Some Distributional Features of Mesopelagic Fishes Off Oregon

William G. Pearcy

Department of Oceanography
Oregon State University

ABSTRACT

Over 200 collections made between June 1961 and August 1962 with a six-foot Isaacs-Kidd midwater trawl at various depths down to 1000 m (mostly down to 200 m) along three latitudes off Oregon have provided preliminary data on species composition, sampling variability, diurnal vertical migrations, depth distribution, and seasonal and geographic variations of adult and large juvenile mesopelagic fishes. Forty-two species were collected. Twenty-three species were present in the 0–200-m collections, the remaining 19 in collections to greater depths. Those species that frequently occurred only in collections from 0 to 500 m or to 1000 m are listed as lower mesopelagic fishes. Those taken after dark above 200 m are considered to be upper mesopelagic fishes; these, primarily lanternfishes, dominated most collections. Differences in the depth distribution of the three most common lanternfishes were evident in the night collections; all ascended through the halocline, and some ascended through the overlying thermocline as well.

Although no marked seasonal changes in species composition were apparent, seasonal changes in the relative abundance of dominant fishes were indicated by large catches during the summer and small catches during other seasons. Mesopelagic fishes were common over the continental slope but were rare over the shelf, indicating that depth may limit their horizontal distribution. The diversity of mesopelagic fishes and of catches of several species increased from north to south.

Introduction. Knowledge of the ecology of animals in the open ocean is very limited. This is particularly true of the small nektonic organisms, such as fish, squid, and shrimp, which are intermediate in the food web between small plankton and larger carnivores. These micronektonic animals, ubiquitous in the oceans of the world, are capable of movements, independent of currents, in horizontal or vertical directions.

The occurrence of vertical migrations of micronekton has been well documented since the CHALLENGER Expedition (Brauer 1906, Murray and Hjort 1912, Beebe and Vander Pyl 1944, Tucker 1951, Bainbridge 1961, and others). Horizontal movements, on the other hand, though described for many of the larger epipelagic nekton, have not been adequately studied for the smaller mesopelagic nekton. Mesopelagic animals are defined as those distributed during daylight between depths of 200 m and 1000 m. (For classifications of epipelagic, mesopelagic, and bathypelagic zones, see Hedgpeth 1957.) The studies of mesopelagic fishes by Tåning (1918), Barham (1956), and Fast (1960) have revealed seasonal differences in the catches of certain species of lanternfishes, and these differences have suggested horizontal movements of these populations. Whether such movements are of a general nature for mesopelagic animals, how these movements are effected, how far they extend, and how they are related to the ecology of the populations are questions of real interest to the biological oceanographer.

The purpose of this study is to examine the distribution of mesopelagic fishes off Oregon in the region of the continental slope—that transitional area of the oceanic region where depth decreases rapidly as the neritic region is approached.

Aron (1959, 1962) conducted extensive midwater trawling studies in the eastern Pacific and contributed much to our knowledge of the zoogeography of oceanic animals. His collections extended over a wide geographic area but were limited to relatively shoal hauls and to the summer and fall seasons. Compared with Aron's collections, the present study entailed systematic sampling of a relatively small area of the Pacific Ocean, at greater depths, and on a year-round basis. No previous studies have surveyed this area.

In view of their swimming capabilities, nektonic animals may be important agents in the distribution and transportation of radioisotopes. Detectable quantities of radioisotopes, such as zinc-65 (induced in low levels by the Hanford nuclear reactors on the Columbia River), have been found in micronekton such as lanternfishes, sergestid prawns, and euphausiids off Oregon (Osterberg 1962, Osterberg et al. 1964). These micronekton are capable of crossing density gradients such as the thermocline and halocline, both of which normally inhibit mixing by physical processes. By migrating vertically into surface waters, the micronekton provide forage for commercial fishes such as tuna and salmon. Inshore migrations of these animals may also make them available to species that are subject to near-shore fisheries. This in turn may make these radioelements available to humans. If the open oceans are used for disposal of radioactive materials, obviously a more comprehensive understanding of nektonic ecology and behavior is essential (Ketchum 1960).

Methods. Micronekton was sampled with a six-foot Isaacs-Kidd midwater trawl (Isaacs and Kidd 1953, Aron 1962). Collections were made during various seasons of the year between June 1961 and August 1962. The stations were located offshore along three parallels of latitude extending westward from the mouth of the Columbia River (35 collections), from Newport (46 collections), and from Coos Bay (29 collections), as shown in Fig. 1. Four of the stations along each parallel were 15, 25, 45, and 65 nautical

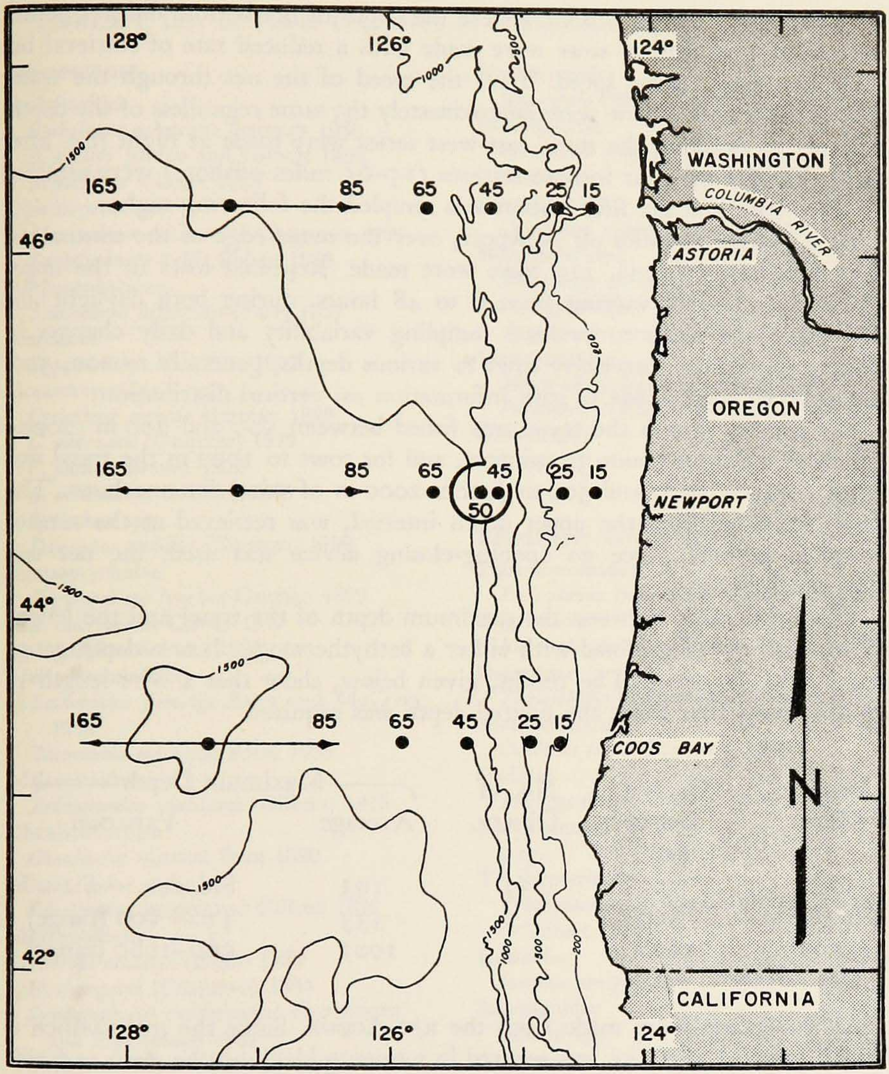

Figure 1. Locations of midwater trawl stations off Oregon. Numbers designate the distance in nautical miles from the coast. The circle includes the area of repeated tows. The offshore stations varied between 85 and 165 miles from shore. Depths are in fathoms.

miles from shore; the fifth station varied between 85 and 165 nautical miles from shore.

Where depth permitted, an oblique tow from 0 to 200 m was made at each station as the ship followed a given compass course at six knots. The net was lowered rapidly until 730 m of wire were paid out and then retrieved at a constant speed of 30 m/min. Where the depth of the bottom did not permit tows to 200 m, shallow tows were made with a reduced rate of retrieval but at an increased towing speed. Thus the speed of the net through the water and the total time of tow were approximately the same regardless of the depth. All collections along the three east-west series were made at night (i.e. after dark). Usually the four inshore stations (15–65 miles offshore) were sampled on one night, and the fifth station was sampled the following night.

At a station 50 miles off Newport, over the outer edge of the continental slope (circled in Fig. 1), 119 tows were made. Repeated tows in the upper 200 m over periods varying from 6 to 48 hours, during both daylight and darkness, were made to evaluate sampling variability and daily changes in relative abundance. Successive tows to various depths, generally to 200, 500, and 1000 m, were made to gain information on vertical distribution.

For tows to 500 m the trawl was fished between 500 and 200 m (2000–730 m of wire) for about 30 minutes, and for tows to 1000 m the trawl was fished between 1000 and 500 m (4000–2000 m of wire) for one hour. The trawl, upon reaching the upper depth interval, was retrieved at the rate of 50–70 m w./min. Since no opening-closing device was used, the net was open at all depths.

The relationship between the maximum depth of the trawl and the length of the wire was determined with either a bathythermograph or a depth gauge attached to the trawl. The results, given below, show that a wire length of approximately four times the desired depth was required.

Meters Wire	Desired Depth (m)	No. of Observ.	Maximum Depth: Average	Maximum Depth: Variation
730	200	39	193	Std. dev. = 8.1
2000	500	3	533	430– 600 (range)
4000	1000	3	1007	960–1080 (range)

All collections were made from the R/V ACONA. Since the main winch is located forward, the wire was secured in a towing block on the stern to facilitate a constant heading while towing. Geographic position at the start and end of each tow, total time of the tow, course, speed, and sea and weather conditions were recorded for all collections.

Samples were preserved at sea in 10% formalin. Later, all fishes and other nekton were sorted, identified, and measured in the laboratory ashore.

Species Composition. About 50 species of fishes were identified, including mesopelagic, epipelagic, and neritic species (Table 1). Mesopelagic fishes dominated the catches in both number and variety. Myctophidae, Melanostomiati-

TABLE I. List of Fishes Collected by Midwater Trawling off Oregon.

Mesopelagic

Bathylagidae
- *Bathylagus ochotensis* Schmidt 1938
- *B. milleri* Jordan and Gilbert 1898
- *B. pacificus* Gilbert 1890

Opisthoproctidae
- *Macropinna microstoma* Chapman 1939
- *Bathylychnops exilis* Cohen 1958

Alepocephalidae
- *Talismania bifurcata* (Parr) 1951

Searsiidae
- *Sagamichthys abei* Parr 1953

Gonostomatidae
- *Cyclothone signata* Garman 1899
- *C. microdon* (Günther) 1878
- *C. pallida* Brauer 1902
- *C. acclinidens* Garman 1899
- *Cyclothone* spp.
- *Danaphos oculatus* (Garman) 1899

Sternoptychidae
- *Argyropelecus lynchus* Garman 1899
- *A. intermedius* Clarke 1877
- *A. pacificus* Schultz 1961

Melanostomiatidae
- *Bathophilus flemingi* Aron and McCrery 1958
- *Tactostoma macropus* Bolin 1939

Malacosteidae
- *Aristostomias scintillans* (Gilbert) 1915

Chauliodontidae
- *Chauliodus macouni* Bean 1890

Idiacanthidae
- *Idiacanthus antrostomus* Gilbert 1890

Myctophidae
- *Hierops crockeri* (Bolin) 1939
- *H. thompsoni* (Chapman) 1944
- *Symbolophorus californiense* Eigenmann and Eigenmann 1889
- *Tarletonbeania crenularis* (Jordan and Gilbert) 1880
- *Diaphus theta* Eigenmann and Eigenmann 1890
- *Lampadena urophaos* Paxton 1963
- *Lampanyctus nannochir* (Gilbert) 1890
- *L. leucopsarus* (Eigenmann and Eigenmann) 1890
- *L. ritteri* Gilbert 1915
- *L. regalis* (Gilbert) 1891
- *Ceratoscopelus townsendi* (Eigenmann and Eigenmann) 1889

Scopelarchidae
- *Neoscopelarchoides dentatus* Chapman 1939

Paralepididae
- *Lestidium ringens* (Jordan and Gilbert) 1881

Cetomimidae
- *Cetostomus regani* Zugmayer 1914

Nemichthyidae
- *Nemichthys scolopaceus* Richardson 1848

Anoplogasteridae
- *Anoplogaster cornuta* (Valenciennes) 1833

Melamphaidae
- *Melamphaes lugubris* Gilbert 1890
- *Poromitra crassiceps* (Günther) 1878

Oneirodidae
- 2 spp.

Epipelagic and Neritic

Petromyzontidae
- *Entosphenus tridentatus* (Gairdner) 1836

Engraulidae
- *Engraulis mordax* Girard 1854

Osmeridae
- *Thaleichthys pacificus* (Richardson) 1836

Scomberesocidae
- *Cololabis saira* (Brevoort) 1850

Gadidae
- *Microgadus proximus* (Girard) 1854

Coryphaenoididae
- 1 sp.

Trachypteridae
- *Trachypterus rexsalmonorum* Jordan and Gilbert 1894

Icosteidae
- *Icosteus aenigmaticus* Lockington 1880

Scorpaenidae
- Several spp.

Cottidae
- *Scorpaenichthys marmoratus* (Ayres) 1854

Agonidae
- *Agonopsis emmelane* (Jordan and Starks) 1895

Liparidae
- *Nectoliparis pelagicus* Gilbert and Burke 1910

Anarhichadidae
- *Anarrhichthys ocellatus* Ayres 1855

Zoarcidae
- *Lycodapus mandibularis* Gilbert 1915

dae, and Gonostomatidae were numerically the most abundant. Three species of Myctophidae (lanternfishes) accounted for 76% of the total catch: *Lampanyctus leucopsarus* 45%, *Diaphus theta* 21%, and *Tarletonbeania crenularis* 10%. Both *L. leucopsarus* and *D. theta* occurred in over 80% of all collections, excluding daylight tows within the upper 200 m and tows in neritic waters. *Tactostoma macropus*, a melanostomiatid, composed approximately 8% of the total catch. These fishes represented the four most abundant species found in our collections.

This is the first list of mesopelagic fishes for the Pacific Ocean along the Oregon coast and it must be considered as preliminary. Many of the species have been previously reported in adjacent regions (e.g. Aron 1962, Ebeling 1962). However, the geographical range of *Talismania bifurcata, Cetostomus regani*, and *Anoplogaster cornuta* has been extended northward (see Ebeling 1962: 140–141 for data on meridional distributions). The specimen of *C. regani* is the second from the Pacific to be reported; the other was collected off Baja California (Rosenblatt, in litt.).

Juvenile and adult epipelagic fishes, though numerically unimportant, were also captured. Included were such oceanic species as the saury, *Cololabis saira*, and neritic species such as smelt and cod (Table 1). Larval fishes were numerous in some collections. Neither epipelagic nor larval fishes are discussed in this paper.

Day-Night Variation and Sampling Variability. Variations in the totals of the four dominant mesopelagic fishes collected during daylight and darkness are illustrated in Fig. 2. The positions of all these collections are circled in Fig. 1. Diurnal (diel) differences are obvious; catches of these fishes within the upper 200 m were large during darkness (night) compared with daylight (day). Seasonal differences, with fishes remaining in surface waters longer during winter than in the summer, are also suggested, although the concentration of night hauls renders this conclusion somewhat dubious.

While differences between day and night catches were clear, no evident trend indicating major variations associated with time is found in the number of fishes collected only in darkness. Since catches made soon after sunset or before sunrise were not consistently lower than those made around midnight, it is believed that fish ascend quickly to the upper 200 m shortly after sunset and remain within this region until shortly before dawn. Therefore, though fishes may have migrated vertically within the upper 200-m region during darkness, it is assumed that all tows during this period sampled the same mesopelagic population. By assuming that these night tows represent replicate samples, a basis is provided for estimates of sampling variability. This is useful to evaluate subsequent spatial and temporal differences and to gain insight into the patchiness of distribution of mesopelagic fishes.

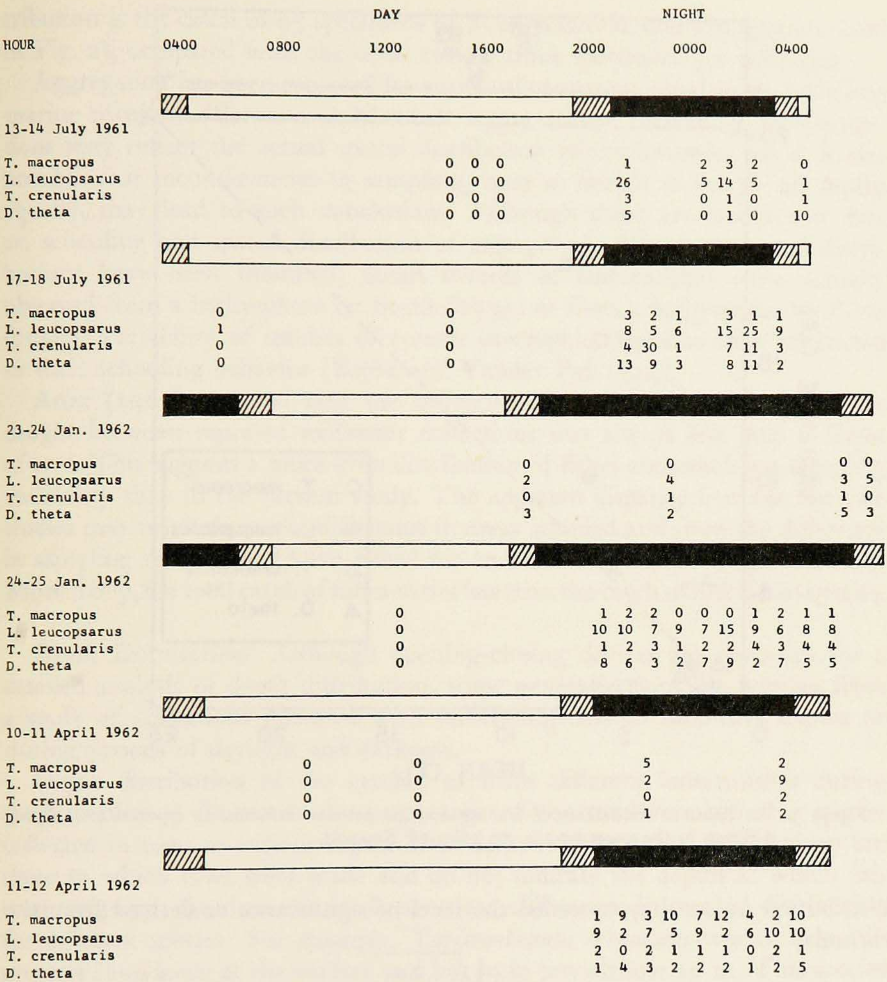

Figure 2. Catches of the four dominant mesopelagic species in the upper 200 m during day-night periods at the station 50 miles off Newport. The horizontal bars denote periods of daylight (open), twilight (hatched), and darkness (solid).

Fig. 3 shows variances (calculated from the data given in Fig. 2, excluding series in which less than four night collections were made) plotted against the average number of each of the four common species noted above. If distributions were random (Poisson), the variance would be approximately equal to the mean, i.e. $s^2/\bar{x} = 1$, and points would be grouped near the 45° diagonal. Coefficients of dispersion, $s^2/\bar{x}$ (Blackman 1942), were calculated. They demonstrate a large range (from 0.3 to 12.3), suggesting lack of a consistent dispersion pattern. Coefficients were considered to demonstrate a random

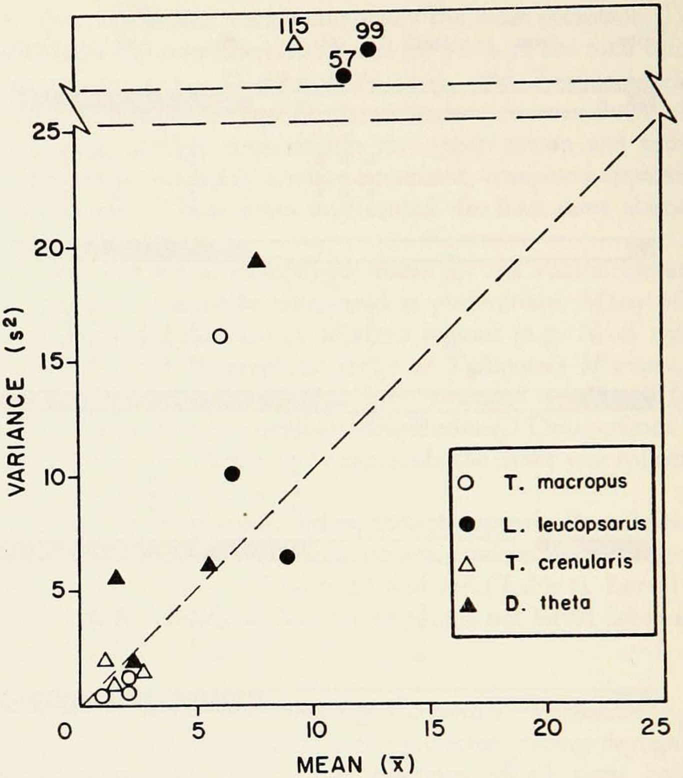

Figure 3. Variability of the catches of four mesopelagic fishes as indicated by repeated tows during darkness in the upper 200 m, 50 miles off Newport.

distribution unless they exceeded the level of significance as derived from the formula,

$$1 + 2\sqrt{\frac{2n}{(n-1)^2}},$$

where n is the number of samples (Holme 1950). Eleven coefficients of dispersion did not significantly depart from unity and are clustered near the 45° diagonal; although this suggests a random distribution, these coefficients occur at low population densities where the sample size is probably too small for reliable estimates of the actual distribution (Cassie 1959). Five coefficients, including one for each of the four species, were significantly greater than would be expected from a randomly distributed population. These large values, indicating aggregated or patchy distribution, were caused by one or two unusually large catches in a series (Fig. 2). All high coefficients were for catches made during the summer. Another noteworthy example of such patchy distribution is the catch of 95 specimens of *T. crenularis* in one tow (not included in Fig. 2), compared with the usual two or three specimens per collection.

Aggregation has been reported for many other natural populations, including marine plankton (Barnes and Marshall 1951). These indications of aggregations may reflect the actual spatial distribution of the animals, but it is also possible that inconsistencies in sampling, such as failure to sample all depths equally, may lead to such conclusions. Although there are insufficient data on schooling and spatial distribution of mesopelagic fishes, aggregated distributions have been indicated. Small schools of lanternfishes were actually observed from a bathysphere by Beebe (1934) or from a bathyscaphe by Pérès (1958). Variability of catches of certain myctophids has also been attributed to their schooling behavior (Beebe and Vander Pyl 1944).

Aron (1962) reported that the difference in the total number of fishes caught between repeated midwater collections was always less than a factor of two. This suggests a more even distribution of fishes and much less sampling variability than in the present study. The apparent disparity between the two studies may result from the difference in areas sampled and from the difference in sampling techniques (Aron fished his trawl at one depth for 30 minutes). More likely, the total catch of fishes varies less than the catch of individual species.

Depth Distribution. Although opening-closing devices are necessary for a detailed analysis of depth distribution, some generalizations are possible from a study of collections obtained with nonclosing nets to successive depths or during periods of daylight and darkness.

Depth distribution of the catches of three different lanternfishes during August (Fig. 4) illustrates the percentage of the total number of a species collected in tows to various depths after dark. Although the depths given are those to which tows were made and do not indicate the depths at which fish were captured, the data clearly demonstrate differences in vertical distribution for different species. For example, *Tarletonbeania crenularis* was collected in greatest abundance at the surface and less so in tows below 10 m. This species is commonly collected with dip nets under night lights. On the other hand, neither *Diaphus theta* nor *Lampanyctus leucopsarus* was captured at the surface and both were found to be most abundant below 10 m; *D. theta* was most abundant in tows to 10–25 m and *L. leucopsarus* in tows to 25–30 m.

Corroborative data on the upper depth distribution of these species are given by other workers. Aron (1959, 1962) noted peak abundance of *L. leucopsarus* and *D. theta* below 30 m off the coast of Washington and in regions south of 50°N, but within the upper 30 m in more northerly regions; he also observed *T. crenularis* at the surface under night lights. Tucker (1951) caught *L. leucopsarus* in abundance in a night tow to 37 m in the Bering Sea, and Fast (1960) considered that the upper range of the adults of this species was about 50 m in Monterey Bay, California.

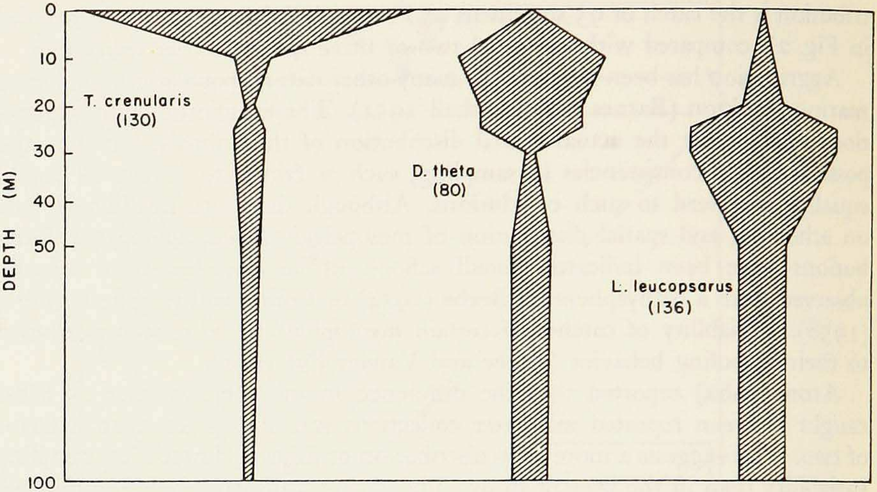

Figure 4. Vertical distribution of the catches of three lanternfishes in night tows to various depths 50 miles off Newport, shown as a per cent of the total catch (number in parentheses) for each species, August 1961.

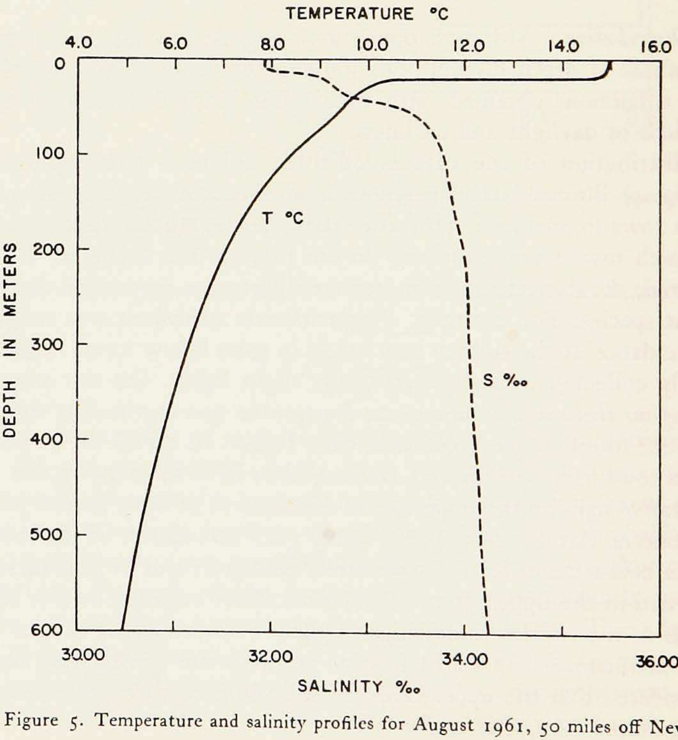

Figure 5. Temperature and salinity profiles for August 1961, 50 miles off Newport.

Temperature and salinity profiles (Fig. 5) for the same month and area where collections were made to successive depths show a thermocline located between 10 and 20 m and a halocline located between the surface-mixed layer and 100 m. The halocline is usually above 200 m depth and is a permanent oceanographic feature in this area of the Pacific (Fleming 1958); upwelling and Columbia River "plume" explain the shallow halocline or haloclines shown in Fig. 5. The thermocline is well developed only in the summer (Tully et al. 1960, Tabata 1961). The temperature and salinity gradients in the upper layers also produce a strong density gradient and high stability in the water column above 200 m. Nevertheless, the dominant mesopelagic fishes migrate through the base of the halocline and into the upper waters during darkness (see Fig. 2); *D. theta* and *T. crenularis* apparently migrate through the thermocline as well. Thus these gradients do not necessarily act as barriers to the mesopelagic fishes that may swim vertically through at least one density gradient during their daily migrations into near-surface waters at night.

Depth distribution of adult fishes within the mesopelagic region was examined using data from successive tows to 200, 500, and 1000 m. About 20 upper mesopelagic species, largely myctophids, were collected from 0 to 200 m during darkness; these fishes penetrated the halocline and invaded epipelagic waters at night. The lower mesopelagic species, obtained mainly from tows to 500 m or below (uncommon above 200 m), were mostly Gonostomatidae, Chauliodontidae, Bathylagidae, and some Myctophidae.

Some common lower mesopelagic species are listed in Table II, which gives the total numbers caught in the tows to different depths. Fully quantitative comparisons are not possible since the exact depths of capture are unknown, and there are differences in fishing intensity at various depths. Yet, the relative

TABLE II. Catches of some Lower Mesopelagic Fishes at the Station 50 Miles off Newport, Oregon.

	Depth and Number of Tows		
	0–200 m (57)	0–500 m (23)	0–1000 m (24)
Bathylagus milleri	0	9	8
Bathylagus pacificus	0	3	60
Searsiidae	0	7	6
Cyclothone microdon	2†	62	211
Cyclothone signata	11†	193	172
Chauliodus macouni	19*	120	71
Lampanyctus nannochir	0	2	39
Lampanyctus regalis	1	24	19
Neoscopelarchoides dentatus	0	7	12
Poromitra crassiceps	0	1	24

† Probably contamination from preceding deeper tow.
* Mostly small specimens.

scarcity of these species in trawl catches within the upper 200 m is obvious. *Talismania bifurcata*, *Macropinna microstoma*, *Cetostomus regani*, *Anoplogaster cornuta*, and oneirodids were all collected in tows to 500 or 1000 m and are also thought to be lower mesopelagic forms.

Geographic Variations. The ocean off Oregon, 42°–46°N, is a boundary region between predominantly Subarctic Water to the north and Transitional Water to the south (Sverdrup et al. 1942, Uda 1963); the temperature and salinity of the waters in the latter region are characteristically higher. Aron (1962) reported changes in the midwater fauna at about the latitude of this boundary region. According to Ebeling (1962), a major change in the meridional distribution of mesopelagic fishes occurs at 40°–45°N in the northeastern Pacific Ocean; he found only 36–38% overlap in the species between Subarctic and North Pacific Transitional Water masses, with a larger number of species of fish in the lower latitudes. Hence the geographic distribution of mesopelagic fishes off Oregon is of special interest.

North-south differences in the species composition of mesopelagic fishes were evident within three degrees of latitude off Oregon. The total number of mesopelagic species collected showed an increase at the stations to the south (Table III), indicating a higher diversity in the mesopelagic fish community at the lower latitudes off Oregon. Moreover, the relative abundance and frequency of occurrence of several species of fishes were clearly higher off southern Oregon than off northern Oregon. These data further demonstrate that Oregon is the northern limit for some oceanic animals and is zoogeographically a transitional area.

Collections along parallels of latitude across the continental slope permit an examination of possible changes in the diversity of mesopelagic fishes with

TABLE III. Total Number of Mesopelagic Species Collected and Total Number of *Bathylagus ochotensis* (*B. o.*), *Hierops crockeri* (*H. c.*), *Symbolophorus californiense* (*S. c.*), and *Lampanyctus ritteri* (*L. r.*) Collected and Number of Tows in which they were taken off Oregon.

Series	Total	*B. o.*		*H. c.*		*S. c.*		*L. r.*	
	No. of Spp.	No. Coll.	Occur. in Tows	No. Coll.	Occur. in Tows	No. Coll.	Occur. in Tows	No. Coll.	Occur. in Tows
Columbia R.... 46°14.4′N 26 tows	10	2	1	3	3	0	0	22	10
Newport .... 44°39.1′N 46 tows	13	9	8	7	4	1	1	33	15
Coos Bay ...... 43°20.5′N 29 tows	17	23	14	30	14	4	3	70	20

TABLE IV. TOTAL NUMBER OF MESOPELAGIC SPECIES AND THE AVERAGE NUMBER OF SPECIES PER TOW COLLECTED OFF OREGON AT VARIOUS DISTANCES FROM SHORE (IN NAUTICAL MILES).

	Columbia River 46°14.4′N		Newport 44°39.1′N		Coos Bay 43°20.5′N	
Distance Offshore	Total	Av./Tow	Total	Av./Tow	Total	Av./Tow
15	3	1.8	1	0.1	7	4.0
25	8	3.3	3	1.1	8	5.4
45	7	4.5	10	4.8	13	7.0
65	6	4.2	11	4.8	6	5.5
>65	4	4.0	9	5.2	11	5.7

increasing distance from shore. In general both the total number of fish species and the average number of species per tow were lowest at the inshore stations and highest at the intermediate stations (Table IV). Aron (1959) found in oceanic water off Washington that the number of species of fishes decreased westward from the coast; therefore, his study and this one suggest that the greatest diversity of mesopelagic fishes may occur over, or just beyond, the outer continental slope.

Mesopelagic fishes were usually collected at the inshore stations, over the continental slope, and at stations located more than 100 miles offshore. However, at the two inshore stations off Newport (Table IV), mesopelagic fishes were rare, and the average number of mesopelagic fishes per tow was very low (Fig. 6). Although considerable numbers of fishes were caught at stations located 15 and 25 miles offshore from the Columbia River and Coos Bay, they were rarely caught at the same distances off Newport, despite numerous collections. The salinity at these stations off Newport is not greatly modified by freshwater runoff; in fact, the inshore stations off the Columbia River were the most neritic of all in regard to reduced surface salinity. In addition, mesopelagic fishes were absent from the inshore stations off Newport even during periods of upwelling, when the characteristics of the water near the surface were more typical of deeper offshore waters. An obvious difference among the inshore stations is the depth of water. Off Newport the water is comparatively shallow; at the two inshore stations the depth is less than 300 m (inside the 200-fathom depth contour in Fig. 1). Of all the stations, these are the only two located over the continental shelf. As seen in Fig. 6, the differences between the catches over the shelf and over the continental slope are striking. Thus, depth appears to be important in limiting the inshore distribution of these fishes, perhaps by affecting vertical migrations so that preferred light intensity during the day is simply not available when the depth is 300 m or less.

L. leucopsarus, *D. theta*, *T. crenularis*, and *T. macropus* predominated in nearly all collections within the upper 200 m during darkness, regardless of

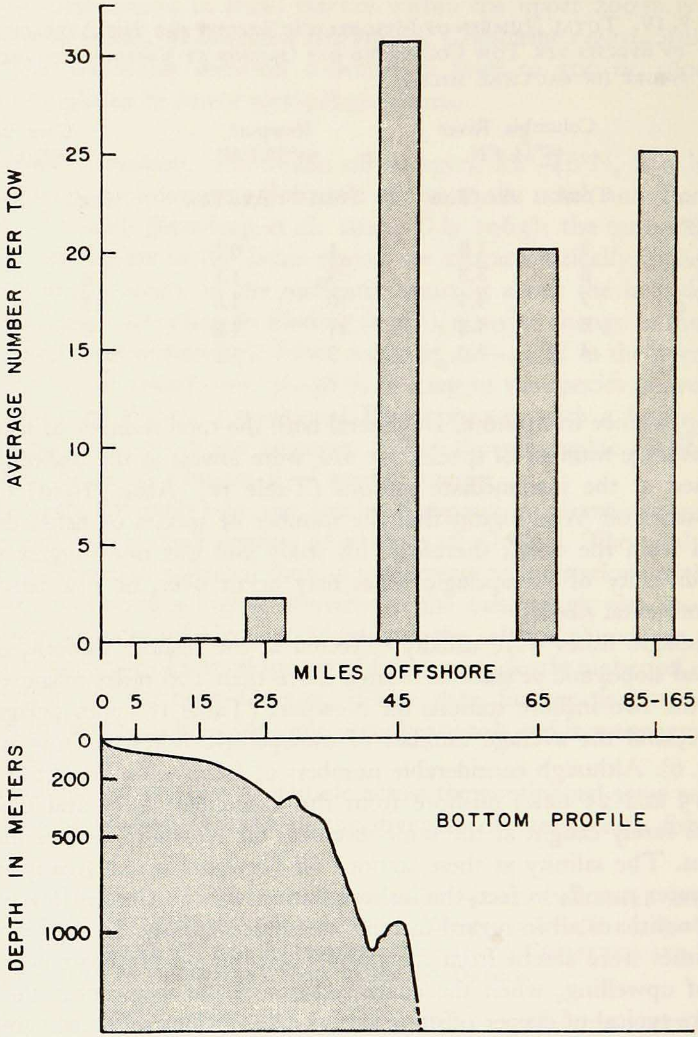

Figure 6. Catches of mesopelagie fishes at the stations off Newport, Oregon, and a bottom profile at the same latitude.

latitude, distance from shore, or season of year. Thus, a single community of upper mesopelagic fishes is suggested by the absence of drastic changes in the occurrence of species.

Seasonal Variations. In order to examine seasonal changes in the distribution and abundance of mesopelagic fishes, catches of the most common species were plotted for various months of the year. These are illustrated for *Lam-*

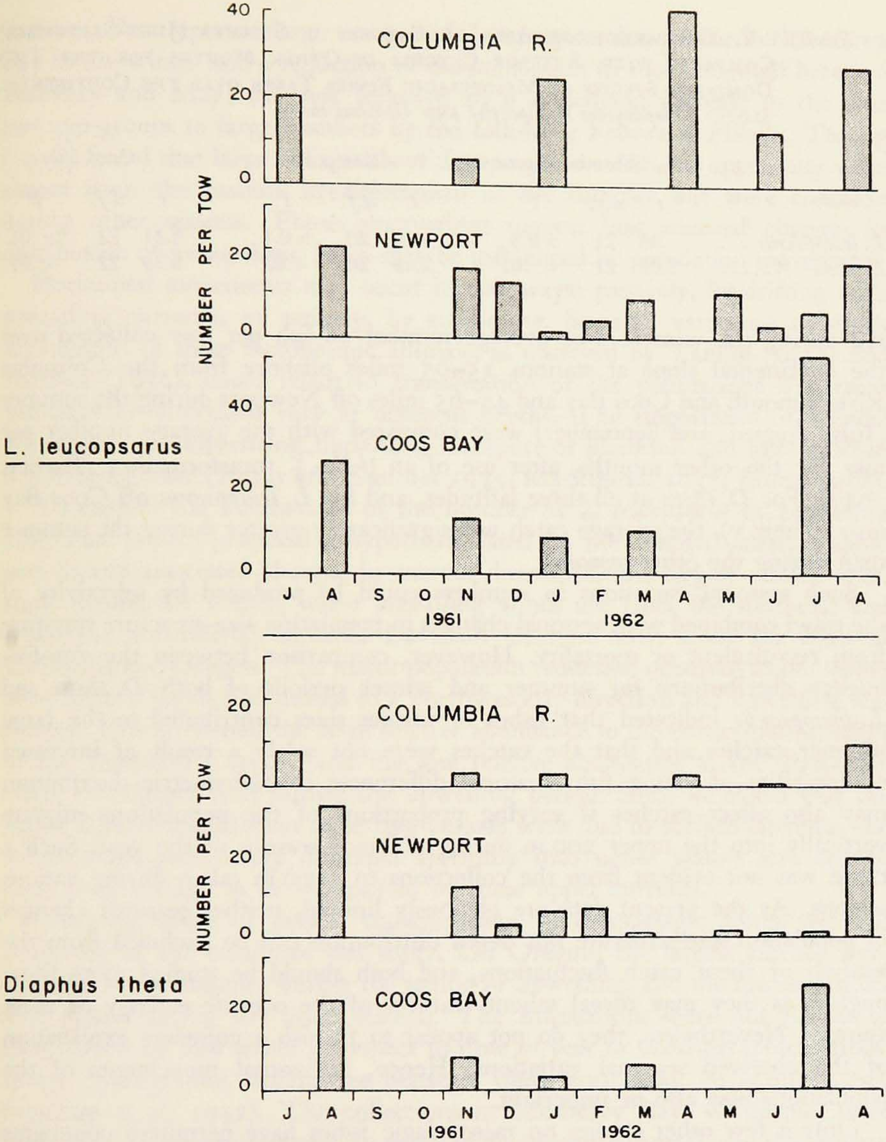

Figure 7. Average number of *Diaphus theta* and *Lampanyctus leucopsarus* collected over the continental slope off Oregon during the period of study.

panyctus leucopsarus and *Diaphus theta* in Fig. 7. Some seasonal variations are apparent. The catches are usually largest during the summer. This was the case for both of the summer periods sampled and for all latitudes, with the exception of the northern stations, where peak catches of *L. leucopsarus* occur-

TABLE V. Comparison of Average Catches in Summer (July–September) Compared with Average Catches in Other Months for the Two Dominant Species of Mesopelagic Fishes Taken over the Continental Slope: *Lampanyctus leucopsarus* and *Diaphus theta.*

	Columbia River			Newport			Coos Bay		
	t	*d.f.*	*P*	*t*	*d.f.*	*P*	*t*	*d.f.*	*P*
L. leucopsarus ...	.98	21	>0.3	1.49	20	>0.1	3.41	22	<.01
D. theta	3.02	21	< .01	2.49	20	<.05	3.79	22	<.01

red during the winter. The average number of fish per tow collected over the continental slope at stations 15–65 miles offshore from the Columbia River's mouth and Coos Bay and 45–65 miles off Newport during the summer (July, August, and September) were compared with the average number per tow for the other months, after use of an $\sqrt{X+\frac{1}{2}}$ transformation (Bartlett 1947). For *D. theta* at all three latitudes, and for *L. leucopsarus* off Coos Bay only (Table v), the average catch was significantly greater during the summer than during the other seasons.

Such seasonal variations in numbers could be produced by selectivity of the trawl combined with seasonal changes in population size-structure resulting from recruitment or mortality. However, comparison between the size-frequency distributions for summer and winter periods of both *D. theta* and *L. leucopsarus* indicated that fishes of various sizes contributed to the large summer catches and that the catches were not solely a result of increased vulnerability of young fish. Seasonal differences in bathymetric distribution may also affect catches if varying proportions of the populations migrate vertically into the upper 200 m during different seasons of the year. Such a trend was not evident from the collections to 1000 m taken during various seasons. As the present data are obviously limited, neither seasonal changes in population size-structure nor depth distribution can be excluded from the analysis of these catch fluctuations, and both should be studied more thoroughly, as they may reveal salient features of the oceanic ecology of these animals. Nevertheless, they do not appear to furnish a complete explanation of the observed seasonal variations. Hence, horizontal movements of the populations may also be important.

Only a few other studies on mesopelagic fishes have permitted comments on seasonal changes in distribution. The studies by Barham (1956) and Fast (1960), conducted in Monterey Bay, California, are of special interest since they were concerned with the species that are also common off Oregon. Barham noted marked seasonal variations in the pattern of sonic scattering layers and in the catches of certain midwater animals. For example, *Diaphus theta*, collected in large numbers in midwinter, when it was thought to be a dominant sound scatterer, disappeared in the spring and reappeared in the summer. Fast reported large catches of *Lampanyctus leucopsarus* in Monterey Bay in the winter and a reduction of the population to about one-half between February and May; this was followed by a subsequent increase in the first two age-groups to large numbers by the following February. Finally, Tåning (1918) found that large individuals of *Lampanyctus maderensis* apparently were absent from the eastern Mediterranean in the summer but were common during other seasons. These observations suggest that seasonal changes in distribution of mesopelagic fishes may be influenced by population movements.

Horizontal movements may occur in two ways: passively, by drifting with prevailing currents; or actively, by swimming. Seasonal variations in depth distribution of these mesopelagic animals, as observed by Tåning (1918) and Barham (1956), could result in translocation of the populations if current velocities or directions vary at different depths. The importance of vertical distribution in influencing horizontal transport of plankton and micronekton is well recognized (Hardy and Gunther 1935, Mackintosh 1937, Brunn 1958).

To explain the fluctuations in the number of *L. leucopsarus* in Monterey Bay, Fast (1960) proposed a hypothesis based on the seasonal oceanographic periods and associated changes in current directions. His largest catches were made during the winter, when prevailing winds are from the southeast and when the northwardly directed Davidson Current flows along the coast of California and Oregon. The major population reduction occurred in the spring after surface winds had shifted to a northwesterly direction and upwelling was evident. Fast attributed the large relative abundance to the concentrating effect of the Davidson Current, and the low relative abundance to the dissipating effect of offshore drift during the upwelling period. Since he stated that the major differences between these two periods were due to surface currents, the lanternfishes presumably migrated vertically into upper waters and resided there long enough to be transported by these upper currents.

This hypothesis of passive transportation of mesopelagic fishes was not supported by the results of this study. Off Oregon, the largest catches were obtained in the summer during the period of upwelling, and the lowest catches were taken during the other seasons. The fluctuations were not similar to those found by Fast either in respect to time of year or oceanographic periods. Other hydrographic differences between these areas may be involved (see Sverdrup et al. 1942). The collections in Monterey Bay, California, were made over a submarine canyon (a depth of about 900 fathoms), and this canyon may act as a concentrating basin (Fast, 1960); on the other hand, the collections off Oregon were made in the waters off the unprotected coast, often where the depth was less than 900 fathoms. Only some of the northern stations off the Columbia River were over a submarine canyon. Clearly, before the effect of currents on the distribution of these animals can properly be assessed, more knowledge is needed concerning the seasonal variations of currents and water masses at all depths frequented by these species.

It is possible that active migrations of these micronekton may be a cause of the seasonal fluctuations. Virtually nothing is known about horizontal movements of small oceanic animals. In general, extensive geographic migrations of nektonic animals on a seasonal basis, as evidenced for larger epipelagic fishes (e.g. Sette 1950, Neave and Hanavan 1960, Clemens 1961), are unexpected for mesopelagic micronekton because of their relatively small size and slow swimming speed, and because seasonal variations in physical factors, such as temperature, are pronounced in only the epipelagic zone. Small-scale movements, however, across the continental slope may be entirely feasible.

Acknowledgments. The author is grateful to William Aron, M. Laurs, C. E. Bond, D. M. Cohen, R. L. Wisner, B. N. Kobayashi, R. H. Gibbs, Jr., A. Ebeling, J. R. Paxton, and R. Rosenblatt for aid in the identification of fishes; to L. D. Calvin for suggestions on statistical procedures; to O. E. Sette and C. L. Hubbs for helpful criticism of the manuscript; and to L. Hubbard and the captain and crew of the R/V ACONA for conducting the trawling operations at sea. This investigation was supported by the Atomic Energy Commission, Contract No. AT(45-1)1726, and by the National Science Foundation, Grant No. GB-1588. Ship operations were supported by grants from the National Science Foundation and the Office of Naval Research.

REFERENCES

ARON, WILLIAM

1959. Midwater trawling studies in the North Pacific. Limnol. Oceanogr., *4*: 409–418.

1962. The distribution of animals in the eastern North Pacific and its relationship to physical and chemical conditions. J. Fish. Res. Bd. Canada, *19*: 271–314.

BAINBRIDGE, RICHARD

1961. Migrations *in* The physiology of crustacea. T. H. Waterman, editor. II. Academic Press, New York. 681 pp.

BARHAM, E. G.

1956. The ecology of sonic scattering layers in the Monterey Bay area, California. Doctoral Dissert. Ser. Publ. No. 21,564, University Microfilms, Inc., Ann Arbor, Mich., 182 pp.

BARNES, HAROLD, AND S. M. MARSHALL

1951. On the variability of replicate plankton samples and some applications of "contagious" series to the statistical distribution of catches over restricted periods. J. Mar. biol. Ass. U. K., *30*: 233–263.

BARTLETT, M. S.

1947. The use of transformations. Biometrics, *3*: 39–52.

BEEBE, WILLIAM

1934. Half mile down. Harcourt, Brace and Co., N.Y. 344 pp.

BEEBE, WILLIAM, AND MARY VANDER PYL

1944. Eastern Pacific expeditions of the New York Zoological Society, XXXIII. Pacific Myctophidae (Fishes). Zoologica, N.Y., *29*: 59–95.

Blackman, G. E.
1942. Statistical and ecological studies in the distribution of species in plant communities. Ann. Bot., N.S. *6*: 351–370.

Brauer, August
1906. Die Tiefsee-Fische. I. Wiss. Ergebn. Valdivia, Syst. Teil, *15* (1): 1–420.

Brunn, A. F.
1958. On the restricted distribution of two deep-sea fishes, *Borophryne apogon* and *Stomias colubrinus*. J. Mar. Res., *17*: 103–112.

Cassie, R. M.
1959. Microdistribution of plankton. N.Z. J. Sci., *2*: 398–409.

Clemens, H. B.
1961. The migration, age and growth of Pacific Albacore (*Thunnus germo*), 1951–1958. Fish. Bull., Calif. Fish and Game, 115: 1–128.

Ebeling, A. W.
1962. Melamphaidae. I. Systematics and zoogeography of the species in the bathypelagic fish genus *Melamphaes* Gunther. Dana Rep., *58*: 1–164.

Fast, T. N.
1960. Some aspects of the natural history of *Stenobrachius leucopsarus* Eigenmann and Eigenmann. University Microfilms, Inc., Mic. 60–6729, Ann Arbor, Mich. 107 pp.

Fleming, R. H.
1958. Notes concerning the halocline in the northeastern Pacific Ocean. J. Mar. Res. *17*: 158–173.

Hardy, A. C., and E. R. Günther
1935. The plankton of the South Georgia whaling grounds and adjacent waters, 1926–27. Discovery Rep., 11: 1–146.

Hedgpeth, J. W.
1957. Classification of marine environments *in* Treatise on marine ecology and paleoecology. J. W. Hedgpeth, editor. I. Mem. geol. Soc. Amer., *67*; 1296 pp.

Holme, N. A.
1950. Population-dispersion in *Tellina tenuis* Da Costa. J. Mar. biol. Ass. U.K., *29*: 267–280.

Isaacs, J. D., and L. W. Kidd
1953. Isaacs-Kidd midwater trawl. Scripps Instit. Oceanogr., Ref. 53-3; 21 pp.

Ketchum, B. H.
1960. Oceanographic research required in support of radioactive waste disposal *in* Disposal of radioactive wastes. Int. Atomic Energy Agency, Vienna, 1960.

Mackintosh, N. A.
1937. The seasonal circulation of antarctic macroplankton. Discovery Rep., *16*: 365–412.

Murray, John, and Johan Hjort
1912. The Depths of the Ocean. Macmillan, London. 821 pp.

Neave, Ferris, and M. G. Hanavan
1960. Seasonal distribution of some epipelagic fishes in the Gulf of Alaska region. J. Fish. Res. Bd. Canada, *17*: 221–233.

Osterberg, Charles
1962. Zn^{65} content of salps and euphausiids. Limnol. Oceanogr., 7: 478–479.

Osterberg, Charles, W. G. Pearcy, and H. C. Curl, Jr.
1964. Radioactivity and its relationship to oceanic food chains. J. Mar. Res., *22* (1): 2–12.

Pérès, J. M.
1958. Trois plongées dans le canyon du Cap Sicié, effectuées avec le bathyscaphe F.N.R.S. III, de la Marine Nationale. Bull. Inst. océanogr. Monaco, 1115: 1–21.

Sette, O. E.
1950. Biology of the Atlantic mackerel (*Scomber scombrus*) of North America. Pt. II. Migrations and habits. Fish. Bull., U. S. Fish Wildl. Serv., *51* (49): 251–358.

Sverdrup, H. U., M. W. Johnson, and R. H. Fleming
1942. The Oceans: their physics, chemistry and biology. Prentice-Hall, Inc., N.Y. 1087 pp.

Tabata, Susumu
1961. Temporal changes of salinity, temperature, and dissolved oxygen content of the water at Station "P" in the northeast Pacific Ocean, and some of their determining factors. J. Fish. Res. Bd. Canada, *18*: 1073–1124.

Tåning, A. V.
1918. Mediterranean Scopelidae (*Saurus*, *Aulopus*, *Chloropthalmus* and *Myctophum*). Rep. Danish oceanogr. Exped. Medit., II, Biol. A.7; pp. 1–154.

Tucker, G. H.
1951. Relation of fishes and other organisms to the scattering of underwater sound. J. Mar. Res., *10*: 215–238.

Tully, J. P., A. J. Dodomead, and Susumu Tabata
1960. An anomalous increase of temperature in the ocean off the Pacific Coast of Canada through 1957 to 1958. J. Fish. Res. Bd. Canada, *17*: 61–80.

Uda, Michitaka
1963. Oceanography of the subarctic Pacific Ocean. J. Fish. Res. Bd. Canada, *20*: 119–179.