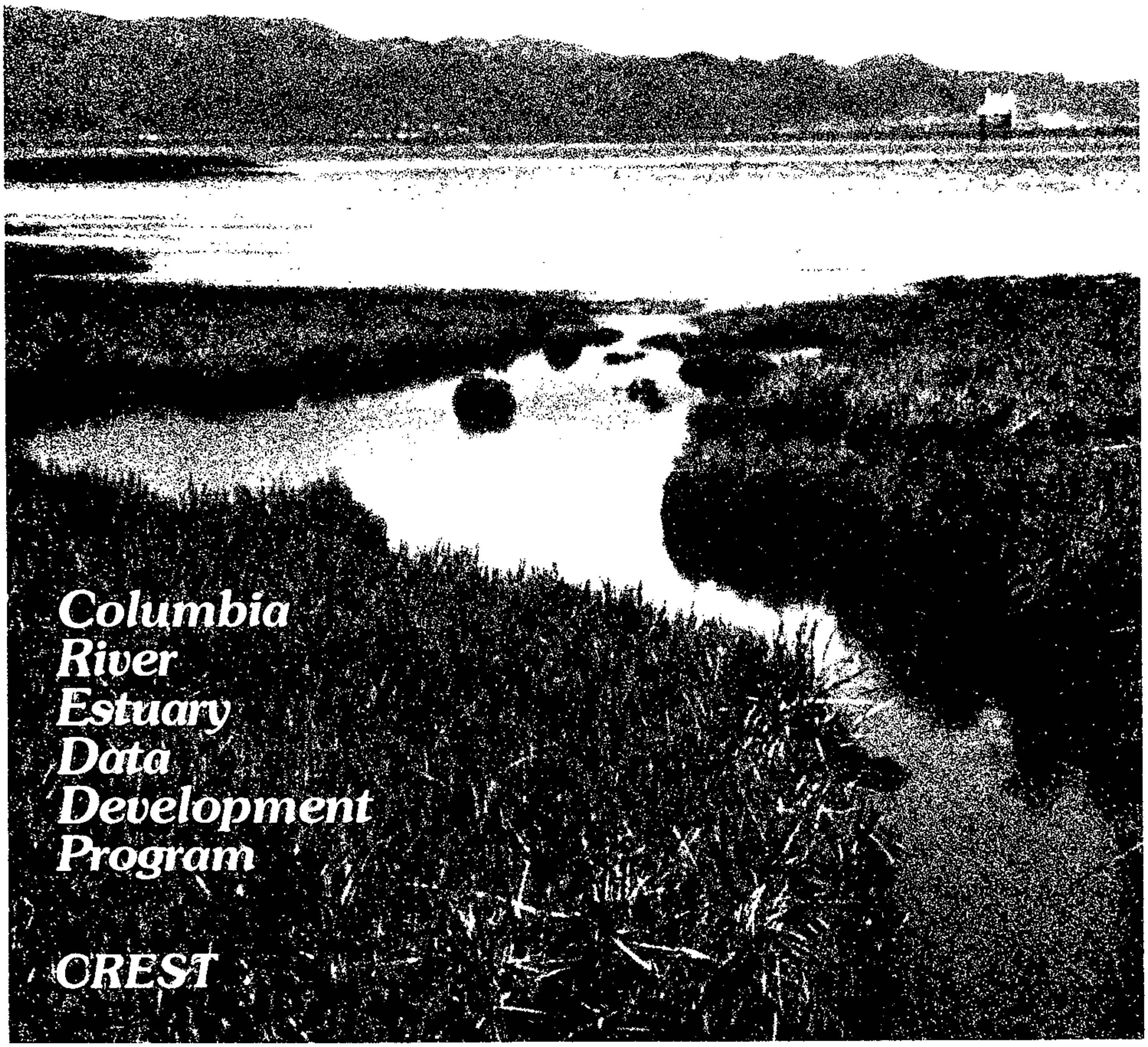
ZOOPLANKTON AND LARVAL FISHES OF THE COLUMBIA RIVER ESTUARY



Final Report on the Zooplankton and Larval Fish Work Unit

of the

Columbia River Estuary Data Development Program

ZOOPLANKTON AND LARVAL FISHES

OF THE COLUMBIA RIVER ESTUARY

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FOREWORD

Columbia River Estuary Data Development Program (CREDDP) provided funds to the Oregon Department of Fish and Wildlife to analyze and interpret data collected by University of Washington under contract to CREDDP.

We appreciate the support of the CREDDP staff, especially Jack Damron and David Fox. Our thanks to Charlie Miller (School of Oceanography, Oregon State University) and Charles Simenstad (Fisheries Research Institute, University of Washington) who contributed ideas and constructive criticism on the report outline and draft. Debbie Santiago, Bruce Miller, and Kathyrn Torvik were responsible for the excellent graphics.

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.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Zooplankton and larval fish data were collected by the University of Washington in 1980-81 as part of the Columbia River Estuary Data Development Program. Oregon Department of Fish and Wildlife analyzed these data. Two aspects of zooplankton and larval fish ecology were emphasized: (1) the structure of assemblages and their relationship to physical and biological factors in the the estuary, and (2) the temporal and spatial distribution and density of zooplankton and larval fish in the estuary.

ZOOPLANKTON ASSEMBLAGES

Zooplankton taxa were distributed among three zones of the estuary--marine (RM-5 to RM-10), estuarine mixing (RM-10 to RM-18), and freshwater (RM-18 to RM-23). Three major zooplankton assemblages were identified by cluster analysis based on their horizontal distribution in the estuary throughout the year. Assemblage 1 was composed of taxa such as *Neomysis kadiakensis*, *Calanus* spp., and *Ctenocalanus* spp., which were rarely found upriver of RM-11 and whose center of abundance was always close to the mouth of the estuary. Assemblage 2 consisted of taxa most commonly found between the mouth of the estuary and RM-13. These taxa were usually in the marine zone of the estuary during all but the low flow periods and included many common marine taxa-- *Acartia* spp. and *Pseudocalanus* spp. Assemblage 3 was composed of taxa in the estuarine mixing and freshwater zones of the estuary including *Eurytemora affinis*, *Daphnia* spp., *Bosmina* spp., and *Cyclops* spp.

ZOOPLANKTON DISTRIBUTION AND ABUNDANCE

A few species composed most of the zooplankton in the estuary. Most of the taxa collected were copepods, cladocerans, and mysids. Zooplankton density was high in the Columbia River Estuary during 1980 and 1981. Densities above $100{,}000/m^2$ were recorded in the marine zone during late spring, in the estuarine mixing zone during late spring and early summer, and in the freshwater zone during late summer.

Four copepod species-- *Acartia clausi*, *Acartia longiremis*, *Centropages abdominalis*, and *Pseudocalanus elongatus* were abundant in the marine and lower estuarine mixing regions of the estuary. *Eurytemora affinis*, also a copepod, was the most abundant taxon in the estuary with densities above $100{,}000/m^2$. The center of abundance of *Eurytemora affinis* moved from the marine and estuarine mixing zones in the spring to the estuarine mixing and freshwater zones in the summer. The copepod *Cyclops bicuspidatus* and cladocerans *Bosmina longirostris*, *Daphnia pulex*, and *Daphnia galeata mendotae*, were abundant during summer in the estuarine mixing and freshwater zones.

Density of mysids was lower than density of the major copepods and cladocerans, but mysids were common throughout the estuary. *Neomysis kadiadensis* and *Archaeomysis grebnitzkii* resided primarily

in the lower estuary but extended upriver into the estuarine mixing zone during summer. *Alienocanthomysis macropsis* and *Neomysis mercedis* resided in the estuarine mixing and freshwater zones of the estuary.

High river discharge and two-layered circulation are dominant forces on biological communities in the Columbia River Estuary. River discharge ranges from 600,000 cfs in spring to 75,000 cfs in summer and causes the upriver boundary of the salt wedge to fluctuate between RM-8 and RM-20. Composition, distribution, and density of zooplankton assemblages in the estuary also vary seasonally with river discharge. It is likely that river discharge exerts direct or indirect control over the distribution of plankton food resources, the temperature of water, the rates of reproduction, and the flushing rate of zooplankton through the system.

Marine taxa in the estuary are influenced primarily by oceanographic conditions. In the summer, taxa abundant in the northeast Pacific are carried south to the Oregon-Washington coast by southerly flowing currents. In the winter, marine taxa in the estuary are dominated by species brought north from California waters in the northward flowing currents of that season.

Taxa in the estuarine mixing zone are influenced by physical processes that control the turbidity maximum in the estuary. Large amounts of particulate organic carbon are trapped at the point of current reversal. This turbidity maximum, or "null point," corresponds with the upstream limit of transport of oceanic zooplankton into the estuary.

During summer, maximum phytoplankton densities and high temperatures are associated with elevated abundances of freshwater taxa in the estuary. Reservoirs behind dams along the mainstem of the Columbia River may provide good habitat for production of freshwater zooplankton.

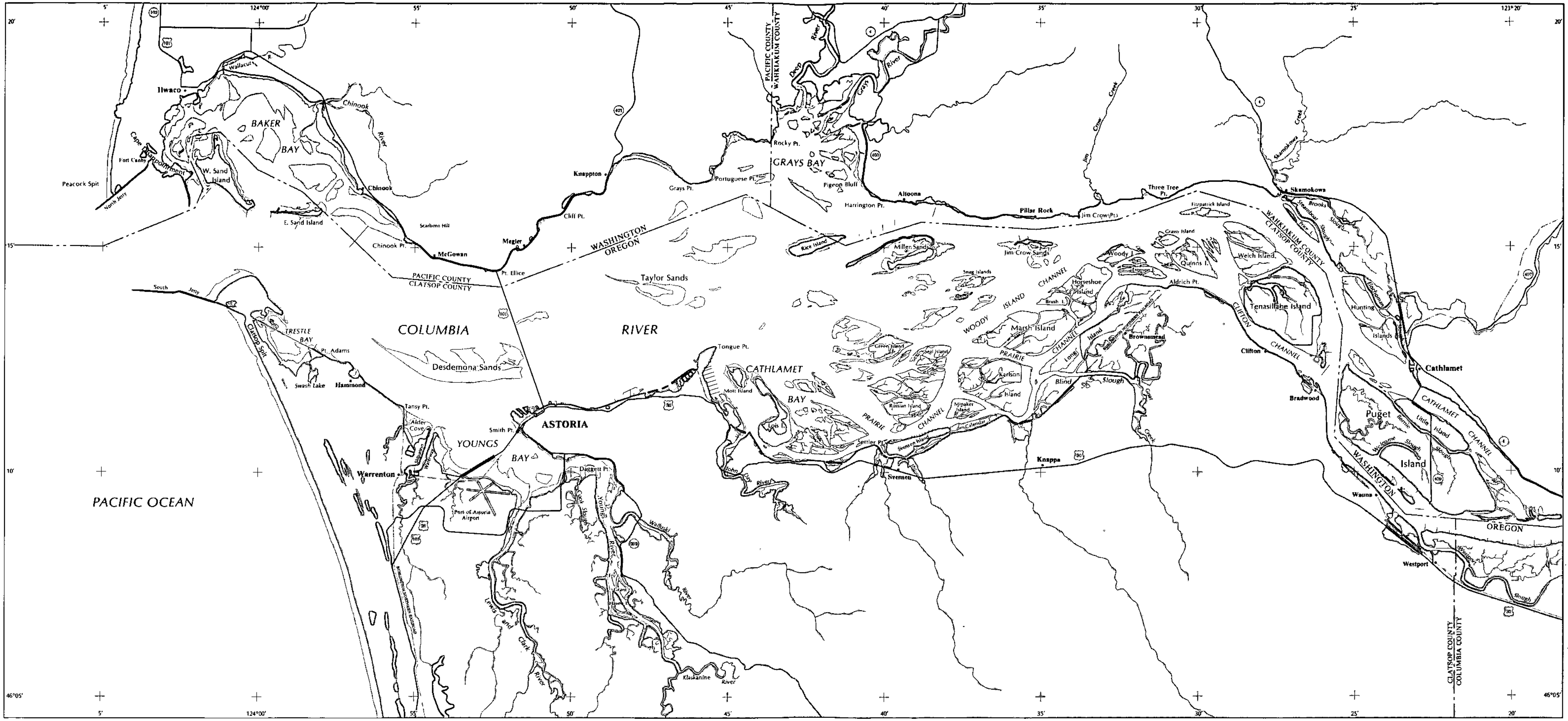
High flushing rates (1 to 5 days) in the Columbia River Estuary may quickly transport zooplankton to the ocean. Several physical and biological mechanisms may enable zooplankton to maintain populations in the estuary. Large bays in the estuary, which provide refuges from high flows, may serve as reproductive reservoirs; zooplankton may spend enough time deep in the stratified channels to be transported upstream with the salt wedge; or zooplankton may have a reproductive rate that balances with the flushing rate.

FISH EGGS AND LARVAE

Fish eggs and larvae in the Columbia River Estuary were predominantly species of Osmeridae during 1973 (Misitano 1977) and 1980-81. Densities of *Spirinchus thaleichthys* and *Thaleichthys pacificus* peaked in March and May, respectively. Osmeridae, *Clupea harengus pallasi*, *Cottus asper*, and *Leptocottus armatus* probably used the estuary for spawning and juvenile growth.

Larval fish composition in the Columbia River Estuary may not parallel that in other Oregon estuaries such as Yaquina Bay (Pearcy and Myers 1974). Whereas *Clupea harengus pallasi* and *Leptogobius lepidus* comprised 90% of all larvae in Yaquina Bay, Osmeridae and *Cottus asper* dominated the larval fish assemblages in the Columbia River Estuary.

Density of fish larvae was highest during winter and spring, whereas abundance of fish eggs peaked in summer. Most of the taxa (13 of 18) during 1980-81 were oceanic in origin and were collected only in the marine and lower estuarine mixing zones. The remaining five taxa, including the numerically dominant Osmeridae, were collected in the estuarine mixing and freshwater zones.



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**

The Columbia River Estuary

1. INTRODUCTION

Zooplankton and larval fish studies began in 1979 as part of the Columbia River Estuary Data Development Program (CREDDP). Estuaries are important rearing areas for fish larvae, including a variety of commercially important species (Pearcy and Myers 1974). Estuarine zooplankton are an important link between primary carbon sources and larval and adult pelagic fishes. The major directive of the CREDDP zooplankton and larval fish survey was to expand the knowledge of estuarine processes that influence the transfer of trophic energy through these important primary and secondary consumers.

The CREDDP study complemented several previous surveys in the Columbia River Estuary. Haertel and Osterberg (1967), Haertel et al. (1969), and Haertel (1970) surveyed zooplankton populations and described ecology, seasonality, and the effects of salinity on taxa distribution. As a result of a monthly survey from December 1971 through December 1973, Misitano (1974, 1977) expanded on these studies by also sampling larval and postlarval fishes and surveying stations in Youngs Bay and Baker Bay. Other surveys have been more site specific (Higley and Holton 1975; Craddock et al. 1976).

During 1980 and 1981 zooplankton and fish eggs and larvae were sampled by the University of Washington under contract to CREDDP. The survey was intended to coincide with concurrent research on other trophic levels and physical processes in the estuary. A brief summary of survey results is presented in English (1980).

Oregon Department of Fish and Wildlife (ODFW) was contracted by CREDDP to provide additional analyses and interpretation of the zooplankton and larval fish survey in this report. Two aspects of zooplankton and larval fish ecology were emphasized in our analyses: (1) the taxonomic structure of assemblages and their relationship to physical and biological factors in the the estuary, and (2) the temporal and spatial distribution and density of zooplankton and of fish eggs and larvae in the estuary. A description of the life history of individual taxa was beyond the scope of this project. A review of the biology of estuarine copepods is available in Miller (1983).

We had several constraints on our analyses and interpretation of the data that were due to the sampling design.

(1) Nauplii and early copepodite stages were poorly sampled with the large mesh nets used for the survey. Life history information is sketchy.

(2) Oblique tows integrated samples throughout the water column. We were unable to determine depth stratification of zooplankton and of fish eggs and larvae in relation to the salt wedge.

(3) No sampling took place between 6 January and 29 April 1981. As a result, the time of entrance of larval fish into the Columbia River Estuary and seasonal increase in zooplankton production cannot be determined from these data.

2. METHODS

2.1 FIELD AND LABORATORY METHODS

Zooplankton and larval fish were collected during 13 cruises at 10 channel stations placed evenly from River Mile 5 to River Mile 23 (RM-5 to RM-23) (Figure 1). Sampling was conducted in 1980 and 1981: twice a month 29 April through 16 September 1980, on 6 January 1981, and on 29 April 1981. Two half-meter nets of mesh sizes 0.254 mm (for zooplankton) and 0.335 mm (for larval fish and mysids) were towed on a double-net sled. Each haul was an oblique tow from the surface to bottom to surface for approximately 5 minutes. Flow meters were calibrated and revolutions were recorded to determine volume of water filtered. Zooplankton taxa were enumerated from a subsample taken out of the 0.254 mm mesh sample; and all mysids, fish eggs, and fish larvae were counted from the 0.335 mm mesh sample. Counts were transformed to densities using the following equation (English 1980):

$$\text{Number/m}^2 = \left(\frac{A}{f}\right)\left(\frac{1}{V}\right)\left(\frac{Z}{1}\right)$$

where: A = count
f = fraction of sample counted
V = volume filtered
Z = depth.

A detailed description of field and laboratory procedures is presented in English (1980).

2.2 DATA ANALYSIS

2.2.1 Hydrologic Seasons

Sampling dates were divided into three time periods to represent the major seasonal changes in river hydrology (Jay 1984). These time periods were chosen to contrast species distribution for three typical flow conditions in the Columbia River Estuary (Simenstad et al. 1984): (1) spring high flow (April-June); (2) summer low flow (July-October); and (3) winter fluctuating flow (November-March). Spring is a period of consistently high river flow (up to 600,000 cfs) when freshwater intrusion into the estuary is at its peak. In 1980, for example, surface salinity at RM-5 was less than 5 ppt during this time. From July through October river discharge was as low as 75,000 cfs, and salinity was detected at 10 meters depth as far upstream as RM-23. River discharge was high relative to summer, but fluctuated during the winter hydrologic season. Sample dates corresponding to each of these hydrologic seasons were as follows:

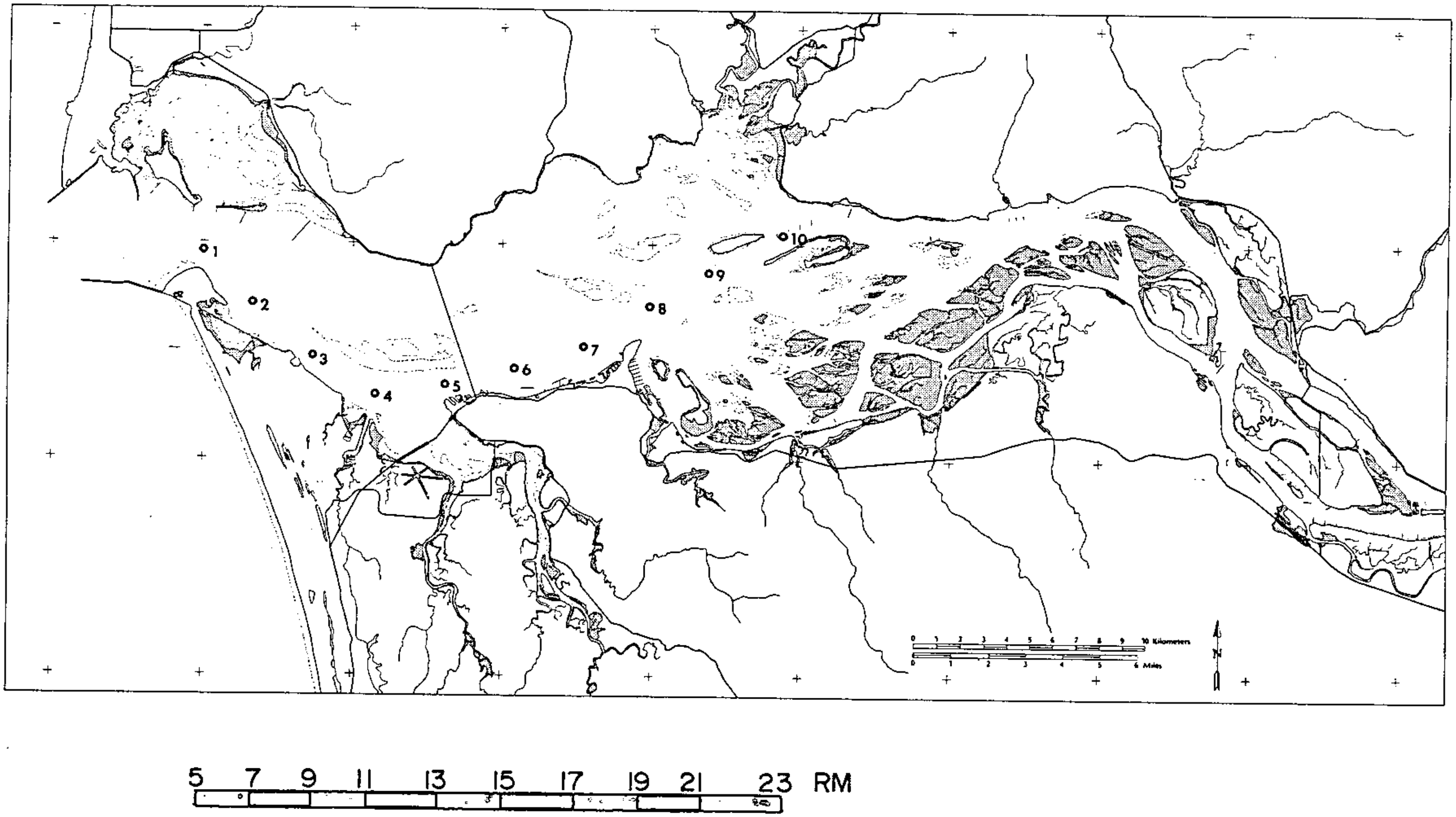


Figure 1. Station locations in the Columbia River Estuary

SPRING	SUMMER	WINTER
29 April 1980	15 July 1980	6 January 1981
13 May 1980	5 August 1980	
28 May 1980	19 August 1980	
10 June 1980	3 September 1980	
25 June 1980	16 September 1980	
29 April 1981	30 September 1980	

2.2.2 Cluster Analysis

Numerical classification methods were used to group taxa of zooplankton and fish eggs and larvae into assemblages, and to group stations into regions of similar taxonomic composition. Data were tabulated in matrix format, species density by station. Station groups were produced using collections as entities and taxa densities as attributes; taxa groups were produced using taxa as entities and station collections as attributes by inverting the data matrix. Clusters were based on group averaging of Bray-Curtis dissimilarity indices using a computer program (CLUSTER) adapted for the Oregon State University CDC Cyber computer (Keniston 1978).

Four different cluster runs were made to describe station and taxa affinities during each hydrologic season and for the entire year. Densities of taxa-life history categories were averaged for each season or year. Since the CLUSTER program can accept only 75 observations or variables, some taxa-life history categories were omitted from the analysis. In the spring, those categories that occurred fewer than four times during the five sampling periods in 1980 were removed. The number of summer taxa was reduced by omitting those that occurred fewer than five times during the three months of sampling. For January 1981, which represented the winter hydrologic season, those taxonomic categories that occurred at only one station were omitted. To create representative clusters for the year, the density of each taxa (including all life history stages) was averaged over the 13 cruises. Because the dendrogram structure varied for each season, cluster groups were defined subjectively based on the level of dissimilarity and the difference in dissimilarity between adjacent groups.

3. RESULTS

3.1 ZOOPLANKTON

3.1.1 Assemblages

Three major taxonomic assemblages were identified using cluster analysis of density data averaged for the entire year (Table 1; Appendices A and B). Assemblage 1 was composed of taxa rarely found upriver of RM-11 (station 4), and its center of abundance was always close to the mouth of the estuary. This assemblage included *Neomysis kadiakensis*, *Calanus* spp., and *Ctenocalanus* spp. Assemblage 2 consisted of taxa (e.g., *Acartia* spp. and *Pseudocalanus* spp.) most commonly found between the mouth of the estuary and RM-13 (station 5). Species in assemblage 3 such as *Daphnia* spp., *Bosmina* spp., and *Cyclops* spp., occurred in both the mid- and upper estuary regions during the year. Two estuarine endemic taxa, *Eurytemora affinis* and *Scottolana canadensis* (an epibenthic harpactacoid copepod), were clustered as members of assembage 3.

Seasonal species assemblages, like the yearly average clusters correspond essentially to regional groups associated with particular distances from the estuary mouth. Three groups were present during spring and summer hydrologic seasons. These represented lower to mid-estuary, mid-estuary, and mid- to upper estuary groups. In summer, only two major species assemblages were defined (Appendix B).

Several common species were abundant and consistently represented in the same regional assemblage despite seasonal changes in river discharge conditions. *Acartia clausi* and *Pseudocalanus elongatus* were abundant in a lower to mid-estuary assemblage throughout the year. *Archaeomysis grebnizkii* and *Paracalanus parvus* were also abundant in this region during winter and spring hydrologic seasons. *Cyclops bicuspidatus* was always represented in a mid- to upper estuary assemblage. *Bosmina longirostris* was also a member of the mid- to upper estuary group except during the summer low flow period. During summer, particularly during late June and July, many of the freshwater taxa and *Eurytemora affinis* were present throughout the estuary.

In Figure 2 we have divided the estuary into lower, mid- and upper estuary regions based on results of station clusters for each hydrologic season (Appendix C). Each region is composed of stations with similar species compositions. The regions generally correspond to marine, estuarine mixing, and freshwater zones based on the general distribution of salinity in the estuary (Simenstad et al. 1984).

In spring the major divisions between station groups occurred at RM-10 and RM-18 (Figure 2). A secondary division between stations, which created lower and upper estuarine mixing zones, occurred near RM-14. During summer low flows three regions were present. The division between the lower and mid-estuarine regions moved upstream to RM-12 (Figure 2). The same three regions were divided at RM-10 and

Table 1. Distribution of zooplankton in the Columbia River Estuary expressed as percent of the average abundance ($\log_{10}$ x + 1) of each taxa during the year

COMPOSITION

- ≥ .70
- ≥ .50
- ≥ .30
- ≥ .10
- < .10

ZONE / TAXA	STATION 1	2	3	4	5	6	7	8	9	10
MARINE (ASSEMBLAGE 1)										
Archaeomysis grebnitzkii	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	< .10	< .10	< .10	< .10	< .10
Podon leuckarti	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	< .10	< .10	< .10	< .10	< .10
Oithona similis	≥ .10	≥ .10	≥ .10	≥ .10	< .10	< .10	< .10	< .10	< .10	< .10
Gastropoda	≥ .10	≥ .10	≥ .10	≥ .10	< .10	< .10	< .10	< .10	< .10	< .10
Oikopleura dioica	≥ .10	≥ .10	≥ .10	≥ .10	< .10	< .10	< .10	< .10	< .10	< .10
Alienocanthomysis macropsis	≥ .30	≥ .10	≥ .30	< .10	< .10	< .10	< .10	< .10	< .10	< .10
Crangonidae	≥ .10	≥ .10	≥ .10	< .10	≥ .10	≥ .10	< .10	< .10	< .10	< .10
Corycaeus affinis	≥ .30	≥ .30	≥ .10	< .10	< .10	< .10	< .10	< .10	< .10	< .10
Sagitta elegans	≥ .30	≥ .10	≥ .10	≥ .10	< .10	< .10	< .10	< .10	< .10	< .10
Evadne nordmanni	≥ .30	≥ .10	≥ .10	≥ .10	< .10	< .10	< .10	< .10	< .10	< .10
Neomysis kadiakensis	≥ .30	≥ .30	≥ .10	< .10	< .10	< .10	< .10	< .10	< .10	< .10
Acartia californiensis	≥ .30	≥ .30	≥ .10	< .10	< .10	< .10	< .10	< .10	< .10	< .10
Paguridae	≥ .30	≥ .30	≥ .10	< .10	< .10	< .10	< .10	< .10	< .10	< .10
Calanus marshallae	≥ .30	≥ .30	< .10	≥ .10	≥ .10	< .10	< .10	< .10	< .10	< .10
Clausocalanus pacificus	< .10	≥ .30	≥ .10	≥ .30	< .10	< .10	< .10	< .10	< .10	< .10
Metridia lucens	≥ .50	< .10	≥ .30	< .10	< .10	< .10	< .10	< .10	< .10	< .10
Clausocalanus lividus	≥ .50	< .10	≥ .30	< .10	< .10	< .10	< .10	< .10	< .10	< .10
Ctenocalanus vanus	≥ .50	< .10	≥ .50	< .10	< .10	< .10	< .10	< .10	< .10	< .10
Calanus tenuicornis	≥ .70	< .10	< .10	< .10	< .10	< .10	< .10	< .10	< .10	< .10
Epilabidocera longipedata	< .10	≥ .10	≥ .70	< .10	< .10	< .10	< .10	< .10	< .10	< .10
Oithona spinirostris	< .10	≥ .30	≥ .50	< .10	< .10	< .10	< .10	< .10	< .10	< .10
Diastylopsis dawsoni	< .10	< .10	≥ .70	< .10	< .10	< .10	< .10	< .10	< .10	< .10
Calocalanus stylicemis	< .10	< .10	≥ .70	< .10	< .10	< .10	< .10	< .10	< .10	< .10
Microcalanus pusillus	< .10	≥ .70	< .10	< .10	< .10	< .10	< .10	< .10	< .10	< .10
Macrocyclops alloidus	< .10	≥ .70	< .10	< .10	< .10	< .10	< .10	< .10	< .10	< .10
MARINE TO LOWER ESTUARINE MIXING (ASSEMBLAGE 2)										
Acartia clausi	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	< .10	< .10	< .10	< .10
Pseudocalanus elongatus	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	< .10	< .10	< .10
Acartia longiremis	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	< .10	< .10	≥ .10	< .10	< .10
Calanus pacificus	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	< .10	< .10	< .10	< .10	< .10
Centropages abdominalis	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	< .10	< .10	< .10	< .10	< .10
Barnacle cypris	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	< .10	< .10	< .10	< .10	< .10
Eogammarus conferuicolus	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	< .10	< .10	< .10	< .10
Bivalvia	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	< .10	≥ .10	< .10	< .10	< .10
Paracalanus parvus	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	< .10	< .10	< .10	< .10	< .10
Euphausiacea	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	< .10	< .10	< .10	< .10	< .10
Polychaeta	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	< .10	< .10	< .10	< .10
ESTUARINE MIXING + FRESHWATER (ASSEMBLAGE 3)										
Bosmina longirostris	< .10	< .10	< .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10
Dopnia gateata mendotae	< .10	< .10	< .10	< .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10
Daphnia pulex	< .10	< .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10
Cyclops vernalis	< .10	< .10	< .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10
Cyclops bicuspidatus thomasi	< .10	< .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10
Diastylopsis dawsoni	< .10	< .10	< .10	≥ .10	< .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10
Ceriodaphnia purchella	< .10	< .10	< .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10
Diaptomus franciscanus	< .10	< .10	< .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10
Barnacle nauplius	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	< .10	< .10
Eurytemora affinis	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	< .10	< .10	< .10	< .10
Copepoda nauplii	≥ .10	< .10	< .10	< .10	< .10	≥ .10	< .10	≥ .10	≥ .10	≥ .10
Neomysis mercedis	≥ .10	≥ .10	< .10	< .10	< .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10
Epishuta lacustris	< .10	≥ .10	< .10	< .10	≥ .10	< .10	≥ .10	≥ .10	< .10	≥ .10
Diaptomus novamexicanus	< .10	< .10	< .10	< .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10
Diaphanosoma brachyurum	< .10	< .10	< .10	≥ .10	< .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10
Cerophium spinicorne	< .10	< .10	< .10	< .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10
Paracyclops fimbriatus poppei	≥ .10	< .10	< .10	≥ .10	< .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10
Eucyclos speratus	≥ .10	< .10	≥ .10	< .10	< .10	≥ .10	≥ .10	< .10	≥ .10	≥ .10
Alona quadrangularis	< .10	≥ .10	< .10	< .10	≥ .10	< .10	< .10	< .10	≥ .10	≥ .10
Chydorus globosus	< .10	≥ .10	< .10	≥ .10	≥ .10	< .10	< .10	≥ .10	≥ .10	≥ .10
Leptodora kindtii	< .10	< .10	< .10	< .10	< .10	≥ .10	≥ .10	≥ .10	≥ .10	≥ .10
Scottolana canadensis	< .10	< .10	≥ .10	≥ .10	≥ .30	< .10	≥ .10	≥ .30	< .10	< .10
Epishura nevadensis	< .10	≥ .10	< .10	< .10	< .10	< .10	< .10	≥ .10	≥ .30	≥ .10
Asplanchia	< .10	< .10	< .10	< .10	≥ .30	< .10	≥ .30	< .10	< .10	≥ .30
Caprella equilibra	< .10	< .10	< .10	< .10	< .10	< .10	< .10	< .10	< .10	≥ .70
Ilyocryptus sordidus	< .10	< .10	< .10	< .10	< .10	< .10	≥ .70	< .10	< .10	< .10
Diaptomus oregonensis	< .10	< .10	< .10	< .10	< .10	≥ .70	< .10	< .10	< .10	< .10
Sida crystallina	< .10	< .10	< .10	< .10	< .10	< .10	< .10	≥ .70	< .10	< .10

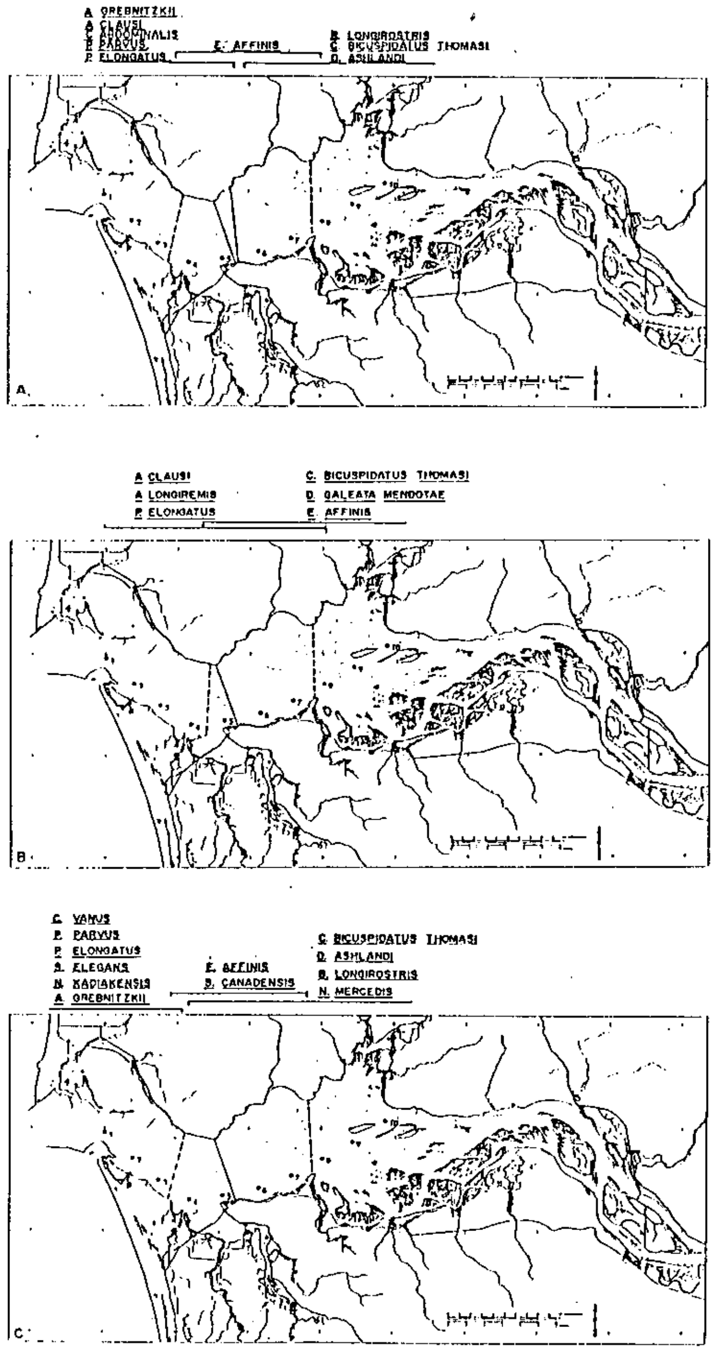


Figure 2. Distribution of common taxa in the Columbia River Estuary for spring (A), summer (B), and winter (C) hydrologic seasons

RM-18 (Figure 2) during winter. The index of dissimilarity between zones was low (less than 0.6) all year except between marine and mixing zones during the winter (dissimilarity = 0.8) (Appendix D).

The dominant assemblage in the marine zone during high flow periods and in the marine and estuarine mixing zones during low flow periods was the Acartia - Pseudocalanus assemblage. Eurytemora and Scottolana -- endemic estuarine species--were most abundant in the estuarine mixing zone during high flow periods. A freshwater (and brackish tolerant) assemblage dominated by Bosmina, Daphnia, and Cyclops was present all year. Its distribution extended downriver as river discharge increased.

3.1.2 Distribution and Abundance

The peaks in total density of zooplankton shifted seasonally (Figure 3). In late April and early May the highest densities were from the river mouth to RM-16. The density of zooplankton was greater between RM-10 and RM-16 during June and July than in any other area of the estuary. Total zooplankton densities decreased throughout the estuary later in the summer. During August and September abundance was maximum from RM-12 to RM-23. Winter densities were low throughout the estuary.

A few taxa composed the bulk of zooplankton in the estuary. Most of the species collected were copepods, cladocerans, and mysids. The temporal and spatial distributions of each of the predominant species in these groups are plotted in Figures 3 through 8. Average seasonal abundance for each species at each station is listed in Appendix D.

Two marine copepods-- Acartia clausi and Acartia longiremis -- were present during the year (Figure 3). The copepodites and adults of both species were only in the lower 9 miles of the estuary during the spring, but extended up to RM-21 during the summer. The cyclopoid copepod Centropages abdominalis also occurred commonly up to RM-13 during spring and late summer (Figure 4). Very few Centropages abdominalis were collected during July and August. The copepodites were present up to RM-17, whereas the adults were usually restricted to the region between RM-13 and the river mouth. Pseudocalanus elongatus was a common calanoid copepod that occurred below RM-14 (Figure 4). Only in late summer did the copepodites and adults of this taxa extend further upstream. The juveniles of the amphipod Eogammarus confervicolus also were most abundant in the lower estuary (up to RM-11). Most of the taxa in Figures 3 and 4 disappeared from the estuary during July 1980.

Eurytemora affinis, a calanoid copepod, was the most abundant taxon in the estuary (Figure 5). High densities of Eurytemora affinis were responsible for the temporal and spatial pattern of total zooplankton abundance (Figure 3). Copepodites of Eurytemora affinis were abundant between RM-10 and RM-16 during spring and early summer and in the region upriver of RM-12 during late summer. The adults resided below RM-14 from late April to early June, but were most

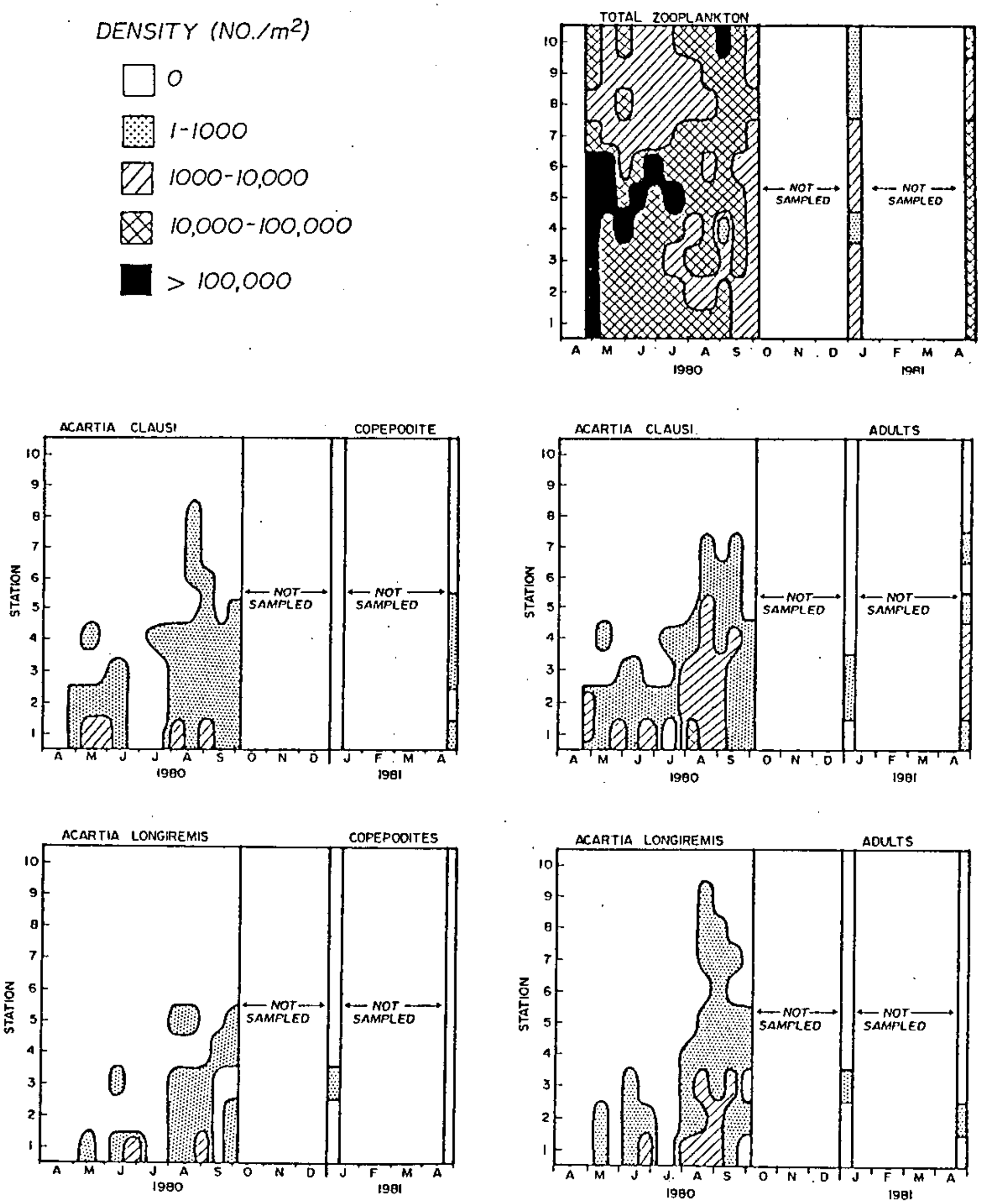


Figure 3. Seasonal density of total zooplankton and lower estuary copepods

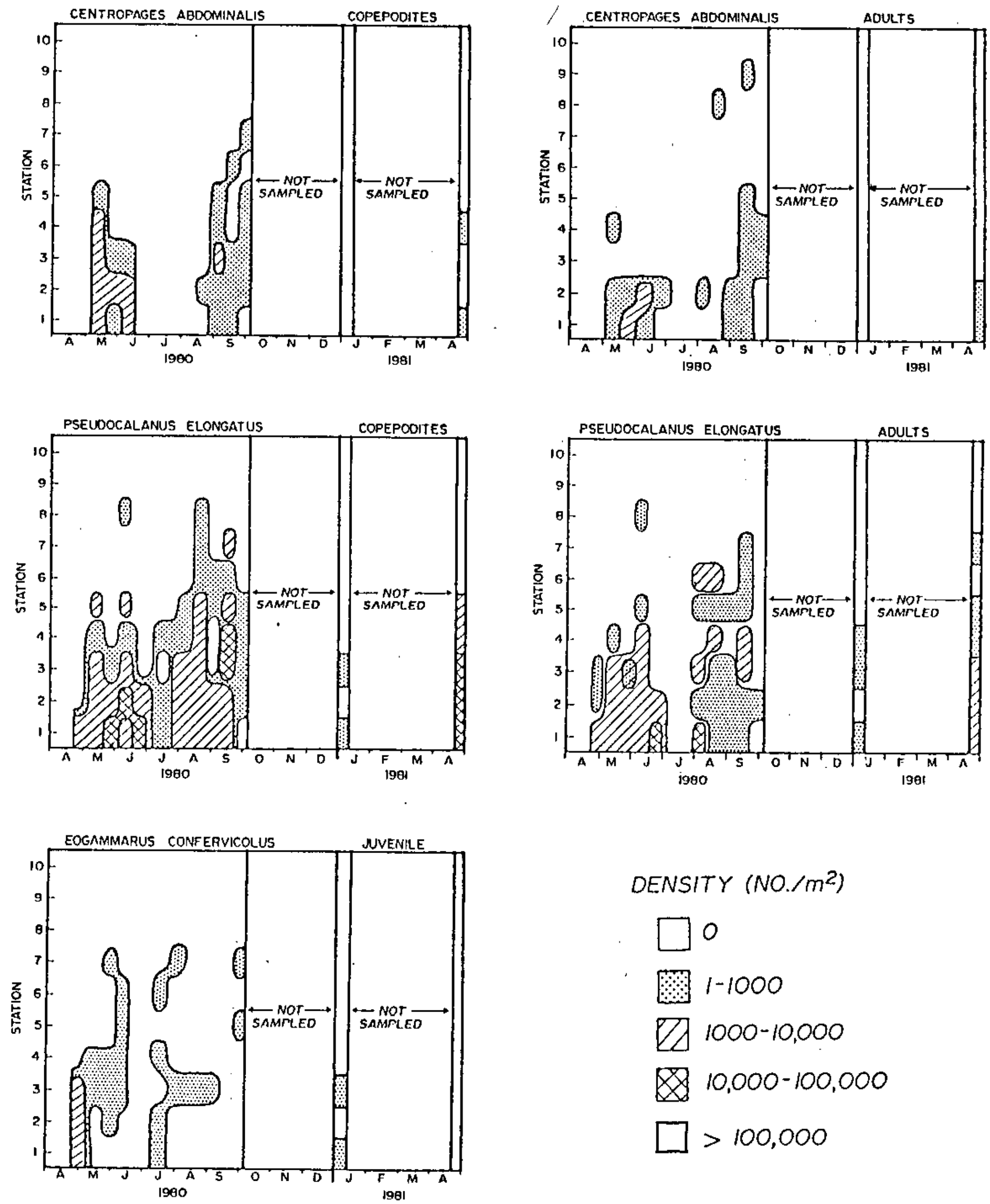


Figure 4. Seasonal density of lower estuary copepods and amphipods

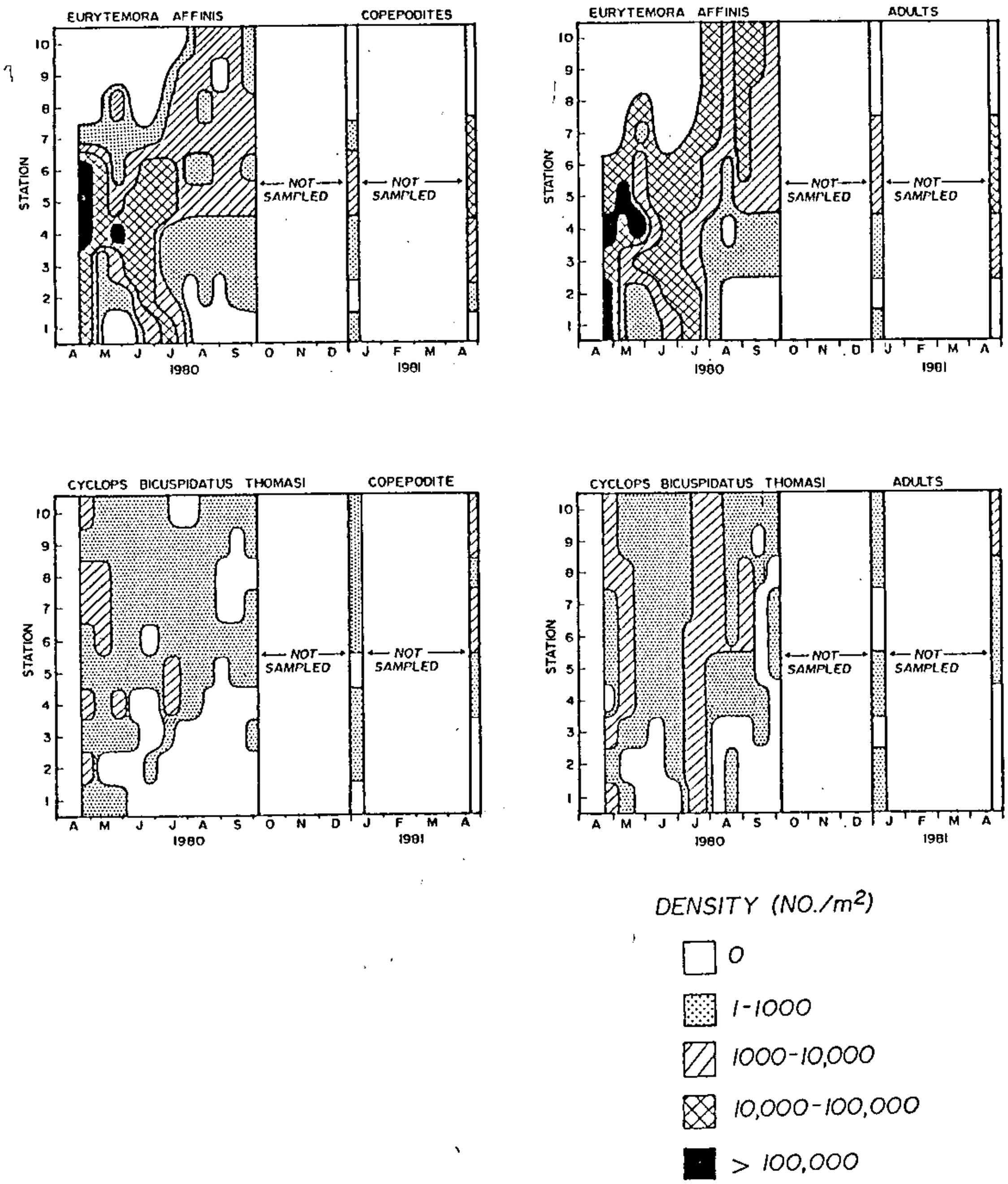


Figure 5. Seasonal density of mid- and upper estuary copepods

abundant below RM-8. In late summer, the adults occurred in lower densities and their distribution was shifted to the mid- and upper estuary above RM-12. In January, adults and copepodites occurred at lower densities but were most common in the region between RM-12 and RM-18.

The distribution and abundance of the cyclopoid copepod Cyclops bicuspidatus thomasi differed from other copepods (Figure 5). It was most common above RM-10 and was abundant in early spring. It was also very abundant throughout the estuary in July, when all the lower estuary copepods disappeared.

Cladocerans were the most abundant zooplankton in the upper estuary (above RM-18) and were consistently present in the region between RM-10 and RM-18 (Figure 6). Adult Bosmina longirostris was common above RM-10 during the spring and early summer; the juveniles were rarely caught. Daphnia pulex was also common in this region during the year. Juvenile Daphnia pulex were sampled primarily during January and April of 1981. Adult Daphnia galeata mendotae had a distribution similar to the other cladocerans, but were abundant only in July and August.

Mysids were not as abundant as copepods and cladocerans, but were an important component of the zooplankton during the year. Juvenile and adult Neomysis kadiakensis resided primarily from the river mouth to RM-10 (Figure 7), athough a few individuals were collected above RM-10. Archaeomysis grebnitzkii also peaked in density below RM-14 (Figure 7). Juvenile A. grebnitzkii were both more abundant in zooplankton samples than adults, and were collected further upriver. Both N. kadiakensis and A. grebnitzkii were present in the lower 12 miles of the estuary during the winter.

Two mysid taxa were common in the mid- to upper estuary (Figure 8). Alienocanthomysis macropsis juveniles and adults were most abundant between RM-8 and RM-20 during the summer, but moved toward the mouth during the winter and spring. Neomysis mercedis, in contrast to the other mysids, was collected primarily above RM-10. Only during late June and early July did its center of abundance shift toward the mouth of the river.

From the time-space diagrams in Figures 3 through 8, we can describe salinity distribution of the common taxa. Lower estuary taxa such as Acartia spp., Pseudocalanus spp, and Neomysis kadiakensis represent marine zooplankton. Two brackish water taxa-- Eurytemora and Alienocanthomysis --were most abundant in the mid-estuary. Daphnia spp., Bosmina spp., Cyclops spp., and Neomysis mercedis are freshwater taxa, with abundance centered in the upper estuary.

3.2 FISH EGGS AND LARVAE

3.2.1. Assemblages

Fish eggs and larvae were grouped into assemblages based on their

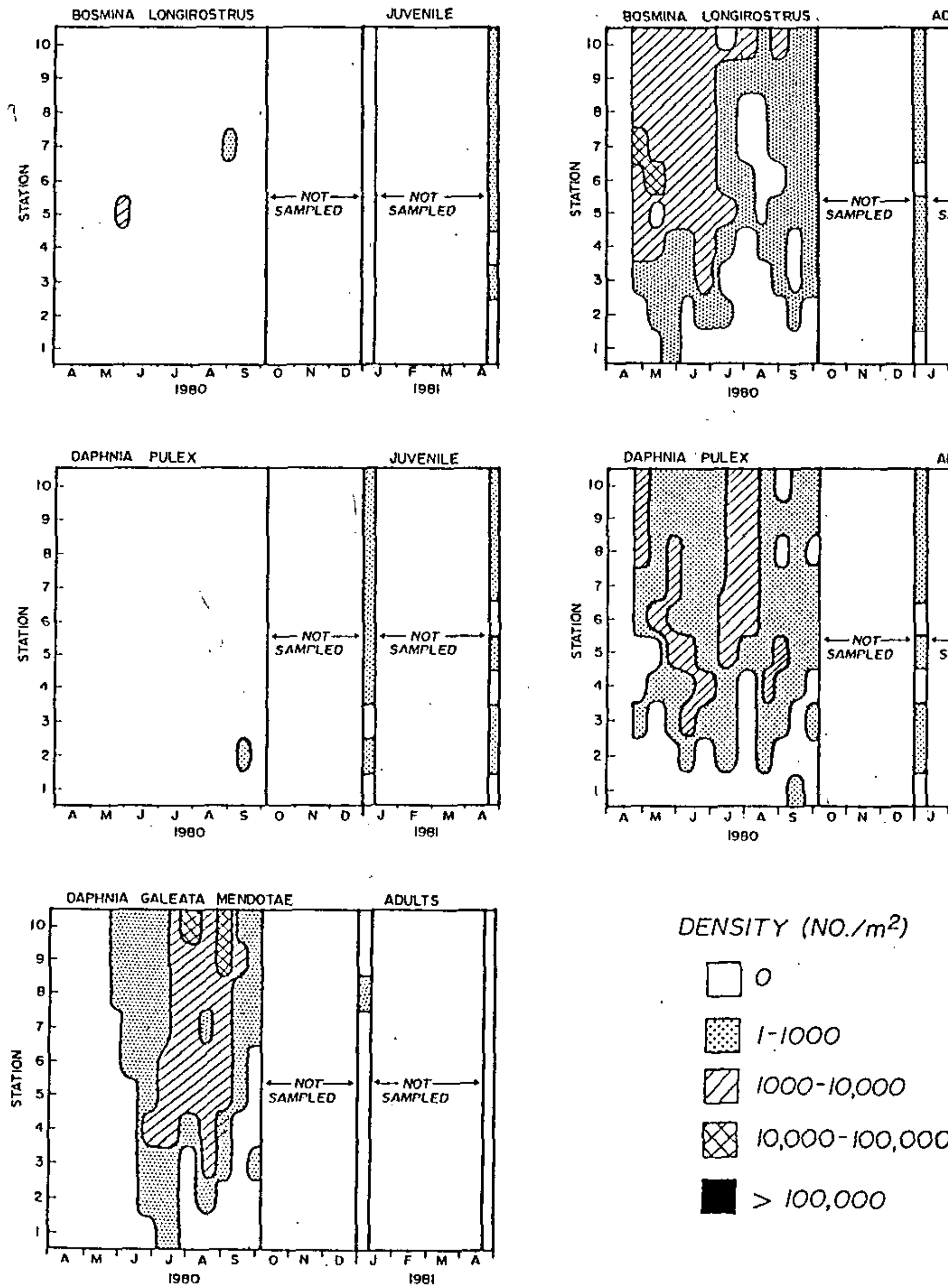


Figure 6. Seasonal density of upper estuary cladocerans

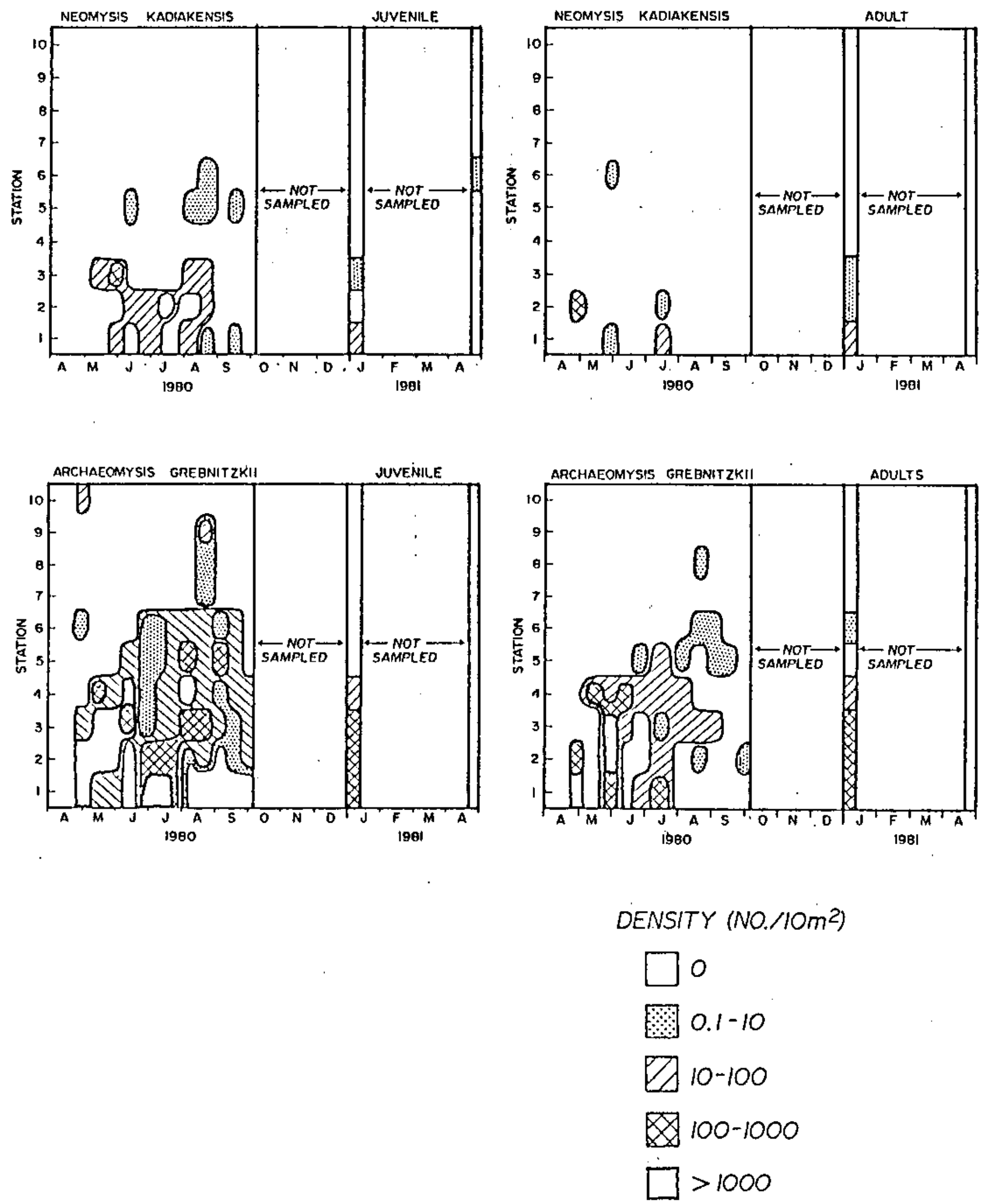


Figure 7. Seasonal density of lower estuary mysids

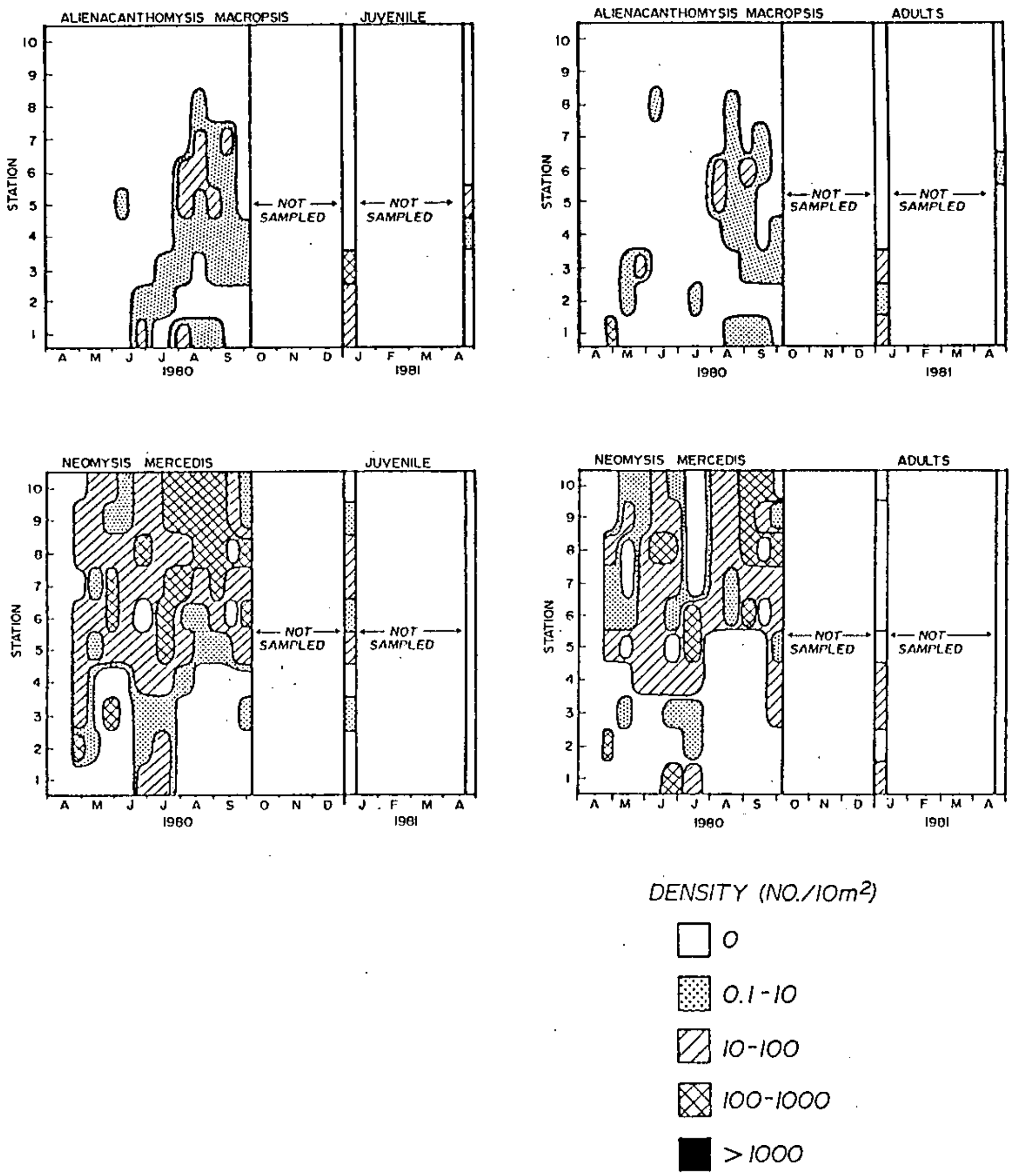


Figure 8. Seasonal density of mid- and upper estuary mysids

distribution and abundance in the estuary (Appendix E). Considering the year as a whole, four assemblages were present (Table 2).

Table 2. Assemblages of fish eggs and larvae in the Columbia River Estuary during 1980-81

ASSEMBLAGE 1 (Lower estuary)	ASSEMBLAGE 2 (Lower and mid-estuary)
Ammodytes hexapterus larvae	*Citharichthys* spp. eggs
Citharichthys spp. larvae	Pleuronectidae eggs
Engraulis mordax larvae	*Engraulis mordax* eggs
Gobiidae larvae	*Thaleichthys pacificus* larvae
Leptocottus armatus larvae	Teleostei larvae
Sebastolbus spp. larvae	*Lyopsetta exilis* larvae
Paraphrys vetulus larvae	
ASSEMBLAGE 3 (Mid and Upper estuary)	**ASSEMBLAGE 4 (Upper estuary)**
Cottus asper larvae	*Platichthys stellatus* larvae
Osmeriidae larvae	
Clupea harengus pallasi larvae	
Osmeriidae eggs	

Seasonal cluster dendograms and abundance by season are compiled in Appendix E. During spring the composition of these assemblages was similar to the average for the entire year except that *Citharichthys* spp. larvae and *Parophrys vetulus* larvae were not present. During the summer only seven taxonomic categories were sampled-- *Citharichthys* eggs, *Citharichthys* larvae, Pleuronectidae eggs, *Engraulis mordax* eggs, *Cottus asper* larvae, undifferentiated Teleostei larvae, and *Clupea harengus pallasi* larvae. Only three taxa were present in January--Pleuronectidae eggs, *Parophrys vetulus* larvae, and Osmeriidae larvae.

When sample dates for the spring hydrologic season were combined, cluster analysis divided the estuary into 4 zones based on species composition and abundance of fish eggs and larval assemblages (Figure 9; Appendix F). Estuarine divisions were located at RM-8, RM-14, and RM-18 corresponding to marine (below RM-8), lower estuarine mixing (RM-8 to RM-14), upper estuarine mixing (RM-14 to RM-18), and freshwater (above RM-18) zones. Three station clusters were distinguished during the summer hydrologic season. In contrast to the spring clusters, the marine zone and lower estuarine mixing zone were combined in summer (Figure 9). In the winter these three zones shifted downriver (Figure 9); the marine zone extended to RM-6, the lower estuarine mixing zone from RM-6 to RM-10, and the upper estuarine mixing zone and freshwater areas formed one region above RM-10.

Table 3 compares relative densities of the taxa in each cluster group for each station averaged over the entire year. Assemblage 1

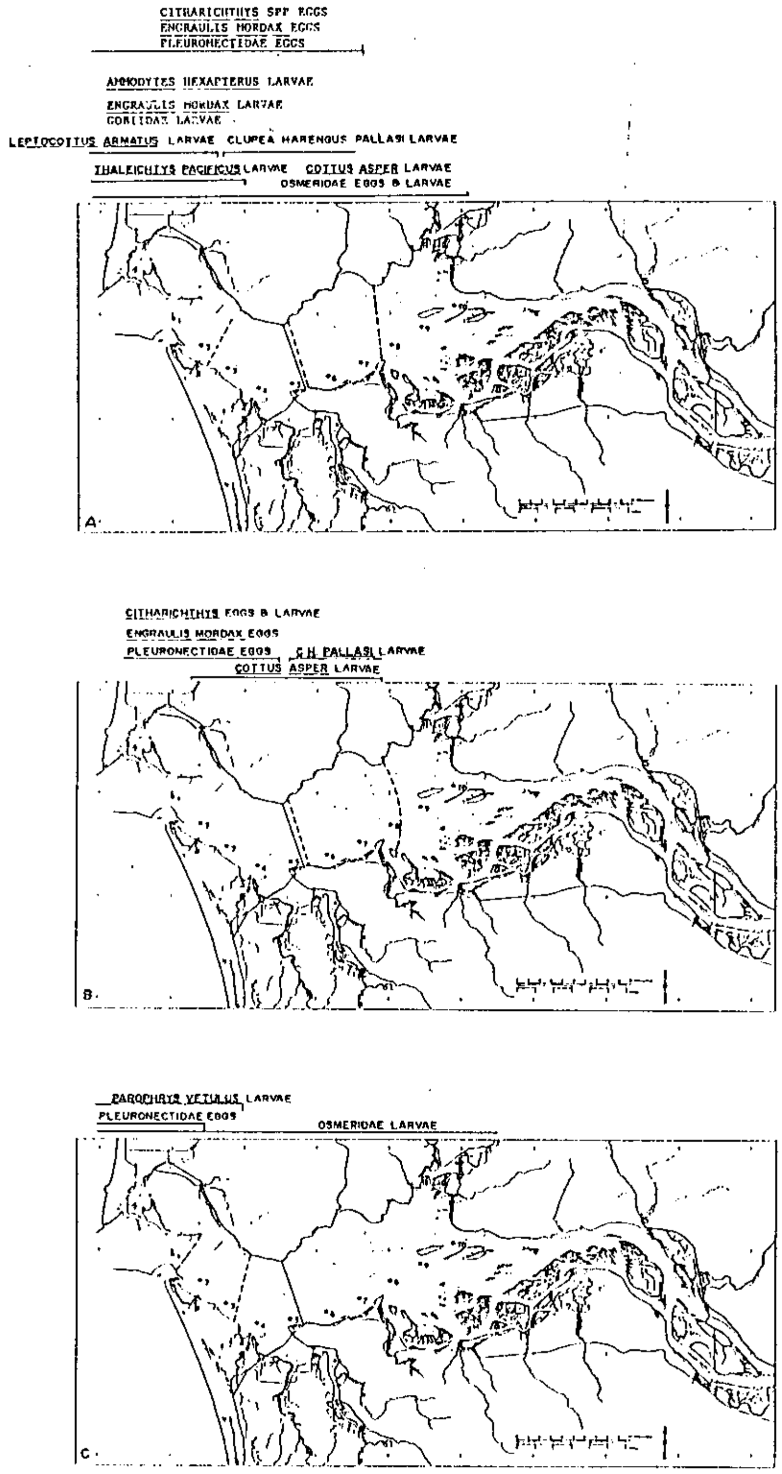
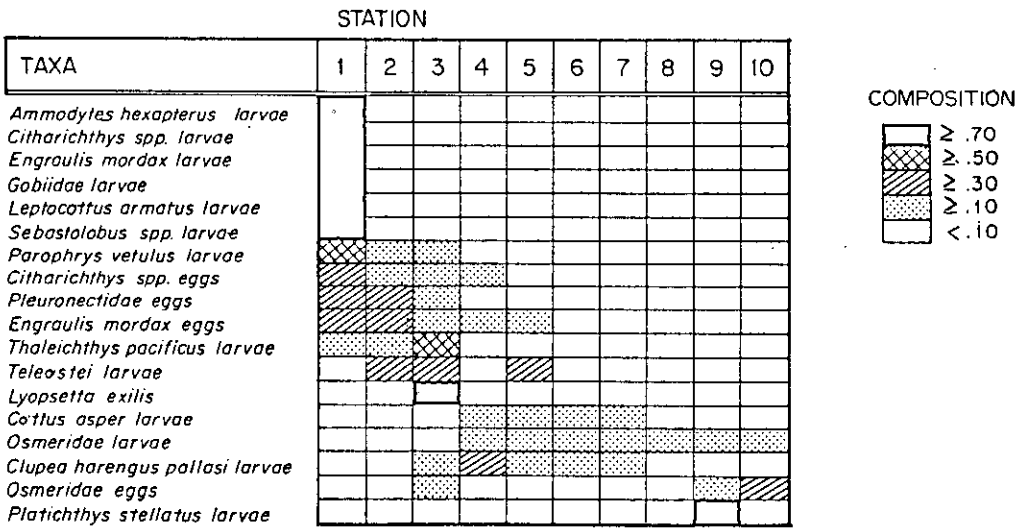


Figure 9. Distribution of fish eggs and larvae in the Columbia River Estuary for spring (A), summer (B), and winter (C) hydrologic seasons

Table 3. Distribution of fish eggs and larvae in the Columbia River Estuary expressed as percent of the average abundance ($\log_{10}$ x + 1) of each taxa during the year



contained those taxonomic categories present only in the marine zone. Assemblage 2 was composed of taxa from the marine and lower estuarine mixing zones. Assemblage 3 occurred in the lower and upper estuarine mixing zone, and the freshwater zone. Assemblage 4 (Platichthys stellatus larvae) was collected once in the freshwater zone in early June.

3.2.2 Distribution and Abundance

Larval fish density was high when sampling began in the spring (Figure 10) and may have been at maximum density earlier in the year. Fish eggs and larvae were abundant throughout the estuary in late April and early May. The density of eggs and larvae shifted downriver with time until peak abundance was reached in the lower 8 miles of estuary in June. Density of eggs and larvae decreased as summer progressed until none were present in late summer. Eggs and larvae began to reappear in January.

The temporal and spatial distribution of the most common fish eggs and larvae are presented in Figures 10 and 11. Distributions can be classified into four general types: marine, marine and estuarine mixing, estuarine mixing, and estuary-wide. Cottus asper larvae, Osmeridae larvae, and Osmeridae eggs were present throughout the estuary. Osmerids were common in early spring and Cottus asper was common throughout the spring. Larvae of Clupea harengus pallasi were found in the estuarine mixing zone (RM-8 to RM-18) during only two periods: late June and August. Eggs of Citharichthys spp. were present during spring and summer in the lower 10 miles of the estuary, although a few eggs were collected up to RM-15. Eggs of Engraulis mordax were also common below RM-14 (marine and lower estuarine mixing zone) in the spring and early summer. The larvae of Engraulis mordax, however, were only present at RM-5 during late May and early June (Figure 11). Larvae of Ammodytes hexapterus, Leptocottus armatus, and Thaleichthys pacificus were rare except near the estuary mouth during late April and early May. Larvae of Thaleichthys pacificus were also found at RM-9 during early June. Larvae of Parophrys vetulus were present only in the January sample in the marine zone of the estuary.

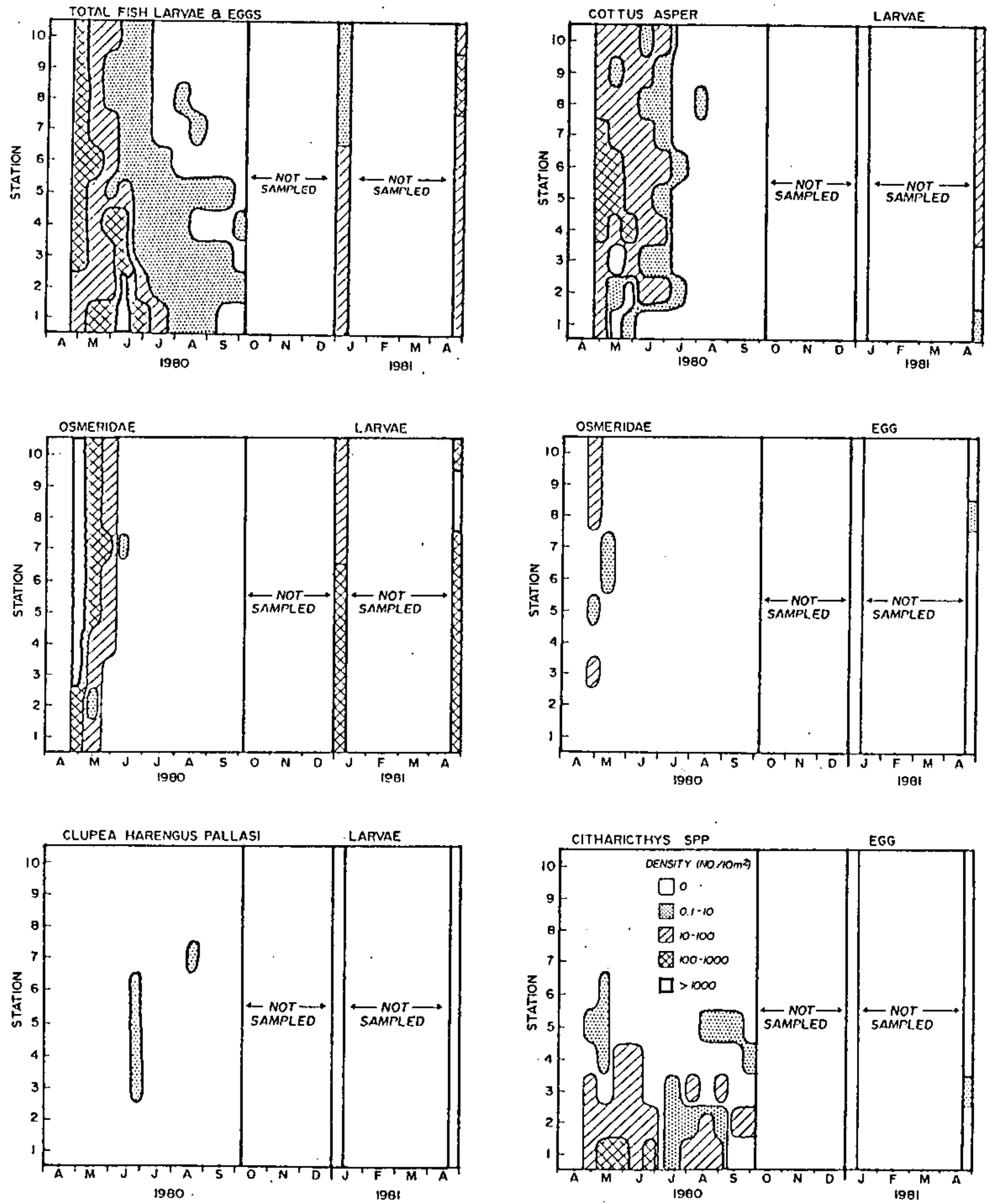


Figure 10. Seasonal density of fish eggs and larvae in the Columbia River Estuary

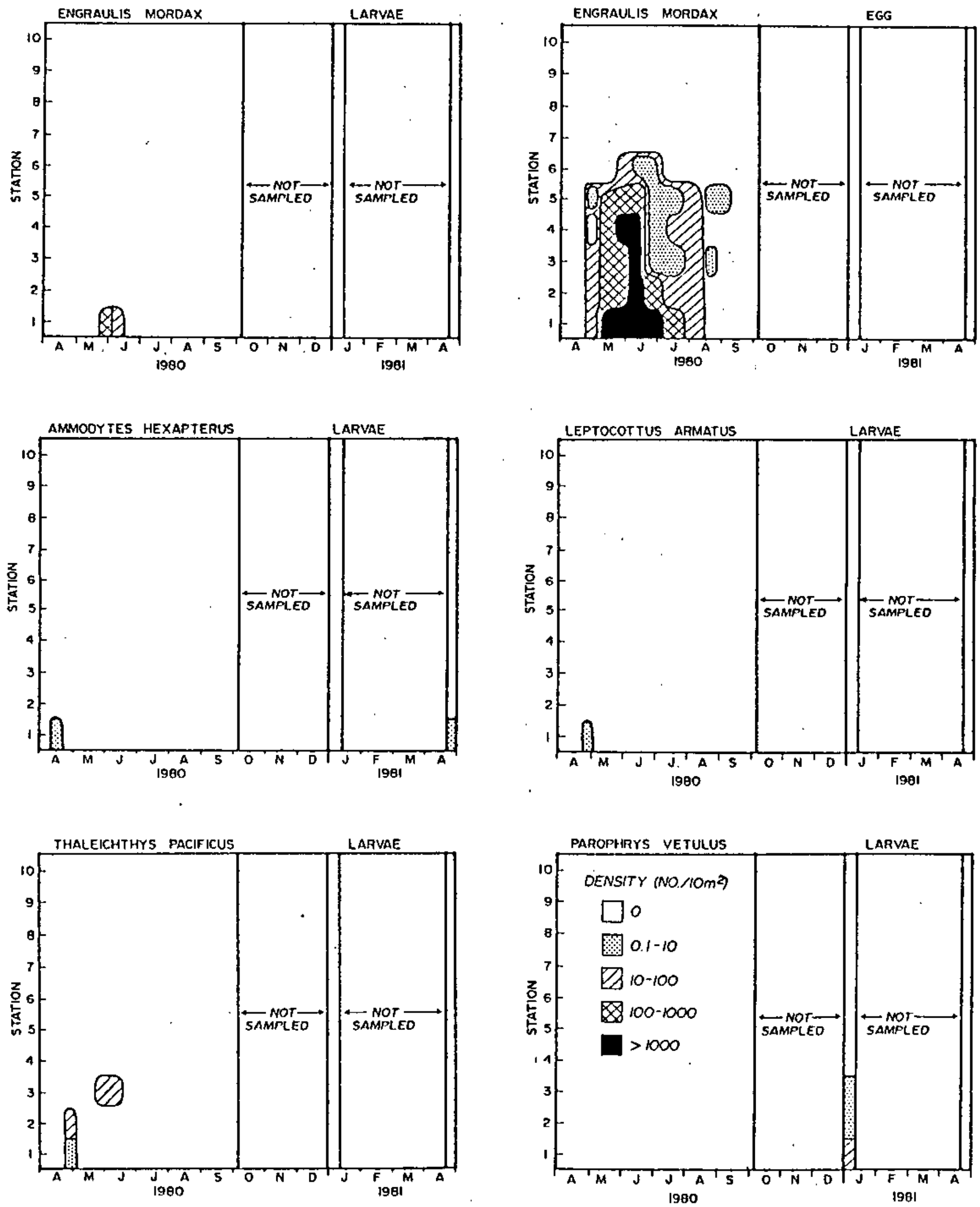


Figure 11. Seasonal density of fish eggs and larvae in the lower Columbia River Estuary

4. DISCUSSION

4.1 ZOOPLANKTON

River discharge and water circulation are dominant forces on biological communities in the Columbia River Estuary. Discharges that range from 75,000 cfs in summer to 600,000 cfs during spring cause the upriver extent of salinity intrusion to fluctuate between RM-8 and RM-20. Composition, distribution, and density of zooplankton assemblages in the estuary also vary seasonally with river discharge. It is likely that river discharge exerts direct or indirect control over the distribution of plankton food resources, temperature of water, rates of reproduction, and rate of flushing of zooplankton through the system, all of which influence the distribution of freshwater, estuarine, and marine species.

4.1.1 Horizontal Distribution

Zooplankton are distributed along a horizontal gradient in the Columbia River Estuary. The gradient corresponds with the distribution of salinity in the estuary (Simenstad et al. 1984). Assemblages present only in the lower estuary enter with the tide and are rarely found above RM-13.

Studies conducted in Yaquina Bay on the central Oregon coast and in nearshore oceanic waters illustrate the influence of oceanic zooplankton on the composition of lower estuarine assemblages (Peterson and Miller 1977; Miller 1983). Yaquina Bay is hydrologically unlike the Columbia River Estuary, although it contains similar marine taxa in the lower estuary. Nearshore oceanographic conditions for the central Oregon coast are similar to conditions in the region near the mouth of the Columbia River Estuary. Ocean currents along the Oregon coast flow southward in the summer, and upwelling brings cold, nutrient-rich water to the surface. In the winter, nearshore currents flow north and coastward. Summer species along the Oregon coast are those of northern origin: *Acartia clausi*, *Acartia longiremis*, *Calanus marshallae*, *Centropages abdominalis*, and *Oithona similis* (Peterson and Miller 1977). Winter taxa are transported from the south by northerly flowing currents. These species include *Clausocalanus* spp., *Corycaeus anglicus*, *Ctenocalanus vanus*, and *Paracalanus parvus*. Oceanic taxa enter Oregon estuaries on flood tides. Summer taxa are much more abundant than winter taxa, and remain in the Yaquina Estuary, though in low abundance, throughout the winter (Miller 1983). A similar situation was found in the Columbia River Estuary during this survey. In winter, *Ctenocalanus vanus* appeared and densities of *Acartia clausi* and *Acartia longiremis* declined.

Freshwater taxa predominate in the upper Columbia River Estuary. Many of these taxa, such as *Bosmina* and *Daphnia*, were also collected in the estuarine mixing zone. During high flow periods, freshwater taxa are swept downriver in surface waters. Numerous Columbia River dams provide a series of stable, lake-like habitats in which cladoceran and copepod populations may thrive and pass into the estuary (Simenstad, personal communication). Cladocerans and copepods are abundant, and zooplankton populations are enhanced where lakes and sloughs feed into the lower Fraser River (Northcote et al. 1976).

Few taxa were present only in the mid-Columbia River Estuary; Eurytemora affinis and Scottolana canadensis were the only endemic estuarine forms identified in this survey (Miller 1983). Other mid-estuary taxa were marine or freshwater forms tolerant of brackish water conditions.

The estuarine mixing zone in the Columbia River Estuary is a dynamic zone where fluvial and estuarine nutrients, detritus, and phytoplankton mix with ocean-derived nutrients and particles. As a result, large amounts of particulate organic carbon are trapped at the point of current reversal, or "null point," which is located approximately at the upstream extent of oceanic zooplankton advection into the estuary (Miller 1983). The null point moves back and forth in the mid-estuary region between RM-8 and RM-20 depending on tidal fluctuations and river discharge (Lara-Lara 1983). Results of this and previous surveys (Haertel et al. 1969) indicate this mixing zone is an area of high zooplankton density. In spring and early summer of 1980 and 1981, total zooplankton density was higher at stations 4, 5, and 6 (RM-11, RM-13, and RM-15) than at other sampling sites in the estuary.

Seasonal patterns of zooplankton abundance correspond closely to changes in phytoplankton densities--high in spring, low in late summer, and very low in winter. Unlike zooplankton, phytoplankton chlorophyll biomass and production were maximum in the freshwater zone. Living phytoplankton may be important as a direct food source; or chlorophyll levels may be indicative of amounts of carbon entering the estuary from the river as detritus from dead phytoplankton cells, plant debris, and other particulate organic matter. Lara-Lara (1983) suggested that freshwater phytoplankton cells lyse as they encounter saltwater downstream and contribute to elevated carbon detrital levels in the central estuary. Increased particulate carbon in this region may have contributed to higher zooplankton density as well as to increased epibenthic crustacean standing crop (Simenstad 1984) during the 1980-81 CREDDP survey.

Total fish densities are also highest in the estuarine mixing zone throughout the year and are seasonally highest in the summer. The relative effects of grazing on pelagic zooplankton densities in the estuary are not known. Results of the CREDDP fish survey suggested that fish may feed more successfully in epibenthic than in pelagic habitats (Bottom et al. 1984).

The Middle St. Lawrence River Estuary has a zooplankton community comparable to the Columbia River Estuary. Like the Columbia, mean discharge is high (300,000 cfs), but there is little seasonal variation (Bousfield et al. 1975, cited in Miller 1983). Bousfield divided St. Lawrence zooplankton species into three assemblages with fauna similar to those in the Columbia River assemblages: (1) marine coastal species derived from the ocean; (2) endemic estuarine species; and (3) freshwater taxa that tolerate brackish water. Predominant species in these assemblages included taxa that are also abundant in the Columbia River Estuary: estuarine species included Eurytemora affinis; a common freshwater taxon was Bosmina longirostris; Acartia longiremis and Acartia clausi were common marine species, although Acartia longiremis had its highest abundance in the estuary. The marine coastal forms extended upstream, and brackish tolerant freshwater taxa extended downstream to the null point. Most of the endemic estuarine taxa were present just above the null point. Despite the geographic distance that separates the Columbia River and Middle St. Lawrence River estuaries, similarities in the physical environments of the two systems are reflected in the composition of their zooplankton communities.

4.1.2 Annual Variation

Two previous zooplankton surveys were conducted in the Columbia River Estuary from 1964 through 1968 (Haertel and Osterberg 1967; Haertel et al. 1969; Haertel 1970) and 1971 through 1972 (Misitano 1974). Together, these data and the current study provide information on zooplankton populations for 7 of the last 20 years. The earlier surveys help to fill data gaps for the period October through April, which was poorly sampled during the 1980-81 CREDDP survey.

Misitano (1974) collected samples each month for 13 months in the channels up to RM-23. The populations were lower throughout 1972 than in 1980-81, and a clear pattern of abundance was not evident (Figure 12). Populations were high in the lower 13 miles of estuary during spring and summer, but distribution was patchy. In late summer, populations were higher in the upper estuary. In November and December of 1972 levels were high throughout the estuary though highest at RM-19. In December and January of 1971-72, population abundance peaked in the estuarine mixing zone.

Haertel and Osterberg (1967) and Heartel et al. (1969) divided the estuarine zooplankton into three major assemblages that were also represented in the 1980-81 survey. The groups were dominated by the following taxa:

FRESHWATER	ESTUARINE MIXING	MARINE
Cyclops vernalis	Eurytemora affinis	Pseudocalanus minutus
Bosmina spp.	Scottolana canadensis	Acartia clausii
Daphnia longispina		

Zooplankton studies in the Columbia River Estuary reveal large-scale variation in timing and distribution of assemblage peaks between years. For example, zooplankton in 1972 (Misitano 1974) did not establish large mid-estuary densities, and zooplankton levels did not appear stable. In 1980, densities peaked in the mid-estuary through late spring and in the upper estuary through August and

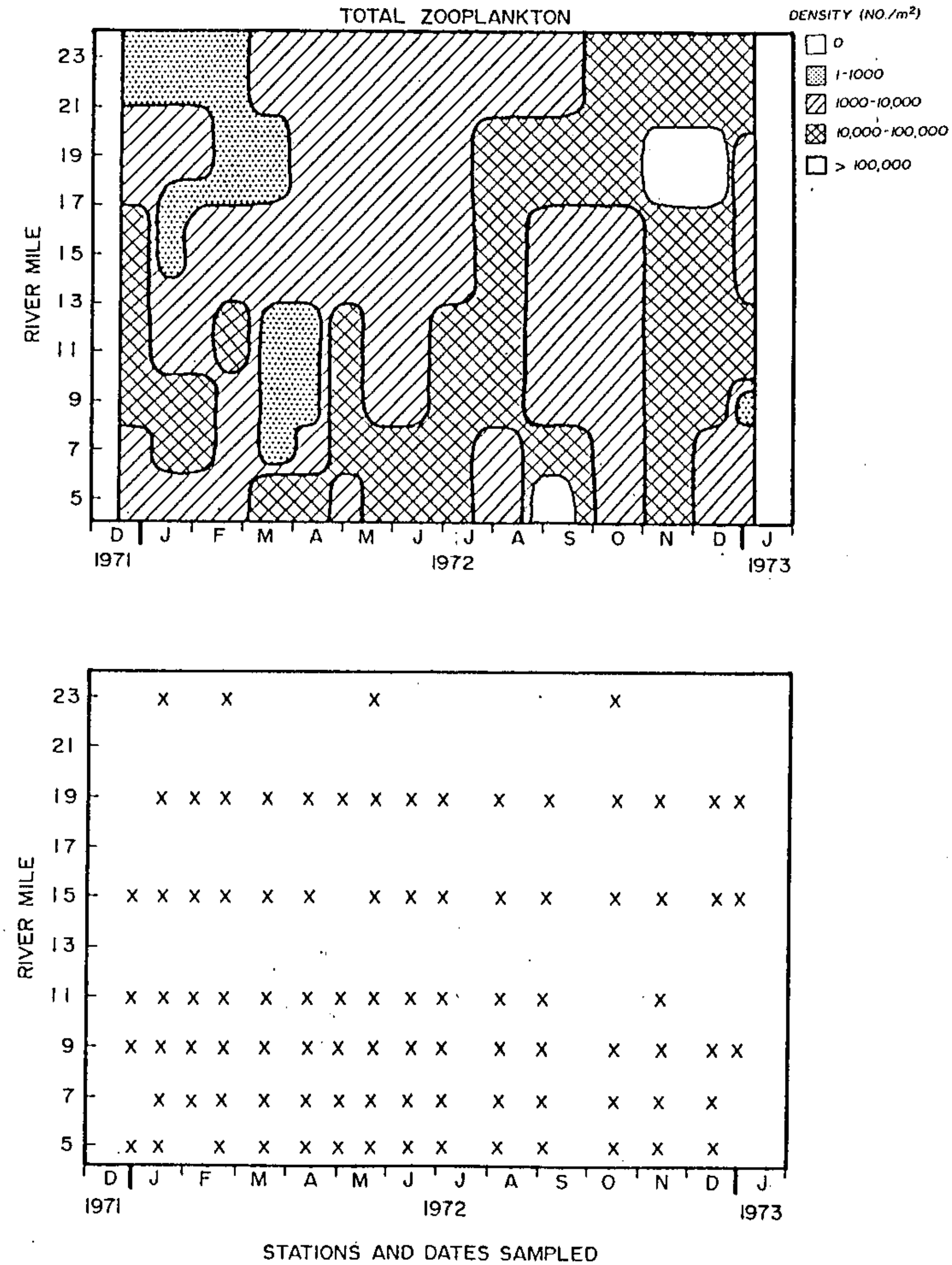


Figure 12. Seasonal density of total zooplankton during 1972(data from Misitano 1974), sampling dates and stations are depicted in lower graph

September. During 1964-68, densities of the mid-estuary assemblages peaked in early spring (Haertel et al. 1969). Haertel (1970) and Misitano (1974) reported high densities in early wnter, particularly in mid-estuary assemblages. Incomplete sampling in 1980-81 prevents similar comparisons for the winter months.

A number of physical or biological factors may account for annual variation in zooplankton densities. Misitano (personal communication) suggested that 1972 was a year of extreme flooding and may have prevented development of a large mid-estuary assemblage. Limited data for 1973 during lower flows showed that Eurytemora affinis rebounded to densities above 100,000/m^3. Haertel et al. (1969) agreed that river discharge may have accounted for large scale variations in Eurytemora affinis densities. Densities of Eurytemora affinis decreased sharply following extremely high discharge in June 1964 and after flooding in December 1965. Flushing out of the estuary in the surface waters may also have caused a large decrease in the density of zooplankton assemblages during 1980. This may explain the sudden disappearance of marine taxa and the downstream extension of fresh and mixing zone taxa in July 1980. Although freshwater discharge peaked in June in 1980 (Lara-Lara 1983), zooplankton distribution and abundance indicated that the estuary was experiencing high discharge condiions in July.

Haertel et al. (1969) stated that high temperatures were limiting to Eurytmora affinis during summer. In 1964-68 Eurytemora affinis densities were low in summer during low river discharge, high water temperature, and high phytoplankton levels (Haertel et al. 1969). Reproduction of freshwater zooplankton, on the other hand, is stimulated by increased river temperatures during summer (Haertel et al. 1969). Haertel et al. (1969) suggested that reproduction more than balanced losses of freshwater zooplankton to the ocean during the summer low discharge period. Species composition and abundance in the freshwater and estuarine mixing zones may represent a balance between reproductive rates and residence time in a high flow system.

4.1.3 Maintenance of Zooplankton in the Estuary

The biological or physical mechanisms maintaining endemic estuarine zooplankton populations are not well understood (Miller 1983). It seems unlikely that an endemic zooplankton population could reproduce at a sufficient rate to maintain itself in an estuary with a water residence time of only 2 to 5 days (Ketchum 1954, cited in Miller 1983). Haertel et al. (1969) suggests Eurytemora affinis may be transported upriver in the bottom layer and thus maintain position in the estuarine mixing zone. The Columbia River Estuary is well stratified most of the year (Jay 1984). In 1967, Eurytemora affinis was ten times more abundant at depth than at the surface (Haertel et al. 1969). Miller (1983) also suggested that in the Middle St. Lawrence River Estuary, Eurytemora herdmani maintained its distribution just downstream of the null point by some form of vertical migration.

The large peripheral bays in the Columbia River Estuary--Cathlamet, Grays, Youngs, and Baker--may provide protected, low current refuges that replenish zooplankton densities in the channel areas. Simenstad (1984) found littoral-flat habitats to have the highest density of zooplankton in the Columbia River Estuary, sometimes greater than 100,000/m^2. Many of these taxa are also abundant in the water column-- Bosmina spp., Cyclops spp., and Eurytemora affinis. In contrast to average abundance levels of 21,809/m^2 in bays, epibenthic zooplankton populations in sublittoral channel habitats averaged 9,996/m^2 (Simenstad 1984).

Studies conducted in the Fraser River Estuary also suggest that low-current refuges may be important to maintain endemic zooplankton populations in the Columbia. River discharge in the Fraser, as in the Columbia, is high and seasonally variable. Mean discharge is 95,000 cfs with extremes that range from 12,000 to 536,000 cfs (Northcote et al. 1976). However, the Fraser River Estuary contains primarily drift organisms (e.g., aquatic insect larvae), and zooplankton (cladocerans and copepods) are most dense in a few sloughs and protected areas (Northcote et al. 1976). Density ranged from 1.4 to 250 organisms per 100 m^3 in the estuary. Zooplankton that wash into the estuary are quickly flushed from the system. The absence of an endemic zooplankton population in the Fraser River Estuary suggests three potential influences: (1) lack of large protected bays; (2) lack of a well stratified channel habitat; and (3) a high flushing rate. The major physical difference that may account for an endemic zooplankton population in the Columbia is the presence of several protected bays and a deeper stratified water column.

4.2 Larval Fish

Most of the fish eggs and larvae sampled during the present survey were oceanic in origin. Six of the 18 taxa sampled were captured only between RM-0 and RM-5, and 7 of the remaining 12 taxa were collected in the marine and lower estuarine mixing zone of the estuary. Eggs of Citharyicthys spp. and Engraulis mordax were common in the lower estuary. Larval Cottus asper, Clupea harengus pallasi, and Osmeridae probably utilized the estuary for juvenile growth, although the existing data do not indicate whether these taxa were estuarine dependent.

In 1973, larval fish were most abundant from January through May (Misitano 1977), a period poorly sampled in the CREDDP survey. Densities peaked in March (Spirinchus thaleichthys) and May (Thaleichthys pacificus and Cottus asper). The greatest diversity of larvae was captured near the mouth in higher salinities. Misitano (1977) suggested that the Columbia River Estuary was used for spawning by several species including Clupea harengus pallasi, Cottus asper, Leptocottus armatus, and a snailfish species. Most notably, Spirinchus thaleichthys appeared to utilize the estuary throughout the year. The results of the 1980-81 CREDDP survey do not contradict these findings.

Other estuaries on the Oregon coast may not be dominated by species of Osmeridae. For example Lepidogobius lepidus and Clupea harengus pallasi composed 90% of all larvae in Yaquina Bay (Pearcy and Myers 1974). Clupea harengus pallasi was the only commercially important species using the Yaquina estuary extensively as a spawning and nursery ground from 1960 through 1970. Clupea harengus pallasi appeared to have two spawning periods in Yaquina Bay: during January through March in the lower estuary and during April and May in the upper estuary. Other larvae using the estuary were noncommercial taxa including cottids, stichaeids, and gobiids. As in the Columbia River Estuary, eggs were most abundant during summer, and larvae were most abundant during winter or spring.

5. CONCLUSIONS AND RECOMMENDATIONS

Copepods, cladocerans, and mysids are the predominant zooplankton taxa in the Columbia River Estuary. During 1980-81, regions of maximum zooplankton densities shifted from the lower estuary (river mouth to RM-16) during late April and early May, to the mid-estuary (RM-10 to RM-16) during May and June, and to the freshwater region (RM-20 to RM-23) during July, August, and September. As in previous studies (e.g., Haertel and Osterberg 1967), *Eurytemora affinis*, an endemic estuarine copepod, was the most abundant taxon sampled during the CREDDP survey.

Zooplankton assemblages in the estuary include oceanic, freshwater, and endemic estuarine species distributed along a horizontal gradient. *Neomysis kadiakensis*, *Calanus* spp., and *Ctenocalanus* spp. were representative of taxa most abundant near the mouth of the estuary. Marine taxa such as *Acartia* spp. and *Pseudocalanus* spp. were commonly found from the mouth of the estuary to RM-13. A third assemblage comprised species from the estuarine mixing and freshwater zones (RM-10 to RM-23) including *Eurytemora affinis*, *Daphnia* spp., *Bosmina* spp., and *Cyclops* spp.

Most of the fish eggs and larvae sampled during the CREDDP survey were oceanic species and were collected only in the marine and lower estuarine mixing zones (RM-5 to RM-14). Species of Osmeridae including *Spirinchus thaleichthys* and *Thaleichthys pacificus* were the most abundant larval fish collected in the estuary.

High river discharge is a dominant influence on zooplankton and larval fish in the Columbia River Estuary. Several factors probably sustain endemic zooplankton populations in the estuary despite high river discharge. Two-layered circulation in deep channels may transport zooplankton upriver. Large shallow bays may offer refuges from strong current velocites and serve as reproductive reservoirs that replenish densities of zooplankton in the main channel.

Results of this and previous surveys suggest several areas for future research to improve our understanding of zooplankton and food chains in the Columbia River Estuary. Specific research objectives should include the following:

(1) Describe the life history of *Eurytemora affinis*.

(2) Estimate rates of secondary production by zooplankton, and quantify the flow of energy from zooplankton to pelagic fishes.

(3) Evaluate the factors that maintain zooplankton in the estuary including:
   (a) Rates of reproduction for endemic species.
   (b) Rates of transport of zooplankton in to and out of the estuary.
   (c) The potential role of shallow bays as reservoirs for reproduction and as slack water refuges for zooplankton.

(d) The effect of two-layered circulation on the distribution and density of zooplankton.

Some specific changes in sampling methodology are needed to increase the resolution of future zooplankton surveys. Samples must be stratified by depth in the water column to determine the effects of two-layered circulation on zooplankton distributions. An increase in sampling frequency to twice a week would improve interpretation of life history data. A smaller mesh net (e.g., 0.125 mm) is needed for life history studies to adequately sample early copepodite and nauplii stages.

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APPENDIX A. List of taxa codes, taxa, and life history stages of zooplankton and larval fishes captured in the Columbia River Estuary, taxa with no life history designation include all life history stages.

FISH EGGS AND LARVAE

AMHL	Ammodytes hexapturus	larvae
CITE	Citharichthys spp.	eggs
CITL	Citharichtys spp.	larvae
CLHL	Clupea harengus pallasi	larvae
COAL	Cottus asper	larvae
ENME	Engraulis mordax	eggs
ENML	Engraulis mordax	larvae
GOBL	Gobiidae	larvae
LEAL	Leptocottus armatus	larvae
LYEL	Lyopsetta exilis	larvae
OSME	Osmeriidae	eggs
OSML	Osmeriidae	larvae
PLSL	Platichthys stellatus	larvae
PLEE	Pleuronectidae	eggs
SEBL	Sebastolobus spp	larvae
TELL	Teleostei	larvae
THPL	Thaleichthys pacific	larvae
PAVL	Parophrys vetulus	larvae

MYSIDACEA

ALIM	Alienacanthomysis macropsis	
ALI1		juvenile
ALI2		immature male
ALI3		mature male
ALI4		immature female
ALI5		mature female
ALI6		female brooding
ALI7		spawned female
ARCH	Archaeomysis grebnitzkii	
ARC1		juvenile
ARC2		immature male
ARC3		mature male
ARC4		immature female
ARC5		spawned female
ARC6		mature female
NEMK	Neomysis kadiadensis	
NEK1		juvenile
NEK2		immature male
NEK3		immature female
NEK4		female brooding
NEOM	Neomysis mercedis	
NEM1		juvenile
NEM2		imm male
NEM3		mature male
NEM4		imm female
NEM5		mature female
NEM6		female brooding
NEM7		spawned female
NEOS	Neomysis spp	juvenile

<u>COPEPODA</u>

ACAC	Acartia californiensis	
ACAA		adult male
ACAC		copepodid
ACA3		adult female
ACCL	Acartia clausi	
ACC1		copepodid
ACC2		adult male
ACC3		adult female
ACLO	Acartia longiremis	
ACO1		copepodid
ACO2		adult male
ACO3		adult female
ALQC	Alona quadrangularis	juvenile,adult
BOSM	Bosmina longirostris	
BOS1		juvenile
BOS2		adult
CALP	Calanus pacificus	
CALA		copepodid
CAMA	Calanus marshallae	
CAM1		copepodid
CAM2		adult female
CALT	Calanus tenuicornis	copepodid
CALO	Calocalanus styliremis	adult female
CENA	Centropages abdominalis	
CEN1		copepodid
CEN2		adult male
CEN3		adult female
CLAU	Clausocalanus lividus	
CLAU		copepodid
CLAF		adult female
CLPA	Clausocalanus parapergens	
CLP1		adult female
CLP2		adult male
COPN	Copepoda	nauplii
CORY	Corycaeus affinis	
COR1		copepodid
COR2		adult male
COR3		adult female
COR4		gravid female
CTVA	Ctenocalanus vanus	
CTV1		copepodid
CTV2		female adult
CYBT	Cyclops bicuspidatus thomasi	
CYB1		copepodid
CYB2		adult male
CYB3		adult female
CYB4		gravid female
CYVE	Cyclops vernalis	
CYV1		copepodid
CYV2		adult male
CYV3		adult female
CYV4		gravid female

DIAA	Diaptomus ashlandi	
DIA1		copepodid
DIA2		adult male
DIA3		adult female
DIA4		gravid female
DIFR	Diaptomus franciscanus	
DIF1		copepodid
DIF2		adult male
DIF3		adult female
DIF4		gravid female
DINO	Diaptomus novamexicanus	
DIN1		copepodid
DIN2		adult male
DIN3		adult female
DIN4		gravid female
DIOR	Diaptomus oregoniensis	
DIO1		copepodid
DIO2		adult female
DIO3		gravid female
EPLO	Epilabidocera longipedata	
EPL1		copepodid
ELAC	Epishura lacustris	
ELA1		copepodid
ELA2		adult female
ELA3		adult male
EPIN	Epischura nevadensis	copepodid
EUSP	Eucyclos speratus	
EUS1		copepodid
EUS2		adult female
EUS3		gravid female
EUS4		adult male
EURY	Eurytemora affinis	
EUR1		copepodid II
EUR2		copepodid III
EUR3		copepodid IV male
EUR4		copepodid V male
EUR5		adult male
EUR6		copepodid IV female
EUR7		copepodid V female
EUR8		adult female
EUR9		gravid female
MACR	Macrocyclops albidus	copepodid
MELU	Metridia lucens	
MEL1		copepodid
MIPU	Microcalanus pusillus	
MIP1		adult female
OSIM	Oithona similis	
OSI1		copepodid
OSI2		adult male
OSI3		adult female
OSPI	Oithona spinirostris	
OSP1		copepodid
OSP2		adult female

PARP	Paracalanus parvus	
PAR1		copepodid
PAR2		adult male
PAR3		adult female
PARF	Paracyclops fimbriatus poppei	
PARR		copepodid
PARM		adult male
PARF		adult female
PARE		gravid female
PSEL	Pseudocalanus elongatus	
PSE1		copepodid
PSE2		adult male
PSE3		adult female
SCOC	Scottolana canadensis	
SCO1		copepodid
SCO2		adult female

CLADOCERA

CERI	Ceriodaphnia puchella	juvenile,adult
CHGL	Chydorus globosus	
CHG1		juvenile,adult
DAGM	Daphnia galeata mendota	
DAG1		juvenile
DAG2		adult
DAPU	Daphnia pulex	
DAP1		juvenile
DAP2		adult
DIAH	Diaphanosoma brachyurum	juvenile,adult
EVAN	Evadne nordmanni	juvenile,adult
ILSO	Ilyocryptus sordidus	juvenile,adult
LEKI	Leptodora kindtii	
LEK1		juvenile
LEK2		adult
PODL	Podon leuckarti	juvenile,adult
SIDA	Sida crystallina	juvenile,adult

AMPHIPODS

ANIS	Anisogammarus confervicolus	
ANIS		juvenile
ANIA		adult
CAPE	Caprella equilibra	
CAP1		juvenile
CORO	Corophium spinicorne	juvenile

CUMACEANS

DIDA	Diastylopsis dawsoni	
DID1		juvenile

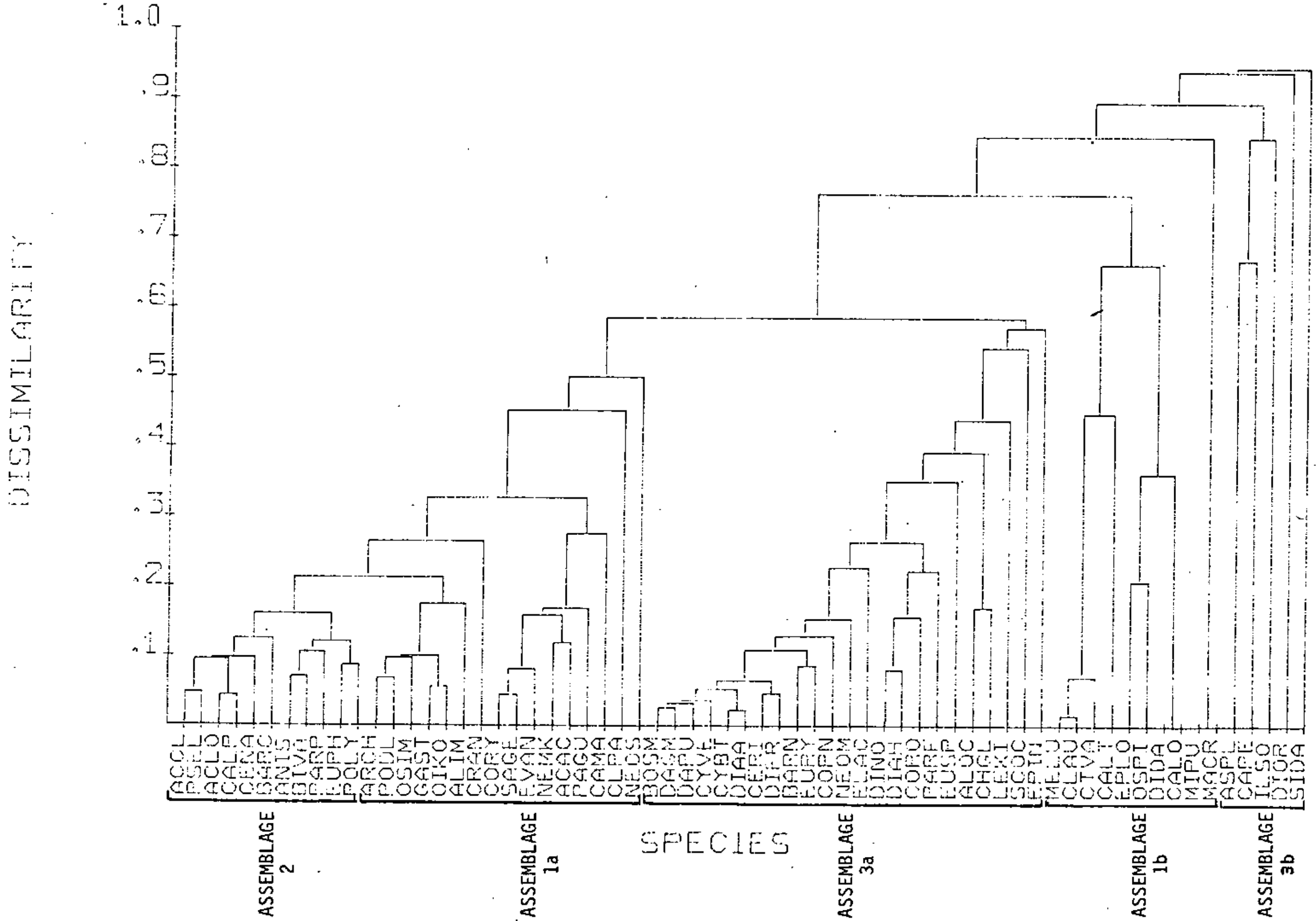
DECAPODS

CRAN	Crangonidae	zoea
EUPH	Euphausiacea	nauplius
PAGU	Paguridae	larvae

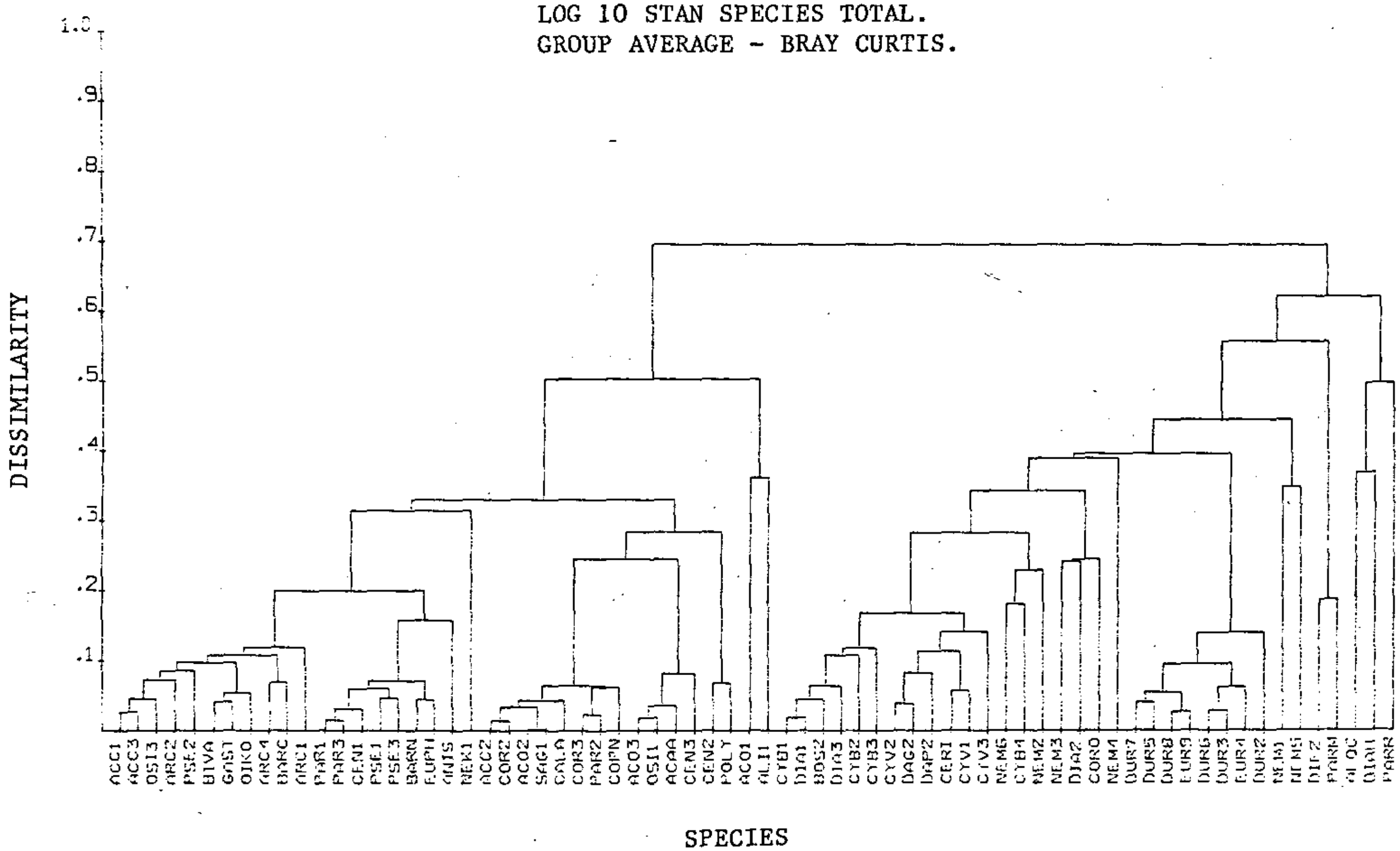
BARNACLES		
BARC	Barnacle	cypris
BARN	Barnacle	nauplius
MOLLUSCS		
BIVA	Bivalvia	veliger
GAST	Gastropoda	veliger
POLYCHAETES		
POLY	Polychaete	larvae
CHAETOGNATHES		
SAGE	Sagitta elegans	
SAG1		juvenile
SAG2		adult
TUNICATES		
OIKO	Oikopleura dioica	adult
ROTIFERS		
ASPL	Aspanchna	juvenile,adult

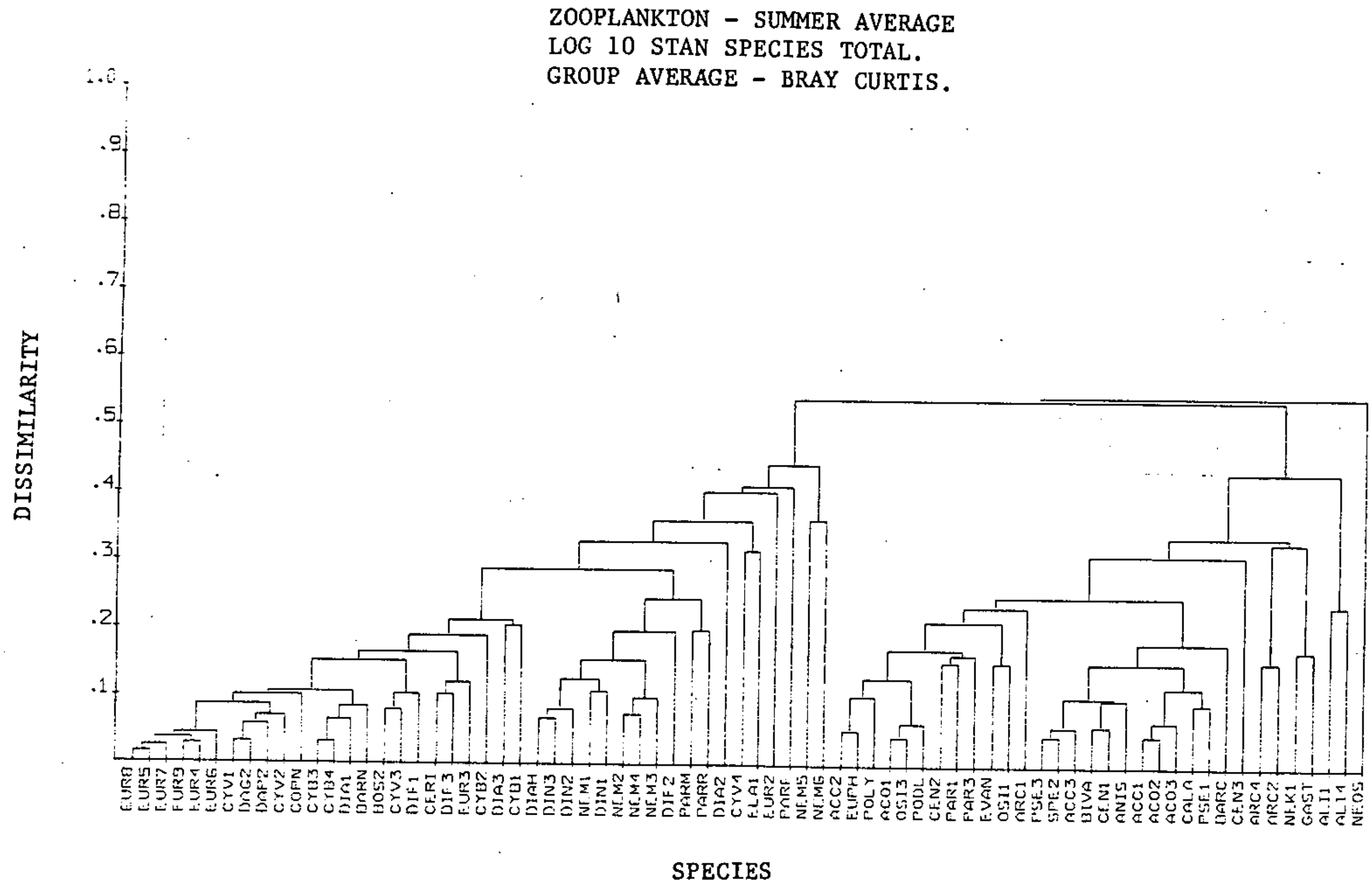
APPENDIX B. Zooplankton clusters

ZOOPLANKTON - ALL TAXA - YEAR AVERAGE
LOG10 STAN SPECIES TOTAL.
GROUP AVERAGE - BRAY CURTIS.

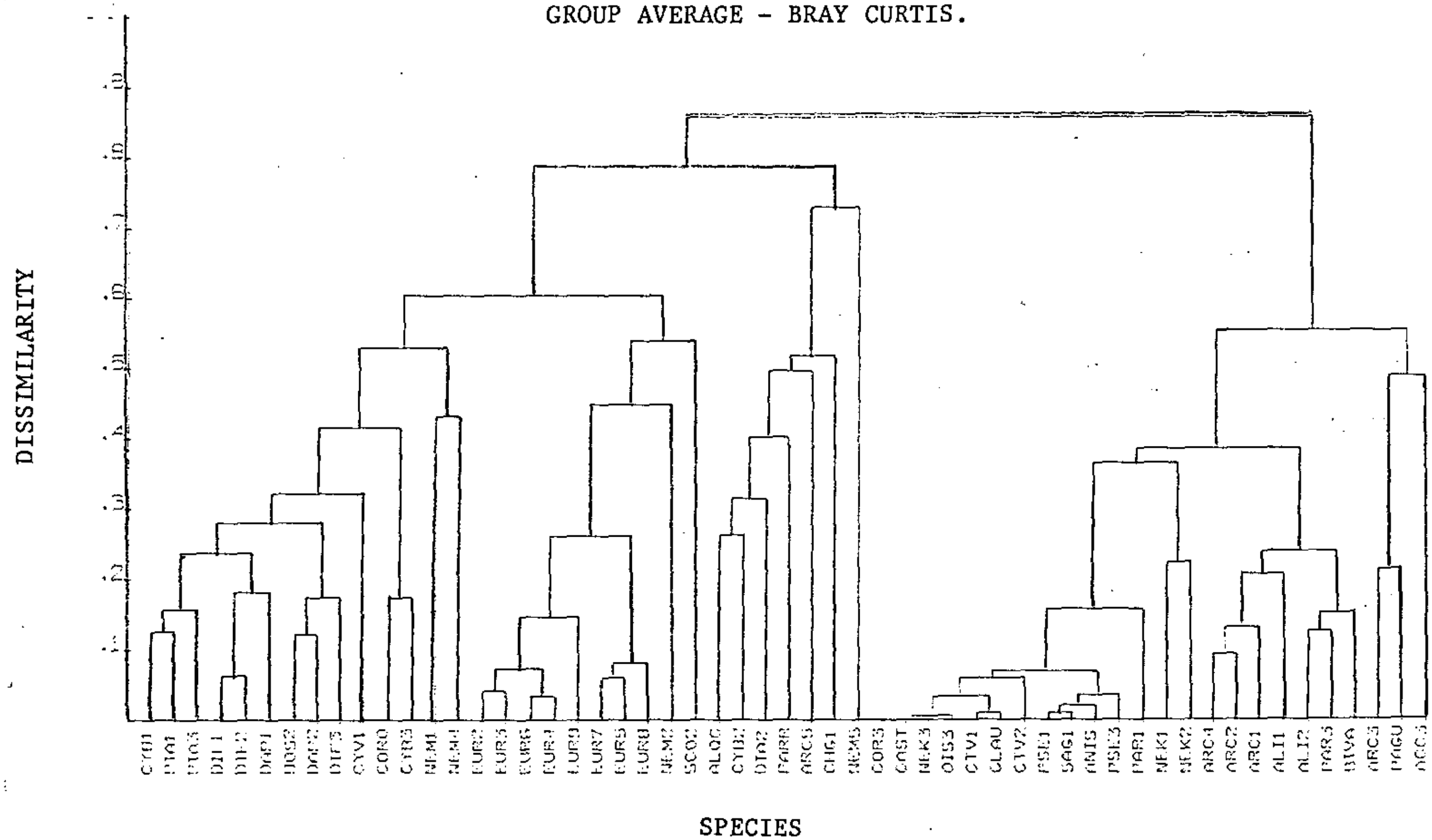


ZOOPLANKTON - SPRING AVERAGE
LOG 10 STAN SPECIES TOTAL.
GROUP AVERAGE - BRAY CURTIS.



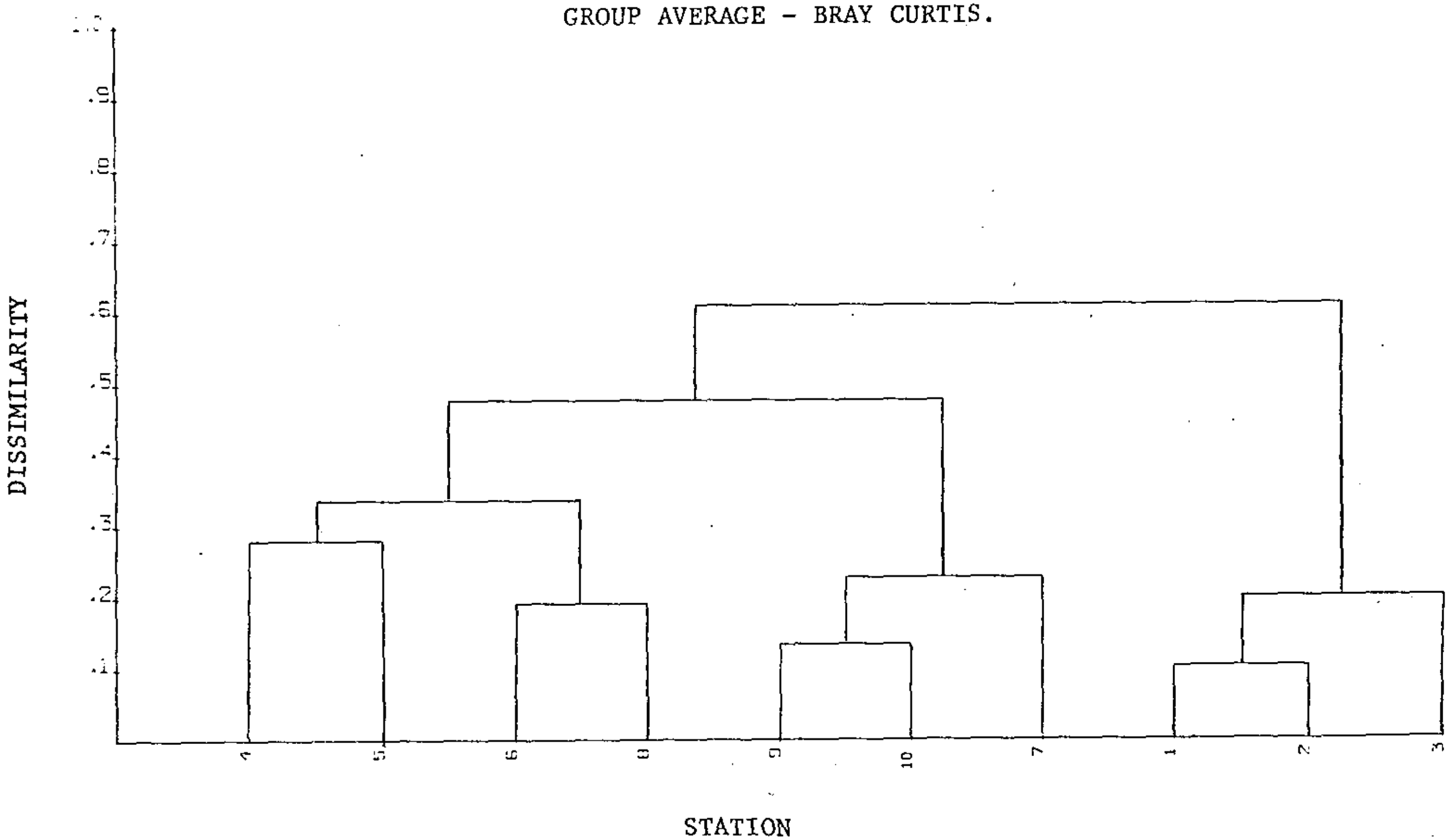

ZOOPLANKTON - SUMMER AVERAGE
LOG 10 STAN SPECIES TOTAL.
GROUP AVERAGE - BRAY CURTIS.
DISSIMILARITY
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
EUR8 EUR5 EUR7 EUR9 EUR4 EUR6 CYV1 DAG2 DAP2 CYV2 COPN CYB3 CYB4 DIA1 DARN BOS2 CYV3 DIF1 CERI DIF3 EUR3 CYB2 DIA3 CYB1 DIAH DIN3 DIN2 NEM1 DIN1 NEM2 NEM4 NEM3 DIF2 PARM PARR DIA2 CYV4 FLA1 EUR2 PARF NEM5 NEM6 ACC2 EUPH POLY ACO1 OSI3 PODL CEN2 PAR1 PAR3 EVAN OSI1 ARC1 PSE3 SPE2 ACC3 BIVA CEN1 ANIS ACC1 ACO2 ACO3 CALA PSE1 BARC CEN3 ARC4 ARC2 NEK1 GAST ALI1 ALI4 NEOS
SPECIES

ZOOPLANKTON - WINTER (JANUARY)
LOG 10 STAN SPECIES TOTAL.
GROUP AVERAGE - BRAY CURTIS.

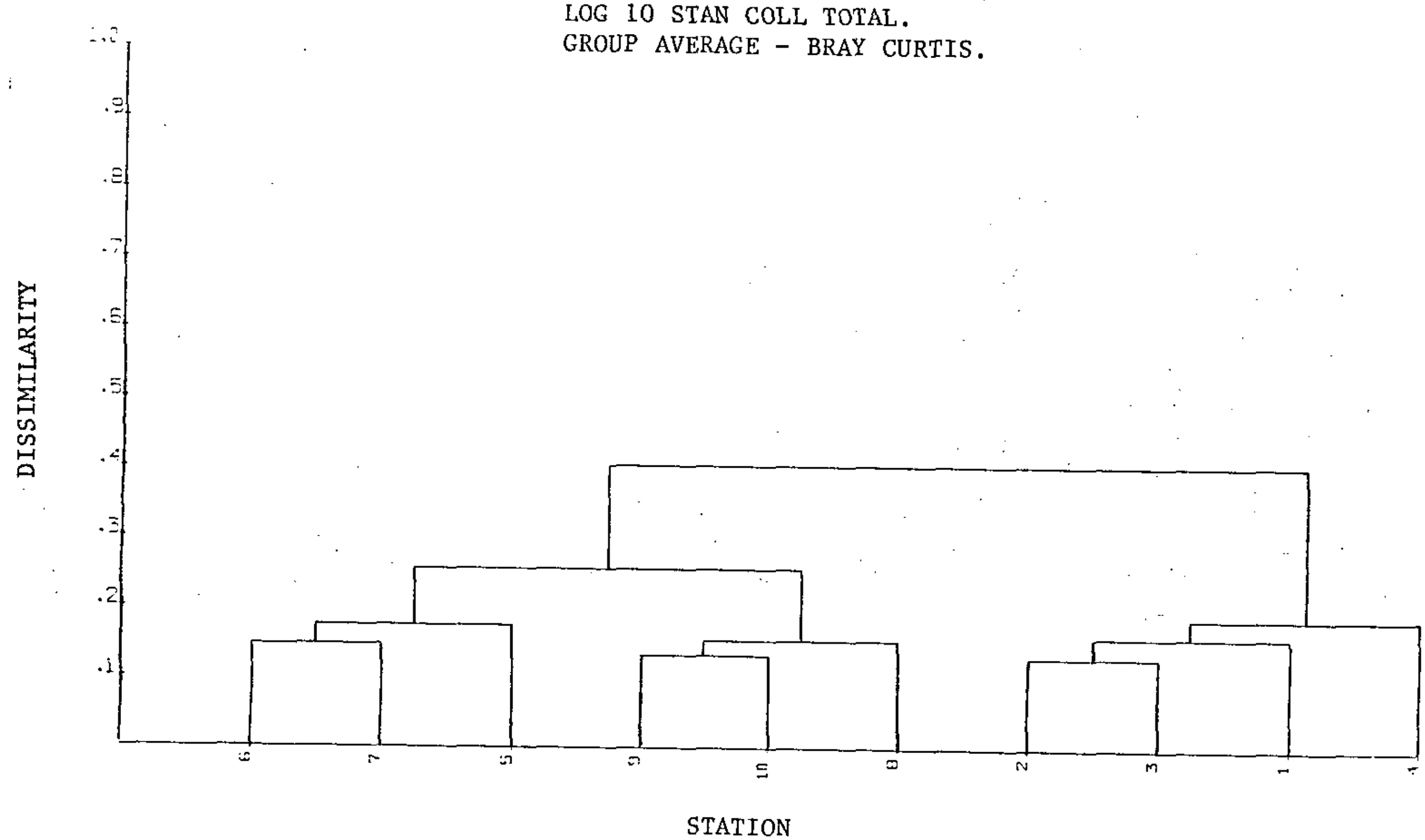


APPENDIX C. Station clusters based on zooplankton composition and abundance

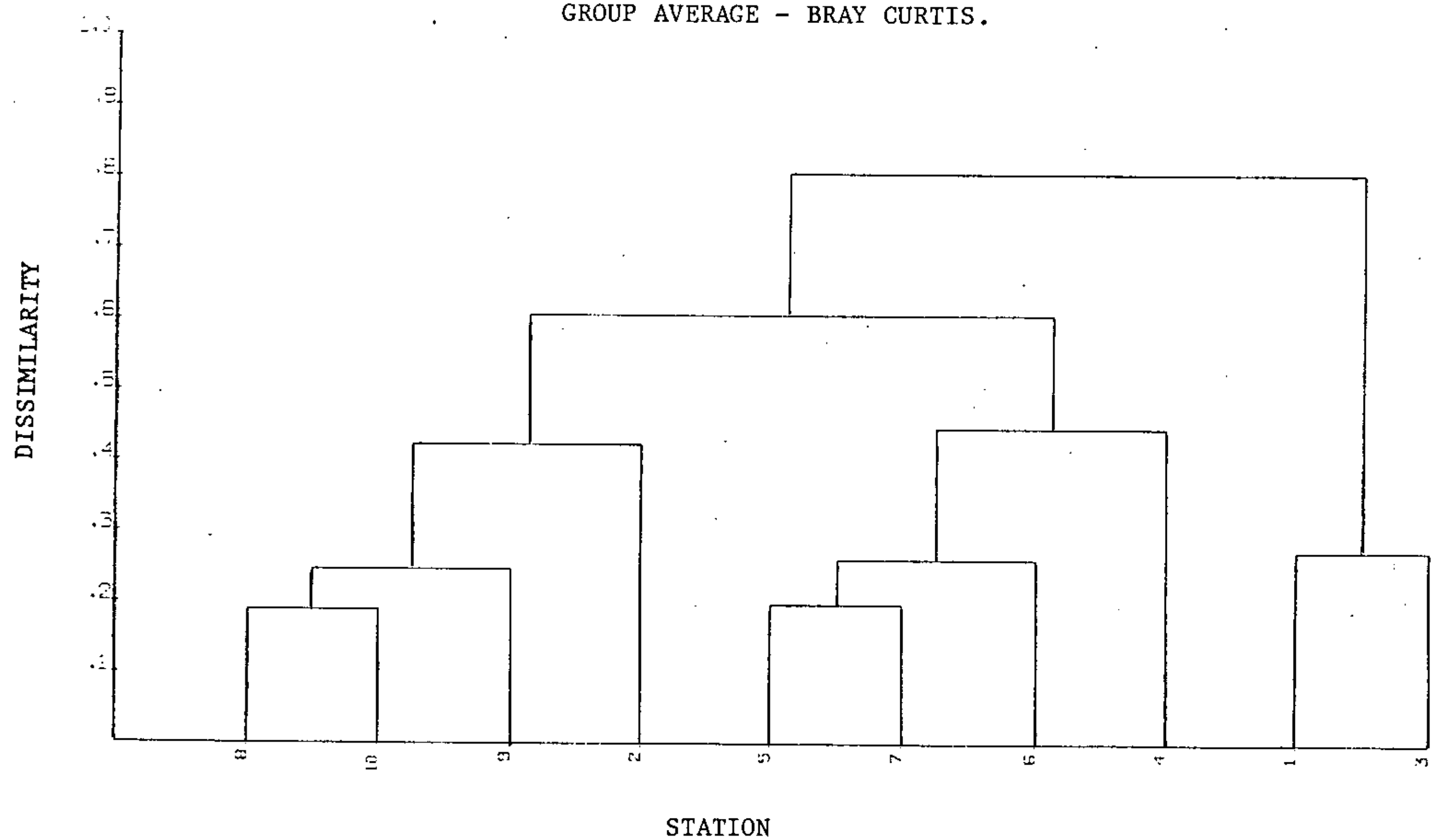
ZOOPLANKTON - SPRING AVERAGE
LOG 10 STAN COLL TOTAL.
GROUP AVERAGE - BRAY CURTIS.



ZOOPLANKTON - SUMMER AVERAGE
LOG 10 STAN COLL TOTAL.
GROUP AVERAGE - BRAY CURTIS.



ZOOPLANKTON - WINTER AVERAGE
LOG 10 STAN COLL TOTAL.
GROUP AVERAGE - BRAY CURTIS.



APPENDIX D. Density ($\log_{10}$ x + 1) of zooplankton during each hydrologic season

SPRING

spp.	station 1	2	3	4	5	6	7	8	9	10
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

SUMMER

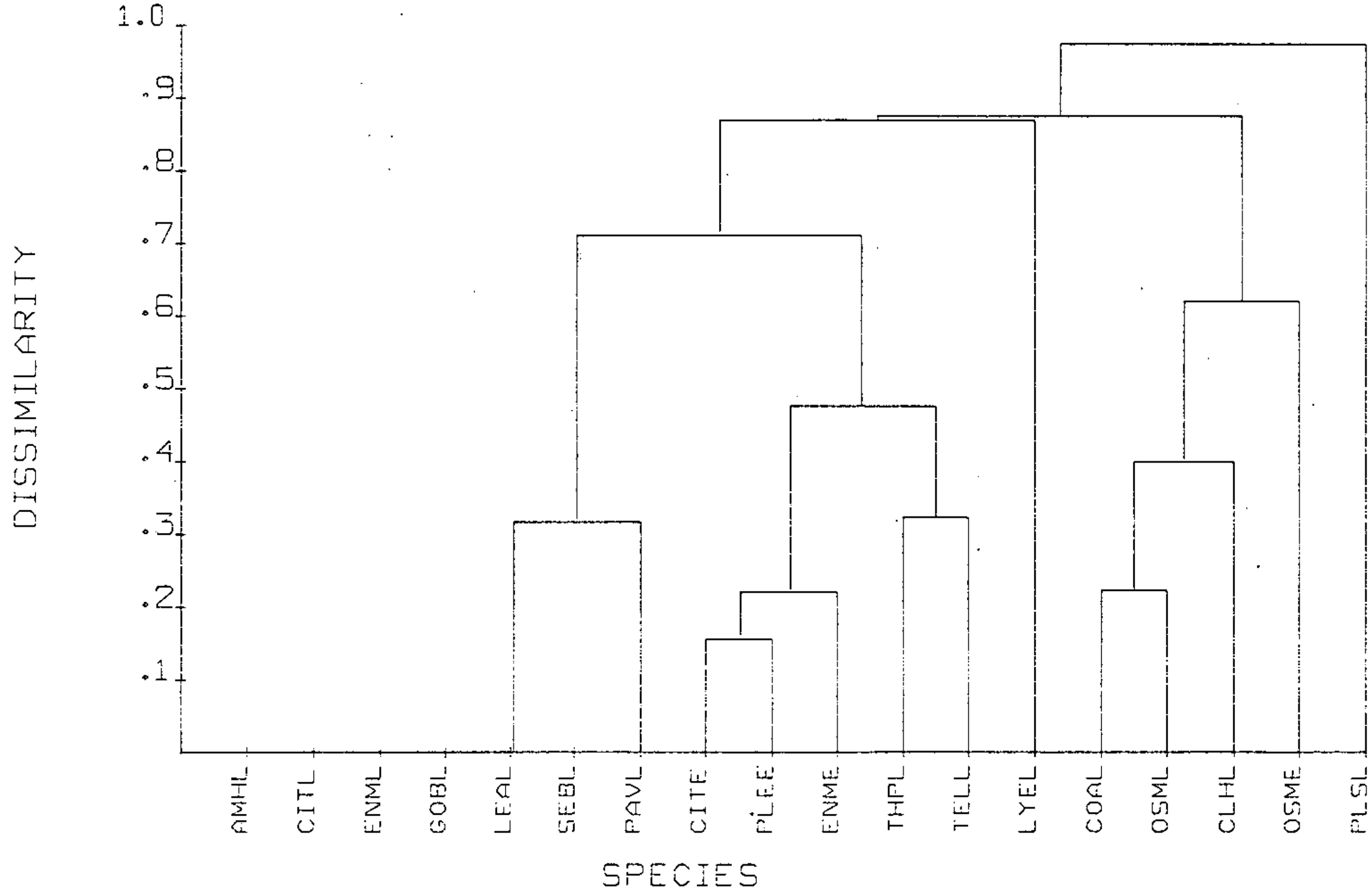
spp.	station 1	2	3	4	5	6	7	8	9	10
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

WINTER

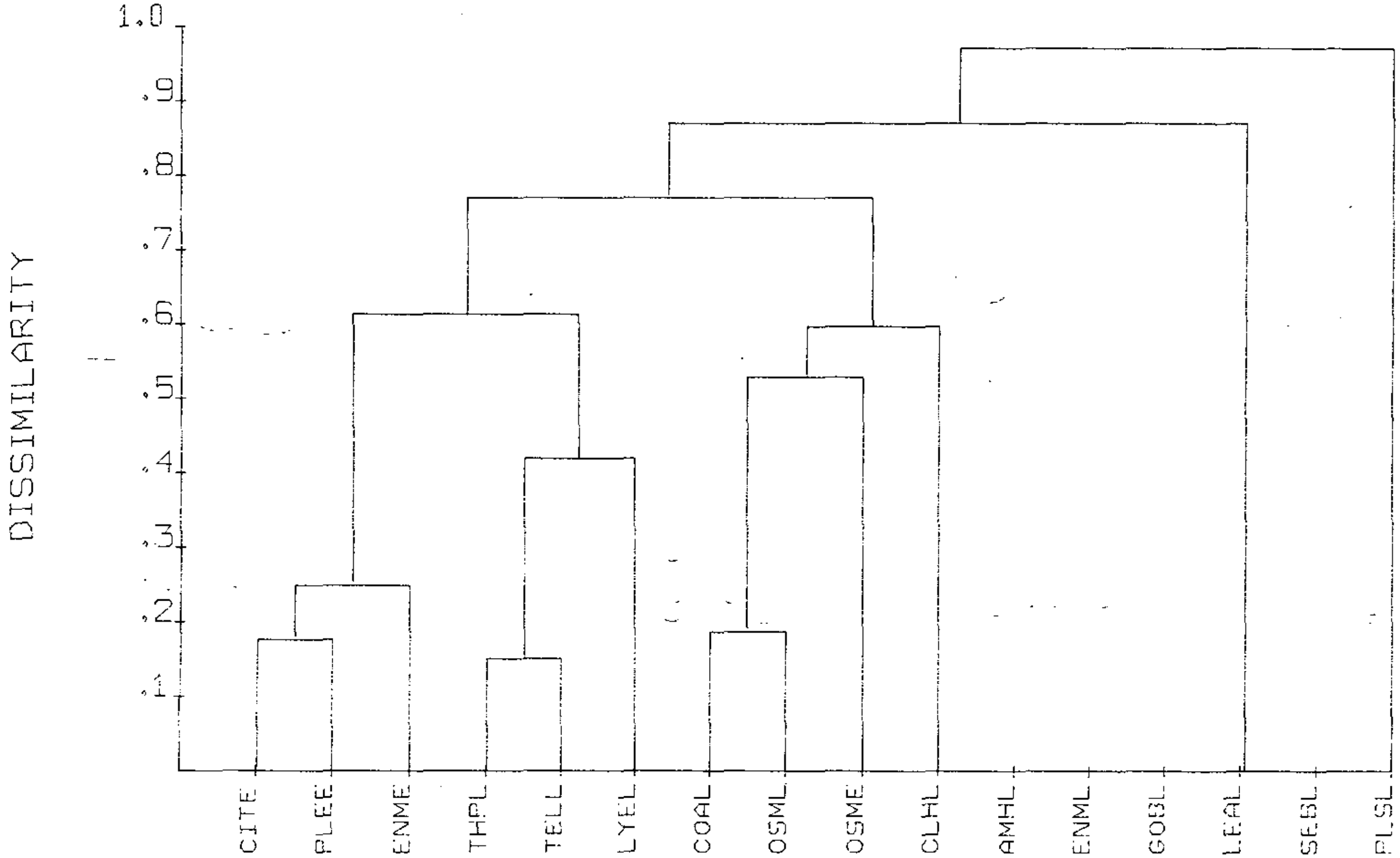
spp.	station 1	2	3	4	5	6	7	8	9	10
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

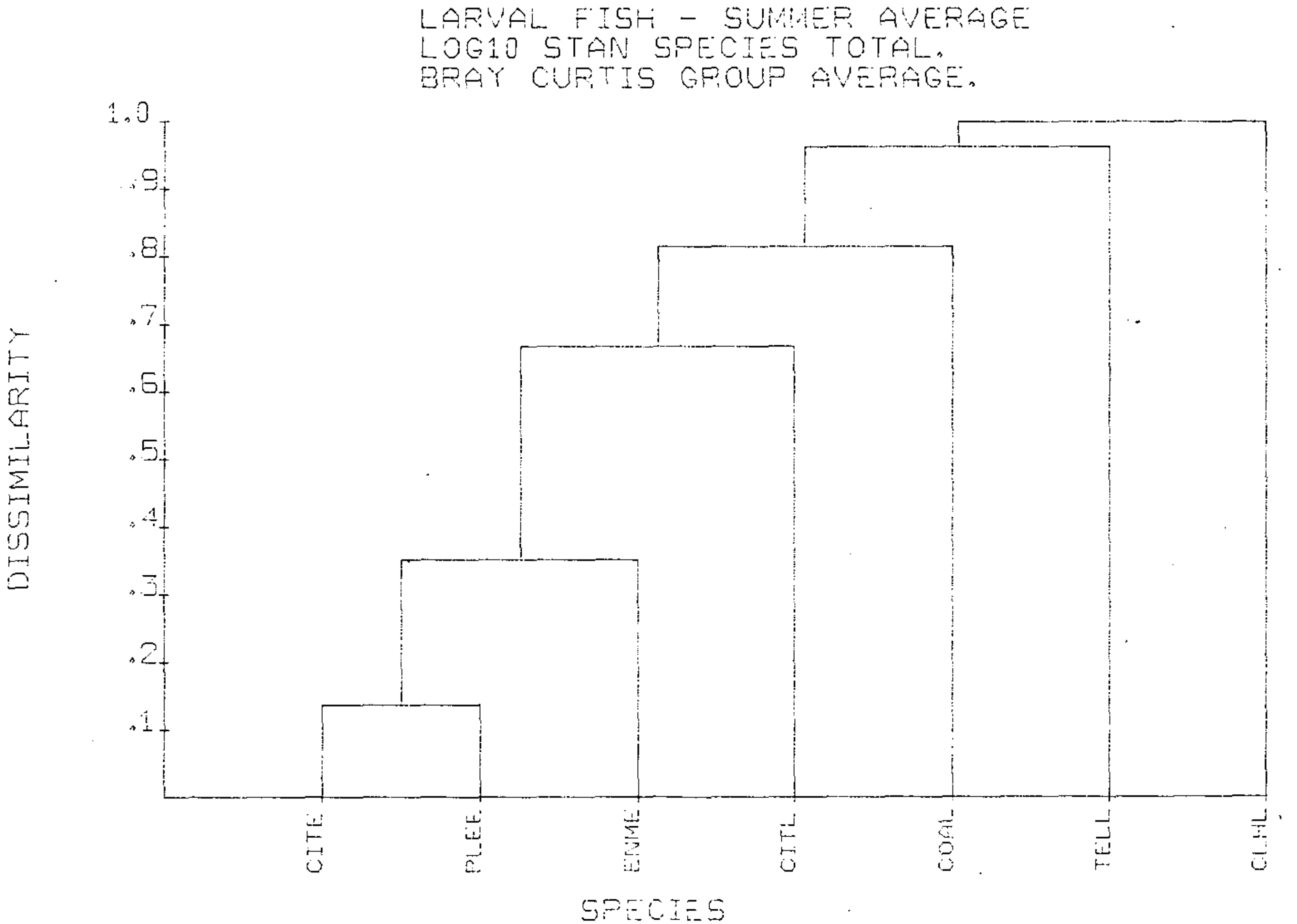
APPENDIX E. Fish egg and larvae clusters

LARVAL FISH - AVERAGE FOR YEAR
LOG10 STAN SPP TOTAL.
BRAY CURTIS GROUP AVERAGE.



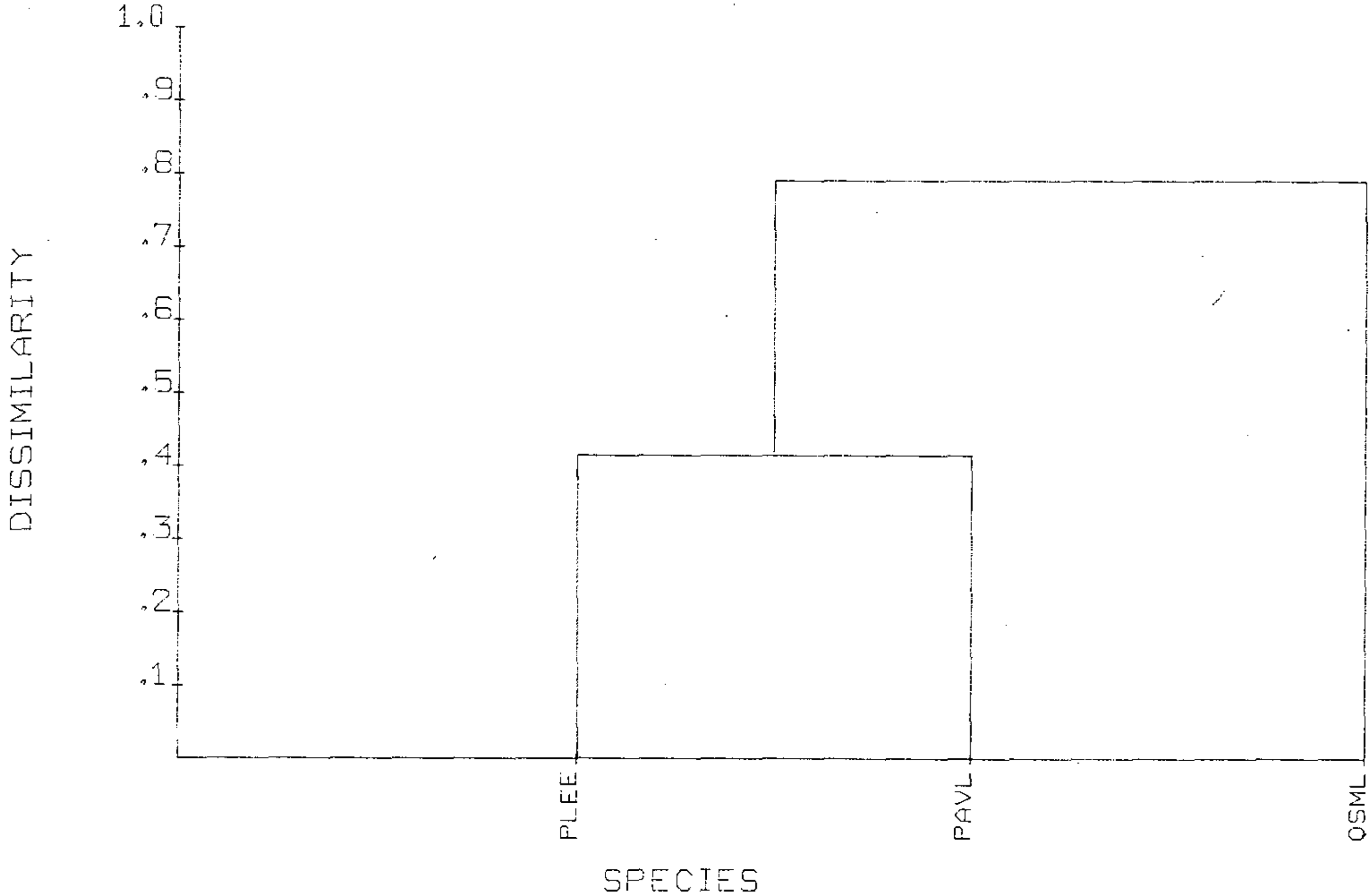
LARVAL FISH - SPRING AVERAGE
LOG10 STAN SPECIES TOTAL.
BRAY CURTIS GROUP AVERAGE.





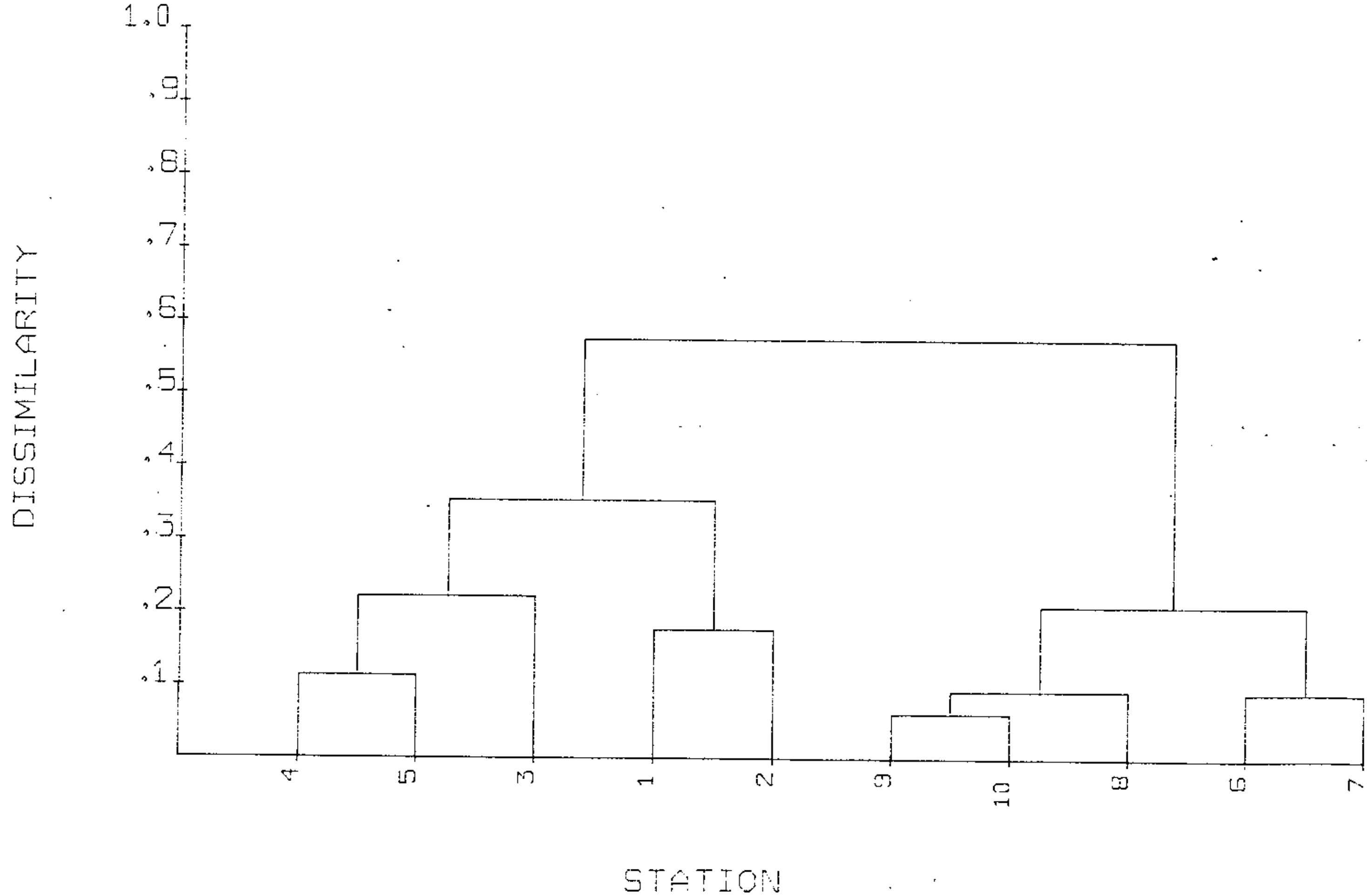
LARVAL FISH - SUMMER AVERAGE
LOG10 STAN SPECIES TOTAL.
BRAY CURTIS GROUP AVERAGE.
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
DISSIMILARITY
CITE
PLEE
ENME
CITL
COAL
TELL
CLHL
SPECIES

LARVAL FISH - WINTER (JANUARY)
LOG10 STAN SPECIES TOTAL.
BRAY CURTIS GROUP AVERAGE.

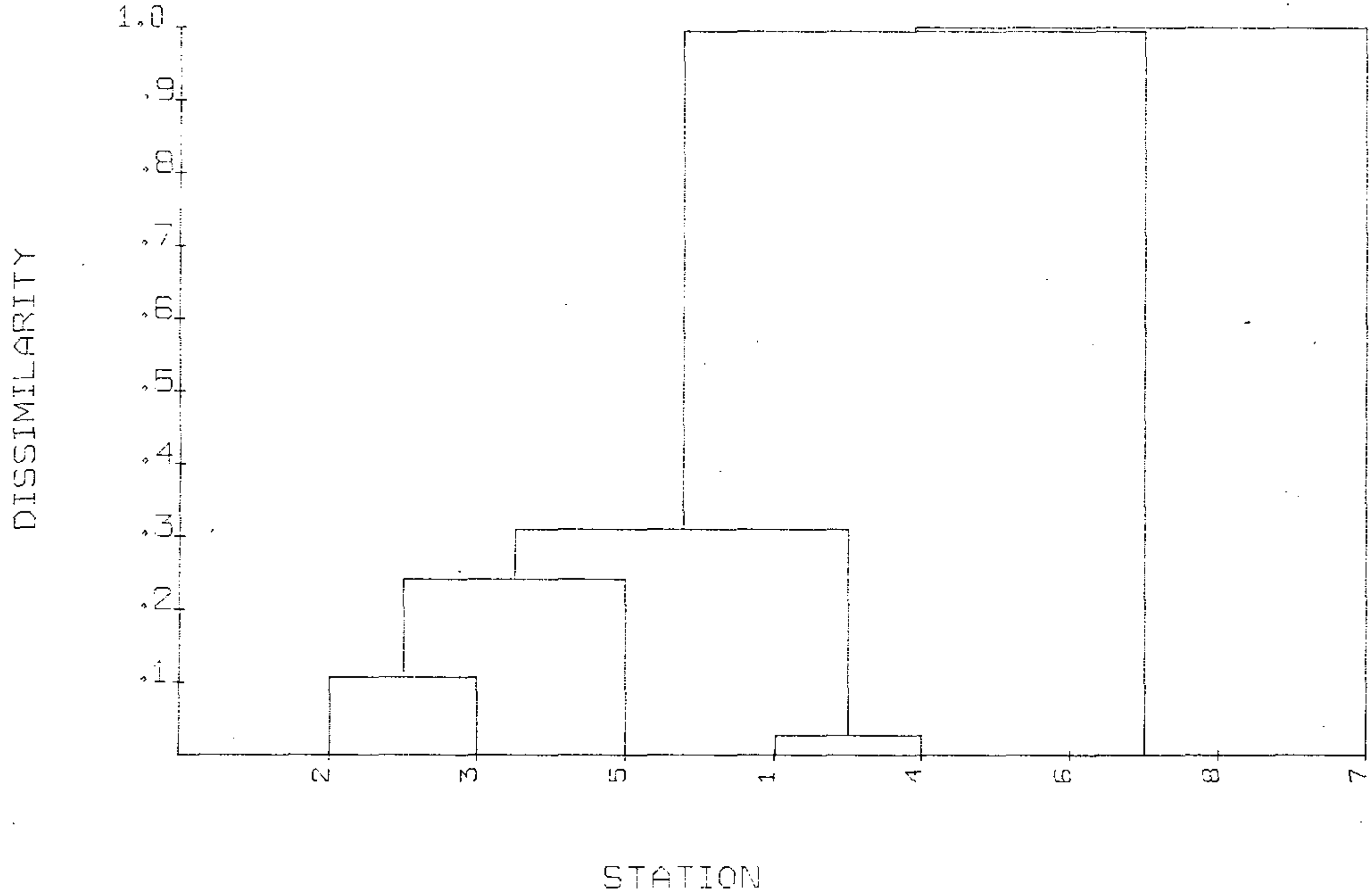


APPENDIX F. Station clusters based on larval fish composition and abundance

LARVAL FISH - SPRING AVERAGE
LOG10 STAN COLL TOTAL.
BRAY CURTIS GROUP AVERAGE.



LARVAL FISH - SUMMER AVERAGE
LOG10 STAN COLL TOTAL.
BRAY CURTIS GROUP AVERAGE.



LARVAL FISH - WINTER (JANUARY)
LOG10 STAN COLL TOTAL.
BRAY CURTIS GROUP AVERAGE.