				10.3	5.4
Coho salmon	V	179							51 – 75	0.5 – 25								0.5 – 25				23.9	4.1
Steelhead trout	V	81							0.5 – 25									0.5 – 25	0.5 – 25			67.1	8.1
Chinook salmon (0)	V	275							51 – 75	0.5 – 25								0.5 – 25				15.0	5.9
Threespine stickleback	V	–																				–	–
American shad (1)	VI	132	0.5 – 25	26 – 50					0.5 – 25													54.4	2.3
American shad (2)	VI	–	0.5 – 25	0.5 – 25																		79.8	2.7
Sockeye salmon	VII	15	0.5 – 25	26 – 50		0.5 – 25																29.9	3.4
Cutthroat trout	VII	6							26 – 50	0.5 – 25								26 – 50				22.3	0.9
Longfin smelt	VIII	72		>75					0.5 – 25							0.5 – 25						3.0	8.5
Pacific herring (1)	VIII	12		>75	0.5 – 25																	11.3	2.6
Surf smelt	VIII	37		>75	0.5 – 25																	6.8	2.0
Chum salmon	IX	9		26 – 50			0.5 – 25											26 – 50				12.6	5.6
Whitebait smelt	X	–																				–	–
Anchovy	X	–																				–	–

Figure 26. Major prey taxa consumed by fishes in each cluster group during the spring hydrologic season. Species clusters are the same as listed for May 1980 in Figure 5.

In the spring two demersal feeding assemblages corresponded with three of the species clusters. Demersal predators and opportunists in cluster groups 1 and 2 consumed amphipods (Corophium salmonis and Eogammarus sp.) and, in a few cases, calanoids or mysids. These fish occurred primarily in the estuarine mixing and freshwater zones and in bays. Demersal species from the estuarine mixing and marine zones (cluster group 3) commonly consumed the mysid, Archaeomysis grebnitzkii.

Salmonids from cluster group 5 composed a distinct feeding assemblage that consumed Corophium salmonis , Corophium spinicorne, and adult insects.

3.7.3 Summer Hydrologic Season

Feeding assemblages were less distinct for the summer hydrologic season than during winter and spring. Food habits of fish species within the representative cluster groups were varied and had greater overlap in diet between cluster groups than during the other seasons (Figure 27). In general, there was a major division between fish that consumed Corophium spp. and those that consumed calanoid copepods or Daphnia spp. or both.

Pelagic feeders within cluster groups 1 and 4--yearling longfin smelt, northern anchovy, and whitebait smelt--ate calanoid and harpacticoid copepods. Most fish in cluster group 5, zero-age longfin smelt (cluster group 1), and American shad (cluster group 8) ate Daphnia spp. in addition to a variety of copepod taxa. Threespine stickleback (cluster group 6) showed a food preference similar to the pelagic feeding species in cluster group 5. Cluster groups 1,4, and 5 occurred most frequently in the marine zone or estuarine mixing zone or both (Figures 12-13).

A large group of demersal and epibenthic feeders present during the summer consumed Corophium salmonis. All age classes of starry flounder, zero-age shiner perch, Pacific staghorn sculpin, prickly sculpin, and white sturgeon from cluster groups 1, 2, 3, and 8 composed this feeding assemblage. All fish in cluster group 2 (except staghorn sculpin) fed on a variety of copepod taxa. Staghorn sculpin and yearling shiner perch also ate fish. Macoma balthica was important in the diet of yearling and adult starry flounder and white sturgeon (cluster groups 1 and 3).

During the summer hydrologic season chinook shifted from a diet of Corophium spp. and insects to Daphnia spp., insects, and a variety of fish species including northern anchovy, longfin and whitebait smelt, and Pacific sand lance.

IRI (PERCENT)

- 0.5 - 25
- 26 - 50
- 51 - 75
- >75

PREDATOR	CLUSTER GROUP	N	Polychaeta	Calanoida	Harpacticoida	Cyclopoida	*Daphnia*	*Bosmina longirostris*	*Corophium salmonis*	*Eogammarus* sp.	*Paraphoxis milleri*	*Archaeomysis grebnitzkii*	*Neomysis mercedis*	*Crangon franciscorum*	Insect parts	*Macoma balthica*	Fish	DIGESTED (%)	OTHER (%)
Longfin smelt (O)	I	56		51-75		0.5-25	0.5-25											13.6	3.3
Longfin smelt (1)		195		>75	0.5-25								0.5-25					7.8	1.3
Pacific tomcod		180		26-50						0.5-25				26-50				12.4	-
Snake prickleback		-																0	-
English sole (O)		67	0.5-25		0.5-25											0.5-25		55.0	2.3
Sand sole		-																-	-
Starry flounder (1)		97							>75							0.5-25		15.5	3.2
Starry flounder (2)		39							0.5-25	0.5-25						26-50		31.6	10.7
Shiner perch (1)	II	16			26-50		0.5-25										0.5-25	26.8	6.8
Staghorn sculpin		217							26-50					0.5-25			0.5-25	24.0	7.1
Starry flounder (O)		101				0.5-25			>75									9.8	1.3
Shiner perch (O)		30		26-50	0.5-25				0.5-25									58.1	3.6
Pacific lamprey	III	-																-	-
White sturgeon		15							51-75				0.5-25			0.5-25		20.8	2.4
Northern anchovy	IV	30		0.5-25	26-50	0.5-25												36.7	8.5
Whitebait smelt		7	0.5-25	>75													0.5-25	0	0
Spiney dogfish		-																-	-
English sole (1)		9			0.5-25						0.5-25	0.5-25						73.8	1.1
Pacific herring (O)	V	119		26-50		0.5-25	26-50											19.3	2.3
American shad (1)		100		26-50	0.5-25		0.5-25											64.2	2.2
Pacific herring (1)		18		26-50		0.5-25	0.5-25											59.9	0.8
Surf smelt		49		26-50		0.5-25	26-50											12.8	0.6
American shad (2)		11		26-50	0.5-25								0.5-25					27.3	12.8
Chinook salmon (O)	VI	432					>75								0.5-25		0.5-25	8.0	5.7
Peamouth		13							0.5-25									93.0	0
Threespine stickleback		9		0.5-25		26-50	26-50											16.5	0
Cutthroat trout	VII	-																-	-
Largescale sucker	VIII	-																-	-
Prickly sculpin		103							>75				0.5-25	0.5-25				20.4	1.4
American shad (O)		40		26-50			0.5-25	0.5-25										41.0	1.5

Figure 27. Major prey taxa consumed by fishes in each cluster group during the summer hydrologic season. Species clusters are the same as listed for August 1980 in Figure 5.

3.8 FEEDING AREAS

Figure 28 compares the Index of Feeding Intensity for all fish collected at each sampling location. Sampling stations for three gear types are grouped into each of three salinity zones defined by station clusters (Figure 7). Bay sampling sites are shown separately because these were sampled by more than one type of gear. Channel bottom, water column, and nearshore and shoal habitats are represented by all other stations sampled with trawl, purse seine, and beach seine, respectively.

Stomach content weight for trawl species was relatively high at the few Baker Bay and Youngs Bay sampling sites and in the estuarine mixing zone between 15 and 27 km from the river mouth (RM 9-16). IFI ranged between 0.48% and 0.94% for bay locations and between 0.33% and 0.63% for stations in the estuarine mixing zone. IFI for fish captured at marine and freshwater stations were generally less and ranged between 0.22% and 0.48% and between 0.12% and 0.52%, respectively.

Few sites in the estuarine mixing zone were sampled with the beach seine. Of those sampled, feeding intensity was greatest in the lower reaches of the freshwater zone between 32 and 35 km from the estuary mouth (RM 19-21) and at stations 701 in Baker Bay and 704 in the lower estuarine mixing zone. Mean IFI for fish captured in the purse seine was low at most locations compared with the other gear types. Values were near or below 0.2% body weight for sites more than 30 km from the river mouth: values between 0.2% and 0.4% occurred in the estuarine mixing zone between 10 and 30 km from the river mouth (RM 6-18).

High mean feeding intensity (Figure 28) frequently corresponded with areas of high fish density, which occurred in Baker and Youngs bays and the mid-estuary region between 10 and 30 km from the river mouth (Table 4). The general distribution of feeding activity was similar for several fish species. Although differences between sampling areas were not statistically significant, mean IFI was relatively high in bay habitats and in the estuarine mixing zone for juvenile chinook and coho salmon, Pacific tomcod, prickly and staghorn sculpin, yearling American shad, and surf smelt (Figure 29). Mean IFI increased with distance from the mouth of the estuary or was maximum at freshwater stations for subyearling Pacific herring, subyearling starry flounder, subyearling English sole, and yearling longfin smelt. High average values for Pacific herring (0) in the freshwater zone may have been an artifact of low sample size (n = 8)

Mean monthly number of empty stomachs was frequently (but not always) lower for areas of high average feeding intensity or higher in areas of low average IFI or both (Table 5). Yearling Pacific herring, surf smelt, subyearling English sole, and Pacific tomcod had the fewest empty stomachs at estuarine mixing zone or bay sampling sites. Salmonids and staghorn sculpin had the lowest number of empty stomachs

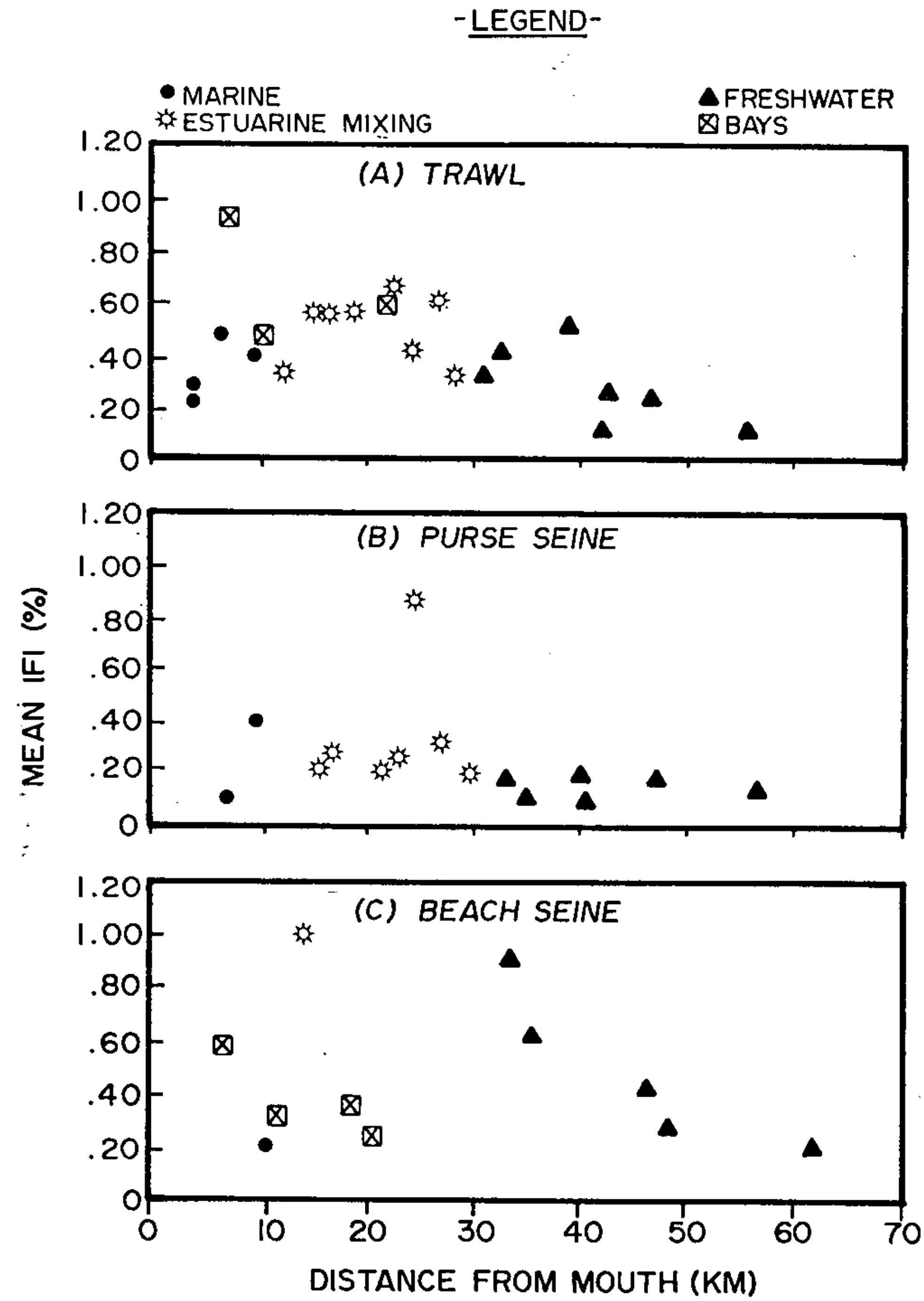


Figure 28. Mean weight of stomach contents as a percentage of mean body weight (IFI) for all fish analyzed from each sampling station. IFI values for 3 estuarine zones and for bay habitats are shown separately within each gear type.

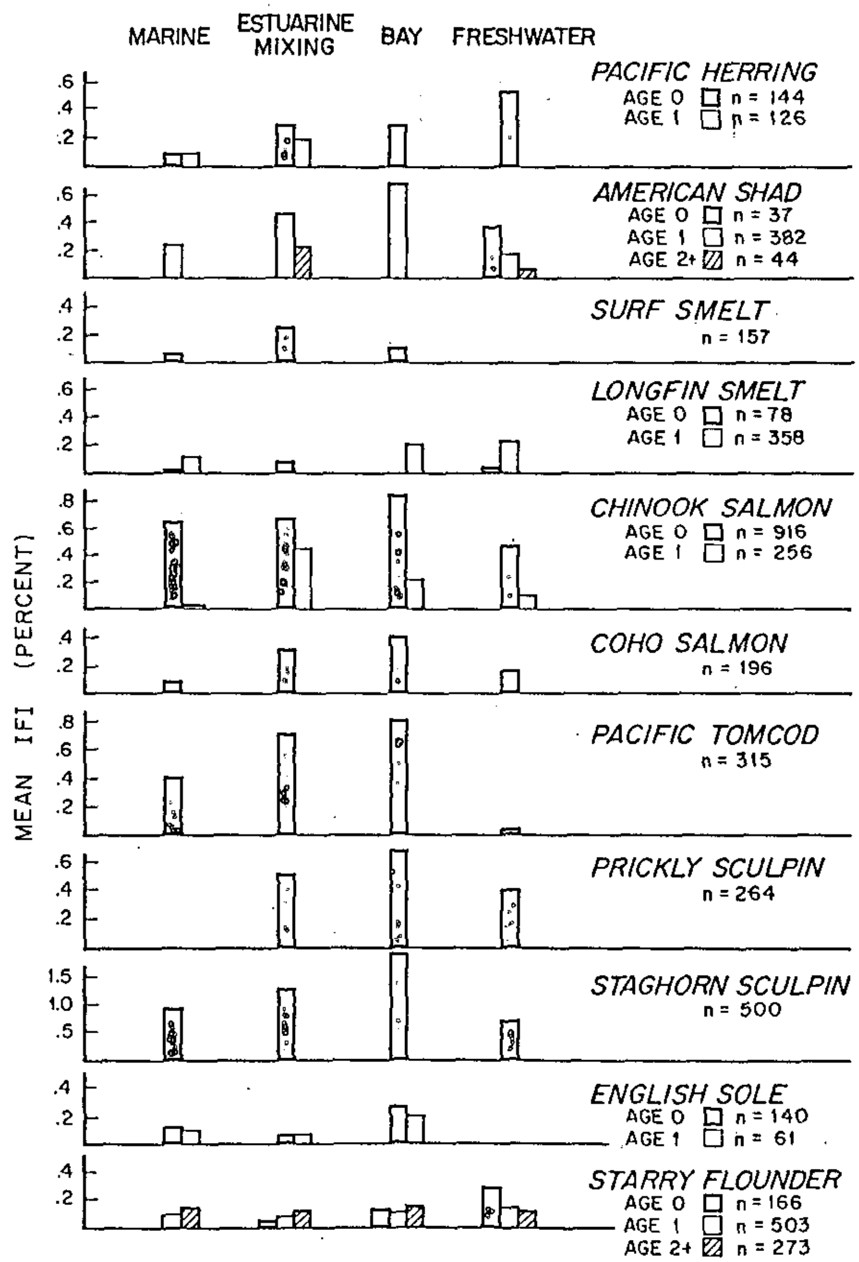


Figure 29. Mean IFI for selected fish taxa-life history stages from marine, estuarine mixing, and freshwater zones and bay habitats. Total number of stomachs (n) analyzed for each species and age class is shown.

Table 5. Geometric mean monthly percentage of empty stomachs among fish collected in four habitats in the Columbia River Estuary*.

	Marine			Brackish			Bay			Fresh		
	X	S.D.	N	X	S.D.	N	X	S.D.	N	X	S.D.	N
Pacific herring (0)	8.74	7.57	3	7.47	7.84	5	0	0	2	0	0	3
Pacific herring (1)	47.04	22.28	4	18.01	25.30	5	-	-	-	-	-	-
American shad (1)	0	0	3	2.84	4.32	8	0	0	4	4.91	12.46	6
Surf smelt	34.30	18.94	4	22.74	22.48	8	15.87	15.48	3	-	-	-
Longfin smelt (1)	8.32	14.47	6	20.00	11.72	9	27.88	11.78	5	28.40	13.70	5
Threespine stickleback	-	-	-	-	-	-	-	-	-	2.60	3.69	2
Coho salmon	13.39	19.45	2	8.43	12.51	3	-	-	-	7.03	5.89	3
Chinook salmon (0)	25.95	14.50	6	18.30	16.12	10	6.86	5.64	6	6.58	8.82	12
Chinook salmon (1)	32.83	10.53	3	23.27	16.75	5	-	-	-	19.10	24.98	6
Pacific tomcod	6.66	8.81	8	2.78	4.30	9	1.98	4.92	6	29.10	43.51	2
Prickly sculpin	-	-	-	4.67	9.54	4	10.96	13.01	6	7.51	5.26	9
Staghorn sculpin	28.76	21.04	7	11.87	7.74	9	14.84	9.77	9	3.08	7.73	6
English sole (0)	24.86	27.48	4	28.57	0	3	13.77	12.96	9	-	-	-
English sole (1)	30.21	26.49	6	0	0	2	-	-	-	-	-	-
Starry flounder (0)	-	-	-	32.29	8.34	2	23.39	27.51	4	12.33	31.76	5
Starry flounder (1)	-	-	-	56.84	8.73	9	28.48	16.27	7	12.90	17.84	9
Starry flounder (2)	27.78	23.77	4	33.86	17.78	8	32.21	19.92	3	41.09	19.66	3

*Months with less than 3 stomachs sampled for a particular species and zone are excluded from the total average. N represents the number of months comprising each mean value. Location of estuary zones shown in Figure 7.

at freshwater stations, even though mean feeding intensity for each species was greater at estuarine mixing and bay locations. Yearling and subyearling starry flounder also had the fewest empty stomachs at freshwater stations; yearling longfin smelt had the fewest empty stomachs at marine sites. There were no empty stomachs among yearling American shad at stations in the marine or estuarine mixing zones.

Calanoid copepods, the most frequent and abundant prey taxa of pelagic feeding fishes (Figure 30), were consumed throughout the estuary. Maximum mean number of calanoids occurred in yearling Pacific herring and surf smelt captured in the lower 10 km of the Columbia River. The mean number of calanoids in the stomachs of yearling longfin smelt was maximum in the upper estuarine mixing zone between 19 and 30 km from the river mouth (RM 11-18). The mean number of calanoids eaten by subyearling Pacific herring increased with distance upriver and was maximum in the freshwater zone between 31 and 44 km from the estuary mouth (RM 19-26).

Demersal and epibenthic fishes in the estuary consistently ate Corophium salmonis. On the basis of total percentage IRI, Corophium salmonis was among the top three prey items for 14 of the 22 species and life history stages represented in Figures 18 - 24. The maximum number of Corophium spp. eaten by several fish species occurred in the mid- to upper regions of the estuary between 19 and 44 km from the river mouth (Figure 31). Mean number of Corophium spp. in fish stomachs increased with distance upriver and was maximum between 31 and 44 km from the mouth for Pacific staghorn sculpin, subyearling chinook salmon, and all age classes of starry flounder. Prickly sculpin contained the largest mean number of Corophium spp. in the upper freshwater reach between 45 and 62 km from the river mouth (RM 27-37). Maximum mean numbers of Corophium salmonis in the stomachs of threespine stickleback and yearling chinook occurred in the upper estuarine mixing to lower freshwater zones (19 to 30 km from the mouth).

3.9 GROWTH RATES

NMFS (1983b) estimated growth rates for five species of Columbia River fishes during 1980 and 1981 from monthly increases in mean weight. Average daily growth for each of these species is plotted in Figures 32 and 33. Peak growth for most of the five species occurred between April and July and was lower during the fall and winter months. Juvenile starry flounder showed little or no growth between September 1980 and February 1981. Relatively rapid growth occurred in fall or winter for yearling longfin smelt and subyearling English sole. Growth rates rarely averaged more than 2.5% body weight per day for any of the five species during the 18-month survey. Maximum mean daily growth exceeded 4% per day in June for subyearling longfin smelt and more than 6.5% per day in July for subyearling starry flounder.

3.10 FEEDING RATES

Periods of high average stomach content weight did not

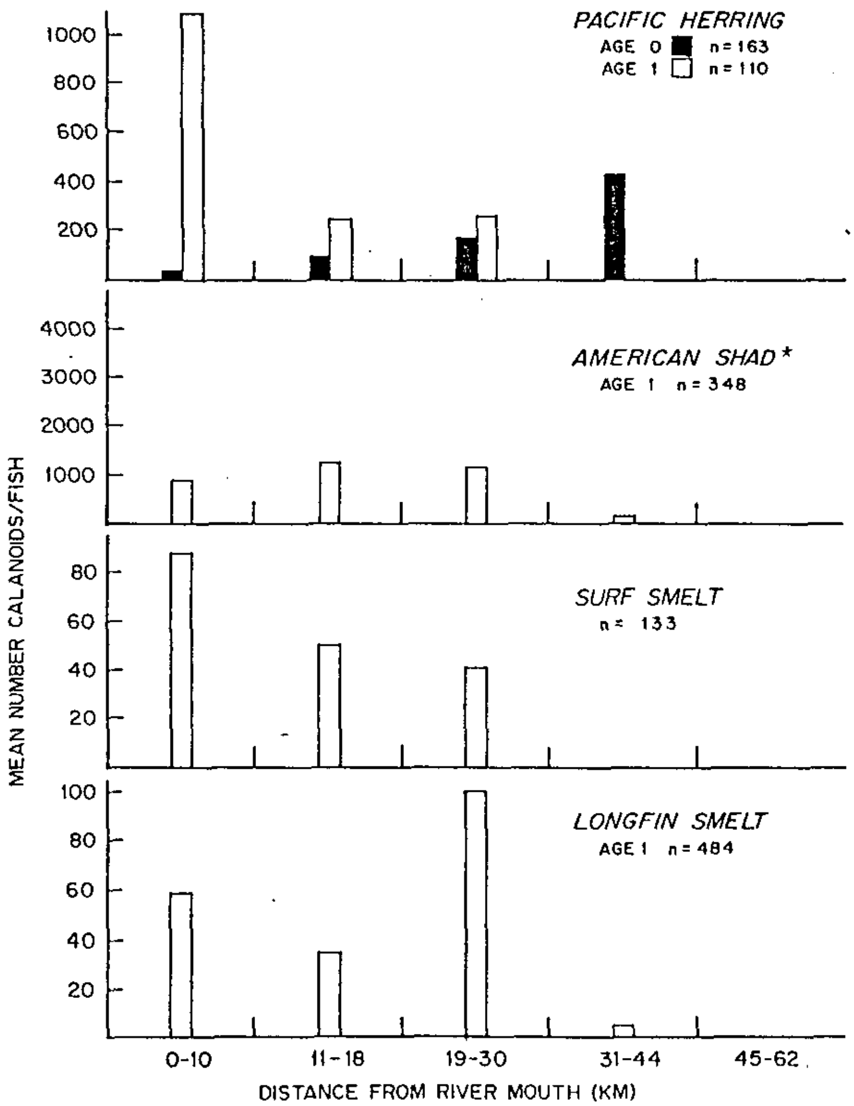


Figure 30. Mean number of calanoid copepods in stomachs of selected fish taxa-life history stages for five regions of the Columbia River Estuary. Total numbers of stomachs analyzed (n) is shown for each species and age class.

* Mean values for zones 11-18 and 19-30 reduced to 568 and 997 if unidentified copepods were not calanoids.

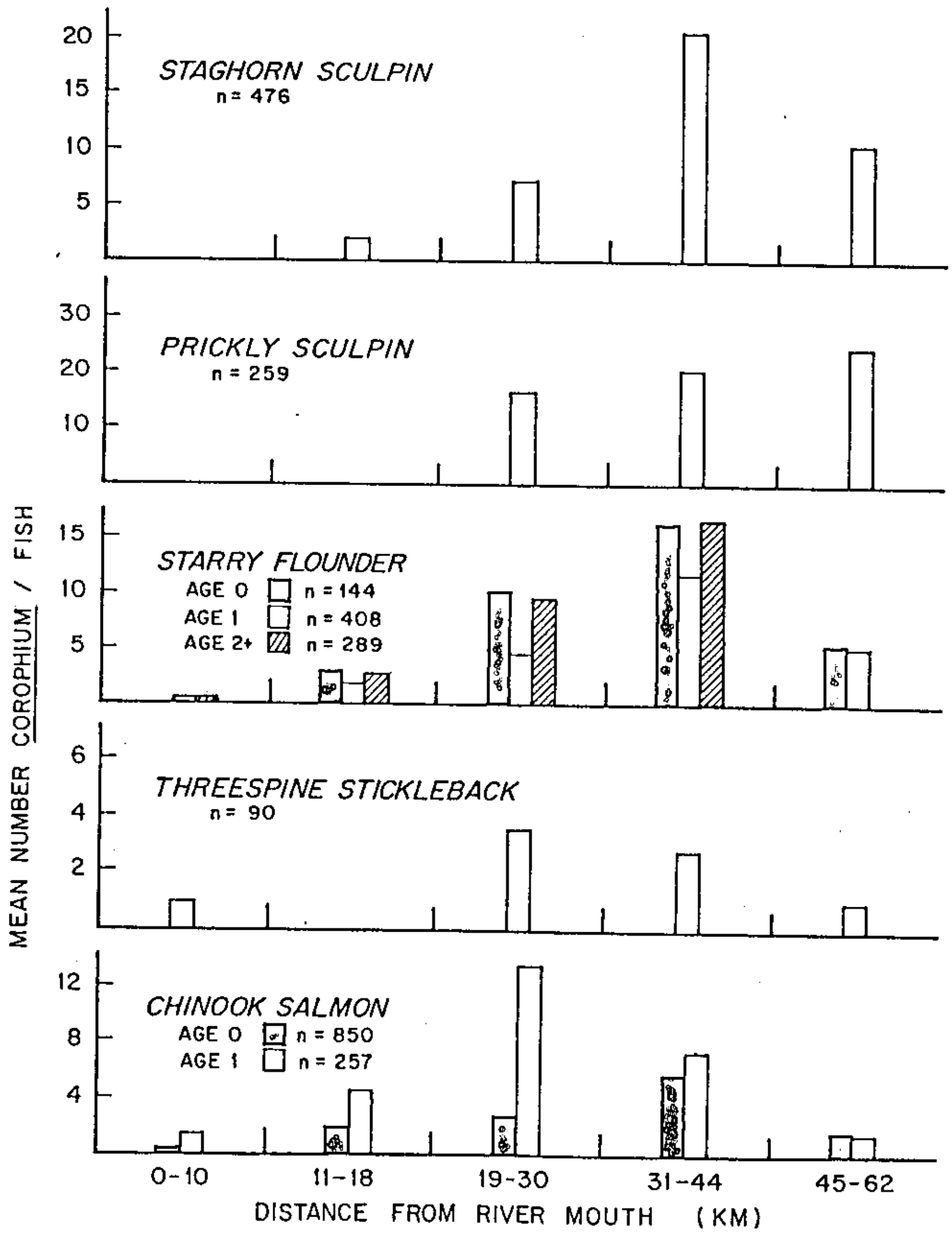


Figure 31. Mean number of Corophium spp. in stomachs of selected fish taxa - life history stages for five regions of the Columbia River Estuary. Total number of stomachs analyzed (N) is shown for each species and age class.

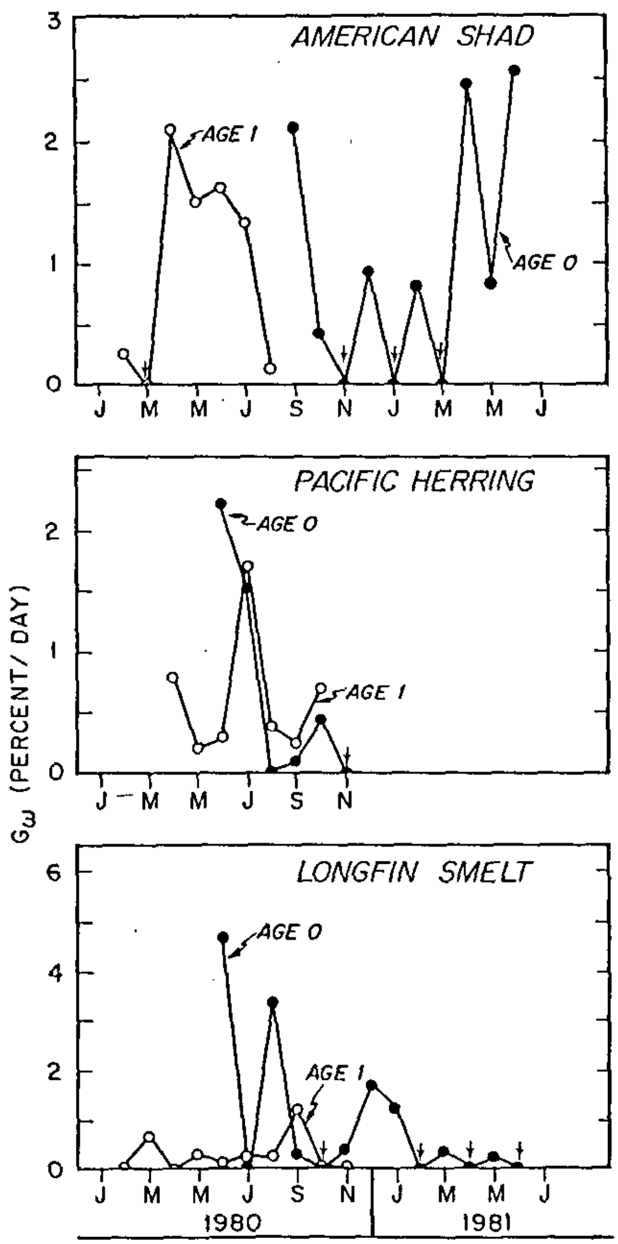


Figure 32. Specific growth rates (G_W) for selected pelagic fishes based on mean monthly biomass.

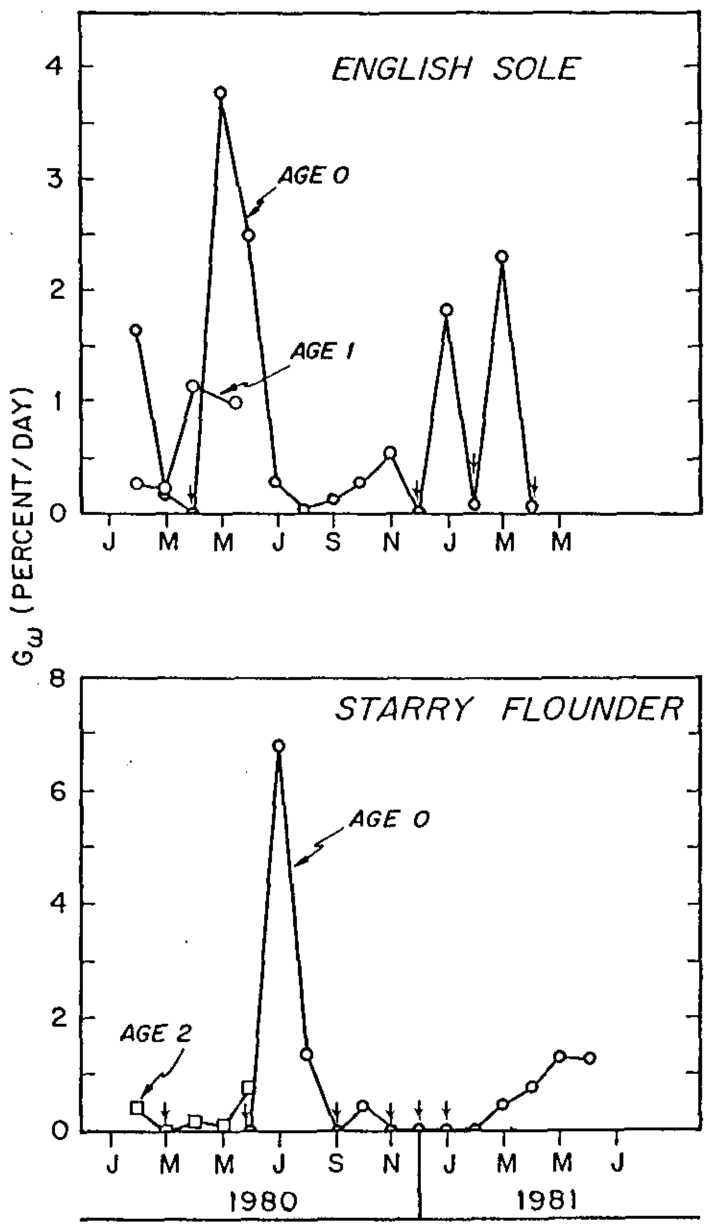


Figure 33. Specific growth rates (G_w) for selected demersal fishes based on mean monthly biomass.

necessarily correspond with periods of increased growth rate. For example, mean growth rate was maximum in the spring or summer for yearling Pacific herring and longfin smelt and subyearling English sole, even though mean IFI for these species was maximum during the winter (Table 6). Of 18 species and life history stages sampled during all three hydrologic seasons, mean IFI peaked during the spring months for 10, during the winter months for 6, and during the summer for 2. Weight of stomach contents will depend on time of sampling, time of feeding by fish, and rates of digestion by fish. If these factors change considerably through the year, IFI may not be a good index of relative daily consumption. A large variance for mean IFI for some species limits our ability to compare feeding intensity between seasonal periods.

In general, mean IFI for the entire study period was low for most species and never reached 1% of total body weight. Highest mean values were recorded for demersal predators such as Pacific staghorn sculpin (0.68%), Pacific tomcod (0.46%), white sturgeon (0.41%), and prickly sculpin (0.34%). Mean IFI for all months did not exceed 0.13% for many pelagic species such as yearling Pacific herring, age 2 American shad, surf smelt, subyearling and yearling longfin smelt, whitebait smelt, and Pacific sand lance. Low values were also typical of several flatfishes--butter sole, subyearling and yearling English sole, and yearling and age 2 starry flounder--and of sockeye salmon, steelhead trout, yearling chinook salmon, and subyearling and yearling shiner perch.

As might be expected from the low IFI values, many fishes sampled in 1980 had a high percentage of empty stomachs (Table 7). Nearly 45% of all yearling starry flounder stomachs analyzed were empty. One-third of all yearling Pacific herring and one-fourth of all surf smelt, yearling longfin smelt, and yearling English sole had empty stomachs. Percentage empty stomachs for starry flounder, Pacific tomcod, and prickly sculpin were of a similar magnitude as values reported during a monthly survey of the Columbia River Estuary from October 1963 to July 1965 (Table 7) (Haertel and Osterberg 1967).

If approximate conversion efficiencies were available for major species in the estuary, it would be possible to deduce daily consumption based on growth rate estimates. Brett et al. (1969) reviewed conversion rates in the literature ranging between 8% and 44%. Paloheimo and Dickie (1966) suggested conversion efficiencies in nature may generally fall in a range equal to or less than the 25% to 75% values noted from laboratory studies. In Table 8 we have predicted consumption from growth rates (Cg) for five species during each hydrologic season for which growth data were available. We have estimated Cg for conversion efficiencies from 10% to 40%. If we assume efficiencies approximated 20% to 30%, then consumption rates for most of the species and age classes in Table 8 would have been less than or equal to 1% body weight per day during the winter hydrologic season (February-March). For the spring (April-June) we estimated consumption rates between 3% and 5% per day for English sole (0) and starry flounder (1 and 2). Relatively rapid growth for

Table 6. Geometric mean for ratio of stomach contents to body weight (IFI) for major predator species for winter (November-March), spring (April-June), and summer (July-October) hydrologic seasons and all months combined.*

Predator	IFI Winter	S.D.	N	IFI Spring	S.D.	N	IFI Summer	S.D.	N	IFI All Months	S.D.	N
White sturgeon	.09	.13	3	.62	.35	9	.37	.29	19	.41	.32	31
Pacific herring (0)	-	-	-	.23	.17	12	.23	.26	133	.23	.26	145
Pacific herring (1)	.36	.36	11	.14	.25	68	.04	.12	52	.11	.23	131
American shad (0)	-	-	-	-	-	-	.32	.23	40	.32	.23	40
American shad (1)	.30	.32	119	.48	.50	135	.13	.16	108	.31	.38	362
American shad (2)	-	-	-	.12	.22	29	.11	.21	17	.11	.22	46
Northern anchovy (1)	-	-	-	.01	.01	3	.20	.19	30	.18	.18	33
Chinook salmon (0)	.32	.47	114	.37	.58	308	.32	.53	494	.33	.54	916
Chinook salmon (1)	.08	.19	53	.13	.33	197	.22	.51	6	.12	.31	256
Coho salmon	.12	.00	1	.18	.31	195	.00	.00	1	.18	.31	197
Sockeye salmon	.01	.00	1	.05	.08	24	-	-	-	.05	.08	25
Steelhead trout	.04	.09	5	.07	.13	119	.02	.05	4	.07	.13	128
Surf smelt	.28	.60	28	.08	.13	58	.08	.25	71	.11	.30	157
Longfin smelt (0)	-	-	-	-	-	-	.05	.12	78	.05	.12	78
Longfin smelt (1)	.24	.91	155	.16	.30	91	.07	.21	265	.13	.49	511
Eulachon	.00	.02	107	.00	.00	1	-	-	-	.00	.02	108
Whitebait smelt	.58	.49	3	.25	.37	5	.06	.21	22	.13	.30	30
Peamouth	.12	.12	12	.00	.00	1	.12	.16	16	.12	.14	29
Pacific tomcod	.51	.63	50	.54	.44	2	.44	.57	195	.46	.54	315
Threespine stickleback	.66	.74	77	.46	.37	70	.58	.56	9	.63	.70	90
Shiner perch (0)	-	-	-	-	-	-	.08	.10	43	.07	.10	43
Shiner perch (1)	-	-	-	.01	.02	9	.06	.23	48	.06	.21	57
Snake prickleback	.14	.20	22	.50	.58	8	.01	.01	2	.21	.34	32
Pacific sandlance	.10	.35	9	.11	.24	21	-	-	-	.11	.27	30
Prickly sculpin	.33	.49	62	.44	.37	84	.28	.41	118	.34	.42	264
Staghorn sculpin	.49	.96	114	.60	.72	132	.81	.92	254	.68	.88	500
Butter sole	.10	.18	4	.12	.13	14	-	-	-	.12	.14	18
English sole (0)	.40	.57	10	.12	.19	42	.11	.27	88	.14	.28	140
English sole (1)	.09	.17	26	.13	.20	21	.04	.05	14	.09	.16	61
Starry flounder (0)	-	-	-	.17	.20	18	.16	.27	148	.16	.26	166
Starry flounder (1)	.05	.13	109	.10	.27	182	.06	.15	212	.07	.20	503
Starry flounder (2)	.06	.17	121	.10	.22	101	.18	.28	51	.10	.22	273
Sand sole	.30	.55	29	.32	.75	15	-	-	-	.31	.61	44

*Species for which no more than 10 stomachs were analyzed for any of the three seasons are excluded.

Table 7. Total number and percentage of empty stomachs for selected Columbia River fishes from this survey and reported by Haertel and Osterberg (1967).

Species	Stomachs Analyzed	Number of Empty Stomachs	Percentage of Empty Stomachs
I. Present Survey			
Pacific herring (0)	171	14	8.2
Pacific herring (1)	113	38	33.6
American shad (1)	354	10	2.8
Surf smelt	134	33	24.6
Longfin smelt (1)	499	120	24.0
Threespine stickleback	91	3	3.3
Coho salmon	188	15	8.0
Chinook salmon (0)	891	107	12.0
Chinook salmon (1)	242	43	17.8
Pacific tomcod	316	16	5.1
Prickly sculpin	258	20	7.8
Staghorn sculpin	487	70	14.4
English sole (0)	128	25	19.5
English sole (1)	55	14	25.4
Starry flounder (0)	141	27	19.1
Starry flounder (1)	417	187	44.8
Starry flounder (2)	236	50	21.2
II. Haertel and Osterberg (1967)			
Starry flounder (0.5-2.5 yr.)	539	287	53.2
Prickly sculpin (all ages)	338	24	7.1
Pacific tomcod (all ages)	285	1	.3

Table 8. Comparison of consumption rate estimates calculated from observed growth rates (C_g).[a]

Species	Mean Growth G_w (%/day)	Consumption Cg (%/day) (Efficiencies) .10	.20	.30	.40
English sole (0)					
April-June	1.18	11.8	5.9	3.9	3.0
July-October	.72	7.2	3.6	2.4	1.8
English sole (1)					
February-March	.22	2.2	1.1	.7	.6
April-June	1.01	10.1	5.0	3.4	2.5
Starry flounder (0)					
July-October	2.06	20.6	10.3	6.9	5.2
Starry flounder (1)					
February-March	.21	2.1	1.1	.7	.5
April-June	.75	7.5	3.8	2.5	1.9
July-October	.71	7.1	3.6	2.4	1.8
Starry flounder (2+)					
February-March	.10	1.0	.5	.3	.2
April-June	.75	7.5	3.8	2.5	1.9
American shad (1)					
February-March	.08	.8	.4	.3	.2
April-June	1.76	17.6	17.6	8.8	4.4
July-August	.73	7.3	3.6	2.4	1.8
Pacific herring (0)					
July-October	.52	5.2	2.6	1.7	1.3
Pacific herring (1)					
May-June	.44	4.4	2.2	1.5	1.1
July-October	.74	7.4	3.7	2.5	1.8
Longfin smelt (0)					
July-October	.88	8.8	4.4	2.9	2.2
Longfin smelt (1)					
February-March	.26	2.6	1.3	.9	.6
April-June	0	0	0	0	0
July-October	.26	2.6	1.3	.9	.6

[a] Cg is calculated for each of 4 levels of conversion.

yearling American shad accounted for estimates of consumption rate between 6% and 9% per day during spring. During the summer low flow season (July-October) consumption rate estimates were 2% to 4% per day for English sole (0), starry flounder (1), American shad (1), Pacific herring (0 and 1), and longfin smelt (0). Subyearling starry flounder probably consumed 7% to 10% body weight per day during summer to sustain growth rates estimated at 2% per day.

3.11 RESIDENCE AND MIGRATION OF JUVENILE SALMONIDS

3.11.1 Catch Composition

Table 9 summarizes the species composition of the total juvenile salmonid catch for 1980 and 1981. No pink salmon were collected, although other studies have reported their presence in the Columbia River system (Basham and Gilbreath 1978). Few adult salmon and steelhead were captured during the study, and they will not be discussed in this report.

Table 9. Composition of the catch of juvenile salmonids, 1980 and 1981.

Species	Percentage of catch
Subyearling chinook	68
Yearling chinook	8
Coho	18
Steelhead	5
Chum, sockeye, cutthroat	1

Most juvenile salmonids were collected in deep channel areas with purse seines. This was the most effective gear for collecting yearling chinook and juvenile steelhead and coho (Table 10). Some yearling chinook and coho, but very few steelhead, were caught in nearshore areas with beach seines. Beach seines and purse seines were effective in capturing subyearling chinook salmon.

Marked fish (adipose or other fin clips, coded-wire tags (CWT), and brands) represented 3.1% of the total salmonid catch in 1980 and 4.0% in 1981. Fish with CWT were from 121 different tag groups and 33 hatcheries. Tagged groups were captured throughout the estuary and seemed to follow the same spatial and temporal distribution as unmarked fish of the same species.

3.11.2 Size Characteristics

Mean lengths of juvenile salmonids followed similar trends for the period April through July during both years of the study (Figure 34). Yearling chinook showed a decline in mean length April to May,

Table 10. Monthly catches of juvenile salmonids collected with purse and beach seines in the Columbia River Estuary.

	Steelhead		Coho		Yearling Chinook		Subyearling Chinook	
	Purse	Beach	Purse	Beach	Purse	Beach	Purse	Beach
1980								
FEB	0	0	0	0	8	68	0	19
MAR	0	0	0	1	10	9	10	232
APR	9	0	41	10	222	4	35	141
MAY	480	0	977	67	474	18	628	245
JUN	40	2	243	2	47	0	901	1,114
JUL	1	0	50	1	1	0	1,009	495
AUG	0	0	0	0	0	0	582	140
SEP	0	0	0	0	0	1	325	186
OCT	0	0	0	0	2	0	44	30
NOV	0	0	0	0	9	0	12	4
DEC	0	0	0	0	21	0	16	11
1981								
JAN	0	0	0	0	1	2	0	18
FEB	0	0	0	0	0	5	0	12
MAR	0	0	0	1	10	10	0	24
APR	4	4	13	7	54	21	10	184
MAY	323	1	921	440	204	48	354	1,197
JUN	51	1	158	11	18	0	329	1,653
JUL	0	0	9	0	1	0	777	744

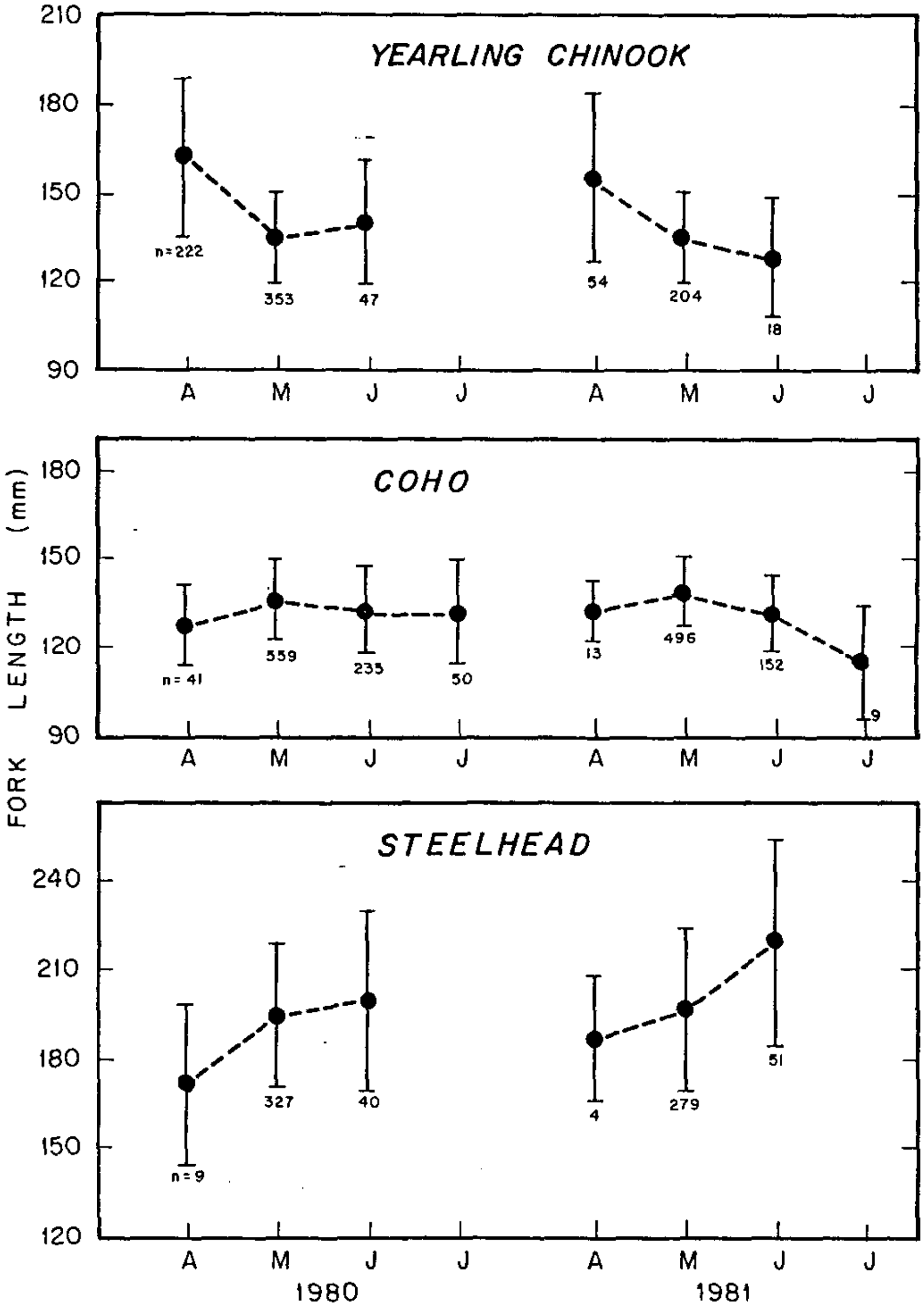


Figure 34. Mean fork lengths and standard deviations of yearling chinook salmon, coho salmon, and steelhead captured with purse seines in the Columbia River Estuary during April-July of 1980 and 1981 (from NMFS 1981).

and juvenile steelhead showed an increase in length May to June in 1980 and 1981. Mean length of coho showed a slight rise during April followed by leveling or a slight decline until July (Figure 34) (NMFS 1981). Durkin (1982) found that the average length of coho smolts in the Columbia River Estuary was greatest in April and decreased during migration. He suggested that larger coho (hatchery and wild) migrate earlier than smaller coho.

During the FRI survey, average lengths of subyearling chinook sampled with bottom trawls and beach seines in bays and shoals were similar in size to beach seine samples taken near shore (Charles Simenstad, FRI, unpublished data). During the NMFS survey, subyearling chinook captured in the water column with purse seines were generally 10 to 20 mm larger than those captured in nearshore habitats with beach seines (Figure 35). Dawley et al. (1982) reported the same trend for marked and unmarked chinook, coho, and steelhead sampled at Jones Beach. Studies in other estuaries have indicated that larger juvenile salmonids are more likely to use deeper channels as they move through the estuary (Meyers 1980; Healey 1982).

3.11.3 Subyearling Chinook

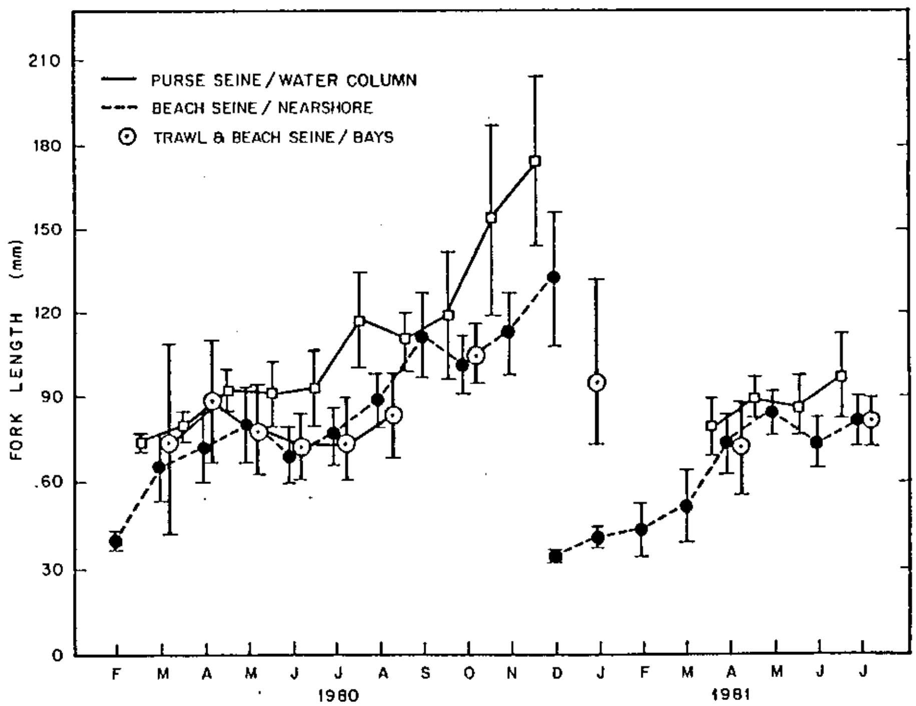
Distribution

Subyearling chinook comprised two-thirds of the total catch of juvenile salmonids. Their distribution was the most diverse of all the salmonids. Juvenile chinook were found in the estuary throughout the year, although their numbers were reduced from October to March. They were captured at shallow nearshore stations and in bays and intertidal areas. The catch-per-effort for purse seines was generally higher in the north than in the south channel. This was also true for yearling chinook and suggests that the north channel is the preferred route for those fish moving in deep water. Distribution of chinook (0) in each salinity zone showed no pattern of movement. Coded-wire-tagged groups of subyearling chinook had the same distribution in the estuary as unmarked fish (NMFS 1981).

In May 1980 there was a shift in catch from beach seines to purse seines (Table 10). This may have marked a migration from nearshore to offshore channels (water column habitats), or it may have been related to the large number of fish released from hatcheries in April and May. This shift was not observed in 1981.

Migration Rates

Subyearling chinook appeared to move more slowly through the estuary than other salmonid species. Data from Dawley et al. (1982) showed the movement rate from Jones Beach (RM 45) to McGowan (RM 10) was slower each year for subyearling chinook than for yearling chinook, coho, or steelhead (Table 11).



	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J
PURSE SEINE/ WATER COLUMN	10	35	555	509	687	531	293	46	21	37	0	0	0	10	354	342	498	_
BEACH SEINE/ NEARSHORE	19	172	133	222	518	378	139	170	30	4	11	18	12	24	183	460	558	410
TRAWL & BEACH SEINE/BAYS	_	27	36	169	92	81	11	_	3	_	_	2	0	_	8	_	47	_

Figure 35. Mean fork lengths and standard deviations of subyearling fall chinook captured in water column, nearshore, and bay habitats in the Columbia River Estuary during 1980 and 1981. Numbers of fish (n) measured each month are listed by gear type and habitat below the figure. (Data from NMFS 1981 and Charles Simenstad, FRI, unpublished.)

Table 11. Average movement rates (km/day) of tagged groups of juvenile salmonids from release site to Jones Beach (JB) and McGowan (MG) (raw data from Dawley et al. 1982).*

	1978		1979		1980	
Species	Release to JB	JB to MG	Release to JB	JB to MG	Release to JB	JB to MG
Subyearling Chinook	16	4	21	11	19	25
Yearling Chinook	20	15	17	15	23	28
Coho	16	26	20	22	18	28
Steelhead	21	44	32	—	29	43

* Jones Beach is 75 km and the McGowan site is 16 km from the river mouth. Average rates for marked groups calculated from date of median fish recaptured. No sample sizes were reported for these data.

Average migration rates for about half the hatchery groups of chinook (0) decreased when the subyearlings entered the estuary (Table 12). Most of the groups of subyearling chinook that increased their rate of migration through the estuary were from releases made in 1980. Movement rates to the lower estuary generally increased with distance of release location from the river mouth (Figure 36). Yearling chinook, coho, and steelhead showed the same trend. The increase in movement rate in relation to release location was proportional for all four salmonid groups. An analysis of covariance of the adjusted mean movement rates shows that subyearling chinook move at a significantly slower rate through the system than the other salmonid groups (Table 13).

Residence Times

The catch-per-effort of subyearling chinook in the estuary was affected by hatchery release schedules, but there were some subyearlings present in the estuary throughout the year. Hatchery releases occurred from April through October and corresponded with the times of peak catches in the estuary. Tagged subyearling chinook released during April and May 1980, were captured in the estuary every month through October 1980. The weekly mean fork lengths of subyearlings sampled at Jones Beach in 1981 fluctuated in relation to the fish size of major hatchery release populations (Figure 37; Dawley

Table 12. Hatchery release groups and migration rates of subyearling chinook to Jones Beach (JB) and to McGowan (MG) (raw data from Dawley et al. 1982).*

Hatchery Location (Km from river mouth)	Tag Code	Release Date	Migration Rates (Km/day) to JB	to MG	Rate Change
Abernathy (91)	055801	Apr 78	8	2	-
	050450	Apr-May 79	1	1	0
	050646	Apr-May 80	0	2	+
Elokomin (94)	632005	Jun 1, 80	1	3	+
Kalama (141)	631746	Jul 12, 78	13	10	-
	631957	Jun-Jul 79	2	2	0
	632105	Jun 80	2	4	+
Toutle (160)	631763	Jun 19, 78	2	4	+
	631941	Jun 17, 79	6	2	-
Lewis (163)	631611	July 78	2	2	0
	010104	Apr-May 79	1	1	0
	010202	Apr 80	1	1	0
Cowlitz (184)	631802	Jun 19, 78	3	4	+
	631942	Jun 27, 79	3	2	-
Washougal (213)	631803	Jun 26, 78	8	7	-
	631946	Jun 14, 79	9	3	-
	632153	Jun 30, 80	6	14	+
Oxbow (219)	072163	May 28, 80	3	4	+
Bonneville (230)	071842	May 79	5	4	-
	972207	Jun 30, 80	11	14	+
Little Wh. Salmon (261)	056301	May 24, 78	14	8	-
	050449	Jun 22, 79	23	12	-
	050643	Jun 10, 80	27	17	-
Spring Cr. (269)	055701	May 18, 78	39	17	-
	050446	Mar 20, 79	28	3	-
	050639	Mar 10, 80	2	4	+
Deschutes (330)	070204	Apr-Jul 78	5	5	0
	072145	Apr-Jun 80	5	7	+
Klickitat (358)	631741	Jun 78	10	11	+
	631949	Jun 1, 79	31	16	-
	631947	May 27, 80	18	13	-
Santiam (416)	071707	Jun 5, 78	11	14	+
Stayton Pd (452)	071841	May 79	13	8	-
	072055	Apr-Jun 80	10	12	+
McNary (470)	LA IF 1	Jun-Jul 78	18	21	+
	LA IF 1	Jun-Jul 80	9	13	+
Ringold (568)	631745	Jun 23, 78	23	15	-
Priest Rapids (639)	632017	Jun 28, 79	18	14	-
	631948	May-Jun 80	11	11	0
Kooskia (863)	RA SU 1	Apr, 29 79	16	28	+

*Jones Beach is 75 Km and the site near McGowan is 16 Km from the river mouth in the North Channel.

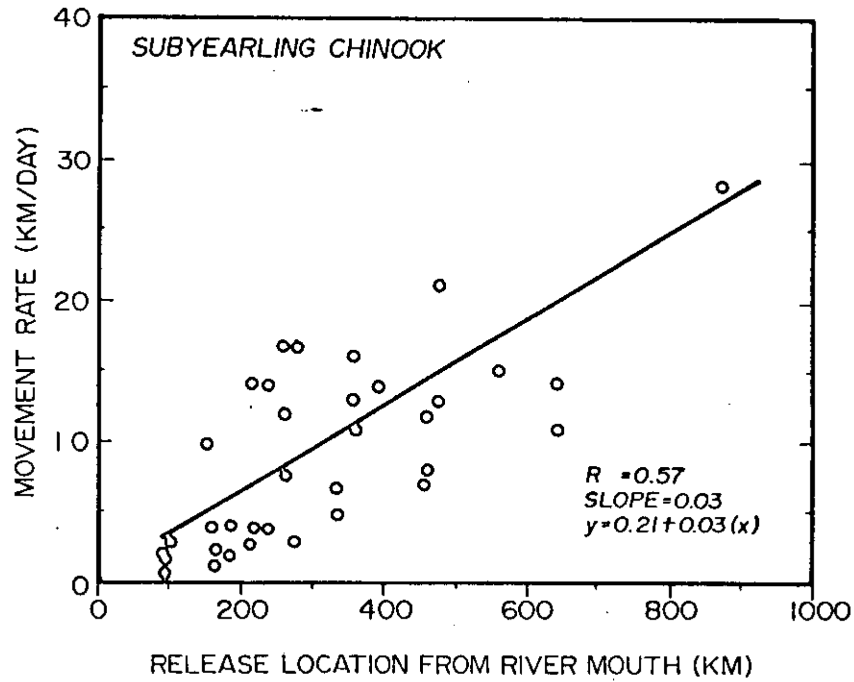


Figure 36. Movement rates in relation to release location of selected groups of tagged subyearling chinook.

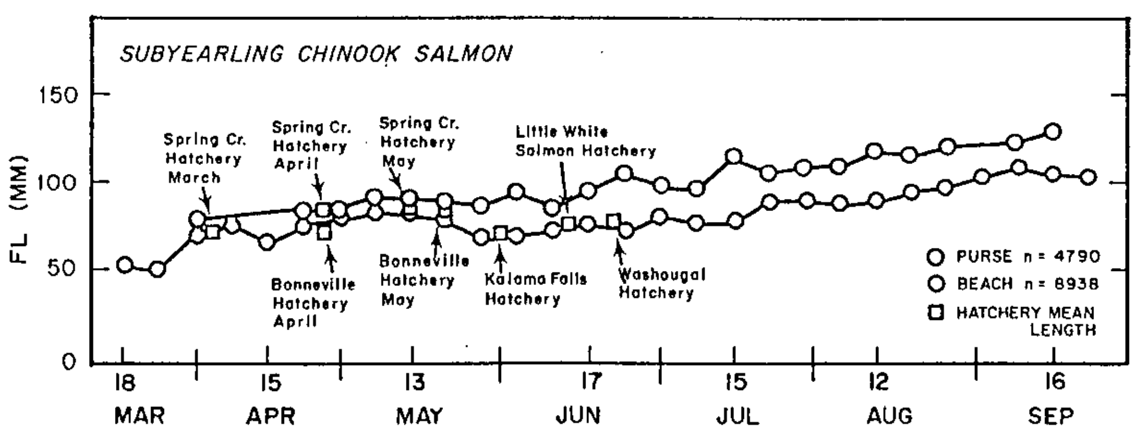


Figure 37. Weekly mean fork lengths of subyearling chinook sampled at Jones Beach compared with mean fork lengths of hatchery subyearlings released March-September 1981.

Table 13. Analysis of covariance of the adjusted mean movement rates of juvenile salmonids in the Columbia River. Movement rates that are significantly different are shown with an asterisk (*).

	Steelhead	Coho	Yearling Chinook
Subyearling Chinook	$F_m = 19.51$	$F_m = 33.00$	$F_m = 19.50$
	*$P = 5.05 \times 10^{-5}$	*$P = 4.86 \times 10^{-7}$	*$P = 5.06 \times 10^{-5}$
Yearling Chinook	$F_m = 9.80$	$F_m = 3.31$	
	*$P = 2.91 \times 10^{-3}$	$P = 0.07$	
Coho	$F_m = 0.51$		
	$P = 0.48$		

Table 14. Groups of tagged subyearling chinook that showed a slowdown in movement rate through the estuary in 1978-80. Tagged groups were recaptured and measured at Jones Beach (JB) and near McGowan (MG) (raw data from Dawley et al. 1982).*

Hatchery Location (Km from river mouth)	Tag Code	X FL (mm) at Release	X FL (mm) at JB	X FL (mm) at MG	Change in X FL
Abernathy (91)	055801	83	90	110	+
Kalama (141)	631746	68	85	90	+
Toutle (160)	631941		73	115	+
Cowlitz (184)	631942	85	92	112	+
Washougal (213)	631803		91	96	+
	631946	95	80	115	+
Bonneville (230)	071842	88	91	98	+
Lit. Wh. Salmon (261)	056301	74	95	90	-
	050449		74	85	+
	050643	73	78	80	+
Spring Creek (269)	055701	92	91	95	+
	050446		70	100	+
Klickitat (358)	631949		89	94	+
	641947		86	85	-
Stayton Pond (452)	071841		90	105	+
Ringold (568)	631745		129	130	+
Priest Rapids (639)	632017		113	125	+

* Jones Beach is 75 Km and the site near McGowan is 16 Km from the river mouth in the north channel.

et al. 1982).

There was some evidence of estuarine growth in groups of tagged subyearlings that showed a migration slowdown as they moved through the estuary (Table 14). All but 2 of the 17 groups of tagged subyearling chinook that decreased their rate of migration through the estuary also showed an increase in mean fork length. The mean fork length of these subyearlings at RM-45 was 89.2 mm and at RM-10 was 101.5 mm (Table 15). In contrast, only 6 of the 16 groups that increase their rate of migration through the estuary also increased their average size (Table 14). The mean fork length of these subyearlings was larger than the slower moving groups and showed insignificant change from RM-45 to RM-10 (Table 15).

Table 15. Mean fork lengths (mm) and standard deviation of selected tagged groups of juvenile salmonids captured at Jones Beach (JB) and at McGowan (MG), 1978-80. Size of tagged groups that slowed and increased their rate of migration through the estuary are shown separately for chinook.

Juvenile Salmonid Group	Migration Rate through Estuary	Fork Length (S.D.) at JB	Fork Length (S.D.) at MG	Sample Size
Chinook (0)	Decreased	89.2 (14.4)	101.5 (14.4)	17
	Increased	107.6 (13.2)	102.2 (13.3)	16
Chinook (1)	Decreased	145.0 (19.6)	144.3 (24.1)	17
	Increased	148.5 (19.5)	139.4 (17.7)	21
Coho	Increased	142.7 (9.5)	142.7 (8.7)	15
Steelhead	Increased	201.5 (24.7)	198.0 (30.4)	23

3.11.4 Yearling Chinook

Distribution

Yearling chinook made up 8% of the total catch of juvenile salmonids in 1980-81. Most were caught in the channel stations with purse seines. During peak migration many more yearling chinook were caught in the north than in the south channel (Figure 38). There were no observable patterns of distribution in relation to salinity zones.

Migration Rates

Yearling chinook appeared to move through the estuary more rapidly than subyearling chinook and more slowly than steelhead (Table 11). Movement rates of hatchery yearlings to the lower estuary

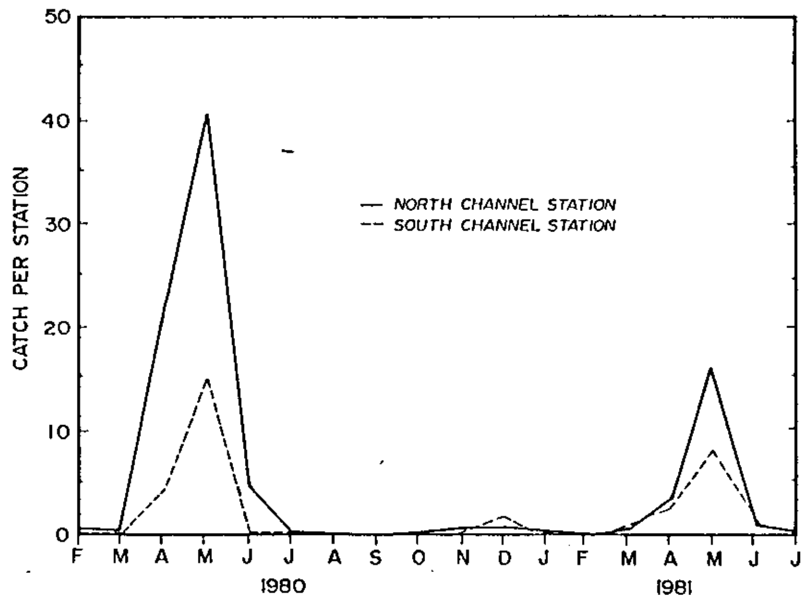


Figure 38. Comparison of catch per station of yearling chinook in north and south channel stations, 1980-81.

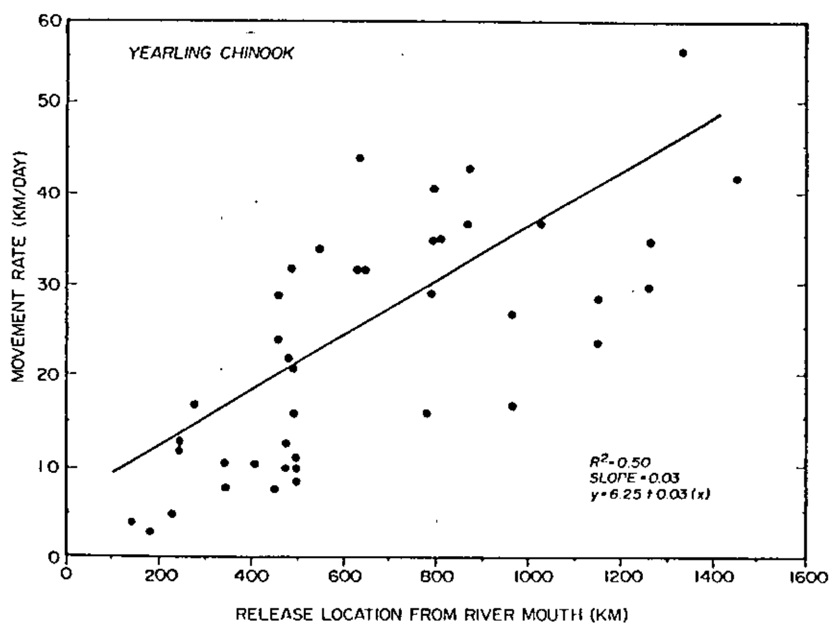


Figure 39. Movement rates in relation to release location of selected groups of tagged yearling chinook.

generally increased with distance of release location from the river mouth (Figure 39) as it did for other juvenile salmonids. Migration rates averaged for selected hatchery groups showed a slowdown of movement through the estuary for 17 of the 42 groups (Table 16).

Residence Times

Most yearling chinook were available in the estuary for a relatively short time in the spring. Peak catches occurred in May of both years.

Although more than half of the tagged groups examined showed a slow down in migration rate through the estuary, only about one third showed an increase in mean fork length while in the estuary. Both the fast moving and the slow moving yearling chinook tagged groups showed no increase in average length from Jones Beach to the lower estuary (Table 15).

3.11.5 Coho

Distribution

Coho made up 18% of the combined catch of juvenile salmonids in 1980-81. Most were caught at channel stations with purse seines. There appeared to be no pattern of distribution in relation to north and south channels and to estuarine salinity zones. Tagged coho released from hatcheries very low in the system (Grays River at RM-34 and Big Creek at RM-29) were more likely to be found in shallow bays and intertidal areas than were the upriver coho (NMFS 1981).

Migration Rates

Juvenile coho appeared to move through the estuary more rapidly than subyearling chinook. Average migration rates for selected hatchery groups showed that about two-thirds of the coho groups increased their movement rate through the estuary (Table 17). Movement rates from release location to the lower estuary generally increased for hatchery coho released further up the Columbia River as it did for the other salmonid groups (Figure 40).

Previous studies have shown that migration rate increases in groups that are released later in the spring. Durkin (1982) suggested that juvenile coho may move downstream at a faster rate if released after late April than if released earlier, no matter where in the system they originate. He also suggested that juvenile coho may have a greater tendency to stray upstream when released before mid-April.

Table 16. Hatchery release groups and migration rates of yearling chinook to Jones Beach (JB) and to McGowan (MG) (raw data from Dawley et al. 1982)*.

Hatchery Location (Km from river mouth)	Tag Code	Release Date	Migration Rates (Km/day) to JB	to MG	Rate Change
Kalama Falls (141)	631705	Mar 23, 78	3	4	+
Cowlitz (189)	631709	Mar 8, 78	3	3	0
	631817	Apr 23, 79	23	12	-
Bonneville (231)	071733	Mar 13, 80	4	5	+
Eagle (247)	901658	Apr 24, 78	10	13	+
	071748	May 1, 79	11	12	+
Carson (275)	050438	Apr 28, 80	25	17	-
Klickitat (358)	631601	Mar 31, 78	12	11	-
	631733	Mar 27, 79	10	8	-
S. Santiam (416)	071946	Mar 14, 80	11	11	0
Marion Forks (452)	100323	Apr 8, 78	22	24	+
	100325	Apr 79	26	29	+
McNary (470)	LA H 1	Apr-May 78	17	22	+
	LA 5 1	Apr-Jul 79	10	10	0
	LA H 1	Apr-May 80	14	13	-
Warm Springs (485)	050627	Apr 80	13	16	+
Oakridge (491)	071741	Mar 20, 79	13	10	-
	072040	Mar 11, 80	11	11	0
McKenzie (492)	072053	Mar 15, 80	12	9	-
Round Butte (489)	071609	May 22, 78	21	17	-
	071825	May 31, 79	46	32	-
	071951	Apr 15, 80	19	21	+
Ice Harbor (551)	LD IS 3	May 79	30	34	+
Little Goose (634)	LA PI 2	Apr 78	43	44	+
	LA P 1	Apr-May 80	37	32	-
Lowex Granite (639)	LA PI 2	Apr 78	43	44	+
	LA K 3	Apr-May 79	31	19	-
Leavenworth (789)	631702	Apr 25, 78	26	29	+
	631810	Apr 26, 79	22	16	-
	LA PP 2	Apr 80	20	41	+
Entiat (790)	631725	Apr 25, 78	30	35	+
Rapid River (967)	100214	Mar 27, 78	25	27	+
	100415	Mar-Apr 79	18	17	-
Kooskia (1026)	101314	Apr 20, 78	30	37	+
(863)	100330	Apr 12, 78	27	37	+
(863)	050532	Apr 16, 80	44	43	-
McCall (1153)	100323	Apr 8, 78	22	24	+
	100325	Apr 79	26	29	+
Hayden Pond (1294)	050454	Apr 79	36	35	-
	102126	Apr 4, 80	39	30	-
Pahsimeroi	100327	May 13, 78	36	56	+
Decker Flats (1446)	100348	Apr 5, 79	43	42	-

*Jones Beach is 75 Km and the site near McGowan is 16 Km from the river mouth in the North channel.

Residence Times

Coho were captured in the estuary between April and July with peak catches in May of both years. A peak migration in May has been reported for coho in the Columbia River Estuary in previous years (Dawley et al. 1978) as well as in other river systems regardless of river size, geographic location, and the origin (hatchery or wild) of the coho population (Durkin 1982).

There was no evidence of growth or a slowdown in movement of coho during their estuarine migration. The mean length of fish did not increase from samples taken in the upper estuary at Jones Beach to samples taken in the lower estuary at McGowan (Table 15). The movement rate of most of the tagged groups we compared increased as the fish moved into the estuary.

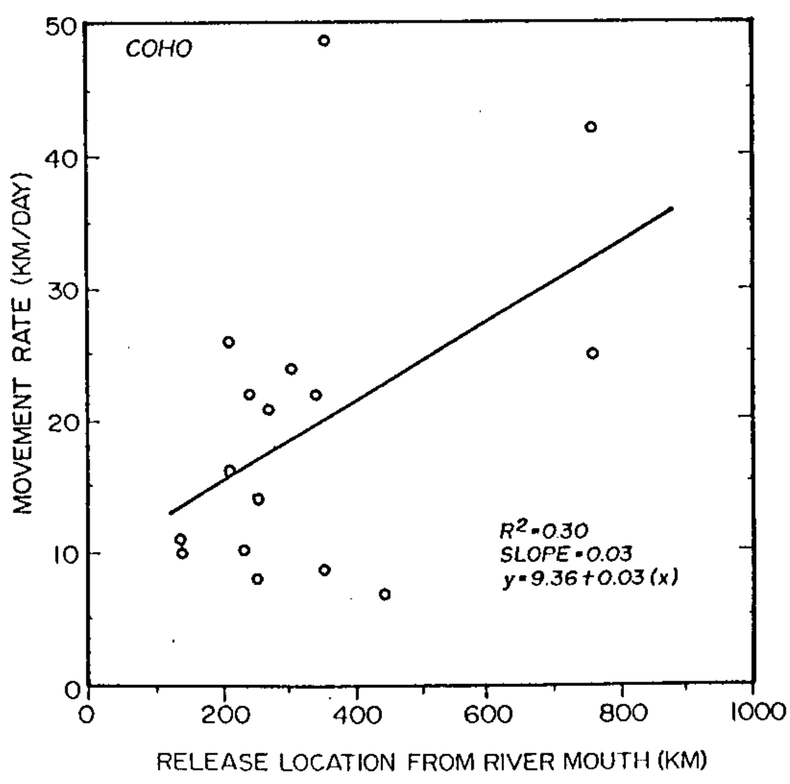


Figure 40. Movement rates in relation to release location for selected groups of tagged juvenile coho.

Table 17. Hatchery release groups and migration rates of juvenile coho to Jones Beach (JB)* and to McGowan (MG), raw data from Dawley et al. 1982.

Hatchery (km from river mouth)	Tag code	Release date	Migration rates (km/day) to JB	Migration rates (km/day) to MG	Rate change
Toutle (160)	631911	May 7, 79	7	10	+
	632058	May 7, 80	9	11	+
Washougal (213)	631926	June 7, 79	21	26	+
	632039	May 8, 80	16	17	+
Cascade (230)	LB B4 3	May 3, 78	16	10	-
Sandy (235)	091645	May 2, 78	18	22	+
Eagle Creek (247)	091657	April 23, 78	6	8	+
	071746	May 22, 79	10	14	+
Willard (268)	WHRDLB	May 23, 78	16	21	+
Nehalem (306)	RD T 2	May, 80	26	24	-
Carson (347)	RP ID 1	May 23, 78	34	22	-
Klickitat (358)	631563	May 4, 78	10	9	-
	631751	May 14, 79	57	49	-
Turtle Rock (768)	631645	May 2, 78	26	25	-
	RA IY 1	May 13, 79	36	42	+

*Jones Beach is 75 km and McGowan is 16 km from the river mouth.

3.11.6 Steelhead

Distribution

Juvenile steelhead made up 5% of the total catch of juvenile salmonids in 1980-81. Virtually all steelhead were caught with purse seines in the deep channel stations. There appeared to be no pattern of distribution in relation to north and south channels or to salinity zones.

Migration Rates

Juvenile steelhead moved rapidly through the estuary. Migration rates averaged for selected hatchery groups showed that more than two-thirds of the steelhead groups increased their movement rate through the estuary (Table 18). Movement rates showed some tendency to increase with distance of release location from the river mouth (Figure 41).

Residence Times

Juvenile steelhead were captured in the estuary for the shortest amount of time of any of the salmonid groups. Most of the catch was

Table 18. Hatchery release groups and migration rates of juvenile steelhead to Jones Beach (JB) and to McGowan (MG) (raw data from Dawley et al. 1982)*

Hatchery (Km from river mouth)	Tag Code	Release Date	Migration Rates (Km/day) to JB	to MG	Rate Change
Cowlitz (189)	631760	May 30, 78	29	29	0
Eagle (247)	091656	Apr 24, 78	8	13	+
	071745	May 1, 79	10	12	+
Skamania (275)	632018	Apr 80	13	14	+
Warm Springs (485)	050439	May 10, 79	13	29	+
Naches (539)	632003	Apr-May 78	15	20	+
Ice Harbor (557)	RA IK 4	May 78	34	32	-
Ringold (568)	631707	Apr-May 78	15	20	+
	631804	Apr 79	17	34	+
Lower Granite (639)	LA P 4	May 78	26	40	+
Chelan (789)	LA 4 2	May 78	38	55	+
Tucannon (793)	LA DT 1	Apr-May 78	34	17	-
Dworshak (809)	100349	Apr 78	33	54	+
(863)	101315	Apr 78	53	61	+
Wells Springs (828)	RD Y 2	May 1, 80	34	54	+
(919)	RA L 2	Apr 27, 78	32	82	+
Wallowa (940)	072201	Apr 21, 80	26	37	+
Niagra (1311)	100345	Apr 7, 78	25	34	+
	100343	Mar 19, 79	48	59	+
	102157	Apr 80	37	36	-
Hagerman (1311)	050423	Apr-May 79	29	28	-
	050636	Feb-Apr 80	13	13	0
	050635	Apr 80	62	52	-

*Jones Beach is 75 Km and the site in the North channel near Mcgowan is 10 Km from the river mouth.

taken in May. Their rapid migration rate suggests that most steelhead spend little time in the estuary but use the channels to move directly from the river to the ocean.

There was much variation in the mean fork length of the steelhead groups we compared. The average length of all the groups from RM-45 above the estuary was not significantly different from the average length of steelhead at RM-10 in the lower estuary (Table 15).

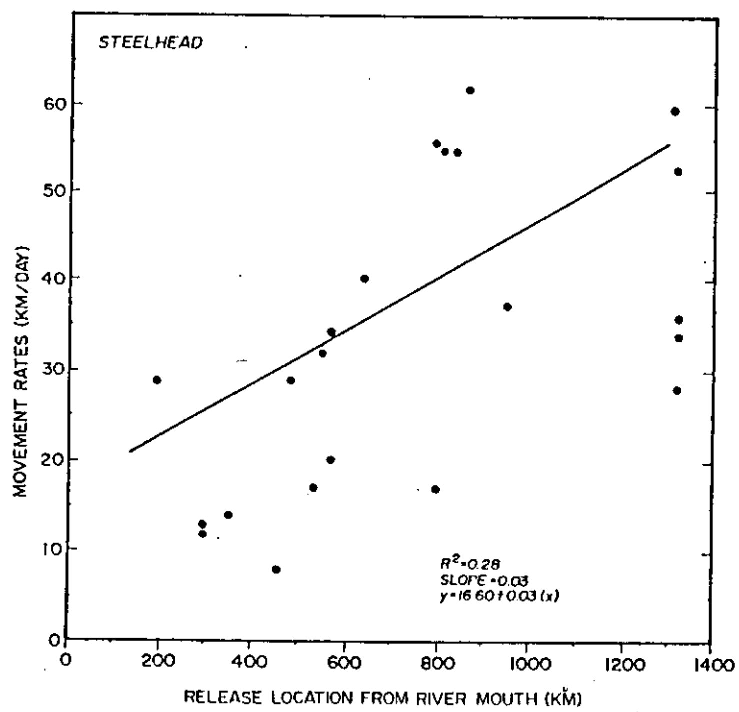


Figure 41. Movement rates in relation to release location of selected groups of tagged steelhead.

4. DISCUSSION

4.1 EFFECTS OF SALINITY AND HABITAT ON FISH DISTRIBUTION

The Columbia River Estuary supports a fish community composed of resident, migratory, and semi-resident species. Many of these are euryhaline fishes common to much smaller Oregon estuaries where freshwater influence is relatively less significant (Cummings and Schwartz 1971; Pearcy and Myers 1974; Reimers and Baxter 1976; Mullen 1977; Bottom and Forsberg 1978). Intensive purse seining in deep channels during this survey allowed capture of many pelagic fishes that have been poorly sampled in other estuaries. Because of minimal oceanic influence there were relatively fewer marine species captured in the Columbia, but a larger number of freshwater representatives were found compared with other estuarine surveys in Oregon (Table 19). Freshwater species included bluegill, coastrange sculpin, mountain whitefish, peamouth, white crappie, and yellow perch.

The composition and distribution of species assemblages in the Columbia River Estuary largely reflect seasonal cycles in the migration and life history of fishes using the estuary. During the winter (calendar season) fewer species and individuals inhabit the estuary relative to other seasons. In spring, subyearling and yearling age classes of several species appear, and anadromous fishes are abundant as juvenile salmonids migrate through the estuary en route to the ocean. Maximum abundance of fishes occurs during summer months. As the number of species and life history stages increase, the composition and distribution of species assemblages become more complex.

Superimposed over natural reproductive cycles are seasonal changes in river flow and salinity patterns that affect the distribution and composition of species assemblages. General distribution of fishes in 1980-81 agreed with results of an earlier study of demersal species in the Columbia River Estuary by Haertel and Osterberg (1967). They reported that fish distribution was largely influenced by salinity; that euryhaline species were the most abundant fishes sampled at all stations; and that the greatest diversity and number of fish were collected in salinities of 0.5 ppt to 18 ppt in a general area between Chinook Point and Astoria. In the present survey, fishes were distributed along a salinity gradient from lower to upper estuary. The most abundant species were found throughout a wide range of salinities, and the greatest diversity and abundance of fish were found in the estuarine mixing zone. The importance of salinity to species distributions was illustrated by results of the seasonal station clusters. Regardless of the type of sampling gear, stations with the most similar species assemblages usually were grouped in one of three zones corresponding to a horizontal salinity gradient.

Of the three estuarine zones, the marine zone was the smallest. It rarely extended more than 12 km from the river mouth. Salinities

Table 19. List of species captured in the Columbia River Estuary and other Oregon estuaries (x=present, o=absent).

	Col.	Til.	Six.	Coos	Ump.	Yaq.	Sal.
American shad	x	x	x	x	x	x	x
Arrow goby	o	x	o	x	x	x	o
Bay goby	o	o	o	x	o	x	o
Bay pipefish	x	x	x	x	x	x	x
Big skate	x	x	o	o	o	x	x
Black crappie	x	o	o	o	o	o	o
Black rockfish	x	o	o	o	o	o	x
Bluegill	x	o	o	o	o	o	o
Brown Irish lord	o	x	x	o	o	x	o
Buffalo sculpin	x	x	x	x	o	x	x
Butter sole	x	x	o	o	o	o	o
Cabezon	x	x	x	x	o	x	x
Carp	x	o	o	o	o	o	o
Chinook salmon	x	x	x	x	x	x	x
Chum salmon	x	x	x	x	o	o	o
C-O sole	x	o	o	o	o	o	o
Coastrange sculpin	x	o	o	o	o	o	o
Coho salmon	x	x	x	x	x	x	x
Cutthroat trout	x	x	x	x	x	x	x
English sole	x	x	x	x	x	x	x
Eulachon	x	o	o	o	o	o	o
Green sturgeon	x	x	o	x	o	x	o
High cockscomb	o	x	o	x	o	x	o
Kelp greenling	x	x	x	x	x	x	x
Largescale sucker	x	o	x	o	x	o	o
Lingcod	x	x	x	x	x	x	x
Longfin smelt	x	x	x	o	o	x	o
Longnose skate	o	x	o	x	o	x	o
Mountain whitefish	x	o	o	o	o	o	o
Night smelt	x	o	o	o	o	o	o
Northern anchovey	x	x	o	x	x	x	x
Northern squawfish	x	o	o	o	o	o	o
Pacific hake	x	o	o	o	o	o	o
Pacific herring	x	x	x	x	x	x	x
Pacific lamprey	x	x	x	x	o	o	o
Pacific sanddab	x	x	o	o	o	x	o
Pacific sandfish	x	o	o	o	o	o	o
Pacific sandlance	x	x	x	x	x	x	x
P. staghorn sculpin	x	x	x	x	x	x	x
Pacific tomcod	x	x	x	x	x	x	x
Padded sculpin	x	x	o	x	o	x	o
Peamouth	x	o	o	o	o	o	o
Penpoint gunnel	o	x	x	x	o	x	o
Pile perch	x	x	o	x	x	x	x
Pricklebreast poacher	x	x	o	o	o	o	o
Prickly sculpin	x	x	x	x	x	x	x
Red gunnel	o	x	o	o	o	o	o
Red Irish lord	x	x	o	o	o	x	o

Redside shiner	o	o	o	o	x	o	o
Redtail surfperch	x	x	x	x	x	x	x
Ringtail snailfish	x	x	x	o	o	o	x
River lamprey	x	o	o	o	o	o	o
Rockfish spp (juv)	x	x	x	x	x	x	o
Sablefish	o	x	o	o	o	o	o
Saddleback Gunnel	x	x	x	x	x	x	x
Sand sole	x	x	o	x	x	x	x
Sharpnose sculpin	o	x	x	o	x	o	x
Shiner perch	x	x	x	x	x	x	x
Showy snailfish	x	o	o	o	o	o	o
Silver spotted sculpin	o	x	x	o	x	o	o
Silver Surfperch	x	x	x	x	x	x	o
Slipskin snailfish	x	x	x	o	o	o	o
Smoothhead sculpin	o	x	o	o	o	o	o
Snake prickleback	x	x	x	x	o	x	o
Sockeye salmon	x	o	o	o	o	o	o
Speckled sanddab	x	o	o	x	o	o	o
Spiny dogfish	x	o	o	o	o	o	o
Spotfin surfperch	x	o	o	o	o	o	o
Starry flounder	x	x	x	x	x	x	x
Steelhead trout	x	x	x	x	x	x	x
Striped surfperch	x	x	x	x	x	x	x
Surf smelt	x	x	x	x	x	x	x
Threespine stickleback	x	x	x	x	x	x	x
Tidepool sculpin	o	x	o	x	o	o	o
Top smelt	o	x	o	x	x	x	x
Tubenose poacher	x	x	o	x	o	x	o
Tubesnout	o	x	o	x	o	x	x
Walleye pollack	x	o	o	o	o	o	o
Walleye surfperch	x	x	o	x	x	x	o
Warty poacher	x	x	o	o	o	x	o
White crappie	x	o	o	o	o	o	o
White seaperch	x	x	o	x	x	x	x
Whitebait smelt	x	o	o	o	o	o	o
White sturgeon	x	o	o	o	o	o	o
Wolf-eel	o	x	o	x	o	x	o
Yellow perch	x	o	o	o	o	o	o

* Col.: Columbia River Estuary (present study)
Til.: Tillamook Estuary (Bottom and Forsberg 1978)
Six.: Sixes River Estuary (Reimers and Baxter 1976)
Coos: Coos Bay (Cummings and Schwartz 1971)
Ump.: Umpqua River Estuary (Mullen 1977)
Yaq.: Yaquina Bay (Pearcy and Myers 1974)
Sal.: Salmon River Estuary (Mullen 1977)

in this zone varied from 0 ppt at the surface to near ocean salinities at the bottom of channels. Only eight species of fish were caught exclusively in the marine zone, and these were infrequent occurrences that represented an insignificant proportion of the total catch for the entire survey (Appendix C).

The station clusters (both for calendar seasons and for representative months) suggested surprising consistency in the location of estuarine zone boundaries between summer low flow and winter fluctuating flow conditions for all gear types. According to species distributions, the marine-estuarine mixing boundary consistently occurred approximately 11 km from the mouth of the estuary during both hydrologic seasons. The boundary between estuarine mixing and freshwater zones remained near Tongue Point (30 km from the river mouth) for all three gear types and sampling depths.

The wide distribution of most fishes made it difficult to discriminate more than general horizontal gradients. The monthly and seasonal distributions of fishes from this survey represent an average over a broad range of salinity conditions. It required up to four weeks to sample all stations during each month of the NMFS survey. Many fish probably adjusted their distribution to daily tidal changes of salinity. Daily variations in the horizontal and vertical salinity gradient may have overshadowed some seasonal effects on fish distribution.

Although salinity zones changed little between summer and winter, the composition of species groups varied as new fish entered the estuary and as euryhaline fishes extended the frequency of their distribution either upriver or downriver from the estuarine mixing zone (Figures 9, 11, and 13). In winter most species were distributed in the estuarine mixing and freshwater regions and were found less frequently in the marine zone. Anchovy, sand sole, and whitebait smelt were among fishes common to the marine zone, where the distribution of many euryhaline fishes stopped. The opposite situation occurred during summer low flows. A large group of euryhaline species occurred frequently from the marine through the estuarine mixing zone but were not commonly found in the freshwater zone. This upper zone was defined primarily by a small number of fishes that included largescale sucker, prickly sculpin, and subyearling shad.

During the spring high flow season and increased water column stratification, vertical and horizontal salinity gradients altered the distribution of Columbia River fishes and the location of major estuarine zones. The composition of fish assemblages varied with depth sampled and the extent of salinity intrusion. This was shown by the location of station cluster groups for each of the gear types during May 1980 (Figure 6). The boundary between fresh and brackish water zones was located near RM-7 for nearshore (beach seine) sites, at RM-14 for water column (purse seine) sites, and at RM-19 for channel bottom (trawl) sites.

Within the three salinity zones species assemblages were generally distributed by habitat type. Bays in the estuarine mixing zone, for example, provided shallow, low-current, fine-sediment areas frequented by Pacific staghorn sculpin, starry flounder, and other demersal species. Salmonids were often captured at nearshore habitats. However, it is surprising that species-habitat associations were not more distinct since only one gear per habitat was used and a few fish species were selectively discarded from specific types of gear. Starry flounder, for example, were not counted in purse seines, and chinook were not included among trawl catches, even though both species were commonly sampled with these gear types. The discriminant and nodal analyses showed that many of the common estuarine fish species were caught in all habitats with all types of gear.

Some habitats in the Columbia River Estuary have not been adequately surveyed to determine their importance to particular fish species or life history stages. There was evidence that bay and freshwater areas had large populations of subyearling fishes such as starry flounder and shiner perch. Very few embayment sites were sampled in the present survey. Tidal marshes in the Fraser River in Canada are rearing areas for juvenile salmonids (Levy and Northcote 1982). Marsh tidal creeks in Cathlamet Bay were not sampled in the present survey and may represent a habitat comparable to the Frazer River marshes. In an estuary like the Columbia, where freshwater flows are very high, marsh channels may provide important areas for refuge and for detrital food production for juvenile fishes.

It is clear that the species assemblages we identified represent general associations along habitat and salinity gradients rather than representing discrete groups. Distribution of the most common fishes in the estuary is governed by broad salinity and habitat preferences rather than by absolute limits of environmental tolerance. The habitat associations we observed may reflect in large part the distribution and abundance of invertebrate prey.

4.2 EFFECTS OF INVERTEBRATE PRODUCTION ON FISH DISTRIBUTION

A relatively small number of invertebrate taxa composed a large proportion of the prey consumed by fishes in the Columbia River Estuary. The most important prey taxa in this and previous surveys (Haertel and Osterberg 1967; Durkin et al. 1977b) were crustaceans, particularly Corophium salmonis ,calanoid and other copepods, and cladocerans (Daphnia spp.). Results suggest a large degree of dietary overlap between demersal and pelagic feeding fishes.

Fishes with similar food habits during the summer low flow period were distributed over a greater diversity of habitats than during other months. This is probably a result of overlapping distributions for euryhaline fishes in the estuary and increased complexity of benthic organism assemblages during summer-autumn low flows (Simenstad 1984).

The apparent overlap in diet among fishes may have been exaggerated. It was difficult if not impossible to distinguish pelagic feeding groups in this survey, because copepod taxa in fish stomachs were not identified to the species level. Plankton and epibenthic surveys have identified general copepod groups associated with marine, estuarine mixing, and freshwater zones of the estuary (Haertel and Osterberg 1967; Jones and Bottom 1984; Simenstad 1984). Haertel and Osterberg (1967) reported that most copepods eaten in fresh water were Cyclops vernalis and in brackish to marine water were Eurytemora affinis and Calanus finmarchicus.

Eurytemora affinis was the most abundant pelagic zooplankton taxon collected during a 1980 survey of the Columbia River Estuary (Jones and Bottom 1984). Maximum densities occurred during the spring when Eurytemora affinis was distributed primarily in the estuarine mixing and marine zones. The distribution and abundance of Eurytemora affinis may explain the importance of calanoid copepods (Figure 26) among pelagic fishes distributed in the estuarine mixing and marine zones (Figure 11). During the spring, longfin smelt, Pacific herring (0 and 1), surf smelt, and Pacific sand lance represented an assemblage that primarily consumed calanoid copepods. Densities of Eurytemora affinis in the water column decreased during the summer low flow season, and its center of distribution shifted to the estuarine mixing-freshwater regions (Jones and Bottom 1984).

During summer the diet of pelagic fishes in the marine and estuarine mixing zones was no longer dominated by calanoids but also included cyclopoid and harpacticoid copepods as well as Daphnia spp. (Figure 27). The diet of subyearling chinook salmon shifted during the summer from Corophium salmonis to Daphnia spp.. In 1980, Daphnia spp. were most abundant during summer low flows, when they were distributed primarily in the estuarine mixing and freshwater zones (Jones and Bottom 1984).

The distribution of demersal feeding groups in the estuary reflected the general distribution of prey species. In the spring, Pacific tomcod, English sole, butter sole, and snake prickleback frequently consumed the mysid, Archaeomysis grebnitzkii (Figure 26). These fish were most abundant in the same general region (estuarine mixing and marine zones) where the mysids were found during invertebrate and zooplankton surveys (Jones and Bottom 1984; Holton and et al. 1984; Haertel and Osterberg 1967). Corophium salmonis is widely distributed throughout the Columbia River Estuary, but its relative abundance diminishes near the estuary mouth (Holton et al. 1984). Demersal fishes that consumed Corophium salmonis occurred throughout the estuary but were particularly abundant in the estuarine mixing and freshwater zones and in nearshore and bay habitats. The average number of Corophium salmonis consumed by fishes generally decreased toward the ocean. Maximum numbers (per fish) were eaten by fish sampled in a broad area between 19 and 44 km from the mouth of the river.

The total density of fishes was maximum at stations in the estuarine mixing zone and in bay habitats. These were also areas with high standing crop of epibenthic and pelagic zooplankton. In 1980 total zooplankton densities in the water column were maximum between 16 and 26 km from the river mouth during the high flow season and between 26 and 37 km during the low flow period (Jones and Bottom 1984). Epibenthic zooplankton density and biomass were greatest in tidal flat and demersal slope habitats in the estuarine mixing zone. Simenstad (1984) reported this zone was 10 to 20 km from the river mouth during high spring flows and 25 to 35 km from the mouth during low flows. Epibenthic zooplankton densities were high during winter and spring in Youngs Bay and during winter in Baker Bay (Simenstad 1984).

High densities of epibenthic and pelagic zooplankton in the estuarine mixing zone may be related to the concentration of organic material at the turbidity maximum (Simenstad 1984). The turbidity maximum, or "null zone," is a region of current reversal in the estuary where nutrients, detritus, and phytoplankton mix with ocean derived particles. It corresponds to the upstream limit of transport of oceanic zooplankton into the estuary (Miller 1983). Lara-Lara (1983) estimated that the position of the null zone varied between 13 and 32 km from the river mouth (RM-8 and RM-20) depending on river discharge and stage of the tide.

Despite large variability in IFI values, mean feeding intensity of Columbia River fishes generally reflected concentrations of epibenthic and pelagic zooplankton in the estuarine mixing zone. Biomass of stomach contents for demersal fishes during 1980 was relatively high in a broad mid-estuary zone between 10 and 30 km from the river mouth (including Youngs Bay) and in Baker Bay.

A survey of infaunal invertebrates during the summer low flow season (September 1981) also showed high biomass in bays and tidal flats throughout the estuary. However, other habitats in the estuarine mixing zone had lower infaunal densities compared with marine and freshwater areas (Holton and Higley 1984). Although other seasonal periods were not sampled, these results suggest that fish distribution and feeding intensity may be more closely associated with epifaunal than with infaunal invertebrate concentrations. This picture ignores the importance of some key benthic invertebrates for particular fish species but may apply to a large number of fishes that feed in the epibenthic region. High average feeding intensity in the estuarine mixing zone may indicate the importance of epibenthic copepods, which were exploited by a diversity of demersal and pelagic fishes. Although some benthic invertebrates such as *Corophium* spp. were major food items, other taxa such as infaunal bivalves and polychaetes that contributed to areas of high benthic standing crop (Holton et al. 1984), were not. Within broad zones of salinity preference, the distribution and feeding of fishes in the Columbia River Estuary are directly influenced by the distribution and abundance of invertebrates, particularly species that are available in epibenthic habitats.

The average weight of stomach contents for all fishes captured with the purse seine was uniformly low at most locations relative to fish collected with the beach seine or trawl. In addition to the possibility of lower feeding success in the pelagic environment, this trend could reflect (1) earlier time of feeding for pelagic species relative to other fishes, (2) higher rates of digestion by pelagic fishes, or (3) effects of handling for species collected in the purse seine. However, low prey availability in pelagic channel habitats is perhaps a more likely explanation. Results of epibenthic surveys showed highest prey densities in tidal flats, intermediate densities along demersal slopes, and lowest densities in channel bottom habitats (Simenstad 1984). Holton et al. (1984) also reported lower mean biomass of infaunal invertebrates in "main channel center" and "main channel side" habitats relative to protected and unprotected flats and minor channels throughout most salinity zones.

4.3 FEEDING INTENSITY AND GROWTH RATES OF JUVENILE FISHES

Mean feeding intensity (IFI) for subyearling chinook salmon in the Columbia River Estuary was lower than reported for a few other estuaries. Feeding intensity averaged 0.37% for spring months and slightly less during summer and winter. Healey (1980) reported mean IFI values for juvenile chinook in the Nanaimo River Estuary (British Columbia) between 1.0 and 2.2% in 1976. He suggested that feeding conditions were poorer in 1976 than in 1975 or 1977 when IFI usually ranged between 2% and 5% of total body weight. These results may or may not be directly applicable to this survey, because dry weight methods were used by Healey (1980), and NMFS IFI values represent wet weights of fish and prey. However, in 1980 in Sixes River Estuary (Oregon), mean monthly IFI for subyearling chinook salmon was in the same range (1% to 2%) as the 1976 Nanaimo River data, even though wet weight methods were used. At the 1980 levels of feeding intensity, growth data suggested that production of subyearling chinook in Sixes River Estuary was limited by availability of invertebrate prey (Daniel Bottom, ODFW, unpublished data).

It may be difficult to compare IFI results for Columbia River fishes with data from other estuarine surveys because of differences in collection, laboratory methods, preservation, and time of sampling. Mean IFI should provide a relative index of feeding conditions within the Columbia River Estuary since NMFS sampled consistently over a large number of months and locations. However, seasonal comparisons of the IFI may be complicated by the natural shift in daylight-tide schedules from winter to summer, which may have altered the time of sampling in relation to the time of feeding by fishes in the estuary. Most species of fish did not show a large difference in mean IFI between seasons.

For the entire NMFS survey the weight of stomach contents for most fish species averaged less than 0.30% of total body weight. Pacific staghorn sculpin had the highest seasonal average for any species at 0.80% during the summer low flow period. Given the potential biases in sampling and in the IFI index, these results may or may not be indicative of a poor feeding environment for fishes in the Columbia relative to other estuaries in the region.

We reviewed growth data in the literature for two demersal species--English sole and starry flounder--to compare growth conditions in the Columbia River with growth conditions in other estuaries. It was necessary to use mean lengths of fish in the estuary from NMFS (1981;1983b) to estimate growth. Size at 1 year was estimated from length-frequency histograms (NMFS 1981). Effects of gear selection or migration of smaller or larger fish into or out of the sample area may have biased growth estimates.

Orcutt (1950) reported that starry flounder reached 106 to 109 mm standard length (SL) in Monterey Bay in December at 1 year of age (Table 20). Growth was similar for subyearling starry flounder in Sendai Bay, Japan, where adults spawned December through February and young-of-the-year reached 110 mm after 12 months (Kosaka 1974). In 1980, 0-age starry flounder were first captured in the Columbia River Estuary in June, three months later than in Monterey Bay. If mean lengths are an accurate index of total annual growth, subyearlings in the Columbia River Estuary averaged approximately 40 mm (SL) less than in Monterey Bay or Sendai Bay. Summer growth rates in the Columbia were similar to results reported for April through July in Monterey Bay, but growth during the winter period was much less. From November through April in Sendai Bay (Kosaka 1974) and October through March in the Columbia River Estuary, starry flounder exhibited little or no growth.

Table 20. Growth estimates for 0-age starry flounder from Orcutt (1950) compared with the present survey.*

Source, location	Size at 1 year (mm SL)	Growth (mm SL/day)	
Orcutt (1950)			
Monterey Bay, CA	106 to 109	April-July	0.43
		July-December	0.20
Kosaka (1974)	110	Entire year	0.30
NMFS (1981)			
Columbia River Estuary	64 to 74	July-October	0.40
		October-March	0.001

*Mean total lengths for fishes sampled in the Columbia River Estuary were converted to standard lengths according the the relationship reported in Orcutt (1950).

Seasonal growth patterns for starry flounder coincide with patterns of feeding activity. During the present study percentage of empty stomachs approached 50% during October, February, and April surveys and declined to 30% to 35% in May and June and 11% in July. Haertel and Osterberg (1967) reported 90% of the starry flounder stomachs collected in winter months in the Columbia River Estuary were empty compared to a minimum of 20% to 30% in summer or fall. Miller (1967) reported 95% to 100% of the starry flounder stomachs were empty from January to June in East Sound, Orcas Island, Washington. In Sendai Bay starry flounder did not feed actively from mid-July through February.

Pronounced seasonality in growth and feeding by starry flounder in many locations may suggest a response to conditions other than food availability. Miller (1967) suggested winter temperatures in the range of 8.0° to 10.5°C were responsible for reduced feeding activity of starry flounder in East Sound, Orcas Island. Similar winter temperatures were measured in the Columbia River Estuary by NMFS in 1980 (NMFS, unpublished data). However, Kosaka (1974) noted that starry flounder is a eurythermal species and spawns in areas of Japan where temperatures are 4°C or less. He suggests that distribution and feeding activity of starry flounder are related to annual cycles of maturation and spawning. In the Columbia River Estuary the seasonality in growth and feeding of starry flounder may also be influenced by annual spawning cycles since the change in mean temperature from fall to winter months may not be sufficient to explain the large variation in growth and feeding activity.

Rosenberg (1982) reviewed growth data for 0-age English sole from studies that used either otolith or length-frequency measurements to estimate rates. We converted NMFS (1981) data from total to standard lengths according to the method of Laroche and Holton (1979) to allow direct comparison with these data (Table 21). Estimated rates for subyearling English sole in the Columbia River Estuary in 1980 were less than reported for Yaquina Bay (Westrheim 1955), Monterey Bay (Smith and Nitsos 1969), and Puget Sound (Kendall 1966; Van Cleve and El-sayed 1969). Estimates for the summer low flow period were similar to other studies, but rates during the remainder of the year were much less. Mean size at 1 year was estimated at 92 to 96 mm SL compared with 108 to 128 mm SL from three other surveys.

Yearly growth rates and size at one year for English sole in the Columbia River Estuary were similar to values reported for Yaquina Bay, Oregon in 1978-79 (Table 21). Rosenberg (1982) noted his estimates based on otolith measurements were less than other results based on length-frequency distributions. He suggested that the growth estimates of Westrheim (1955) and Kendall (1966) (Table 21) may be inflated by their sampling method because of the migration of small fish out, migration of large fish in, or differential mortality of small fish. If such problems also affect length-frequency distributions for fish in the Columbia River Estuary, growth rates of English sole would also be less than reported by Rosenberg (1982).

We have no direct estimates of daily ration or comparative growth data for most estuarine species to conclude that rearing conditions in

Table 21. Growth estimates for 0-age English sole from previous studies compared with present survey.*

Location	Size at 1 yr (mm SL)	Daily Growth (mm/day)	Data Source	
Yaquina Bay, OR	117	0.40	Westrheim	1956
Monterey Bay, CA	108-126	0.36-0.43	Smith & Nitsos	1969
Puget Sound, OR	128	0.44	Van Cleve & El-sayed	1969
Yaquina Bay, OR	87.9**	0.28	Rosenberg	1981
Moolach Beach, OR	87.4**	0.28	Rosenberg	1981
Puget Sound, WA	--	winter 0.48 summer 0.73	Kendall	1966
Columbia River Estuary (1980)	92-96	March-Dec. 0.23 March-June 0.08 June-Oct. 0.42 Oct.-Dec. 0.08	NMFS	1983b

* All data from previous studies from Rosenberg 1981. Data from Columbia River Estuary converted from total length to standard length according to LaRoche and Holton (1979).

**Sizes estimated from slope of regression line of standard length to age after the first 140 days of life.

the Columbia River Estuary are poor relative to other estuaries. Seasonality of growth in flatfishes may represent physiological conditions not directly related to feeding opportunity. However, consistently low IFI values for most fishes, a large percentage of empty stomachs, and relatively low annual growth for a few species in 1980 suggest the need for additional research on diel feeding periodicity and growth and consumption for key species in the Columbia River Estuary.

4.4 USE OF THE ESTUARY BY JUVENILE SALMONIDS

Research on Sixes River Estuary in the late 1960s (Reimers 1973) provided the first detailed account on the importance of estuarine rearing to fall chinook salmon. More recent data exists for this and other salmonid species from a variety of estuaries, including studies on the Nanaimo (Sibert 1975; Healey 1979; 1980; 1982), Nitinat (Healey 1982), and Fraser (Levings 1982; Levy and Northcote 1982) estuaries in southern British Columbia; Hood Canal (Simenstad et al. 1980) and Grays Harbor in Washington (Simenstad and Eggers 1981); and the Yaquina (Meyers 1980), Rogue (McPhearson and Cramer 1981), and several more estuaries in Oregon (Herring and Nicholas 1983). Most of these studies have concentrated on the behavior of wild juvenile salmonids. Although the patterns of migration and rearing for each species are similar among many estuaries, findings from these studies may not be applicable to a large, altered system like the Columbia. Today most of the salmon that pass through this estuary are of hatchery origin. Studies done at Jones Beach have estimated that about 70% of the downstream migrant fall chinook are from hatcheries (R.D. Legerwood, NMFS, personal communication, 11-21-83).

During much of the year, juvenile salmonids can be found in the Columbia River Estuary as they migrate to sea. Their duration of estuarine residence and habitat preferences vary by species and size. Since most are hatchery fish, their numbers and size in the estuary depend on hatchery practices upriver. The shift from a wild to a hatchery production system in the Columbia River basin may have dramatically changed the historical patterns of use as well as the historical role of the estuary in the life history of young salmon.

4.4.1 Changes In Historical Production Of Wild Salmonids

The Columbia River basin produces the world's largest runs of anadromous chinook salmon and steelhead trout (Cheney 1978) as well as significant runs of coho, sockeye, and chum salmon, and cutthroat trout. Historically these runs consisted of native stock. By the 1860s a gill net fishery was developing on the lower Columbia River. By 1883 39 canneries were operating between Astoria and Portland (Bohn 1983). In 1883, and again in 1884, 42.9 million pounds of salmon--almost exclusively upriver races of spring and summer chinook--were harvested from the lower Columbia. The years that followed showed a decline in catch, and targets began to diversify.

As gear was adapted the catch included more fall chinook, coho, sockeye, and steelhead, but fewer spring and summer chinook.

The first part of the twentieth century showed a continued decline in catch of all salmon species. This coincided with the era of big water development projects along the mainstem and tributaries that blocked access to spawning habitat, inundated rearing habitat, and altered the character of the Columbia from a free flowing river to a chain of lakes and dams. Habitats were further altered by increased logging and agricultural activity within the Columbia River watershed (Cheney 1978).

These changes have affected each species to a different degree. Spring and summer chinook from upper tributaries, once the mainstay of the commercial fishery, have been severely reduced in number. The Snake River produced roughly 1.4 million chinook before dam developments and today produces only about 113,000 chinook (PFMC 1979). Summer and fall chinook from the Snake River and upper Columbia are at dangerously low levels after 71% of the original spawning and rearing habitat was lost to dam construction (PFMC 1979).

Wild coho spawn predominantly in the lower tributaries of the Columbia River, some of which are now blocked or inundated by dams. The smaller populations from upriver tributaries have been virtually eliminated. An estimate of the present wild production of coho in the Columbia is 400,000 fish, less than half the estimated population before water developments (PFMC 1979). Sockeye salmon spawned and reared in eight lake areas in the upper Columbia drainage, but access to all but two have been cut off by dams. Before water development activities, about 500,000 sockeye were produced annually in the Columbia basin. Presently, only about 80,000 are produced in the system (PFMC 1979).

Chum salmon use only the tributaries of the lower 300 km of the Columbia, where the impact on spawning and rearing habitat has been relatively small. However, only a remnant of the Columbia River chum population remains today. Similar declines have been documented for chum populations along the entire Pacific coast, although populations in British Columbia and Alaska have begun to recover.

Steelhead trout were once abundant and widely distributed throughout the Columbia River. The summer-run population has been drastically reduced in number by dam related mortality and migration impediments. Summer steelhead from above the confluence of the Snake and Columbia rivers are being considered for threatened or endangered status (Garcia et al. 1983). Most natural production of winter run steelhead occurs below Bonneville Dam. Therefore, the runs do not face the same mortality and passage problems from dams as do summer run steelhead (Fulton 1970).

Fish passage facilities have been added to most existing hydropower dams because of growing concern over fish losses. Plans for fish replacement are required for all new dams constructed on the

Columbia River. Compensation for salmon and steelhead losses, although incomplete, has resulted in the construction of over 40 hatcheries in the Columbia system. Improvements in propagation techniques have made these hatcheries the major producer of salmon in the system. In 1981 Columbia River hatcheries produced 128 million chinook, 68 million coho, and 9 million steelhead smolts (Figures 42 and 43). There are no estimates for wild production, but they are assumed to be much less than hatchery production.

4.4.2 Present Day Use Of The Estuary By Wild And Hatchery Salmonids

During the spring of 1980 juvenile salmon and steelhead made up 32.5% of the fish captured in the Columbia River Estuary. Subyearling chinook was the most abundant fish species during this period, representing 17.7% of the total catch (Table 4). Gear selectivity and sample locations may have biased catch composition. Nonetheless, hatchery records attest to the large numbers of salmonids released into the Columbia River system.

Subyearling chinook are more likely to use the estuary as a rearing habitat than other age classes and species of juvenile salmonids. Of all the salmonid groups, subyearling chinook moved through the estuary most slowly and were available for a longer period of time in the greatest variety of estuarine habitats. Tagged subyearlings released in April and May were caught in the estuary every month through October. Tagged groups that showed a slowdown in their migration rate through the estuary also showed evidence of growth in the estuary.

Most of the tagged groups of chinook (0) we analyzed that increased their rate of migration through the estuary were released in the spring of 1980 (Table 12). The eruption of Mt. St. Helens on 18 May 1980 caused a sharp increase in turbidity of the estuary, which may have affected migration rates and increased mortality of subyearling chinook. The catches of subyearling chinook in 1980 were less than half the average catch from the previous three years. Dawley et al. (1981) suggested that suspended ash on salmonid gills caused increased mortality rates. In the NMFS survey substantially more subyearling chinook were captured in channel areas and fewer were caught near shore in 1980 than were caught in 1981. Poor water conditions in the estuary may have forced more subyearling chinook into the channels and out of the estuary along with the other faster moving salmonids.

Research in Sixes River, Oregon (Reimers 1973), suggested that a period of estuarine rearing is critical to the survival of fall chinook. Comparative surveys from several Oregon estuaries have shown that long-term residence of juveniles is a common life history characteristic of wild coastal chinook (Herring and Nicholas 1983). Healey (1982) and Levings (1982) have begun to describe the estuarine resources important to rearing chinook in British Columbia estuaries. Data from the Columbia River Estuary are consistent with the hypothesis that some period of estuarine residence is important to

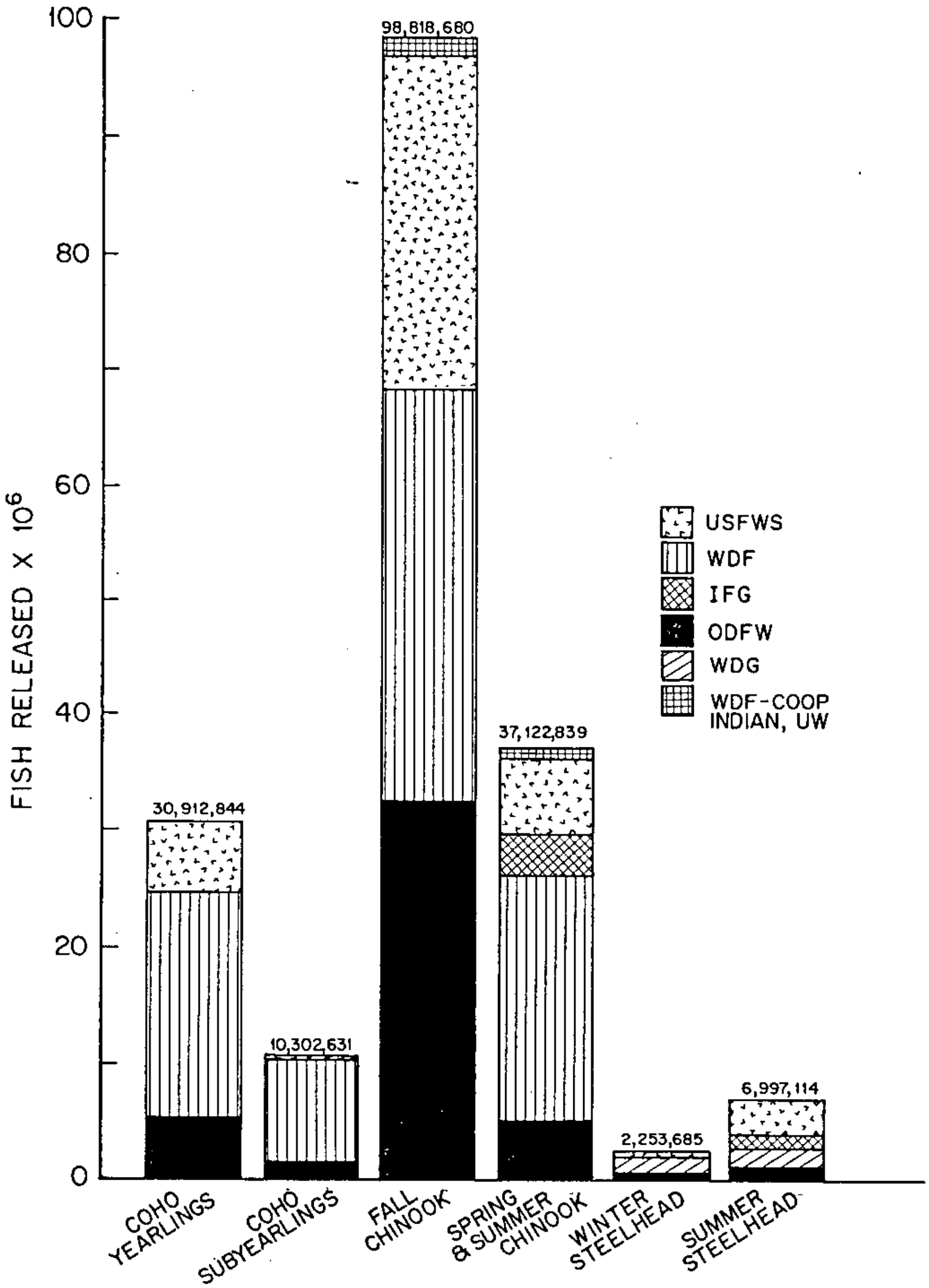


Figure 42. Number of hatchery salmonids released in the Columbia system, 1980, by U.S. Fish and Wildlife Service (USFWS), Oregon Department of Fish and Wildlife (ODFW), Washington Department of Fisheries (WDF), Washington Department of Game (WDG), Idaho Fish and Game (IFG), University of Washington (UW), Indian Tribes (Indian), and Washington Department of Fisheries-Cooperatives (WDF-COOP).

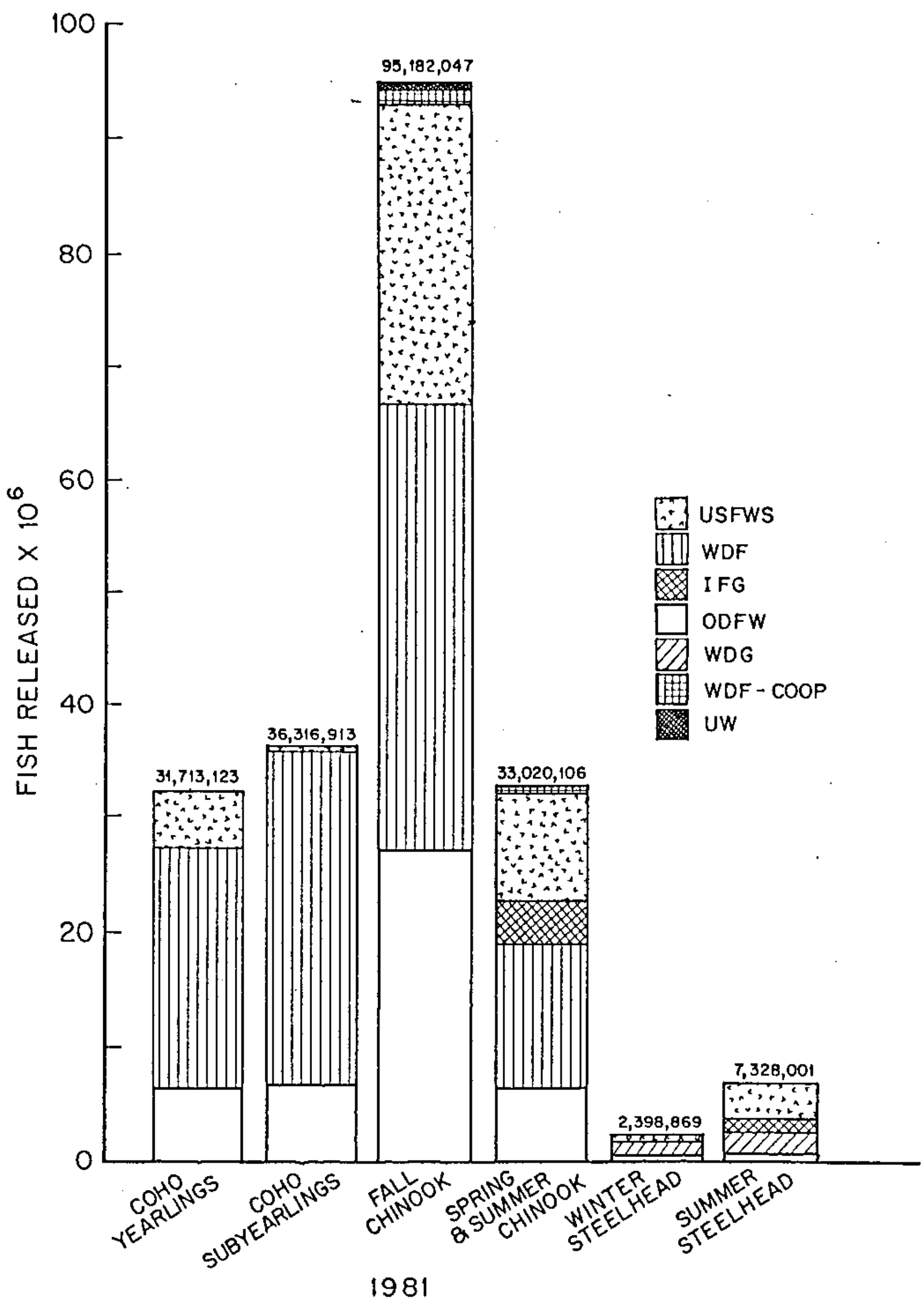


Figure 43. Number of hatchery salmonids released in the Columbia system, 1981, by U.S. Fish and Wildlife Service (USFWS), Oregon Department of Fish and Wildlife (ODFW), Washington Department of Fisheries (WDF), Washington Department of Game (WDG), Idaho Fish and Game (IFG), University of Washington (UW), Indian Tribes (Indian), and Washington Department of Fisheris - Cooperatives (WDF - COOP).

growth and survival of migrating subyearling chinook.

We found little evidence of extensive estuarine rearing by yearling chinook, coho, or steelhead. These salmonids moved quickly through the system and were present for a shorter amount of time than subyearling chinook. Although more than half of the yearling chinook tag groups we examined showed a slow-down in migration rate, only about one-third showed an increase in mean fork length in the estuary (Table 16). Similar findings were noted for juvenile coho and steelhead. The apparent distribution of yearling chinook, coho, and steelhead was restricted primarily to deep channel areas that they probably use as a route to the ocean.

Groups of hatchery salmonids move through the estuary at different rates depending in part on where and when they are released. Fish released higher in the system tend to move more quickly through the estuary than fish released nearer the mouth. We do not have historical data on the abundance, distribution, or migration rates of wild salmonids through the Columbia River system. Since there are currently no methods to distinguish hatchery from wild salmonids, we are unable to evaluate the effects of hatchery releases on natural patterns of migration and residence in the estuary. Development of a hatchery-wild discriminant function using scale analysis would be a valuable research tool to study use of the Columbia River Estuary by juvenile salmonids, particularly subyearling chinook.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 HABITAT PROTECTION AND FISHERY MANAGEMENT

(1) Among the major factors influencing the composition and distribution of fish assemblages in the Columbia River Estuary are:

(a) Seasonal cycles in migration and life history of fishes using the estuary.

(b) Horizontal salinity distribution as influenced by seasonal changes in river flow.

(c) Habitats located within broad salinity zones including bay, shoal, water column, channel bottom, and nearshore habitats.

(d) Density and distribution of preferred invertebrate prey species.

Accordingly, changes in river flow and salinity distribution, alteration of preferred habitats, or reduction in prey availability are likely to change the distribution of fish assemblages, reduce the production of key fish species, or both in the Columbia River Estuary.

(2) Results of the fish survey indicate several estuarine regions that should be protected to maintain productivity of key fish species and assemblages. Invertebrate standing crop, fish density, and fish feeding intensity were generally greatest in the estuarine mixing zone between 10 and 30 km from the mouth of the river and in bay habitats. Feeding intensity was generally higher in nearshore and demersal habitats relative to the pelagic zone.

(3) The importance of key habitats for fish production is underscored by the small number of invertebrate prey taxa and potential overlap in the diet of Columbia River fishes. Epibenthic copepods and *Corophium salmonis* are among the major prey items for many fishes in the estuary. Epibenthic copepod production is high in the estuarine mixing zone, in bay habitats, and in intertidal and shallow subtidal flats. Density of pelagic copepods is also relatively high in the estuarine mixing zone relative to other regions of the estuary. *Corophium* spp. production is high in freshwater and upper estuarine mixing zones and in bay habitats.

(4) The food web in the Columbia River Estuary is dependent on detrital materials. Upriver and estuarine sources of detritus and habitats responsible for retention of detritus in the estuary (marshes, bays, and shallows) should be protected.

(5) The greatest number and diversity of fishes use the Columbia River Estuary during summer months. Salmonids are abundant in the estuary April through September. Fishery conflicts from dredging or

other alterations to the estuary can be reduced by restricting these activities to months when fish and invertebrate densities are low.

(6) Columbia Basin salmonid fisheries are difficult to manage because of the many jurisdictions involved. Regulations are made by four state agencies, two federal councils, and two tribal commissions. Many more state and federal agencies and user groups have nonregulatory fishery programs operating in the Columbia (Table 22). Salmon and steelhead produced in one state migrate through several other states and are often harvested within the boundary waters of yet another state or nation (SSAC 1983). The goals and viewpoints of these agencies may conflict while their jurisdictions overlap. Restoration and protection of Columbia River salmonid runs will require improved coordination among management agencies. A system-wide management structure with representatives from existing state and federal agencies could improve coordination of the many hatchery production, habitat protection, habitat restoration, and harvest management activities in the Columbia Basin.

5.2 RESEARCH NEEDS

(1) Objectives of future fish surveys in the Columbia River Estuary should emphasize study of selected habitat types. Greater sampling effort in bay habitats seems warranted from results of epibenthic invertebrate surveys. Marsh channels in Cathlamet Bay have not been studied. These may be important rearing areas for juvenile salmonids as shown in the Fraser River Estuary (Levy and Northcote 1982).

(2) A better understanding of energy flow in the Columbia River Estuary would improve management of biological resources in the system. Several areas of research would be helpful:

(a) Results of CREDDP have shown the importance of detrital food chains in the estuary. However, additional research will be needed to define the sources and amounts of particulate and dissolved organic carbon that support estuarine food chains.

(b) The flow of energy from secondary producers to key fish species has not been quantified. Limited results of this survey suggest that food availability may be relatively low in the Columbia River Estuary. Improved consumption rate estimates for key fish species are needed to evaluate the estuarine feeding environment. Diel surveys should be planned for a few important feeding areas to estimate daily ration for selected demersal and pelagic fishes. This would also provide data on daily feeding periodicity for key species to interpret the IFI values from single daytime samples collected during this survey. Data are also needed to relate dry weight and wet weight methods for comparison with results in the literature.

(c) Factors that control food availability for Columbia River

Table 22. Agencies and organizations affecting Columbia River anadromous fish (from PNRBC 1980).

Regulatory Agencies

State

Idaho Department of Fish and Game
Oregon Department of Fish and Wildlife
Washingtom Department of Fisheries
Washington Department of Game

Federal

Department of Commerce

Pacific Fishery Management Council
North Pacific Fishery Management Council

Tribal Commissions

Columbia River Inter-Tribal Fish Commission
Northwest Indian Fisheries Commission

Nonregulatory Agencies

State

Pacific Marine Fisheries Commission
Columbia River Fisheries Compact

Federal

U.S. Fish and Wildlife Service
National Marine Fisheries Service
Fisheries Program of the U.S. Army Corps of Engineers
Fisheries Program of the Bonneville Power Administration

State-Federal

Columbia River Fisheries Council
Pacific Northwest Regional Commission
Committee on Fisheries Operations
Fisheries Research and Protection Coordination Committee
Columbia River Water Management Group
Washington Salmon-Steelhead Research Council

fishes are not understood. Total standing crop estimates for invertebrate prey do not necessarily reflect energy available for consumption and growth. Further research is needed to define the feeding ecology of estuarine fishes and the behavioral adaptions of invertebrate prey that limit the transfer of energy to fish. Diel variations in feeding activity may help to explain tidal or other effects on daily consumption by fishes. For example, migrations of Corophium spp. into the water column at night may influence food availability for juvenile chinook salmon. In this case, consumption may be heavily dependent on brief periods at dawn and dusk when amphipods are out of their tubes but light levels are sufficient to allow successful foraging by sight feeding fishes (Daniel Bottom, Oregon Department of Fish and Wildlife, unpublished data).

(3) Daily changes of the tide may have a greater affect on salinity and fish distribution than the seasonal averages represented in the present survey. The overlap in distribution of euryhaline species emphasized in this report may be exaggerated, if tidal effects were masked by a sampling design that required four weeks to complete and included all stages of the tide. Simultaneous samples at fewer locations or diel surveys in a few key areas would help to define the short period tidal or salinity effects on horizontal and vertical fish distribution. Diel changes in the composition of fish assemblages could be identified using cluster analysis.

(4) Estimates of salmonid migration rates were difficult in our analysis because sites in the lower Columbia River Estuary were sampled infrequently compared with the intensive program at Jones Beach. Increased sampling at one or more estuarine locations to complement the Jones Beach data would improve estimates of migration rate through the estuary. Such studies should emphasize 0-age chinook.

(5) All conclusions in this report regarding salmonid residence were from an analysis of hatchery fish. Results would probably differ for wild salmonids since we measured effects of hatchery release location on migration rates. The importance of the estuary to wild salmonids cannot be determined without some method to discriminate wild from hatchery fish. Development of a hatchery-wild discriminant function based on scale analysis may provide the best tool to identify wild salmonids. It might be argued that because wild fish are of little significance to the total salmonid population, they need not be considered in the estuary. However, the current emphasis on habitat restoration and improved wild production in the Columbia Basin (Northwest Power Act and the Salmon and Steelhead Conservation and Enhancement Act) suggest an increasing need for research to identify freshwater and estuarine limitations on growth and survival of wild salmonids.

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APPENDIX A

Fish Data Reports

Written by Staff at NOAA,
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Northwest and Alaska Fisheries
Center, Hammond Field Station

The specific data used to compile much of this manuscript are contained in four reports produced by NMFS. The first report is a tabulated print-out of catch weight, density, and standing crop by month, site, and gear for all fish species caught in the distributional sampling. Data for eight of the ten key species are separated into life history stages. The second report is a compilation and analysis of physical and biological information. Included in this report are:

1) An estuary map showing site locations and a table of fish catches by season and "representative" month.

2) Plots of physical data (depth, salinity, and temperature) for the four seasons and "representative" months.

3) Results of cluster analysis by species and by site for each season and "representative" month.

4) Results of principal component analysis of sampling sites using physical factors for the four "representative" months.

5) Maps of physical factors for each "representative" month and transparent overlays detailing locations of specific cluster groups for each month.

6) Methods of data preparation and analysis used in the report.

The third report contains a voluminous amount of data on the food habits of fish in the Columbia River estuary. Computer generated tables and figures depict the results from 12 months of stomach analyses. Nine months (February-October 1980) include all important selected species, while three months (November 1980 - January 1981) include only juvenile salmonids. The food habit data are presented in seven computer runs, with each run representing a different combination of estuarine habitats.

The fourth report contains growth information on American shad, Pacific herring, Longfin smelt, English sole, and Starry flounder. Length-weight regression equations and monthly growth rates (by weight) are presented for each of the above species.

Hardcopies of the four reports can be requested from the Columbia River Estuary Taskforce (CREST), P. O. Box 175, Astoria, Oregon 97103. Data in reports one, two, and three are also available on magnetic tape from the U. S. Army Corps of Engineers, Portland District, Portland, Oregon.

APPENDIX B

Quality Assurance Procedures
and
Data Adequacy

Written by Staff at NOAA,
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QUALITY ASSURANCE PROCEDURES

Field Sampling

Sampling sites were selected throughout the estuary in a variety of habitats. An attempt was made to select sites that were compatible with the gear type; for instance purse seines were not used in extremely shallow areas. Sampling sites were located by using fixed landmarks, aids to navigation, and bottom depths. Trawl and purse seine sites were generally several hundred meters long. Because of tidal currents in the estuary, particularly in the lower estuary, sometimes it was necessary to begin a trawl or purse seine set (at a given sampling site) at a slightly different point than during a previous month. Geographic locations of the sampling stations are given in Table 1.

Fish, except those selected for stomach analyses, were generally measured in the field using a measuring board and weighed using a spring type scale. This information was recorded on a standard data form prepared by NMFS (Hammond, Oregon).

Laboratory Procedures

Fish stomachs were stored in labeled plastic vials that contained 70% ethyl alcohol until they could be analyzed. The label contained the following information: date of capture, gear used for collection, sampling site, fish species, total length, and weight. After each stomach was dissected, individuals from each prey group were identified, counted, and placed in labeled plastic vials containing 70% ethyl alcohol.

Fish prey items were weighed on a Mettler balance (type H6T). The balance was leveled and zeroed before all weighing sessions. The balance calibration was checked approximately once a week; the calibration was never incorrect.

Prey organisms, which were stored in alcohol, continued to lose weight, even after blotting and air drying for 10 minutes. Since large organisms contain more alcohol and lose alcohol through evaporation slower than smaller organisms, their wet weights should be considered high. These high readings were not considered to be significant.

Computing

Addition of total catches and weights (by sampling effort) were double-checked for the 10 key species. Computer print-outs for all species were compared with catch and weight totals on the raw data sheets. Date, set identification number, gear type, station number, species code, total number, and total weight were verified on the print-outs. Physical data contained in a computer file were checked against raw data sheets. Using the computer, a further check was made to insure that each set identification number was unique.

A FORTRAN program was used to calculate densities (no/m^2) and standing crops (g/m^2) for each species (by sampling effort). Output of the program was spot checked manually to insure that the program worked properly.

All CREDDP stomach analysis information was coded and entered on stomach analysis data sheets. These data were keypunched and entered in a computer file. Computer print-outs were compared to the raw data sheets and any errors were corrected. The corrected file was again checked for errors.

A FORTRAN program was used to analyze stomach data. Output from the program was checked to insure proper performance of the program. Output from the computer consisted of a table showing: fish species name, zone designation, gear type, number of fish stomachs analyzed, mean total length and weight of fish, prey item names, prey frequency of occurrence, prey percent number, prey percent weight, prey Index of Relative Importance (IRI), prey percent total IRI, average and standard deviation of the Index of Feeding Intensity (IFI), the diversity H^1, total number and weight of prey consumed, and mean number and weight of prey consumed with accompanying standard deviations and ranges. The program also produced histograms of fish food habits.

The following quality assurance procedures were used in checking the growth data. Individual lengths and weights used to generate length-weight regressions were verified by comparing computer print-outs with raw data sheets. Mean monthly weights for each fish age class were calculated at least two times, then compared with raw data. Results from the computer program used to calculate growth rates were manually checked to verify that the program worked properly.

INACCURACIES, POTENTIAL ERRORS, AND DATA ADEQUACY

Data Transformations

Density (no/m^2) and standing crop (g/m^2) values must be used with much caution. These values were computed for each gear type, yet the sampling efficiency of each gear type is not the same. Sampling efficiency of any one gear type will vary with such factors as fish species, size of fish, wind, and tidal current. The sampling efficiencies of all three gear types--trawl, purse seine, and beach seine--in the Columbia River estuary are unknown. In addition the volume of water sampled by each gear type was not considered in the transformation. The depth of the purse seine is 9.8 m; however this depth varies with water velocity. The greatest depth of a beach seine is 4.0 m, and the depth of the trawl is even less. Also, the total area sampled during trawl and purse seine sets varied because of tidal currents and wind; yet one average value was used for each type in making the transformations. (Under the original plan of study NMFS did not contract to measure the area sampled.) The density and standing crop values should not be used in making fish production estimates.

Eruption of Mount St. Helens

On May 18, 1980 Mount St. Helens erupted. As a result of the eruption and subsequent mudflows, large amounts of mud and ash were deposited in the Columbia River estuary. In addition turbidities increased dramatically for a short time. Fish in the estuary, particularly demersal species in the upper estuary, were affected by the increases in sediment and turbidity. Because of this major perturbation we chose not to use June 1980 data for cluster analyses and principal component analyses. Undoubtably, the effects of the eruption extended beyond June, but the most obvious effects were seen in June. May distributional sampling was completed on May 19, 1980 (prior to the onset of high turbidities).

Food Habits

Sample size must be considered when interpreting the food habit data since only five individuals from each species at each site were taken for stomach analyses. In general, a sample size of five is too small to accurately identify food habits. Data from similar sites should be combined until the sample size is at least ten.

Results from the stomach analyses generally identify the food habits of Columbia River estuary fish; however these habits may change. Fish used in the analyses were collected during daylight hours under various tide conditions. Fish change their feeding habits in response to tidal stage, time of day, and prey abundance; in addition fish have maximum and minimum feeding times. If stomach data are used to estimate consumption rates, some consumption rates will be underestimated. Also, it may be falsely concluded that the major prey item is always the same during maximum and minimum feeding periods.

Growth

Age classes were determined from length-frequency histograms; however, the age classes were not validated with lengths derived from age determinations made on scales or bones. In this study cohort does not necessarily represent fish of the same population. The estuary is an open system; consequently estuarine and oceanic populations of marine species are indiscrete.

Growth rate was considered to be exponential and instantaneous growth was computed on a monthly basis. Von Bertalanffy's growth equation probably would have been the most realistic equation to use in this study. The ages of fish are needed to ascertain the times when the lengths of fish would be theoretically zero, but we could not determine these since scales or bones were not analyzed.

Table 23. Geographic locations (longitude and latitude) of NMFS sampling sites. All longitudes are either 123 or 124^0 (the 12 is not shown) and all latitudes are 46^0 (not shown).

NMFS STATION LOCATIONS

TRAWL SITES

Station	Location	Remarks
1	4-03.4-15.7	Start buoy "10" to buoy "11" on tip Jetty A.
2	4-03.1-15.2	Start buoy "10".
3	4-02.2-16.8	Ilwaco Channel. Tow S from 100 yds N of dolphin "10" to 100 yds N of dolphin "9".
4	4-00.7-15.5	From shore marker E between two Sand Islands.
5	3-59.1-14.3	Clatsop Spit from buoy "19" SE to buoy "21".
6	3-57.8-15.6	Chinook Channel.
7	3-56.9-13.5	Desdemona Slot from dolphin.
8	3-55.8-12.0	From Bioproducts; N side of navigational channel to buoy "27".
9	3-51.1-10.1	Youngs Bay center dolphin "6".
10	3-51.8-11.7	From buoy "33" E to buoy "35A" across from port dock.
11	3-53.1-14.3	Tow ENE to Interstate Bridge.
12	3-51.5-14.4	Off Megler, NE above bridge.
13	3-49.1-12.0	From buoy "39" NE along channel.
14	3-46.1-12.8	Off Coast Guard station, Tongue Point.
15	3-46.2-16.2	Off Grays Point.
16	3-43.2-17.8	Brix Bay; buoy "8" to buoy "10".
17	3-38.1-15.4	Start buoy "12" outside channel on Oregon side; head to right of buoy "14".
18	3-42.9-12.5	North Channel; start dolphin "3".

Table 23. (Cont.)

Station	Location	Remarks
19	3-39.0-10.9	Start below dolphin "12A" on Svensen Island.
20	3-37.0-13.3	Start N of submerged jetty on Marsh Island; about 300-400 yds from shore.
21	3-33.3-14.9	Start red dolphin on NW corner of Woody Island; head toward range marker.
22	3-26.6-15.1	Off Price Island.

PURSE SEINE SITES

Station	Location	Remarks
1	3-59.1-14.5	Off buoy "19".
2	4-00.8-15.6	Off West Sand Island.
3	3-55.4-11.8	From buoy "27".
4	3-57.1-14.8	Chinook jetty.
5	3-51.2-11.8	Below Interstate Bridge, Oregon.
6	3-52.4-14.2	Below Interstate Bridge, Washington.
7	3-48.9-11.8	Buoy "40", buoy "39".
8	3-49.5-16.1	Knappton Point.
9	3-45.3-13.0	Tongue Point; S of "44".
10	3-45.9-16.2	Green marker at Grays Point; tow NE.
11	3-42.8-12.5	North Channel dolphin "3".
12	3-42.1-14.8	Lower Rice Island, SW corner.
13	3-38.2-15.4	Buoy "14", Miller Sands.
14	3-38.9-13.2	NE of Green Island ruins.
15	3-33.0-15.0	Woody Island.
16	3-26.5-15.1	Off Price Island.

Table 23. (Cont.)

BEACH SEINE SITES

Station	Location	Remarks
1	4-01.8-16.5	West Sand Island.
2	3-59.2-13.5	Clatsop Spit.
3	3-58.1-15.9	East Sand Island.
4	3-56.7-12.1	Hammond beach (west of walkway).
5	3-54.0-10.8	Youngs Bay (W side).
6	3-43.4-11.2	Lois Island (center of cove).
7	3-42.2-15.2	Rice Island; NE part of island by orange marker on beach.
8	3-34.0-15.7	1st beach W of Jim Crow Point.
9	3-32.6-15.0	Woody Island; N shore.
10	3-25.4-12.2	NE tip of Puget Island.
11	3-51.9-11.2	Port docks - Astoria.

APPENDIX C

Seasonal and Geographic Distribution of Fish in the Columbia River Estuary

Species	Gear*	Zone**	1980 F	M	A	M	J	J	A	S	O	N	D	1981 J	F	M	A	M	J	J
American shad (0)	P,T,B	M										X	X							
		E								X	X	X	X					X		
		F							X	X	X	X	X							
American shad (1)	T,P,B	M	X				X	X	X	X	X			X	X	X	X			
		E	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		F	X	X		X	X	X	X	X	X	X		X	X	X	X	X	X	X
American shad (2)	P,T	M					X													X
		E				X	X	X	X		X	X		X	X			X	X	X
		F				X	X	X	X		X					X	X	X	X	X
Bay pipefish	P	M			X															
		E	X		X									X						
		F																		
Big skate	T	M					X		X	X		X	X	X	X	X			X	
		E																		
		F																		
Black crappie	P	M																		
		E		X													X			
		F																		
Black rockfish	T	M		X																X
		E																		X
		F																		
Bluegill	P	M																		
		E														X				
		F																		
Buffalo sculpin	T,P	M																		
		E	X									X	X							
		F																		
Butter sole	T,B	M	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	
		E		X	X	X	X							X		X		X		
		F																		
Cabezon	T	M			X															
		E										X								
		F																		
Carp	B,P	M					X												X	
		E				X	X		X	X									X	X
		F					X	X	X									X	X	X
Chinook (0)	B,P	M			X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
		E	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
		F	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Species	Gear*	Zone**	1980											1981						
			F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J
Chinook salmon (1)	P,B	M		X	X	X	X				X		X					X	X	
		E	X	X	X	X	X			X		X	X	X		X	X	X	X	
		F	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X
Chinook salmon (Jack)	P,B	M																		
		E					X		X											
		F					X													
Chinook salmon (Adult)	P	M																		
		E					X			X										
		F								X								X		
Chum salmon	T,B,P	M															X			
		E	X				X										X	X		
		F			X	X											X			
C-O sole	T	M																		
		E		X	X															
		F																		
Coastrange sculpin	T	M																		
		E																		
		F			X									X			X			
Coho salmon (1)	B,P	M				X	X	X										X	X	
		E		X	X	X	X	X								X	X	X	X	X
		F			X	X	X	X	X								X	X	X	X
Coho salmon (Jack)	P	M								X										
		E																		
		F								X										
Coho salmon (Adult)	P	M										X								
		E								X										
		F								X	X	X	X							
Cutthroat trout	P,B	M				X		X												X
		E			X	X			X	X								X		
		F			X	X		X	X	X	X	X						X		
English sole (0)	T,B	M	X	X		X	X	X	X	X	X	X	X				X	X	X	
		E	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X
		F																		
English sole (1)	T	M	X	X	X	X	X	X	X					X	X			X	X	X
		E	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	
		F																		
Eulachon	T,P,B	M	X	X	X									X	X	X	X			
		E	X	X	X							X		X	X	X	X			
		F	X	X	X								X	X	X	X	X			

Species	Gear*	Zone**	1980											1981						
			F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J
Green sturgeon	P	M																		
		E							X											
		F																		
Kelp grenling	P	M																X		X
		E	X		X					X										
		F																		
Largescale sucker	T,B,P	M																		
		F	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Lingcod	P	M																		
		E			X	X		X	X	X	X									
		F																		
Longfin smelt (0)	T,P	M						X	X			X	X							X
		E					X	X	X	X	X	X	X							
		F					X			X	X	X	X	X						
Longfin smelt (1)	T,P,B	M	X			X	X	X	X	X		X	X	X	X	X	X	X	X	X
		E	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		F	X	X	X	X	X		X	X	X	X	X	X	X	X	X		X	X
Mountain whitefish	B	M																		
		E																		
		F										X								
Night smelt	T	M	F																	
		E																		
		F																		
Northern Anchovy (0)	P,T	M										X	X							
		E									X	X	X							
		F																		
Northern Anchovy (1)	P,T	M		X			X	X	X	X	X			X	X	X		X	X	X
		E				X	X	X	X	X	X			X	X			X	X	X
		F									X									
Northern squawfish	P,B	M																		
		E																		
		F					X	X	X	X	X								X	X
Pacific hake	T,P	M					X	X											X	
		E					X													
		F																		
Pacific herring (0)	T,P,B	M					X	X	X	X	X	X							X	X
		E				X	X	X	X	X	X	X	X				X		X	X
		F									X	X								

Species	Gear*	Zone**	1980											1981						
			F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J
Pacific herring (1)	T,P,B	M	X	X	X	X	X	X	X	X	X	X	X		X	X		X	X	X
		E	X	X	X	X	X	X	X	X	X	X	X	X			X	X	X	X
		F								X										
Pacific lamprey	P,T	M					X													
		E	X	X		X	X						X		X	X				
		F	X										X	X		X			X	
Pacific sanddab	T	M							X											
		E																		
		F																		
Pacific sandfish	P	M					x													
		E																		
		F																		
Pacific sandlance	T,P,B	M	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X
		E				X				X			X		X		X			
		F																		
Pacific staghorn sculpin	T,P,B	M	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		E	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		F	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
Pacific tomcod	T,P,B	M	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		E	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		F									X									
Padded sculpin	T,P	M		X				X												
		E												X						
		F																		
Peamouth	T,P,B	M						X												
		E		X	X	X	X	X	X	X	X	X				X	X	X	X	X
		F	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Pile perch	T,P	M																		
		E					X	X	X											
		F																		
Pricklebreast poacher	T	M	X	X			X		X	X	X	X		X	X			X	X	
		E																		
		F																		
Prickly sculpin	T,P,B	M													X					
		E	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		F	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Red Irish lord	T	M																		
		E															X			
		F																		

Species	Gear*	Zone**	1980											1981						
			F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J
Redtail surfperch	T,P,B	M	X		X	X		X		X	X	X				X	X			
		E		X		X	X	X	X	X	X		X				X			
		F																		
Ringtail snailfish	T	M			X	X	X													
		E					X													
		F																		
River lamprey	T,P,B	M					X											X		
		E			X	X	X	X	X	X								X	X	X
		F																		
Saddleback gunnel	T	M									X							X		
		E	X	X	X			X		X	X	X	X	X		X	X	X	X	
		F																		
Sand sole	T,B,P	M	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
		E	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
		F																		
Shiner perch (0)	B,T,P	M					X	X	X	X	X	X	X							
		E					X	X	X	X	X	X	X						X	X
		F							X	X	X	X								
Shiner perch (1)	T,P,B	M		X	X	X	X	X	X	X	X	X		X		X	X	X	X	X
		E		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		F							X	X	X									
Showy snailfish	T	M			X	X	X		X			X			X				X	
		E			X							X							X	
		F																		
Silver surfperch	P	M					X													
		E					X		X				X							X
		F																		
Slipskin snailfish	T	M													X		X			
		E																		
		F																		
Snake prickleback	T,B,P	M	X	X	X	X	X	X	X	X							X	X	X	X
		E	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		F																		
Sockeye salmon	B,P	M				X	X											X		
		E	X			X	X											X	X	X
		F				X	X											X	X	
Speckled sanddab	T,B	M	X	X	X	X	X	X		X		X		X	X	X		X		
		E	X		X		X	X		X	X	X	X				X	X		X

Species	Gear*	Zone**	1980											1981						
			F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J
Spiny dogfish	T	M			X			X	X	X	X	X								
		E										X	X							
		F																		
Spotfin surfperch	T	M		X	X					X	X	X	X		X		X			
		E							X									X		X
		F																		
Starry flounder (0)	B,T	M						X	X	X	X	X								
		E				X	X	X	X	X	X	X	X						X	X
		F					X	X	X	X	X	X	X					X	X	X
Starry flounder (1)	T,B	M		X		X	X	X		X	X	X			X	X			X	
		E	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		F	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Starry flounder (2)	T,B	M		X	X	X	X	X	X	X	X			X		X	X	X		
		E	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		F	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X
Steelhead trout	P,B	M		X		X	X											X	X	
		E	X	X		X	X	X					X				X	X	X	X
		F	X	X		X	X									X	X	X	X	X
Striped surfperch	T	M																		
		E						X												
		F																		
Surf smelt	P,T,B	M	X	X	X	X	X	X	X	X	X	X			X	X	X	X	X	X
		E	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		F										X		X	X					X
Threespine stickleback	T,P,B	M				X	X					X	X		X	X	X	X	X	
		E	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		F	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Tubenose poacher	T	M													X					
		E																		
		F																		
Walleye pollack	T	M						X												
		E																		
		F																		
Walleye surfperch	T	M																		
		E					X													
		F																		
Warty poacher	T	M			X			X												
		E																		
		F																		

Species	Gear*	Zone**	1980											1981						
			F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J
White crappie	P	M																		
		E												X						
		F												X						
White seaperch	T	M				X														
		E																		
		F																		
Whitebait smelt	T,P	M	X				X	X	X	X		X	X	X	X	X	X	X		X
		E	X				X	X	X	X	X	X	X	X	X		X	X		
		F																		
White sturgeon	T,B,P	M																		
		E		X		X		X	X		X	X	X	X	X			X	X	X
		F		X	X	X		X	X	X	X	X		X	X	X	X	X		X
Yellow perch	B	M																		
		E						X												
		F																	X	

*Gear of capture: T = Trawl; P = Purse seine, B = Beach seine
**Zone of capture: M = Marine; E = Estuarine mixing; F = Freshwater

APPENDIX D

Station Clusters from NMFS Species

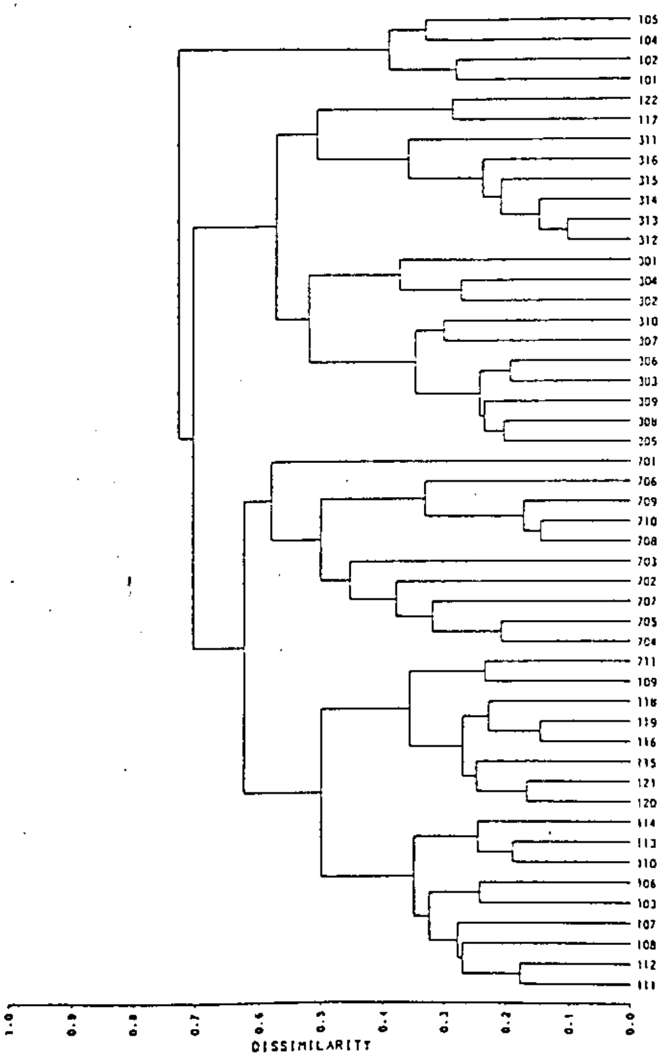
Density Data for Each

Calendar Season

CREDDP FINFISH WORK UNIT
OBJECTIVE TWO

CLUSTER ANALYSIS

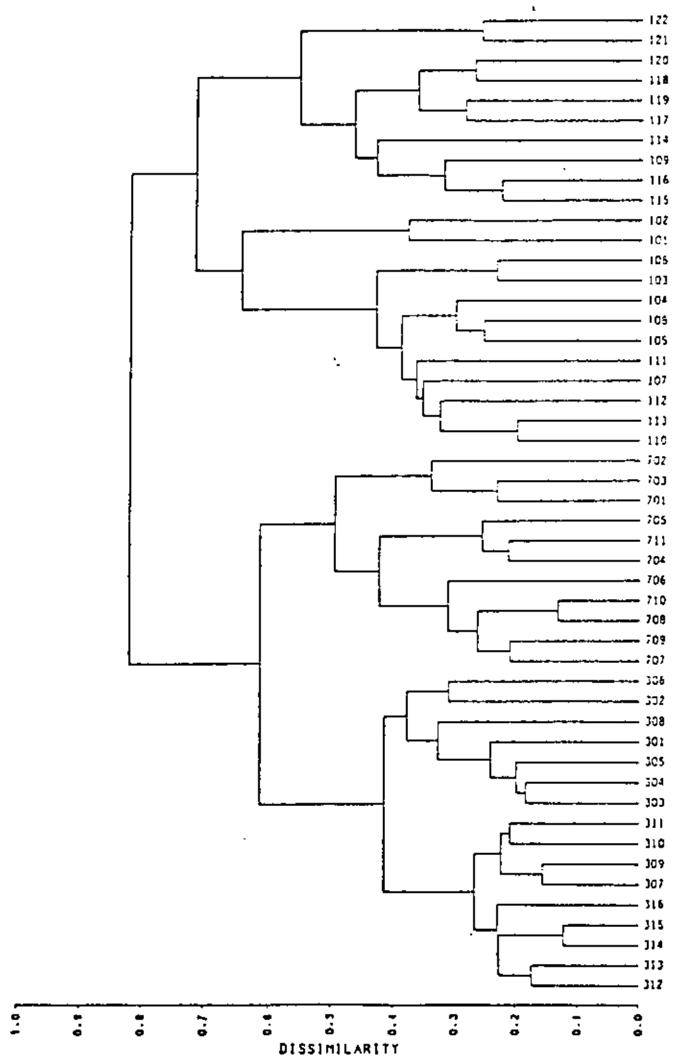
WINTER BY SITE



CREDDP FINFISH WORK UNIT
OBJECTIVE TWO

CLUSTER ANALYSIS

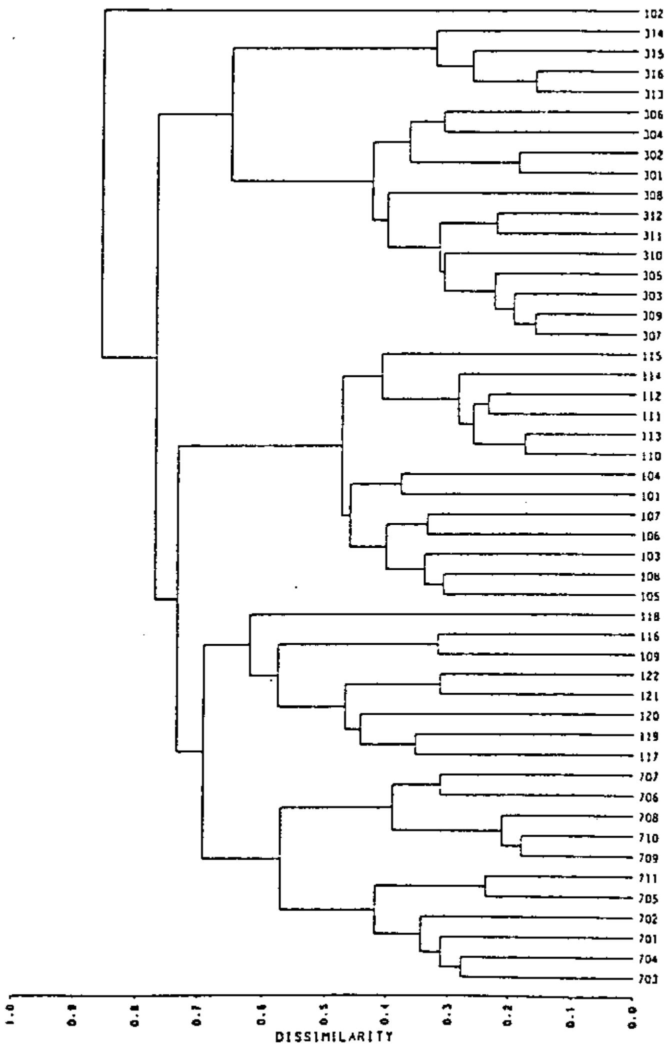
SPRING BY SITE



CREDDP FINFISH WORK UNIT
OBJECTIVE TWO

CLUSTER ANALYSIS

SUMMER BY SITE



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CLUSTER ANALYSIS

AUTUMN BY SITE