AN ABSTRACT OF THE THESIS OF

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Title DISTRIBUTION OF EUPHAUSIACEA AND COPEPODA OFF OREGON IN RELATION TO OCEANOGRAPHIC CONDITIONS

Abstract approved [signature]
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Fifty-two one-meter plankton net samples from four stations off Newport, Oregon, were examined for composition and abundance of euphausiids and copepods. They provided data on dominance, species associations and environmental relationships.

The euphausiid-copepod population off Oregon is composed of 12 numerically dominant species. These species occurred in most of the samples regardless of season or location. In order of their percentage contribution these species were Euphausia pacifica, Metridia pacifica, Calanus finmarchicus, Calanus pacificus, Eucalanus bungii, Calanus plumchrus, Calanus A., Metridia lucens, Thysanoessa spinifera, Acartia longiremis, Aetideus armatus and Calanus tenuicornis.

Sixty-seven other species were collected, several undergoing distributional changes in response to changing oceanographic conditions. Three species, Nematoscelis difficilis (d), Rhincalanus

nasutus and Acartia danae are associated with the fall influx of water from the south. Tessarabrachion oculatus, Eucalanus elongatus hyalinus, Pseudocalanus minutus and Oithona spinirostris were primarily summer species. Eighteen other species occurred consistently at NH-45 and beyond throughout the year with an occasional shoreward extension in distribution during the winter.

Two methods of association analysis were used. The Fager-McConnaughey method, which utilizes only presence or absence, produced 47 separate associations. Most of these were determined by a few infrequent or rare species. The Sanders method, which utilizes relative abundance, produced six basic associations which differed mainly in the proportions of the dominant species rather than major changes in species composition. Neither method revealed well defined communities off Oregon, probably because of the absence of rapid or extreme fluctuations in the environment or because of the small geographical area sampled.

The similarity between species associations were compared with the temperature and salinity relationships indicative of changes in the physical environment. Higher affinities occurred between samples taken under similar temperature and salinity conditions than occurred between samples from different conditions.

DISTRIBUTION OF EUPHAUSIACEA AND COPEPODA OFF OREGON IN RELATION TO OCEANOGRAPHIC CONDITIONS

by

JAMES FRANK HEBARD

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DISTRIBUTION OF EUPHAUSIACEA AND COPEPODA OFF OREGON IN RELATION TO OCEANOGRAPHIC CONDITIONS

INTRODUCTION

Most studies of the zooplankton are descriptive and deal mainly with distribution and abundance of species, for example, Bigelow (1926), Clarke, Pierce and Bumpus (1943), Deevey (1956), Digby (1950, 1954), Esterly (1912), Fraser (1952, 1955) and McGowan (1963). However, some of these studies relate distribution and abundance to environmental factors. Russell (1935, 1939) and Fraser (1952, 1955) correlated distribution and abundance of the chaetognath, Sagitta elegans, with the influx of North Atlantic water into the English Channel and the North Sea. Clarke, Pierce, and Bumpus (1943) also correlated S. elegans with hydrographic features of Georges Bank.

The separation of oceanic surface waters from one region into obviously different environments is difficult. The persistence of distribution patterns by many marine species has encouraged investigators to look for a biological means of defining these environments. Bary (1959) plotted plankton abundance by species on T-S diagrams and found that particular temperature and salinity combinations were often correlated with the abundance of some zooplankton species.

In all the above studies, factors of the physical environment have been correlated with the distribution and abundance of individual species. This approach neglects the effect one species has upon the presence of another. Haffner (1952) demonstrated the importance of species interrelationships in the horizontal distribution of several species of the mesopelagic fish Chauliodus. Where overlapping distributions occurred, the result was a vertical separation of the species. Where overlapping did not occur, the species were found at the same depth and under quite similar oceanographic conditions. Conover (1956), in his study of the relationship between Acartia tonsa and Acartia clausi, demonstrated that seasonal changes in the relative abundance of these species was the result of a competitive advantage of one species over the other. Either species of copepod alone was shown to live and reproduce throughout the year in Long Island Sound, but when found together, the seasonal fluctuations in temperature gave the competitive advantage to Acartia tonsa in summer and to Acartia clausi in winter. Therefore, temperature fluctuations indirectly controlled the abundance of these two copepods.

It is difficult to determine interspecific effects of the many species of an area. Methods described by Fager (1957) and utilized by Fager and McGowan (1963) define plankton associations as those plankton species which recur together. Comparison of seasonal variation of recurring groups of species with variations in the physical environment permits us to suggest which physical fluctuations are ecologically most significant since they affect groups of species rather than a single species. If we examine the seasonal distribution of a group of species, the absence of one species does not greatly alter the trends suggested by the group. Alternatively, when a great number of the species undergo a change of abundance and distribution, the fluctuation is more likely caused by a change in the physical environment rather than in the biological environment.

The major objectives of this study are: 1) to determine what species of the Copepoda and the Euphausiacea occur off Oregon, 2) to describe the groups or associations of co-occurring species, 3) to investigate the seasonal and inshore-offshore changes in species and co-occurring species groups, and 4) to correlate changes in the distribution and occurrence of species and species groups with the physical environment.

Previous studies of the Copepoda and Euphausiacea off Oregon have been primarily taxonomic (Davis, 1949; Olson, 1949; Banner, 1949; Boden, Brinton and Johnson, 1955). Distributional studies were made of the copepods by Frolander (1962), Cross (1964) and of the euphausiids by Brinton (1962), but only Cross utilized seasonal collections from a limited area. Cross restricted his study to the small copepods.

METHODS AND MATERIALS

The hydrographic data were collected during cruises made by the Department of Oceanography, Oregon State University, between January, 1962 and July, 1964. The stations occupied were from 15 miles to 165 miles offshore, with stations usually located at 20 mile intervals. Most of the collections were made from stations along a line extending westward from Newport, Oregon at latitude 44° 39'N.

Hydrographic data from each station includes temperature, salinity, and oxygen content at standard depths from the surface to 1000 meters as defined by Sverdrup et al. (1942). An estimate of heat storage was obtained by linear integration, using the temperature between the surface and 30 meters.

Plankton data used in this study were collected on hydrographic surveys between May, 1963 and July, 1964. All collections at regular hydrographic stations were taken between dusk and dawn in order to minimize the effects of vertical migrations.

All zooplankton samples were collected with one-meter nets contstructed of "O" mesh netting (571 micron aperture). Nets used at regular hydrographic stations were three meters in length and those used in the special day-night vertical distribution studies were six meters in length. All nets were equipped with flowmeters.

Zooplankton were collected from vertical and oblique tows between the surface and 200 meters. The tows between May and December, 1963, were oblique tows, but after December, 1963 vertical tows were made. The change was made because the oblique tows sampled the various depths unequally (Figure 1). The change to vertical tows alleviated this bias because the net was brought from 200 meters to the surface at a constant rate (50 meters per minute) and all depths were sampled equally.

Laboratory methods of analysis depended upon the number of animals present in a sample. If the number of euphausiids was between 100 and 200 in the whole sample, all were removed, identified and enumerated, but if euphausiids were abundant, the sample was divided repeatedly with a Folsom Plankton Splitter (McEwen, Johnson and Folsom, 1959) until there were between 100 and 200 euphausiids in the subsample. Subsequently, further splitting was done until an aliquot containing 100-200 copepods remained.

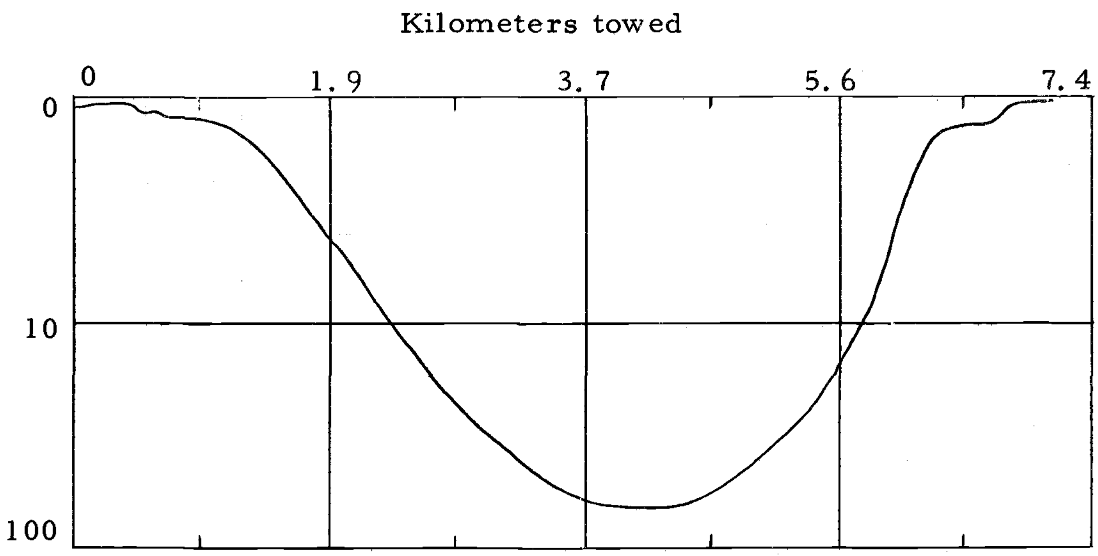

Figure 1. Illustration of typical depth-distance recorder trace used on all oblique tows.

PHYSICAL OCEANOGRAPHY OF THE COASTAL WATERS OF OREGON

Studies of the oceanographic conditions off Oregon by Tibby (1941), Fleming (1958), and Rosenberg (1963) show that the Oregon coastal waters are primarily Pacific Subarctic in characteristics. Both Tibby and Rosenberg, considering the Pacific Subarctic and Pacific Equatorial water masses as primary source waters for Oregon, subjected the Oregon oceanographic data to an isentropic analysis of water mass. These data reveal that the Oregon ocean waters below 200 meters are approximately 70% Pacific Subarctic. A permanent halocline between 100 and 150 meters off Oregon also suggests a relationship to the Pacific Subarctic. This feature is the result of an excess of precipitation over evaporation combined with a downward mixing of diluted surface waters by winter storms (Fleming, 1958). Further details of the halocline are discussed by Fleming (1958), Tabata (1961), Dodimead, Favorite and Hirano (1963), and Tulley and Giovando (1963).

The California Current, Davidson Current, seasonal upwelling and southerly offshore flow of surface waters are prominent features of the Oregon region.

The California Current is the southerly flowing extension of the North Pacific Drift, the name being specifically applied to the portion of the current between 48° and 23° North Latitude (Rosenberg, 1963). The current, broad and slow moving, and lying generally in a band 300 to 800 kilometers off the Oregon coast, flows in a transition zone between coastal waters and the Eastern North Pacific Central water mass.

Inshore from the California current, the circulation changes with season. During the winter, October through March, a warm northward flow of water (often called the Davidson current) develops along the Oregon coast. This current has been examined recently by Burt and Wyatt (1964). Using returns from drift bottle releases, they found this and other inshore surface currents to reflect the local wind stress on the water surface.

During summer months Oregon coastal waters are subjected to the stress of prevailing northwesterly winds which set up southerly surface currents (Maughan, 1963) and establish a period of nearshore upwelling. The surface current is responsible for the southerly transport of the Columbia River plume water. Upwelling is responsible for the cool, high salinity water found near shore during April through September.

As an area for the study of the relationships between groups of animals and their environment, the coastal waters off Oregon are unique. The offshore environment, more than 120 kilometers from the coast, undergoes regular cyclic fluctuations in temperature and salinity, the fluctuations of temperature and salinity being out of phase with one another (Figures 2 and 3). Inshore the environment changes from dilute water of the Columbia River plume to the cold, high salinity water of the upwelling period during approximately a one month period. The change from upwelling to warm water flow from the south also occurs in a very short period (approximately one month). The animal populations living in this region must either have wide temperature and salinity tolerances (eurythermal and euryhaline) or there must be changes in the population composition.

The fluctuations in 10 meter temperature off Newport for 1962, 1963 and 1964 are shown on Figure 2. The fluctuations of salinity during the same period are shown on Figure 3. Offshore (beyond NH-65) temperature at this depth varies with the rate of solar radiation given by Lane (1965). Temperatures of 18° C are found during the summer, reaching maximum value during August and September. Minimum temperatures of 9°-10° C occur during the winter. The salinity at 10 meters during the year is maximal (32.5 ‰-32.6 ‰) in the winter and are minimal during the summer (31.8 ‰). This differs from the deeper depths of 100 meters where salinity is highest during the summer and lowest during the winter (Hebard, 1965). The difference can be ascribed to the dominating influence of the Columbia River runoff upon the surface waters during the summer.

Temperature @ 10 meters Newport

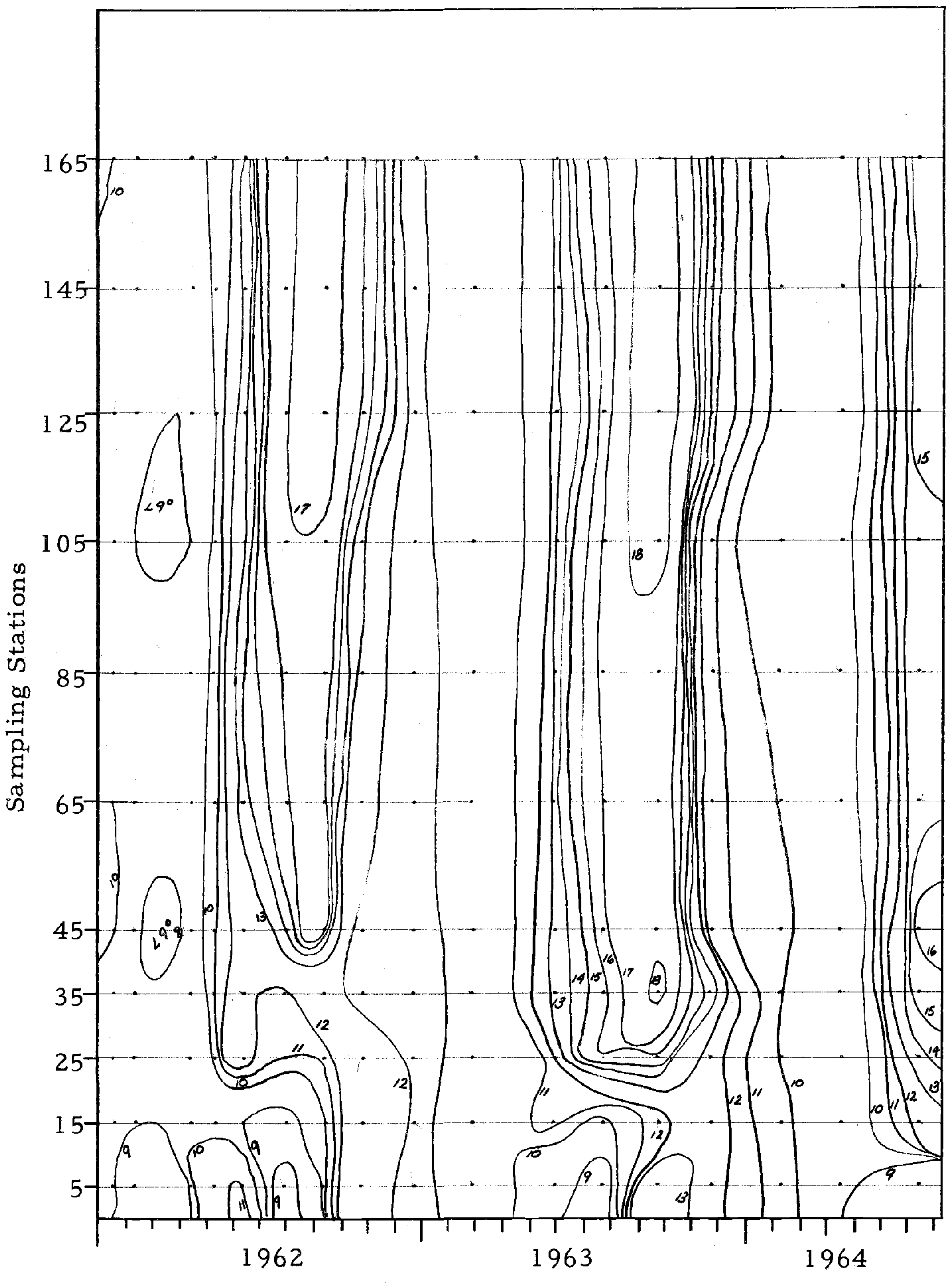

Figure 2. Temporal distribution of temperature at 10 meters depth during 1962, 1963, 1964.

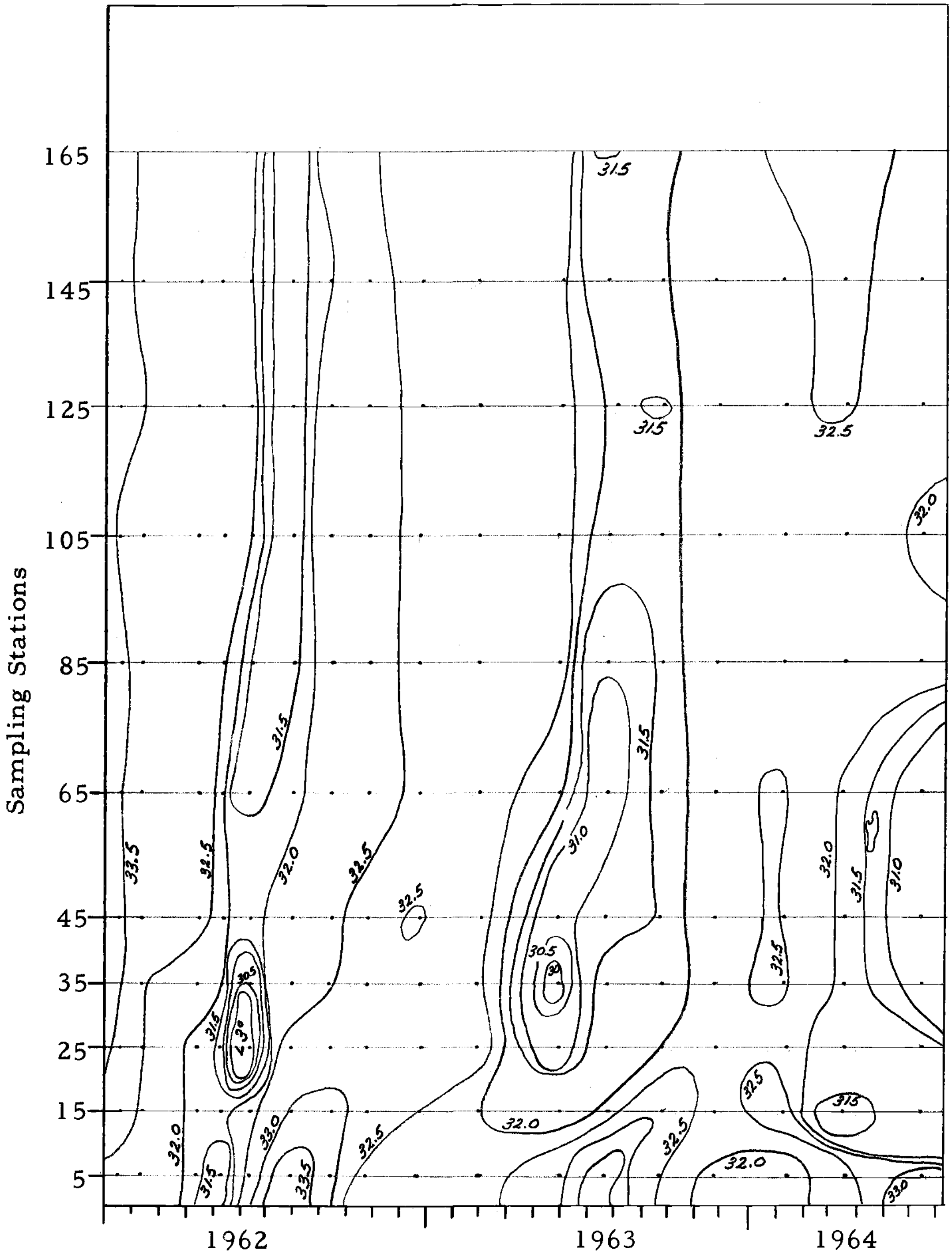

Figure 3. Temporal variation of salinity at 10 meters depth off Newport, Oregon during 1962, 1963 and 1964.

During the winter the offshore temperature and salinity prevail inshore to the coast.

Inshore (less than 120 kilometers from shore), temperature and salinity fluctuate more rapidly and over a greater range than in offshore waters. Following the homogeneous conditions that prevail during the winter, local runoff and Columbia River plume waters dilute the salinity during April. In June, when a northwest wind pattern becomes established, an offshore flow of the surface waters (including Columbia River water) begin. This offshore movement of surface water forces upwelling of cold, saline water to the surface from a depth of 150 meters to 200 meters (Collins, 1964). During this period from June to September, upwelling dominates the inshore environment; the salinity becomes greater than 33 ‰ and the temperature occasionally drops below 9° C.

The effects of upwelling on temperature and salinity were limited to nearshore waters. Upwelling was detectable to 27 kilometers off Newport (NH-15) in 1962, but it was inshore of this point in 1963 and 1964 (Figures 2 and 3). A definite and strong temperature gradient occurs offshore of the upwelled water. This gradient is probably the near-surface expression of the front reported to be present during upwelling (Collins, 1964).

With the cessation of upwelling in about October warm water begins to move inshore and northward along the Oregon coast; its presence is readily detected by temperatures of approximately 13° C. during October and November. The coastal waters of Oregon reach maximum temperature during the initial stages of this advection of warm water. The northerly flow continues until March, but the rather steady decrease in the temperature during winter suggests that warm water transport is not great enough to offset local winter cooling.

Although both regions (inshore and offshore) have rather distinct cycles during most of the year, temperature and salinity indicate that the whole region (NH-15 to NH-165) is essentially homogeneous from November through February. Temperature during this period varies from year to year, but is approximately 11° C. Salinity also varies annually, but generally falls between 32.0 ‰ and 32.5 ‰.

Recently Pattullo and Denner (1965) established a model of the physical environment off Oregon. By statistical analysis of surface temperature-salinity relationships they ascribed changes in the physical environment to effects of heating, runoff and upwelling. Runoff is separately considered as (1) Columbia River, and (2) local runoff and precipitation.

I have revised the surface model of Pattullo and Denner using the temperature and salinity values at 10 meters depth for all hydrographic stations taken from May 1963 to August 1964 off Newport, Oregon (Figure 4). The result is a model cell of water with temperatures of 9° to 10° C. and salinity of 32.0 ‰ to 33.0 ‰. This model cell is about one degree Celsius colder and one part per thousand less saline than found by Pattullo and Denner. This difference can be ascribed to several factors, 1) my rather limited amount of data (88 observations), 2) the more intense upwelling present during 1961 and 1962, the period studied by Pattullo and Denner, and 3) the fact that my data is from 10 meters rather than at the surface and at the coast.

Temperature-salinity (T-S) relationships for 1963-1964, with superimposed process sectors from modified Pattullo and Denner diagram, indicate seasonal changes in hydrographic conditions (Figures 5 to 8). Three seasonal patterns of T-S sequence were detected. These illustrate important physical processes affecting the ecology of pelagic animals in Oregon coastal waters.

At NH-15 (Figure 5) the sequence of monthly observations form a figure eight pattern. During the late summer, upwelling results in increased salinity and low temperature. During 1963 and 1964 the rate of upwelling was slow and the upwelled water was warmed through solar heating during its transport toward the surface. Thus, the values during upwelling (August and September) did not fall in the upwelling sector but in the upwelling plus heating sector.

A period of heating and dilution occurred during the fall. This

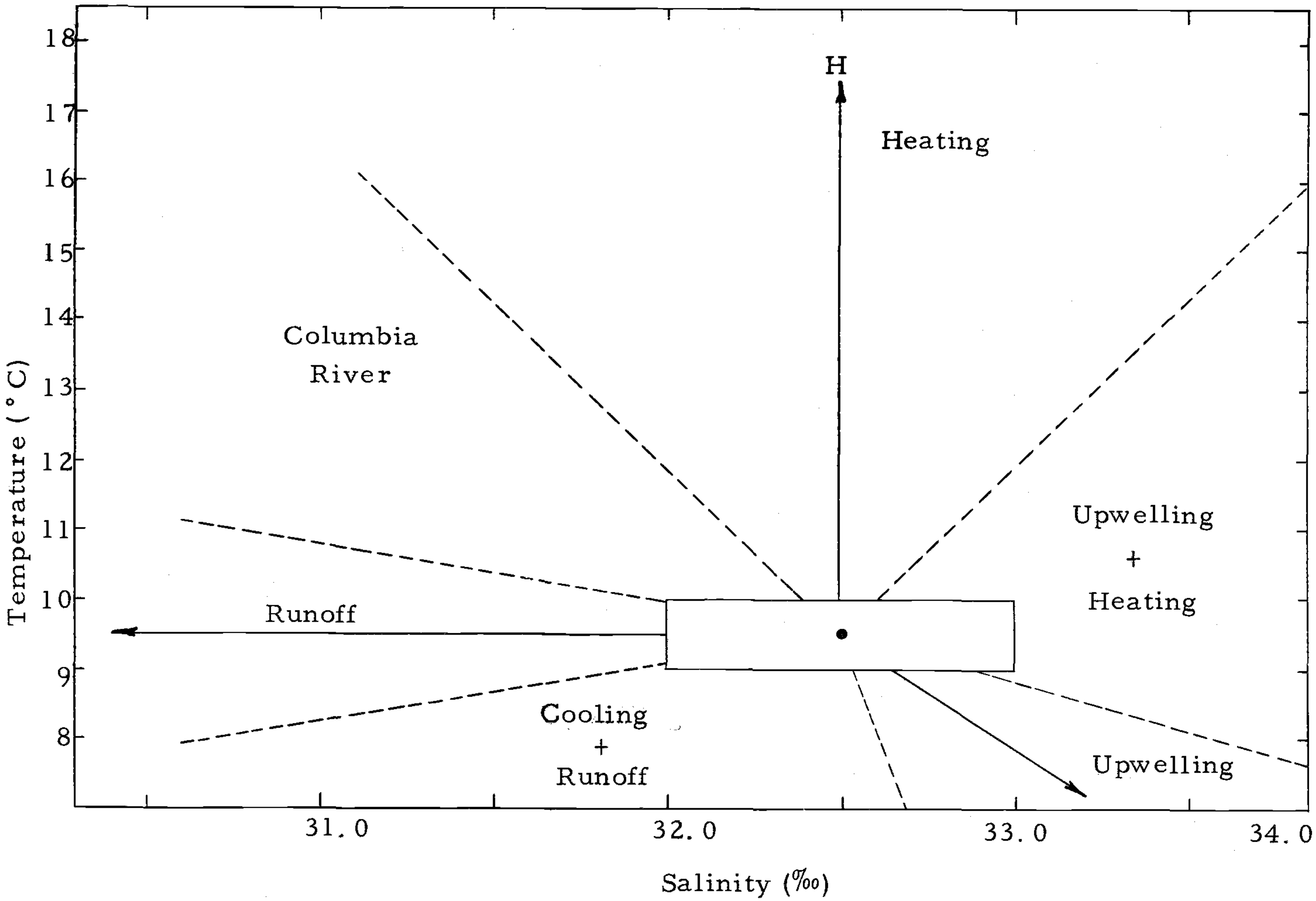

Figure 4. Modified process sector diagram described by Pattullo and Denner (1965).

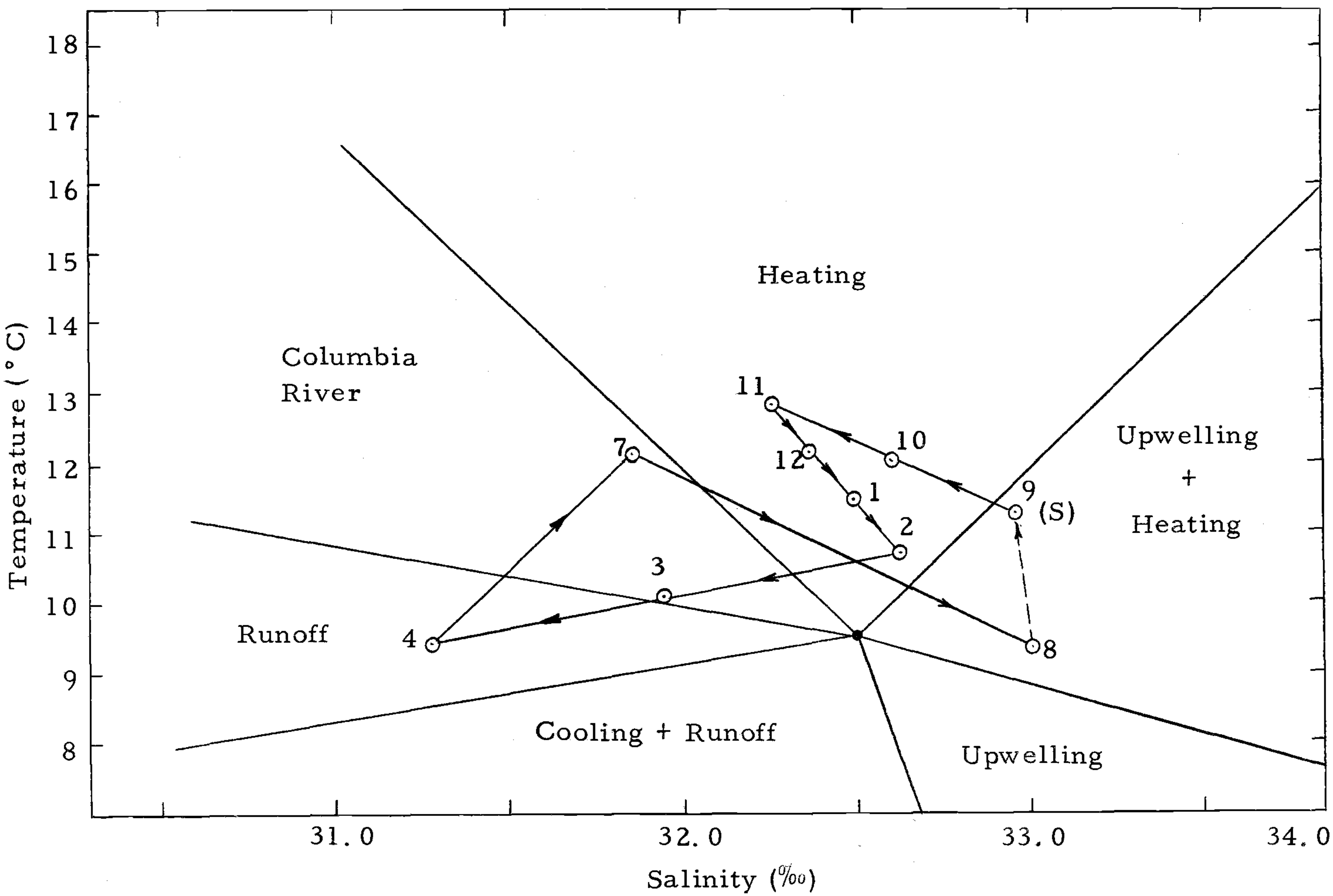

Figure 5. Seasonal fluctuation in 10 meter T-S relationship at NH-15. Numbers indicate month of collection beginning in September, 1963 (S). Process sectors are presented for reference.

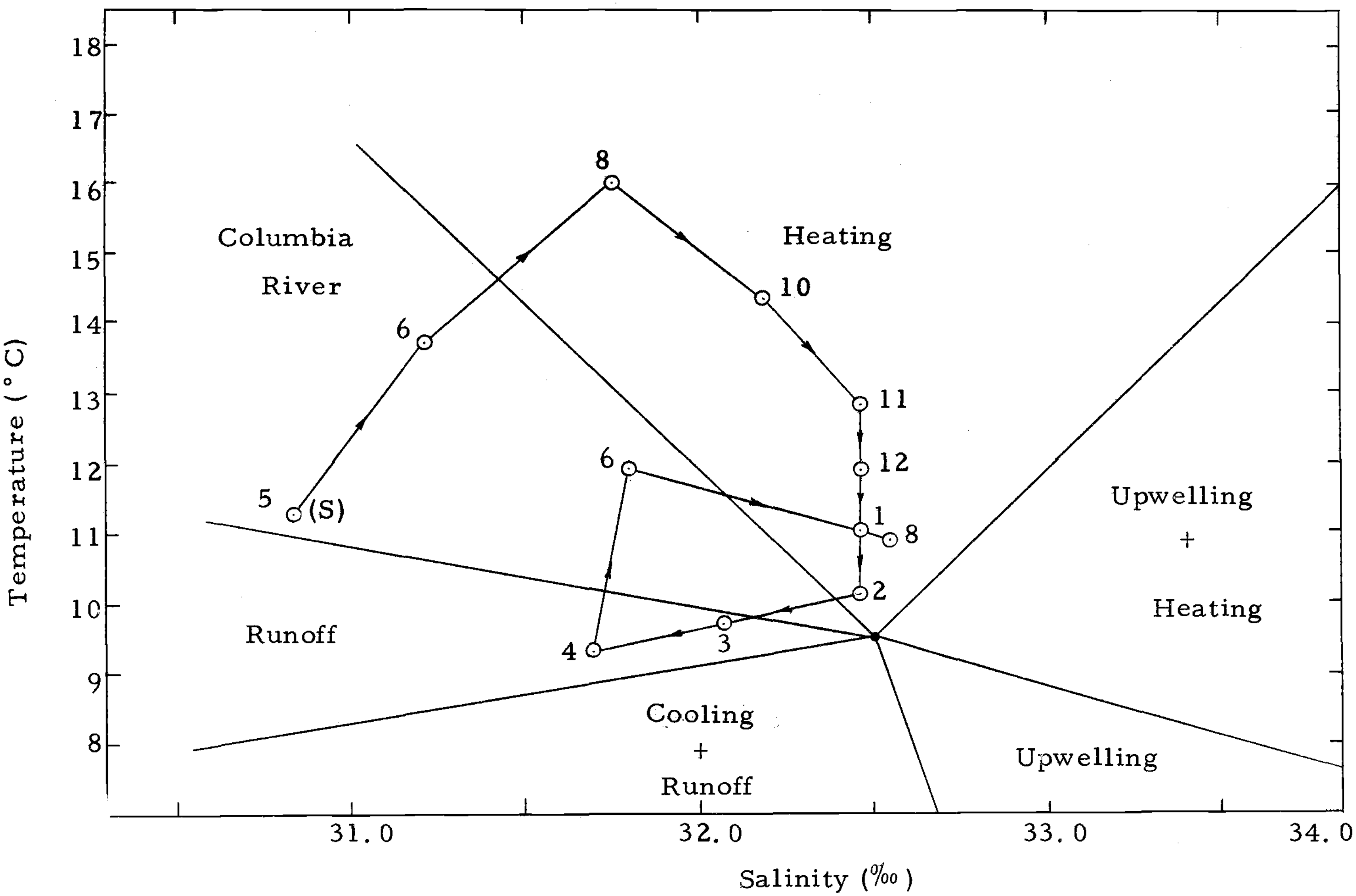

Figure 6. Seasonal fluctuation in 10 meter T-S relationship at NH-25. Numbers indicate month of collection beginning in May, 1963. Process sectors are presented for reference.

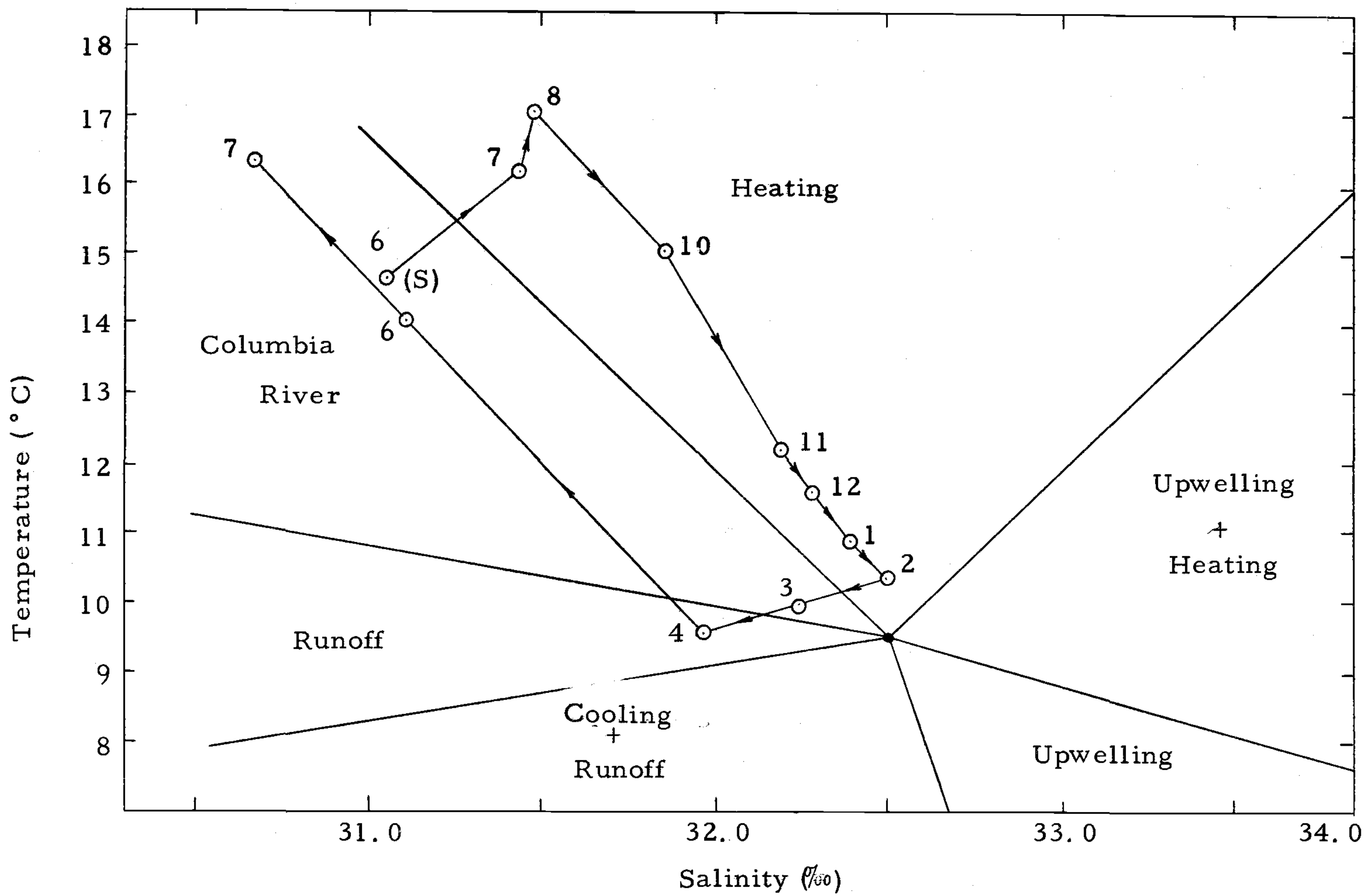

Figure 7. Seasonal fluctuation in 10 meter T-S relationship at NH-45. Numbers indicate month of collection beginning in June, 1963. Process sectors are presented for reference.

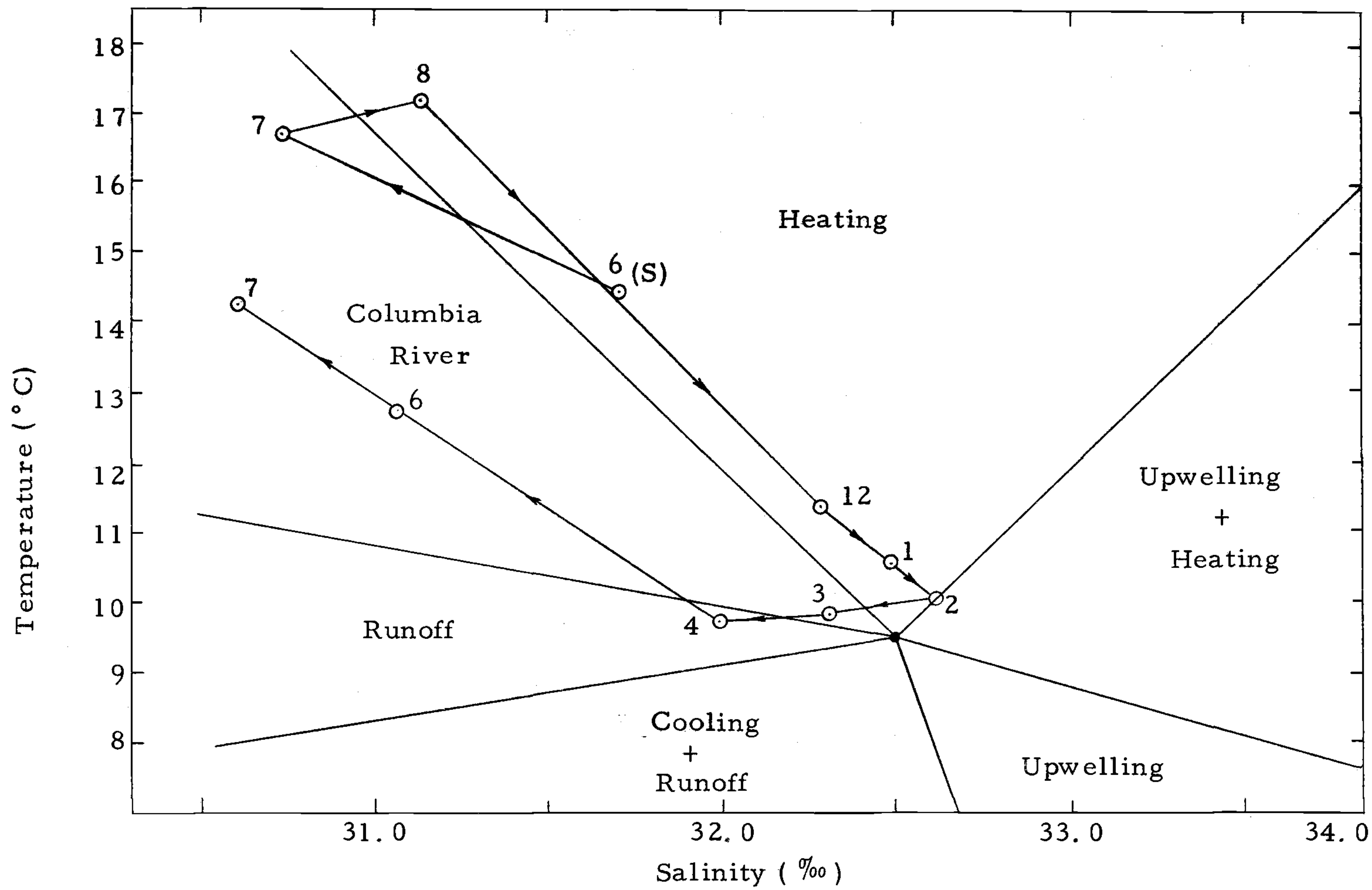

Figure 8. Seasonal fluctuation in 10 meter T-S relationship at NH-65. Numbers indicate month of collection beginning in June, 1963. Process sectors are presented for reference.

was the period of warm water advection and dilution due to precipitation. In late fall and winter, a combination of cooling and mixing caused an increase in salinity and a decrease of temperature. Runoff and precipitation occurred from February through April, at which time the T-S relationship fell into the runoff process sector. Runoff continued to dominate the waters at NH-15 through July. During April local runoff was thought to be primary source of fresh water. After April Columbia River runoff was predominant.

The northwest winds which bring the Columbia River water southward also instigate and maintain the process of upwelling. Therefore, there is a rapid change over to an upwelling regime after the Columbia River influence at NH-15.

At NH-25 many of the same processes are still present but to a lesser extent than at NH-15 (Figure 6). The pattern almost forms a circle instead of a figure eight. The only suggestion of upwelling is during August when decreased temperature and increased salinity occurred. At NH-25, the waters are diluted with local runoff and cooled during March and April. During May and June the waters are further diluted, but this time with warm Columbia River water. Maximum temperature occurs when upwelling is greatly reduced, about August. From October through February there is little change in salinity, but there is continuous cooling.

At NH-45 and NH-65, the T-S relationships fell into only three sectors: runoff and precipitation, Columbia River, and heating (Figures 7 and 8). Maximum heating and diluting occurred during July or August, followed by a combination of cooling and increasing salinity. This is brought about by back radiation and mixing due to increased storm frequency and intensity. After February, precipitation and reduced mixing cause a dilution of the surface waters. By June and July the Columbia River plume water is present and dilution combined with heating changes the water characteristics.

From these data, definite areas of the T-S diagram can be pointed out as being characteristic of either spring-summer or fall-winter conditions (Figure 9). The spring-summer values are split into two areas, one having high salinity as a result of the influence of upwelling and the other being rather dilute as a result of precipitation and runoff (both local and Columbia River plume). The fall-winter T-S relationships all fall between the two summer areas. They are distinctly separate except in two cases where slight overlap occurs, once on the high salinity region and once in the runoff precipitation region.

The previously discussed changes in the coastal environment are also reflected in the vertical distribution of temperature and in heat storage. The general equation for calculation of stored heat (ΔH) is as follows (Pattullo, 1957):

$$\Delta H = \rho c \, \Delta T \, \Delta z$$

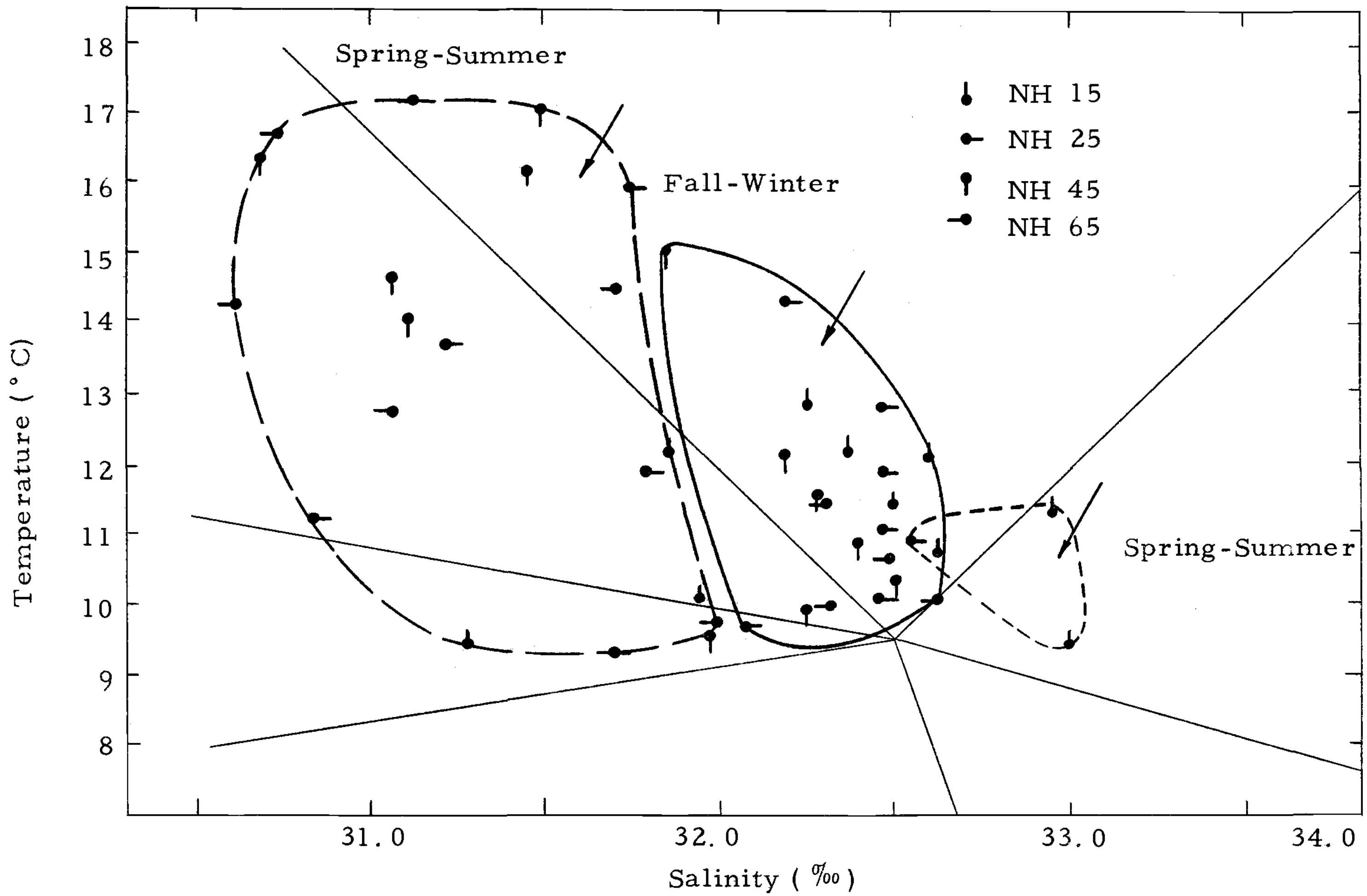

Figure 9. Combined temperature-salinity relationships for the four Newport, Oregon sampling stations.

where

ρ = sea water density (assumed to be constant at 1.02 grams/cm^3)

c = specific heat of seawater (here assumed to be 0.98 calories/degrees/gram-cm.)

ΔT = difference between the observed temperature at a particular depth and the reference temperature.

Reference temperature used here is 5° C.

Δz = depth interval over which ΔT applies. Must be in centimeters for use with equation to yield ΔH in gm. cal. cm^{-2} above 5° C.

In the present analysis, the water column (0-30 meters) was divided into depth intervals and H for each increment determined as follows:

$$\Delta H_{n-m} = \rho c\left(\frac{\Delta T_n - \Delta T_m}{2}\right)(\Delta z_{meters})(10^2\ cm/m)$$

where

ΔT_n = ΔT at the top of the depth interval of interest. Subscript n indicates depth in meters of sample

ΔT_m = ΔT at the bottom of the depth interval of interest. Subscript m indicates depth in meters of sample.

The factor "10^2 centimeters/meters converts Δz in meters to Δz in centimeters.

Combining three such equations into one for the 10 meter spacing of my observation data, removing common factors, assuming ρc equal to 1.00 and reducing to lowest terms this equation becomes:

$$\Delta H_{0-30} = \left(\frac{10^3}{2}\right)(\Delta T_o + 2\Delta T_{10} + 2\Delta T_{20} + \Delta T_{30})$$

Inshore-offshore values of heat storage are shown for the four seasons in (Figure 10). In the winter (December through April) the heat storage is nearly uniform from NH-15 to NH-165.

In spring there is a decrease in heat inshore and a corresponding increase offshore. The decrease inshore reflects the establishment of the upwelling period. In summer while recovery from upwelling has not yet been completed, there is a secondary maximum heat storage at approximately 45 miles. Offshore of 45 miles there is an initial decrease followed by an increase in maximum heat storage. In the fall (October) increased heat is present inshore and a combination of mixing and seasonal cooling has lowered the overall heat storage. Cooling continues after October until the previously mentioned situation of constant heat storage from NH-5 to NH-165 exists.

If we examine the seasonal fluctuation of heat storage at each station, we find cyclic changes through the year (Figure 11). All four stations have a minimum heat storage during the early spring. At NH-15 the time of the minimum depends upon upwelling. During

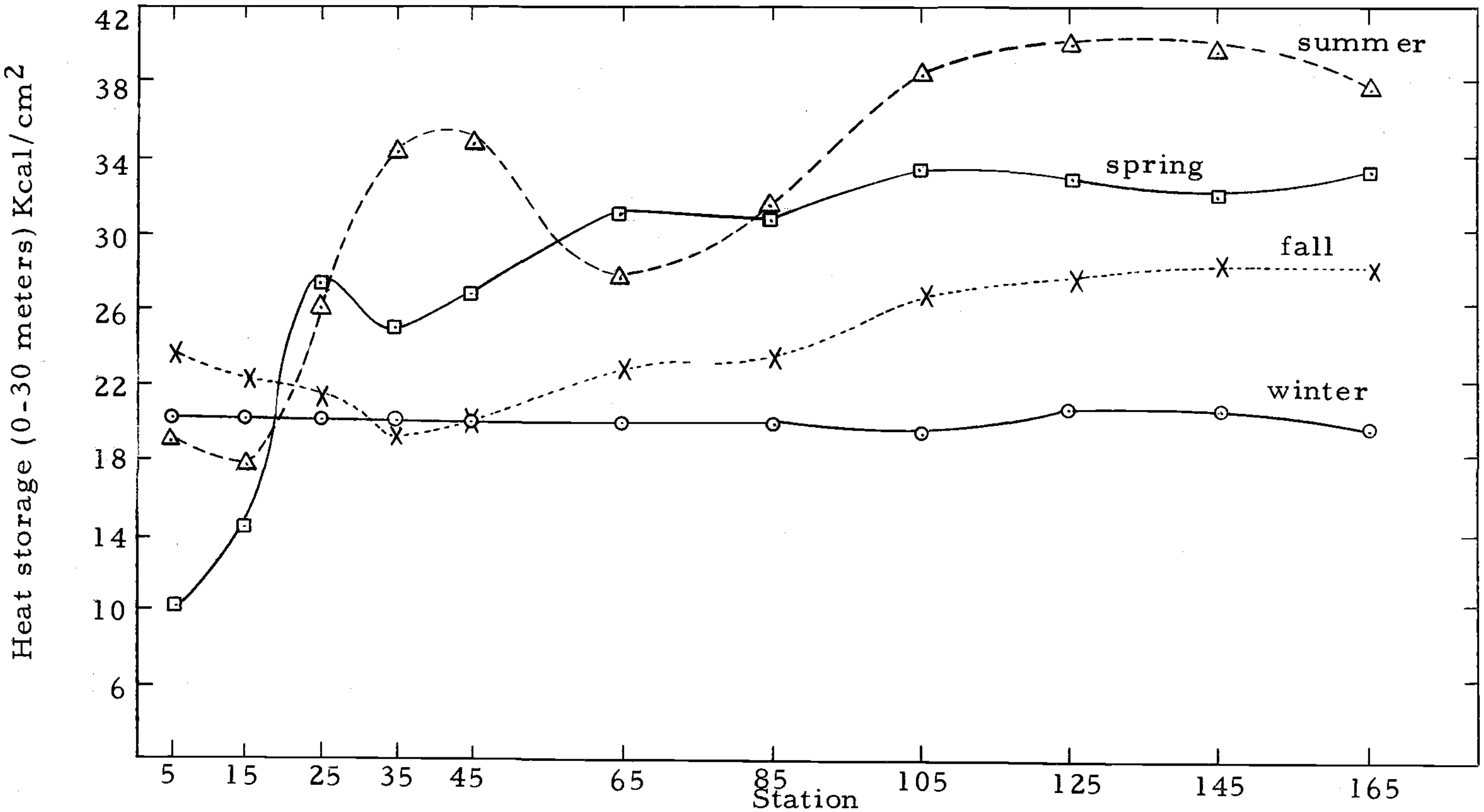

Figure 10. Inshore-offshore seasonal patterns of heat storage off Newport, Oregon, 1963-1964.

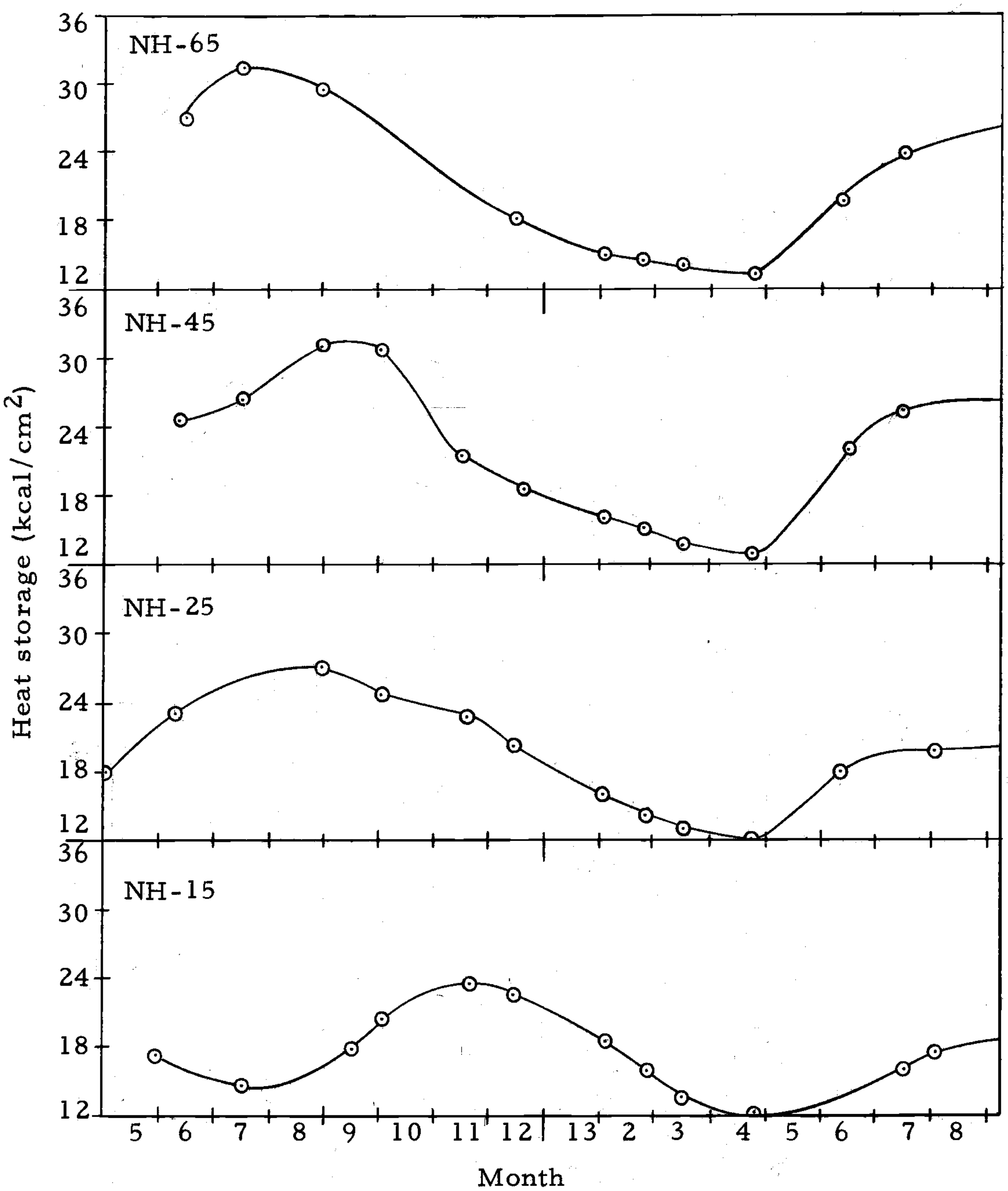

Figure 11. Temporal variation in heat storage at four stations off Newport, Oregon.

July 1963, upwelling was present and minimum temperatures were present at this time. Maximum heat storage at NH-15 occurs in conjunction with the cessation of upwelling and the onset of the Davidson Current. This maximum occurs between October and November. On the remaining stations, heat storage increases from the spring minimum through the summer to a maximum in late summer (August-September). After November, 1963, heat storage at all four stations was similar.

THE STRUCTURE OF THE COPEPOD-EUPHAUSIID POPULATION OF THE COASTAL WATERS OF OREGON

In this study 52 collections were made and studied. Copepods and euphausiids were identified and enumerated and associations were noted. The average abundance of each species at each station is shown on Table 1. In all, 79 species were found, 67 species of copepods and 12 species of euphausiids. Combining both taxa, an average of nine individuals per cubic meter were present.

The difference in relative abundance of the copepods and euphausiids with distance offshore are shown in Figure 12. The euphausiids exceeded the relative abundance of the copepods at only one station (NH-25) where the euphausiids constituted 57% of the individuals found. A drastic decrease in abundance of euphausiids occurred between NH-25 and NH-45. At NH-45 and beyond, the abundance remained rather low (approximately 0.6 individuals per cubic meter).

The copepods, on the other hand, generally increased in abundance with distance offshore reaching their maximum concentration (nine per cubic meter) at NH-65.

The seasonal fluctuations in abundance of adult euphausiids and copepods is shown in Figure 13. The copepods were generally more abundant than euphausiids. Euphausiids were most abundant at

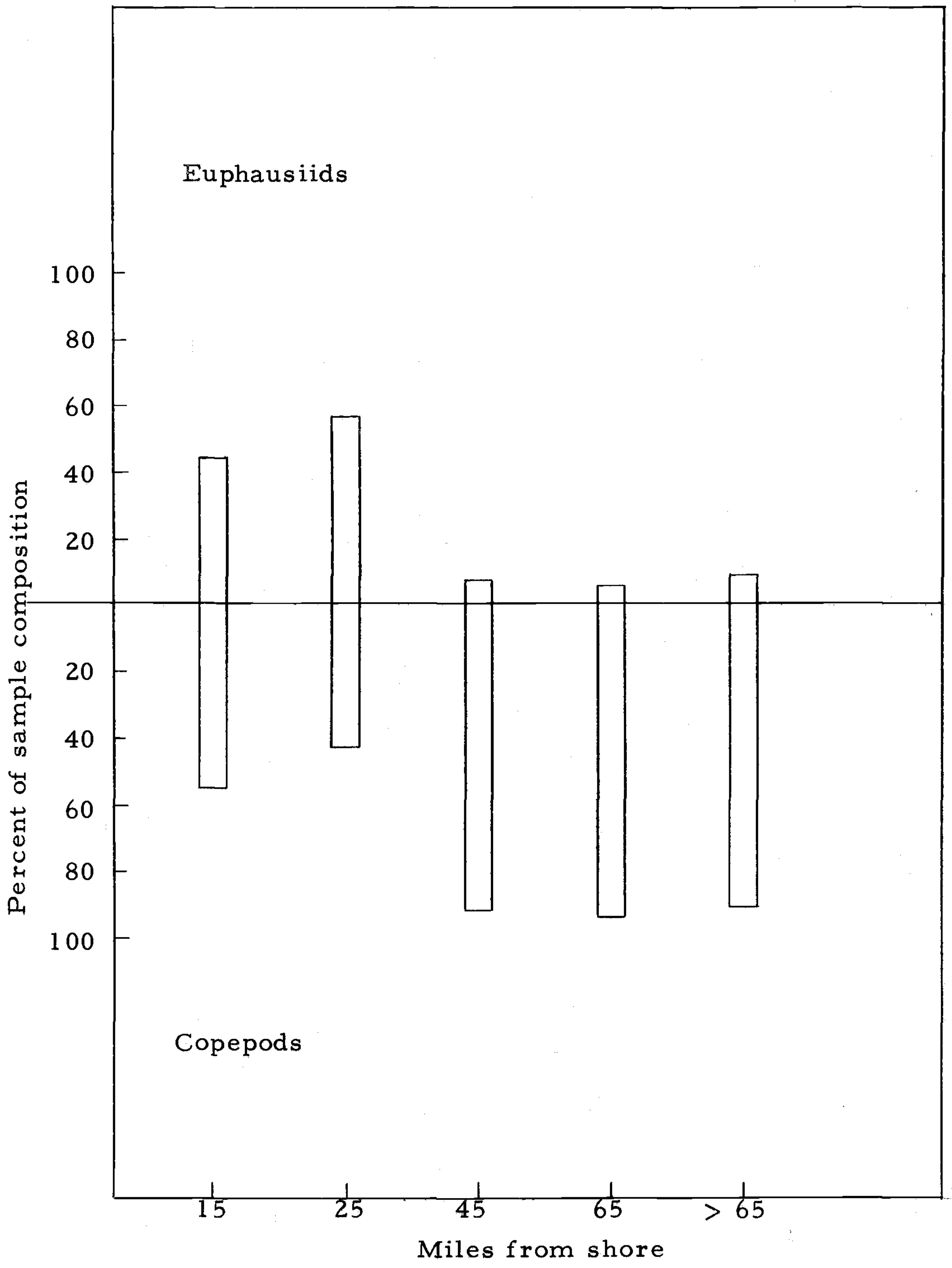

Figure 12. Inshore-offshore variation in relative abundance of adult copepods and euphausiids off Newport, Oregon, May 1963-August, 1964.

Table 1. Average abundance of Copepods and Euphausiids at five stations off Newport.

Species	NH15 Average No./1000M^3	NH25 Average No./1000M^3	NH45 Average No./1000M^3	NH65 Average No./1000M^3	NH65+ Average No./1000M^3
Euphausia pacifica	2133	9150	519	329	220
Thysanoessa spinifera	739	169	5		
Thysanoessa longipes			10	4	
Thysanoessa inspinata	8	49	37	235	62
Thysanoessa gregaria	4	3	1	T	8
Tessarabrachion oculatus		1	1	8	8
Nematoscelis difficilis (nd)	7	49	22	20	115
Nematoscelis difficilis (d)	7	68	16	2	20
Nematobrachion flexipes			1	1	T
Stylocheiron abbreviatum		1		4	2
Stylocheiron maximum				T	
Stylocheiron longicorne			1	2	11
Calanus finmarchicus	748	1887	286	442	3
Calanus pacificus	548	1755	419	257	5
Calanus A.	607	465	231	197	
Calanus plumchrus	143	497	318	676	
Calanus cristatus	6	1	78	108	29
Calanus tenuicornis	39	91	148	145	57
Eucalanus bungii	245	53	445	1046	1655
Eucalanus elongatus hyalinus	26	1	30	17	51
Rhincalanus nasutus	23	45	173	17	150
Paracalanus parvus	163			2	
Pseudocalanus minutus		36	163	214	
Microcalanus pusillus				2	
Clausocalanus arcuicornis	48	63	50	64	
Clausocalanus dubius			12	53	
Aetideus armatus		206	106	254	194
Aetideus pacificus		32			
Gaidius brevispinus		3		27	3
Gaidius variabilis			11	27	13
Gaidius tenuispinus			5		
Gaidius pungens	2	23	87	89	81
Gaetanus simplex			25	31	22
Euchirella rostrata		5	32	273	15
Euchirella pulchra		19	88	59	94
Euchirella galeata			2	1	11
Euchirella curticauda			45	2	3
Undeuchaeta plumosa		2		6	
Undeuchaeta intermedius			9	17	
Pseudochirella polyspina			1		
Pareuchaeta japonica		2	128	79	232
Phaenna spinifera			T		
Scottocalanus A.		1		6	
Scottocalanus persecans		58	5	12	53
Lophothrix frontalis			1		5
Scaphocalanus brevicornis	38	5	46	156	23

Table 1. (continued)

Species	NH15 Average No./1000M^3	NH25 Average No./1000M^3	NH45 Average No./1000M^3	NH65 Average No./1000M^3	NH65+ Average No./1000M^3
Scaphocalanus subelongatus			15		
Scaphocalanus minutus			15	4	
Amallothrix vorax			4		3
Racovitzanus antarctica			30	5	
Racovitzanus porrecta			23	27	9
Scolecithricella minor			2	19	
Scolecithricella ovata			13	5	8
Metridia lucens	8	132	287	558	51
Metridia pacifica	821	1464	2751	3784	1431
Pleuromamma A.				3	
Pleuromamma abdominalis		1	4	T	
Pleuromamma xiphias		14	40	81	83
Pleuromamma borealis		5		12	
Pleuromamma quadrungulata		2	67	63	29
Pleuromamma scutullata		23			51
Gaussia princeps		2	3		
Lucicutia flavicornis			53	5	
Heterorhabdus A.			2	8	
Heterorhabdus papilliger		1			
Heterorhabdus tanneri		2	39	109	8
Heterostylites longicornis					3
Heterostylites major				2	
Arietallus plumifer			3		
Candacia columbiae			2	63	25
Candacia bipinnata	2		32	15	
Epilabidocera amphitrites	11	146		12	3
Acartia longiremis	57	61	534	131	
Acartia danae	6	39	17	38	
Tortanus discaudatus		18			
Oithona spinirostris	3	23	5	117	27
Microsetella A.	4	63	21	2	3
Lubbockia squillimana			2		
Total species	28	46	62	63	44
Number of samples	11	13	13	10	5

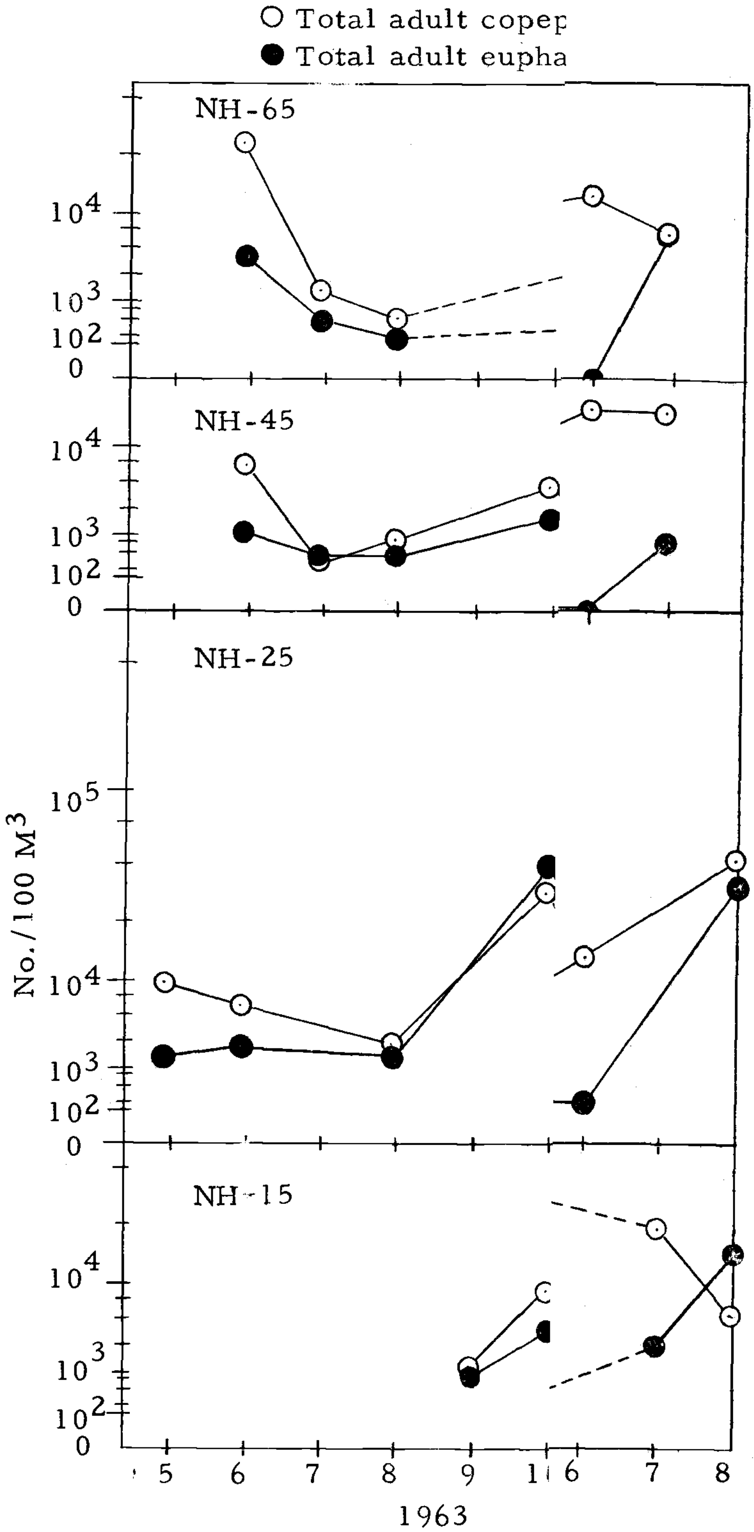

Figure 13. Seasonal variatic
euphausiids off N
sample made wit

NH-25 where maximal numbers occurred during late summer or fall. The seasonal abundance at NH-15 is similar to that at NH-25, but concentrations are reduced. Euphausiids were least numerous off Oregon during the winter and spring at all stations.

Adult copepods also had greatest concentrations at NH-25. A well defined pattern of fluctuation was not found at NH-25. Two abundance maxima occurred, the smallest during October and the largest during March. At NH-15 a bimodal fluctuation in abundance occurred with peaks during the fall (October and November) and also during April. At the two offshore stations the only noticeable pattern in abundance was an overall increase from July, 1963 through July, 1964. The catches at NH-45 and NH-65 were generally lower than those at NH-15 and NH-25.

The total number of species (N) on each station is shown on Table 1. The least number of species (28) occurred at NH-15, and the largest, 62 and 63, occurred at NH-45 and NH-65, respectively. While these are the total number of species considering all samples at each station, seasonal variations of the number of species are present at each station (Figure 14). A bimodal distribution and a general offshore increase characterizes the variation in species number. Maximum numbers occurred during December on all stations. A secondary maximum which varies in both extent and in time of occurrence was apparent at each station. This secondary maximum

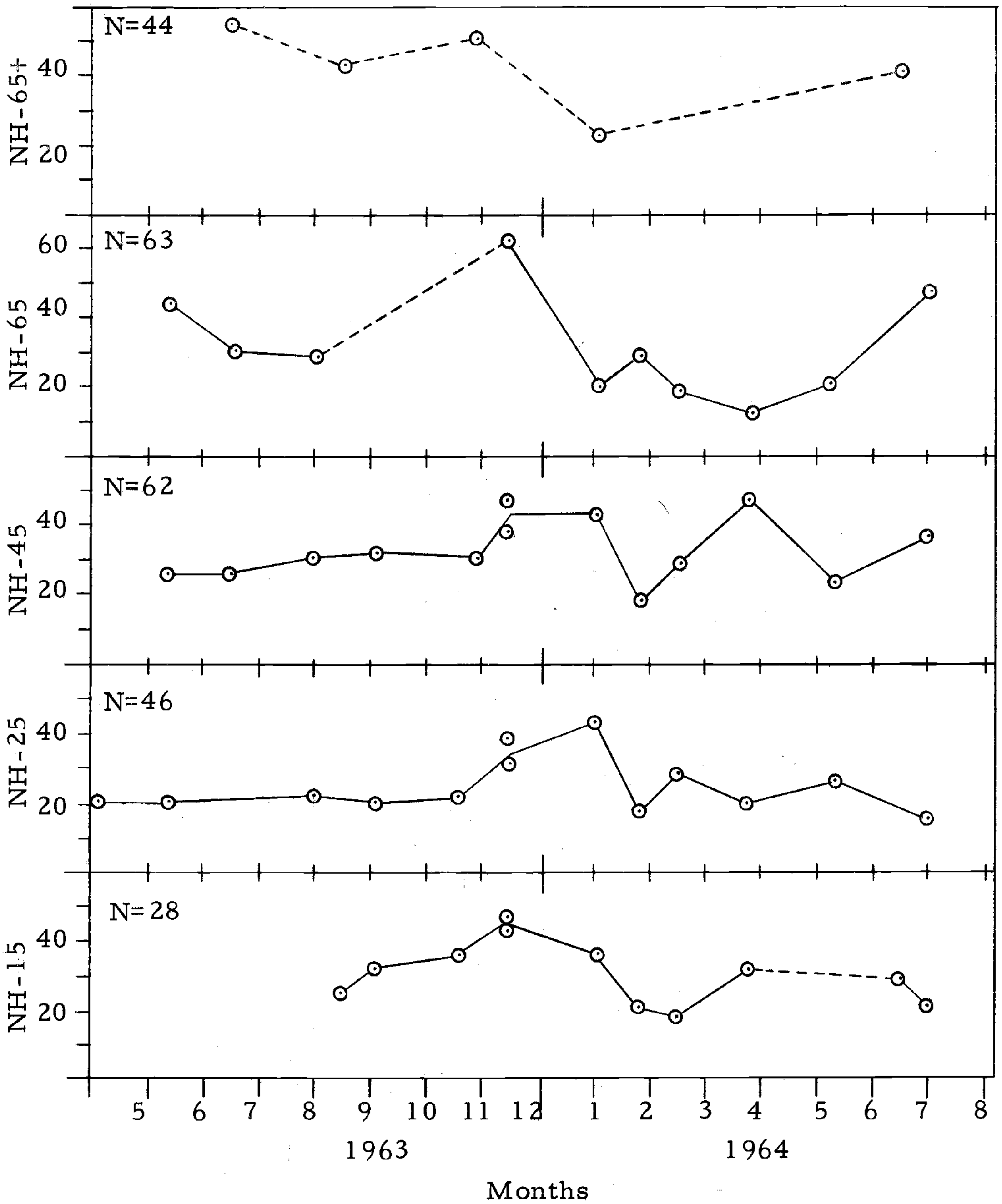

Figure 14. Monthly species variation; based upon the number of species present compared to the total number (N) of species collected at the respective station.

occurs during May-July on NH-15 and appears to occur progressively earlier with distance offshore.

Abundance, percent contribution to the total population and the frequency of occurrence of species which occurred in more than five samples are tabulated in Table 2. From these data, the numerical predominance of a few species is readily detected. Of the 79 species occurring off Newport, Oregon, 45 species occur more than five times. These constituted over 99% of the total number of individuals collected. Two species, Euphausia pacifica and Metridia pacifica, alone account for over 50% of the individuals (30% and 21%, respectively); and 10 additional species each account for more than 1% of the individuals. These 12 species make up 88% of the total.

To show that dominance by a few relatively abundant, frequently occurring species is not an artifact of a few samples, the species occurring in each sample have been ranked by abundance as described by Sanders (1960). This involves ranking the various species within each sample on the basis of numerical abundance. For each ranking of 1, the species is given 10 points; for each 2 ranking, 9 points; etc. until for each 10 ranking, 1 point. The summing of these individuals ranking values yields an index number which has been defined by Sanders (1960) as the "biological importance value" of each species.

Biological importance values (BIV) for the various species are included in Table 2. The highest possible BIV for my data is 520 if

Table 2. Total abundance, percent of total abundance, frequency of occurrence and biological importance value for each species collected. Listed in order of total abundance.

Species	Total abundance	Percent of total	Frequency of occurrence	BIV
Euphausia pacifica	153,545	30.08	49	292
Metridia pacifica	108,834	21.32	44	372
Calanus finmarchicus	40,900	8.01	44	288
Calanus pacificus	36,891	7.23	31	201
Eucalanus bungii	27,902	5.47	36	241
Calanus plumchrus	18,919	3.71	12	55
Calanus A.	17,695	3.47	17	114
Metridia lucens	11,376	2.23	20	97
Thysanoessa spinifera	10,380	2.03	21	73
Acartia longiremis	9,661	1.89	10	62
Aetideus armatus	7,561	1.48	19	94
Calanus tenuicornis	5,261	1.03	25	99
Pseudocalanus minutus	4,752	0.93	11	62
Rhincalanus nasutus	4,004	0.78	14	68
Thysanoessa inspinata	3,864	0.76	22	88
Pareuchaeta japonica	3,628	0.71	24	75
Euchirella rostrata	3,291	0.64	13	42
Scaphocalanus brevicornis	2,755	0.54	10	47
Gaidius pungens	2,742	0.54	22	67
Clausocalanus arcuicornis	2,629	0.52	8	23
Euchirella pulchra	2,452	0.48	20	50
Calanus cristatus	2,325	0.46	16	39
Epilabidocera amphitrites	2,155	0.42	5	18
Heterorhabdus tanneri	1,949	0.38	20	51
Pleuromamma xiphias	1,925	0.38	23	57
Paracalanus parvus	1,821	0.36	1	0
Nematoscelis difficilis (nd)	1,781	0.35	27	38
Oithona spinirostris	1,683	0.33	8	26
Pleuromamma quadrungulata	1,676	0.33	17	44
Nematoscelis difficilis (d)	1,285	0.25	15	24
Acartia danae	1,173	0.23	12	31
Microsetella A.	1,166	0.23	10	10
Eucalanus elongatus hyalinus	1,104	0.22	12	36
Racovitzanus porrecta	1,063	0.21	4	21
Candacia columbiae	782	0.15	4	6
Gaetanus simplex	748	0.15	11	13
Lucicutia flavicornis	746	0.15	4	5
Clausocalanus dubius	682	0.13	4	4
Euchirella curticauda	619	0.12	5	5
Candacia bipinnata	575	0.11	7	10
Pleuromamma scutullata	559	0.11	3	11
Scottocalanus persecans	521	0.10	9	10
Gaidius variabilis	481	0.09	8	13
Racovitzanus antarcticus	449	0.09	3	5
Aetidus pacificus	421	0.08	1	8

Table 2. (continued)

Species	Total abundance	Percent of total	Frequency of occurrence	BIV
Gaidius brevispinus	314	0. 06	4	3
Undeuchaeta intermedius	281	0. 06	7	6
Scolecithricella ovata	257	0. 05	6	2
Tortanus discaudatus	238	0. 05	1	4
Scaphocalanus minutus	231	0. 05	4	0
Scolecithricella minor	219	0. 04	3	10
Scaphocalanus subelongatus	191	0. 04	1	0
Pleuromamma borealis	184	0. 04	2	2
Thysanoessa longipes	163	0. 03	2	0
Thysanoessa gregaria	140	0. 03	6	4
Tessarabrachion oculatus	136	0. 03	12	3
Heterorhabdus A.	108	0. 02	3	0
Stylocheiron longicorne	87	0. 02	5	1
Euchirella galeata	87	0. 02	5	2
Undeuchaeta plumosa	81	0. 02	4	3
Scottocalanus A.	68	0. 01	3	11
Gaussia princeps	66	0. 01	6	8
Stylocheiron abbreviatum	63	0. 01	5	1
Pleuromamma abdominalis	63	0. 01	4	6
Gaidius tenuispinus	59	0. 01	1	0
Amallothrix vorax	59	0. 01	3	0
Arietallus plumifer	43	0. 01	3	0
Lophothrix frontalis	34	0. 01	2	0
Pleuromamma A.	34	0. 01	2	2
Lubbockia squillimania	33	0. 01	1	0
Microcalanus pusillus	24	<0. 01	1	0
Heterostylites major	23	<0. 01	1	1
Nematobrachion flexipes	19	<0. 01	5	0
Heterostylites longicornis	17	T	1	0
Pseudochirella polyspina	8	T	1	0
Heterorhabdus papilliger	8	T	1	5
Stylocheiron maximum	3	T	1	0
Phaenna spinifera	1	T	1	3
Total	510, 372		52 samples	
Average No. /1000M^3	9, 815			

the same species ranked number one in all 52 samples. The BIV obtained for my collections ranged from a maximum of 372 to zero. Examination of the BIV values and frequency of occurrence shows that the dominance indicated by the high number of individuals present in our collections is a reflection of the importance of a species. It is not the result of a limited number of samples containing extremely high concentrations of the species.

In this study I have separated the euphausiids and copepods into three categories: (1) dominant, (2) common and (3) infrequent species. The dominant group contains those species having biological importance value greater than 90 and constituting over one percent of the individuals of the whole population. The common species are intermediate in abundance. The infrequent species are those that either occurred less than five times or whose BIV was less than 10.

Dominant Species

There were nine species whose numerical abundance and BIV ranked them as dominant species. The abundance of these species was generally high although a few were sporadic in occurrence. The seasonal abundance and distribution of these nine species is of interest since one or several of these species constituted the bulk of the copepod-euphausiid population at all times.

Euphausia pacifica. This species had the highest average abundance of any species in the copepod-euphausiid population. The abundance of this species followed a seasonal progression with the greatest concentrations occurring during the fall at all stations (Figure 15). Seasonally, highest average abundance occurred at NH-25 with a progressive decrease in abundance at the offshore stations. This species was absent from only three collections, two at NH-15 and one at NH-65.

Metridia pacifica. This copepod contributed fewer individuals to the copepod-euphausiid population than Euphausia pacifica but was the most important species based upon the biological importance value. Large fluctuations in abundance occurred (Figure 16). Highest numbers occurred from October through May at NH-15 and NH-25. At NH-45, the abundance tended to increase from early 1963 through the sampling period. At NH-65, high abundances occurred during June and again between December and March.

Calanus finmarchicus. Three different patterns of seasonal abundance are shown by this species (Figure 17). At NH-15 and to some extent at NH-45, long periods of uniform abundance occurred. At NH-25, a cyclic change in the abundance of Calanus finmarchicus was evident with high catches during the spring and summer. At NH-65, this species followed an increasing trend in abundance from June 1963 through June 1964.

Calanus pacificus. This species was the fourth most abundant

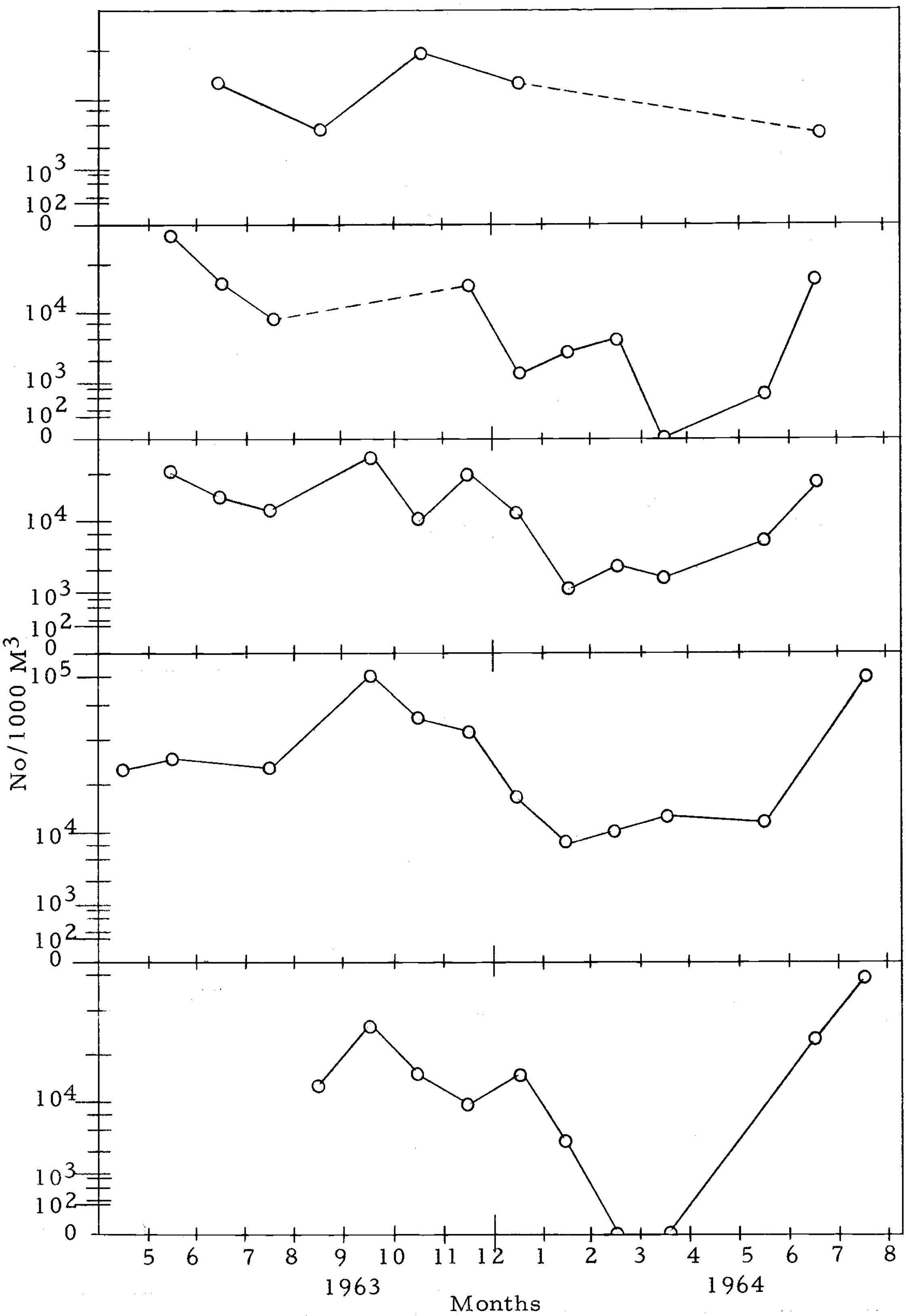

Figure 15. Temporal fluctuation in abundance of Euphausia pacifica at each of the Newport sampling stations.

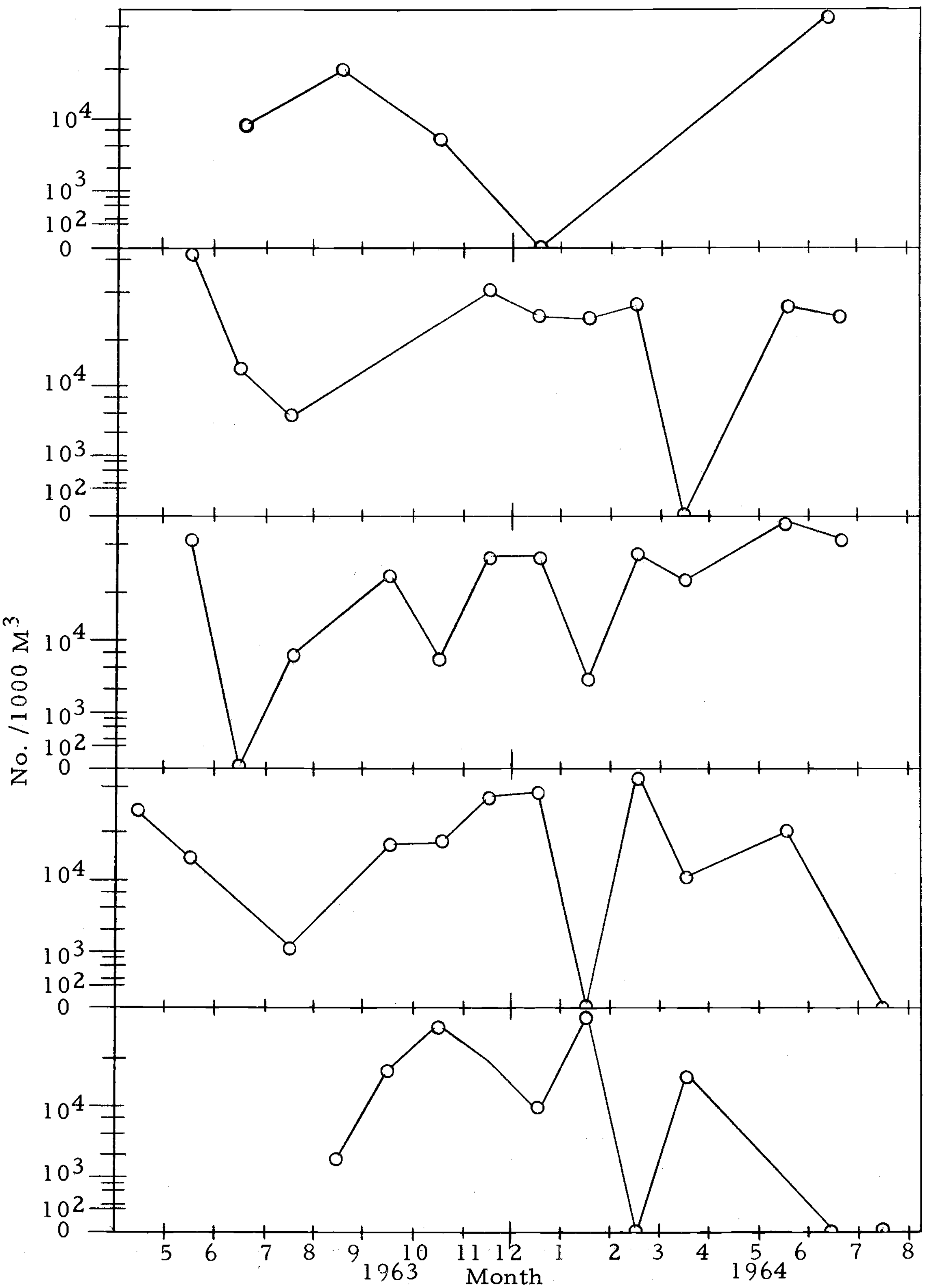

Figure 16. Temporal fluctuation on abundance of Metridia pacifica at each of the Newport sampling stations.

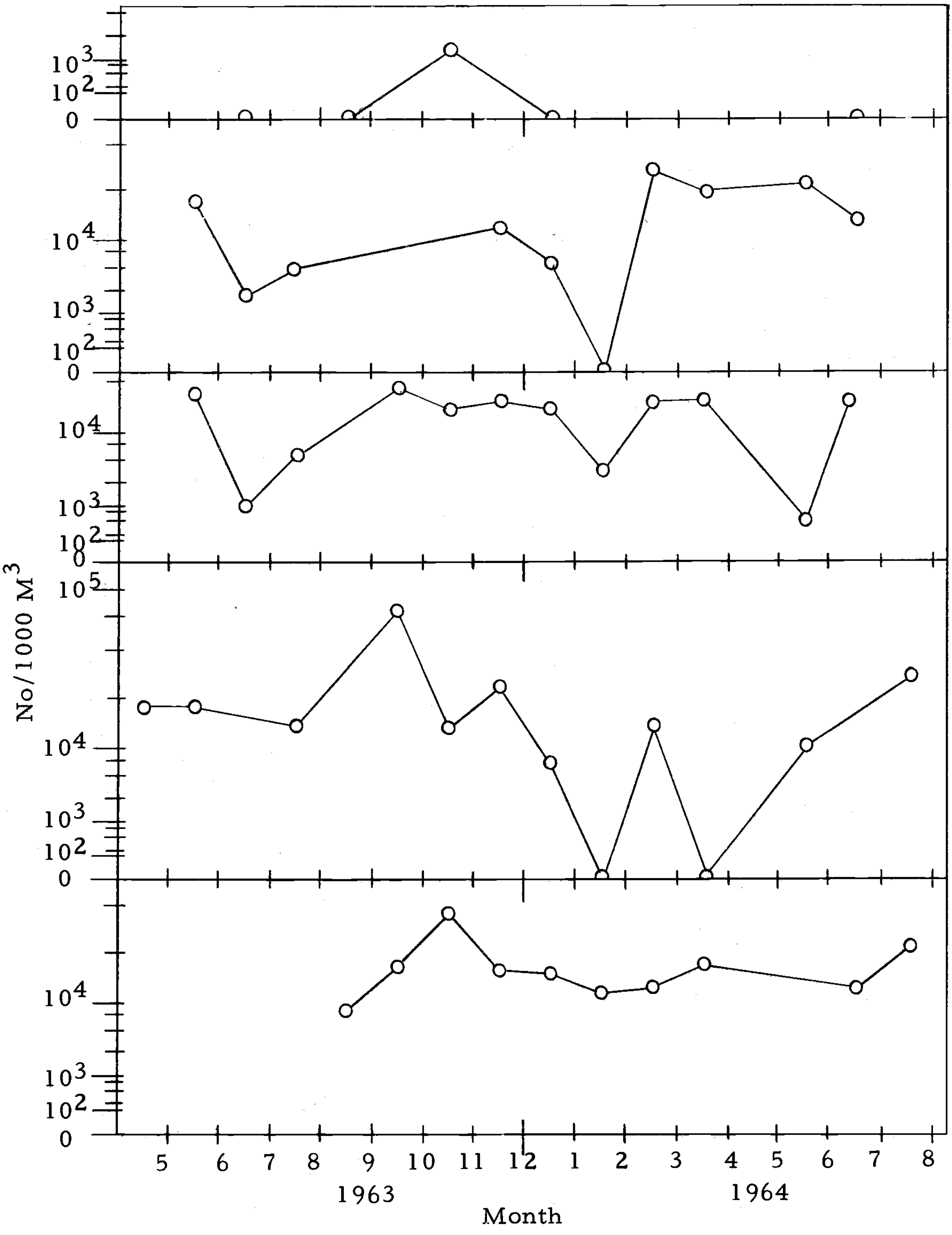

Figure 17. Temporal fluctuation in abundance of Calanus finmarchicus at each of the Newport sampling stations.

species (Figure 18). The period when this species was most abundant varied with station. At NH-15 and NH-25 highest abundance was between October and December. At the remaining stations the highest abundance appeared progressively later.

The concentrations of this species at NH-25 are in general greater than the other three stations.

Eucalanus bungii. This species occurred more regularly and in greater numbers at NH-45 and NH-65 than at the inshore stations (Figure 19). The concentrations at NH-45 remained rather uniform between June 1963 and April 1964. At NH-65 this species showed a more restricted period of abundance (February through April). It was low in abundance and sporadic in occurrence at NH-15 and NH-25.

Calanus A.[1] This species was absent from the 1963 collections. It began to increase in abundance in February 1964 and developed peaks of abundance between March and July (Figure 20). It was similar in abundance at NH-15, NH-45 and NH-65. Rather sporadic occurrence was found at NH-25.

Metridia lucens. This species, as with Calanus A., was rather uncommon during 1963 (Figure 21). It became most abundant during the spring and summer. Abundance was lowest at NH-15 and

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[1] The letter A is used to distinguish a morphologically distinct species from other species. Specific identification is lacking at the present time.

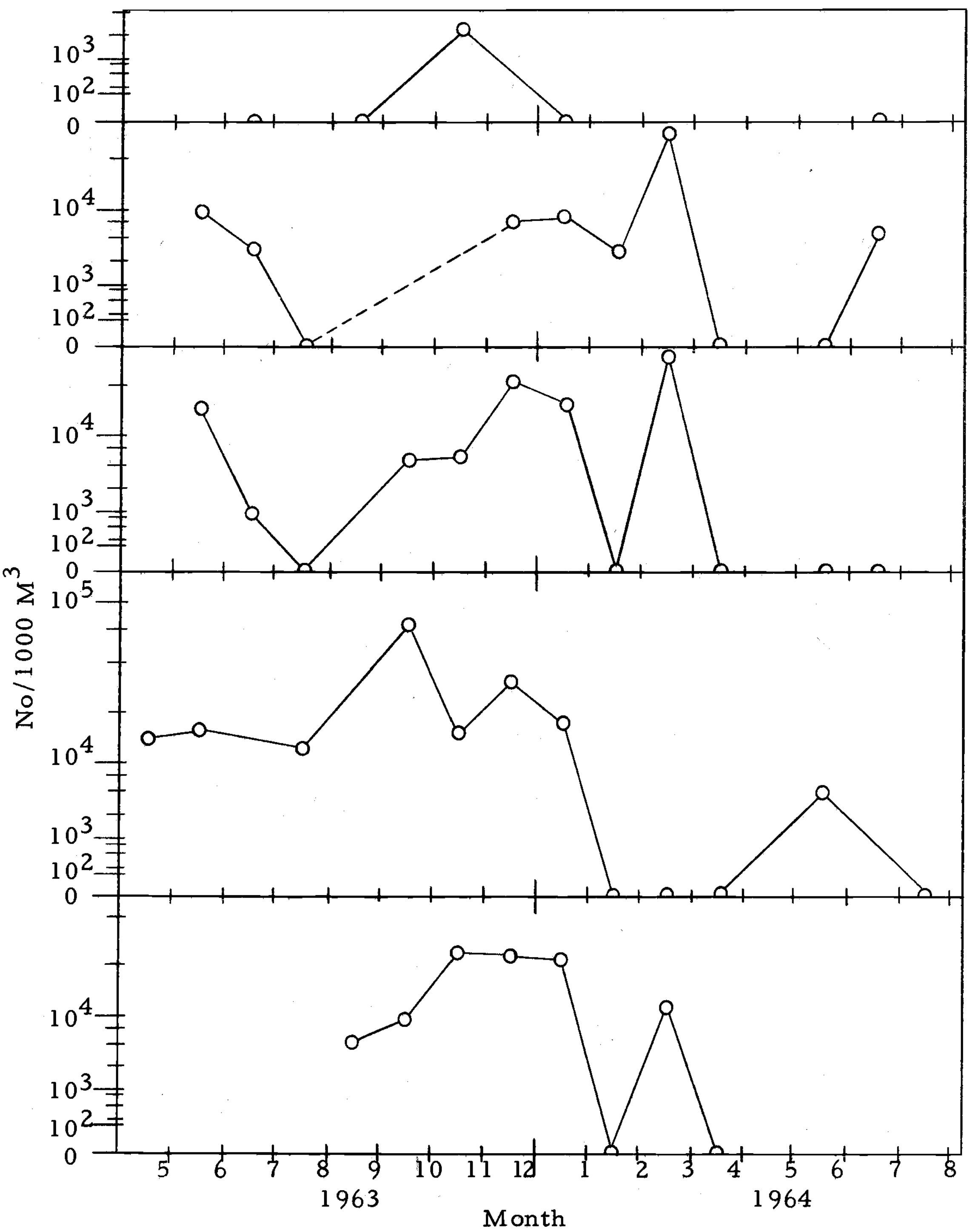

Figure 18. Temporal fluctuation in abundance of <u>Calanus pacificus</u> at each of the Newport sampling stations.

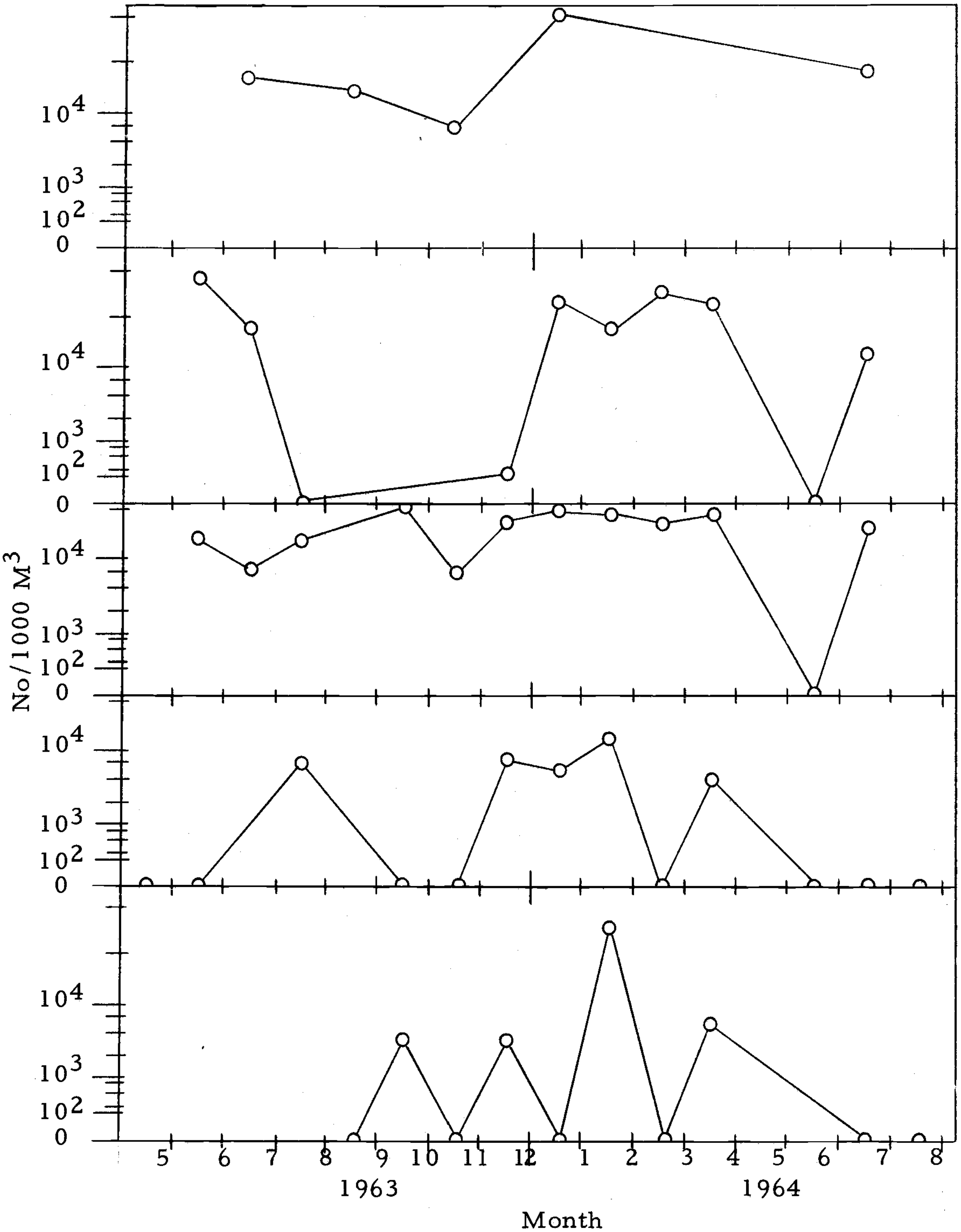

Figure 19. Temporal fluctuation in abundance of Eucalanus bungii at each of the Newport sampling stations.

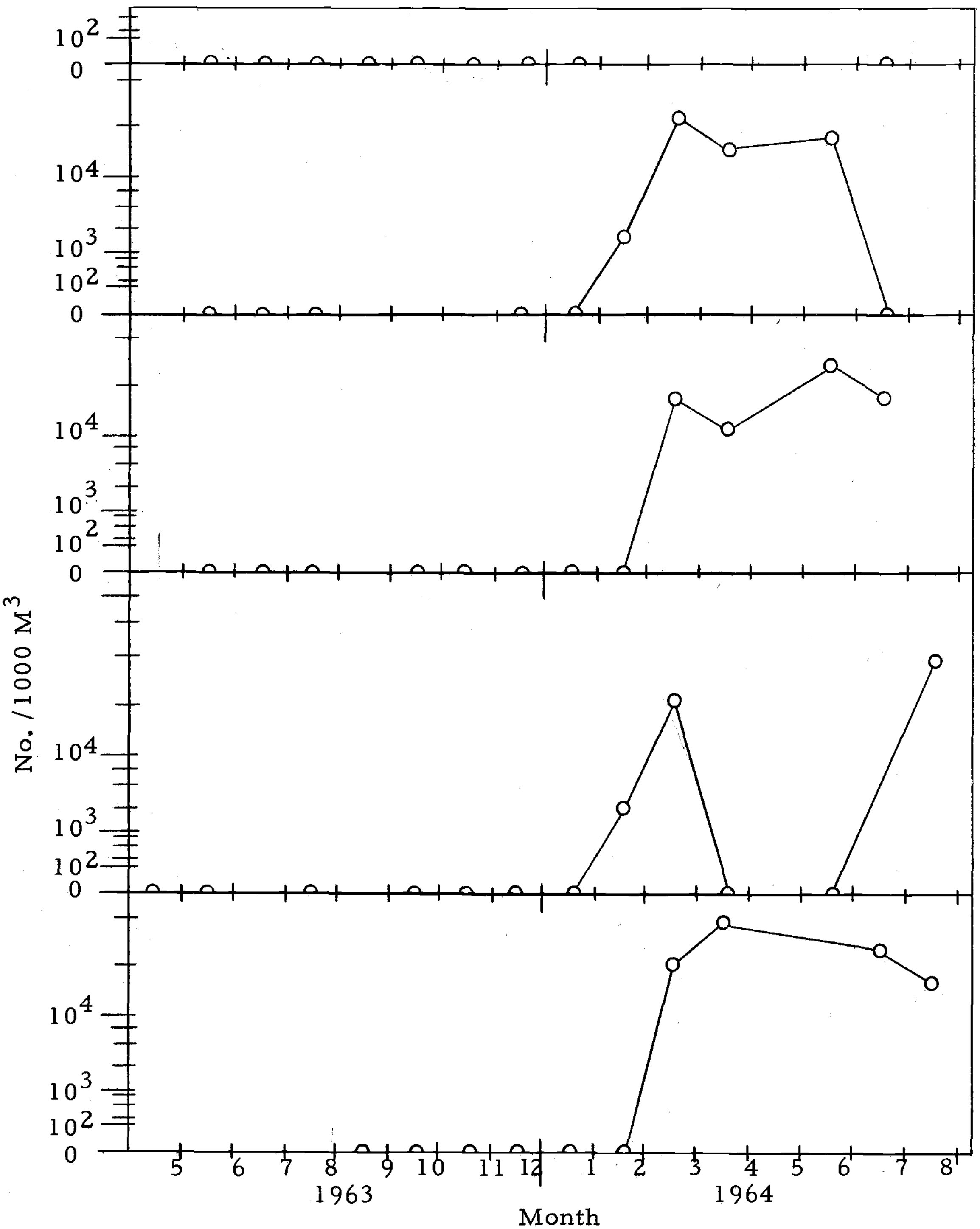

Figure 20. Temporal fluctuation in abundance of Calanus A. at each of the Newport sampling stations.

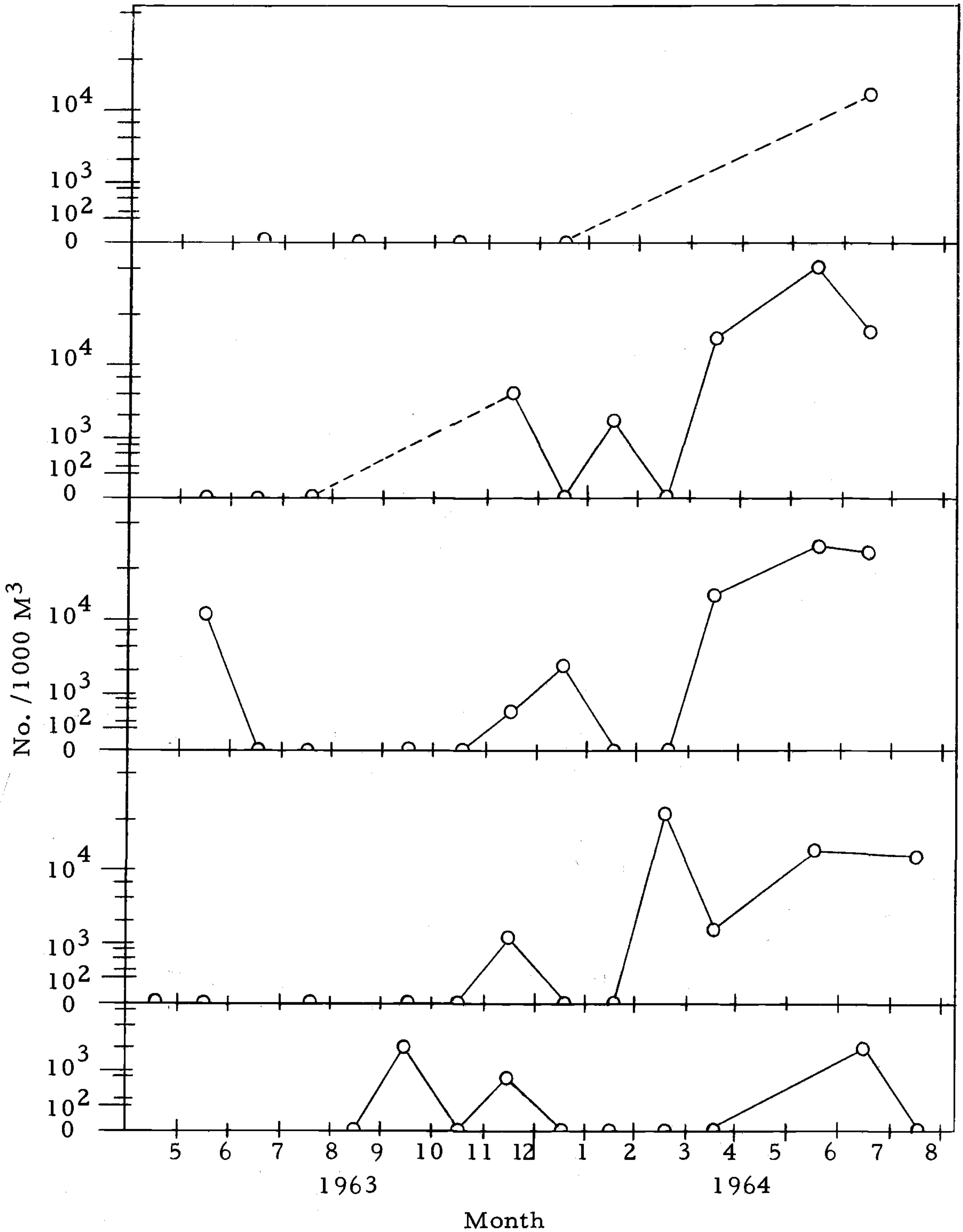

Figure 21. Temporal fluctuation in abundance of Metridia lucens at each of the Newport sampling stations.

increased offshore.

Aetidius armatus. This species was sporadic in occurrence at NH-25, NH-45 and NH-65 and was absent from the collections at NH-15 (Figure 22). It occurred primarily during the winter and spring.

Calanus tenuicornis. This is the least abundant species of the dominant group. Maximum abundances occurred during winter and spring at NH-25, NH-45, and NH-65, but during the fall at NH-145 (Figure 23). Numbers tend to be greater at NH-45 and NH-65 than at NH-15 and NH-25.

Non-Dominant Species

The nine species previously discussed have a biological importance value greater than 90 in addition to contributing more than 1% of individuals to the copepod-euphausiid population. Three additional species also contribute more than 1% to the population but have a much lower BIV and occur less frequently than the other nine species. These species are the copepods, Calanus plumchrus, Acartia longiremis and the euphausiid, Thysanoessa spinifera. These species occurred seasonally and in large numbers, hence, the high number of individuals but lowered biological importance value. The greatest abundances of these species was found inshore of NH-45.

Seasonally, Thysanoessa spinifera was most abundant off

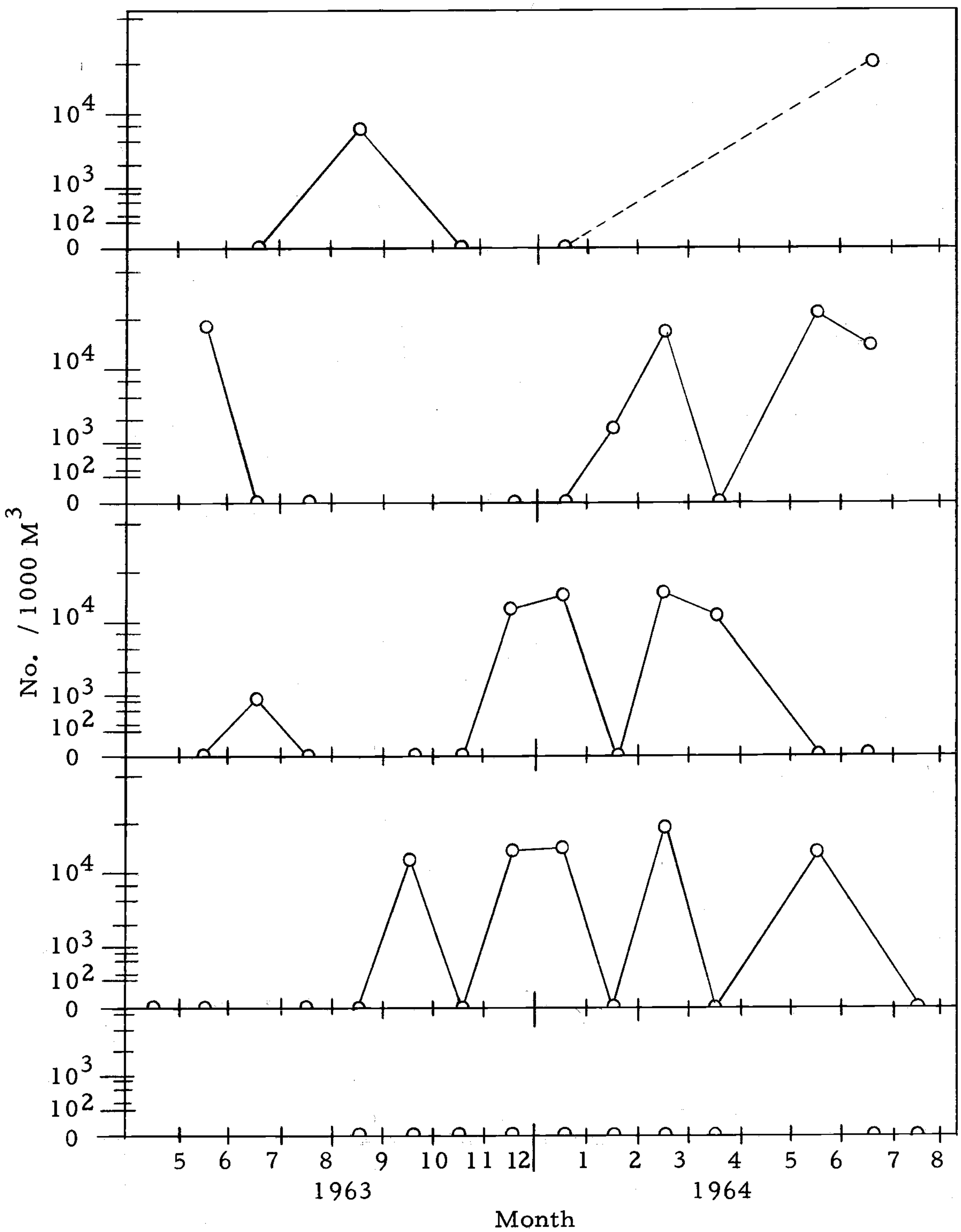

Figure 22. Temporal fluctuation in abundance of Aetideus armatus at each of the Newport sampling stations.

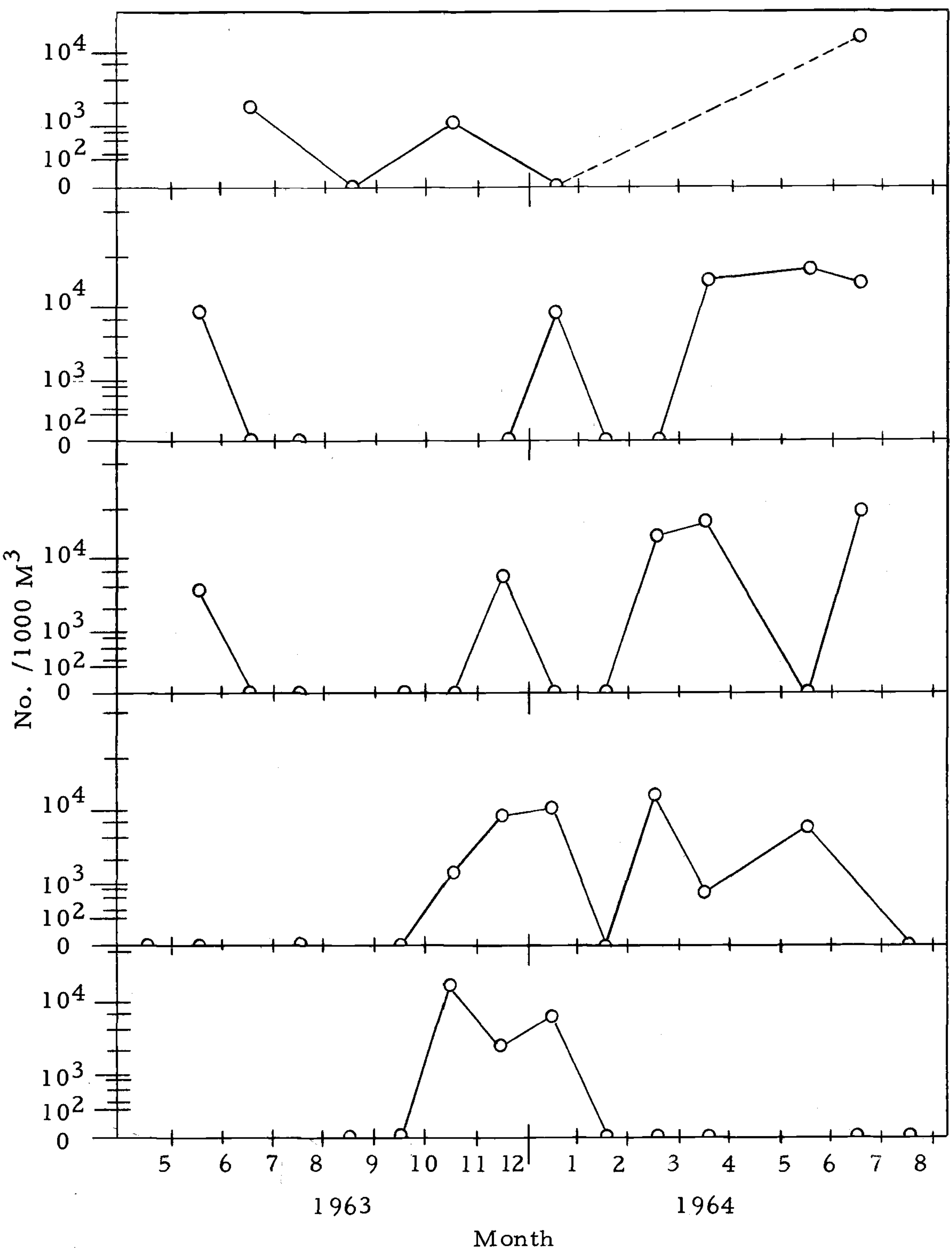

Figure 23. Temporal fluctuation in abundance in Calanus tenuicornis at each of the Newport sampling stations.

Newport from September through February. Although previously reported to be an indicator of upwelling by Brinton (1962), this species was not associated with upwelling off Oregon during 1963. Greatest abundances coincided with the northerly flow during the fall. During 1964, upwelling was weakly developed and high concentrations of Thysanoessa spinifera were found.

The two copepods, Acartia longiremis and Calanus plumchrus, like Thysanoessa spinifera, were strongly seasonal in occurrence. Acartia longiremis was an inshore, spring and summer species. This species was not present during 1963, but in 1964 it was abundant, reaching a maximum in July. Calanus plumchrus had an even more restricted period of occurrence (March and April) with maximum numbers occurring during March. As with Acartia longiremis, concentrations of Calanus plumchrus were greater at the inshore stations (NH-15 and NH-25).

The remaining 67 species contributed less than 1% of the total individuals to the copepod-euphausiid population off Oregon (Table 2). These species were separated into two groups on the basis of their biological importance value. Those species that occurred in more than five samples or whose biological importance value was greater than 10 were considered to be common species and the remainder, infrequent species.

Twenty-seven species were found that belong to the common species category. These species occurred frequently enough that we are able to detect patterns in their distribution that suggest relationships to changes in the physical environment. A large number of the common species (18) were present throughout the year with very little seasonal change in their distribution. The only distributional change that occurred within this group of species was an occasional shoreward movement of the species during the winter.

The second major group of common species show definite seasonal variation in occurrence. Four species, Psuedocalanus minutus, Oithona spinirostris, Eucalanus elongatus hyalinus and Tessarabrachion oculatus were most common in the summer. Three species were associated with winter collections, these being Nematoscelis difficilis (d),[2] Rhincalanus nasutus and Acartia danae. Another group of two, Thysanoessa gregaria and Clausocalanus arcuicornis, suggest onshore movement when environmental conditions are rather uniform from the coastline offshore.

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[2] Two forms of this species have been recognized. The difference between these forms is the presence or absence of a denticle on the lateral margin of the carapace. The above symbol (d) refers to the denticled form, (nd) refers to the non-denticled form.

Table 2 includes a large number of infrequent species (that is, found in less than 10% of the 52 samples). Out of 79 species, 40 fall into this category. Most of these species cannot be reliable indicator species because they may be nothing more than an artifact of chance collection. Others suggest possible relationships with the ocean conditions.

Of greater value as indicators are those species whose distribution changes in some consistent pattern throughout the year. Most species were closer inshore during the winter period (October-March) than during summer. This inshore distribution is expected since at that time conditions inshore to offshore were essentially uniform, as indicated by the temperature and salinity at 10 meters. During the summer sharply different conditions exist between NH-65 and NH-15.

Catches of three species, Heterorhabdus A., Lophothrix frontalis, and Amallothrix vorax, indicate a different distribution from the other species. They were found offshore (NH-65, NH-65+) during the winter and were present into NH-45 during the summer.

ASSOCIATION ANALYSIS OF THE COPEPOD-EUPHAUSIID POPULATIONS

To further describe the copepod and euphausiid populations off Oregon, I have attempted to detect species associations. Few analyses of this type have been attempted with the plankton, the most recent being that described by Fager (1957) and subsequently modified by McConnaughy (1964). I have used the Fager-McConnaughey method, based on presence or absence of species, and the Sanders method (Sanders, 1960), which considers relative abundance, to determine associations of copepods and euphausiids off Oregon.

Step by step the Fager-McConnaughey method can be summarized as follows:

1. Species are arranged in order according to the number of samples in which each was found. (A code number is assigned to each species for ease of handling. Different life history stages and environmental conditions may be treated as species.)
2. Prepare a trellis diagram with species in order of decreasing occurrence frequency.
3. In each block, where species pairs are compared, place the number of joint occurrence, and the correlation coefficient calculated from the following

relationship:

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

where:

c = correlation coefficient

A = number of occurrences of species A

B = number of occurrences of species B

C = number of joint occurrences

Correlation coefficients will range from positive to negative but only the positive values need be calculated since only they represent a degree of association.

4. The grouping of species is determined by comparison of the correlation coefficients in the trellis diagrams.

Initial association analysis was carried out following the steps of McConnaughey (1964). This analysis yielded 47 associations of euphausiids and copepods. This number of associations points out the problem of only using occurrence in an area where a relatively few dominant species contribute almost 90% of the individuals and where 34 of 79 species contribute less than 2% of the individuals collected.

The dominant species were present in most of these 47 associations, but the associations were separated by the 34 species of infrequent occurrence. Because of the great number of similar associations it is obvious that this method places too much emphasis upon the infrequent species at the expense of the more abundant species. To eliminate weakly defined associations caused by the infrequent species, I arbitrarily set 0.50 as the lowest coefficient to be included in an association and again calculated the associations.

Two major groups of species and six species pairs were found using this method (Figure 23). Interspecies relationships greater than 0.50 are shown by solid lines. The length of the lines between species reflects the degree of correlation between the species. Those species not connected by a line are positively correlated but the distance of separation on the figure is not proportional to the extent of correlation.

Of the two major groups, the most closely associated group A contained Calanus finmarchicus and Calanus pacificus and the more loosely associated group B contained the copepods Eucalanus bungii, Pareuchaeta japonica, Pleuromamma xiphias, Gaidius pungens and Euchirella pulchra and the euphausiid, Nematoscelis difficilis. The two groupings were not completely separate, however; the euphausiid Euphausia pacifica and the copepod Metridia pacifica had a correlation of 0.85 and were common to both defined groups.

The within group association coefficient is at least 0.50 for groups A and B. The correlation coefficient between the two groups was 0.16, suggesting that the groups are associated but not nearly

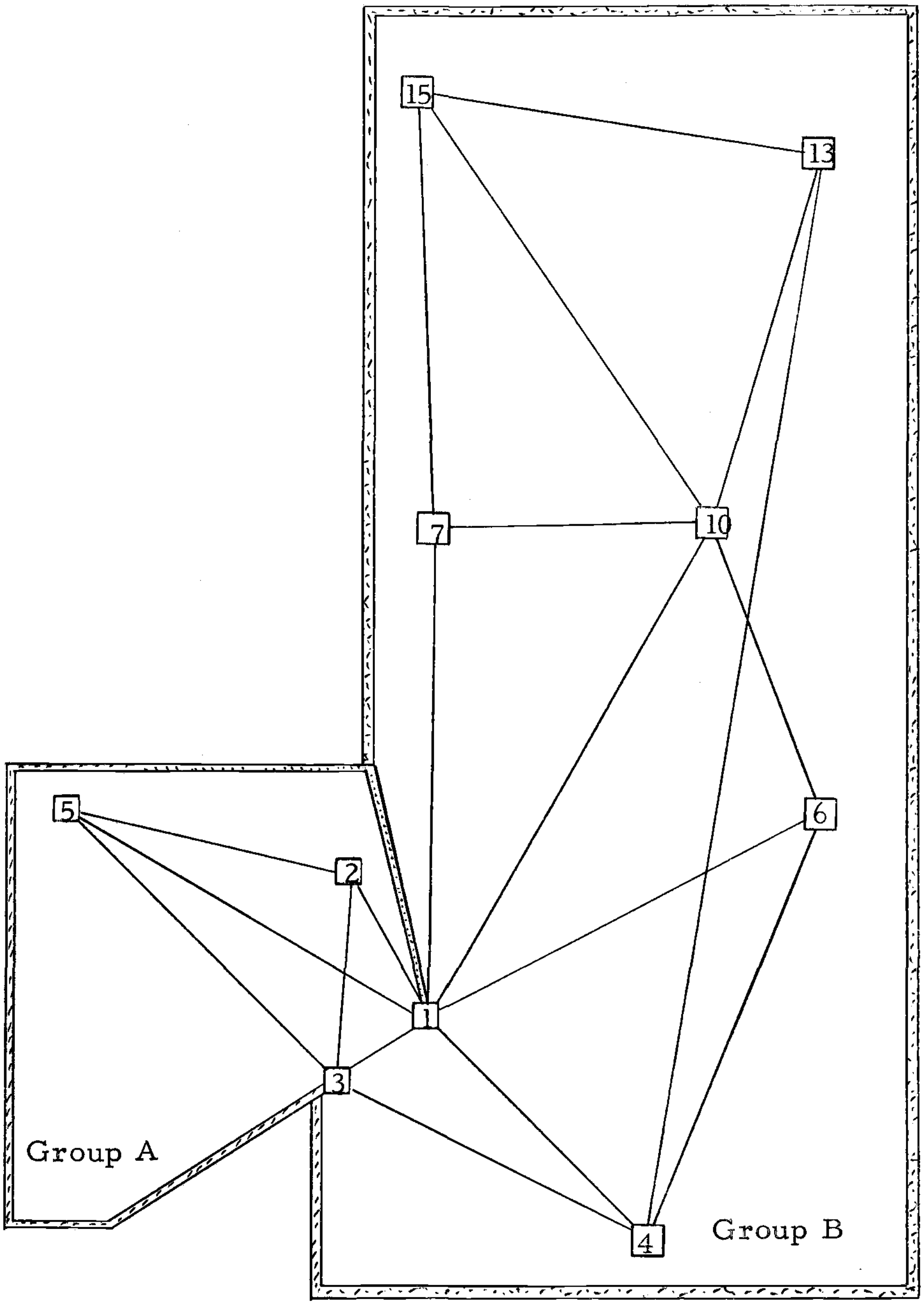

Figure 24. Association of species as indicated by the Fager-McConnaughey method of analysis. Solid lines indicate correlation coefficient greater than 0.50.

as closely as the species within each association.

Most of the six species pairs were infrequently collected (found in less than five of the 52 samples collected). The most closely associated species pair was *Pleuromamma quadrungulata* and *Gaetanus simplex*. They occurred together in 10 of 16 samples. The species pairs are listed below.

Pleuromamma quadrungulata-*Gaetanus simplex*

Oithona spinirostris-*Candacia columbiae*

Gaidus brevispinis-*Pleuromamma borealis*

Lucicuta flavicornis-*Racovitzanus antarcticus*

Lophothrix frontalis-*Pseudochirella polyspina*

Pleuromamma A. -*Stylocheiron maximum*

Although grouping in this manner eliminates the large number of species groups caused by the infrequent species which defined the associations, it also eliminates species that may show real association to other species.

Considering the loss of data and the rather uniform species occurrence of the collections, other methods of association analysis were considered. The second method that I used for determining the associations of species within an area was that described by Sanders (1960) in his study of a benthic soft-bottom community in Long Island Sound. He determined faunal homogenity of all samples with respect to species composition and relative abundance. The relative abundance of each species, expressed as a percent of the total abundance, is determined for all species present within each sample. For each pair of samples the relative abundance of each species is compared and the smaller percentage is taken as the common abundance value. The common abundance values for each pair of samples are summed and the result is a quantitative estimate of the affinity between the two stations. To demonstrate the determination of the Index of Affinity consider the following comparison between two samples:

Species	Sample i	Sample ii
Species A	15%	75%
Species B	27%	0
Species C	58%	25%

The common abundance values are 15% for species A, zero for species B and 25% for species C. The sum is the Index of Affinity and is 40%.

After determination of the Index of Affinity for all sample comparisons the results are displayed upon a matrix table or "trellis diagram." The samples can be rearranged so as to place those samples of highest affinity closest together, thereby revealing similarities between samples.

The trellis diagram for my 52 samples off Oregon, arranged by stations and season, is presented in Table 3. The most obvious feature of the trellis diagram is the extent of variation, not only between stations but also seasonally within the samples for a station. The overall average affinity is 29%. This is rather low compared to that obtained by Sanders in his benthic-soft bottom community (59%), but his results were quite high when compared to the data presented by Renkonen (1944) in his study of lake shore beetle fauna (24%), by Wieser (1960) for the microfauna of Buzzards Bay (27%), and as reported by MacFadyen (1960) for the Collembola populations of Jan Mayen Island (25%). The average affinity of the copepod-euphausiid populations off Oregon are similar to the coefficients found in these latter studies.

The average within and between station affinities are shown on Figure 25. The range of affinity values is not large, 15-35%, and those stations separated by the largest distance geographically have the least affinity. The three inshore stations (NH-15, NH-25, and NH-45) show greater within than between station affinity. Station NH-15 shows equal affinity to itself and to NH-25 which suggests that there is a little difference between the composition and abundance of the populations occurring at these stations. The remaining between stations affinities for NH-15 and all between station affinities for NH-25 and NH-45 have a lower value than the within station value.

Stations

	15	25	45	65	65+
15	30	30	26	22	15
25		34	33	27	22
45			35	34	32
65		Overall Average 29%		31	30
65+					27

Figure 25. Average Index of Affinity for comparison of within and between station affinity. Within station indexes are stippled and placed along the diagonal.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
1		64	61	69	41	71	10	14	15	15	31	43	63	66	58	43	36	60	28	5	10	20	16	30	27	19	25	35	55	35	36	20	7	28	15	7	12	14	25	23	18	12	10	33	8	16	17	14	9	22	2	9
2		·	68	58	54	48	35	14	16	15	39	68	66	60	54	55	47	67	49	9	32	45	32	38	53	28	30	60	59	68	49	46	9	37	33	31	39	41	30	24	39	36	36	40	11	26	34	19	33	33	6	33
3			·	67	56	43	33	17	15	11	19	66	57	53	44	37	30	67	49	5	33	39	34	19	46	13	16	42	47	47	62	43	7	46	32	31	49	38	19	21	41	39	36	45	11	32	34	16	39	12	2	40
4				·	59	64	16	15	15	12	17	46	53	53	45	36	28	54	28	3	16	18	21	17	26	5	12	27	44	28	41	21	7	36	22	14	20	18	15	14	21	19	16	40	9	22	21	8	15	9	2	15
5					·	61	38	13	12	12	12	51	39	38	33	39	36	60	53	12	34	45	31	12	48	18	24	42	37	58	64	52	15	51	33	30	38	43	26	20	41	43	39	44	11	22	33	21	38	25	11	37
6						·	8	18	13	16	30	39	49	51	50	41	32	54	27	6	9	19	14	30	25	19	25	32	42	32	36	17	8	28	15	5	13	12	22	22	14	12	8	31	13	15	16	17	7	23	2	7
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8								·	37	34	15	14	14	14	14	14	10	21	12	7	9	3	8	36	10	2	4	8	13	15	24	17	3	16	20	10	9	2	2	6	4	10	3	21	15	14	8	1	0	3	7	3
9									·	57	16	14	16	10	8	13	9	16	10	9	16	18	19	50	14	3	6	16	16	12	14	13	7	17	32	24	79	9	10	13	14	11	9	24	15	23	30	7	13	5	1	9
10										·	20	12	12	13	13	15	10	13	9	13	9	17	28	56	13	8	10	12	15	10	9	8	4	7	25	23	24	7	7	12	8	2	2	13	10	18	38	7	2	7	2	2
11											·	25	38	52	71	71	73	30	10	13	8	12	6	63	16	49	22	38	29	34	10	7	4	11	11	8	9	7	16	17	7	2	2	19	12	11	8	11	2	40	2	+
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13													·	65	60	53	47	62	30	5	34	25	18	37	34	29	29	48	55	47	37	26	8	53	22	13	39	22	30	26	23	16	16	58	31	19	21	20	16	32	3	13
14														·	79	56	57	55	22	14	4	22	8	51	26	52	34	52	52	50	37	24	15	27	18	1	9	19	31	21	12	15	13	36	17	8	12	22	13	49	14	9
15															·	73	69	54	20	5	3	13	8	55	21	51	22	40	43	42	29	13	5	22	8	1	6	9	18	18	10	5	3	27	8	8	9	12	3	43	2	1
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17																	·	44	34	7	16	25	19	45	32	50	27	44	31	59	31	27	7	26	17	14	19	22	29	21	19	18	17	26	3	18	22	16	16	48	4	15
18																		·	55	9	30	39	38	29	45	22	29	50	53	60	61	53	10	57	40	23	34	35	30	27	33	31	29	50	13	35	40	18	30	30	10	35
19																			·	9	44	57	38	10	71	16	22	38	26	62	58	59	9	41	33	54	46	67	28	21	71	55	57	34	5	30	38	22	39	23	9	67
20																				·	6	23	1	13	11	23	35	20	16	15	10	18	75	9	20	8	10	19	35	14	7	40	27	23	19	4	10	38	16	16	78	8
21																					·	47	38	10	43	2	7	26	10	40	42	45	5	63	39	52	46	42	11	8	43	43	42	52	45	36	35	6	34	5	T	48
22																						·	41	16	66	28	34	50	26	54	45	51	21	33	52	60	50	65	41	20	52	65	68	37	28	30	48	36	46	21	30	60
23																							·	11	33	5	10	30	13	33	37	36	7	33	46	56	58	29	14	11	30	30	28	28	11	55	49	7	29	7	1	38
24																								·	18	43	22	38	28	34	10	8	4	7	15	16	13	7	16	17	8	2	2	19	13	15	13	10	2	40	2	2
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35																																			·	39	45	42	30	22	30	39	38	49	34	45	62	28	41	27	19	42
36																																				·	54	62	13	8	62	45	63	27	9	37	38	8	32	5	2	64
37																																					·	43	22	18	47	43	41	26	17	48	48	17	39	15	9	44
38																																						·	38	25	76	58	78	34	13	22	35	35	50	31	17	75
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40																																								·	22	9	13	12	9	18	20	38	18	45	15	14
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Stations NH-65 and NH-65+ differ from the other three stations in that a decrease occurs in within station affinity offshore, NH-65+ having the lowest within station affinity. The highest affinity for these two stations is with NH-45. There is a higher affinity of NH-65+ to NH-65 than there is within the collections at NH-65+.

The interrelationship between samples possessing an Index of Affinity equal to 65 or greater is shown on Figure 26. Thirty-four stations are included forming six station groups. The two large groups represent an inshore and an inshore-offshore group. The inshore group (I) consists of 11 samples from NH-15 and NH-25 of which all but four are from winter months. Group (II) also consists of winter samples but are from NH-45. Group III contains winter and summer samples from all four stations (NH-15 through NH-65). The occurrence in group III of winter samples from all four stations suggests that the uniformity of the physical environment during the winter is reflected in the biological populations.

Groups IV, V, and VI contain relatively few stations and are quite distinct from each other and from the other three groups. Group IV contain two stations widely separated in space and time. Groups V and VI show consistency in seasonal occurrence of the member collections. Group V contains February collections from NH-25, NH-45, and NH-65+. Group VI contains three summer collections from NH-45, NH-65 and NH-65+.

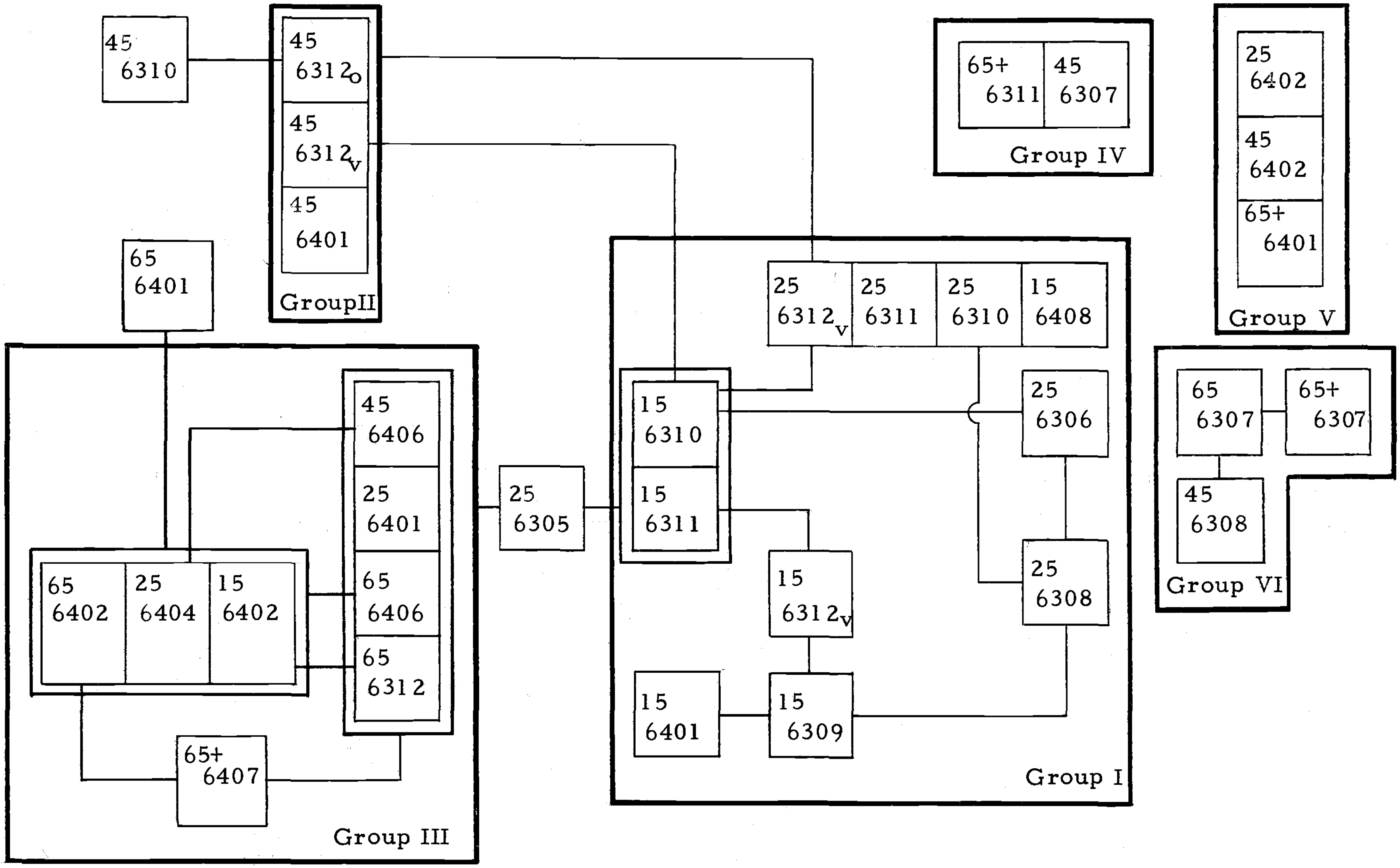

Figure 26. Station groups as determined by the Index of Affinity. An Index of Affinity equals 65 or greater used for compilation of this figure.

The species composition and BIV of each group compared to all other groups reveals that a great number of species occur in several or all of the associations. The most important difference between the station associations is the ranking of the dominant species within the group. Only 14 dominant species were present. Euphausia pacifica was a dominant in all associations. Most of the remaining dominant species were present in reduced numbers at all stations when they were not actually dominants at that time. However, Calanus pacificus, Metridia lucens, Calanus tenuicornis, and Aetideus armatus are entirely absent from at least one group.

Very little fidelity, or the restriction of a species to an association, can be seen among the species composing the various associations. Seventeen species were restricted to one grouping only. These species are:

Group I

Tortanus discaudatus

Harpacticoid copepods

Group II

Clausocalanus dubius

Phaenna spinifera

Racovitzanus antarcticus

Lubbockia squillimana

Group III

Paracalanus parvus

Microcalanus pusillus

Pleuromamma borealis

Heterorhabdus A.

Candacia columbiae

Group IV

Thysanoessa longipes

Psuedochirella polyspina

Lophothrix frontalis

Group V

None

Group VI

Heterostylites longicornis

Arietallus plumifer

While these species show restriction to one of the groups, their occurrence is extremely limited. All are low in BIV and frequency. They show apparent fidelity to a group, but may actually be rare species that occurred by chance in a restricted number of samples within a group.

The similarity of the six groupings also can be determined by comparing BIV's as we did in the relative abundance of species in the Sander's method. By taking the reciprocal of the resulting numbers for sample similarity, values are obtained which are small if the groups are closely related and large if the groups are distantly related. These values, represented as distances between groups in Figure 27, indicate two separate associations. One contains groups I, II and III, the other groups IV, V and VI. The first association contains 24 stations, the other contains only eight stations.

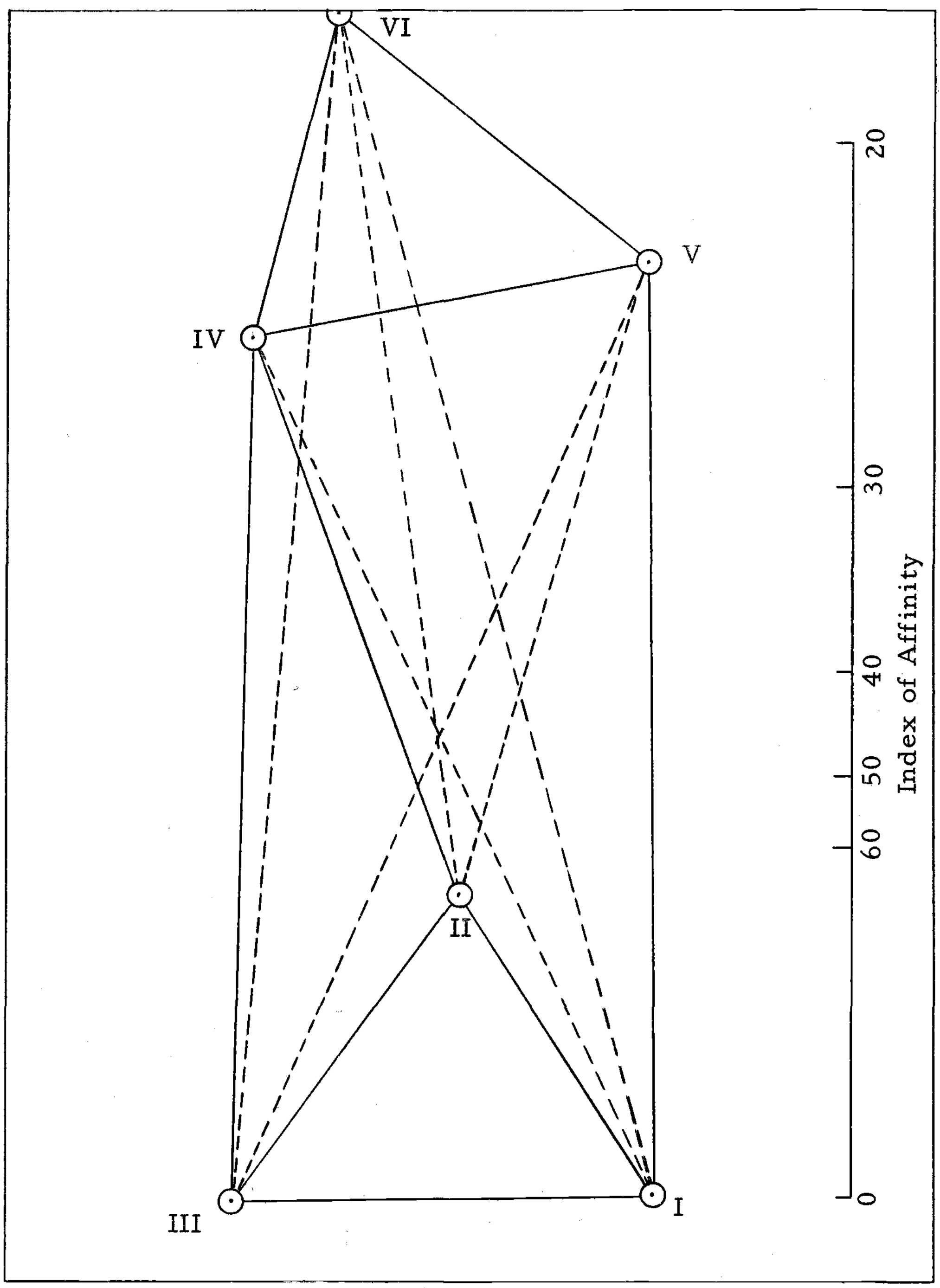

Figure 27. Relationship between groups based upon a summation of the lowest relative common biological importance value of each pair of stations. Distances along solid lines equal the reciprocal of the relative common biological importance value. Common BIV can be obtained by comparison lines joining species to scale measurement using "o" as scale origin.

DISCUSSION

The physical environment off Oregon has been shown to have many characteristics of the Pacific Subarctic Water mass (Tibby, 1941; Fleming, 1958; Rosenberg, 1963). This alliance with Pacific Subarctic is not complete, as indicated by the northerly flow of water present inshore during the fall and winter (Burt and Wyatt, 1964).

Recent studies of zooplankton from the region support the conclusions derived from studies of the physical environment, namely, that the area is actually a region of transition. Johnson and Brinton (1963) divide the northwestern Pacific Ocean into several regions, of which their Pacific Subarctic and Transition zones are adjacent to the coastal area of Oregon. The characteristic species which they list in the Pacific Subarctic are the copepods Calanus tonsa,[3] Calanus cristatus, Eucalanus bungii and the euphausiids, Euphausia pacifica and Thysanoessa longipes. These species are all common members of the zooplankton in the coastal waters of Oregon.

The transition zone described by Johnson and Brinton (1963) is a region between subarctic and central Pacific populations. Characteristic species of the transition region are the copepod, Calanus pacificus, and the euphausiids, Nematoscelis difficilis and

[3] Calanus tonsa is considered by some authors as synonymous with Calanus plumchrus. V. V. Vervoort (personal communication, 1960) considers it Calanus plumchrus. I have followed his identification.

Thysanoessa gregaria. These species are also common members of the local populations, Calanus pacificus being one of the more abundant species off Oregon.

In addition to those species that can be definitely assigned to a particular water mass, these are many species which have distributions suggesting possible northern or southern extensions during certain seasons.

Off Oregon, the most likely period of shoreward distributional extension is during the winter when the physical environment is most nearly uniform and surface currents have a strong onshore component (Burt and Wyatt, 1964). The distribution of Thysanoessa gregaria and Clausocalanus arcuicornis in the winter extends shoreward to NH-15 whereas in the summer they were not found shoreward of NH-45. Nematoscelis difficilis (d), Rhincalanus nasutus and Acartia danae occurred only during the winter. These species are all found in greater concentrations in the waters to the south of Oregon (California, 1964; Johnson and Brinton, 1962). Previous use of Acartia danae as indicative of northward flow has been recorded by Frolander (1962) and Cross (1964). These data provide strong evidence for advection of southerly water into ocean off Oregon during the fall and winter.

In the foregoing discussion the dominant species have not been considered. Since these species occur in most collections, they cannot be used as indicators of modest changes in the environment. The dominant species demonstrate fluctuations in abundance, rather than in occurrence. Comparing Figures 15 through 23 with Figure 11 demonstrates the relationship between species abundance and heat storage. The abundance of four species, Euphausia pacifica, Calanus A., Metridia lucens, and Aetideus armatus are correlated with changes in heat storage. Euphausia pacifica is positively related to heat storage. The other three species are inversely related to heat storage.

The remaining five species have different relationships depending upon station. Two species, Calanus tenuicornis and Metridia pacifica are found in highest numbers during high heat storage at NH-15, but at the remaining stations are inversely related to heat storage. The abundance of Calanus finmarchicus and Calanus pacificus increase and decrease with heat fluctuation at NH-15 and NH-65. Eucalanus bungii shows no particular response to heat storage except at NH-65 where its abundance is greatest during the winter when heat storage is at a minimum.

One source of variability between the dominant species and heat storage is caused by using heat storage only from the surface to 30 meters. This surface layer is most subject to change, and should conditions in this layer not be suitable for a particular species existence, they may move to greater depths. Because our samples are from 200 meters to the surface, heat storage should be calculated for 0-200 meters rather than 0-30 meters. The most serious problem in using surface to 200 meter heat storage however is the loss of data due to the shallow depth at NH-15 (50 meters) and at NH-25 (160 meters).

Several authors have shown the distribution and abundance of marine zooplankton to be a valuable aid in the detection of advection (Russell, 1935 and 1939; Fraser 1952 and 1955; Clarke, Pierce and Bumpus, 1943). These authors use the "indicator species" approach to detection of changes in oceanographic conditions. The use of an indicator species is subject to several factors that may result in erroneous interpretation of data. As an example, reduced concentration or an absence of the indicator species may be actually the result of field and laboratory sampling error and/or a change in life history stage. Instead of using individual species as a means of indicating advective changes, the Index of Affinity can also be used. Affinity values based upon the relative abundance of all species are not as affected by random fluctuation in the concentration as those of a single species.

To demonstrate this use of the Index of Affinity, I have studied the seasonal changes in affinity between NH-45 and the stations immediately inshore (NH-25) and offshore (NH-65) (Figure 28). During the greater portion of the sampling period (December through June),

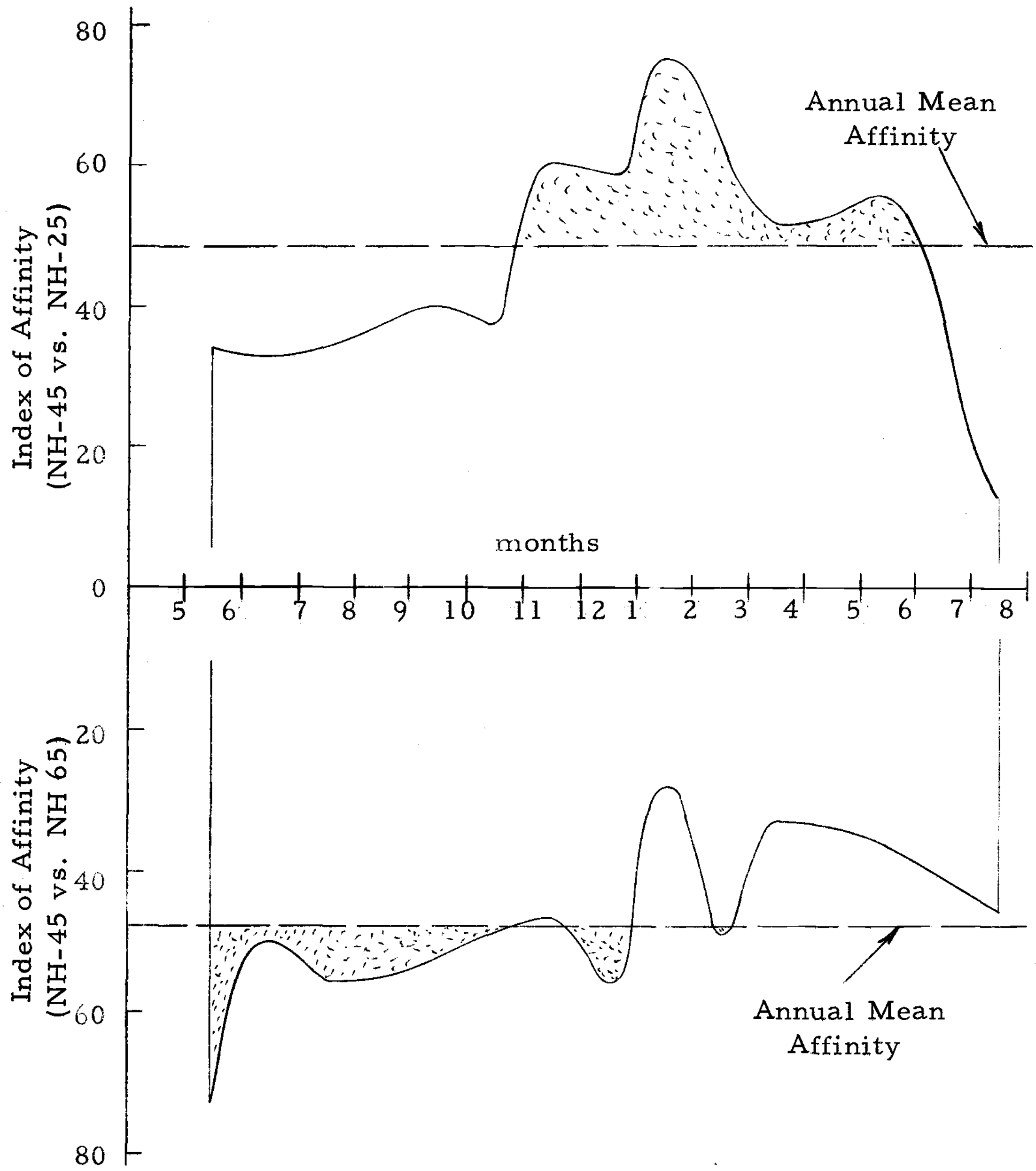

Figure 28. Relationship of NH-45 to NH-25 and NH-65 based upon the Index of Affinity.

NH-45 and NH-25 were most similar. During June through August, however NH-45 has greater affinity to NH-65 than NH-25. On only one occasion during the winter (December) was the affinity between NH-45 and NH-65 greater than 50%. These seasonal changes suggest a biological response to the changing physical environment as brought about by the wind patterns and their associated currents. During late spring and summer the affinity between NH-65 and NH-45 is greatest. In the late fall and winter the prevailing wind pattern has a southerly component and the conditions of the surface layers of the ocean become homogenous. At this time (December through March) NH-65 possessed increased affinities to both NH-25 and NH-45. The greater similarity to NH-25 is probably a reflection of the onshore movement of surface water during this period.

The values of affinity can also be used on the process sector diagram to demonstrate similarity of the biological collections to the processes that bring about the changes in the physical environment off Oregon. Where associations of species are specifically related to the different seasonal conditions the affinity between collections (see Table 3) within a process sector should be high compared to the affinity between the collections of two process sectors.

There are several cases indicating high within sector and low between sector affinity. At station NH-45, for example, reduced affinity occurred between the Columbia River sector and the heating sector (Figure 29). A similar pattern also occurred at NH-25 and NH-65.

These affinity values suggest a difference in composition and/or relative abundance of the collections within the various sectors. To determine the validity of this difference, collections from NH-45 were examined for differences in composition and abundance between the heating and Columbia River process sectors.

A total of 40 species were found at the stations included in the heating and the Columbia River sectors. Of these 40 species, 28 were found in the heating sector and 22 were found in the sector influenced by the Columbia River. Only ten species were common to both sectors. Of the five dominant species present, only two species, Euphausia pacifica and Metridia pacifica, were common to both sectors.

In conclusion, even though obvious and distinct associations of species were not found, the use of the Index of Affinity and the biological imporance value was useful in discerning relationships of the biological populations to the physical environment. The samples utilized for analyzing the copepod-euphausiid communities and relating changes to the physical processes of Oregon were from years 1963 and 1964 when the seasonal range of conditions were not as extreme as during other years. For instance, much stronger upwelling, indicated by the high inshore salinity and low inshore

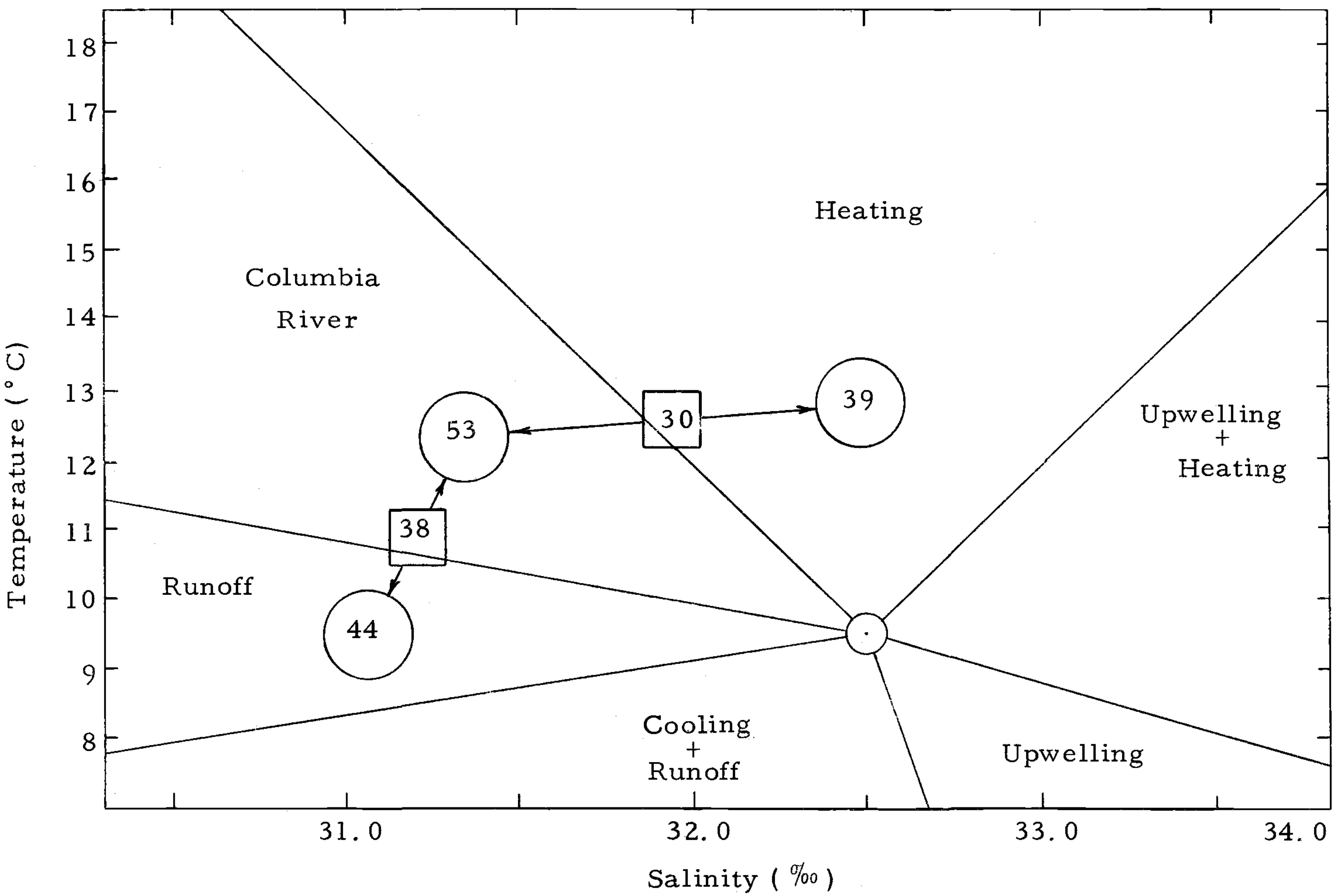

Figure 29. Comparison of the Index of Affinity for stations within and between each sector at NH-45.

temperature, occurred during the summer of 1962 than during the summers of 1963 and 1964 (Figure 1 and 2).

CONCLUSIONS

1. The copepod-euphausiid population off Oregon consisted of 12 numerically dominant species, 22 common species and 45 infrequent species. The 12 numerically dominant species each constituted more than one percent of the total population. Together they composed 88% of the total population. Two species, Euphausia pacifica and Metridia pacifica, account for over 50% of the individuals in the population.
2. Oceanographically the coastal waters of Oregon can be considered a transition region. The copepod-euphausiid population contains species which have been defined as members of the Pacific Subarctic population or of the transitional populations to the south. The Pacific Subarctic species Thysanoessa spinifera, Calanus plumchrus and Acartia longiremis are abundant during the spring and summer. The southern species, recurring primarily during the fall and winter, are Nematoscelis difficilis (d), Rhincalanus nasutus, and Acartia danae. Two other species were found offshore during the summer but moved shoreward during periods when inshore and offshore regions are more similar oceanographically.
3. Probably because of the few abundant species and the numerous infrequent species, association analysis did not define discrete,

well structured communities. Sanders method showed six associations that merely differed by relative abundance of component species rather than the presence of numerous new species. Thus, we might say that the region off Oregon contains but one community whose species fluctuate in abundance through the year.

4. The Index of Affinity from Sanders analysis is useful in showing the relationship between the environment and copepod-euphausiid populations. Comparison of seasonal changes in Index of Affinity between NH-45 and its two adjacent stations (NH-25 and NH-65) showed that during the summer NH-45 is affected by offshore transport of water. In winter when winds cause onshore movement of water, NH-45 shows highest affinity with NH-25, although greater than average affinity occurred with NH-65.
5. Changes in the physical environment were described as a series of processes on a temperature-salinity diagram. Collections within each sector have a high affinity compared to collections from different sectors.

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