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Title SEASONAL AND SPATIAL DISTRIBUTION OF HARPACTICOID COPEPODS IN RELATION TO SALINITY AND TEMPERATURE IN YAQUINA BAY, OREGON

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Seventy-three samples from mud flat, channel and eel grass in Yaquina Bay, Oregon, collected during three seasons in 1965, were examined for species composition and abundance of harpacticoid copepods.

Fifty-seven harpacticoid species were found and also four species of cyclopoid species were recorded. All species identifications were carried as far as possible.

Temperature and salinity values were taken throughout 1965 and variations in these factors were related to distributional patterns of harpacticoid copepods.

Spatial differences in harpacticoid species composition were marked. Upstream, downstream and intermediate type species

assemblages were identified from mud flats and eel grass and these assemblages were related to spatial differences in salinity and temperature.

Seasonal differences in species composition and total numbers were observed. These changes were also attributed to fluctuations of salinity and temperature. The winter period seemed to have been dominated by factors resulting from heavy rains; winter samples showed very low species numbers and total numbers.

A slough leading from the lower bay exhibited patterns of salinity and temperature similar to a portion of the bay. Harpacticoid distributions were also comparable in the slough to those of the bay except that distributions were compressed into a shorter horizontal distance in the slough.

Although some species were found in all three biotopes, eel grass, channel and mud flat, samples generally contained different species composition and different dominant forms.

Species relationships or groupings were determined graphically and statistically and comparable results were obtained with both methods. Another method was used which compared entire core samples and gave somewhat different results than the species oriented methods.

SEASONAL AND SPATIAL DISTRIBUTION OF HARPACTICOID COPEPODS IN RELATION TO SALINITY AND TEMPERATURE IN YAQUINA BAY, OREGON

by

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SEASONAL AND SPATIAL DISTRIBUTION OF HARPACTICOID COPEPODS IN RELATION TO SALINITY AND TEMPERATURE IN YAQUINA BAY, OREGON

INTRODUCTION

An estuary is a zone of transition between the marine and freshwater environment, and organisms inhabiting an estuary are therefore subjected to great ranges of salinity, temperature and sediment type. Not only must the animals and plants cope with great seasonal changes, but they must also endure large fluctuations of salinity and temperature on each tidal cycle. Planktonic organisms move with the tides and currents and in this way reduce the daily and seasonal range of variation within their habitat. Sessile macrobenthos such as pelecypods, due to their lack of mobility and the length of their life cycle, must physiologically endure the seasonal changes at a given point in an estuary; however, benthic harpacticoid copepods have shorter life cycles and motility, and although subjected to daily variations in physical parameters, they may shift populations seasonally to fit changing temperature and salinity patterns.

This study when conceived was to have been primarily taxonomic, but due to the interesting aspects of the changing estuarine environment and the taxonomic problems of the group, it has evolved into

an ecological investigation; nevertheless, all species determinations have been carried as far as possible.

Copepods of the suborder Harpacticoida are a very diverse group abundant both in genera and species and are found in fresh water, brackish water and salt water. They are, with a few exceptions, benthic and occur on a substrate of sand, mud or plant life, interstitially, particularly in coarser sand, commensally, and parasitically with plants or animals. Although harpacticoids occur in the oceanic deeps, (Sars, 1911) most marine species are found in shallow water or intertidally.

The importance of harpacticoids in the food chains of their environment is relatively unknown. Perkins (1958) has stated that they are important food for larval fish, particularly flat fish, and that harpacticoids also are fed upon extensively by nereid worms which in turn are important food sources for fish and other organisms. Although they represent a small percentage of the benthic biomass, harpacticoids build up rapidly and production may be relatively high.

Nearly all of the early studies of harpacticoids were taxonomic and due to the large numbers of species and genera much confusion and synonomy ensued. Some order was made from the group with the publication in 1911 of Sars' Crustacea of Norway, Volume 5,

the excellent illustrations of which are still useful. The most important single publication on harpacticoids is the Monographie Harpacticoida by Lang in 1948 which is in two volumes and has keys and illustrations for all species. In spite of their abundance and diversity, harpacticoids have been little studied on the eastern shore of the Pacific. In 1884 Poppe described two new species and a new variety from the Bering Sea and North Pacific Ocean. In 1912 Baker described one new species from southern California; and in 1920 Willey described eleven species, three of them new, from northern Alaska and the Northwest Territories. Campbell in 1929 and 1930 recorded six species including three new ones, from the Vancouver Island Region, British Columbia. Monk in 1941 described sixteen species including eight new ones and two new varieties from California.

Two recent publications dealing with West Coast harpacticoids are useful. Chappius (1957) listed thirty-eight species of copepods from Puget Sound sand samples and gave a key to an important genus of marine interstitial water, Parastenocaris kessler. The most important work from West Coast investigators is that of Lang (1965) titled "Copepoda Harpacticoidea from the Californian Pacific Coast" which has 560 pages and 302 figures. Although most of the references given are to West Coast investigations, any taxonomic

study will involve other publications. Numbers of the species present here are cosmopolitan in distribution and although not recorded for this area may have been described from some other locality. Many species indicate a boreal distribution and are therefore described in European works.

Mare in 1942 divided the benthos into three groups: the macrobenthos, usually the only group studied, consists of animals retained by 1 mm. mesh net; the meiofauna, in which most harpacticoids fall, are caught with 0.1 mm. mesh net; the remainder are microbenthos. In benthic faunal studies harpacticoids are often overlooked due to their small size or are lost through coarse screens during sorting; there are therefore few ecological studies involving this taxon. Many of the early ecological works on meiobenthos were done in England. Moore in 1931 found that harpacticoids were one of the major groups of meiofauna and discussed the depth distribution in mud of the most abundant forms. He also subjected forms to low oxygen tensions in an attempt to determine tolerances. Krogh and Sparck in 1936 sampled harpacticoids, determined densities and attempted to determine biomass of the meiofaunal forms. Rees in 1940 and Mare (1942) also collected harpacticoids in the meiobenthos. A more recent worker is Wieser who studied the meiofauna of Buzzards Bay (1960) and related abundances to

sediment type and the depth of the animals in the sediment. Weiser also studied the effects of grain size and tidal level on harpacticoid copepods in Puget Sound sands (1959).

Wells (1963) has published an extensive list of harpacticoids taken from an estuary in England and it is anticipated that this will also be published as an ecological study.

Other papers of note on harpacticoids should be mentioned. Perkins (1958) discussed diet and the food chains within the meiobenthos and also attempted to determine the resistance of meiofaunal organisms to varying temperatures. Fahrenbach (1962) wrote on the biology of a harpacticoid copepod. Jakobi (1959a, 1959b) in two papers compared the morphological characters of the harpacticoids from environments of different substrates and of different salinities. Battaglia (1957), and Battaglia and Bryan (1964) carried out several studies in which were found genetic and physiological differences in a polymorphic species of harpacticoid.

The objectives of the present study are threefold: to identify the harpacticoid copepods of Yaquina Bay Oregon; to determine spatial and seasonal variations in distributions for the harpacticoid species; to relate the distributional patterns to environmental factors, particularly salinity and temperature.

This investigation introduces a subject in which a great number of future investigations can be made to answer the multitude of unsolved taxonomic, ecological and physiological problems.

DESCRIPTION OF SAMPLING AREA

Yaquina Bay is a positive type estuary located in the drowned valley of the Yaquina River which enters the Pacific Ocean at 44° 37'N latitude on the Oregon coast. The estuary extends inland about 23 miles (27.6 naut. miles), but this study includes only the lower reaches of the bay to buoy 39, a point about 8.5 nautical miles from the entrance. Except for two large tide flats in the lower bay, one to the north and one to the south, the estuary is quite narrow and winding.

The channel is dredged to 20 feet in the lower bay, and a depth of 12 feet is maintained in the upper channel. The tidal flats are of varying width and composed of mud except in the lower 1.5 to 2.0 miles where sand prevails. Channel sediments are marine sand in the lower reaches and river sand primarily above buoy 21. For a complete discussion of Yaquina Bay sediments see the thesis by Kulm (1965).

Leading into the bay at a point 2.5 nautical miles from the jaws is King Slough which stretches to the southwest about 1.5 miles from the bay channel. A small creek introduces fresh water into the upper end of the slough and at low tide the upper reaches are composed of mudflats with a narrow shallow channel winding across

them. The lower portion of the slough has a deeper channel, which is shown in figure 1, with depths to 10 feet, but the sill at the mouth of the slough is covered by only two or three feet of water at low tide.

Burt and McAlister (1959) classified Oregon estuaries using the system developed by Pritchard (1955). He classified estuaries according to the salinity difference between the surface and bottom water into: Type A, 20‰or over; Type B, between 4 and 19‰; and Type D, 3‰ or less. Burt and McAlister found Yaquina Bay to be Type B or partly mixed during February, April, and May and well mixed in January, August, October, and November. A hydrographic and plankton survey which has been conducted by Dr. Herbert F. Frolander (1965a) for several years in Yaquina Bay indicates that this general pattern is accurate, but there are many seasonal variations which depend on climatological conditions. Kulm (1965) stated, "the principal factor effecting changes in the type of hydrographic system during the year, assuming constant tidal and basic characteristics, is river discharge, which is related to seasonal climatic variations", and he presented data correlating the average, monthly salinity difference between surface and bottom waters with the average monthly rainfall at Newport.

Data presented in this investigation show that following periods

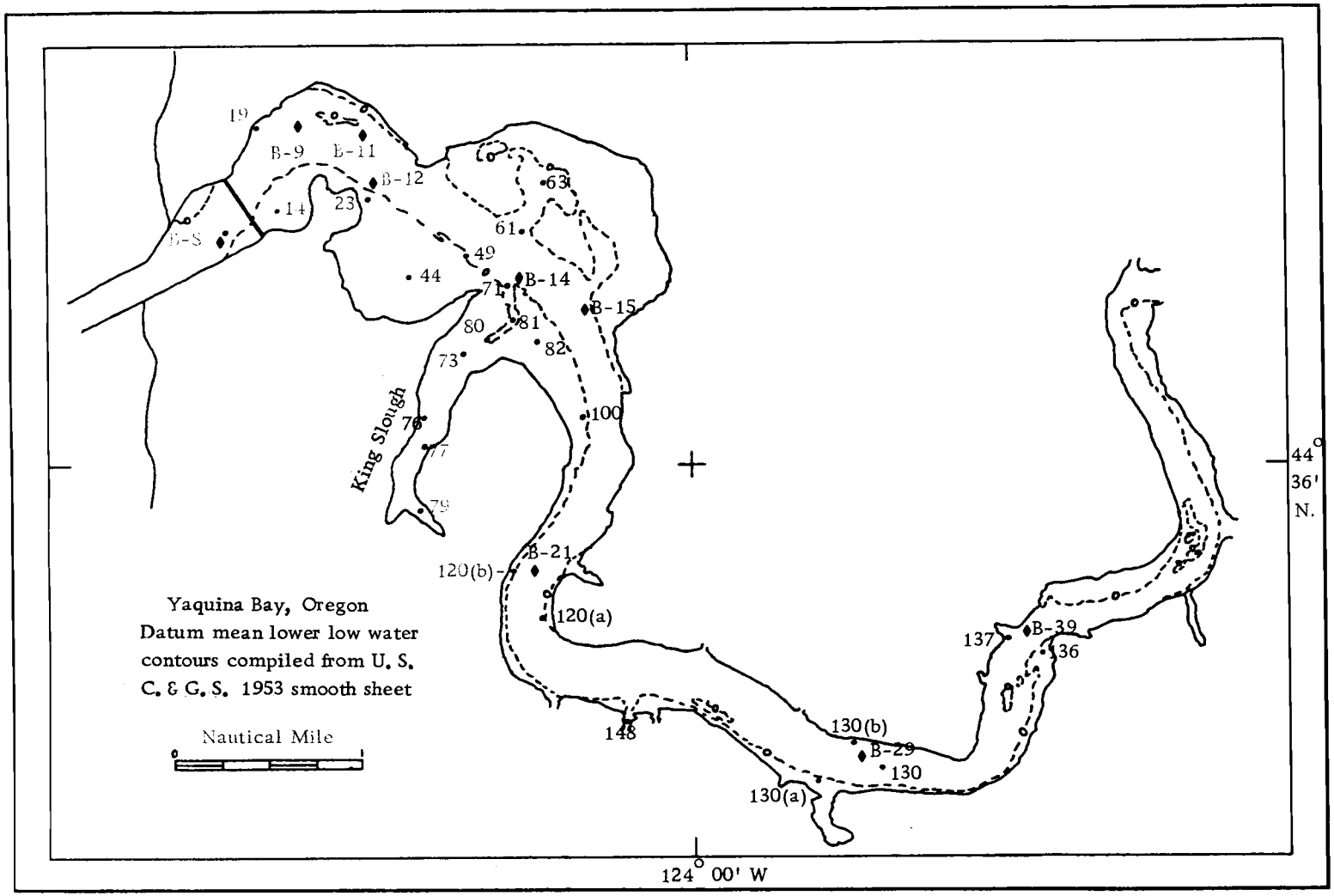


Figure 1. Chart of Yaquina Bay, Oregon with sampling sites indicated. Diamonds represent channel stations, and dots represent core stations.

of extremely heavy runoff in the winter, Yaquina Bay can become a Type A or two-layered system (figure 9) according to Pritchard's definition.

An unpublished manuscript by Dr. H. F. Frolander (1965a) discusses more completely the physical and chemical characteristics of Yaquina Bay.

Figure 1 depicts location of coring stations, biological channel stations and hydrographic stations utilized in this study. The diamond shape marks indicate the channel stations where physical data and skimmer samples were taken. The round marks are the coring stations. The high numbers, 136, 137, etc. which represent coring stations do not indicate that this many stations were sampled. Before sampling was begun a grid of stations was plotted on a chart of Yaquina Bay and these stations were numbered from one to over 150. Some of the stations used for sampling sites retained the high numerical designations.

METHODS AND MATERIALS

All biological samples for this problem were collected during three periods during 1965 which will be referred to as the winter, spring and fall sampling periods. The winter period had three sampling days, February 22, 25 and March 3. Spring samples were collected on June 15, 16, and 18, and the fall samples on October 22 and 27 and December 11 and 14.

The physical data, temperature and salinity, were collected at intervals of one to three weeks throughout the year as well as during biological sampling periods. Some physical data collected from King Slough during 1962 for a class project will also be presented. Graphs of temperature and salinity over a 28 hour period in the bay were gathered 9-10 August, 1963 (Frolander, 1964).

The majority of the samples used in this study were cores of sediment which were collected in two ways. In the shallow areas, samples were taken by hand using a piece of butyrate core lining with an inside diameter of 3.5 cm. In deeper water the cores were taken using a piston corer on a length of pipe which was described by Reish and Green (1958). The piston corer also utilizes the 3.5 cm. core lining. Following extraction, the top two centimeters of undisturbed sediment from the coring tube with its overlying

water were collected in 4 oz. bottles and preserved with 10% formalin-seawater.

Channel samples were obtained with a bottom skimmer which consists of a Clark-Bumpus type sampler located in a sled. This sampler was described by Frolander and Pratt (1962). Bottom skimmer tows varied in duration from four to 15 minutes depending on the bottom type and the degree of clogging. Harpacticoid species collected in this manner have been listed as percentages of the total population because this type of sampling is not quantitative.

In February a series of six Smith-McIntyre grabs were taken at the channel stations. These were then subsampled with core liners to obtain relatively quantitative channel samples, although there was some slight flushing. These cores were treated in the same way as the other cores.

In the spring sampling period eel grass samples were collected either by hand or as at station 63 from the bottom skimmer after a tow on station. Eel grass samples were also preserved in 10% formalin-seawater.

Water samples for determining salinities were collected using Nansen bottles at deeper stations and by direct sampling at the shallow stations. Salinities were determined in the marine laboratory at Newport using an inductive salinometer and are shown in all

graphs as parts per thousand (o/oo). Values used for graphing seasonal changes in salinity and temperature at six points along the bay were taken from water samples collected in the main channel opposite the indicated channel marker (B-8, B-11-12, B-15, B-21, B-29, B-39).

Temperatures were obtained with all water samples and were taken with reversing thermometers on Nansen bottles for bottom readings and by bucket thermometers at the surface.

In the laboratory copepods were separated from the sediment by washing and hand picking. The top two centimeters of sediment from each core were mixed in a 32 oz. jar with water which was allowed to settle for a few seconds. The supernatant fluid was poured through a 0.061 mm meshed screen and the residue placed in a petri dish from which the harpacticoids were picked with the aid of a dissecting microscope. The washings were continued until no harpacticoids were found. Although often time consuming, this method was found to be reliable.

Eel grass and skimmer samples were also washed, screened and hand picked. Because these samples were nonquantitative, the number of harpacticoids picked depended on their abundance in the samples.

After separation of all copepods from one core and storage in

a vial, they were placed in a clean petri dish and species counts were carried out using an 80x dissecting microscope and a compound microscope for the dissected appendages. Dissection of appendages was done in water soluble Turtox CMC mounting medium which was placed on the slide and allowed permanent slides to be made easily. The first and fifth pair of legs are the most necessary for species identification, and they must be observed with high magnification.

Identification was made using Lang's Monograph (1948) and Volume 5 of Sars' Crustacea of Norway (1911) as the basic references. Volume 8 of Sars (1918) was used to identify the four species of cyclopoid copepods encountered.

RESULTS AND DISCUSSION

Temperature and Salinity

The temperatures and salinities presented here for 1965 do not necessarily represent the specific ranges under which the organisms lived, because the values interstitially and at the sediment water interface can vary greatly from the overlying water (Reid, 1932) (Alexander, Southgate and Bassindale, 1932). Most of the salinity and temperature readings were taken at the bottom in the channel rather than at the shallower coring stations and should be considered in terms of relative differences spatially and seasonally rather than as specific ranges of temperature and salinity to which the animals were exposed. Differences between bottom values in the channel and those of the shallower lateral areas were less than six o/oo during a large part of the year (see discussion of figures 9 through 12 below). Only during winter periods of high runoff, when a two layered system of salinity was established (figure 9) were vertical salinity gradients pronounced.

Some samples were taken during February to indicate possible lateral differences in salinity and temperature. Variations were found to be less than 0.2 o/oo from one side of the bay to the other

at B-39, B-29, and B-9. Temperatures taken concurrently with salinities had lateral variations of from 0.1 to 0.4 degrees centigrade. Lateral gradients in salinity and temperature are not believed to appreciably affect the harpacticoids, which are normally submitted to large daily fluctuations, except where a slough or creek introduces enough fresh water to greatly decrease the salinity or alter the temperature.

Figures 2a and 2b (Frolander, 1964) show the ranges of salinity and temperature at six points on the bay during a 28 hour period in August 1963. The greatest difference in salinity values during any tidal cycle in the 28 hour study occurred at the upstream stations 29 and 39, and there was little variation in salinity at the lower stations, 15 and bridge. The temperature values show a different picture with relatively little difference in temperature between high and low tide at the upstream stations, B-45, B-39. However, B-21 shows very pronounced tidal differences in temperature as does B-15 to a lesser degree.

Figures 3, 4, 5, 6, 7, 8 depict seasonal ranges of temperature and salinity in six points on the bay during 1965; B-39, B-29, B-21, B-15, B-11, 12, and B-8. The year studied was characterized by heavy rainfall and high runoff during January followed by a long period with below normal rainfall until late in December. This

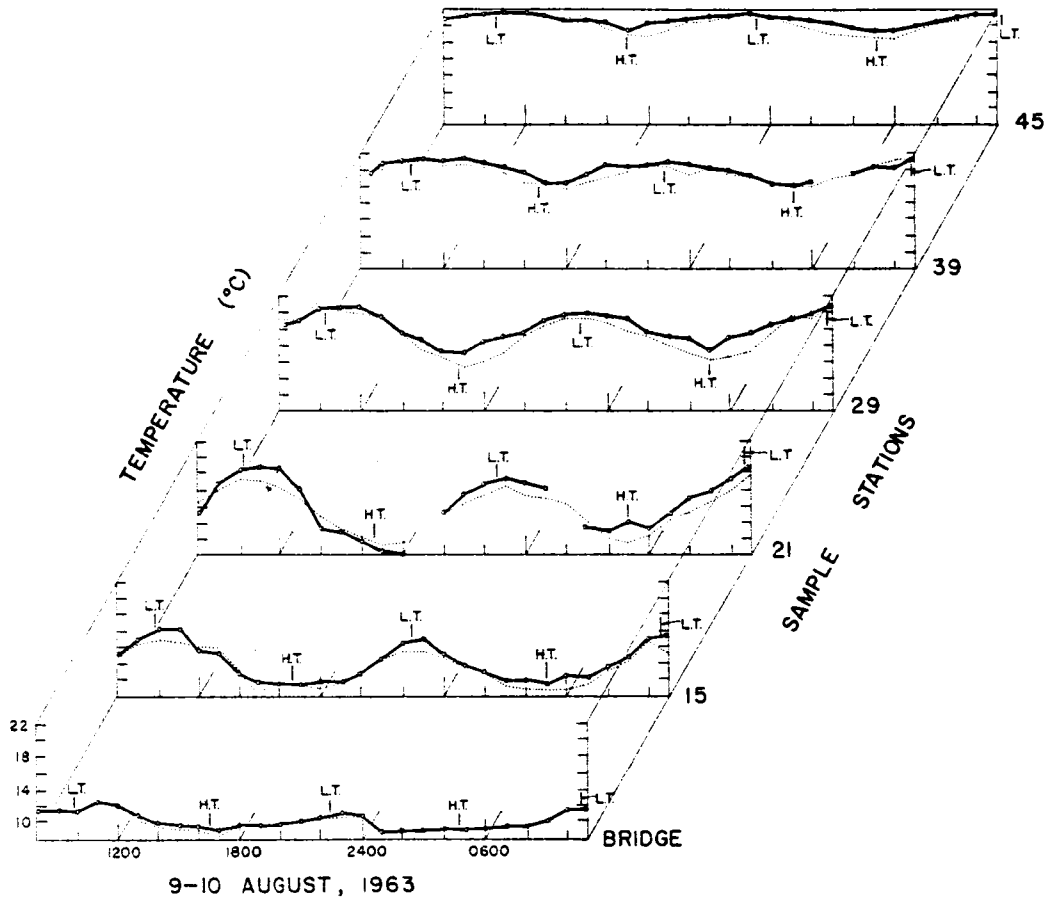


Figure 2a. Temperatures taken hourly for 28 hours at six stations in Yaquina Bay, on 9-10 August 1963. Solid lines indicate surface values; dotted lines, bottom values. High tide (H. T.) and low tide (L. T.) readings are from concurrent tide gauge observations. (from Frolander, 1964).

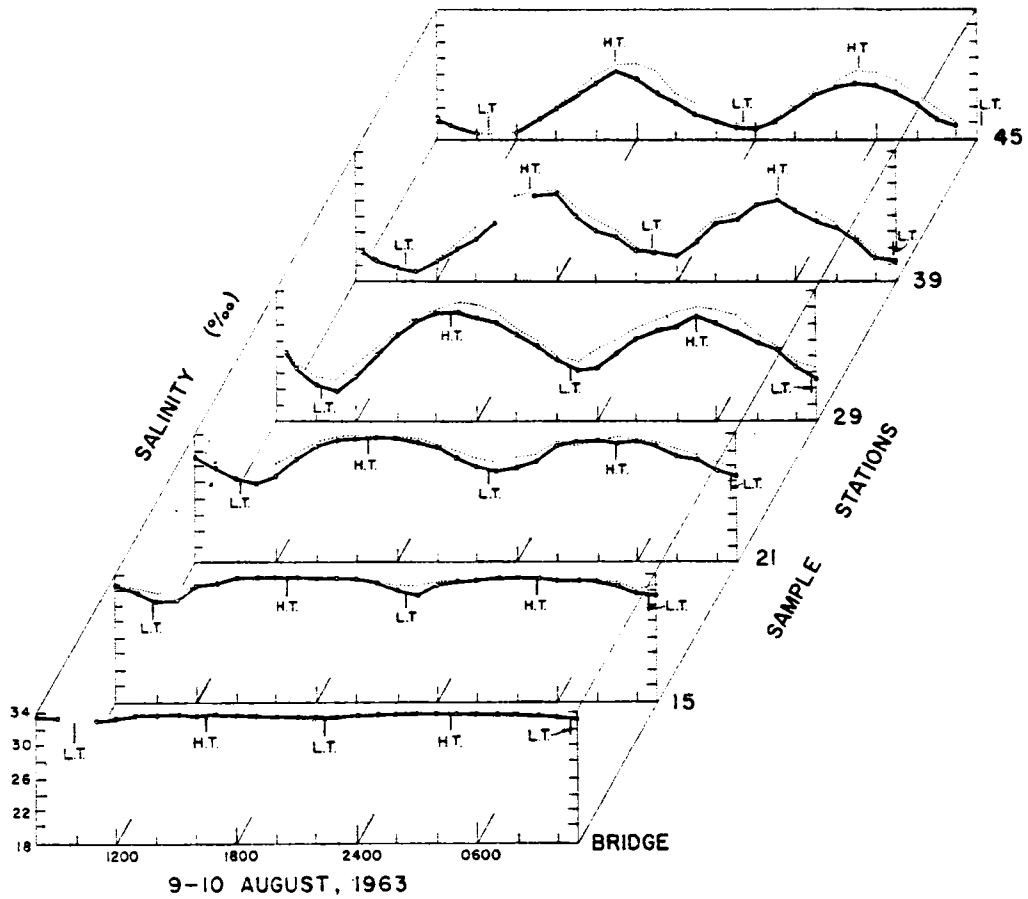


Figure 2b. Salinity values taken hourly for 28 hours at six stations in Yaquina Bay, on 9-10 August 1963. See explanation of Figure 29. (from Frolander, 1964).

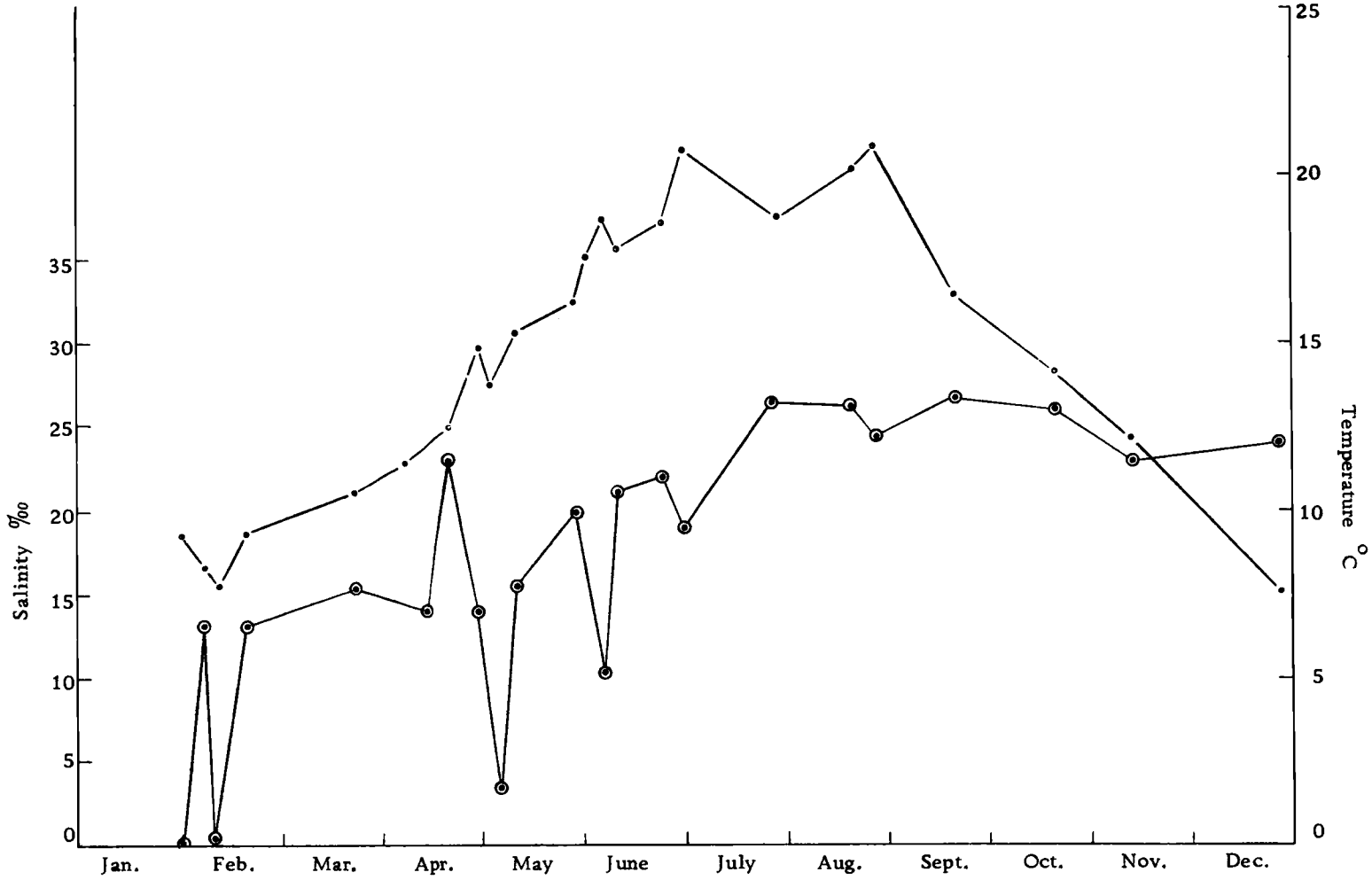


Figure 3. Bottom salinity and temperature values for 1965 at B-39. Circles represent salinity values, and dots represent temperature values.

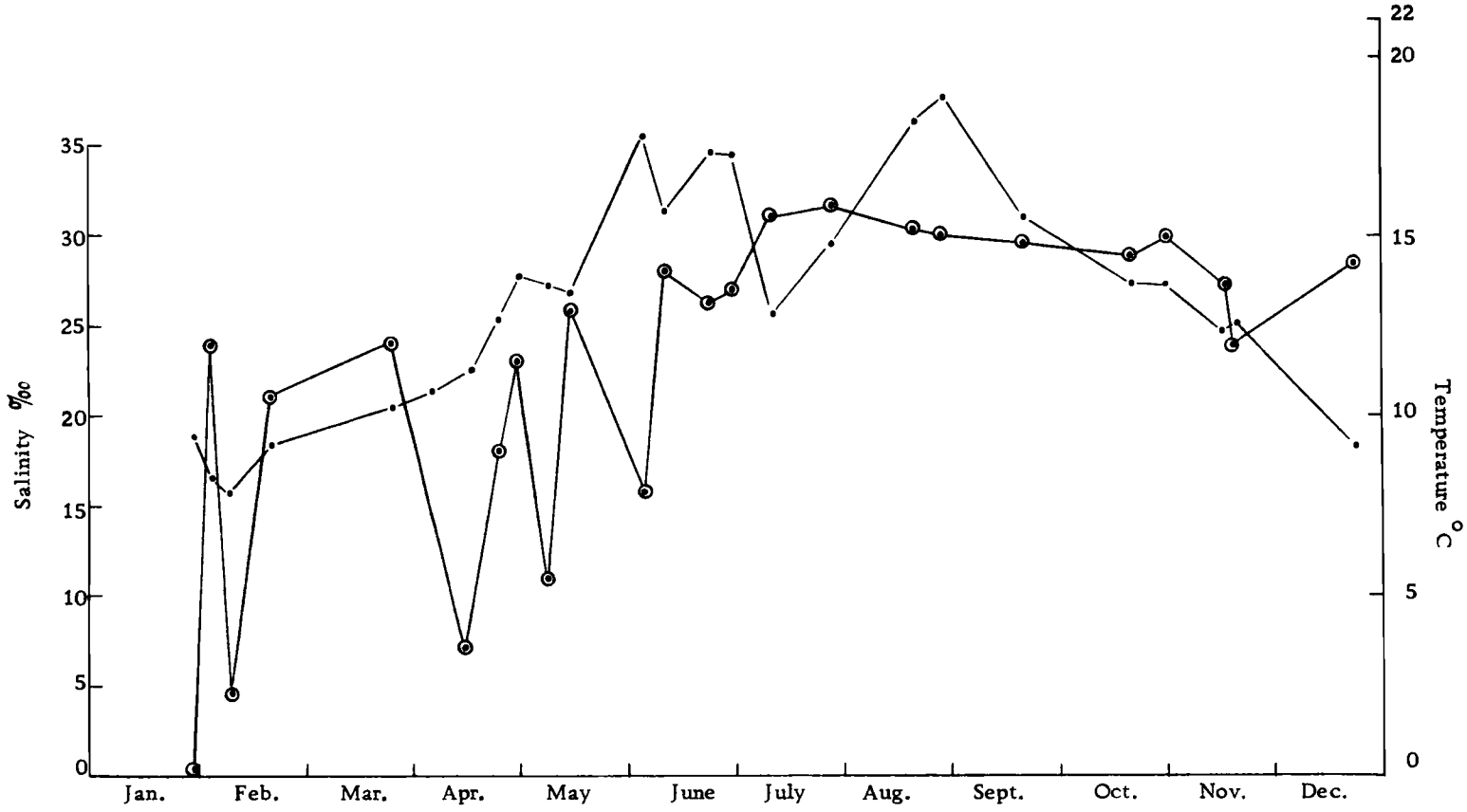


Figure 4. Bottom salinity and temperature values for 1965 at B-29. Circles represent salinity values, and dots represent temperature values.

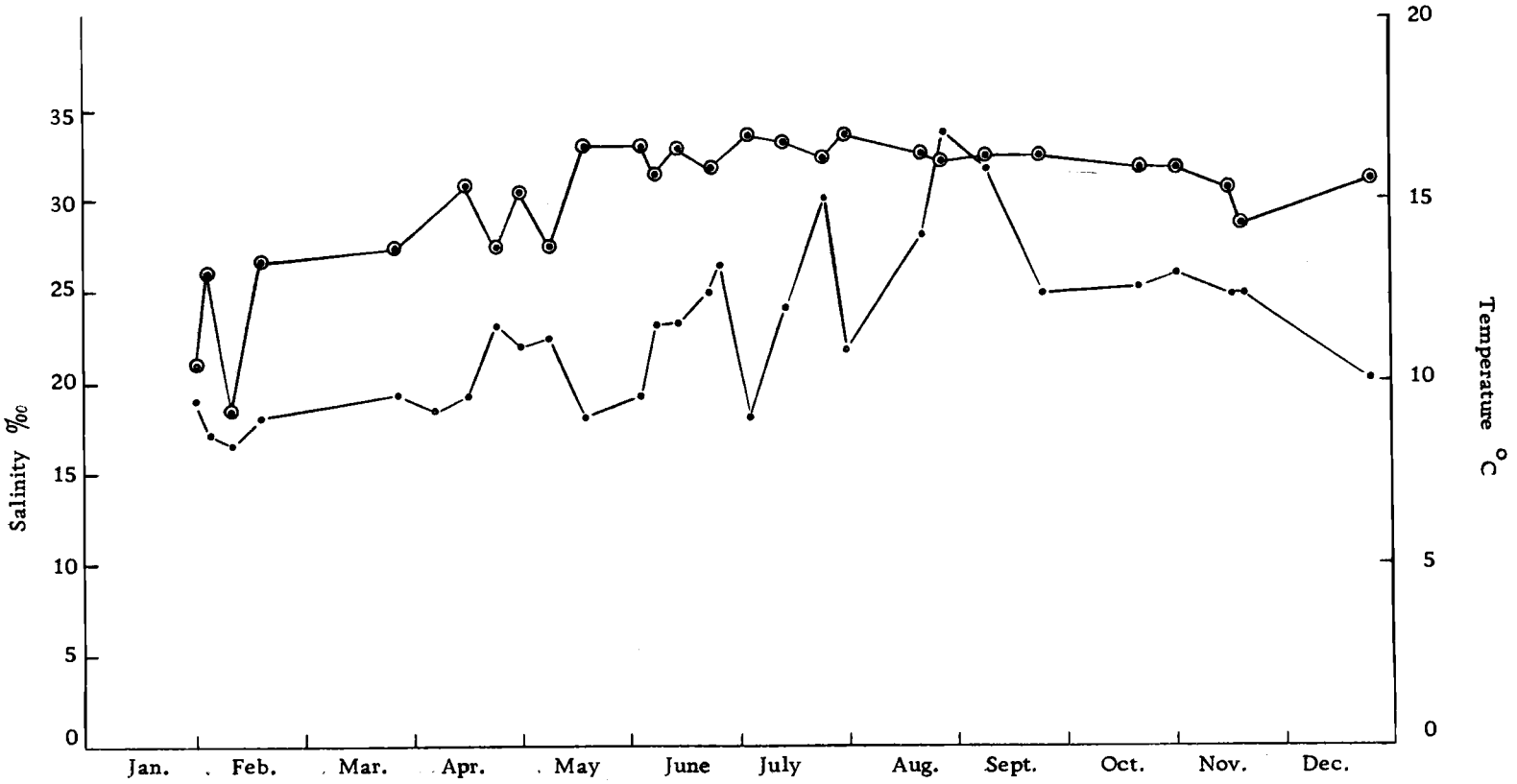


Figure 5. Bottom salinity and temperature values for 1965 at B-21. Circles represent salinity values, and dots represent temperature values.

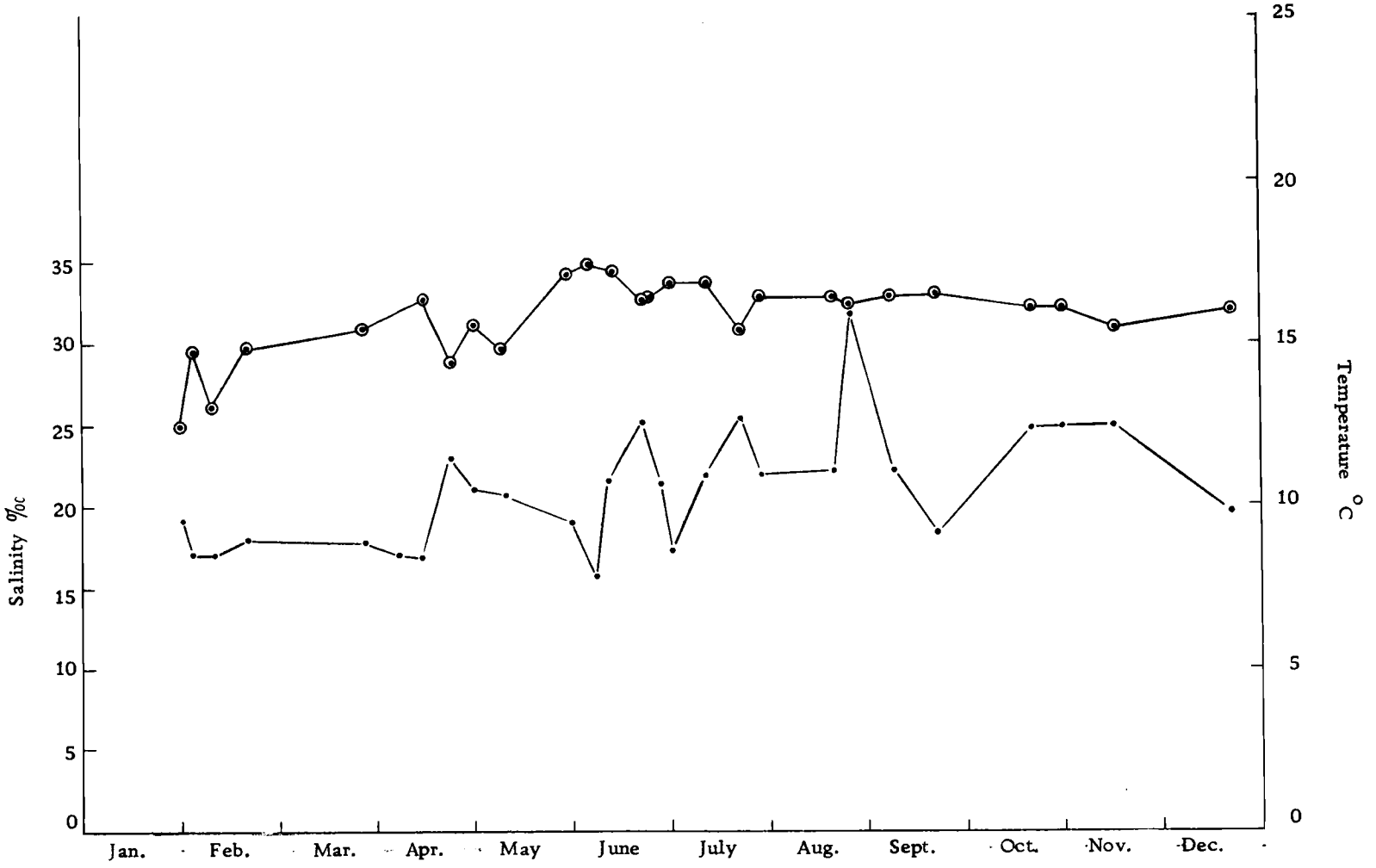


Figure 6. Bottom salinity and temperature values for 1965 at B-15. Circles represent salinity values, and dots represent temperature values.

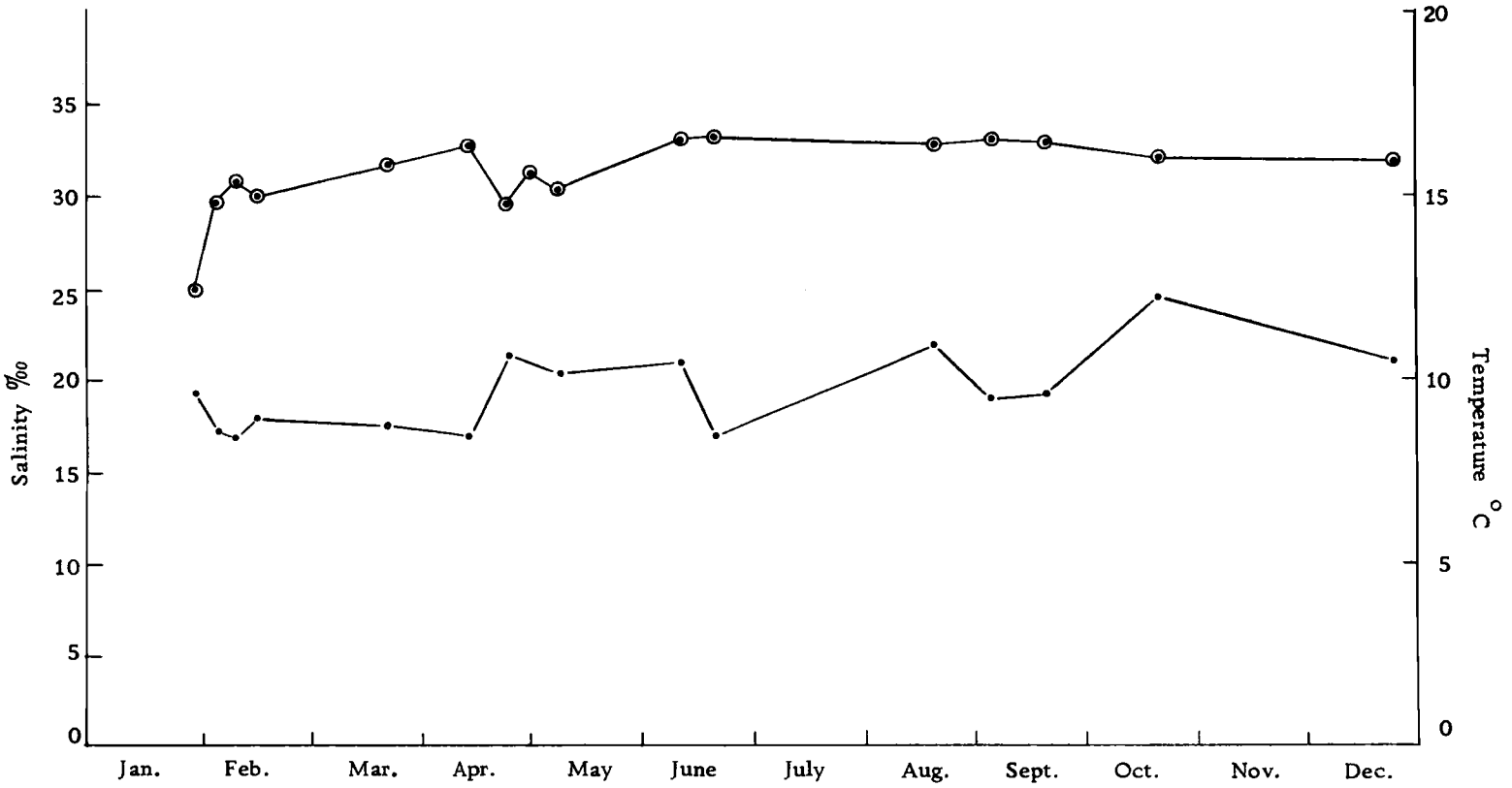


Figure 7. Bottom salinity and temperature values for 1965 at B-11, 12. Circles represent salinity values, and dots represent temperature values.

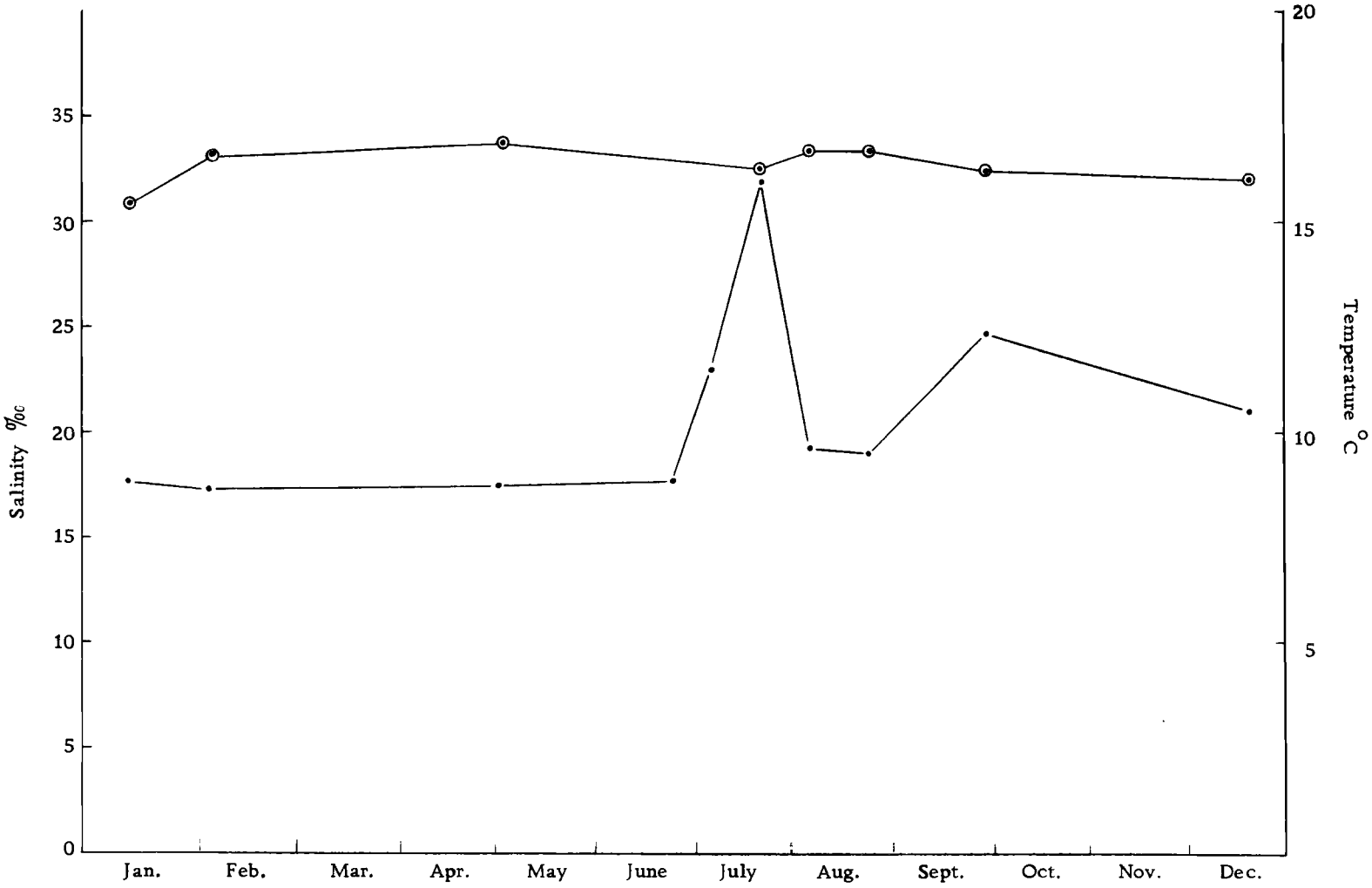


Figure 8. Bottom salinity and temperature values for 1965 at B-8. Circles represent salinity values, and dots represent temperature values.

rainfall pattern can be seen in the graphs (figures 3, 4, 5, 6, 7, 8) which show low salinities in January and February followed by gradually increasing values into July and August. Because of low runoff in the fall, there was actually little decrease in salinity in December which was higher at the upstream stations, B-29, B-39, than in the spring (figures 3 and 4). The salinity pattern for downstream stations, B-8 (figure 8) and B-11, 12 (figure 7), was much less varied with only one pronounced drop in salinity which occurred during flood conditions in January. B-15 (figure 6) and B-21 (figure 5) had typical patterns similar to the upstream stations with low salinities early in the year, high salinities from May until October, and dropping salinities in late October and November.

Seasonal temperature differences were also more pronounced at the upstream stations, B-29 (figure 4), B-39 (figure 3), which had lower temperatures from January through April and from the middle of October to the end of December. The remainder of the year showed higher values. Downstream stations (B-8 (figure 8), B-11, 12 (figure 7), had fairly uniform temperatures throughout the year with a much narrower range than upstream, and B-15 (figure 6), and B-21 (figure 5), had the same general salinity patterns as the upstream stations but also with less variation from summer to winter.

Figures 9, 10, 11, and 12 demonstrate the spatial differences and vertical gradients for salinity and temperature on four dates during 1965. The first survey on January 30th (figure 9) indicates some of the effects of the extremely high runoff which occurred during that month. A well defined two layered system existed at the lower three stations and the salinity was nearly zero at bottom and surface at the upper stations. Temperatures were almost uniform throughout the water column, and there was only 0.5°C drop in temperature from the downstream to the upstream station. By February 18th (figure 10) the upstream salinities had begun to rise and the salinity system had become mixed. The temperatures on February 18th varied little from those of January. June 24th (figure 11) was characterized by high salinities and lower temperatures downstream and low salinities and high temperatures upstream. On this date no surface values were taken; however, data from June 4th showed 1.0 o/oo vertical salinity gradient at B-21 and less than 0.1 o/oo difference from surface to bottom at B-29 and B-39. Temperature differences were also negligible. Figures 2a and 2b (Frolander, 1964) taken on August 9 and 10, 1963, also show small vertical salinity and temperature gradients present in the summer. On December 23rd (figure 12) the higher salinities and temperatures were downstream and the lower salinities and

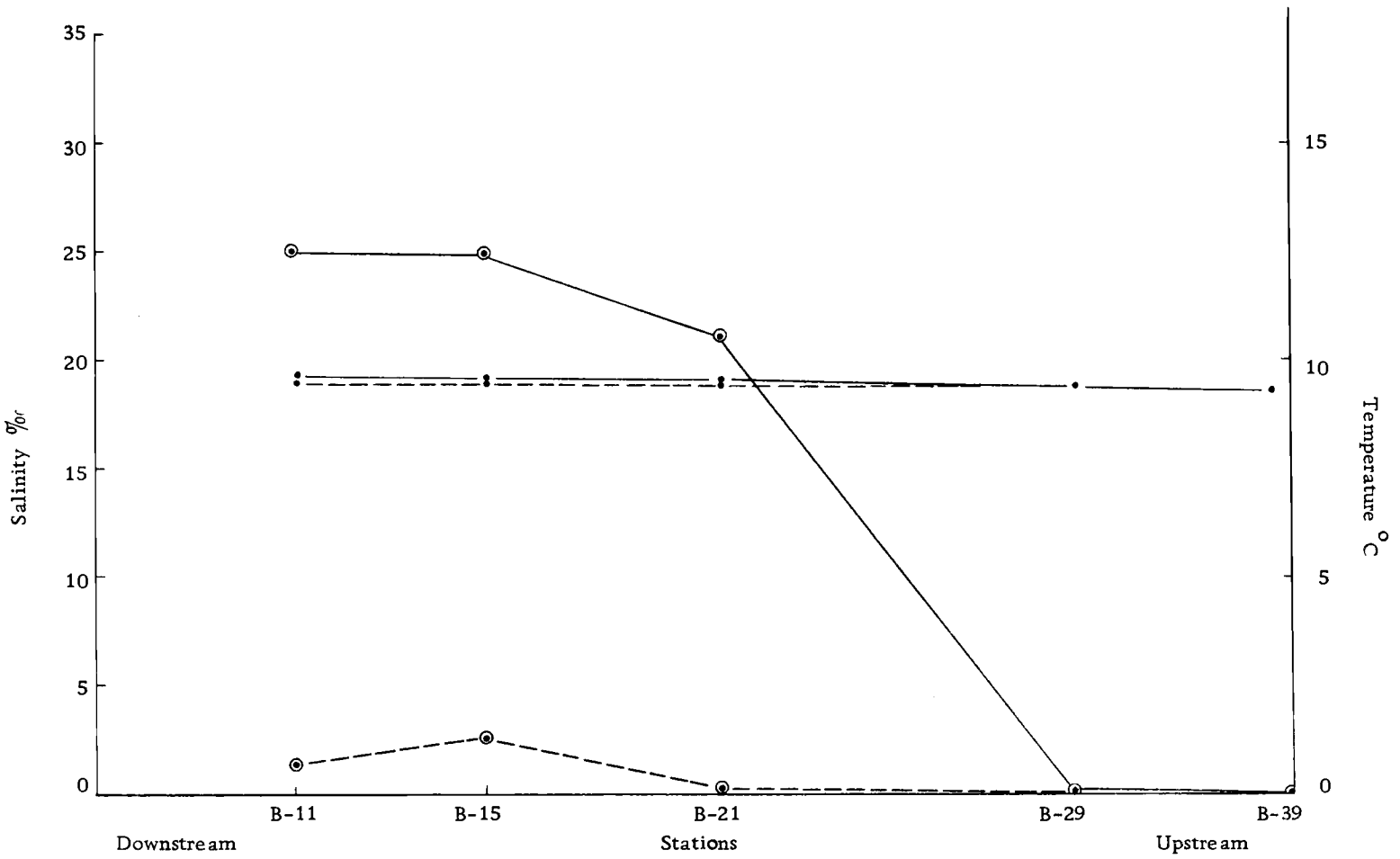


Figure 9. Spatial survey 30 January 1965. Circles represent salinities, and dots represent temperatures. Dotted lines indicate surface values, and solid lines indicate bottom values.

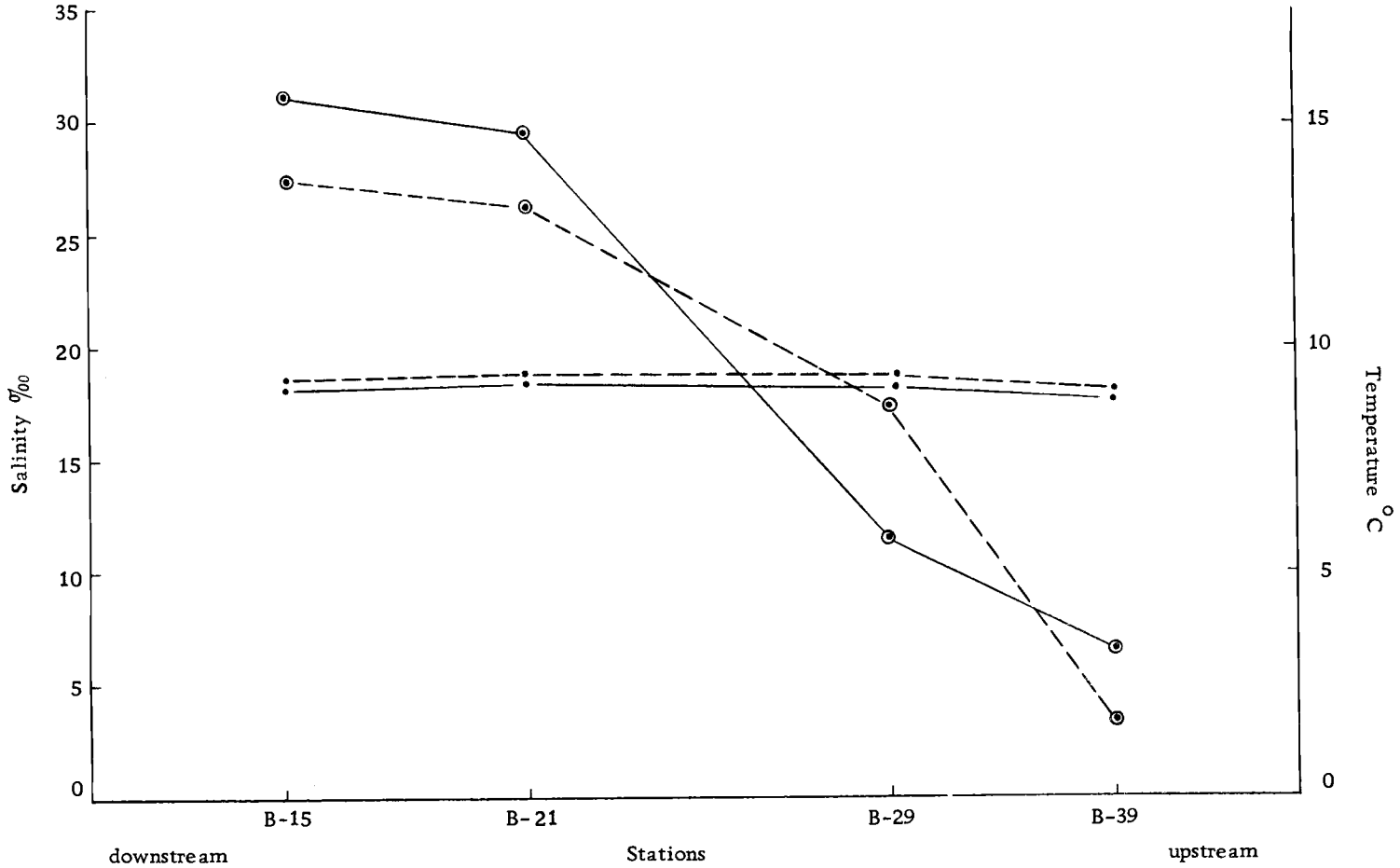


Figure 10. Spatial survey 18 February 1965. Circles represent salinities, and dots represent temperatures. Dotted lines indicate surface values and solid lines, bottom values.

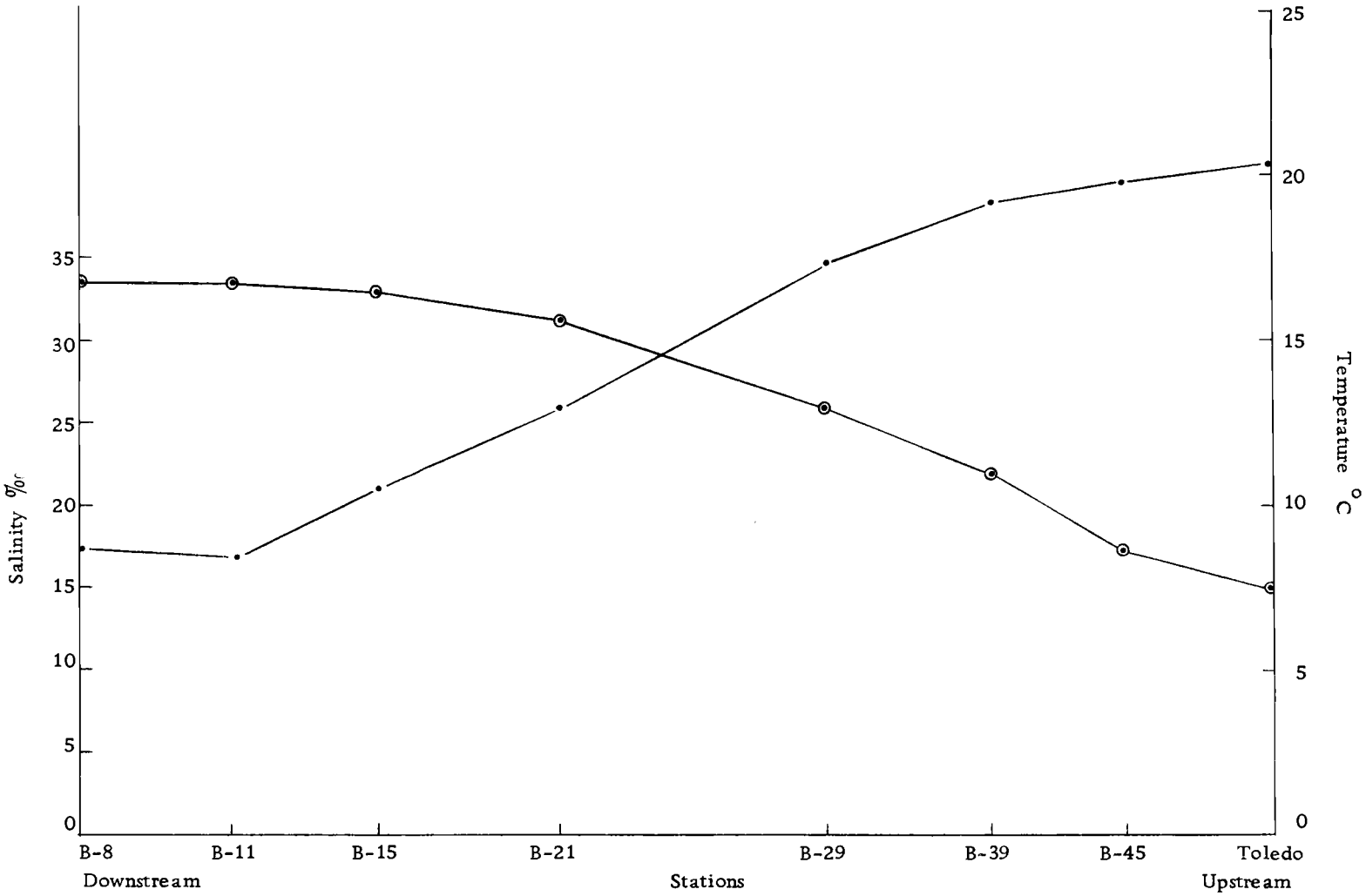


Figure 11. Spatial survey 24 June 1965. Circles represent salinities, and dots represent temperatures. Only bottom values are shown.

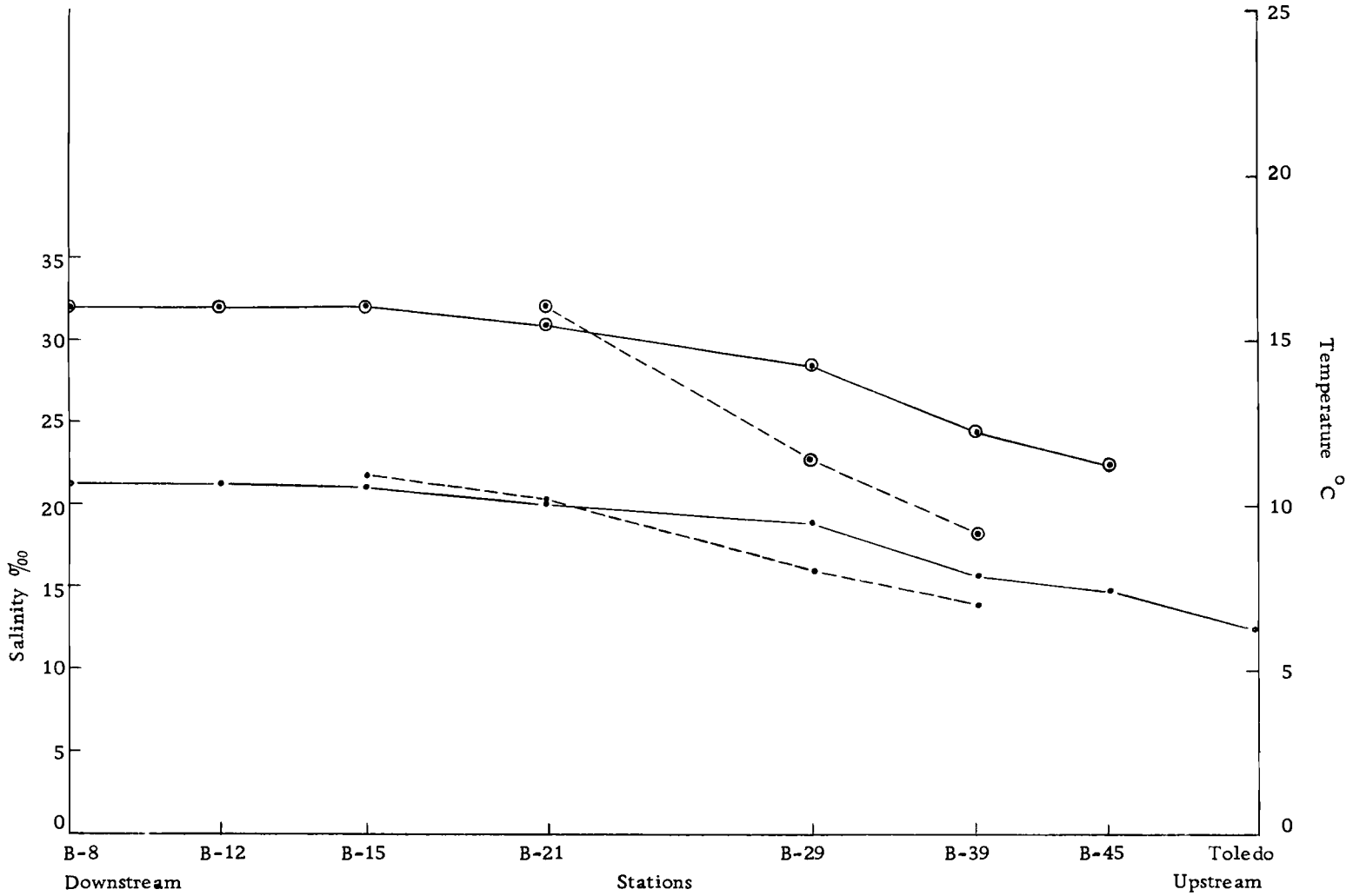


Figure 12. Spatial survey 23 December 1965. Circles represent salinities and dots represent temperatures. Dotted lines indicate surface values and solid lines, bottom values.

temperatures were upstream. The salinities upstream were similar to the June values, but they can't be compared directly because the June samples were at low tide and the December samples at high tide. However, in figures 3 through 8 the relatively high salinities throughout the fall are shown.

All samples were taken randomly with respect to tidal stage, and tidal effects tend to average out over a period of several sampling dates; however, when any individual value or date is considered, attention must be paid to the tidal stage at the time the samples are taken.

King Slough physical data are shown by figures 13, 14, and 15. The graph from February 1965 (figure 13) is complex because samples were taken on different dates and at different stages of the tide; however, the pattern of lower salinity and temperature upstream can be seen. The data from 1962 (figure 14) show the same pattern. These data relate to a station in the bay, B-14, and show tidal differences in salinity and temperature at the lower stations. No low tide values are available from upstream to King Slough because it is not navigable at low tide. Possibly, the salinity differences between high and low tide in the lower slough could be extrapolated to the upper reaches of the slough, which would give salinity values 3 to 4 o/oo lower than the high tide readings. In fact, considering

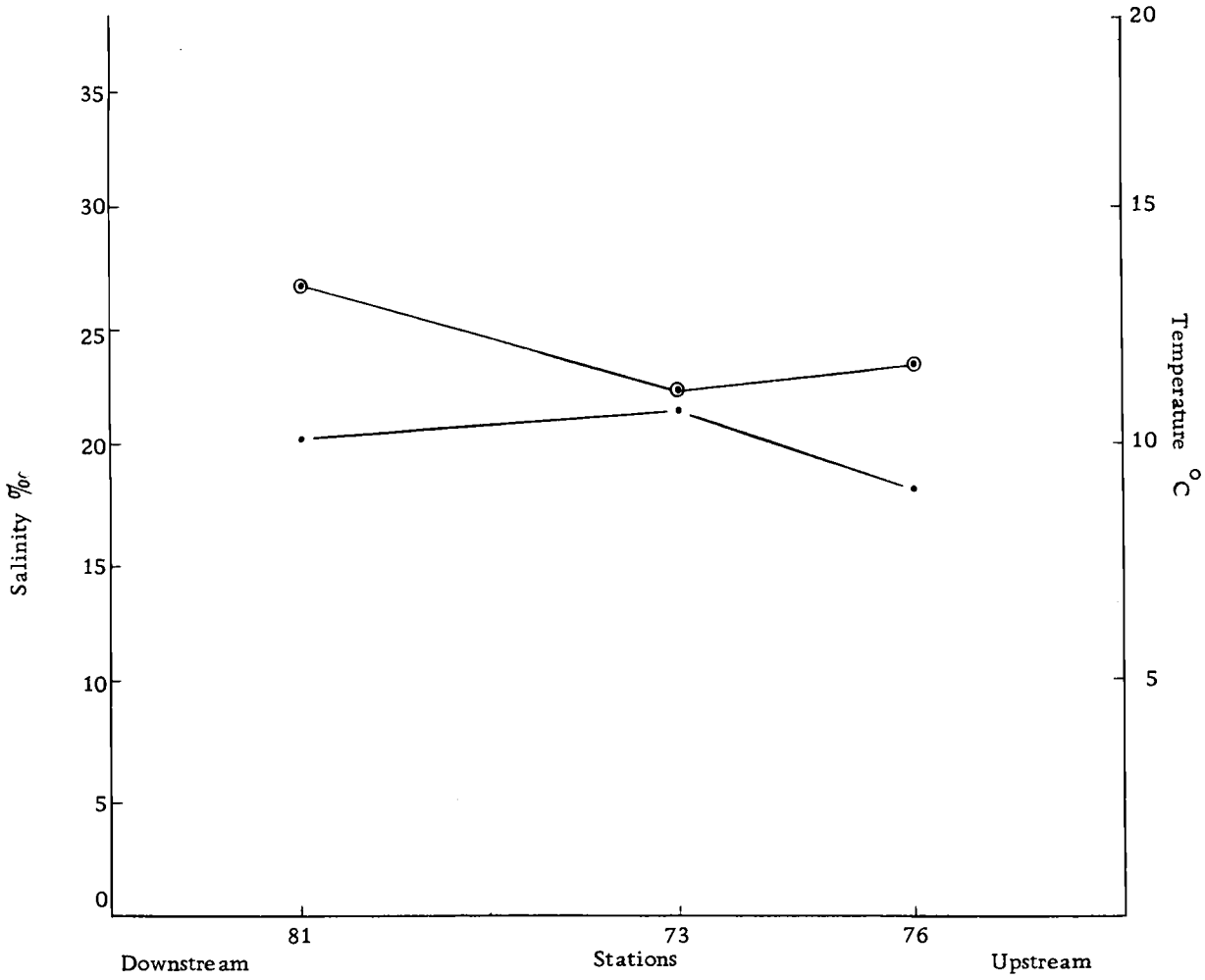


Figure 13. Bottom salinities and temperatures taken 25 February and 3 March 1965, in King Slough.

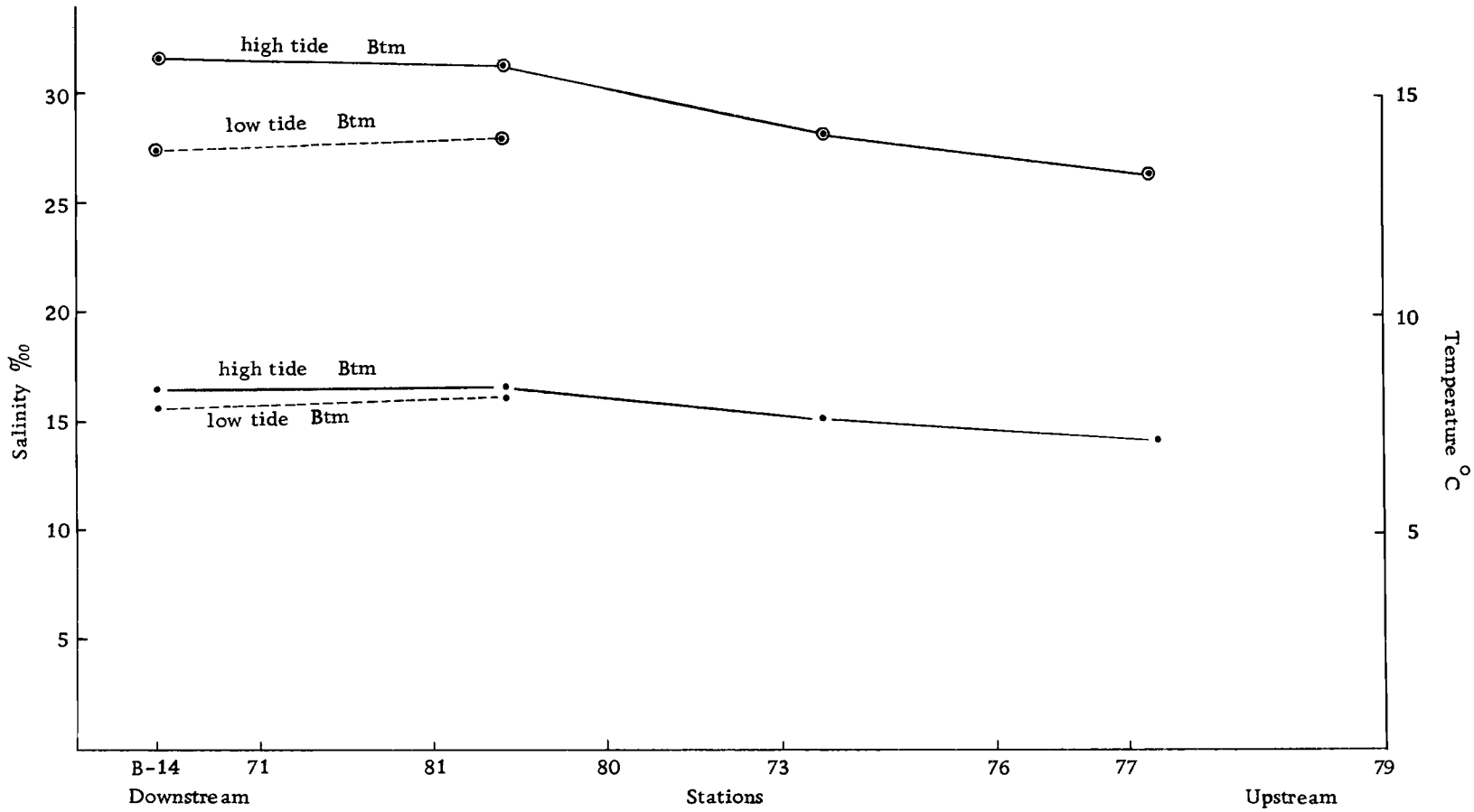


Figure 14. Bottom salinity and temperature values averaged for four spatial surveys taken in King Slough between 16 January and 6 February 1962. Circles represent salinities and dots represent temperatures. High tide values are solid lines, and low tide values are dotted.

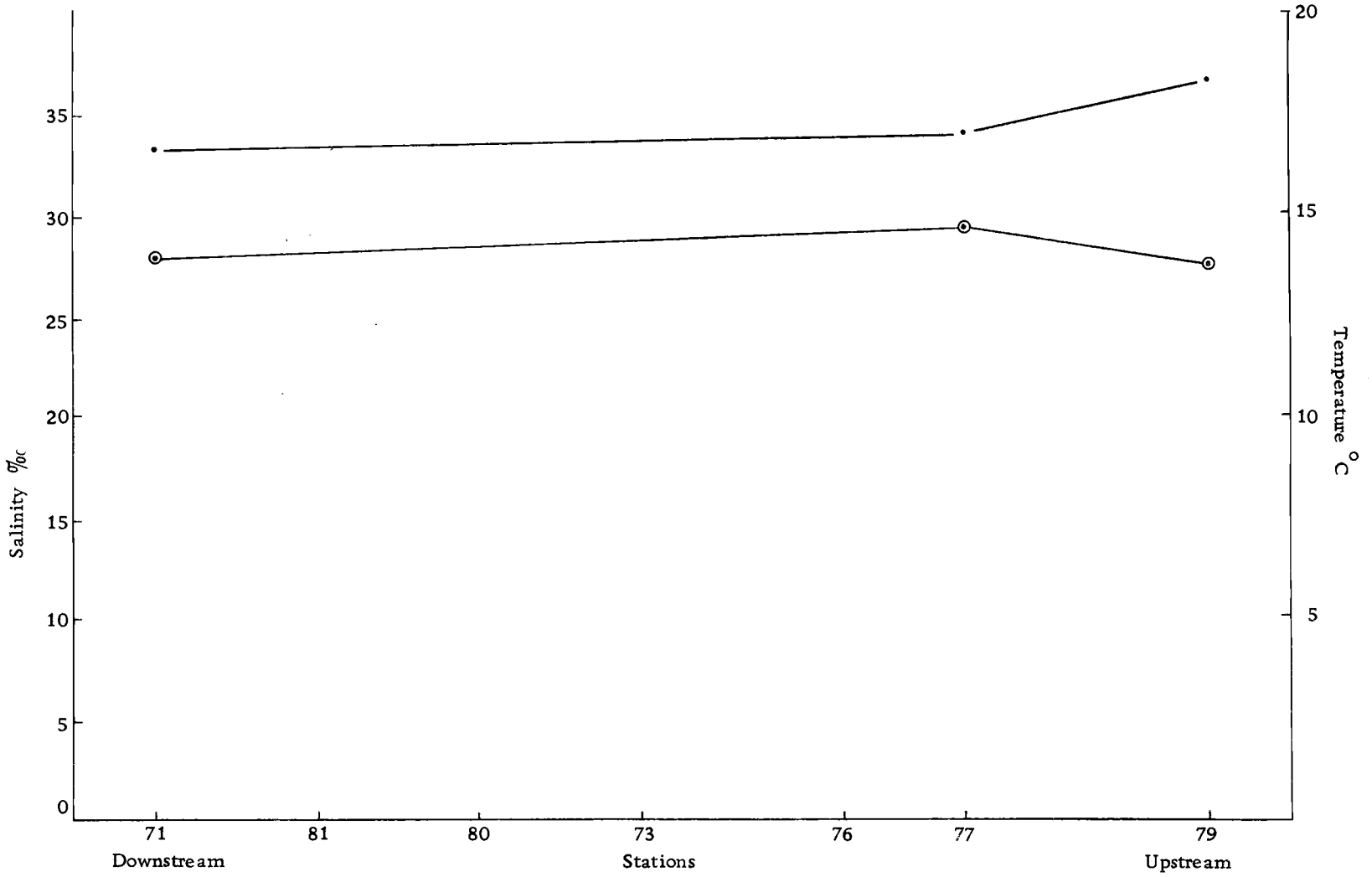


Figure 15. Spatial survey 18 June 1965 in King Slough. Circles represent salinities and dots represent temperatures. Only bottom values are shown.

that the deeper channel in the lower slough with the shallow sill probably retains the more dense, higher salinity water, the bottom values may be lower upstream at low tide than would be inferred by the downstream salinity differences with tides. A greater salinity variation with tidal change occurred upstream than downstream during the 28-hour survey (figure 2b) (Frolander, 1964).

Figure 15 indicates that the same general pattern in salinity and temperature occurs during the spring in the slough as in the bay. Upstream salinity is lower and temperature is higher. The horizonal gradients at least at high tide however, are not as great as in the slough.

Tabular Presentation of Samples and Species

All biological samples are presented in a tabular form in table 1 showing the distribution of samples seasonally and by method of collecting. Skimmer samples can be considered synonymous with channel samples since all bottom skimmer samples analyzed were taken in the main channel on a sandy substrate. The cores are more numerous and also are quantitative and therefore, are given more emphasis in analyses of the data.

Table 1

Samples utilized in the investigation listed by season and sample type

	Cores	Skimmer	Eel grass	
Winter '65	*14	5	0	
Spring '65	19	5	5	
Fall '65	14	5	0	
	53	15	5	73 Total

* Six of these cores were from channel Smith-McIntyre grab.

All species encountered in this study are listed in Table 2a by order and family. Where a species is undetermined, or in doubt, the species to which it is most closely related is given. Where there is more than one unidentified species in a genus, numbers have been assigned. It is emphasized that although many of these species may be new or their determination uncertain, all forms have been separated without confusion except possibly in the genus Ectinosoma. The species total of 61 undoubtedly does not include all species of benthic copepods in Yaquina Bay. The upper region of the estuary is unsampled and samples from salt marshes and the high intertidal zones have not been included in this study, although they probably contain additional species. There probably are also rarer species which inhabit the regions sampled but were not encountered. Several single specimens were found which were lost or destroyed during dissection and were possibly additional

Table 2a. Species listed by order and family.

HARPACTICOIDA

Longipediidae

Longipedia weberi A. Scott

Canuellidae

Canuella canadensis Willey

Ectinosomidae

Ectinosoma (*Halectinosoma*) *gothiceps* Giesbrecht

Ectinosoma (*Ectinosoma*) *melaniceps* Boeck

Ectinosoma (*Halectinosoma*) *neglectum* Sars

Pseudobradya sp. #1 similar to *P. similis* (T. & A. Scott)

Pseudobradya sp. #2 similar to *P. beduina* Monard

Pseudobradya sp. #3

Tachidiidae

Microarthridion littorale (Poppe)

Microarthridioninae This designation refers to one form (species) which could not be identified beyond subfamily and will be referred to by the subfamily name.

Danielssenia fusiformis (Brady and Robertson)

Harpacticidae

Harpacticus uniremis Krŏyer

Harpacticus sp. #1

Harpacticus sp. #3 similar to *H. flexus* Brady and Robertson

Zaus aurelii Poppe

Tisbidae

Tisbe furcata (Baird)

Scuttelidium hippolytes (Krŏyer)

Tegastidae

Tegastes sp.

Table 2a (continued)

Thalestridae

Diathrodes sp. very close to D. sarsi (A. Scott)

Parathalestris sp. #1 similar to P. jacksoni (T. Scott)

Parathalestris jacksoni (T. Scott)

Ryncothalestris sp. similar to R. helgolandica (Claus)

Dactylopodia tisboides (Claus)

Paradactylopodia latipes (Boeck)

Paradactylopodia sp. #1

Paradactylopodia sp. #2 very similar to P. brevicornis (Claus)

Diosaccidae

Stenhelia (Stenhelia) sp. #1 similar to S. (St.) aemula (T. Scott)

Stenhelia (Stenhelia) sp. #2

Stenhelia (Delavia) normani T. Scott

Amphiascus parvus Sars

Amphiascopsis cinctus (Claus) This may be a new variety

Metamphiascopsis monardi (Lang)

Paramphiascopsis sp. similar to P. pallidus (Sars)

Bulbamphiascus imus (Brady)

Typhlamphiascus confusus (Sars)

Amphiascella debilis (Giesbrecht)

Schizopera sp. very close to S. tobae Chappius

Ameridae

Ameria sp. similar to A. minuta Boeck

Proameria simplex (Norman and T. Scott)

Nitocra sp. similar to N. affinis Gurney

Ameriopsis sp. similar to A. nobilis Sars

Canthocamptidae

Mesochra pygmaea (Claus)

Cyllindropsyllidae

Cyllindropsyllidae sp.

Paraleptastacus sp.

Table 2a (continued)

Cletodidae

Enhydrosoma buchholtzi (Boeck)

Enhydrosoma propinquum (Brady)

Enhydrosoma sp.

Nannopus palustris Brady

Huntemannia jadensis Poppe

Limnocletodes behingi Borutzky

Metidae

Metis ignea Philippi

Laophontidae

Heterolaophonte sp. #1 similar to H. strömi (Baird)

Heterolaophonte sp. #2

Heterolaophonte sp. #3

Paralaophonte sp. similar to P. brevirostris (Claus)

Paranychocamptus sp. similar to P. capillatus (Wilson)

CYCLOPOIDA

Cyclopidae

Euryte sp. #1

Euryte sp. #2

Halicyclops sp.

Ascomyzontidae

Ascomyzon latum (Brady)

Unknown Copepod

species. Wells (1963) in a study in the River Exe in Great Britain found 96 species of benthic copepods of which 22 were unrecorded for the region. This is the only investigation which compares to the present study in total number of species from one area.

Table 2b lists all species by number of occurrences in the cores and also indicates: number of occurrences in eel grass and skimmer samples; total numbers counted in cores; individual and cumulative percentages in cores; total percentages encountered in eel grass and skimmer samples; and the seasons in which they occurred in each sample type. From this table it can be seen that in all three types of samples there were many species which had few occurrences and low total numbers. Most species which had a large number of occurrences in the cores also were the important forms according to their numbers. The species with low incidences of occurrence and low total counts will often be omitted from graphs and discussion although they are included in graphs depicting total numbers per core and species per core.

Table 3 is a compilation of species' numbers according to sample type (biotope). The dominance of the core (flats) species is shown both by total species (46) and by endemic species (21). The 13 species found in all three sample types does not indicate that, although present in all three type samples, some of the 13

Table 2b. All species encountered in this study are listed in order of number of occurrences in the cores. Also indicated are number of individuals and individual percentages and cumulative percentages in cores, number of occurrences and total percentages for each species in eel grass and skimmer samples, and the seasons in which the species occurred, winter (W), spring (S), and fall (F).

		CORES					EEL GRASS		SKIMMER		
	Species	No. Occurrences	Total No. Individuals	Individual %	Cumulative %	Season	No. Occurences	Total %	No. Occurrences	Total %	Season
1	Ectinosoma gothiceps	33	897	15.4	15.4	W,S,F	1	1.6	2	8.2	S
2	Amphiascella debilis	24	649	11.1	26.5	W,S,F	4	19.5	2	70.0	W,S
3	Microarthridion littorale	22	1576	27.1	53.6	W,S,F	2	3.2	5	194.7	W,S,F
4	Paramphiascopsis sp.	20	449	7.7	61.3	W,S,F	3	24.3	3	35.2	S
5	Microarthridioninae	18	222	3.8	65.1	W,S,F			2	19.3	S
6	Schizopera sp.	13	220	3.7	68.8	W,S,F	2	7.9	1	50.0	W
7	Huntemannia jadensis	13	61	1.0	69.8	W,S,F	1	1.5	5	45.3	W,S,F
8	Danielssenia fusiformis	12	120	2.0	71.8	S,F	1	1.6	1	0.9	F
9	Limnocletodes behingi	11	154	2.6	74.4	W,S,F					
10	Canuella canadensis	11	139	2.3	76.7	W,S,F	1	3.2	3	58.3	W,S
11	Heterolaophonte sp. #1	11	59	1.0	77.7	S,F	3	26.3	1	5.0	S
12	Ectinosoma neglectum	11	28	0.4	78.1	S,F			1	2.7	S
13	Mesochra pygmaea	11	84	1.4	79.5	W,S,F	4	46.8			
14	Paralaophonte sp.	10	40	.6	80.1	S,F	2	6.4			
15	Enhydrosoma propinquum	9	69	1.1	81.2	S,F			1	25.0	S
16	Harpacticus sp. #3	8	267	4.6	85.8	S,F					
17	Stenhelia (St.) sp. #1	8	56	0.9	86.7	W,F					
18	Diathrodes sp.	8	10	0.1	86.8	S,F	3	17.7	2	16.6	W,F
19	Nannopus palustris	7	175	3.0	89.8	W,S,F			1	6.2	S
20	Nitrocra sp.	7	46	0.7	90.5	W,S,F					
21	Typhlamphiascus confusus	7	28	0.4	90.9	W,S,F			2	16.2	S
22	Amphiascus parvus	7	27	0.4	91.3	W,S,F	3	77.0	1	3.7	F
23	Bulbamphiascus imus	6	16	0.2	91.5	W,S,F					
24	Proameria simplex	5	82	1.4	92.9	S,F					
25	Ectinosoma melaniceps	5	18	0.3	93.2	S,F					

Table 2b (continued)

	Species	CORES No. Occurrences	Total No. Individuals	Individual %	Cumulative %	Season	EEL GRASS No. Occurrences	Total %	SKIMMER Occurrences	Total %	Season
26	Pseudobradya sp. #1	4	168	2.8	96.0	W,S					
27	Stenhelia(Del.) normanni	4	34	0.5	96.5	W,F					
28	Harpacticus uniremis	4	12	0.2	96.7	S	3	68.4			
29	Enhydrosoma sp.	4	6	0.1	96.8	S,F					
30	Heterolaophonte sp. #2	3	4	0.0	96.8	W,S	1	1.5	1	7.6	F
31	Metamphiascopsis monardi	2	7	0.1	96.9	F			3	36.2	F
32	Tisbe furcata	2	4	0.0		S,F	1	6.4	10	314.6	W,S,F
33	Paradactylopodia latipes	2	4	0.0		F					
34	Longipedia weberi	2	3	0.0		S,F			2	12.7	F
35	Pseudobradya sp. #2	2	2	0.0		F					
36	Enhydrosoma buchholzti	2	2	0.0		F					
37	Metis ignea	2	2	0.0	97.2	W,F					
38	Ameriopsis sp.	1	14	0.2	97.4	W					
39	Tegastes sp.	1	3	0.0		S	2	8.0			
40	*Euryte sp. #1	1	42	0.7	98.1	W			2	18.1	F
41	Amphiascopsis cinctus	1	1	0.0		F					
42	Ameria sp.	1	1	0.0		F					
43	Pseudobradya sp. #3	1	1	0.0		W					
44	Paranychocamptus sp.	1	1	0.0		F					
45	Cyllindropsyllidae	1	1	0.0		F					
46	Stenhelia (St.) sp. #2	1	1	0.0		W					
47	Parathalestris sp. #1						1	1.6	2	50.4	F
48	Parathalestris jacksoni						1	3.2			
49	Paradactylopodia sp. #1						1	1.6			
50	Paradactylopodia sp. #2						1	15.8			

Table 2b (continued)

	CORES					EEL GRASS		SKIMMER		
Species	No. Occurrences	Total No. Individuals	Individual %	Cumulative %	Season	No. Occurrences	Total %	No. Occurrences	Total %	Season
51 Heterolaophonte sp. #3						1	3.1			
52 *Ascomyzon latum								1	41.5	F
53 *Euryte sp. #2								1	1.8	F
54 Ryncothalestris sp.								2	25.9	S,F
55 Zaus aurelii								2	28.2	W,F
56 Unknown								2	25.9	S,F
57 Dactylopodia tisboides								1	7.6	F
58 Scuttelidium hippolytes								1	7.6	F
59 Harpacticus sp. #1								1	5.0	S
60 Paraleptastacus sp.								1	22.2	S
61 *Halicyclops sp.								1	11.1	F
Total		5804								

*Indicates cyclopoid copepod

species were in a much greater concentration in one type sample than in the others. The number of endemic forms in core and

Table 3

Species numbers according to biotope. Total numbers, items 1, 2 and 3; the same species separated into endemic and cosmopolitan forms, items 4 through 10

1.	Total no. of species in cores (flats)	46
2.	Total no. of species in skimmers (channel)	32
3.	Total no. of species on eel grass	22
4.	Species endemic to cores	21
5.	Species endemic to skimmers	10
6.	Species endemic to eel grass	4
7.	Species endemic to cores and skimmers	8
8.	Species endemic to skimmers and eel grass	1
9.	Species endemic to cores and eel grass	4
10.	Species in all three sample types	13

skimmer samples (eight) is higher than that of species found either in skimmer and eel grass samples (one) or in core and eel grass samples (four). This may indicate that the populations on the sediment (cores and skimmers) are more closely related to each other than the eel grass population is to either of the sediment populations. The eel grass had more species in common with the cores (four) than it did with the channel (one). This seems reasonable when it is recalled that the cores were taken on the flats close to where the eel grass was growing. Any discussion of relative numbers of species in different type samples should include

again mention of the total number of samples taken in each category (Table 1). More species were found in core samples, at least in part, because there were more core samples.

Reliability of Sampling Method

In order to ascertain the reliability or reproducibility of the core data, a series of six cores was taken in a line one meter apart near station 29 in a sandy sediment. The results are shown in tabular form in table 4. Four species occurred in all six samples and represented at least 88.6% of the count in each core. A fifth species occurred in four out of the six samples and brought the lowest cumulative percent in any core to 89.8%. Figure 16 shows the average percentages of the total number of species (in six cores) found in one core and the multiples thereof as indicated on the abscissa. In plotting the species percentages, the average percentages found in 1, 2, 3, 4, 5, and 6 cores were determined by taking all possible combinations of the respective number of cores. The graph shows that, if it is assumed that the number of species encountered in six cores is the maximum occurring at that point, 65% of the species will be found in one core, 81% in two cores, 90% in three cores, etc.

Table 4. Data from six replicate core samples. Indicated are species, the six samples (Sm-1 through Sm-6), the number of specimens of each species in each sample, the percentage of the total count of each sample represented by each species and the cumulative percentages of the species in each sample.

Species	SM-1			SM-2			SM-3			SM-4			SM-5			SM-6		
	No.	%	Cum. %	No.	%	Cum. %	No.	%	Cum. %	No.	%	Cum. %	No.	%	Cum. %	No.	%	Cum. %
Huntemannia jadensis	23	17.4	17.4	47	37.9	37.9	68	47.8	47.8	23	38.2	38.2	34	44.7	44.7	38	55.8	55.8
Ectinosoma gothiceps	74	56.1	73.5	9	7.2	45.1	56	39.5	87.3	25	41.6	79.8	22	28.9	73.6	22	32.3	88.1
Mesochra pygmaea	7	5.3	78.8	63	50.8	95.9	9	6.3	93.6	3	5.0	84.8	4	5.2	78.8	3	4.4	92.5
Microarthridioninae	13	9.8	88.6	2	1.6	97.5	3	2.1	95.7	3	5.0	89.8	8	10.5	89.3	1	1.4	93.9
Harpacticus sp. #3	3	2.2	90.8	1	.8	98.3							1	1.3	90.6	1	1.4	95.3
Diathrodes sp.	1	.7	91.5				1	.7	96.4	1	1.6	91.4						
Paralaophonte sp.	3	2.2	93.7							1	1.6	93.0	1	1.3	91.9			
Amphiascella debilis										2	3.2	96.2	1	1.3	93.2			
Cyllindropsyllidae sp.				2	1.6	99.9	2	1.4	97.8									
Paradactylopodia sp. #2	1	.7	94.4															
Unidentified copepodites	7	5.3	99.7				3	2.1	99.9	2	3.2	99.4	5	6.5	99.7	3	4.4	99.7
Totals	132		99.7	124		99.9	142		99.9	60		99.4	76		99.7	68		99.7

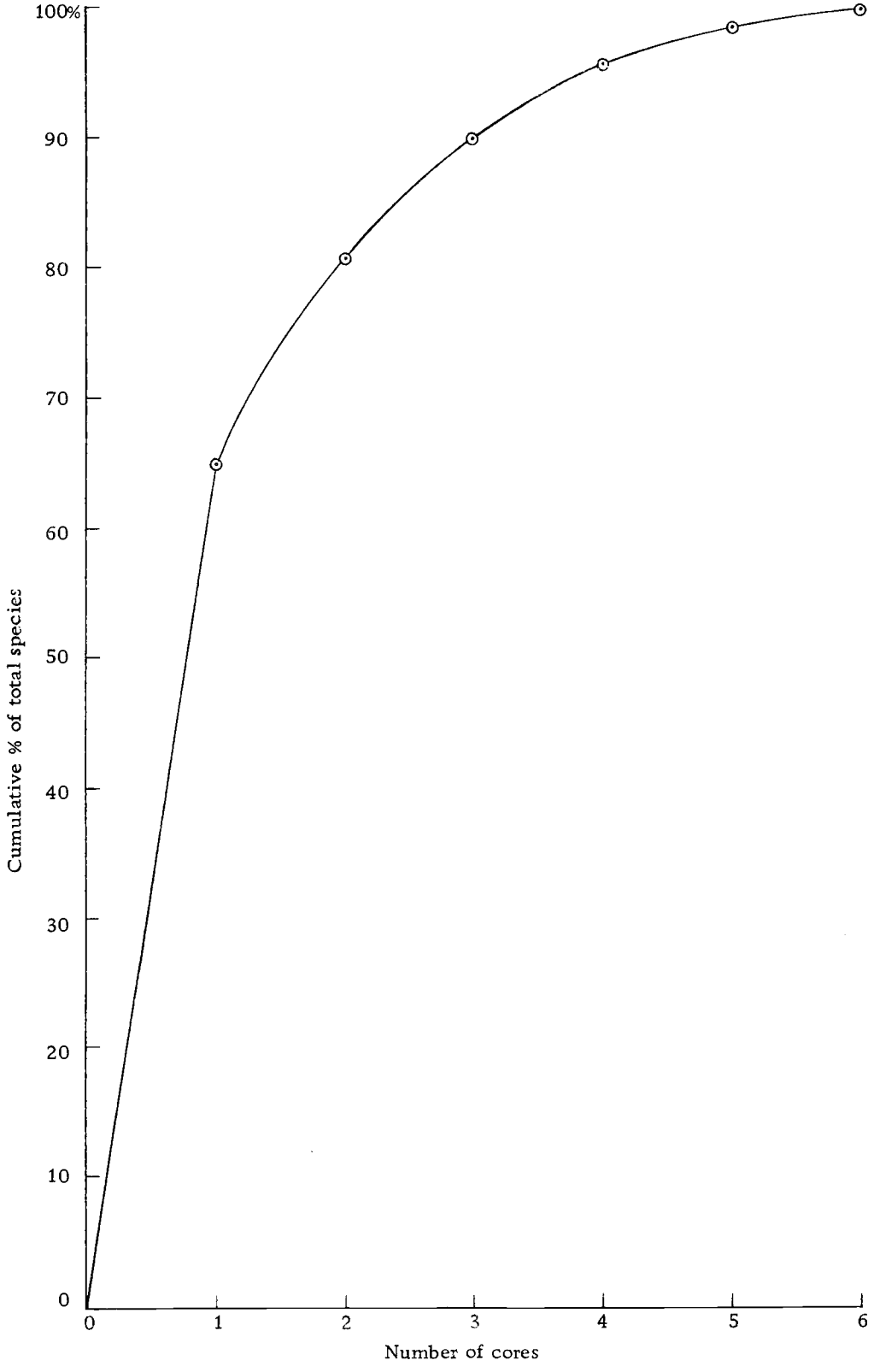


Figure 16. Cumulative percentages per core of the total number of species taken in six replicate cores.

Total numbers of harpacticoids in each of the six cores are graphed in figure 17. The first three cores show a relatively constant value as do the last three, but there is a significant difference in numbers between the first three and the last three which suggests that two different environments were sampled, each three times. This indicates that population numbers fluctuate widely over short horizontal distances which may be more pronounced on mud flats; on tidal flats, sediment changes from fine grained mud to coarser sediment in dendritic drainage channels.

Some unknown factor affec ted the totals· however, the samples were taken in what appeared to be a uniformly sandy sediment, the salinity and temperature difference should have been negligible and the line of samples was taken parallel to the water's edge so that there should have been minimal difference in exposure time. Possibly some beach drainage pattern introduced more rain runoff or interstitial fresh water at one point or there was a difference in sediment composition.

Of importance is the fact that although the total numbers dropped drastically due to possible sediment difference, the species composition remained basically the same. In concluding then, it can be said that one core gives the following information: the major species, that is, the species which constitute most of the

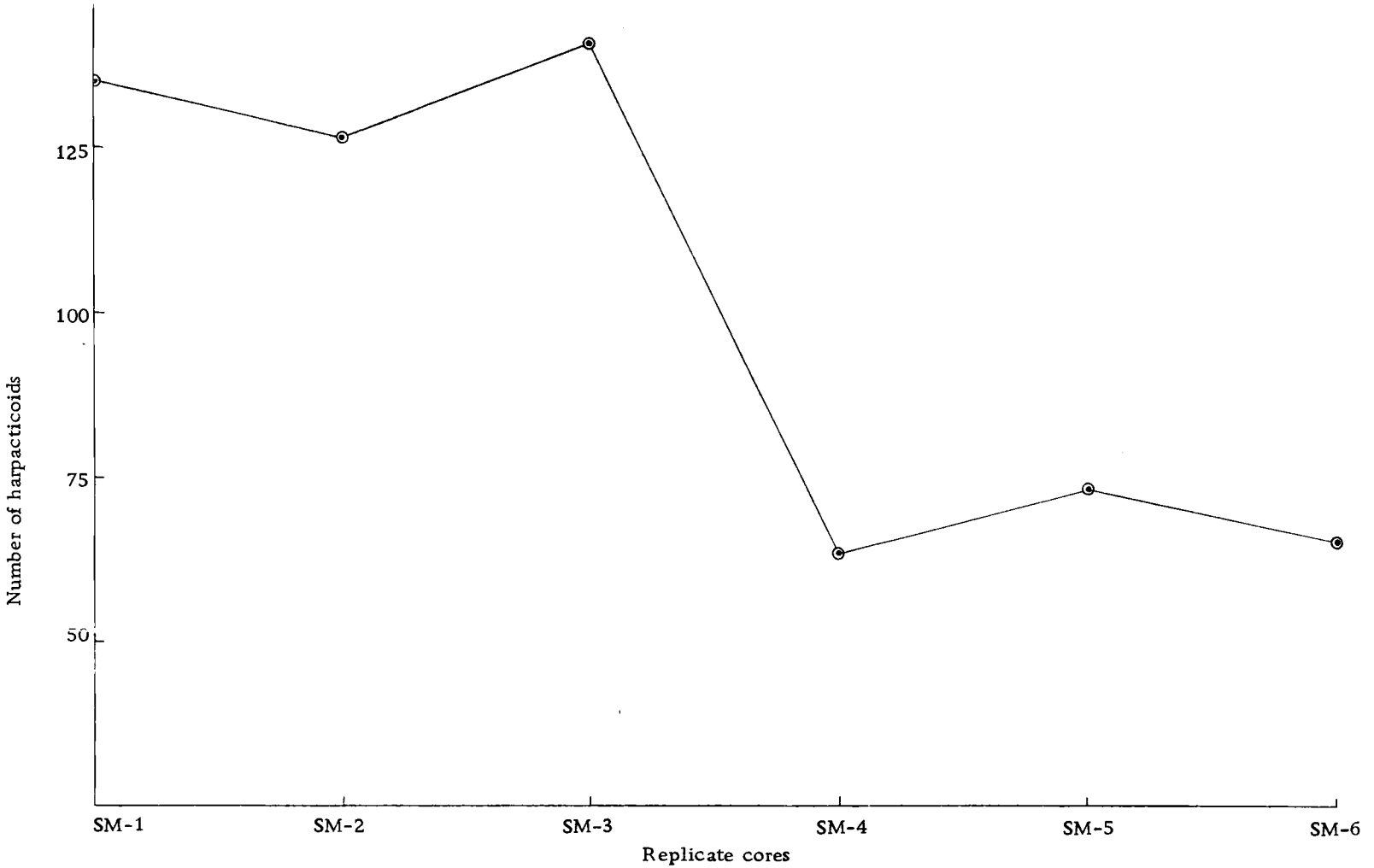


Figure 17. Number of harpacticoids found per core in six replicate cores.

population; possibly up to 65% of the number of species that are present; and, some idea about the number of harpacticoids per unit of area. The data presented certainly is not completely conclusive and additional sampling of this type would be useful. No numbers or graphs should be taken as absolute values but as indications or trends, although evaluations based on percentages may be quite valid and the presence or absence of the major forms should be significant.

Most core data is presented using the average of two cores, one from each side of the channel, to represent one point on a graph. Such averages should lessen the effects of sediment variation when discussing distributions in relation to salinities and temperatures. These important stations, 136-137, 130(a)-130(b), 120(a)-120(b), 49-61, and 14 all were used in pairs except 14 and all were taken subtidally or at the very lowest intertidal region to minimize the effects of different exposure times. These cores when referred to in pairs are considered to be representative of stations B-39, B-29, B-21, B-14 and B-9 respectively.

Selection of Coring Depth

The depth to which core sediment was analyzed, two centimeters, was based on previous work. Moore (1931) found almost all

harpacticoids in the top one centimeter. He also tested for interstitial oxygen, and found no free O_2 in any of the mud samples. When harpacticoid copepods were exposed to anaerobic conditions most appeared dead but some recovered when placed again in oxygenated water. Nematodes were completely resistant to anaerobic conditions. Mare (1942) found all harpacticoids to be in the top $\frac{1}{2}$ cm. It is probable that in mud the low values or the complete absence of O_2 prevents all but shallow excursions into the substrate by harpacticoids and probably most of them reported from deeper than a few millimeters were drawn to that depth by the coring tube. It is suggested that harpacticoids essentially live at the mud water interface. However, in sands where oxygen is found interstitially (Brafield, 1964), meiofauna including harpacticoids have been reported deeper than 50 centimeters (Raymont 1963). The sand samples used in this study, cores from stations 19 and 14 and the channel samples, cannot be considered as taken to adequate depth and most of the highly modified interstitial harpacticoids probably were missed. This study is primarly an investigation of the epifauna, although a few interstitial forms were found.

Harpacticoids in the Plankton

This entire study is based on an assumption that harpacticoid

copepopods are benthic, and that they remain on or in the substrate and do not shift with the currents and tides as do the members of the plankton.

Table 5 lists the number of harpacticoids found in plankton counts through August 26, 1965. Only the samples containing harpacticoids have been shown. In most samples the harpacticoids made up less that 1% of the plankton, and the highest percentage, on 3 February, was 6.7%.

Several explanations are presented to explain harpacticoids in plankton. Occasionally the plankton sampler strikes the bottom or runs through an eel grass bed and collects benthic forms. Harpacticoids are on debris such as bark, wood fragments and unattached clumps of eel grass all of which are encountered by plankton samplers. At the upstream stations on a hard running tide, debris from the bottom is mixed throughout the water column again introducing some harpacticoids into the plankton net. During brief excursions from the substrate harpacticoids can be captured by strong tidal or river current. Harpacticoids in aquaria can be observed to swim freely above the substrate. To avoid adverse environmental conditions harpacticoids might swim into the current to be transported to a more desirable area. This free swimming may be a mechanism which extended the ranges of harpacticoids

Table 5

Harpacticoids in Plankton 1965 through 26 August

Date	Station	No. of individuals per sample
14 Jan	B-21	1
30 Jan	B-15	6
30 Jan	B-21	6
3 Feb	B-39	27
3 Feb '65	B-29	1
9 Feb '65	B-21	1
19 Feb '65	B-39	4
18 Feb '65	B-29	8
18 Feb '65	B-21	1
25 Feb '65	B-15	3
12 Mar '65	B-39	2
18 Mar '65	B-39	1
26 Mar '65	B-39	7
7 Apr '65	B-39	19
7 April '65	B-21	1
14 Apr 165	B-39	6
23 Apr '65	B-39	1
23 Apr '65	B-15	1
30 Apr '65	B-15	4
30 Apr '65	B-21	1
30 Apr '65	B-39	1
8 May '65	B-29	1
8 May	B-39	4
14 May	B-15	1
4 June	B-39	1
4 June	B-21	1
4 June '65	B-21	2
11 June '65	B-39	2
1 July '65	B-39	1
1 July '65	B-29	4
1 July '65	B-15	1
12 July '65	B-21	1
19 Aug '65	B-21	3
19 Aug	B-15	1
26 Aug	B-15	3
26 Aug	B-21	5

from spring to fall, although planktonic larval stages are undoubtedly an important factor. B-39 was the site of nearly all high harpacticoid numbers in the plankton, and all of the higher values occurred in the early part of the year (Table 5). Two B-39 samples, February 3rd and April 7th, were examined for species. In the February sample eight Huntemannia jadensis and two Microarthridion littorale were counted. The harpacticoids in the April sample consisted primarily of M. littorale of which six were counted to only one other unidentified harpacticoid. These are species common to the flats and it is believed that they were adventitiously present in the plankton due to one or more of the factors discussed above.

Factors Which Influence Distribution

"The assumption is made that distribution of species (hence composition of communities) is the result of several external agencies acting on a variety of physiological systems. Substrate, food supply, water movements, tidal exposure, salinity and temperature are important." (Stickney and Stringer, 1957). The question in a field problem such as this is how to separate the effects of these environmental factors on top of which are superimposed biological factors such as interspecific competition and reproduction.

Oxygen as discussed above in connection with depth distribution in the sediments undoubtedly is a limiting factor to harpacticoids. Oxygen data was taken for the bay, but because it is non-conservative and to relate to the animals, values should have been taken at the substrate water interface, oxygen data will not be presented. It is apparent however that harpacticoids less resistant to low oxygen concentrations of the mud, would find higher oxygens on the eel grass particularly during periods of high photosynthesis. Also the eel grass environment moves them from the sediment to a point in the water column where more oxygen might occur.

Temperature considerations may be overlooked in some studies, but in estuaries temperature distributions are thought to be critical to the success of some species (Hedgpeth, 1957). Perkins (1958) mentioned, based on some laboratory experiments, that of the three major groups of meiofauna, nematodes, harpacticoids, and ostracods, the harpacticoids were the least resistant to varying temperatures.

Salinity in an estuary is one of the most obvious variables and probably of major importance to most organisms present. Harpacticoids are generally classified as freshwater, marine or brackish water species. These terms are broad and there usually is no quantitative salinity data presented. It seems possible that rather

than three categories of salinity tolerances there may be many. Jakobi (1959b) separated harpacticoids into seven groups based on their salinity tolerances including: a stenohaline marine group, an oligohaline freshwater group, and five intermediate groups. He had no success correlating morphological characters with salinity tolerances, although earlier (1959a) he had obtained relationship between morphology and substrate in harpacticoids.

Battaglia (1957) and Battaglia and Bryan (1964) in studies on Tisbe reticulata found that polymorphic forms of the same species had different salinity tolerances. The polymorphic forms were identified by color patterns which indicated different genotypes. These genotypes were found to breed true and heterozygotes of these forms were found to be more viable which suggests that they would be better adapted to the estuarine environment. This might explain forms which appear to be euryhaline for almost the entire range of salinities; there may be several races, not easily separated, with different physiological tolerances.

The importance of sediment type to benthos has been discussed for many groups but little is in the literature concerning harpacticoid sediment relationships. There is a great difference in harpacticoid faunas from mud and sand, but little is known about changes brought about in fauna due to subtle variations in sediment

composition. Wieser (1959) showed that two species of harpacticoids in Puget Sound preferred substrate with a median diameter of less than 200μ and that grain size was more important than tidal exposure in determining harpacticoid distributions. In a separate study on a cumacean Cumella vulgaris, Wieser (1956) noted that when there was no food in the sand, i. e., organic material, the animals were driven out into the water. Sanders (1957) related biomass of Nephthys incisa to the silt-clay fraction of the sediment which he suggested was closely related with organic matter in the sediments. It may be that the silt-clay fraction of the sediment is important as an index of the organic matter available as food. Organic carbon values for this study were determined, but will not be presented. The values were distorted due to the quantities of wood in the sediment which are not immediately available to harpacticoids as food but give high carbon readings. Some organic values based on nitrogen were presented by Kulm (1965) and will be discussed.

The major source of currents in estuaries is the tide (Hedgpeth, 1957). During periods of peak runoff the fresh water also creates strong currents primarily on the surface. Because there is a direct relationship between current velocity and grain size it seems possible that some harpacticoids are in low numbers in the channel because rather than preferring the fine sediments and

muds they are physically removed from the coarser sands by tidal currents. During winter freshets the river current could also displace harpacticoids from flats and eel grass.

As was mentioned above, Wieser found grain size more important than exposure time for harpacticoids in sand. Rees (1940) working on a mud flat found that there were more animals in the upper intertidal zone, but that among three species of harpacticoids there was no obvious differential zoning. In the present study, most samples are subtidal or at least very low intertidal with little exposure time. The samples from the intertidal stations, 106, 82, and 44, have been omitted from the distributional graphs but will be discussed. Exposure time and position intertidally can also affect the salinities to which animals are exposed. Intertidal forms may extend further into the bay from the ocean by existing high in the intertidal zone where they would be covered only by the higher tides. For example, in figure 2b benthic animal at B-29 in the summer living in the region covered only by high tides would be exposed only to salinities in the range of 30 o/oo, but an animal living subtidally would be exposed to salinities near 22 o/oo as well as to the higher values. Intertidal forms are, however, exposed to temperature extremes, particularly downstream where water temperatures in the summer are low.

Numbers of Harpacticoids Per Core

The number of harpacticoid copepods taken per core ranged from 0 to 842, and 16 cores had more than 150 harpacticoids. Values from other workers, as compiled by Smidt (1951) and shown by Raymont (1963), were presented as numbers per square meter. By extrapolating core values from Yaquina Bay to a square meter, a value over 750,000 is obtained for station 136 in June and values in the neighborhood of 450,000 are recorded for several other stations. The only value in the literature to exceed this was the more than one million harpacticoids reported by Barnet and discussed in Raymont (1963). Numbers per core are presented in figures 18, 19 and also in figure 20 which presents the average of two cores for each point in the bay. Numbers will also be discussed when seasonal variations are considered.

Descriptions of Harpacticoid Distributions

The Winter Sampling Period

Core and skimmer samples. Figure 21 indicates that the number of species and the number of harpacticoids per core in the bay were both low during the winter. The only station which showed good numbers of species and animals in the winter was station 76 in

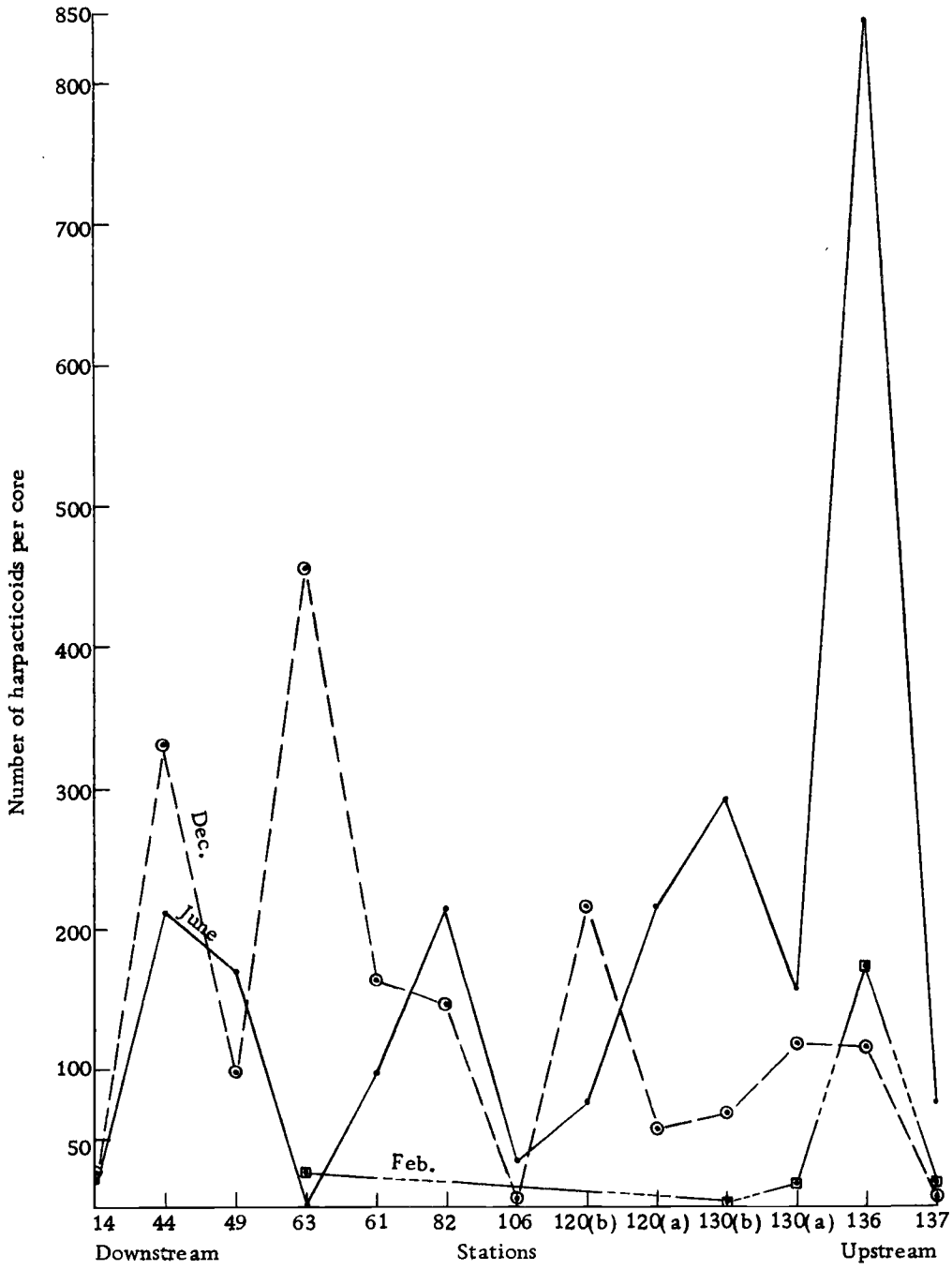


Figure 18. Number of harpacticoids per core in the bay in the three seasons sampled.

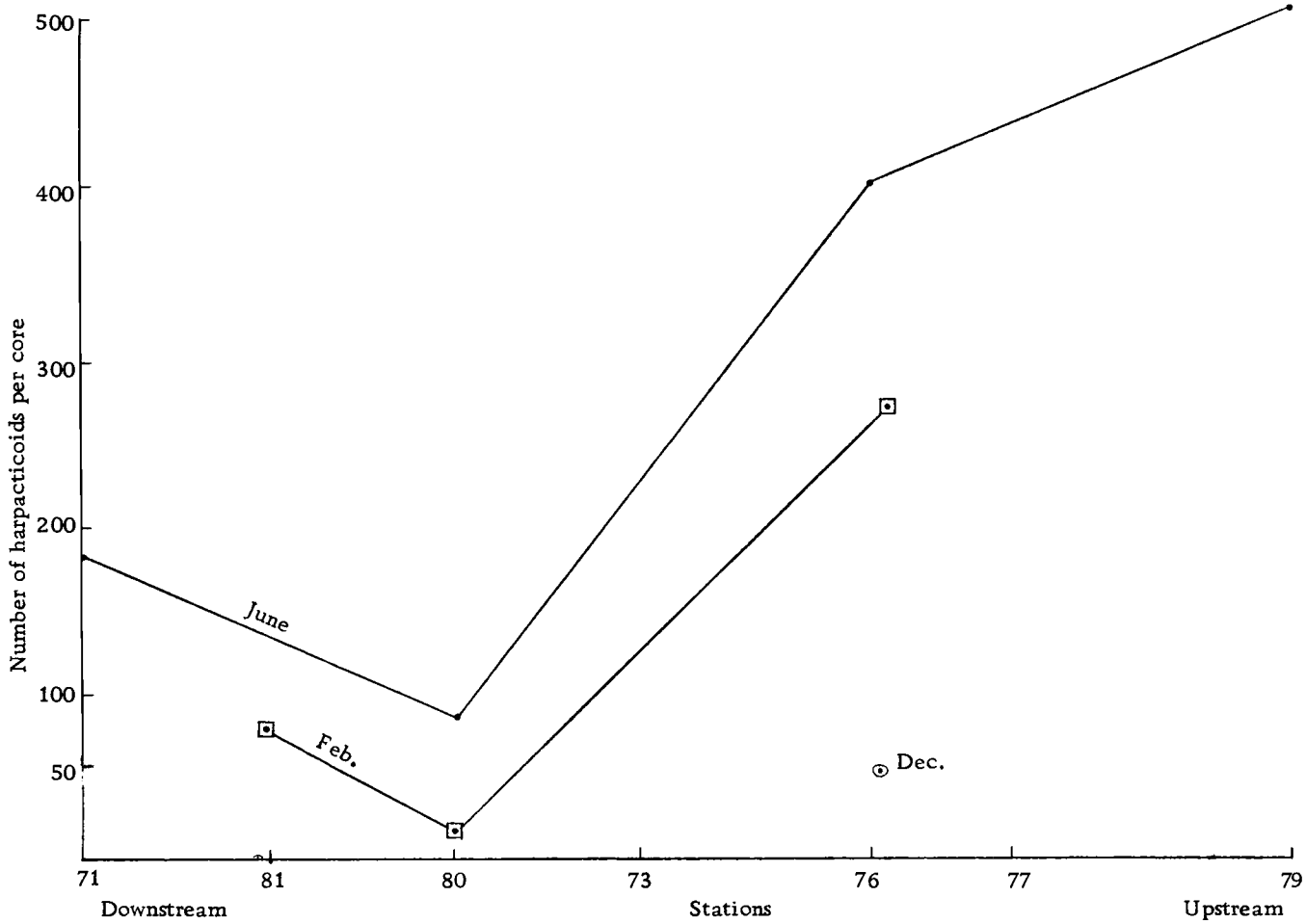


Figure 19. Number of harpacticoids per core in King Slough in the three seasons sampled.

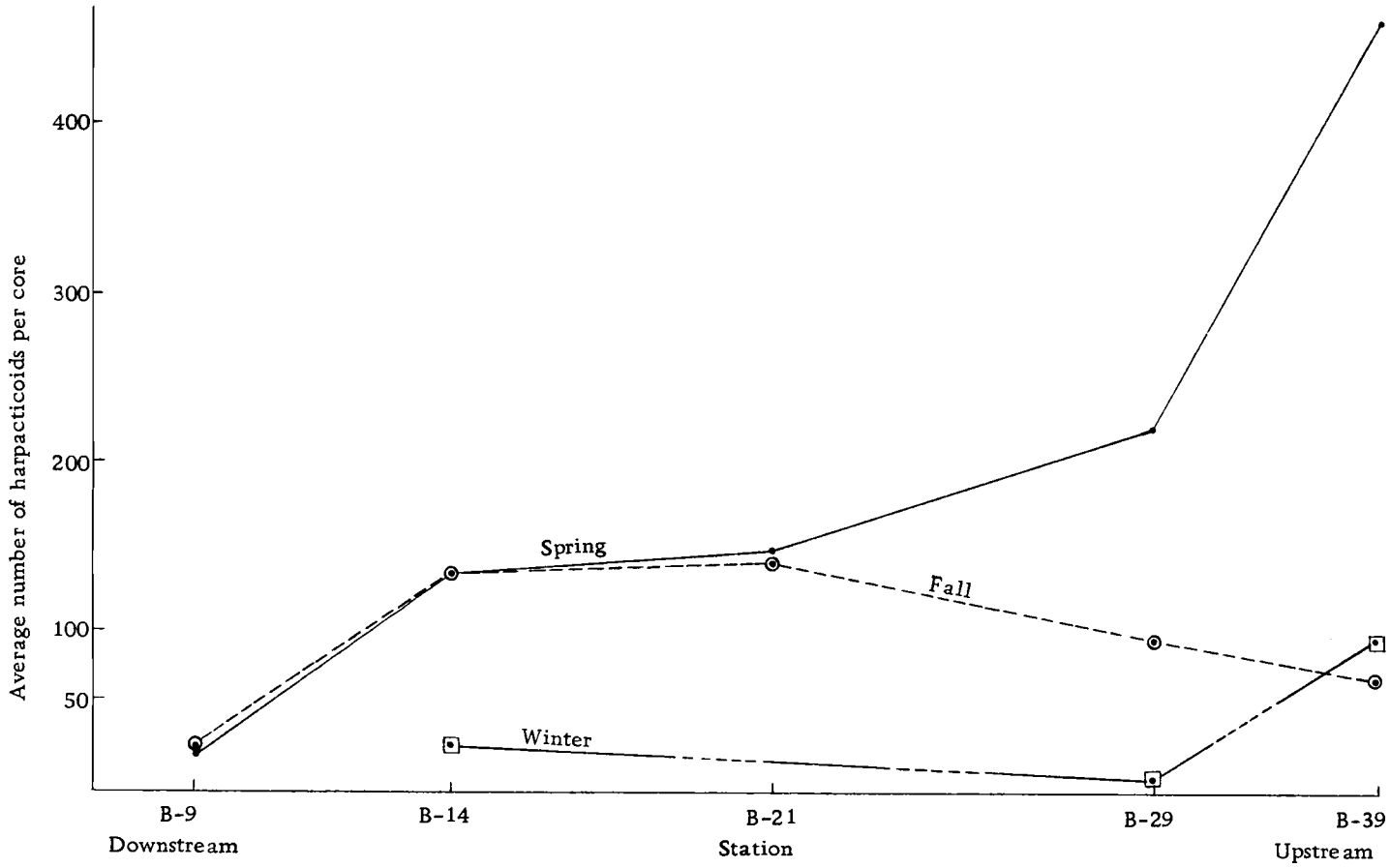


Figure 20. Number of harpacticoids per core in the bay in the three seasons sampled; based on the average of two cross channel cores at B-39, B-29, B-21, B-14 and one core (station 14) at B-9.

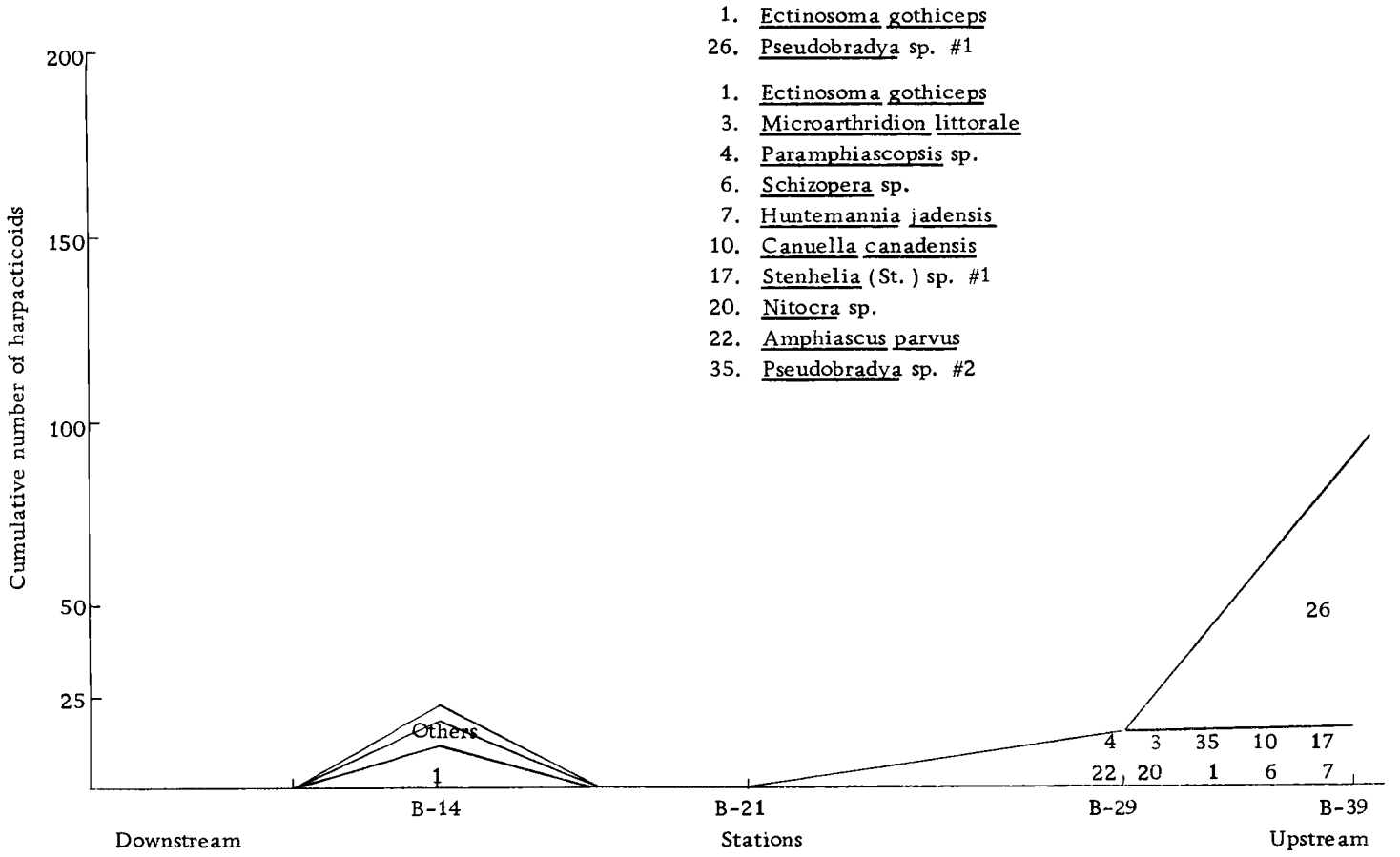


Figure 21. Cumulative species distributions for the bay in the Winter (22 and 25 February and 3 March); based on the average of two cross channel cores at B-39, B-29, and one core (station 63) at B-14.

King Slough (figure 22) where Schizopera sp., Limnocletodes behingi, Microarthridion littorale, Stenhelia normanni, and Euryte sp. #1 were the dominant forms. In the bay (figure 21) B-39 had the highest numbers consisting almost entirely of Pseudobradya sp. #1 and low numbers of ten other species. Unfortunately the only downstream station taken other than in King Slough was station 63 which had low numbers with Ectinosoma gothiceps and Microarthridioninae dominating. Station 81 toward the mouth of King Slough had fair numbers of Amphiascella debilis and Paramphiascopsis sp. Dead harpacticoids or exoskeletons were observed in many of the cores indicating possibly a rapid kill due to reduced salinities.

February channel samples with the skimmer (figure 24) while not quantitative indicated very low populations which were corroborated by cores taken from six Smith-McIntire grab samples. The cores contained from zero to two harpacticoids each in the top two centimeters. The skimmer (channel) samples when plotted (figure 24) were separable clearly into three groups: the upstream forms, Microarthridion littorale, Canuella canadensis and Huntemannia jadensis; the downstream forms, Tisbe furcata, Zaus aurelii and Diathrodes sp. and the intermediate group, Shizopera sp. and Amphiascella debilis. This grouping may have been due to the salinity gradient, but it is not conclusive because sample sizes were

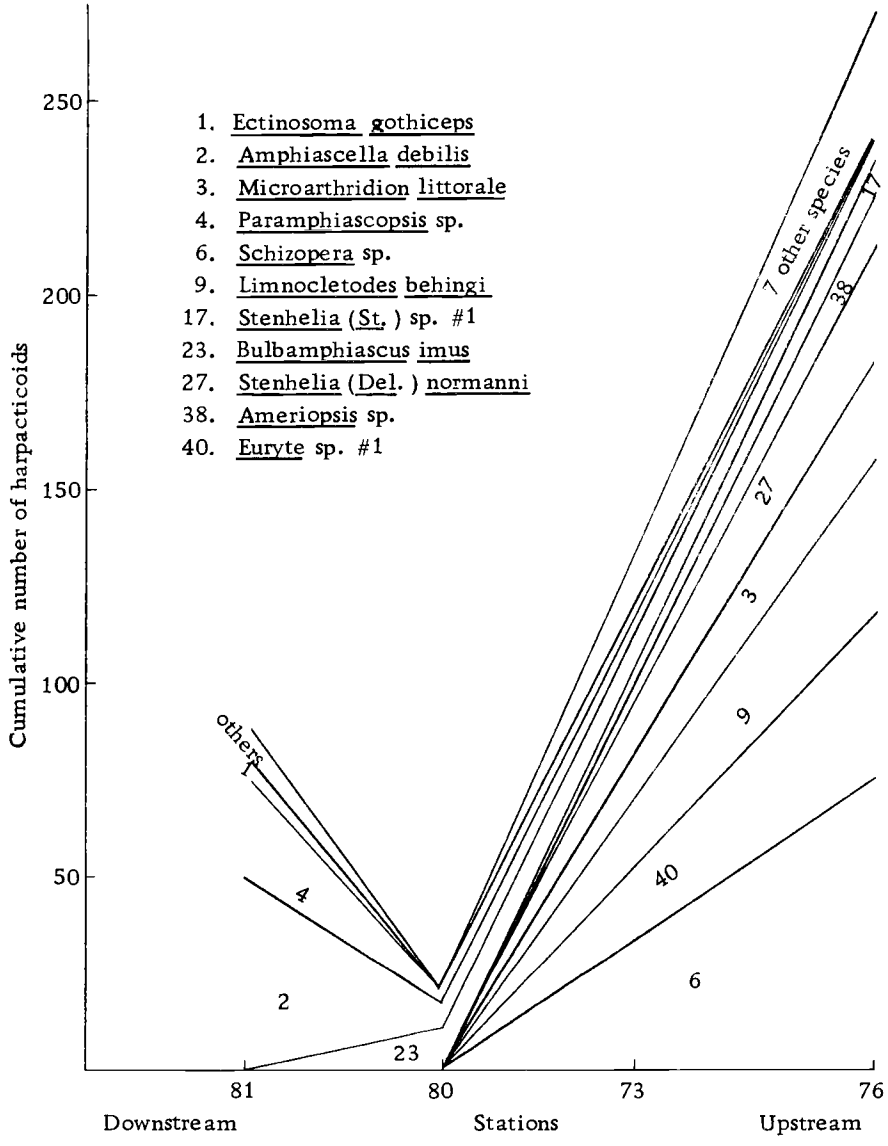


Figure 22. Cumulative species distributions for King Slough in the Winter (22 and 25 February and 3 March); based on one core per station.

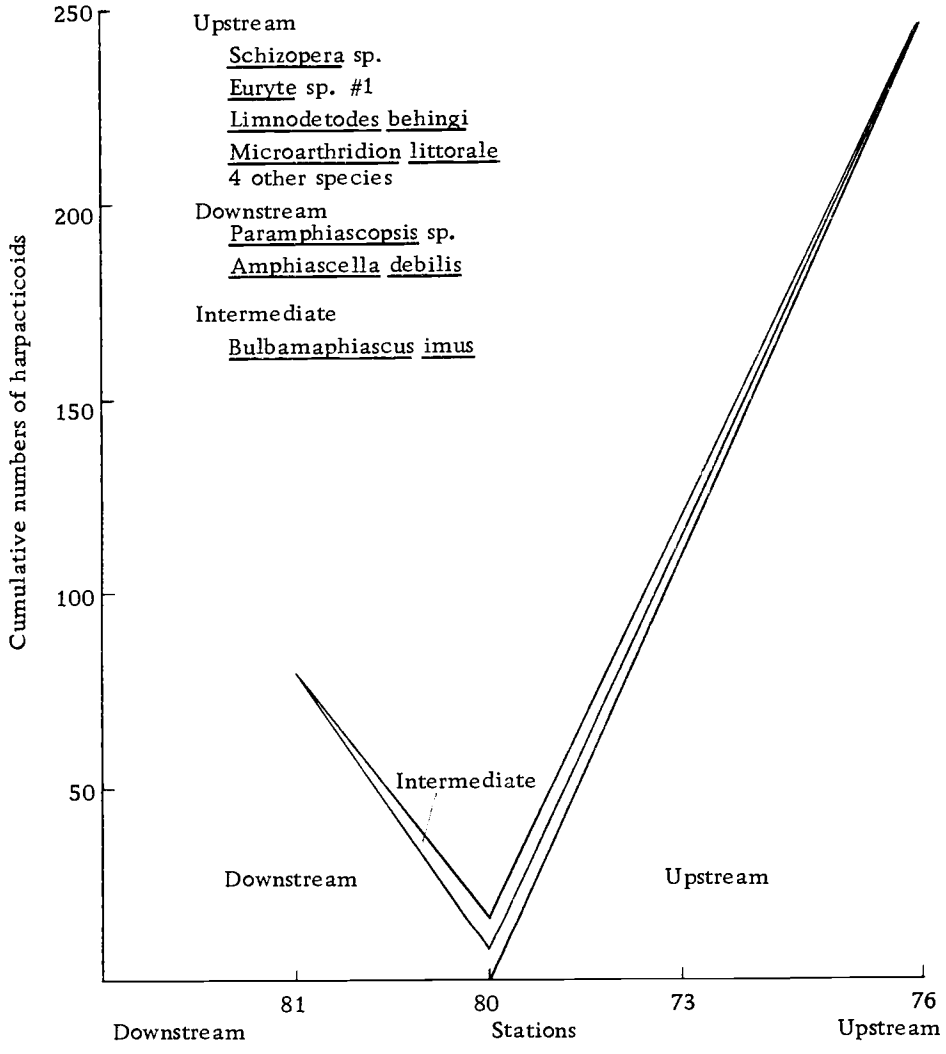


Figure 23. Cumulative King Slough species distributions (as seen in Figure 22), grouped into three assemblages.

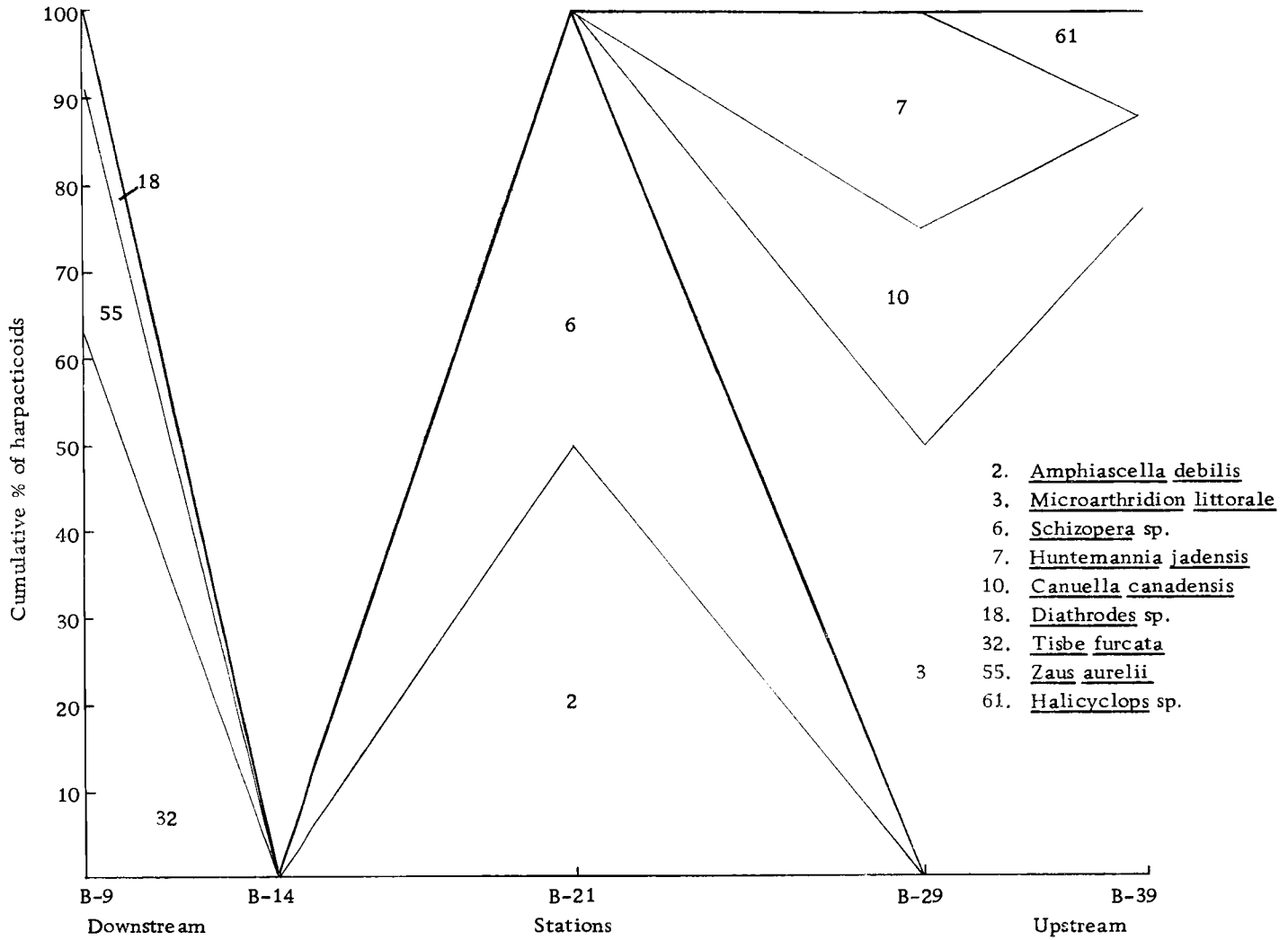


Figure 24. Cumulative species distributions in the bay in the Winter from bottom skimmer samples.

small ranging from 0 to 11 harpacticoids. The upstream channel (skimmer) sample (B-39) was dominated by Microarthridion litterale whereas the cores from B-39 were dominated by Pseudobradya sp. #1. This difference may be attributed to sediment difference or to the presence of a two layered salinity system which existed during some of the winter. Possibly as the salinity approached zero on the lateral mud flats, Microarthridion littorale was forced into the channel where a slightly higher salinity was present, or the M. littorale on the flats perished due to low salinities or competition with forms better adapted to the fresh-water conditions. During other seasons M. littorale dominated on these flats, but Pseudobradya sp. #1 may be better adapted to the low salinity conditions. It is suggested that the downstream forms required nearly open ocean salinities and the species at B-21 were more euryhaline. Even though salinities were low in the channel, there may have been enough infusion of salt water with the salt wedge at high tide and retention by the sediments to sustain animals, which couldn't survive on the flats.

The winter sampling period was preceded by the unusually heavy rains and flooding of December 1964 and January 1965. Figures 3, 4, 5, 6, 7 and 8 of the seasonal variation at points on the bay and the spatial survey of 30 January, 1965, (figure 9) show the low salinities which resulted. Probably of more

importance to the harpacticoids than the salinities encountered was the duration of the low salinity period which ran from Dec., 1964 into February with little respite. Other workers such as Dimick (1942) have emphasized the duration of low salinity periods rather than low point values in explaining distributions of estuarine organisms.

The data suggests that the harpacticoids found in the upper bay are euryhaline to withstand short term fluctuations of salinity but most of the species cannot endure the low salinities for long periods of time. Other factors associated with the flooding which may have affected harpacticoids were silting and displacement by current.

It seems certain that the extreme conditions preceding the sampling period affected the harpacticoid populations drastically. Of interest is the fact that the upper stations in the bay and in King Slough were the most productive, and possible reasons will be suggested. The higher population at B-39 was almost entirely one species, Pseudobradya sp. #1 which was encountered only one other time in this investigation, at station 79 in King Slough in June. It is possible then that this is an entirely fresh-water form which was brought down by the flooding and survived in the almost 0 o/oo water. The King Slough population was diverse with six or more

quite successful forms. It is possible that the Slough was protected somewhat from adverse conditions during flooding. Although there is a creek entering the Slough, it is small and even after abundant rain, the heavy runoff should be of short duration compared to prolonged low salinity in the upper bay. Also the adverse effects of silting and strong currents were probably minimized in the Slough which was near enough to the ocean to get an infusion of salt water at least on high tide. The salinity profile for February and March 1965 (figure 13) shows a salinity of nearly 24 o/oo at station 76 in the Slough but at B-39 (figure 10) in February and March, salinities were below 15 o/oo. The data plotted from 1962 in King Slough (figure 14) show even higher values with an average reading at station 77 of 26.5 o/oo which indicates the salinities that occur in this area during a drier winter.

The Spring Sampling Period

Cores. Spring cores were characterized by high population numbers upstream both in the main bay (842 animals at station 136) and King Slough (507 and 404 animals at stations 79 and 76 respectively). Total counts (figures 18, 19, 20) were lower downstream particularly at stations 14 and 19 which were sandy.

Of the numerically dominant upstream forms, Microarthridion

littorale completely overshadowed the other species at B-29 and B-39 (figure 25). Downstream from B-21 M. littorale disappeared quickly with only one specimen recovered at station 106 and 82. Canuella canadensis showed a similar pattern and was absent downstream from B-29 (figure 25). Schizopera sp. and Nannopus palustris were low in numbers, but they seemed to show the same upstream distribution with the heaviest concentration at B-39. Mesochra pygmaea, Tegastes sp. and Harpacticus uniremis possibly were upstream forms but occurred in such low concentrations that nothing can be concluded about their distribution from this data alone. The incidence of other species was too low to be of any significance.

The downstream patterns (figure 25) were not as clear and there were not such obvious dominants. Harpacticus sp. #3 is a downstream species which did not occur above B-14. Amphiascella debilis, which occurred the length of the bay (figure 25) had the highest population numbers in the lower bay. Paramphiascopsis sp. (figure 25) was similar to A. debilis in pattern and seems more successful downstream. A. debilis and Paramphiascopsis sp. occurred in very low numbers above B-21. Heterolaophonte sp. #1 (figure 25) had a distribution entirely below B-21 as did Typhlamphiascus confusus and Bulbamphiascus imus, although the latter two were

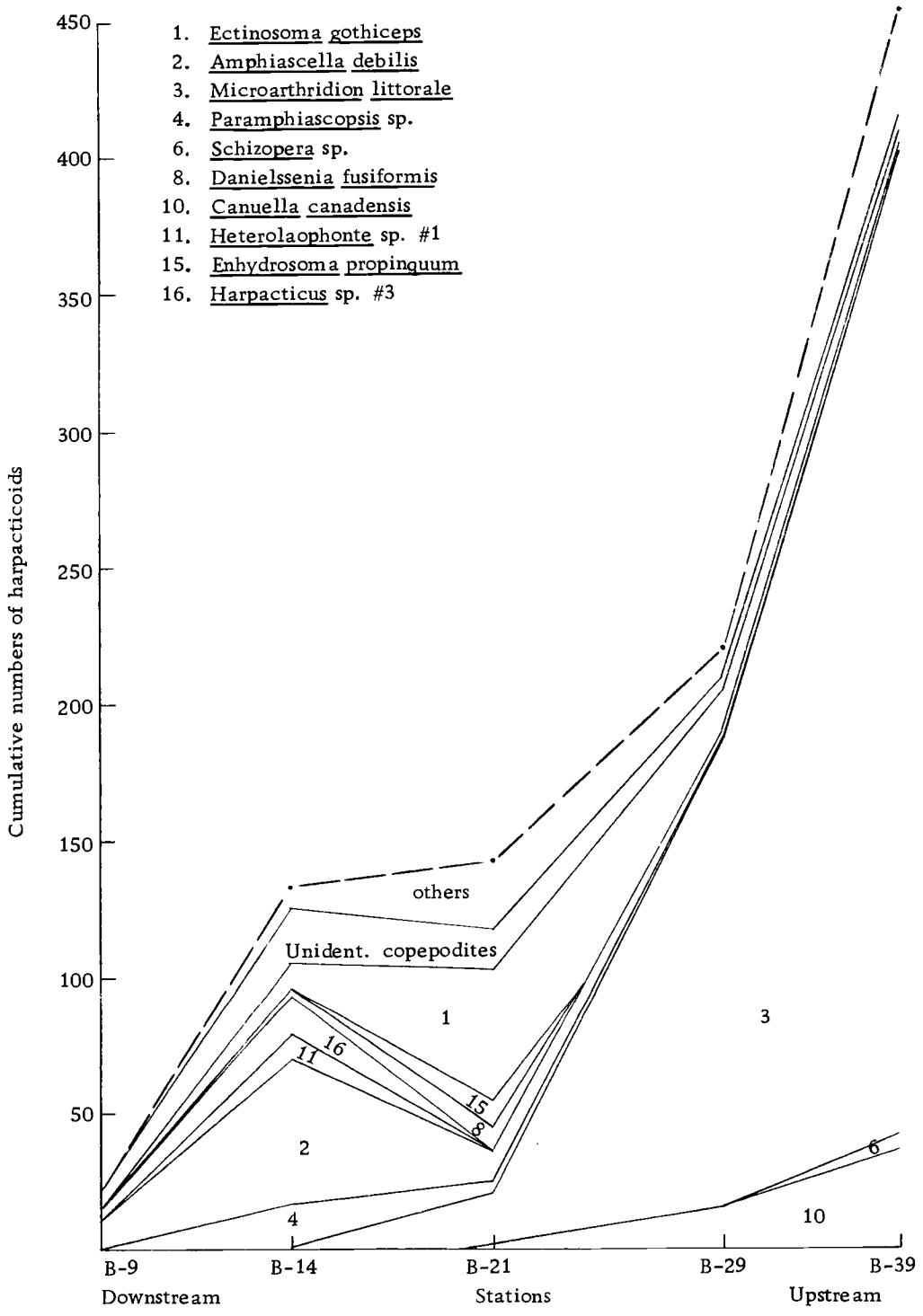


Figure 25. Cumulative species distributions for the bay in the Spring (15, 16 and 18 June); based on the average of two cross channel cores at B-39, B-29, B-21, B-14, and one core (station 14) at B-9.

too poorly represented to draw conclusions. Diathrodes sp. and Heterolaophonte sp #2 may have been downstream forms, but the nu mbers again weren't of sufficient magnitude to draw conclusions. The last four species mentioned occur in the "others" category in figure 25.

Peaking in population at B-21 were Enhydrosoma propinquum, Ectinosoma neglectum, Danielssenia fusiformis and Enhydrosoma sp. #1. Only E. propinquum, D. fusiformis and E. neglectum occurred in sufficient numbers to warrant distributional comparison; these three, the former two of which are graphed on figure 25, showed suggestively similar patterns. The most occurrences in all cores for any of these forms was six, and all three were in the same sample five times which is a high degree of concurrence.

Microarthridioninae (in "others" category, figure 25) although occurring in higher numbers upstream gives little clue to its population center when plotted. Microarthridioninae was found the length of the bay, and although it constituted a higher percentage of the population downstream it was more abundent numerically upstream at station 136 than at any other single station. Huntemannia jadensis (in "others" category, figure 25) occurred at six stations in the main bay but in low numbers. There are several species in the genus Ectinosoma which are difficult to separate. The

harpacticoid tentatively identified as Ectinosoma gothiceps (figure 25) which was in most samples, was found in the highest numbers at stations 82 and 44 and in slightly lower numbers at 120(a) (figure 1 for station locations). Stations 44 and 82 are intertidal and probably this is of significance in determining distribution of this species.

The King Slough spring distributions (figure 26) were enough different and of adequate interest to be treated separately. Microarthridion littorale, Schizopera sp. and Canuella canadensis showed the same basic distributional patterns in King Slough as in the bay (figure 26) with peak concentrations upstream. Microarthridion littorale comprised almost 30% of the population at the upper station 79 (figure 26). It should be noted here that the above forms occurred upstream in the main bay, disappeared at a point upstream from where King Slough enters the bay, and then reappeared in King Slough. Microarthridioniae (in "others" category, figure 26) also was found in upper King Slough, and at station 76 where it was found in higher numbers than at any station in the bay. Ectinosoma gothiceps (figure 26) occurred but at higher concentrations upstream than down, converse to the bay distributions. Nannopus palustris and Nitocra sp. (figure 26) peaked at a lower station than in the bay where they reached maximum numbers at the same location

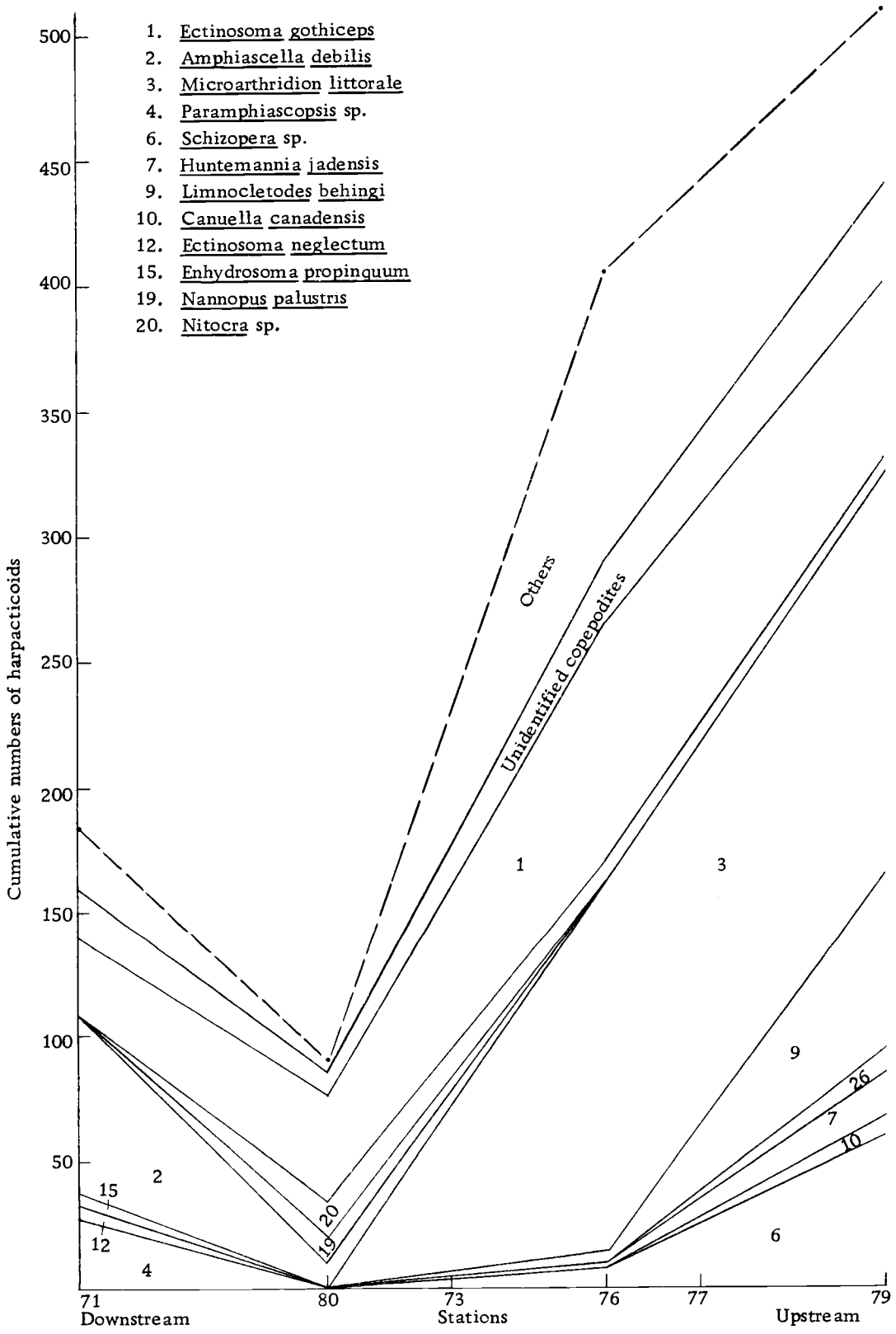


Figure 26. Cumulative species distributions for King Slough in the Spring (15, 16 and 18 June); based on one core per station.

as Schizopera sp., Canuella canadensis, and Microarthridion littorale. The biggest difference between the Bay and Slough was the occurrence of Limnocletodes behingi in numbers at station 79 in the slough, (figure 26). This species was not found in the main bay during the spring sampling period.

At the lower end of the slough (figure 26) Amphiascella debilis and Paramphiascopsis sp. became numerically dominant along with Ectinosoma gothiceps which extended in good numbers the length of the slough. Also occurring at the lower station, 71, (figure 26), which may still be under the dilution effects of slough water, were Ectinosoma neglectum, Danielssenia fusiformis, Enhydrosoma propinquum, Enhydrosoma sp. #1, Typhlamphiascus confusus and Heterolaophonte sp. #1, of which some are in the "others" category in figure 26. In species composition this station was nearly identical with station 106 which is approximately 1 mile upstream in the bay.

The species sampled indicate that King Slough generally has species composition and distributional patterns similar to the main bay from B-39 4.5 miles downstream to station 106, but in the slough the gradients are compressed into a distance of slightly more than one mile.

The physical data presented in the spatial survey of the bay for

June 24 (figure 11) and the slough for 18 June (figure 15) cannot be compared too closely because the bay data from B-39 and B-29 was taken near low tide and the data from King Slough was taken at high tide; however, the seasonal data (figures 3, 4, 5, 6, 7, 8) indicate that King Slough salinities are similar to values taken at B-29. Temperature readings for the upper slough and upper bay are similar, but the B-39 values are slightly higher during the spring. The fresh-water introduced by a stream into the Slough during the summer may be somewhat cooler because it has a shorter period in which to receive insolation. Also, air temperatures are lower and fog and low overcast which also reduces insolation are probably more common over the Slough which is near the ocean.

Differences in populations between upper bay and upper slough could be attributed then to higher salinity or lower temperatures in the slough or to unknown factors. The biological affinity relationships plotted in figure 42 related the upper slough stations closely to stations 120 (a) and 120 (b) as well as the upper bay stations. It is striking and possibly demonstrative of causative relationships that the populations and salinity and temperature distributions are similar for both upper bay and upper slough regions.

The species distributional patterns in the main bay fall into four categories: those with population centers above B-21; those

with populations centers below B-21; species whose populations seem centered at B-21; and those with apparently no pattern, which may be found at nearly every station in varying numbers or appear to be randomly scattered. Of the latter group, consisting of Ectinosoma gothiceps, Microarthridioninae and Huntemannia jadensis, only Ectinosoma gothiceps was in adequate numbers to plot (figure 25).

The dominant species as shown in figure 25 were placed into four groupings in figure 27 based on where populations peaked. The upstream and downstream groups appear quite clear, but the evidence for a third discrete group centered at B-21 is inconclusive due to low numbers.

The downstream assemblage was divided into two groups, group 1 which peaked at B-14 but extended to upper stations in low numbers and group 11 which occurred only at B-14. For King Slough figures 26 and 28 show a surprisingly similar pattern to that of the bay; although there are some differences in species composition, the species can be grouped into upstream, downstream and intermediate groups. The data suggest that in the bay and slough the horizontal salinity and/or temperature gradients affected species distribution.

Hedgpeth (1957) stated that the minimum number of species is

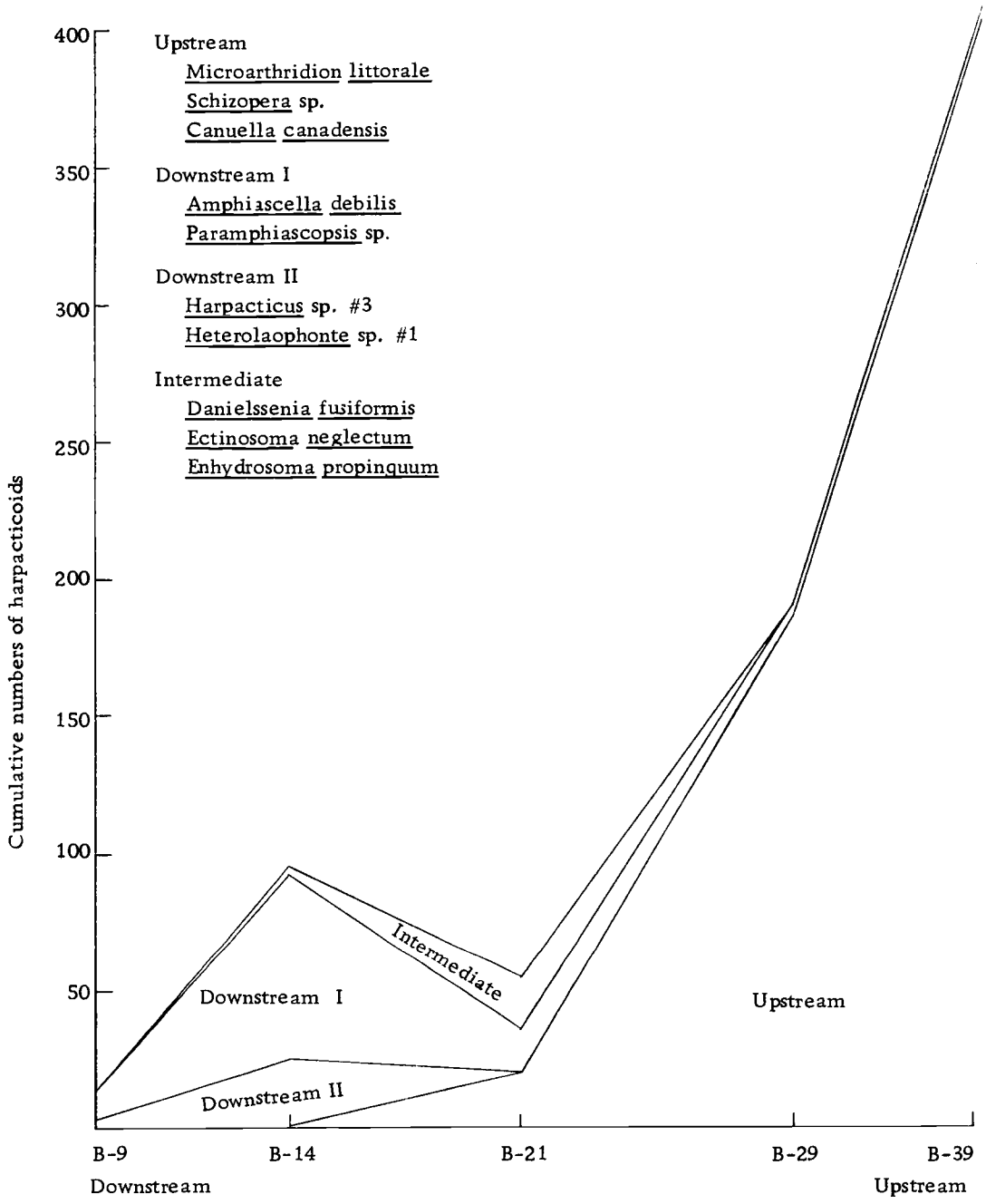


Figure 27. Cumulative species distributions for the bay (as seen in Figure 25) grouped into four assemblages.

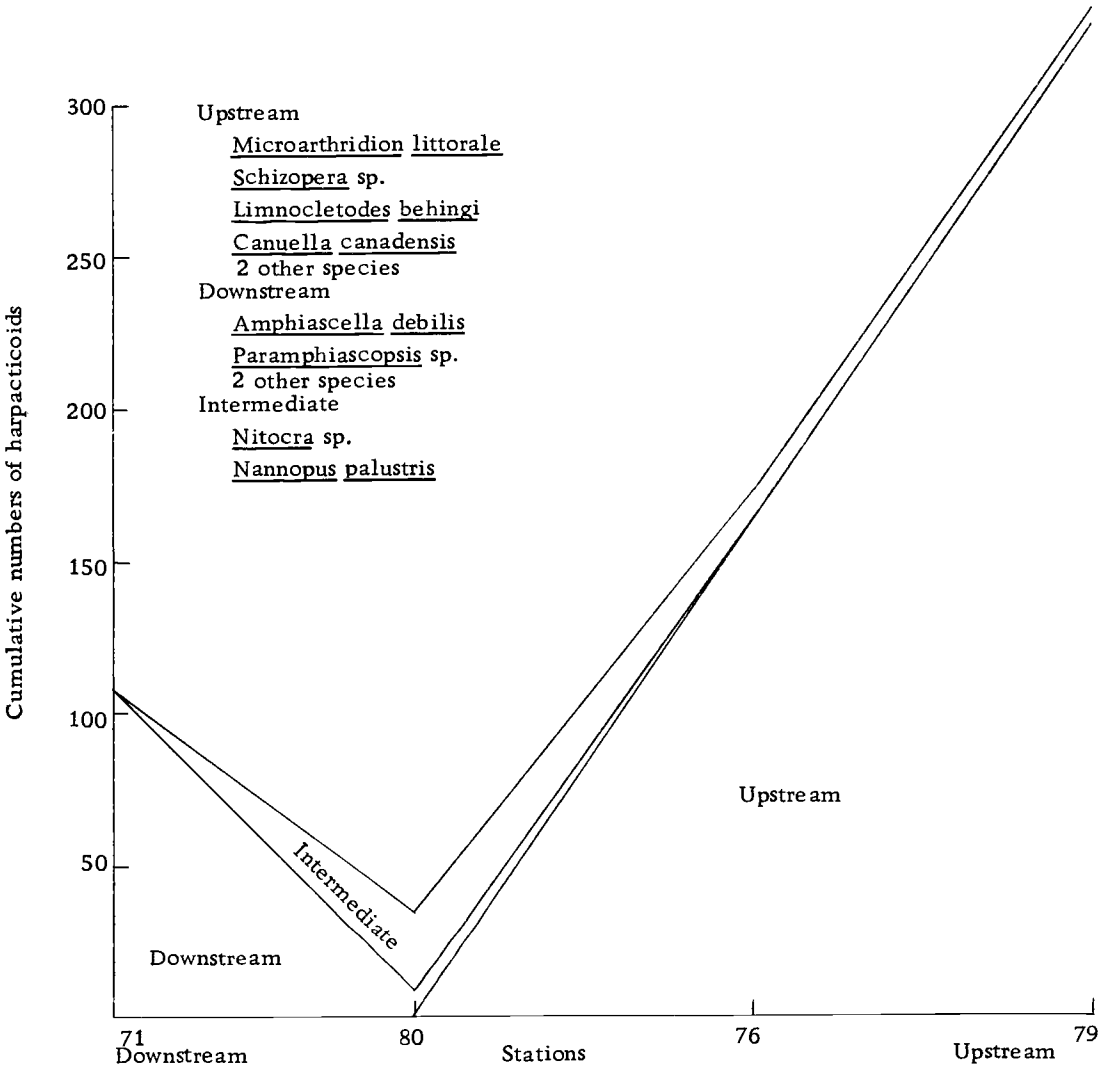


Figure 28. Cumulative species distributions for King Slough (as seen in Figure 26) grouped into three assemblages.

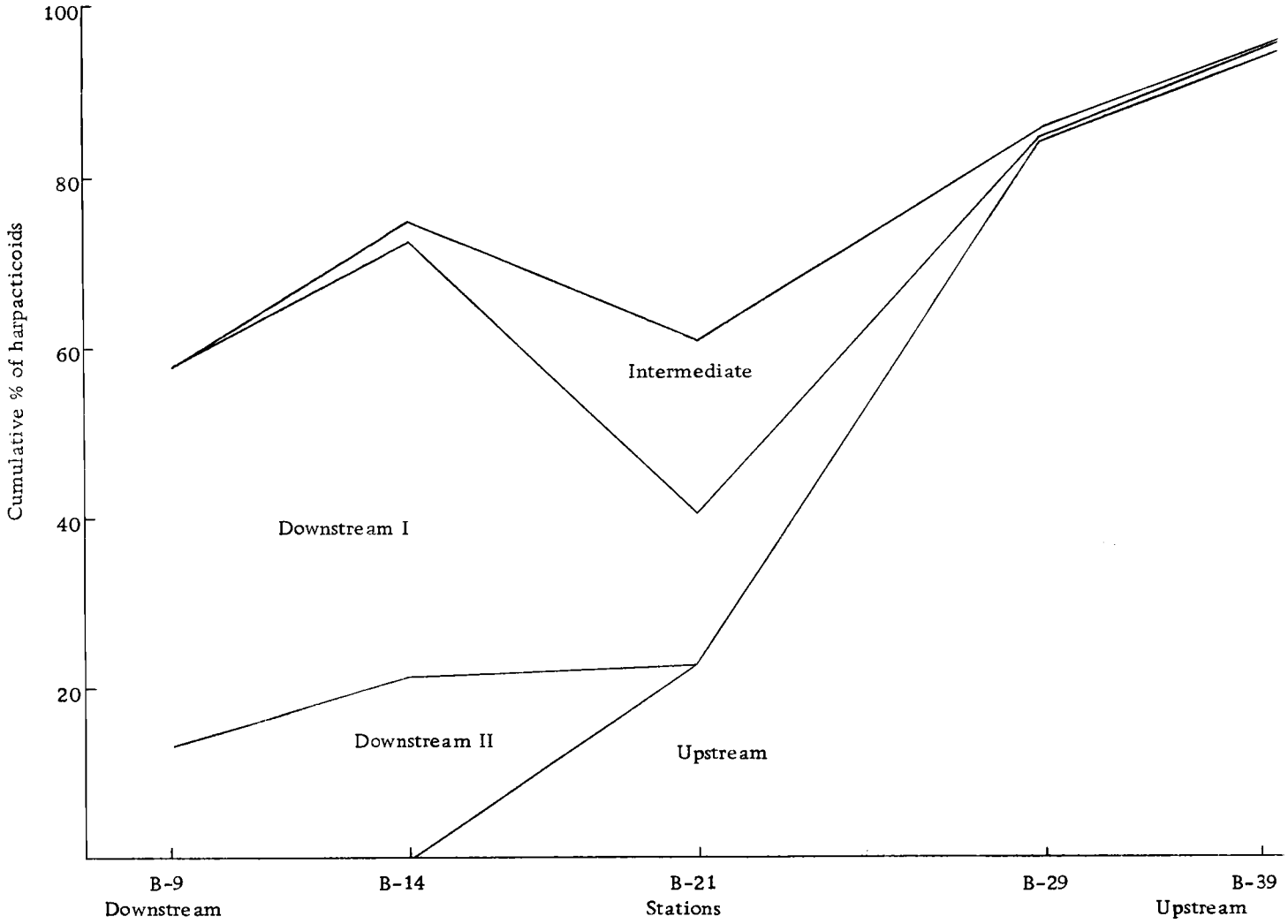


Figure 29. Assemblages from the bay (Figure 27) expressed as cumulative percentages of the total population.

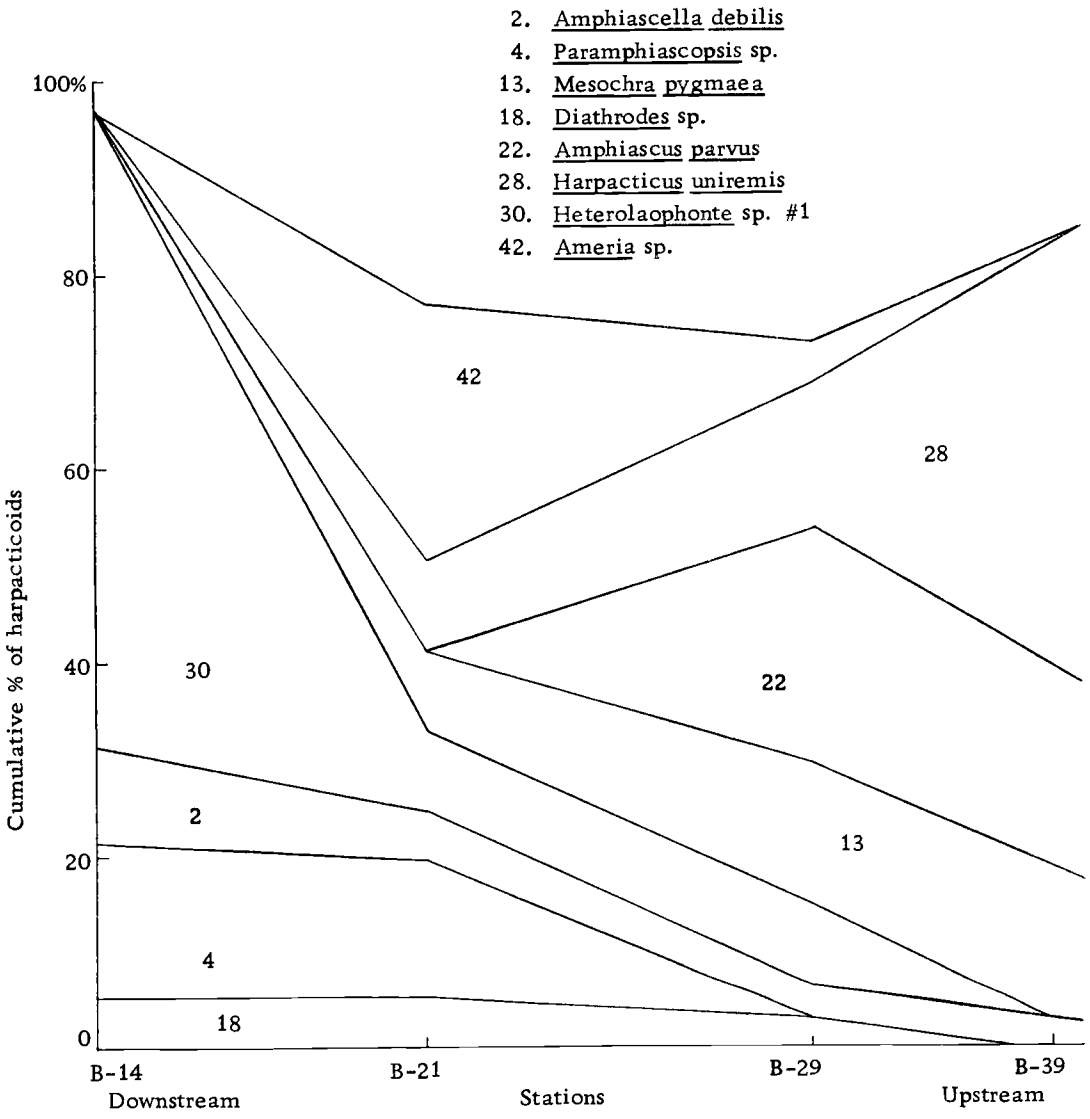


Figure 30. Species distributions of the major forms on eel grass (15, 16 and 18 June) expressed as cumulative percentages.

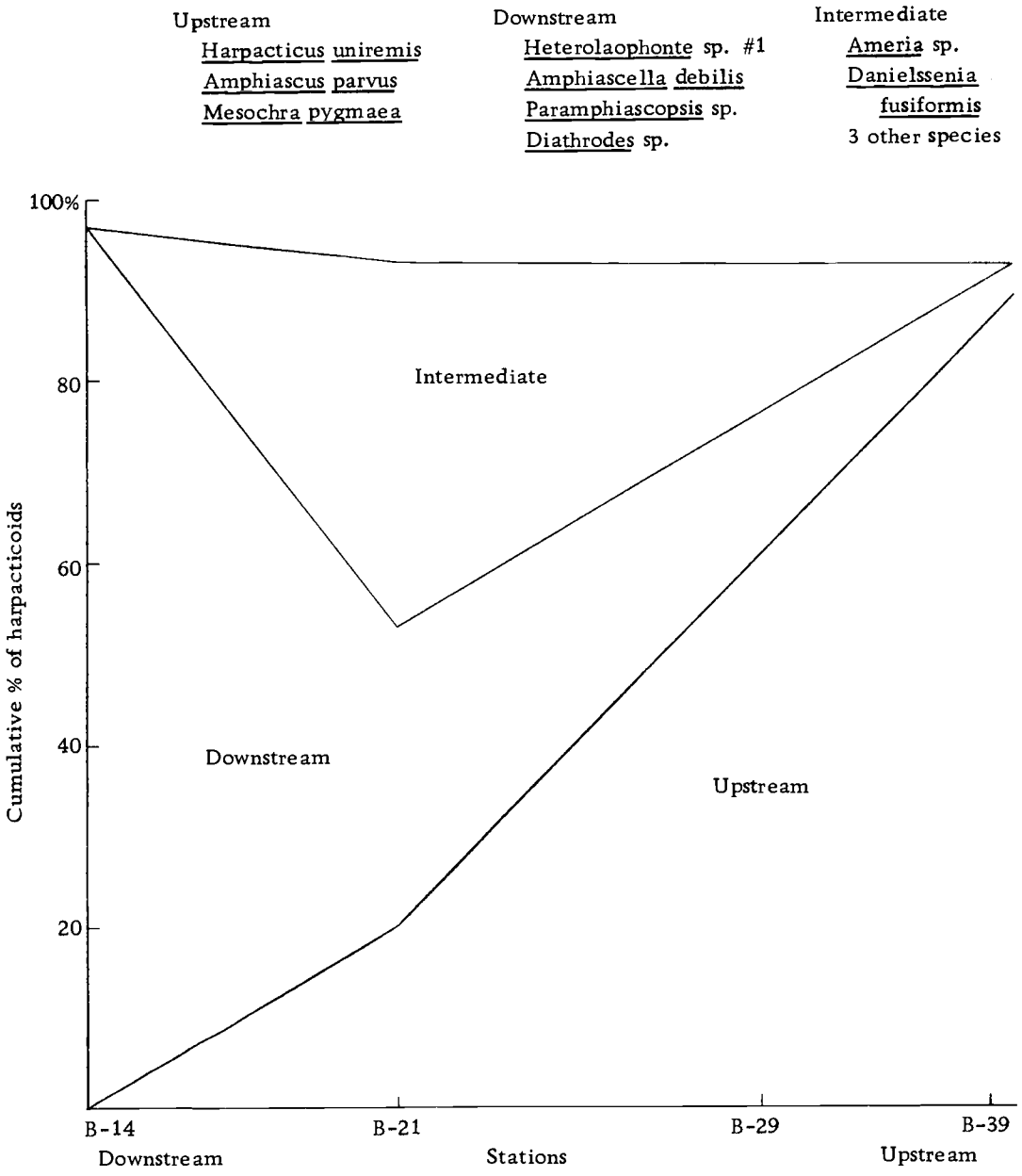


Figure 31. Cumulative species distributions on eel grass (as seen in Figure 30) grouped into three assemblages.

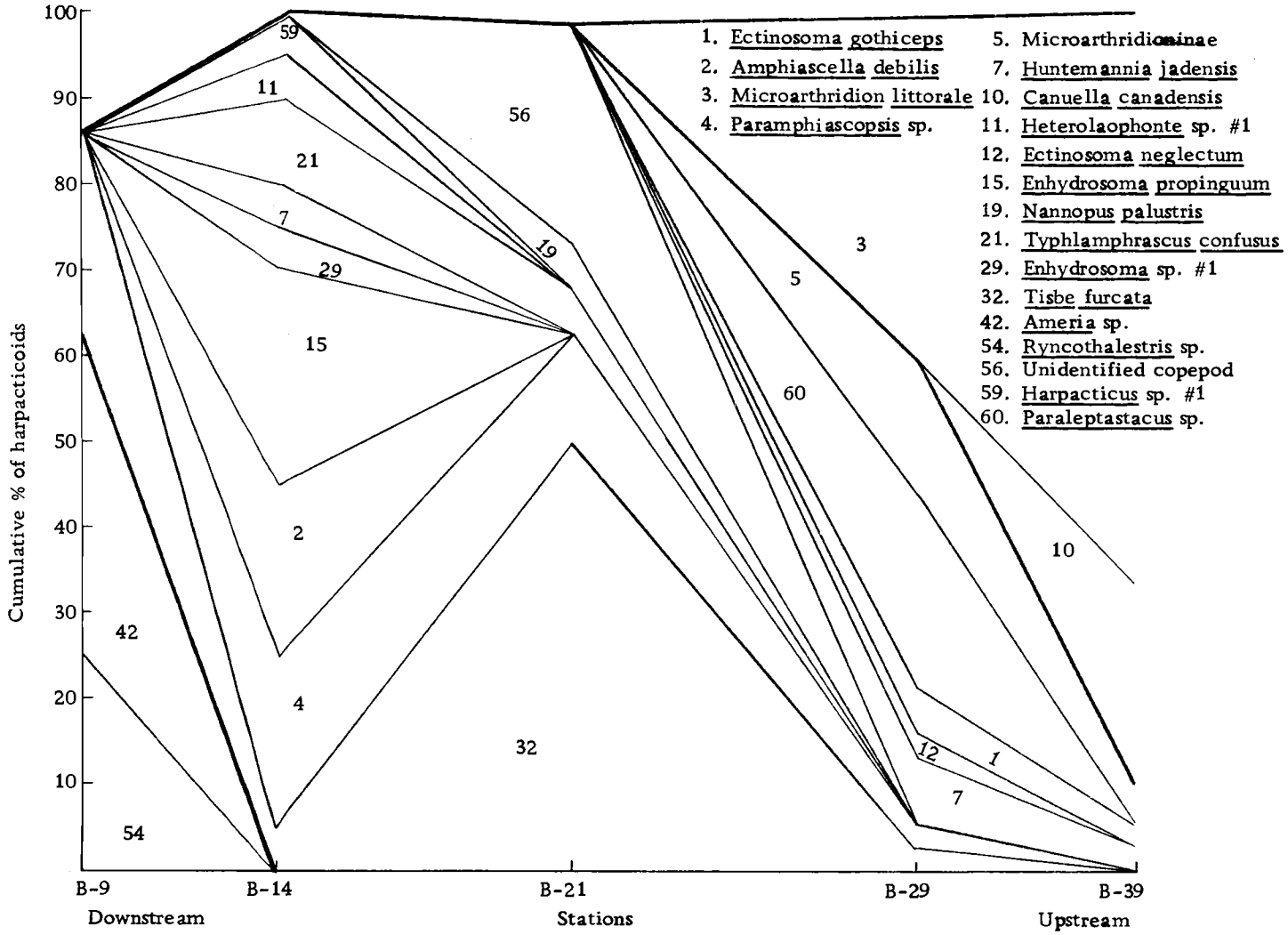


Figure 32. Cumulative species distributions from skimmer samples in the Spring (15, 16 and 18 June). The heavy lines group the species into three assemblages.

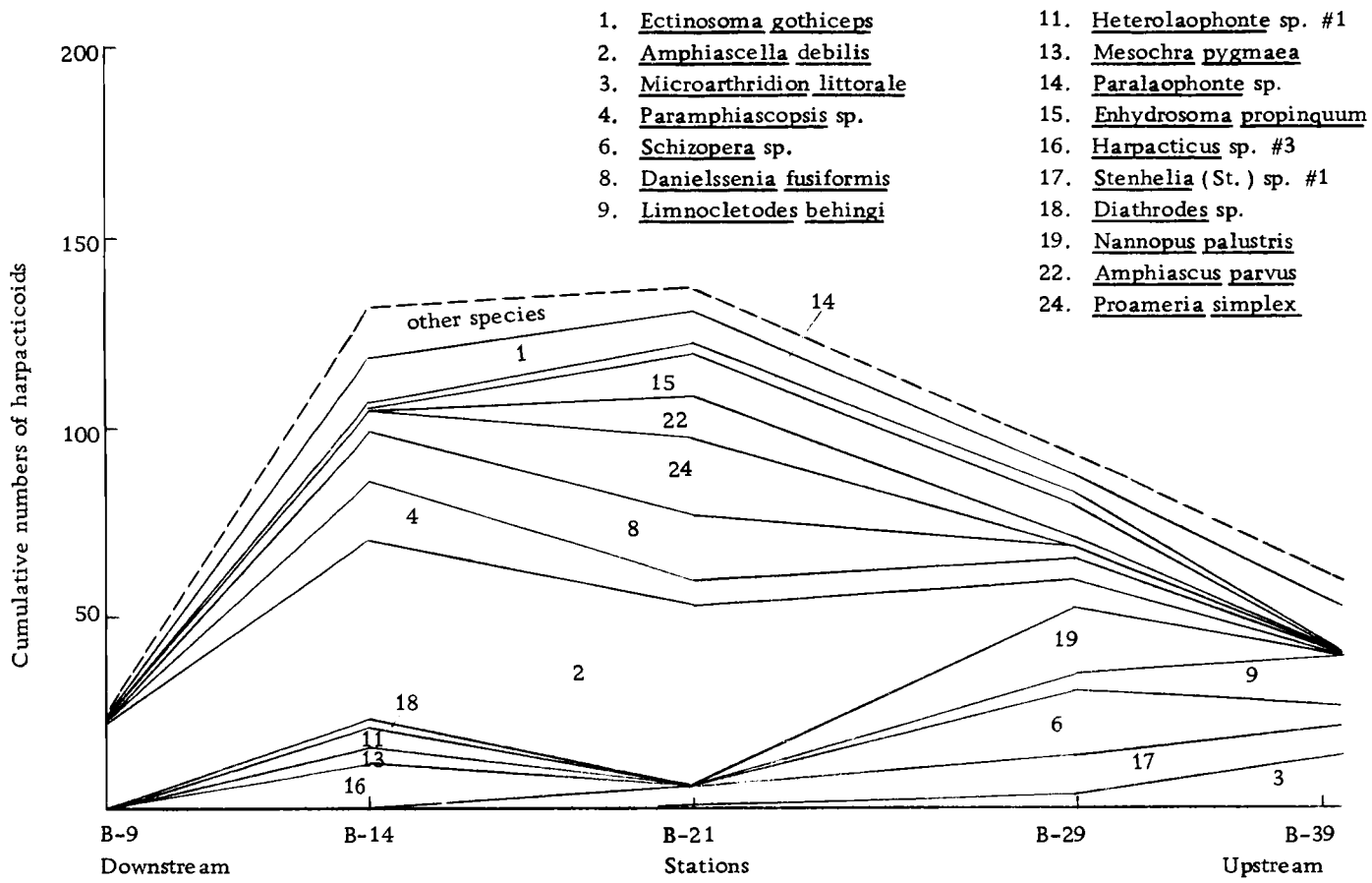


Figure 33. Cumulative species distributions for the bay in the Fall (11 and 14 December); based on the average of two cross channel cores at B-39, B-29, B-21, B-14 and one core (station 14) at B-9.

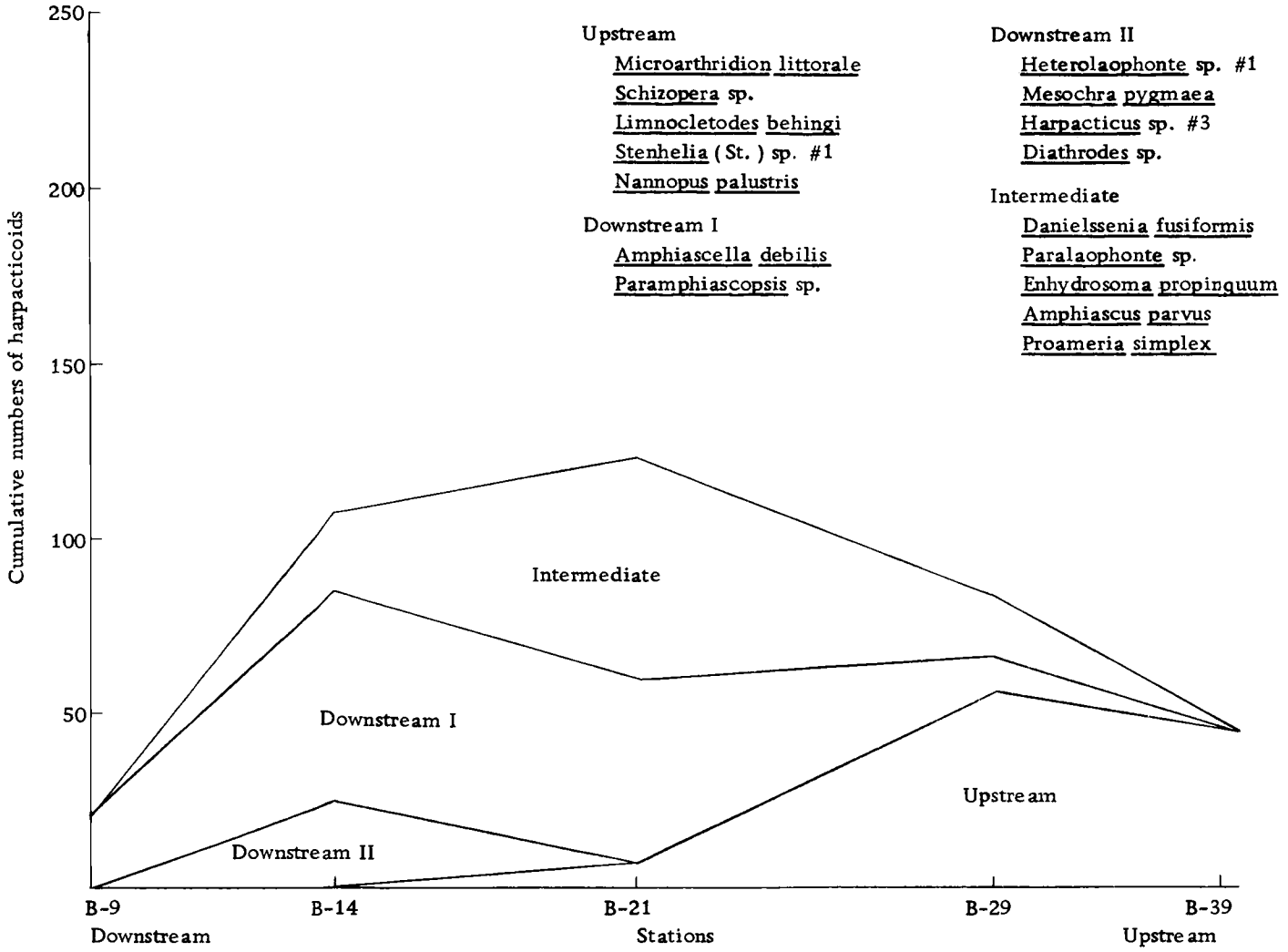


Figure 34. Cumulative species distributions for the bay (as seen in Figure 33) grouped into four assemblages.

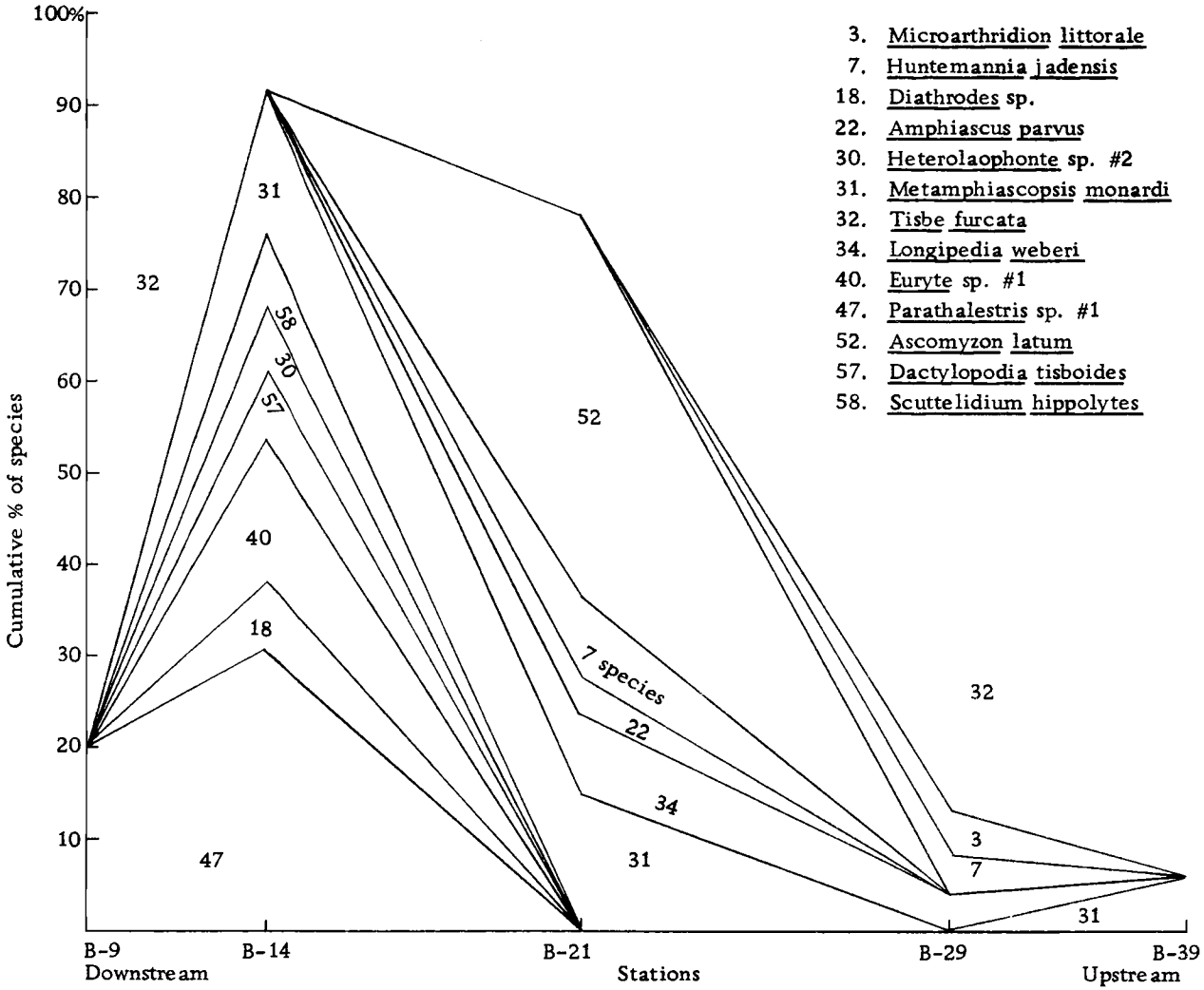


Figure 35. Cumulative species distributions for the bay in the Fall (22 and 27 October) from skimmer samples.

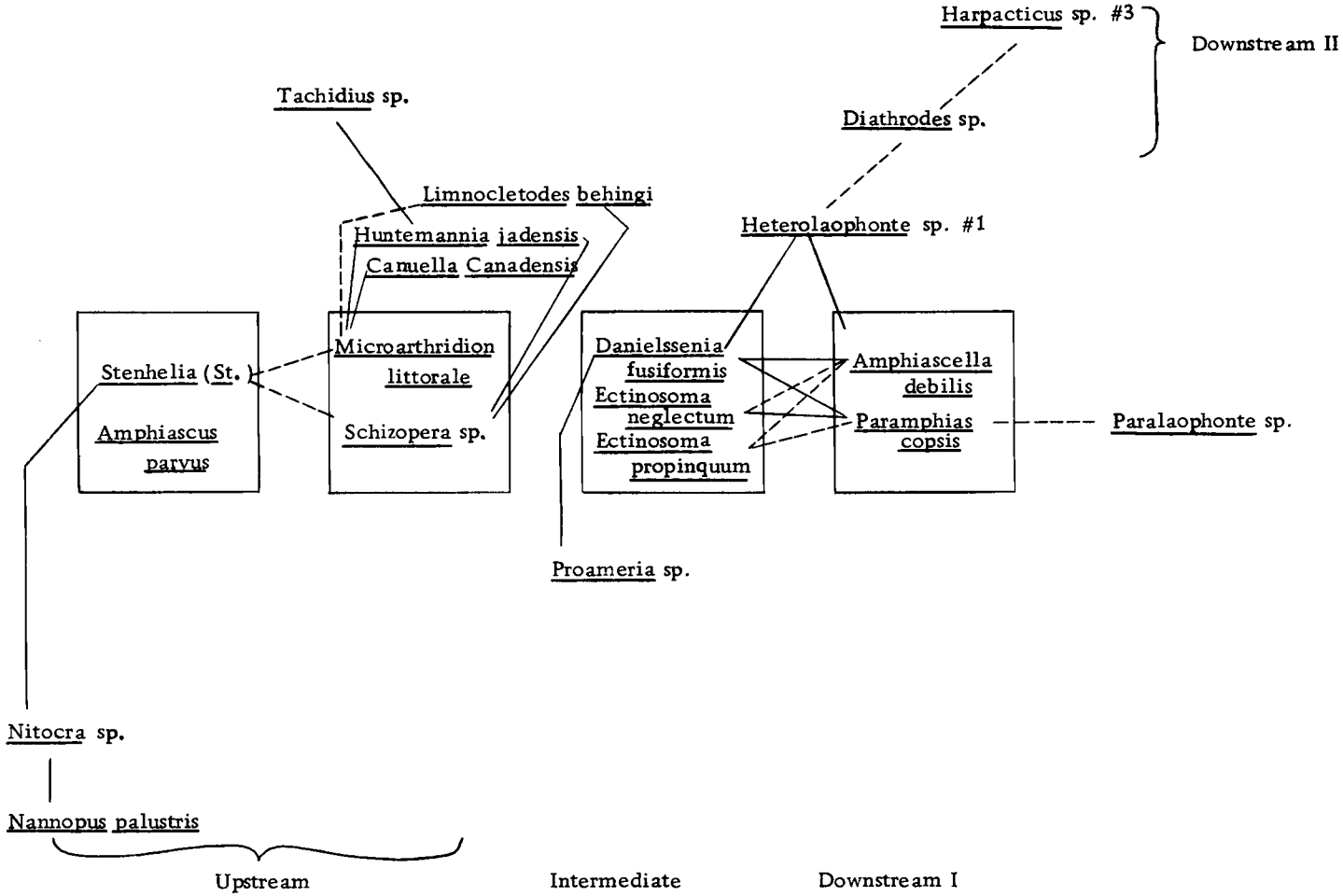


Figure 36. Species associations as determined by the Fager-McConnaughey method. (from the core data)

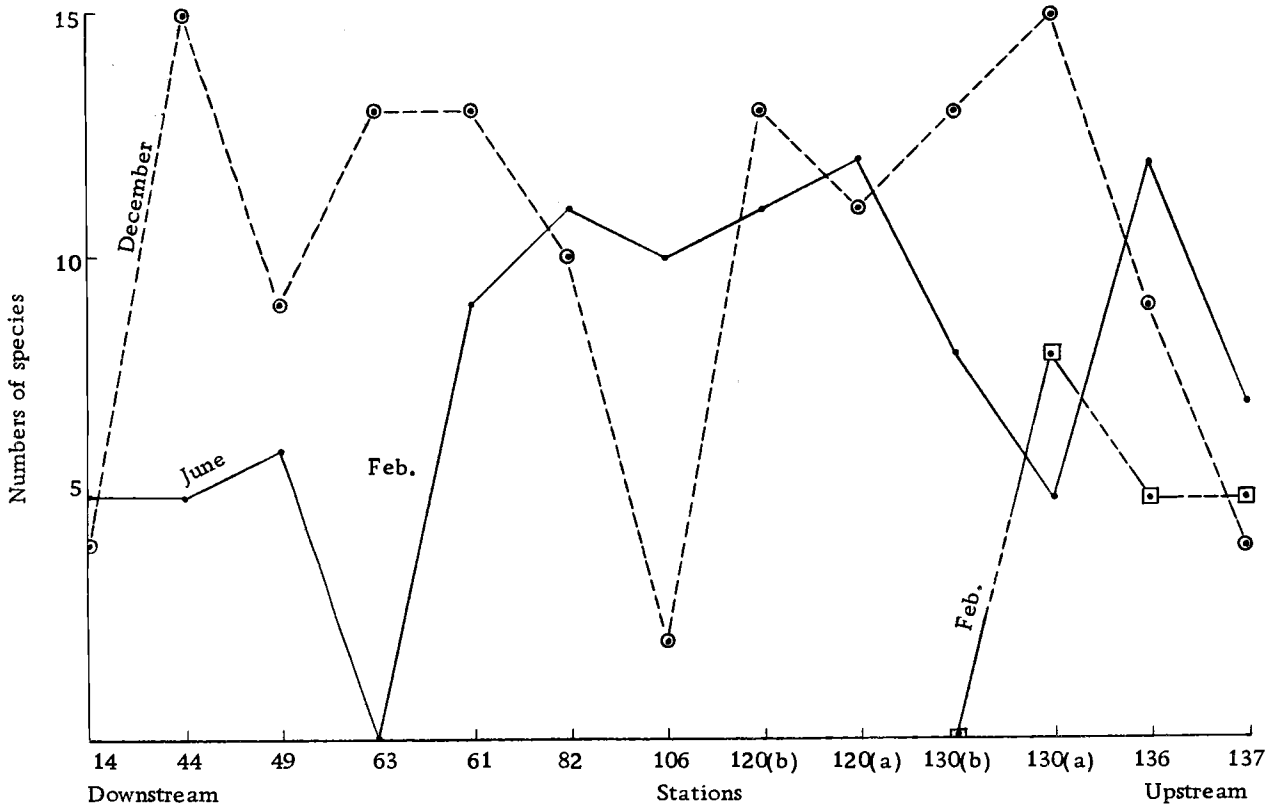


Figure 37. Number of species per core during the three seasons sampled; based on one core per station.

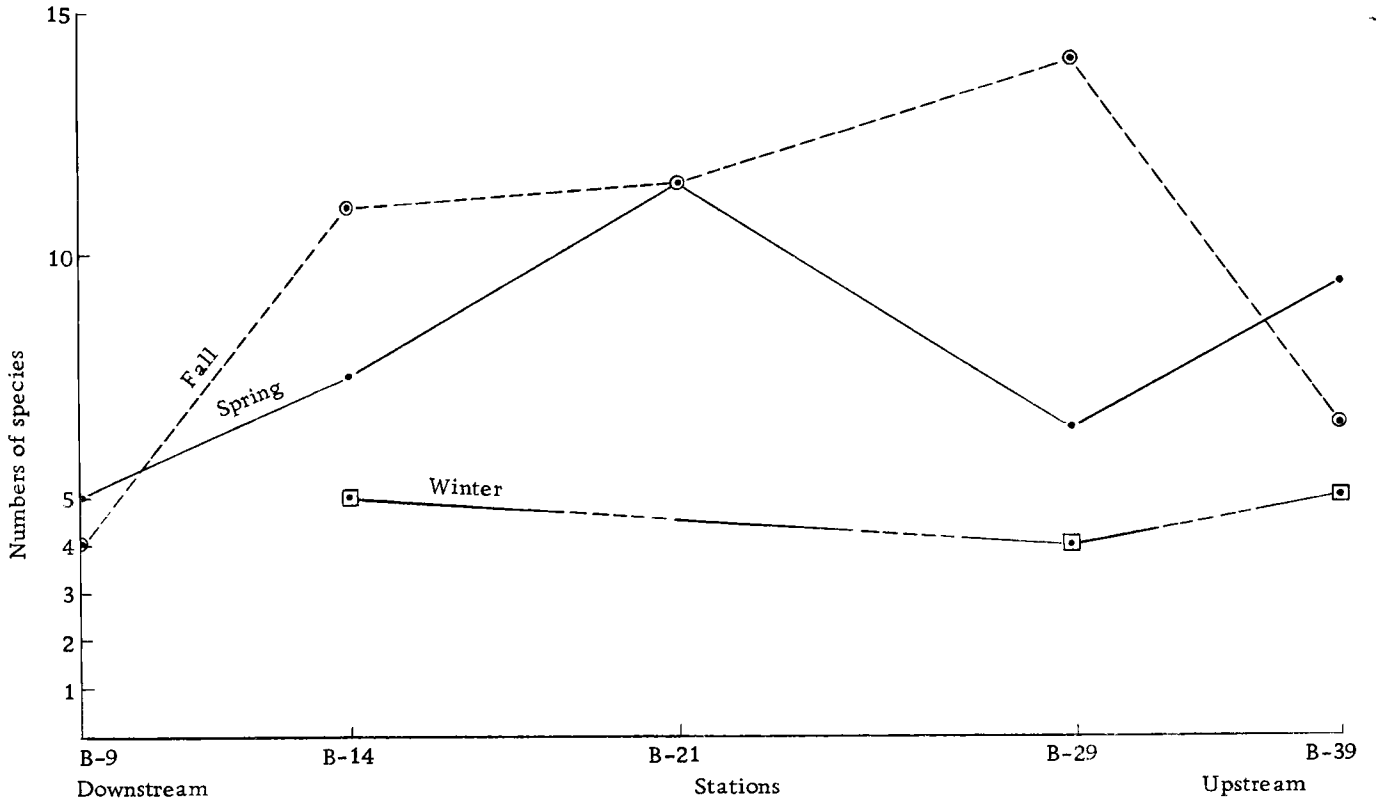


Figure 38. Number of species per core on the bay during the three seasons sampled; based on the average of two cross channel cores at B-39, B-29, B-21 and one core (station 14) at B-9.

to be expected in that part of the estuary where the salinity variation is greatest, and he also stated that this appears to be true for numbers of individuals. Data on numbers of species are inconclusive in this study, but it appears that as many species occurred (figure 37, 38) where the daily temperature change was greatest, at B-21 (figure 2a) as anywhere in the bay during June. The upstream stations, 136 in the bay and 79 in King Slough, were higher in total numbers (figures 18, 19, 20) and as high or higher in numbers of species (figures 37, 38) relative to any other station, and 136 was in the area of greatest salinity change (figure 26) in the bay and probably 79 was in a similar region in the slough. If daily temperature change were critical for populations numbers and numbers of species, station 82 should be low in both because it is high intertidally with high temperatures when exposed and low temperatures at high tide; however, station 82 was relatively high in both numbers of individuals and numbers of species. Harpacticoids appear not to support the theory that the lowest numbers of individuals and species occur where the salinity variation is greatest nor does temperature variation seem to affect total populations or species numbers adversely. In harpacticoids there may be species adapted to the points at which the greatest changes in physical factors occur.

Eel grass samples. Eel grass was sampled only during the spring at five stations and because it was not treated quantitatively only relative values or percentages of total harpacticoid populations can be discussed. Although no quantitative evaluations can be made, it is noted that the harpacticoids were present in moderate numbers on the eel grass substrate, and in the case of station 63 downstream in Sally's Bend, the harpacticoid population was much denser than at the other stations. The eel grass at this station had been picked from a bottom skimmer and therefore had been more deeply submerged and had lush microplant growth which may have affected the harpacticoid density.

Whereas the species composition and dominant forms found on the eel grass (figure 30) differ considerably from those of the cores (figure 25), three categories of distribution occur (figure 31). For a better comparison, core groups were plotted as cumulative percent (figure 29). There are forms with distribution centers upstream; those which peak downstream; and those concentrating in "mid-bay" or at B-21.

The dominant upstream forms on the eel grass (figure 30) were Harpacticus uniremis which was poorly represented in the cores, Amphiascus parvus of which one specimen at station 79 in King Slough was found in cores, and Mesochra pygmaea also in low

numbers in cores. Other forms with upstream maximums were Tisbe furcata, Tegastes sp., Schizopera sp, Canuella canadensis and Parathalestris sp. #1. Tegastes sp. and Tisbe furcata were in higher numbers on eel grass than in core samples, and Canuella canadensis was markedly lower. Schizopera sp. showed about the same numbers on eel grass and in the cores. Parathalestris sp. #1 was not found in any cores. Probably the most striking difference between the upstream core (figure 25) and eel grass (figure 30) distributions was the almost complete absence of Microarthridion littorale and the emergence of Harpacticus uniremis and Amphiascus parvus as numerical dominants.

In the only downstream eel grass sample (figure 30), station 63 (B-14), Heterolaophonte sp. #1 represented over 64% of the harpacticoids of which there were only three other species, Amphiascella debilis, Paramphiascopsis sp. and Diathrodes sp. Amphiascella debilis and Paramphiascopsis sp. had eel grass distributions similar to those of the cores with representatives the length of the bay but population centers downstream. Diathrodes sp. was more abundant on eel grass than in cores (three specimens from cores) and extended upstream to B-29; in the cores it was found at three lower stations and not above station 61.

Station 120 (a) (B-21) was characterized by a large number of

Ameria sp. which were not found in the cores, plus the appearance of four species which did not occur in other eel grass samples. These latter, Ectinosoma gothiceps, Danielssenia fusiformis, Paradatylopodia sp. #1, and Parathalestris sp. #2 were in low numbers, but Ameria sp. was abundant and showed a population concentration at B-21.

The only eel grass sample taken in King Slough, at station 76, was comprised of Amphiascus parvus, Paradactylopodia sp. #2, Schizopera sp., Diathrodes sp., Paramphiascopsis sp., Heterolaophonte sp. #2, Heterolaophonte sp. #3 and Huntemannia iadensis ranking in abundance from highest to lowest in the order given. Amphiascus parvus and Schizopera sp. showed relative abundance similar to that found at station 136 on eel grass. The others except Huntemannia jadensis did not occur at station 136 (B-39) and two of them, Heterolaophonte sp. #3 (tentative identification) and Paradactylopodia sp. #2 were found in no other sample, core, skimmer or eel grass. The only similarity between station 76 (King Slough) and B-39 was the presence of Amphiascus parvus and Schizopera sp. at both stations. Differences were the additional species at station 76 and the absence there of species which were present at station 136, particularly Harpacticus uniremis and Mesochra pygmaea which were 42% and 17% of the upstream

population respectively.

The data indicate that the eel grass samples, although comprised primarily of species which occurred in the cores, were dominated by species which were entirely absent or in very low numbers in the cores. This was particularly true upstream where Harpacticus uniremis, Amphiascus parvus, and Mesochra pygmaea represented over 80% of the eel grass population and 0.6% of the mud dwellers, and the overwhelming core dominant, Microarthridion littorale was nearly absent from the eel grass environment. At station 120 (a) (B-21) the most numerous species was Ameria sp. which didn't occur in June cores. At the downstream station the difference between eel grass and mud populations was not as clear, but Heteroolaophonte sp. #1 replaced Amphiascella debilis as the dominant form. The eel grass has its own populations clearly distinct from those of the mud, but some species are found in moderate numbers in both habitats. These latter species probably move freely from one habitat to the other and therefore might be caught and transported more easily by current. This could help to explain how Paramphiascopsis sp. and Amphiascella debilis, which occur in both eel grass and mud and have downstream centers of populations, extend upstream. Ectinosoma gothiceps is a numerous form in cores which apparently is not suited to the eel grass environment.

The distribution of Diathrodes sp. suggests limitation by oxygen deficiency. Several specimens of Diathrodes sp. were counted in the downstream cores during June, but none upstream at the more muddy stations; on the eel grass it was found at all stations except 136, which suggests that lower salinity and higher temperatures upstream are not limiting factors, but that the low oxygen tensions in the sediment drives it to the eel grass where oxygen is more available. Possibly a more reasonable alternative is that it is an eel grass form found only adventitiously in core or skimmer samples.

The three group distributional pattern in the eel grass samples (figure 31, discussed on page 39) which is similar to that of the core samples as plotted by percent (figure 29), is of particular value because the sediment samples are represented by two samples from opposite sides of the channel to minimize differences due to sediment. The eel grass samples were all taken from a uniform substrate so that distributions must be due to other effects, i. e. salinity, temperature or oxygen. Because patterns for eel grass and sediment are similar, the assumption that sediment effects have been minimized in the core analyses appear reasonable. Also the presence of a marked peak in population for Ameria sp. plus four other endemic species on the eel grass at B-21 (figure 31)

indicates that the intermediate groups shown for the cores (figures 28, 29) and for the eel grass (figure 31) are probably both valid although species composition is different for the two groups.

Skimmer samples. The harpacticoids from the channel (figure 32) taken by bottom skimmer were so few in number that it is difficult to draw many conclusions from them.

The upper channel stations B-39, and B-29 were dominated by Microarthridion littorale as were the cores. Also present at one or both stations were Canuella canadensis, Microarthridioninae, Ectinosoma gothiceps, Ectinosoma neglectum, Paramphiascopsis sp., Huntemannia jadensis and Tisbe furcata. Tisbe furcata made up 50% of the count at B-21 where also were Typhlamphiascus confusus, Paramphiascopsis sp., Nannopus palustus, and an unidentified form. B-14 had as dominants Enhydrosoma propinquum, Amphiascella debilis, and Paramphiascopsis sp. as well as low percentages of Enhydrosoma sp. #1, Huntemannia jadensis, Typhlamphiascus confusus, Heterolaophonte sp. #1, Harpacticus uniremis, and Tisbe furcata. At B-9 were Ryncothalestris sp. Ameria sp. and Tisbe furcata. It should be noted that Tisbe furcata was in all channel samples except B-39 after appearing only twice in all cores and eel grass samples.

Channel samples in the spring were composed primarily of forms found in the shallower flat areas which may have been adventitiously washed into the channel by tidal currents. Tisbe furcata plus possibly Ryncothalestris sp. and Paraleptastacus sp. may comprise the truly endemic channel population. The presence of Ameria sp. only at B-9 in the channel and on eel grass at B-21 cannot be explained, although possibly oxygen values may influence this form in the manner suggested for Diathrodes sp. on eel grass. Paraleptastacus sp. is an interstitial form found in sand which was collected by a more deeply digging sampler at B-29. The samples presented here do not generally represent these deeper forms. Grab samples which have been taken from the channel recover these species and will be processed at a later date. Although channel samples were nonquantitative, it appeared that population densities were low in the channel generally and that the higher numbers of harpacticoids in the channel were upstream.

The Fall Sampling Period

Core samples. December core samples had more harpacticoids per core at the downstream stations than at the upper stations (figure 18, 20). King Slough although represented by one station, 76, had a small population (figure 19) comparable to the upper bay

B-39. The dominant upstream forms (figure 33) were Microarthridion littorale, Stenhelia (St) sp., Schizopera sp., Nannopus palustris and Limnocletodes behingi. Species which occurred only at B-14 were Harpacticus sp. #3, Mesochra pygmaea, Heterolaophonte sp. #1 and Diathrodes sp. Species which peaked in population at B-14, but extended to other stations were, Paramphiascopsis sp. and Amphiascella debilis, of which the latter was the dominant species at B-9, B-14 and at B-21. The major forms which had population peaks at B-21 were Danielssenia fusiformis, Proameria sp., Amphiascus parvus, and Enhydrosoma propinguum. Ectinosoma gothiceps was distributed nearly equally at all stations.

Major forms in King Slough (not graphed because only one station taken) were Microarthridion littorale, Ectinosoma gothiceps and Microarthridioninae plus 10 other species represented by only 13 individuals. At the upstream bay station and in King Slough there was lack of dominance by any one species; for example, at B-39 five species occurred in nearly equal numbers.

In figure 34 an attempt has been made to separate the animals into groups according to the station at which their population peaks occurred. Patterns are not clear and much overlap is present; however, there does appear to be a definite upper bay population and lower bay group. The downstream species have been divided

into two groups; downstream I, found only at B-14 and downstream II which peaks at B-14 but also extends upstream and downstream. The group centered at B-21 is listed as intermediate and is composed of four species which occurred in moderate numbers; Danielssenia fusiformis, Enhydrosoma propinquum, Amphiascus parvus, and Proameria simplex.

Skimmer samples. The channel skimmer samples taken in late October (figure 35) contained very different animals from those taken in the cores. Tisbe furcata predominated at B-9, B-29, and B-39 and was also present at B-14, B-21 and B-39. Parathalestris sp. was present at B-9 and B-14. Ascomyzon latum, a flattened cyclopoid copepod, was present at B-21 in large numbers. Other species were present in lower numbers.

In the channel there were primarily endemic cyclopoid and harpacticoid copepods some of which were characterized by a dorsal-ventral flattening. This flattening found in Tisbe furcata, Ascomyzon latum, Scuttelidium hippolytes, Zaus aureliis, Euryte sp. #1, Euryte sp. #2, and Dactylopodia tisboides probably is an adaption which helps the animals to maintain position against the channel currents. However, it is known that species of Ascomyzon are parasitic or commensal on invertebrates and algae. Therefore it is possible that some of these flattened forms are facultative

parasites which drop from the host in reduced salinity. The skimmer samples were taken in late October when many anadromous fish (salmon) were in the bay. Four of the species found were present only in fall skimmer samples.

The seasonal graphs of salinity and temperature (figures 3 through 8) show that there was little decrease in salinity in the fall of 1965. The salinities are higher than June at B-29 and B-39 and the values through the fall were near 25 o/oo at these stations. The spatial survey taken 23 December, 1965 (figure 12) indicates that the salinity gradient from B-8 to B-39 was less that 8 o/oo at high tide. Lack of rain and low river runoff maintained salinities at a high level. Decrease in air temperature and insolation because of the season lowered the water temperatures upstream so that the higher temperatures, because of the marine influence, were found in the lower bay. Salinity and temperature gradients existed and it is suggested that they played a role in the distributional patterns presented for harpacticoid copepod species. Which factor was critical and what other factors may have affected these distributions cannot be determined, but it is hoped that seasonal comparisons will answer some of these questions.

Correlation Coefficient

In order to validate the species assemblages shown in figures 23, 27, 28, 31 and 34 a quantitative method of comparing individual species described by Fager (1957) and modified by McConnaughey (1964) was used. This system, based on presence or absence of species, uses a "trellis diagram" with species listed in order of decreasing occurrence (Table 6). In each square species pairs are compared according to the following relationship:

$$c = \frac{(A+B)C}{AB} - 1$$

Where:

A = number of occurrences of species A
B = number of occurrences of species B
C = number of joint occurrences

Correlation coefficients c, range from positive to negative but only positive values are considered.

Table 6 shows the correlation coefficients for the most commonly occurring 23 species in the cores. Figure 36 presents species assemblages. The boxes (figure 36) indicate correlation coefficients $> .50$, the solid lines coefficients $< .50$ and $> .40$, and the dotted lines coefficients $> .40$ to $.19$. Ectinosoma gothiceps, not included in the scheme because of its ubiquitous distributions, relates most closely to the Amphiascella debilis assemblage. Typhlamphiascus confusus and Mesochra pygmaea are not included

because of low or minus correlation coefficients.

The species compared break into four assemblages at the .50 correlation coefficient level. These four groups (figure 36) fit the relationships deduced from the graphs (figures 23, 27, 28, 29 and 34) and are matched with the appropriate assemblage in figure 36. Downstream I contains Amphiascella debilis and Paramphiascopsis sp. in both cases. Intermediate contains Danielssenia fusiformis, Ectinosoma neglectum, and Enhydrosoma propinquum in the Fager-McConnaughey representation (figure 36) and in the graphic representation for fall (figure 34), Amphiascus parvus is included in this group. The upstream element of the graphic analysis is divided into two groups which represent fall and spring. The downstream II of the graphic analysis is represented by Harpacticus sp. #3, Diathrodes sp. and Heterolaophonte sp. #1 which shows correlation to both downstream I and intermediate in the Fager-McConnaughey analysis. The four major assemblages in the boxes in figure 36 combine into two groups, an upstream and a downstream element, when correlation coefficients as low as .19, as indicated by the lines, are considered. There is a close correlation between the downstream II and the intermediate group shown by the numerous lines among the five species. If Ectinosoma gothiceps were included in the downstream I group, it would connect the upstream and downstream elements with its

lines of correlation.

This analysis supports the division of species into assemblages as was done graphically. There are minor differences, but the two independent analyses are in general agreement.

Seasonal Variation in Population

A. Cores (numbers)

Figure 18 shows numbers of harpacticoid copepods per core for all cores taken, and figure 20 presents the same material averaged for two cores at B-39, B-29, B-21 and B-14 plus the one core at B-9. Figure 19 depicts numbers per core for King Slough. The winter period had the lowest numbers at all stations except B-39 and station 76 in King Slough where fall values were lower. Spring had very high values upstream which dropped rapidly at B-21 in the bay and at station 80 in the slough. Fall had higher numbers downstream and the lowest values of any season upstream.

Spring upstream highs are interpreted as being indicative of optimum conditions of salinity and temperature for certain species. By late fall there had been little change in salinity and yet populations dropped drastically due almost completely to the reduction in numbers of Microarthridion littorale.

It appears that the lowering of temperature in the fall is

responsible for the reduction in numbers and that M. littorale is a spring and summer form requiring lower salinities and nigh temperatures. Downstream differences in total numbers of harpacticoids from spring to fall are not pronounced, although figure 18 shows a possible increase in fall harpacticoid numbers over spring based on two stations, 44 and 63. These are intertidal stations and lower temperatures in the fall possibly enabled the more marine stenothermal forms to better survive on the cooler flats.

Low numbers in winter have already been attributed to low salinities and other factors associated with high runoff. Also it should be noted that reduction of phytoplankton, zooplankton and benthic algae greatly reduce the available food supply in the muds (Perkins, 1958) thus affecting benthic copepod numbers.

The number of species by season and by type sample is tabulated in Table 7. Although the cores had the most species, there were were far too few skimmer and eel grass samples taken for conclusions to be drawn. Seasonal differences are of significance and the low winter values were undoubtedly due to the factors discussed in the paragraph above.

Figures 37, 38, 39 and Table 7 indicate higher species numbers for fall than spring in the cores. Upstream the difference is less

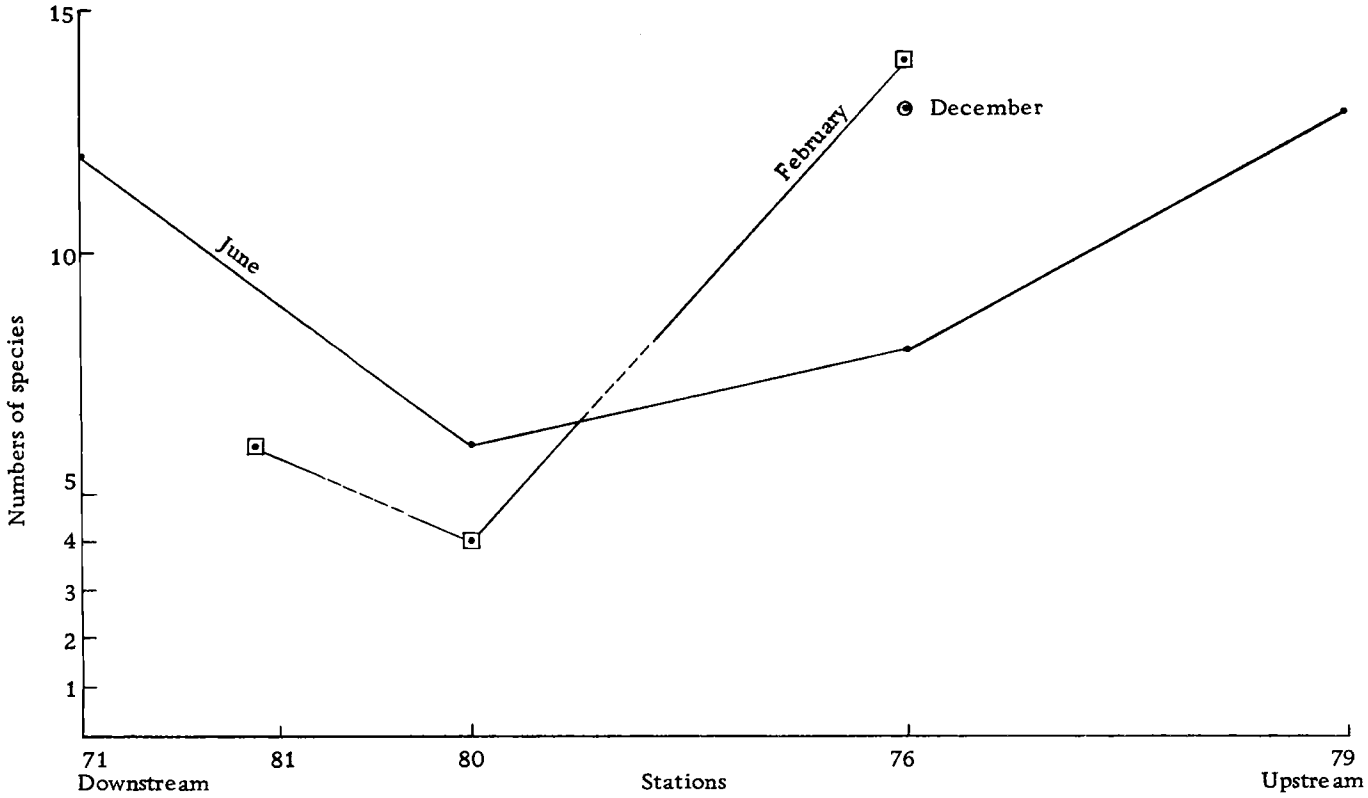
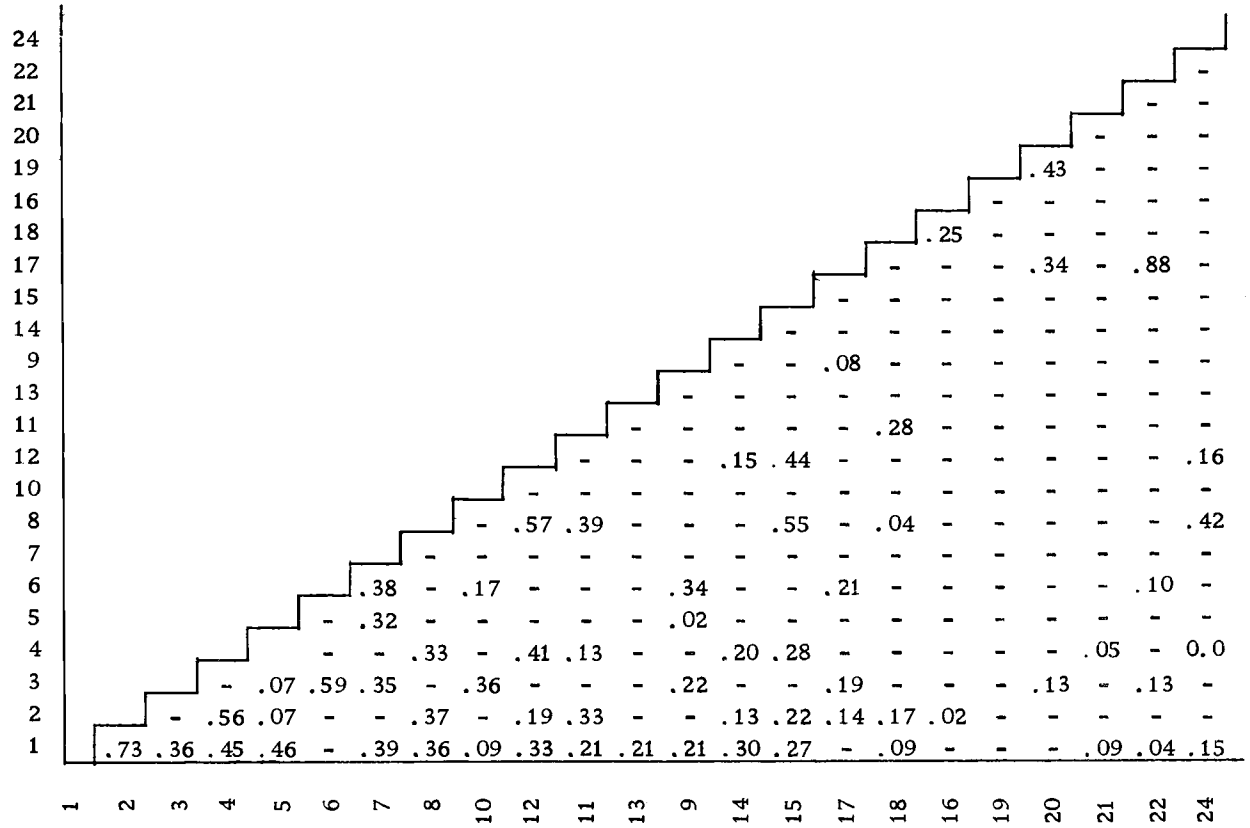


Figure 39. Number of species per core in King Slough during the three seasons sampled; based on one core per station.

Table 6. Trellis diagram comparing all possible pairs of 23 species to determine correlation coefficients, the numbers in the table. The numbers on the axes represent the species and can be matched with the numbered species in Table 2b.



clear, but at downstream stations 61, 63, 49, and 44 there is a clear cut increase in fall species numbers. An explanation could be that the prolonged period without appreciable decrease in salinity (summer and fall), plus the absence of intrusions of warmer upstream water and cooler temperatures on the tide flats enabled more stenohaline, stenothermal marine forms to enter the lower portion of the bay. The temperature may not be critical; it is possible that merely the long period of time without salinity dilution was responsible, particularly since there is not a great difference in the lower bay between summer and fall temperatures except in the tide flats.

Table 7

Number of species by type sample and season

	Core	Skimmer	Eel grass
Winter '65	23	9	--
Spring '65	31	19	23
Fall '65	36	18	--

Upstream increases in species number could be attributed to: the reduction of temperature which allowed stenothermal cold forms to move upstream; the reduction in numbers of Microarthridion littorale which removed competition and permitted other forms to enter; a prolonged period of time which enabled individuals or new

generations to invade upstream areas; or a combination of these factors.

The specific changes from spring to fall in the groups of species classed as upstream were as follows: a great reduction in the numbers of M. littorale and Canuella canadensis; increase in numbers of Schizopera sp. and Nannopus palustris; and the introduction of Limnocletodes behingi, previously found only in upper King Slough in June, and Stenhelia (St.) sp., unobserved from previous sampling periods. The intermediate group centered at B-21 increased from spring to fall in numbers of individuals and species with the addition of Proameria simplex and Amphiascus parvus. This group also extended its distribution both upstream and downstream. The downstream I group, Amphiascella debilis and Paramphiascopsis sp. changed little downstream from spring to fall but increased in numbers upstream at B-21 and B-29. The only change in the fall for the downstream II group was the addition of Mesochra pygmaea which had been upstream in distribution in spring both on eel grass and in cores. This type distribution correlates with warmer temperatures upstream in the spring and warmer temperatures downstream in the fall which indicates that this species may be stenothermal to warmer temperatures and euryhaline. The further extension upstream of forms from the downstream I and intermediate

groups has been discussed above; however, the downstream extention of the intermediate group indicates that the survivors of the winter conditions may have been centered near B-21 and gradually extended their distributions both ways throughout the remainder of the year. From the physical data, an upstream shift in the population center would have been expected, but the center of distribution at B-21 is more pronounced in winter than in the spring. Another possible explanation is that this group requires the salinity ranges found at B-21 and is more successful under cooler temperatures. The downstream II group appears to be a stenohaline group requiring nearly marine conditions because it did not migrate upstream with the relaxing of high temperatures upstream.

Seasonal changes in King Slough are not as marked as in the bay. The winter population in the slough compares well with the spring population in numbers (figures 22, 26). At station 81 in both seasons the dominant forms were Amphiascella debilis and Paramphiascopsis sp. from the downstream I assemblage. Upstream in the slough the winter period was characterized by a lack of species dominance and by a large number of forms which included four fall or winter forms: Stenhelia (Del) normani, Stenhelia (St.) sp., Euryte sp. #1, and Ameriopsis sp. of which the latter occurred only in this sample. Unfortunately only one sample from the slough was

taken in the fall, which held a small number of individuals, as did the upstream station in the bay, but had 13 species present. The winter transect in King Slough is of particular interest, if it is assumed that this would be the pattern in the main bay with reduced runoff. It indicates that there would be little change in the fauna downstream with seasons and that in late winter species numbers would be high as well as total population, but without one dominant form as in spring. The high numbers at station 76 in winter may be indicative of a slight bloom in zooplankton and phytoplankton which does occur in February with fair and warm weather (unpublished data, Frolander, 1965b). The upstream and downstream assemblages appear in spring and winter (figures 23 and 28), however, the intermediate group may be absent due to the more compressed salinity and temperature gradients. The assemblage listed as intermediate for the slough doesn't contain the same species as that assemblage in the bay and is probably an artificial grouping.

Table 7 shows nine winter species in channel samples, 19 in spring and 18 in December. The winter and spring channel samples had species which were abundant on the mud flats, while in December the numerically important mud flat forms were almost absent from the channel (figures 24, 32, 35). Again, the only

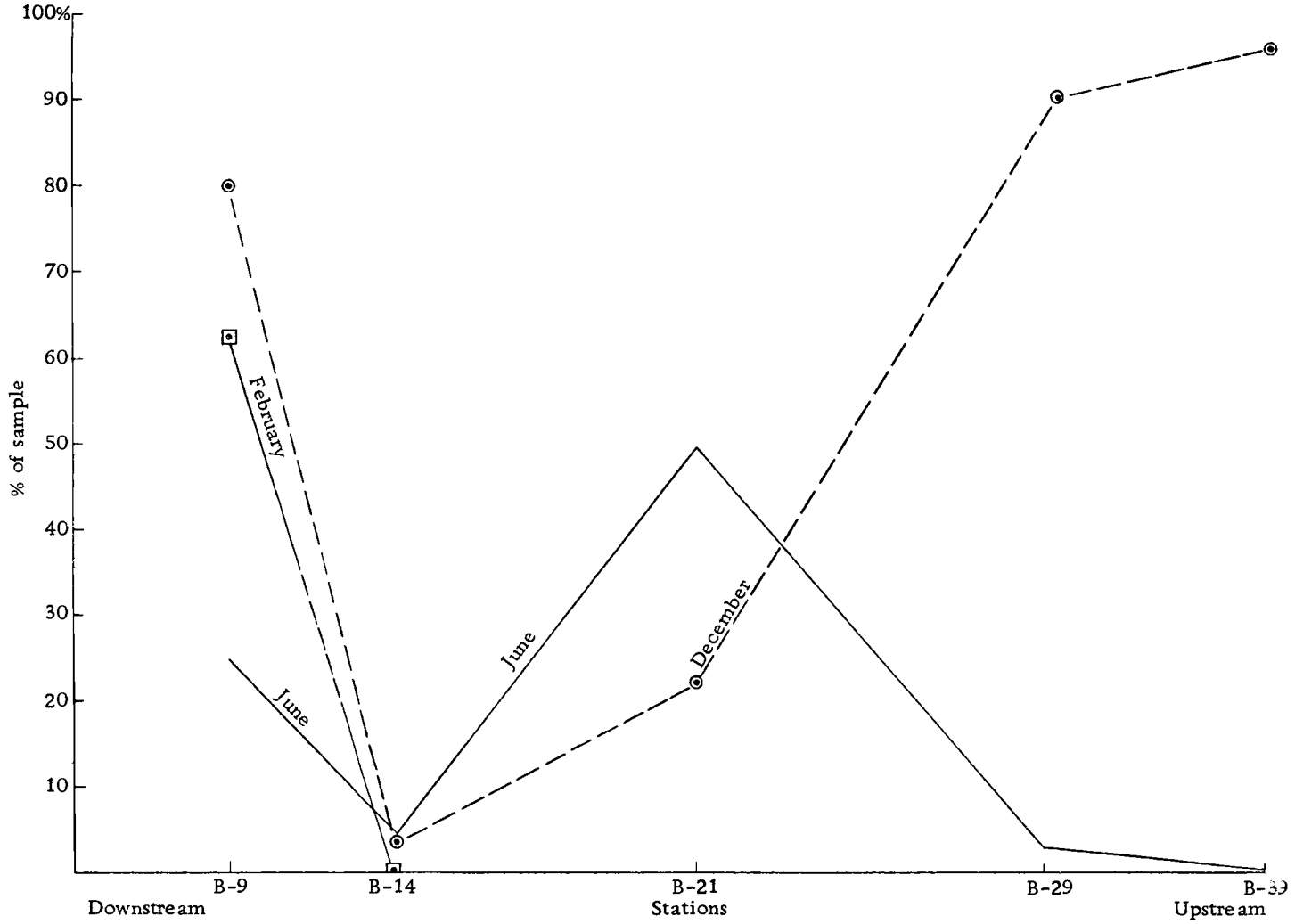


Figure 40. Distributional patterns of Tisbe furcata in the channel during the three seasons sampled. (from skimmer samples)

obvious changes in environment were a reduction of temperature plus slightly higher salinities over a period of time. It is hypothesized that the salinity and temperature factors enabled the stenohaline, stenothermal marine forms to move up the channel; because they were better adapted to the conditions of the channel, they replaced the mud flat forms.

Figure 40 shows curves for Tisbe furcata, the most numerous of the true channel forms for the three seasons. In winter it occurred only at B-9. In the spring it had maximum abundance at B-21 and extended up the bay. By late fall it was present at all stations and was the dominant form upstream. Again, this shows the upstream movement of the endemic channel population. Whether the cooling temperatures of late fall or the time element was most critical is not known.

Seasonal Species

Species which were encountered in only one season are listed by environment (channel, flat, or eel grass) in table 8. The fall period had the highest number of seasonal forms present, ten, followed by the spring period with eight. However, the difference between fall and spring becomes more significant when it is noted that half of the spring seasonal forms were on eel grass which was

Table 8

A list of the numbers of species, by season and environment, which were found in only one season

Environment	No. Endemic Species
Spring	
Eel grass	4
Channel	2
Flats and eel grass	2
	8
Fall	
Channel	4
Flats	5
Flats and channel	1
	10
Winter	
Flats	3
Channel	1
	4

not sampled in the fall or winter. If the eel grass had been sampled in the fall and winter probably some of the same species listed as seasonal on eel grass in the spring would have been found in the fall and winter, eliminating them from the list of seasonal species. Only four seasonal forms were found in the winter of which three were present at station 76 in King Slough. This indicates that in a year of more normal precipitation more winter seasonal forms might have been found in the bay. From the table it appears that there was a definite fall population with species which did not occur during the spring or winter, although many of these forms may have occurred during the winter of an average year. Most of the spring species were present during some other season of the year.

Reasons for seasonal species could be several. Most probable is that the higher temperatures of the spring and summer restrict some forms which are stenothermal cold species. Also, a prolonged period of high salinity in late summer and fall may allow more stenohaline marine forms to enter the bay. Several of the species apparently are adapted to lower salinities and cooler temperatures. These, such as the Stenhelia (St) sp., represent the true late fall or winter population upstream (figure 36).

Where the winter and fall forms are during the other seasons can only be guessed; some may have moved into the sampling

area from the ocean or from upstream; they could exist in the bay in such low numbers that they were not encountered during sampling; some mechanism for resisting unfavorable conditions such as a delay in hatching of eggs may exist.

Index of Diversity

Another means of looking at species numbers and diversity is a graphic method proposed by Sanders (1963) which gives an "index of diversity." To obtain this index, the diversity of a sample is compared to the maximum possible diversity. Maximum diversity or unity is obtained when all species within a sample occur in the same numbers. When the cumulative percentage of species is plotted against the cumulative percentage of individuals in a sample a curvilinear line is obtained like the example (figure 41). The ratio, "area of sample diversity," (X, Y, B)/"area of maximum diversity," (X, Y, A), is the "index of diversity." This method gives more an index of dominance of some species over others than the diversity of the sample. For example, if a population of 100 animals had two species with 50 individuals each, the index of diversity would be 1.0, but the population wouldn't be diverse.

The results of an analysis of some stations by this method (Table 9) gives much the same information that the graphic method

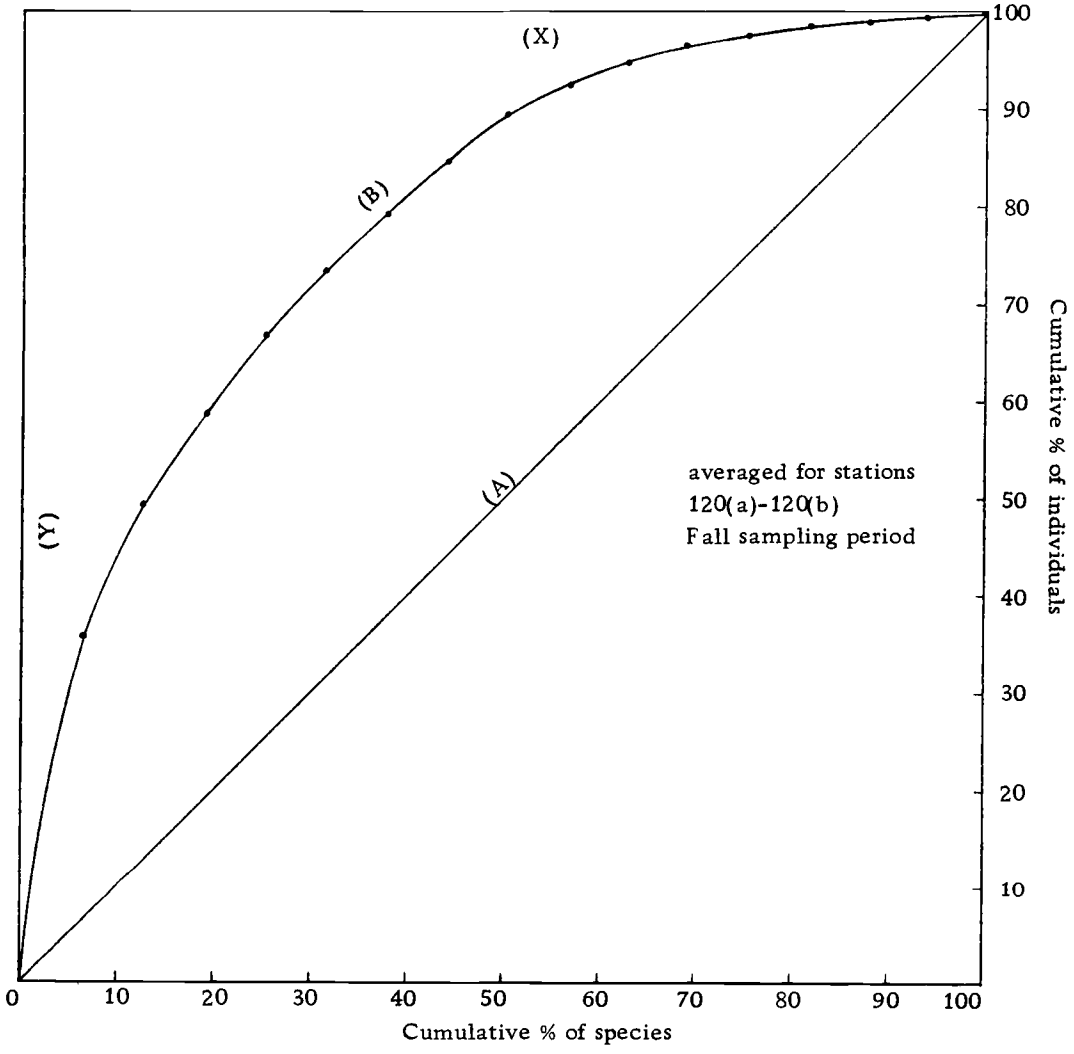


Figure 41. Example of graphic method of determining "index of diversity."

Table 9

Indices of diversity for individual stations or for an average of two stations at B-39, B-21 and B 14

Stations	Winter	Spring	Fall
B-39 (136-137)	.33	.19	.45
B-29 (130 (a)	.63	--	--
B-21 120 (a)-120 (b)	--	.40	.42
B-14 (49-61)	--	.44	.43
B-9 (14)	--	.52	.37
(80)	.61	--	--
(76)	--	.53	--
(79)	--	--	.39
Average	.51	.416	.411

The lines indicate that no sample was taken or that the value was not computed.

did. B-39 in the spring was dominated by one species, Micro-arthridion littorale which is reflected in the "indices of diversity."

Index of Affinity

When biological samples have been taken, it becomes a problem to determine how much uniformity or difference there is among samples. A system of measuring the degree of uniformity or affinity among biological samples has been explained by Sanders (1960) and is used here. The abundance of each species is expressed as a percentage of the total population. The percentages of each species are compared for two samples, and if the species is present in both samples, the lower percentage is taken as the common abundance value. These values are added for each species occurring in both samples and the total becomes an index of the fauna common to both samples. All samples are arranged at right angles to each other and all possible samples are compared in a "trellis diagram" (Table 10). This method of comparison has been used by several workers. Sanders (1960) presented a table which indicates some of the values which have been considered significant enough to separate faunas into associations or communities. Values considered of importance range as low as 24.6, although generally, values above 30.0 are used. Macfayden (1954) criticized the method,

Table 10. Trellis diagram comparing all possible pairs of core stations to determine indices of affinity, the numbers in the table. The core stations are listed on the axes followed by a letter to indicate the season, winter (W), spring (S), fall (F). The asterisk (*) indicates that calculation was greatly influenced by Ectinosoma gothiceps.

	137 S	136 S	130(a) S	130 S	130(b) S	120(a) S	120(b) S	106 S	82 S	61 S	49 S	44 S	14 S	79 S	76 S	80 S	71 S	137 F	136 F	130(a) F	130(b) F	120(a) F	120(b) F	106 F	82 F	61 F	63 F	49 F	44 F	23 F	14 F	76 F	137 W	136 W	130(a) W	63 W	80 W	81 W	76 W
76 W	52.4	56.5	42.8	47.8	22.7	22.6	3.2	1.7	0.0	0.0	0.0	1.2	45.4	41.2	20.6	0.0	42.6	28.2	16.2	5.6	0.0	0.4	0.0	8.3	1.2	1.2	1.2	1.2	2.4	0.0	30.8	39.4	9.2	36.6	0.0	0.0	1.2	16.8
81 W	84.8	81.7	86.4	25.0	23.8	4.4	5.0	3.3	1.2	4.7	4.4	48.1	43.6	2.0	1.2	39.5	28.3			8.2	6.8	1.2	1.6	0.0	2.1	1.2	1.2	.9	1.2	4.7	.9	31.3	17.3	5.8	14.1	4.4	.9	2.4	12.5	
80 W	79.6	84.0	30.8	28.5	10.9	10.9	4.8	7.7	11.9	5.1	47.0	49.6	8.8	7.7	37.5	34.2				9.8	9.1	4.0	7.9	0.0	1.9	1.2	2.3	7.7	7.7	12.3	4.6	29.5	27.9	4.6	12.4	12.3	7.2	7.8	10.5	
63 W	88.9	36.1	27.9	16.1	15.1	2.1	7.6	14.2	0.0	47.9	51.5	14.2	14.2	37.5	36.1					8.4	7.1	3.4	9.0	0.0	1.3	1.2	1.7	15.9	12.2	14.2	4.0	38.5	14.2	4.6	6.2	14.2	6.6	7.2	10.2	
136 W	32.1	30.5	13.6	8.0	4.4	6.8	7.1	0.3	43.4	44.8	7.1	10.4	37.5	29.0						9.2	10.8	6.0	10.3	0.0	3.2	3.4	2.7	8.4	9.7	7.7	4.0	32.0	18.3	4.6	10.6	7.1	6.6	7.2	11.9	
137 W	46.3	30.3	56.6	13.8	15.0	51.6	7.2	50.2	62.8	52.8	29.6	21.9	44.1							12.6	27.0	21.6	21.6	0.0	3.1	12.1	9.5	30.9	21.2	48.8	10.0	51.5	14.6	5.0	8.0	46.9	14.0	14.6	10.8	
76 F	34.0	15.3	23.9	31.9	12.7	14.6	29.2	29.2	17.8	37.6	21.3	27.9								14.3	46.9	41.0	41.2	0.0	3.7	37.4	28.7	25.9	26.1	6.6	17.3	36.0	12.4	4.6	13.7	6.6	31.9	33.8	10.2	
14 F	24.8	42.4	28.6	19.4	16.1	16.1	16.1	23.0	40.5	3.2	16.9									15.5	34.2	34.4	33.8	28.9	5.2	30.3	28.7	25.1	25.7	12.9	20.1	22.0	10.3	3.2	6.4	20.1	25.9	25.2	4.6	
44 F	14.8	17.6	53.2	10.1	18.9	28.3	55.3	27.6	1.3	25.0										8.7	14.8	11.2	15.1	3.2	2.7	11.2	10.9	30.0	29.5	58.8	11.8	31.0	7.8	.9	1.3	96.5	14.8	14.7	2.3	
49 F	56.7	29.4	10.0	26.6	7.1	0.0	0.0	21.2	12.6	12.0	1.7									6.8	31.4	29.6	32.5	17.0	3.1	37.8	25.7	40.4	51.5	7.0	25.5	10.0	2.1	0.0	3.1	4.2	28.6	28.6	.3	
23 F	4.0	20.1	7.1	2.9	0.0	55.9	6.6	6.0	2.0											6.9	21.7	39.6	33.1	0.0	0.6	46.0	19.3	16.0	17.7	11.9	45.4	11.7	0.0	2.9	0.0	4.5	26.6	45.4	.3	
44 F	20.4	12.1	18.6	7.1	0.0	.6	10.5	15.3	14.7	1.8										6.6	10.4	9.5	13.0	0.0	1.9	6.7	7.8	52.4	49.6	49.2	10.1	31.2	7.1	0.0	0.0	49.0	12.7	12.1	.3	
49 F	10.7	14.2	3.5	20.6	11.2	1.7	0.0	6.2	4.6	33.9	49.5	1.5								9.1	38.9	53.3	43.6	1.7	1.9	73.4	39.5	15.8	17.7	8.1	55.4	15.7	7.1	.5	6.2	7.6	46.5	75.5	.3	
63 F	43.9	19.2	22.5	3.6	54.2	11.1	.6	0.0	6.2	.6	40.5	73.4	1.5							6.8	31.4	29.6	32.5	17.0	3.1	37.8	25.7	40.4	51.5	7.0	25.5	10.0	2.1	0.0	3.1	4.2	28.6	28.6	.3	
61 F	3.6	3.9	1.3	4.6	4.1	1.3	9.2	1.3	0.0	7.4	3.9	1.9	1.9	2.2						8.7	14.8	11.2	15.1	3.2	2.7	11.2	10.9	30.0	29.5	58.8	11.8	31.0	7.8	.9	1.3	96.5	14.8	14.7	2.3	
82 F	0.0	6.0	1.4	3.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	3.8	50.0	0.0	1.1					15.5	34.2	34.4	33.8	28.9	5.2	30.3	28.7	25.1	25.7	12.9	20.1	22.0	10.3	3.2	6.4	20.1	25.9	25.2	4.6	
106 F	0.0	3.5	49.3	25.0	36.1	36.2	8.7	37.1	15.4	7.3	0.0	13.4	6.9	36.8	44.3	4.3				14.3	46.9	41.0	41.2	0.0	3.7	37.4	28.7	25.9	26.1	6.6	17.3	36.0	12.4	4.6	13.7	6.6	31.9	33.8	10.2	
120(b) F	52.4	0.0	6.2	52.9	35.7	9.4	15.5	5.1	43.0	13.2	3.4	.4	16.4	7.2	40.3	54.5	3.9			12.6	27.0	21.6	21.6	0.0	3.1	12.1	9.5	30.9	21.2	48.8	10.0	51.5	14.6	5.0	8.0	46.9	14.0	14.6	10.8	
120(a) F	67.7	45.3	1.4	8.2	42.1	33.9	17.4	21.4	6.5	25.7	24.7	9.9	4.2	21.8	4.3	37.5	39.9	17.0		9.2	10.8	6.0	10.3	0.0	3.2	3.4	2.7	8.4	9.7	7.7	4.0	32.0	18.3	4.6	10.6	7.1	6.6	7.2	11.9	
130(b) F	26.8	20.0	14.7	0.0	36.1	6.3	9.5	5.8	7.5	11.6	5.6	23.6	15.5	10.5	53.0	8.3	9.1	11.5	38.5	8.4	7.1	3.4	9.0	0.0	1.3	1.2	1.7	15.9	12.2	14.2	4.0	38.5	14.2	4.6	6.2	14.2	6.6	7.2	10.2	
130(a) F	35.4	25.7	11.0	10.5	0.0	3.3	0.6	2.5	21.0	10.8	27.9	4	55.2	21.3	9.7	27.1	27.0	6.6	8.4	38.0																				
137 F	31.7	21.4	6.8	3.6	0.0	.6	0.0	0.0	0.0	0.3	0.0	0.0	29.7	14.2	8.0	31.2	0.0	0.0	2.4	39.2																				
71 S	62.0																																						
80 S	0.0	19.0	10.1	47.9	56.6	47.5	1.6	4.2	59.7	41.1	27.3	24.0	18.7	41.6	26.3	7.1	0.0	6.2	19.2	46.5	61.3	.3																	
76 S	28.3	0.0	21.1	17.5	17.7	15.2	18.8	0.0	15.9	11.9	11.8	27.2	20.4	49.3	14.1	31.4	7.1	0.0	24.1	47.1	16.7	16.1	.3																
79 S	27.0	18.2	40.1	51.1	12.2	9.4	3.4	7.3	0.0	3.1	1.0	2.1	21.6	11.2	34.9	4.0	68.2	16.1	6.7	9.5	51.2	6.6	7.2	13.6															
14 S	56.8	18.0	14.9	61.4	65.8	28.8	18.7	3.8	7.5	0.0	3.3	1.8	3.1	17.2	13.3	23.8	4.0	53.5	25.9	12.9	23.5	18.3	6.6	7.2	39.2														
44 S	6.6	4.7	11.2	38.1	0.0	6.2	6.9	21.7	39.6	33.1	0.0	0.6	46.0	19.3	16.0	17.7	11.9	45.4	11.7	0.0	2.9	0.0	4.5	26.6	45.4	.3													
49 S	19.3	18.3	28.7	56.0	9.2	0.0	25.2	6.6	10.4	9.5	13.0	0.0	1.9	6.7	7.8	52.4	49.6	49.2	10.1	31.2	7.1	0.0	0.0	49.0	12.7	12.1	.3												
61 S	13.7	45.9	7.6	7.6	17.7	64.5	0.0	7.6	9.1	38.9	53.3	43.6	1.7	1.9	73.4	39.5	15.8	17.7	8.1	55.4	15.7	7.1	.5	6.2	7.6	46.5	75.5	.3										
82 S	30.8	43.3	35.5	4.2	4.2	13.3	34.3	0.0	4.2	6.8	31.4	29.6	32.5	17.0	3.1	37.8	25.7	40.4	51.5	7.0	25.5	10.0	2.1	0.0	3.1	4.2	28.6	28.6	.3									
106 S	24.8	42.4	28.6	19.4	16.1	16.1	16.1	23.0	40.5	3.2	16.9	15.5	34.2	34.4	33.8	28.9	5.2	30.3	28.7	25.1	25.7	12.9	20.1	22.0	10.3	3.2	6.4	20.1	25.9	25.2	4.6							
120(b) S	34.0	15.3	23.9	31.9	12.7	14.6	29.2	29.2	17.8	37.6	21.3	27.9	14.3	46.9	41.0	41.2	0.0	3.7	37.4	28.7	25.9	26.1	6.6	17.3	36.0	12.4	4.6	13.7	6.6	31.9	33.8	10.2						
120(a) S	46.3	30.3	56.6	13.8	15.0	51.6	7.2	50.2	62.8	52.8	29.6	21.9	44.1	12.6	27.0	21.6	21.6	0.0	3.1	12.1	9.5	30.9	21.2	48.8	10.0	51.5	14.6	5.0	8.0	46.9	14.0	14.6	10.8					
130(b) S	32.1	30.5	13.6	8.0	4.4	6.8	7.1	0.3	43.4	44.8	7.1	10.4	37.5	29.0	9.2	10.8	6.0	10.3	0.0	3.2	3.4	2.7	8.4	9.7	7.7	4.0	32.0	18.3	4.6	10.6	7.1	6.6	7.2	11.9				
130 S	88.9	36.1	27.9	16.1	15.1	2.1	7.6	14.2	0.0	47.9	51.5	14.2	14.2	37.5	36.1	8.4	7.1	3.4	9.0	0.0	1.3	1.2	1.7	15.9	12.2	14.2	4.0	38.5	14.2	4.6	6.2	14.2	6.6	7.2	10.2			
130(a) S	79.6	84.0	30.8	28.5	10.9	10.9	4.8	7.7	11.9	5.1	47.0	49.6	8.8	7.7	37.5	34.2	9.8	9.1	4.0	7.9	0.0	1.9	1.2	2.3	7.7	7.7	12.3	4.6	29.5	27.9	4.6	12.4	12.3	7.2	7.8	10.5		
136 S	84.8	81.7	86.4	25.0	23.8	4.4	5.0	3.3	1.2	4.7	4.4	48.1	43.6	2.0	1.2	39.5	28.3	8.2	6.8	1.2	1.6	0.0	2.1	1.2	1.2	.9	1.2	4.7	.9	31.3	17.3	5.8	14.1	4.4	.9	2.4	12.5		
137 S	52.4	56.5	42.8	47.8	22.7	22.6	3.2	1.7	0.0	0.0	0.0	1.2	45.4	41.2	20.6	0.0	42.6	28.2	16.2	5.6	0.0	0.4	0.0	8.3	1.2	1.2	1.2	1.2	2.4	0.0	30.8	39.4	9.2	36.6	0.0	0.0	1.2	16.8	

137 S	136 S	130(a) S	130 S	130(b) S	120(a) S	120(b) S	106 S	82 S	61 S	49 S	44 S	14 S	79 S	76 S	80 S	71 S	137 F	136 F	130(a) F	130(b) F	120(a) F	120(b) F	106 F	82 F	61 F	63 F	49 F	44 F	23 F	14 F	76 F	137 W	136 W	130(a) W	63 W	80 W	81 W	76 W

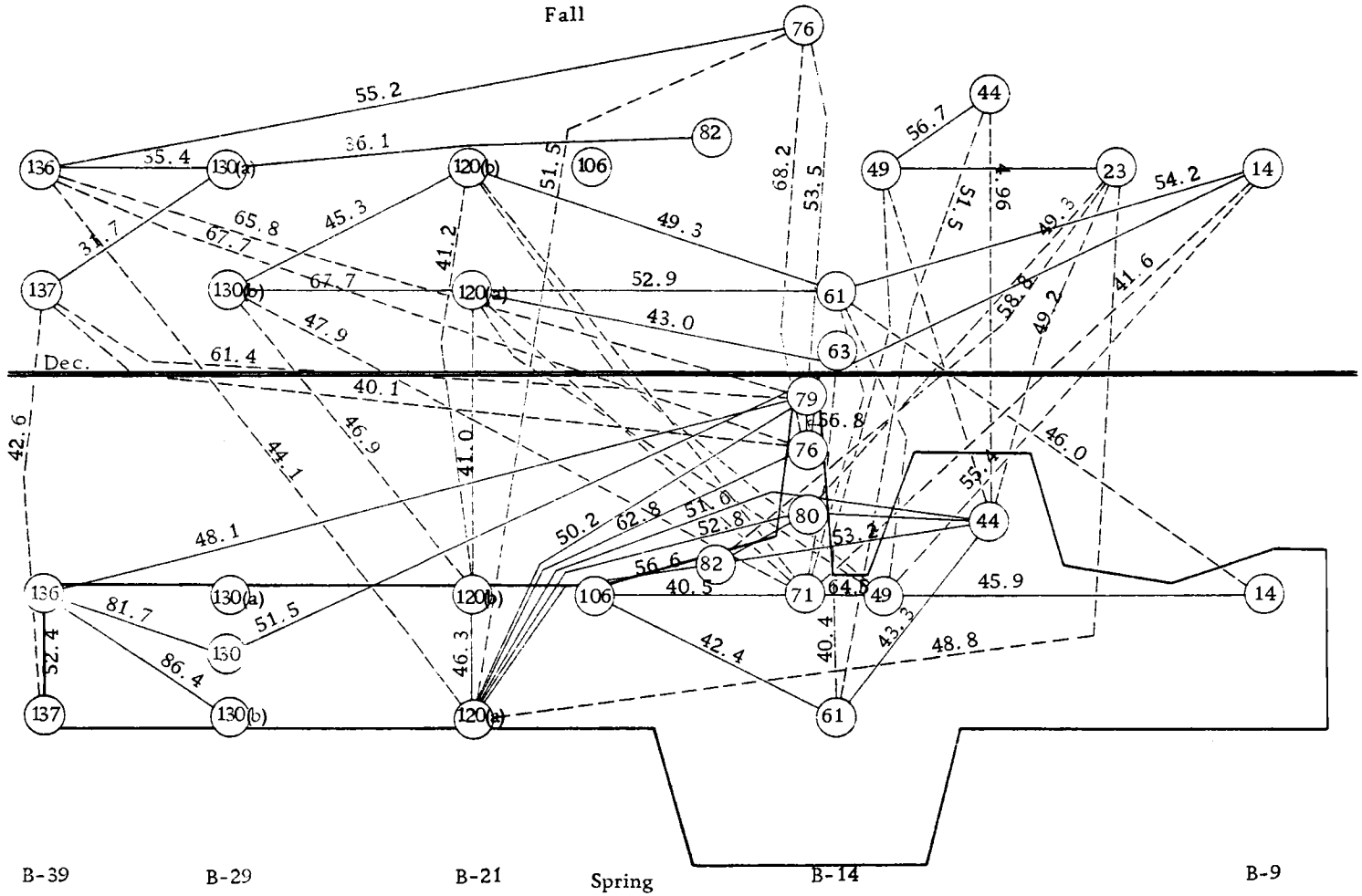


Figure 42. Spatial presentation of "indices of affinity among coring stations. Numbers within circles are the coring stations placed on a diagramatic outline of the bay. The lines among stations indicate affinity and the numbers on the lines indicate the indices of affinity among the two connected stations. The dotted lines represent the affinity among stations in the two stations in the two seasons shown, Spring and Fall.

stating that the "trellis diagram" was weak where a ubiquitous species was present. Such a species is present in this data, Ectinosoma gothiceps; however, it is often in low enough numbers that the indices of affinity are little affected. Moreover, the varying abundances of this nearly ubiquitous form may indicate valid changes in populations due to environmental changes. Indices greatly affected by E. gothiceps are starred in Table 10.

Figure 42 is a spatial representation of the indices of affinity found for the fall and spring sampling periods. The circles represent the coring stations and the lines the affinities among stations. No indices of affinity below .40 have been shown unless no higher affinity occurred for a core. The dotted lines indicate affinity among stations occurring in different seasons.

During the spring there was a high degree of affinity among the upstream bay stations, 136, 137, 130 (a), 130 (b) and 130, which had three indices of affinity over 80.0. These upstream stations also held affinity with the two upper King Slough stations, 76 and 79 but with no others. These seven stations contained what has been called the upstream fauna which was dominated in the spring by Microarthridion littorale. Station 120 (a) also related closely to stations 79 and 76, particularly the latter with an index of 62.8, based primarily on the abundance of M. littorale and Ectinosoma

gothiceps in these samples. Stations 106, 71, 49, and 14 running along the south side of the bay subtidally or low intertidally showed relating affinities. High affinities occurred among stations 80, 82, and 44 all of which are removed from the main channel; however, 80 is in the lower King Slough channel, 44 is on a flat composed primarily of sand and 82 is on a mud flat, all of which indicates few common environmental factors. Lengthy exposure time is a common factor for 82 and 44. These three stations in turn related to 120 (a), and all these affinities were based on high numbers of Ectinosoma gothiceps which was nearly ubiquitous in the bay. If the effects of E. gothiceps had been neglected, all lines of affinity on figure 42 would have been removed from 120 (a) except that linking it with 120 (b) and these two stations would have represented the intermediate assemblage discussed above. The spring samples would have then separated into three groups representing the species assemblages developed with the Fager-McConnaughey method and the graphic method.

During the fall, stations separated longitudinally by considerable distance showed significantly high indices of affinity. This should have been expected from the fall distributional patterns (figures 33, 34) which indicated broad distributions and much overlapping of the four assemblages. The spreading of the fauna in

both directions from B-21 as shown in figure 34, is indicated by the affinity lines between the B-21 stations and station 61 downstream and the B-21 stations and station 130 (b) upstream.

Compared with the spring indices the fall values are generally lower due in part to the lack of the dominant upstream spring form Microarthridion littorale. Of particular note when comparing seasons is that many of the lines of affinity from the spring to the fall run to more upstream stations indicating the shifting of populations upstream, as seen from figures 33 and 34. This is shown most clearly by the spring stations 49, 71, 120 (a) and 120 (b).

The winter period indices of affinity at upstream stations 136, 137, 130 (a) were low. Station 63 showed higher values due solely to Ectinosoma gothiceps which may invalidate these relationships. The King Slough stations which had more "normal" populations showed higher indices of affinity tabulated in Table 10. Station 76 in the slough showed affinities for the upstream stations of other seasons and the lower stations, 80 and 81 related to the stations near B-14 in fall and spring.

Comparison of Methods of Analysis

In this study three methods have been used for analyzing the biological data obtained from the core samples. Two of the methods

of analysis grouped species into assemblages without respect to the samples. These species-grouping methods, a graphic method (figures 27, 28, 29 and 34) and a statistical method (figure 36), produced similar results which were discussed in the section on correlation coefficients. The third method of analyzing core data was described by Sanders (1960) and the results of this method are presented in figure 42. This method (Sanders, 1960) compares entire samples by species composition rather than individual species as in the first two mentioned methods.

The fact that the sample-comparing method does not completely agree with the species-grouping methods can be better understood by looking at figures 27 and 34. In these figures it can be seen that a single core, taken at any of several stations during either the spring or winter, would have intersected three or four of the species groupings, assemblages.

There is more agreement between species-comparing and sample-comparing methods when one particular species dominates, as in the upstream group in the spring (figure 27). Figure 42 shows "lines of affinity" with high numerical values among the upstream stations which are representative of the upstream group, as seen in figure 27.

During the fall, indices of affinity (figure 42) were of lower

magnitude than during the spring because of the broader distribution of the species assemblages (figure 34).

Eel grass samples and channel (skimmer) samples were not treated statistically and have been presented only graphically. The eel grass forms were separated into groups, graphically, according to their spatial distributions (figure 31), and the assemblages on eel grass were compared to the sediment assemblages. Attempts to obtain horizontal-distribution patterns, graphically, for channel samples were generally without success.

Organics and Cross Channel Population Differences

Kulm (1965) measured nitrogen as an index of organic content in Yaquina Bay sediments. He found in general that organic nitrogen increases with decreasing grain size, and that the highest organic nitrogen was in sloughs and the lowest in fine sands. Some of Kulm's 15 stations are in close proximity to the stations in this study and might explain some population variations. Two of Kulm's stations with the highest organic carbon content correspond to stations 106 and 148 in this study which had very low numbers of animals. Another sample with high organic nitrogen was in the lower channel of King Slough between stations 73 and 80. Station 80 also had low population numbers. It is possible that high

organic content in the sediment produces anaerobic and toxic conditions which inhibit or prohibit harpacticoid populations.

Some of Kulm's nitrogen values also indicate steep lateral gradients in organic content. The present study indicated that small differences in salinity and temperature were found laterally. The differences in numbers of individuals from one side of the bay to the other, such as at B-39 in the spring, could be due to differences in organic content or some other parameter of the sediment. In the example given, 136 and 137 in the spring, there were 842 harpacticoids at station 136 and 77 at station 137; however, the major species were represented in both and the index of affinity was over .50 (figure 42) between the stations. This suggests that when sediment conditions are unfavorable as they may have been at station 137 in the spring the numbers of individuals are low, but species composition remains the same. This phenomenon was also discussed in relation to the replicate cores which were analyzed.

Low numbers suggested in channel samples can be related to lower organic content, but the effects of current and grain size must also be considered. The low organic values can be applied to the downstream stations, 14 and particularly 19 which also had low population numbers.

Kulm (1965) described three major sediment realms, marine

fluviatile and marine-fluviatile in the bay based on sediment texture and minerology. These realms may be related to the harpacticoid distributions, but they may instead reflect the effects of the same factors which affect the harpacticoids, i. e. salinity, runoff, current, etc.

Biological Factors

The presence of high numbers of copepods in the spring after low numbers in the late winter indicates rapid build-up and high rates of reproduction. No evidence is available as to the length of the harpacticoid reproductive cycle, nor were specific periods listed in the literature. It is assumed that the life cycle is similar in length to that of calanoid copepods, six weeks to three months. Very small nauplii which were assumed to be harpacticoid nauplii were numerous in the spring cores and were much more sparse during the other seasons. The effects of other factors such as interspecific competition and predation are completely unknown. The abundance of Microarthridion littorale upstream in the spring may by competition prevent other species from becoming established. It is believed generally however that the external limiting factors in this environment are more physical and chemical than biological based on the fact that population changes can be correlated with changes in salinity and temperature.

SUMMARY

1) Harpacticoid copepods were collected from mud flats (three seasons), channel (three seasons), and eel grass (spring only) in Yaquina Bay, Oregon in 1965. A total of seventy-three samples was studied of which fifty-three were core samples.

2) Fifty-seven harpacticoid copepod species were found and also four cyclopoid copepod species. All species determinations were carried as far as possible.

3) Temperature and salinity values were also taken in Yaquina Bay during 1965 in order to relate these factors to harpacticoid distributional patterns. Temperature and salinity patterns were studied seasonally and spatially.

4) The three biotopes: mud flat, channel, and eel grass had distinctly different harpacticoid populations, although some species were found in all three environments.

5) Spatial differences in populations were marked. Upstream, downstream and intermediate type distributions were identified for mud flats, and the downstream assemblage was broken into two groups. The dominant species in the groups were Microarthridion littorale upstream, Amphiascella debilis and Paramphiascopsis sp. downstream, and Danielssenia fusiformis and Enhydrosoma propinquum intermediate. These differences in populations were

attributed to changes in salinity and temperature, the effects of which were difficult to separate. Salinities were lower upstream in the spring and temperatures were higher. In the spring, the highest numbers of animals were upstream accentuated by high numbers of one species, Microarthridion littorale. In the fall, when temperatures were lower upstream than down and the horizontal salinity gradient was not as pronounced, species were more widely distributed, and the grouping of distributions into three assemblages was not as distinct. Populations in the fall were smaller upstream than down, but the fall period had more species than spring. Winter harpacticoid populations were small (fewer than 100 harpacticoids per core in the bay) and few species were present. Periods of heavy rain during the winter of 1964-1965 which reduced salinity upstream to nearly 0.0 o/oo is thought responsible for low winter populations. The presence of numerous harpacticoid exoskeletons in the winter cores suggests that low salinities and other factors associated with the winter flooding produced an extensive kill of harpacticoids.

King Slough, which had horizontal salinity and temperature gradients similar to part of the main bay, also had similar species and species distributional patterns in the spring and fall. Winter populations in the slough, however, were higher than in

the bay, due probably to the presence of less extreme flooding conditions in the slough than in the bay.

6) Species relationships or groupings from core samples were determined in two ways, graphically and statistically. Comparable results were obtained with both methods. Another statistical method was used which compared entire core samples and produced somewhat different results than the species-oriented systems.

7) A distinct seasonal difference in upstream populations from spring to fall was thought due, in part, to a reduction of temperature in the fall as well as to high salinities for a long period. Several species such as Stenhelia (St.) sp. #1 occurred only during the fall and/or winter sampling. Downstream differences from spring to fall were not as pronounced.

8) Eel grass samples, which were taken only in the spring, exhibited three assemblages, upstream, downstream, and intermediate, as were observed in the mud flat samples during spring and fall, but the eel grass assemblages were dominated by different species, Harpacticus uniremis, Heterolaophonte sp. #1, and Ameria sp. respectively.

9) Channel samples, although not quantitative, indicated low numbers per unit area compared to the mud flat and eel grass samples. In the winter the channel fauna was made up primarily

of mud flat forms, but by fall there was an endemic channel fauna the dominant species of which was Tisbe furcata. This was thought related to lower water temperatures in the fall, plus a long period with relatively high bottom salinities which enabled more marine forms to enter the bay along the channel.

10) Differences (as many as 10 times more harpacticoids in one core than another) in total harpacticoid numbers from core samples over short horizontal distances were observed, although the basic species compositions remained relatively unchanged. These changes were attributed to possible variations in sediment such as organic content or grain size which were not determined.

11) Distributions of several species such as Ectinosoma gothiceps were difficult to relate to salinity or temperature gradients. Abundance of these species may be related to some other variable of the environment such as sediment type or intertidal exposure.

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