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STUDIES ON THE FAUNA ASSOCIATED WITH THE DEEP SCATTERING LAYERS IN THE EQUATORIAL INDIAN OCEAN, CONDUCTED ON R/V *TE VEGA* DURING OCTOBER AND NOVEMBER 1964

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ABSTRACT

Acoustic studies show the daytime scattering pattern in the equatorial Indian Ocean to consist of a main deep scattering layer (DSL) (sometimes a double layer) with a top at 300 to 350 m and an intermediate layer (not always present) at about 200 to 250 m, as well as surface scattering. At night, a combined layer forms in the upper 150 to 250 m by merging of surface scattering with the ascended main DSL and deeper elements. A nomenclature for scattering features is suggested. Horizontal distributions from Africa to the Nicobar Islands are given for 161 species of midwater animals, including 16 siphonophores, 14 pteropods, 10 heteropods, 3 mysids, 7 euphausids, 19 shrimps, 8 tunicates, and 79 fishes. Vertical distributions are discussed for 56 genera and species that were taken frequently enough to suggest diel patterns. Of these, 13 were taken primarily at main DSL depths and lower in daytime and in the combined layer (upper 100 to 150 m) at night, indicating that they are vertical migrators. The six species showing the strongest association with the main DSL were *Ablyopsis tetragona* (a siphonophore), *Cymbulia* sp. (a pteropod), *Thysanopoda* sp. and *Nematobrachion* sp. (euphausiids), *Vinciguerria nimbaria* (a stomiatoid fish), and *Notolychnus valdiviae* (a myctophid fish). Partial migrators of the genus *Argyropelecus* (stomiatoid fishes) were also strongly associated with the main DSL, but not with the combined layer.

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INTRODUCTION

Cruise 5 of R/V *Te Vega,* operated by Stanford University under the auspices of the National Science Foundation,[2] departed from Mombasa, Kenya, on 5 October 1964 and terminated 12 December 1964 in Singapore (Fig. 1). A major objective of the scientific party aboard[3] was to gather information on the association of organisms occurring at the depths of the deep scattering layer (DSL) and at levels immediately above and below the DSL. Previous studies of the DSL (reviewed by Hersey and Backus, 1962) have stressed problems of recording and comparing echograms or have been concerned primarily with determining the species responsible for sonic scattering at DSL depths. In the present study, we have been concerned mainly with three topics: (1) the behavior of the DSL as interpreted from fathometer and sonar echograms; (2) the kinds of macroscopic organisms present in and near the DSL at various times of day and night, their numbers and their movements; and (3) the food habits of these organisms. Although the work covered only a 2-month period and was carried out within a restricted range of latitudes, the results obtained have yielded a picture of the DSL fauna somewhat broader than that obtained in most previous studies.

Acoustic and trawling operations were conducted in the area between Kenya and the northern tip of Sumatra over a cruise-track distance of about 4,300 nautical miles (Fig. 1). Three stops were made along this track for supplies and biological work on inshore communities. The trawling and DSL observation stations therefore fall into four series:

1. Mombasa, Kenya, to Port Victoria, Seychelles, across the southern portion of the Somali Basin; 1,400 nautical miles, traversed 5 to 14 October 1964.
2. Port Victoria, Seychelles, to Male Atoll, Maldive Islands, across the Somali Basin, the Carlsberg Ridge, and the southern portion of the Arabian Basin, terminating on the Mid-Indian Ridge; 1,500 nautical miles, traversed 27 October to 4 November 1964.
3. Male Atoll, Maldive Islands, to Colombo, Ceylon; 400 nautical miles, traversed 9 to 12 November 1964.
4. Colombo, Ceylon, to the northern tip of Sumatra across the southern portion of the Bay of Bengal; 1,100 nautical miles, traversed 19 to 26 November 1964.

The first and last stations were made on 7 October and 24 November, respectively; they were therefore about 7 weeks apart and are separated in space by a straight-line distance on the chart of about 3,000 nautical miles. All stations were made in open waters ranging in depth from 2,012 to 5,121 m. Proximity to land masses varied with the station, but no stations were made on island or continental shelves (insert, Fig. 1).

Weather conditions varied considerably during operations. The first leg of the cruise and the initial part of the second were made during the last of the southeast monsoon, with a heavy swell on the starboard bow and stiff breezes. As the ship neared the Maldive Islands, the winds declined to almost nothing, then shifted to westerlies. East of the Maldive Islands, we experienced our only serious storm. In the vicinity of Ceylon, the westerlies moderated until, at the last station in the Bay of Bengal, we operated in a dead calm. The northeast monsoon began about 5 December, after all trawling operations had been completed.

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[2]Supported by National Science Foundation grant G17465.

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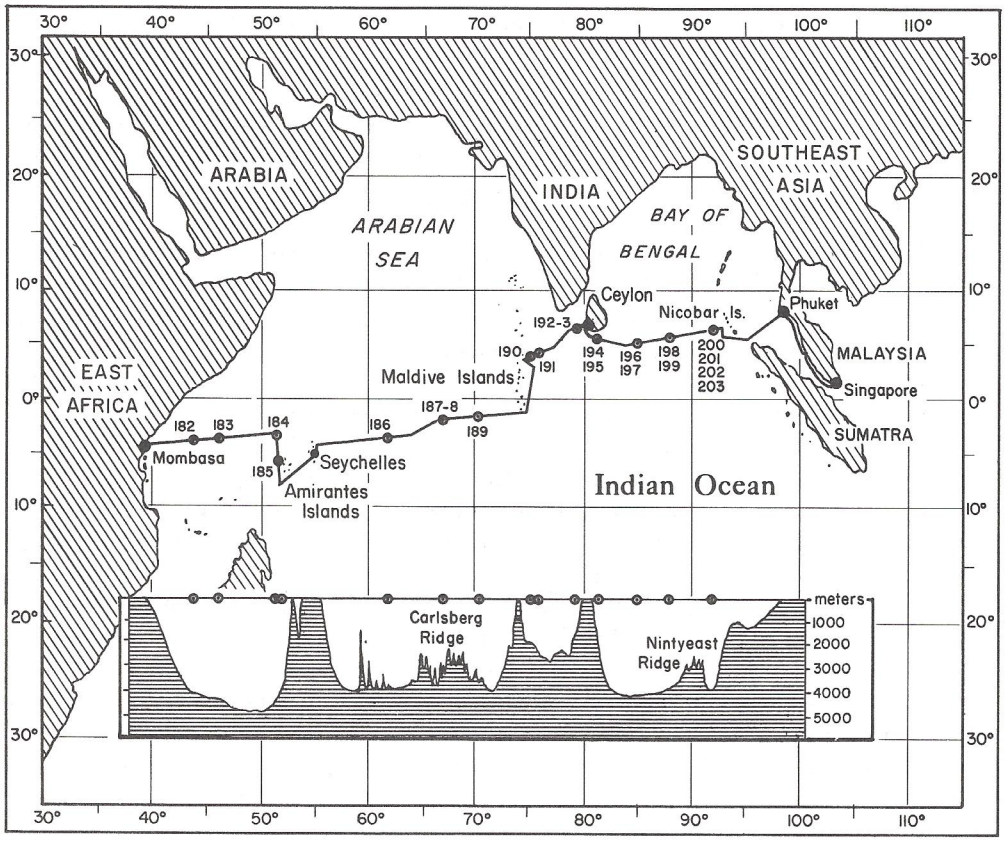

Figure 1. Map of the track of R/V *Te Vega* during Cruise 5, showing midwater trawling localities. Number shown along the cruise track are station numbers. Inset shows a section profile of the cruise track.

MATERIALS AND METHODS

Twenty-two DSL stations were completed at 14 localities (Table 1). Each trawling station (not locality) was assigned a *Te Vega*, station number. Although the number of stations was limited by the regimen of the ship and by periods of unfavorable weather, an attempt was made to sample different geographic regions as well as to sample the DSL and layers adjacent to it around the clock (Fig. 2).

No complete hydrographic casts were made, but thermal conditions were recorded at each trawling station (Fig. 3). Surface temperatures, taken by bucket thermometer, showed little variation (25.5° to 27.0°C). Temperatures below the surface were measured with a 900-foot bathythermograph (GM Mfg. Co. Thermarine Recorder). The 10°C isotherm was recorded at roughly 300 m at all trawling stations. Between the surface and 300 m, thermal conditions were variable, but a thermocline was always present, varying in slope from gradual to abrupt, and in depth from 30 to 120 m. Incident illumination, recorded on deck periodically during trawling and monitoring of the DSL, was measured with a Norwood Director light meter.

Table 1. Summary of Data for Individual DSL Hauls

Station number	Locality	Date (1964)	Ship's time at midpoint of haul	Depth range fished most effectively (m)	Relation of effective fishing range to scattering layers
182	3°23′S, 43°44′E	7 Oct	1013	550-750	In and below DSL curtain
183	3°28′S, 46°10′E	8 Oct	0926	600-750	In and below DSL curtain
184	3°22′S, 51°15′E	10 Oct	0930	800-1250	Below DSL curtain
185	5°15′S, 51°27′E	11 Oct	0940	400-525	In main DSL
186	3°15′S, 61°28′E	29 Oct	1900	140-240	In combined layer
187	1°38′S, 66°28′E	31 Oct	1348	175-215	In surface curtain
188	1°38′S, 66°28′E	31 Oct	1513	275-525	In main DSL
189	1°07′S, 69°37′E	1 Nov	1829	275-375	In combined layer curtain & night condensation
190	4°27′N, 74°15′E	9 Nov	2245	265-500	In and below combined layer curtain and night condensation
191	4°25′N, 74°57′E	10 Nov	0643	250-400	In main DSL
192	6°43′N, 78°47′E	11 Nov	1814	70-80	In combined layer
193	6°43′N, 78°47′E	11 Nov	1950	450-600	Below combined layer curtain & night condensations
194	5°46′N, 81°13′E	20 Nov	0937	300-390	In main DSL
195	5°46′N, 81°13′E	20 Nov	1108	150-240	In surface curtain and clear layer above main DSL
196	5°06′N, 84°51′E	21 Nov	2026	75-85	In combined layer
197	5°06′N, 84°51′E	21 Nov	2224	75-85	In combined layer
198	5°44′N, 88°24′E	23 Nov	0327	75-120	In combined layer
199	5°44′N, 88°24′E	23 Nov	0535	75-90	In surface layer
200	6°00′N, 92°01′E	24 Nov	1047	80-85	In surface layer
201	6°05′N, 92°06′E	24 Nov	1228	225-280	In intermediate layer and surface curtain
202	6°05′N, 92°06′E	24 Nov	1358	400-475	In main DSL
203	6°05′N, 92°06′E	24 Nov	1537	750-850	Below main DSL and DSL curtain

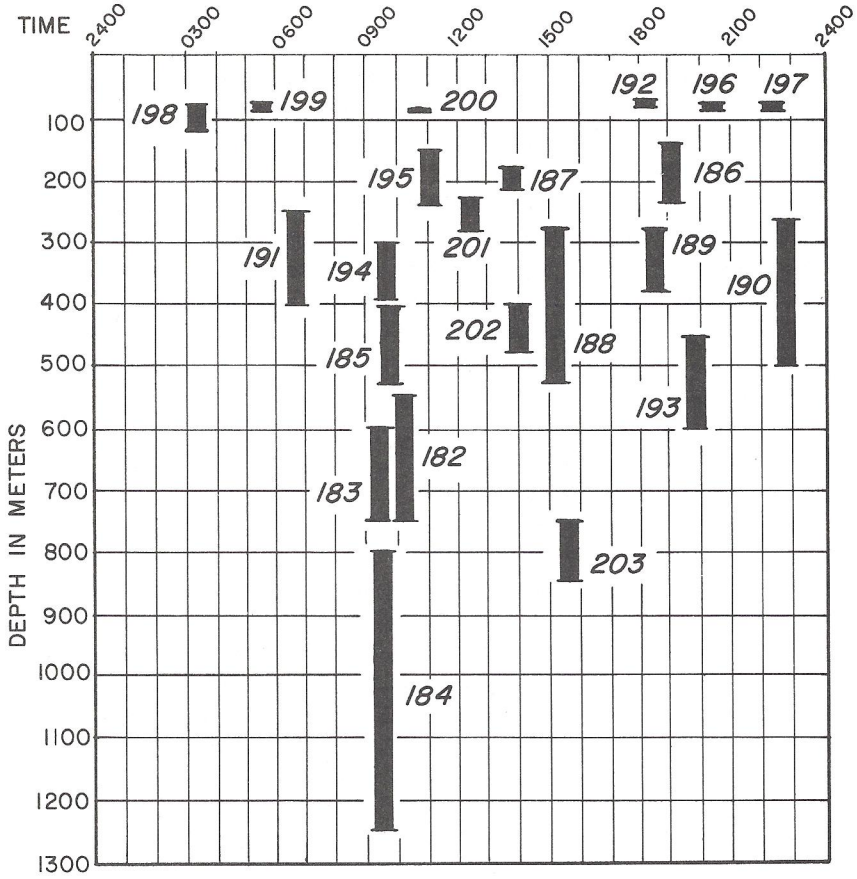

Figure 2. Distribution of midwater hauls with respect to time of day. Black bars represent individual hauls; length and vertical position of each bar indicate the depths the trawl was estimated to have fished most effectively.

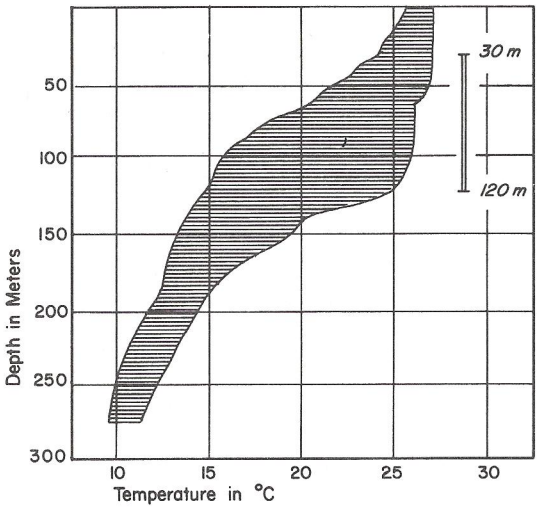

Figure 3. Composite bathythermograph tracings; the perimeter of the shaded area encompasses all tracings made during midwater trawling stations. Vertical bar from 30 to 120 m indicates region of the thermocline.

All samples of organisms reported in this paper were taken in a Tucker trawl. The mouth of the net was 10 by 10 feet, framed above and below by bars of 3-inch galvanized iron pipe and along each side by a braided nylon rope that connected the upper and lower bars. The net was 26 feet long, tapered evenly from mouth to cod end, and consisted of four sections of knotless nylon netting whose mesh sizes decreased from mouth to cod end as follows: an 8-foot section nearest the mouth with square mesh size 3/8 inch (stretched mesh 3/4 inch); a second section 9 feet long with square mesh size 1/4 inch (stretched mesh 1/2 inch); a third section 4 1/2 feet long with square mesh size 1/16 inch (stretched mesh 1/8 inch); a cod-end section 4 1/2 feet long of 1/16 inch square mesh Ace netting (stretched mesh 1/8 inch). The cod end terminated in a canvas collar into which fitted a stainless steel bucket 8 1/2 inches in diameter and 10 inches deep. The upper bar of the mouth frame was connected by a bridle and swivel to a tow cable of 3/8-inch wire rope that passed over a meter block suspended from an A-frame about 12 feet above the sea surface.

From stations 182 to 185 inclusive (between Mombasa and the Seychelles), the trawl was used as described above. For all subsequent stations, the trawl was modified in two ways. First, four 15-lb bronze homogeneous depressors, evenly spaced, were attached to the lower bar of the mouth frame to improve diving performance. Second, the cod-end section was lined inside with a cone of nylon gauze 20 meshes per inch. This lining not only aided in retaining organisms which formerly passed through the 1/16-inch square mesh of the outer net, but it reduced turbulence in the cod-end bucket so the trapped plankton and smaller nekton arrived at the surface in much better condition than they had before the net was modified.

On most stations, the trawl was lowered with the ship running slow ahead and the winch either running free or rapidly powering out the towing wire to avoid fishing above the desired depths as much as possible. On some occasions, when the ship was driven by a following sea and wind, the net was lowered with the propeller dead. In either case, following braking of the winch, the trawl was towed at 1 to 1.5 knots for 30 minutes, then recovered with the engines either stopped or on slow ahead. We assumed that the trawl continued to fish to some extent during recovery.

The depth of the net at all stages of a haul (Figs. 4 to 6) was estimated by calculations based on amount of wire paid out and the wire angle as measured by a Scripps inclinometer. The error introduced by the catenary of the wire was probably greatest during the period when the wire was being paid out and for the first few minutes after the winch was braked. (See Backus and Hersey, 1956, and Barham, 1957, Figures 9 and 10, for analyses of similar situations.) Depth-time recorders on board were all malfunctional, so no independent check on the accuracy of depths calculated from wire angles was available. However, the pull exerted by the large trawl and the action of the four depressors put such a heavy strain on the towing wire that we have assumed that once the wire angle became stabilized after braking the winch, the catenary of the towing wire, while unknown, was not enough to introduce a significant error into our depth calculations, considering the relatively short lengths of wire paid out. Times required for stabilization of wire angles for different lengths of wire out are shown in Figure 7. For hauls at depths to 150 m, wire angles stabilized within 2 to 5 min after the winch was braked; for hauls at depths of 200 to 500 m, wire angles usually stabilized within 10 min after the winch was braked. During some hauls (e.g., Stations 190 and 195), and with ship's speed maintained the while, wire was taken in *after* the wire angle was stabilized; the strain on the wire increased on such occasions, and wire angles appear to reliably indicate net depth. Also, the calculated path of the net during recovery, with the ship moving ahead at 1 to 1.5 knots, is considered to be reliable for all hauls. The curves shown in Figures 4 to 6 represent our best estimates of the path of the trawl for each haul. At a few stations, which were made in rough water and with a

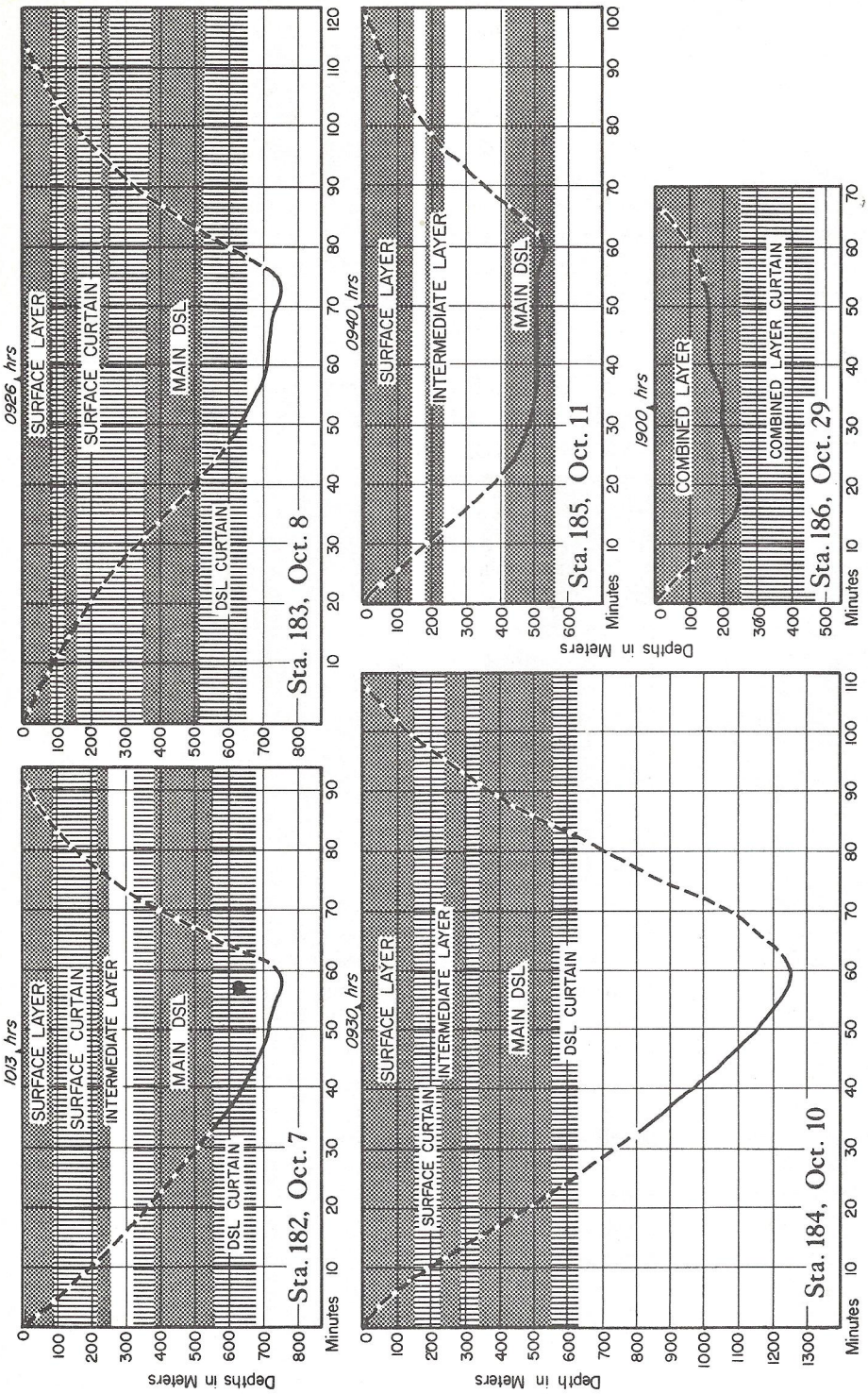

Figure 4. Profiles of Stations 182 to 186. For each profile, the heavy line indicates the estimated path of the trawl; the solid portion of the line indicates the portion of the haul during which the net was estimated to be fishing most effectively. Stipple pattern indicates heavy scattering; vertical bars indicate light scattering.

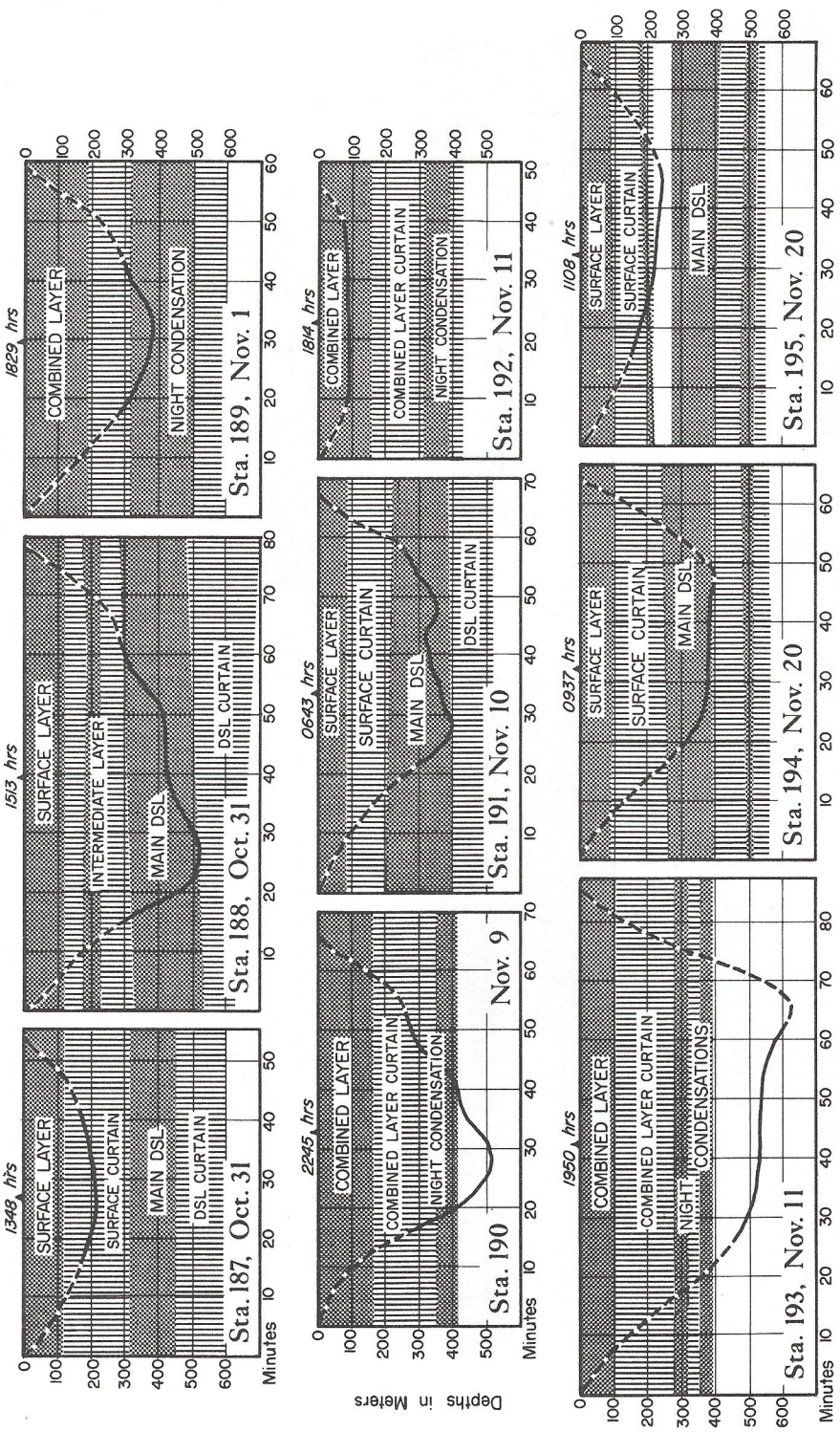

Figure 5. Profiles of Stations 187 to 195. For each profile, the heavy line indicates the estimated path of the trawl; the solid portion of the line indicates the portion of the haul during which the net was estimated to be fishing most effectively. Stipple pattern indicates heavy scattering; vertical bars indicate light scattering.

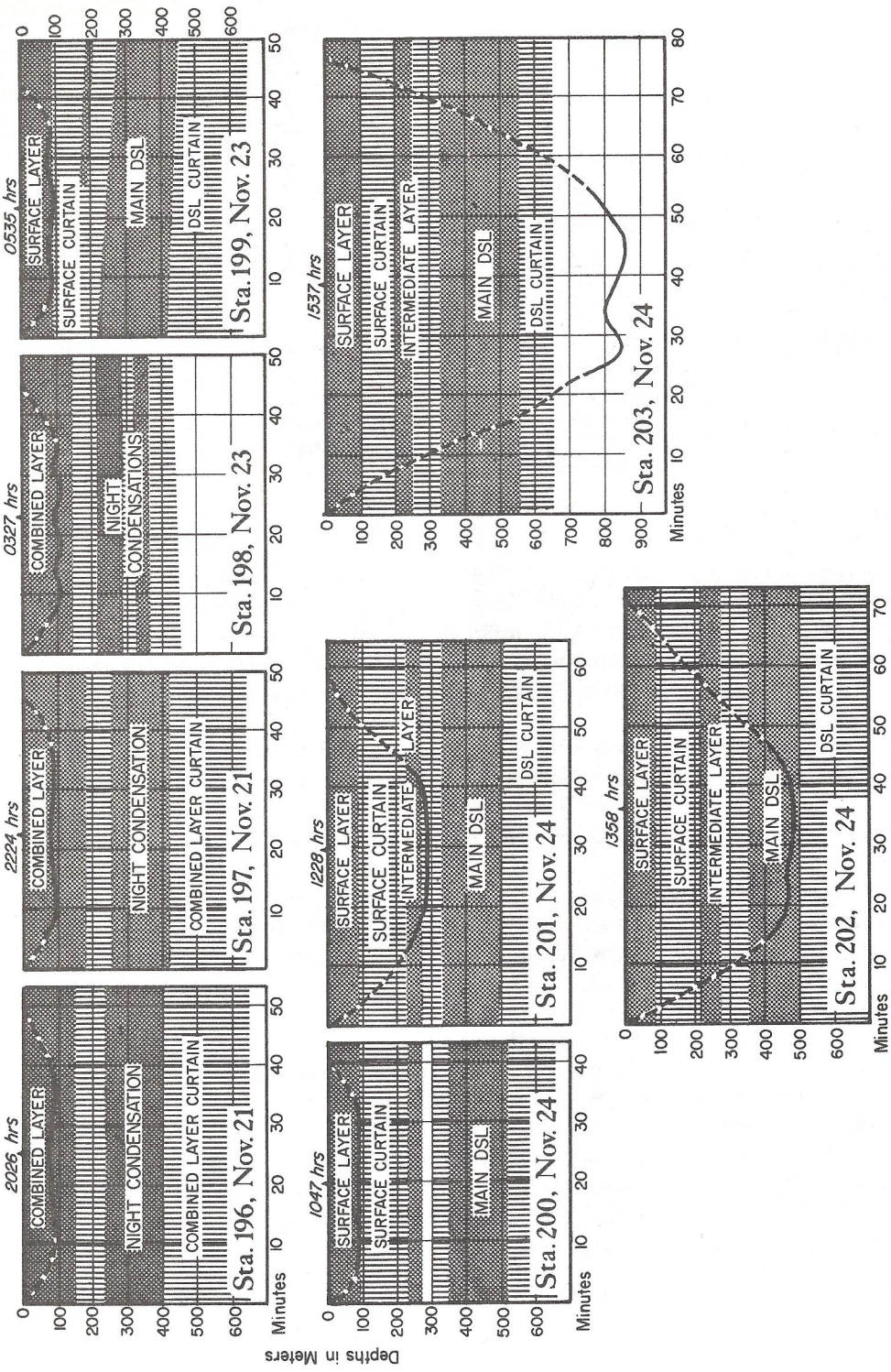

Figure 6. Profiles of Stations 196 to 203. For each profile, the heavy line indicates the estimated path of the trawl; the solid portion of the line indicates the portion of the haul during which the net was estimated to be fishing most effectively. Stipple pattern indicates heavy scattering; vertical bars indicate light scattering.

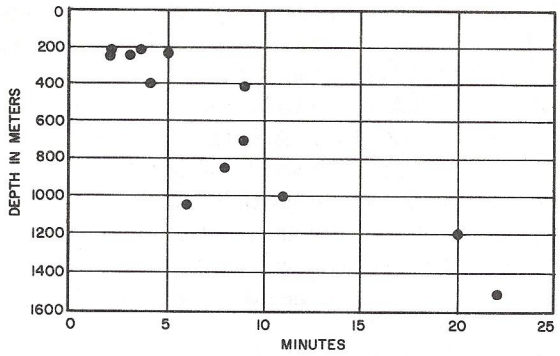

Figure 7. Time required to stabilize the wire angle for various lengths of wire paid out (omitting cases in which the wire was taken in or the ship's speed altered before the wire angle stabilized, or in which the wire angle never stabilized)

following wind and sea (e.g., stations 191, 198), the inclinometer was difficult to read and wire angles did not stabilize satisfactorily; under those conditions, adjustments in the ship's speed were made during the haul in an attempt to maintain wire angles within the range desired. The calculated depth curves for these stations show a wavy line, which appears to indicate marked changes in the depth of the net during the main trawling period; actual variation in net depth is probably less than that indicated.

On recovery, after the bucket was retrieved from the cod end, the net was flushed with sea water and picked over for organisms caught in the mesh; organisms recovered in this fashion were included in the rest of the catch. The catch was rough-sorted and preserved immediately thereafter. Members of the scientific party, each responsible for a different taxon, made tentative identifications and counts of each species taken and examined gut contents of selected specimens. Those responsible for particular groups were Proctor (siphonophores), Fielding (chaetognaths), Buchsbaum (mollusks), Ogden (amphipods), McPhearson (penaeids), Taylor (carideans), Jeanne Christofferson (euphausiids), Jay Christofferson (mysids and stomatopod larvae), Barber (tunicates), Stromborg, Wourms, and Bradbury (fishes). After the expedition, it was possible to recheck the identifications of the following groups: siphonophores, mollusks, penaeids, carideans, mysids, tunicates, and most fishes.

The following references proved the most useful. Siphonophores: Bigelow, 1911; Totton, 1954; Totton and Bargmann, 1965. Mollusks: Stubbings, 1938; Tesch, 1946, 1948, 1949; Thore, 1949. Euphausiids: Einarsson, 1945; Tattersall, 1939. Mysids: Sars, 1885; Tattersall, 1939; Tattersall and Tattersall, 1951. Stomatopods: Townsley, 1953. Penaeids: Alcock, 1905; Boone, 1931; Dana, 1852; Hall, 1962; Hansen, 1896; Ramadan, 1938; Wood-Mason and Alcock, 1891. Carideans: Barnard, 1950; Borradaile, 1916; Calman, 1939; Chace, Jr., 1936; DeMan, 1920; Kemp, 1939; Holthuis, 1955. Tunicates: Thompson, 1948. Fishes: Bauchot-Boutin, 1953; Beebe and Crane, 1937; Bertelsen, 1951; Bertin, 1937; Bolin, 1959; Cohen, 1964; D'Ancona, 1928; D'Ancona and Cavinato, 1965; Fraser-Brunner, 1949; Gibbs, 1964a, 1964b; Grey, 1960, 1964; Lea, 1913; Marshall, 1966; Morrow, 1964a, 1964b; Morrow and Gibbs, 1964; Parr, 1960; Rofen, 1966a, 1966b; Roule and Bertin, 1929; Schultz, 1961; Walters, 1964. We

were assisted in the identifications by a number of specialists (see Acknowledgments). Some specimens have been retained by the specialists, but most have been deposited in the Smithsonian Oceanographic Sorting Center, Washington, D.C.

Recordings of the DSL were made with two instruments. The most generally useful was a Simrad Sonar, Model 540-4 (Simonsen Radio A.S., Oslo), powered through a 24-V Constavolt battery eliminator model 6024. Pulse power was 1,000 W with a frequency of 30 kHz. The instrument was used on echo-location (depth-sounding) setting and was set to record echos from the upper 1,500 m. Best recordings were obtained with a pulse length of 11 msec (dial setting of 3) and a sensitivity setting between 6 and 10, with best results between 6 and 7. Signal-to-noise ratio was unfavorable while underway with the main engine, so all recordings were taken with the ship's propeller stopped.

Subsidiary recordings were taken, often simultaneously, with a Simrad Echo-Sounder Type 513-1. Power was supplied by the ship's generators, raised from 115 to 220 V by a Simrad Transformer Type 517-33. Pulse power was 800 W, with a frequency of 11 kHz. Best recordings were obtained with a pulse length of 8 msec (dial setting of 3) and a sensitivity setting of about 6. The Simrad Echo-Sounder, when used to record only the acoustical phenomena in the uppermost 500 m, provided a finer resolution of the upper DSL than did the Simrad Sonar, but it proved the less useful instrument for our purposes for two reasons: first, slight fluctuations in the strength and frequency of the ship's generator output or marked fluctuations in power usage aboard caused some artificial variations in recordings of the DSL; second, at several critical depths, a bottom echo from a previous pulse was recorded on the tape at DSL levels, obscuring the recorded DSL.

THE PATTERN OF THE DSL

Data on the sonic scattering layers were collected as follows.

Echograms were taken before and during each DSL trawling station to establish the position and structure of the sound scattering layers .

On five different days, 28 October to 2 November, 15 minutes of tracings were made at 3-hour intervals to assess the variability of the scattering pattern at specified hours of the day and night. During each period of recording, water and air temperature, sea conditions, wind force, and incident light were also recorded.

The DSL was recorded continuously for 37 hours from the evening of 24 November through the early morning of 26 November except for short periods when the tape was replenished. During the day, incident light was measured at 15-min intervals.

Isolated recordings of the DSL were made on a variety of other occasions.

The high read-out rate of the Simrad Sonar (about 2 m per hour) resulted in detailed resolution of scattering-layer changes per unit of time, which allowed careful analysis of these changes but made it impractical to publish photographs of complete echograms. Therefore, echograms were converted to diagrams (i.e., Figs. 4 to 6, 8, and 9) by greatly compressing the time axis of the echogram tape and reducing the various light and dark portions of the scattering recording to two or three categories represented respectively by light lines, medium lines, and dark stippling on the diagrams. Conversion from tape record to diagram involved interpretation and simplification but was done with consistency and care, so that the diagrams reflect fairly accurately the real differences in layers shown on the echograms.

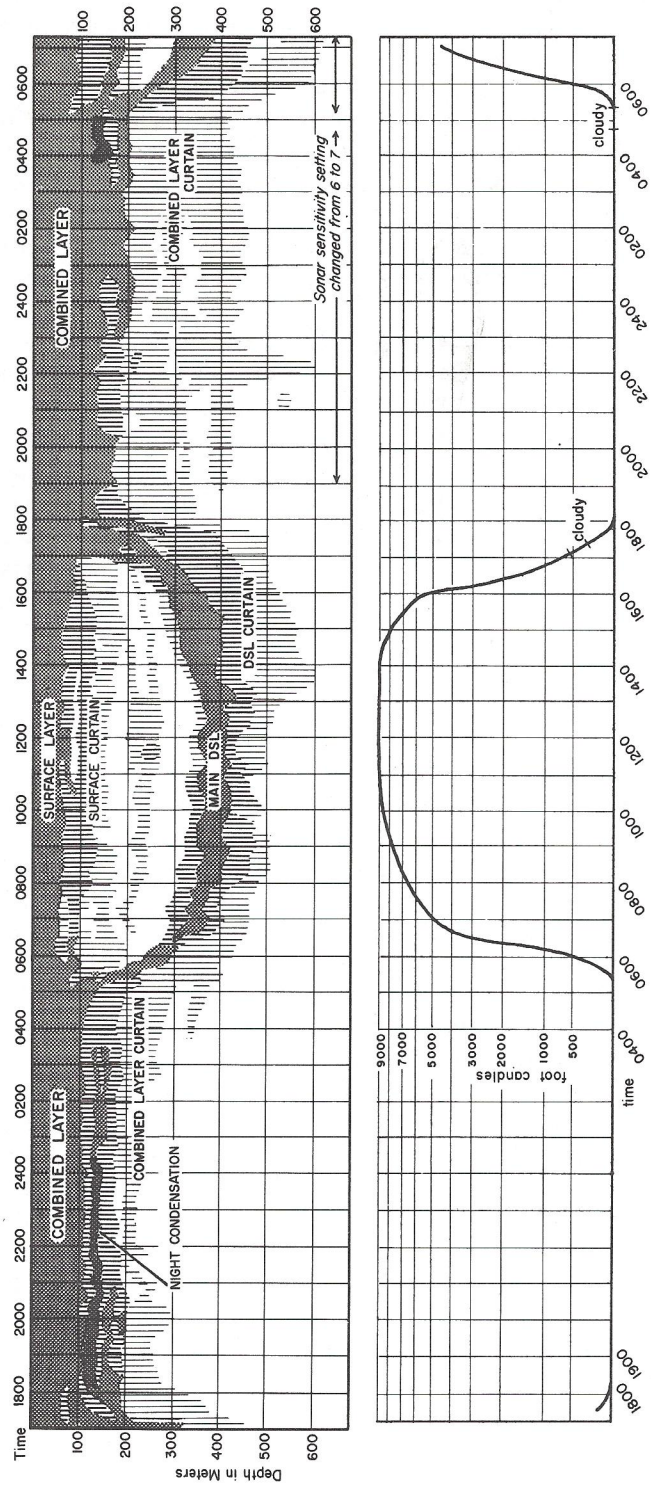

Figure 8. Above: diagram of scattering layers prepared from a 37-hour-long echogram recorded in the Bay of Bengal at 06°10′N, 93°07′E, beginning 1700 hours November 24 and ending 0715 hours November 26. Stippled patterns indicate heavy scattering, medium and light vertical lines indicate medium and light scattering respectively (see Figs. 10 and 11 for photographs of the actual echogram). Light scattering between the surface curtain and main DSL, centered at 250 m during the day, corresponds in position to the intermediate layer seen as heavy scattering on numerous other echograms (Figs. 4 to 6). Below: curve showing intensities of incident light for the period the echogram was being recorded.

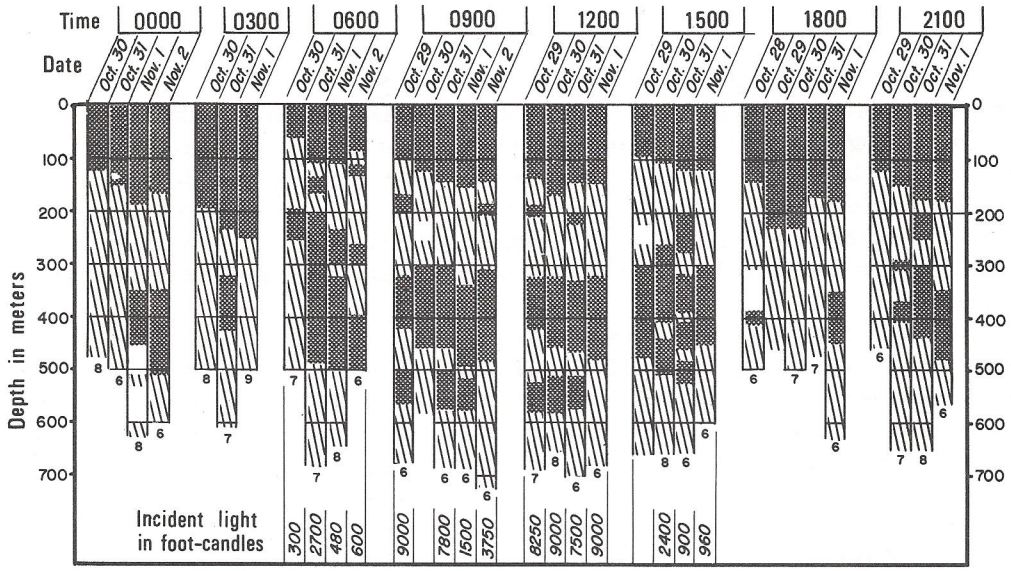

Figure 9. Diagrams showing variation in scattering layers recorded at specific hours between 28 October and 2 November between the Seychelles and Maldive Islands. Numbers below columns show sonar sensitivity settings.

General Features of DSL Patterns

Although echograms taken at the same time of day on consecutive days usually showed variation in thickness, vertical position, and number of bands, there were features that occurred regularly, or at least very frequently. For our comparative purposes it was convenient to designate each of these features by a distinctive term; Figures 4 to 6 and 8 show bands labeled with the terms we used. Definition of the terms are given as follows.

Main DSL. A layer of heavy scattering at least 50 m thick (e.g., Fig. 8) but generally thicker (e.g., Fig. 5, Sta. 187, 188, 191, etc.), represented on echograms by a dark band, which during the main part of the day lay with its top about 300 to 350 m below the surface. Sometimes the main DSL was very thick and subdivided into two bands, the lower band centered at or below 500 m (e.g., Fig. 6, Sta. 194 and 195; Fig. 9 shows that this split in the main DSL occurred frequently between 29 October and 2 November).

DSL curtain. A region of lightly recorded scattering that appeared on echograms as a fringe below the main DSL. The width of this band varied directly with the sensitivity setting of the sonar, but in general, the DSL curtain was not detectable more than 200 m below the bottom of the main DSL, tending to thicken in late afternoon because its lower margin did not ascend through as many meters as did the main DSL.

Surface layer. A layer of heavy scattering that occupied the top 60 to 150 m in daytime. We do not know whether the surface scattering resulted from the outgoing signal or whether there were actually sound scatterers present near the surface whose recording merged with that of the outgoing signal on the echogram.

Surface curtain. A layer of lightly recorded scattering extending from the surface layer to the main DSL. This layer often showed some heavy scattering within it (see Intermediate Layer) or clear layers from which no scattering was recorded (e.g., Fig. 4, Sta. 182; Fig. 5, Sta. 195; Fig. 6, Sta. 200; Fig. 8).

Intermediate layer. Any daytime layers that registered as relatively heavy scattering within the surface curtain (numerous echograms shown in Figs. 4 to 6).

Combined layer. A nighttime surface layer that occupied the top 150 to 250 m and that appeared on echograms to represent the band of the main DSL merged with the surface layer.

Combined layer curtain. A layer of lightly recorded scattering extending as a fringe below the combined layer. The combined layer curtain was continuous with the DSL curtain.

Night condensation. One or more layers of heavy scattering often recorded at night from below the combined layer but within the combined layer curtain. These night condensations sometimes persisted throughout the night, and on cloudy days they sometimes appeared at sunset.

The only bands consistently present on echograms were the main DSL, the surface layer, and the combined layer, and the main DSL showed variation in width and vertical position at any given hour from day to day. The most notable feature of the scattering layers was the 350-m migration of the main DSL downward from the surface at dawn and its return to the surface at sunset. Each migration was completed within 1.5 to 2 hours and was recorded on the sonar tape as a solid band or as several poorly separated bands moving gradually up or down. The main DSL remained at lower depths during the daylight hours. The intermediate layer, when present, underwent a similar migration at dawn and sunset. It is likely that the vertical movements of scattering layers are influenced by light intensities and by rates of change of light intensities, as Clarke and Backus (1964) were able to show for scattering layers in the north Atlantic.

The combined layer persisted throughout the night, and often, between 2400 and 0300 hours, a part of it appeared to descend 50 m, where it remained until sunrise.

Comparisons With Other DSL Studies

The generalized equatorial Indian Ocean DSL pattern is similar in its daytime DSL pattern to patterns recorded in the equatorial and North Pacific (Dietz, 1948), the southeastern Pacific (Hersey and Backus, 1962), the Mediterranean (Frassetto and Della Croce, 1965) and the eastern central Pacific (Barham, 1966). In the echograms reproduced in these publications, the daytime depth of the center of the main DSL is between 350 and 400 m, which is approximately the daytime depth of the main DSL in Fig. 8. In view of the differences in latitude and light regime between all these areas, the similarity of daytime depth of the main DSL is striking.

However, Hersey and Backus (1962) report that in the North Atlantic, the DSL band appears as two layers, one centered at 250 m and the other at 500 m. This generalized pattern is based on the examination of about 150 separate recordings. The echogram of Moore (1950, his Fig. 1a) from the North Atlantic shows a very similar pattern, with an intermediate layer at 250 m and a main layer between 500 and 600 m. These data indicate that the main scattering layer is consistently about 100 m deeper in the North Atlantic than it is in the equatorial Indian Ocean, but in both oceans there is usually an intermediate layer at 250 m. The DSL's recorded by Dietz (1948) and Barham (1966) in the Pacific conspicuously lack the intermediate layer that is present at 250 m in the Indian Ocean, the North Atlantic, and the Pacific off the coast of Chile (Hersey and Backus, 1962, their Fig. 6).

Barham (1966) noted that an echogram, which was being recorded on Scripps Research Vessel T-441 as it accompanied the diving saucer *Soucoupe* during Dive 3 off Baja California, showed an intermediate layer splitting off from the main layer; shortly thereafter, the intermediate layer disappeared from the echogram. Barham, who was in the diving saucer while the echogram was being recorded, saw scattering organisms in what corresponded to the intermediate

layer as it was splitting off from the downward-migrating main layer (his Fig. 2). About 45 min later, he saw no organisms at the depth where the intermediate layer would have been, that is, at 220 to 240 m.

In the Indian Ocean, the intermediate layer becomes most distinct in the middle of the day, from 0900 to 1300 hours. Hersey and Backus (1962, their Fig. 6) show a heavy intermediate layer present throughout daylight hours. The 250-m intermediate layer appears to be a most variable component of the scattering layers.

Continuous 37-Hour Recording

The 37-hour length of fathometer tape is diagramed in Figure 8, in which the time axis is reduced to about .0032 that of the actual tape length. The figure illustrates how the size, number, and vertical position of individual bands varied within short periods of time, and also how a change of one unit in the sensitivity setting of the sonar could introduce bands that were not previously recorded. Photographs of portions of the 37-hour echogram are shown in Figures 10 and 11.

Light-intensity readings taken at 15-min intervals during most of the period of continuous sonar recording are shown below the echogram in Figure 8. Note that with the first daylight, the main DSL began its migration downward, reaching its lowest depth at the time of greatest light intensity. As the light intensity dropped in the late afternoon, the main DSL approached the surface.

Variation in Scattering Layers

Figure 9 illustrates variation in scattering layers recorded at particular times of day on different days from 28 October to 2 November. During each 15-min DSL observation, records were also made of the amount of incident light, the barometric pressure, air and water temperatures, wave height, wind force, and percent of cloud cover. The variability in layering that was recorded did not show any clear correlation with variations in any of these factors.

The amount of light at a particular time of day did not appear to have any consistent effect on the type and depth of the scattering layers that formed. For example, the light conditions at 0600 hours were similar on 30 October, 1 November, and 2 November (Fig. 9); incident light in foot-candles (ft-c) registered 300, 480, and 600 ft-c, respectively. However, the pattern for 1 November does not resemble that for 30 October nearly as much as it resembles the pattern for 31 October, when the incident light registered 2,700 ft-c at 0600 hours, or approximately 5.5 times that measured for 1 November. At 0900 hours on 29 October and 31 October, the incident light readings were similar (9,000 and 7,800 ft-c, respectively), yet the echogram for 29 October includes an intermediate layer, whereas that for 31 October does not. The main DSL was split into two bands at 1200 hours on 30 October, but not on 1 November, although the illumination was the same on the two days. Interpretation of these findings would require knowledge of the light conditions for the hour or two immediately preceding each observation, but such data were not recorded.

HORIZONTAL DISTRIBUTION OF ANIMALS

Horizontal distributions of animals taken during the cruise are very incomplete because only 14 localities were sampled along a cruise track of 4,300 nautical miles. However, our data show some agreement with the works of others. For example, the stomiatoid fish *Diplophos taenia* is known only from the western Indian Ocean (Grey, 1960), and we collected this form at three

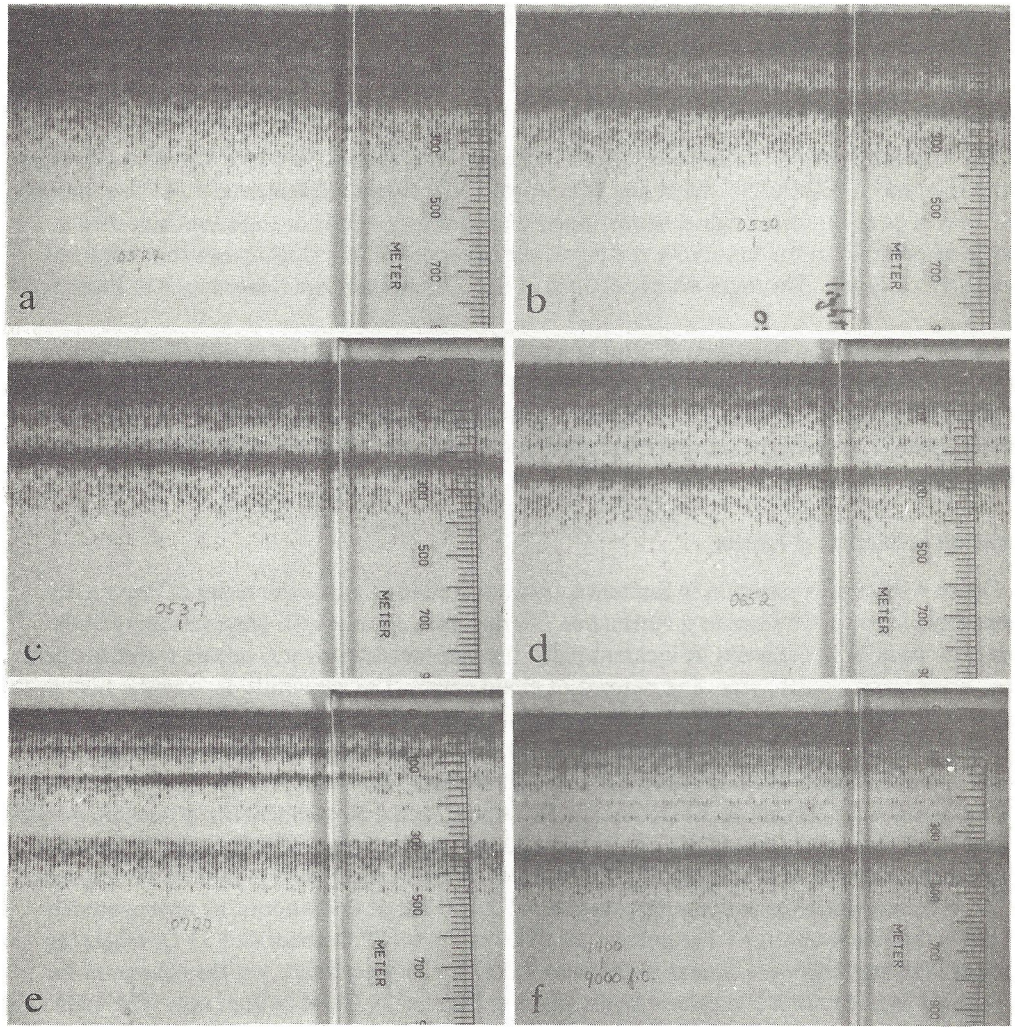

Figure 10. Photographs of selected portions of the 37-hour echogram. a-e; descending main DSL on 25 November. f; main DSL at daytime depth on 25 November. Times covered by photographs are as follows: a, 0521 through 0525; b, 0528 through 0532; c, 0535 through 0539; d, 0650 through 0654; e, 0718 through 0722; f, 1359 through 1403.

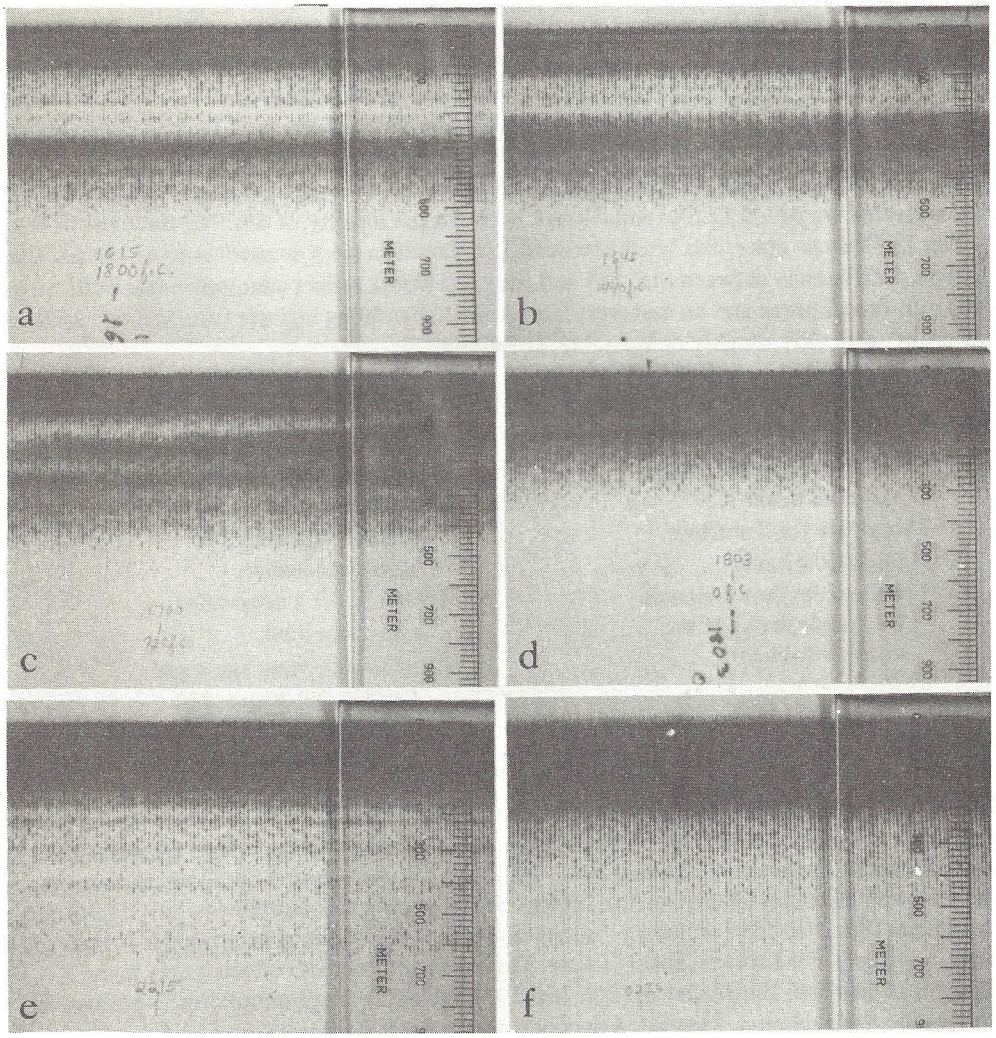

Figure 11. Photographs of selected portions of the 37-hour echogram. a-c, ascending main DSL on 25 November, d-f; combined layer on 25 and 26 November (e shows a night condensation). Times covered by photographs are as follows: a, 1614 through 1618; b, 1644 through 1648; c, 1659 through 1703; d, 1801 through 1805; e, 2214 through 2218; f, 0229 through 0233.

localities west of the Maldive Islands but never east of them (Fig. 1). The myctophid fishes *Benthosema suborbitale* and *Centrobranchus nigro-ocellatus* are apparently restricted in the Indian Ocean to latitudes south of the equator, while *Benthosema fibulatum* has a northerly distribution in the Indian Ocean (Nafpaktitis and Nafpaktitis, 1969), and our data agree with these findings. Gibbs and Hurwitz (1967) have reaffirmed that two species of *Chauliodus* occur in the Indian Ocean, *Chauliodus pammelas* to the north in the Arabian Sea and Bay of Bengal and extending just south of Ceylon, and *Chauliodus sloani* in more southerly portions of the Indian Ocean, its horizontal range overlapping that of *Chauliodus pammelas* somewhat. Thus, during the southerly leg of our cruise (southwest of the Maldive Islands), we took only *Chauliodus sloani*, as might be expected, and we took *Chauliodus pammelas* on the northern leg.

The literature concerning the horizontal distributions of midwater animals in the Indian Ocean suggested we would find a faunal break between the locality of Sta. 189 and that of Sta. 190 (Fig. 1). Because our cruise track extended in a direction from southwest to northeast, the geographical difference between Sta. 189 and Sta. 190 would reflect simultaneously both a north-south faunal break and an east-west faunal break. Sampling regimes from the two sections of the cruise were only roughly comparable, as follows.

Southwest Cruise track, seven localities (Sta. 182-189)	Northwest Cruise track, seven localities (Sta. 190-203)
5 localities for 5 deepwater daytime hauls	3 localities for 4 deepwater daytime hauls
2 localities for 2 shallow nighttime hauls	3 localities for 4 shallow nighttime hauls
(1 shallow daytime haul was also made at one of the above localities)	1 locality for a deepwater nighttime haul
	(4 shallow daytime hauls and 1 additional deepwater nighttime haul were also made at the above localities)

Of the 161 species of invertebrates and fishes eventually identified (Table 2), only 73 were taken in both the southwestern and northeastern equatorial Indian Ocean; these forms include 11 siphonophores, 7 pteropods, 2 heteropods, 2 mysids, 7 euphausiids, 8 decapod crustaceans, 7 tunicates, and 29 fishes. There were 52 species collected only in the southwestern equatorial Indian Ocean (Sta. 182-189), including 2 siphonophores, 4 pteropods, 5 heteropods, 4 cephalopods, 6 decapod crustaceans, and 31 fishes. There were 36 species collected only in the northeastern equatorial Indian Ocean (Sta. 190-203), including 3 siphonophores, 3 pteropods, 3 heteropods, 1 cephalopod, 1 mysid, 5 decapod crustaceans, 1 tunicate, and 19 fishes.

Examples of fishes we collected in both the southwestern and northeastern equatorial Indian Ocean that were already known to have distributions that broadly span the entire equatorial Indian Ocean are *Danaphos oculatus* (Grey, 1960) *Vinciguerria nimbaria* and *Valenciennellus tripunctulatus* (Grey, 1964), *Chauliodus sloani* (Morrow, 1964b), *Stomias affinis* and *Stomias nebulosus* (Morrow, 1964c), *Argyropelecus lychnus* (Schultz, 1961) and some of the lantern fishes, for example, *Notolychnus valdiviae, Diaphus elucens, Diaphus lutkeni, Diaphus splendidus,*

Table 2. Species with Numbers of Individuals Taken at Each Station

Station Numbers	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203
SIPHONOPHORA																						
Physonectae																						
Agalma okeni Eschscholtz	–		–	–	–	–	–	x*	–	–	x	x	x	–	x	x	x	–	–	x	x	–
Agalma sp.	–		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–
Halistemma rubrum (Vogt)	–		–	–	–	–	–	–	–	–	–	–	–	–	x	x	–	–	–	–	–	–
Unidentified physonects	–		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x
Calycophorae																						
Abyla trigona Quoy & Gaimard	2		–	4	4	5	2	–	–	–	1	–	–	–	–	–	1	–	–	–	1	–
Abylopsis tetragona (Otto)	14		19	48	54	1	23	3	8	10	394	11	3	9	103	176	227	1	1	–	32	11
Ceratocymba dentata (Bigelow)	–		–	–	2	1	–	–	–	–	–	1	–	–	1	2	–	–	–	–	–	–
Ceratocymba leuckarti (Huxley)	–		–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3	–	–
Ceratocymba sagitta (Quoy & Gaimard)	–		–	–	–	–	–	–	–	1	–	–	–	–	–	3	–	–	–	1	–	–
Chelophyes appendiculata (Eschscholtz)	–		5	6	–	2	–	4	–	–	3	–	–	–	–	–	–	4	8	10	–	4
Chelophyes contorta (Lens & van Riemsdijk)	–		–	–	–	76	–	–	–	–	–	–	–	1	–	1	9	5	–	7	–	7
Chuniphyes multidentata Lens & van Riemsdijk	1		3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Diphyes bojani (Eschscholtz)	–		–	–	–	49	1	–	–	–	–	–	–	–	–	1	–	–	9	9	6	–
Diphyes dispar Chamisso & Eysenhardt	–		–	–	1	–	–	–	–	–	3	–	2	13	1	9	6	7	5	–	1	–
Eudoxoides mitra (Huxley)	–		1	–	–	14	–	–	–	–	2	–	–	3	–	1	3	–	1	1	–	3
Hippopodius hippopus (Forskål)	–		x	–	x	x	x	x	–	–	x	–	–	x	x	–	x	–	–	x	x	x
Vogtia spinosa Keferstein & Ehlers	–		x	–	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Unidentified calycophorans	–		3	–	–	4	1	–	–	–	3	1	–	–	7	7	–	–	–	1	–	–
MOLLUSCA																						
Gastropoda, Pteropoda																						
Cavolinia globulosa (Rang)	2	–	–	–	–	3	–	1	–	–	–	–	–	–	–	–	3	–	–	–	–	–
Cavolinia inflexa (Rang)	9	2	–	1	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cavolinia longirostris (Lesueur)	–	–	–	4	–	1	2	–	23	1	1	–	–	12	7	22	1	–	–	3	1	–
Cavolinia uncinata (Rang)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–
Cavolinia sp.	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–
Creseis (probably *acicula* or *virgula*)	–	1	–	–	–	1	–	–	–	3	–	–	2	8	1	9	–	–	–	–	–	–
Cuvierina columnella (Rang)	2	–	2	–	–	–	2	4	–	–	–	–	–	–	–	–	–	–	–	–	–	–

All siphonophores from this trawl were lost

x = nectophores present; siphonophore individuals could not be counted.

Table 2. Species with Numbers of Individuals Taken at Each Station (Continued)

Station Numbers	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203
Diacria q. *quadridentata* (Lesueur)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	14	72	14	12	11	3
Diacria q. *costata* Pfeffer	20	15	8	3	–	3	5	–	1	–	2	1	–	5	4	4	–	3	–	–	–	–
Diacria quadridentata juveniles (*Cleodora pygmaea* Boas)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	1	–	–	–
Diacria trispinosa major (Boas)	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Euclio cuspidata (Bosc)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3	–	–	–	–	–	–
Euclio pyramidata (Linné) (or possibly *balantium* (Rang))	3	15	3	–	6	–	25	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Euclio sp.	–	–	–	–	–	–	–	3	–	–	–	–	–	–	–	3	–	–	1	–	–	–
Styliola subula Quoy & Gaimard	–	–	–	–	–	–	9	3	1	–	–	–	–	–	–	–	–	–	–	–	–	–
Limacina (more than one species?)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	8	1	–	–	–	–	–
Cymbulia sp.	20	*	1	33	10	–	100	20	3	28	59	9	4	90	190	284	30	1	1	–	–	2
Peraclis (more than one species?)	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	6	–	1	–	–	–	–
Gastropoda, Snails																						
Columbellidae, sp.	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–
Tonna "sinusigera" larvae	–	–	–	–	–	–	–	–	–	–	–	–	–	3	–	–	–	–	–	–	–	–
Natacidae, sp.	–	–	–	–	–	5	4	1M	–	–	–	–	–	6	1	3M	4	5M	–	–	–	–
Natacidae	–	–	–	–	–	1	–	–	–	–	–	3	–	5	–	1M	–	–	1	–	–	–
Unidentified snails	–	–	–	–	–	–	–	–	–	–	1	3	–	2	–	–	–	1M	1	–	–	–
Gastropoda, Heteropoda																						
Oxygyrus keraudreni (Lesueur)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	1	–	–
Atlanta (more than one species)	–	–	–	–	–	10	5	2	5	2	–	–	1	12	–	70	21	111	26	7	1	18
Cardiapoda placenta (Lesson)	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	–	–	–	–	–	–	–
Carinaria cithara Benson	–	–	–	–	–	–	1	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–
Carinaria cristata (Linné)	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Carinaria sp.	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pterosoma planum Lesson	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–
Pterotrachea coronata Forskål	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pterotrachea minuta Bonnevie	–	–	–	–	–	1	1	1	–	–	–	–	–	–	2	–	–	–	–	–	–	–
Pterotrachea scutata Gegenbauer	1	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pterotrachea sp.	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Unidentified neteropods	–	–	–	–	–	–	1	3	–	–	–	–	1	3	3	1	–	1	–	–	–	–

Table 2. Species with Numbers of Individuals Taken at Each Station (Continued)

Station Numbers	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203
Cephalopoda, Decapoda																						
Chiroteuthidae, juvenile	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cranchia scabra	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–
Unidentified cranchiids	–	–	–	–	–	–	1	–	–	–	2	1	–	2	1	–	–	2	–	–	–	–
Pterygioteuthis sp.	1	–	–	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Calliteuthis sp., juvenile	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Unidentified histioteuthid juvenile	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–
Ctemoptoryx sp., juvenile	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Unidentified squid, adult	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–
Unidentified squids, juveniles	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Cephalopoda, Octopoda																						
Amphitretus pelagicus Hoyle, adult	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Amphitretus pelagicus Hoyle, juveniles	–	–	2	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Amphitretidae, sp.	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–
Unident. larval & juvenile cephalopods	–	–	3	–	–	9	2	2	–	–	4	–	–	2	1	6	2	1	–	2	–	–
CRUSTACEA																						
Amphipoda																						
Scina	2	–	3	1	2	–	–	–	1	–	5	–	–	–	1	–	–	–	–	–	–	–
Cystosoma	–	–	1	1	–	–	2	–	1	1	–	1	–	–	–	–	–	–	–	2	6	2
Paraphronima	–	–	1	–	5	–	–	1	–	–	–	–	–	–	–	–	–	1	–	–	–	–
Phronima	10	1	3	4	3	9	9	3	1	1	1	1	–	–	7	4	–	10	5	3	2	–
Anchylomera	–	–	15	–	6	25	3	8	70	2	2	2	–	–	–	–	30	48	2	6	6	12
Euprimno?	–	–	–	–	–	–	–	–	–	–	1	3	–	–	–	–	–	–	–	–	–	–
Phrosina	–	–	1	–	3	3	2	2	–	1	1	–	1	–	1	1	–	4	1	7	–	1
Oxycephalus	–	–	–	2	1	–	–	–	–	–	1	–	–	–	2	1	–	–	1	1	–	–
Oxycephalidae	–	–	–	–	–	–	–	–	3	–	–	–	–	–	–	–	4	3	–	–	–	–
Cranocephalus	–	–	1	–	1	3	–	1	–	–	–	–	–	–	3	2	–	–	–	1	–	–
Rhabdosoma	2	1	1	–	1	1	3	1	–	–	–	–	–	–	2	4	64	57	1	1	–	4
Hyperiidae	–	–	–	–	–	–	–	2	3	–	–	1	2	–	–	3	–	–	–	–	–	–
Platyscelidae	–	–	–	6	2	10	8	8	1	5	2	1	1	–	6	1	12	25	7	3	4	8

Table 2. Species with Numbers of Individuals Taken at Each Station (Continued)

Station Numbers	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203
Vibilia	–	–	–	–	2	4	5	5	–	–	3	–	–	–	–	–	5	–	–	–	–	1
Gammaridae	1	–	–	1	–	–	1	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–
Unidentified amphipods	1	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3	–	–
Mysidacea																						
Siriella gracilis Dana	–	–	–	1	1	–	–	–	–	–	–	–	–	–	–	–	81	–	–	–	–	–
Siriella thompsoni Milne-Edwards	–	–	–	–	–	1	–	–	–	–	1	–	–	–	–	–	5	2	–	–	–	–
Gnathophausia sp.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3
Hoplocarida																						
Lysiosquilla larvae	2	1	1	5	–	1	–	–	–	–	3	1	–	–	–	–	5	1	5	3	2	4
Odontodactylus larvae	–	–	–	3	–	–	–	–	–	–	–	–	1	–	–	–	4	–	–	1	–	–
Pseudosqilla larvae	–	1	1	3	x	–	–	–	–	–	–	1	5	–	1	–	13	–	1	3	–	–
Squilla larvae	1	–	4	23	–	–	–	–	–	3	6	10	9	37	3	3	45	1	–	2	1	1
Euphausiacea																						
Thysanopoda sp.	44	26	47	72	66	1	219	50	131	33	142	128	254	3	132	490	601	17	–	–	56	37
Thysanoessa sp.	36	–	–	5	56	11	11	8	5	1	13	10	4	–	–	–	4	1	–	–	–	–
Stylocheiron, species s	–	6	1	6	–	117	9	37	89	5	179	70	26	47	61	247	275	40	173	37	8	13
Stylocheiron species L	2	–	6	–	10	–	–	5	–	–	3	5	1	–	3	7	–	–	–	–	–	–
Nematoscelis sp.	–	–	20	–	2	–	–	–	47	6	–	6	20	–	1	3	3	–	–	–	–	15
Nematobrachion sp.	–	–	–	–	19	–	3	2	1	3	2	5	3	–	–	4	2	13	–	–	4	1
Bentheuphausia sp.	–	2	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–
Unidentified euphausids	21	31	22	3	40	15	106	54	121	121	107	135	214	12	127	269	274	2	37	14	16	45
Decapoda, Penaeidea																						
Hemipenaeus crassipes (Wood-Mason)	–	–	20	–	18	–	–	7	22	–	–	25	46	–	–	–	–	–	–	–	–	44
Sergestes robustus Smith	13	–	6	–	13	–	–	26	24	5	159	23	–	4	47	88	14	–	–	–	–	19
Sergestes sp.	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Aristeus sp.	–	–	6	–	12	–	–	5	–	–	–	17	–	–	–	–	–	–	–	–	–	10
Eusicyonia carinata (Olivier)	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Acetes indicus (Dana)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–
Leucifer acestra (Dana)	–	–	4	2	3	1	–	22	1	5	–	–	6	57	15	–	62	136	403	29	49	27

Table 2. Species with Numbers of Individuals Taken at Each Station (Continued)

Station Numbers	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203
Decapoda, Caridea																						
Acanthephyra acutifrons Bate	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Acanthephyra indica Balss	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2
Acanthephyra quadrispinosa Kemp	–	–	6	–	6	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Acanthephyra smithi Kemp	–	–	–	–	6	–	–	5	2	5	–	6	–	–	–	–	–	–	–	–	–	–
Acanthephyra sanguinea Wood-Mason	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Oplophorus gracilirostris A. Milne-Edwards?	1	–	–	–	2	–	–	–	–	2	1	1	–	–	–	–	–	–	–	–	1	–
Oplophorus typus H. Milne Edwards	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Systellaspis cristata (Faxon)	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Eupasiphae gilesii Wood-Mason	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2
Heterocarpus ensifer A. Milne-Edwards	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–
Parapandalus zurstrasseni Balss	–	–	–	–	1	–	–	3	–	–	–	–	–	–	4	2	2	–	–	–	–	5
Thalassocaris lucida (Dana)	–	–	–	–	–	–	–	–	18	13	–	45	–	–	207	262	–	–	–	–	–	5
Unidentified decapod larvae	5	10	3	17	–	–	–	–	–	5	2	2	–	9	2	–	6	11	–	–	–	9
CHAETOGNATHA																						
Unidentified chaetognaths	5	56	156	87	186	106	78	22	340	1040	75	575	150	155	390	130	915	515	6	23	61	80
UROCHORDATA																						
Pyrosoma atlanticum Peron (colonies)	6	–	4	–	204	–	500	800	5	1	17	7	–	–	10	1	16	6	–	–	2	8
Dolioletta gegenbauri (Uljanin)	–	–	–	–	–	–	–	–	2	1	1	–	600	114	–	–	28	13	–	–	–	–
Metcalfina hexagona (Quoy & Gaimard)	–	–	–	–	–	–	–	14	–	–	–	–	–	–	–	–	3	–	–	–	–	–
Cyclosalpa virgula (Vogt)	–	–	–	–	–	50	–	–	–	–	–	–	–	–	–	5	10	–	31	2	11	–
Pegea confoederata (Forskal)	–	–	–	–	–	50	2	11	6	2	–	1	–	–	–	–	13	31	–	3	–	–
Iasis zonaria (Pallas)	23	5	7	17	32	–	16	57	34	27	–	–	–	2	3	–	38	–	–	–	–	–
Salpa fusiformis Cuvier	–	–	–	–	12	–	200	100	1	–	–	–	–	–	12	13	24	–	–	–	–	–
Thalia democratica (Forskal)	–	–	1	–	3	1	2	–	4	–	–	–	1000	132	–	2	–	–	–	1	–	1
young (*Pegea?*)	–	–	–	–	–	–	1000	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
FISHES																						
Argentinoidei																						
Bathylagus sp.	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Opisthoproctus soleatus Vaillant	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–

Table 2. Species with Numbers of Individuals Taken at Each Station (Continued)

Station Numbers	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203
Stomiatoidei																						
Vinciguerria nimbaria (Jordan & Williams)	1	–	1	2	1	–	1	–	1	–	4	1	6	–	23	45	1	–	–	–	–	1
Diplophos taenia Günther	1	–	–	–	3	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ichthyococcus ovatus (Cocco)	–	–	–	–	–	–	2	–	–	2	–	1	–	–	–	–	–	–	–	–	1	–
Gonostoma atlanticum Norman	1	–	–	–	–	–	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cyclothone alba Brauer	45	84	92	74	–	–	24	–	12	67	–	131	30	–	–	–	–	–	–	–	3	44
Cyclothone pallida Brauer	24	7	47	–	–	–	–	–	–	–	–	–	18	–	–	–	–	–	–	–	–	39
Cyclothone pseudopallida Mukhacheva	13	6	5	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	10
Cyclothone acclinidens Garman	6	–	44	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	10
Danaphos oculatus (Garman)	–	–	–	–	–	–	1	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–
Valenciennellus tripunctulatus (Esmark)	–	–	–	1	–	–	1	1	–	1	–	–	–	–	–	–	–	–	–	–	–	–
Gonostomatid larvae	–	–	–	–	–	–	6	–	–	–	2	–	–	–	–	7	7	–	–	–	–	–
Unidentifiable gonostomatids	9	2	–	–	1	–	–	1	–	2	–	2	–	–	7	–	–	–	–	–	–	1
Argyropelecus lychnus sladeni Regan	–	–	–	1	1	–	1	2	1	3	–	–	1	–	–	–	–	–	–	–	2	–
Argyropelecus hemigymnus Cocco	–	–	–	–	–	–	4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Argyropelecus affinis Garman	–	–	–	–	–	–	–	–	3	1	–	6	–	–	–	–	–	–	–	–	–	–
Unidentified *Argyropelecus*	–	2	–	3	–	–	1	–	–	3	–	–	1	–	–	–	–	–	–	–	–	–
Sternoptyx diaphana Hermann	–	–	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Unidentified sternoptychids	–	–	–	–	–	–	–	–	1	–	–	1	–	–	–	–	–	–	–	–	–	1
Chauliodus sloani Bloch & Schneider	–	–	–	–	1	–	–	1	1	1*	–	–	–	–	–	2	3	–	–	–	–	–
Chauliodus pammelas Alcock	–	–	–	–	–	–	–	–	–	1	2	3*	4	–	–	–	–	–	–	–	–	–
Stomias nebulosus Alcock	4	2	4	–	5	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Stomias affinis Günther	2	–	–	–	–	–	–	–	–	–	–	2	–	–	–	1	–	–	–	–	–	–
Unidentifiable *Stomias*	1	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	4
Idiacanthus fasciola Peters	1	–	2	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Astronesthes cyaneus (Brauer)	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Astronesthes indicus Brauer	1	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Melanostomias valdiviae Brauer	1	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Photonectes albipennis (Döderlein)	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Bathophilus pawneei Parr	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Table 2. Species with Numbers of Individuals Taken at Each Station (Continued)

Station Numbers	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203
Eustomias sp. (probably *bifilis* Gibbs) *Stylephorus*	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Alepocephaloidei																						
Holtbyrnia sp.	1	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Myctophoidei																						
Coccorella atrata (Alcock)	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–
Scopelarchoides ?	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Scopelosaurus sp.	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Hygophum (*proximum* Becker?)	1	–	–	–	–	–	–	–	–	–	12	–	–	–	–	–	–	–	–	–	–	–
Benthosema fibulatum (Gilbert & Cramer)	–	–	–	–	–	–	–	–	–	–	4	–	3	–	4	–	–	–	–	–	–	–
Benthosema suborbitale (Gilbert)	1	1	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Diogenichthys panurgus Bolin	–	–	1	–	–	–	–	1	–	–	8	1	–	–	1	3	3	–	–	–	–	–
Myctophum lychnobium Bolin	–	–	–	–	–	–	–	–	–	–	1	–	–	–	2	–	–	–	–	–	–	–
Myctophum spinosum (Steindachner)	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–
Myctophum nitidulum Garman	–	–	–	–	–	–	–	–	–	–	3	–	–	–	–	–	–	–	–	–	–	–
Myctophum asperum Richardson	–	–	–	–	–	–	–	–	–	–	–	1	–	–	1	–	–	–	–	–	–	–
Symbolophorus sp. (*evermanni* (Gilbert)?)	–	–	1	–	–	–	–	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Symbolophorus sp.	–	–	–	–	3	–	–	–	–	–	–	2	–	–	–	–	1	–	–	–	–	–
Centrobranchus nigro-ocellatus (Günther)	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Diaphus problematicus Parr	–	–	–	–	9	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Diaphus splendidus (Brauer)	–	–	–	–	–	–	–	1	–	–	–	–	–	–	1?	–	–	–	–	–	–	–
Diaphus garmani Gilbert	–	–	–	1	1	–	–	1	–	–	–	–	–	–	1	1	–	–	–	–	–	–
Diaphus lucidus Goode & Bean	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Diaphus regani Tåning	–	–	–	–	–	–	–	–	2	1	7	1	–	–	2	2	–	–	–	–	–	1
Diaphus jenseni Tåning	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Diaphus elucens Brauer	1	1	–	–	1	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–
Diaphus termophilus Tåning	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Diaphus parri Tåning	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	6	–	–	–	–	–	–
Diaphus (*mollis* Tåning?)	–	4	–	–	1	–	–	–	–	4	8	1	5	–	6	–	–	–	–	–	–	–
Diaphus kendalli Fowler	–	–	–	–	–	–	1	–	2	1	–	3	–	–	–	–	–	–	–	–	1	–
Diaphus richardsoni Tåning	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Table 2. Species with Numbers of Individuals Taken at Each Station (Continued)

Station Numbers	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203
Diaphus lutkeni Brauer	–	–	1	–	7	–	–	–	–	2	5	1	–	–	27	24	–	–	–	–	–	–
Diaphus glandulifer	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–
Diaphus fragilis	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Unidentifiable *Diaphus*	1	–	1	–	1	–	1	–	1	5	–	–	3	–	–	4	1	–	–	–	–	1
Lobianchia gemellari (Cocco)	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Notolychnus valdiviae (Brauer)	–	–	1	5	11	–	16	–	–	–	7	7	3	–	39	80	–	–	–	–	–	6
Lampadena sp.	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lampanyctus macropterus Brauer	–	–	–	–	–	–	1	–	–	–	5	–	–	–	2	–	–	–	–	–	–	9
Lampanyctus nigrescens Brauer	3	–	–	–	4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lampanyctus nobilis Tåning	–	–	4	–	–	–	–	–	1?	–	4	2	–	–	1	5	–	–	–	–	–	–
Lampanyctus niger Günther	1	1	–	–	–	–	–	3	–	–	–	1	–	–	–	–	–	–	–	–	–	4
Lampanyctus alatus Goode & Bean	4	–	3	–	11	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lampanyctus australis Tåning	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Unidentifiable *Lampanyctus*	–	–	–	–	–	–	–	–	–	–	–	3	–	–	–	–	–	–	–	–	–	1
Lepidophanes pyrsobolus Alcock	–	–	–	–	1	–	–	–	–	–	1	–	–	–	–	1	5	–	–	–	–	–
Ceratoscopelus warmingi (Lütken)	–	–	–	–	–	–	–	–	1	–	1	–	–	–	5	7	3	–	–	–	–	–
Unidentifiable *myctophids*	1?	4	2	–	5	–	2	8	5	–	–	12	–	–	2	–	1	–	–	–	–	3
Giganturoidei																						
Bathyleptus indicus (Brauer)	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Stephanoberycoidei																						
Poromitra megalops (Lütken)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Scopeloberyx robustus (Günther) "dwarf"	–	–	–	–	3	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–
Scopelogadus m. mizolepis (Günther)	–	–	–	–	–	–	–	–	1	–	–	2	–	–	–	–	–	–	–	–	–	2
Berycoidei																						
Diretmus argenteus Johnson	–	–	2	3	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Percoidei																						
Howella brodiei Ogilby	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Ceratioidei																						
Cryptopsaras couesi Gill	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–
Gadoidei																						
Bregmaceros macclellandii Thompson	–	–	–	–	–	–	–	–	–	–	4	3	–	–	–	–	–	–	–	–	–	–
Bregmaceros rarisquamosus Munro	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–

Table 2. Species with Numbers of Individuals Taken at Each Station (Continued)

Station Numbers	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203
Anguilloidei																						
Cyema atrum Günther	–	–	–	–	–	1	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Serrivomer sector Garman	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–
Nemichthys sp.	–	–	–	–	–	–	1	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–
Leptocephalus mirabilis Brauer	–	–	–	–	–	–	–	–	–	–	1?	–	–	–	–	–	–	–	–	1	1	–
Unidentified leptocephali	1	–	–	1	1	–	–	–	–	1	–	1	1	–	5	3	–	–	–	1	–	–
Muraenidae ?, leptocephali	–	–	–	–	–	–	–	–	–	–	1	2	–	–	1	–	–	–	1	–	1	–
Myctophid larvae	–	–	–	–	–	–	–	–	–	–	–	–	–	–	5	–	–	–	–	–	–	–
Stomiatoid larvae	–	–	–	–	–	–	–	–	6	–	–	–	–	–	–	–	–	–	–	–	–	–
Flatfish larvae	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Other, larvae & juveniles	4	4	5	8	6	16	2	14	12	14	77	14	33	14	14	51	47	16	8	4	5	2

Lampanyctus niger, *Lampanyctus macropterus*, *Lepidophanes pyrsobolus*,[4] *Hygophum proximum*,[5] and *Diogenichthys panurgus* (Bolin, 1959; Fraser-Brunner, 1949). On the other hand, we took *Sternoptyx diaphana* (Schultz, 1961) only once and *Ceratoscopelus warmingi* (Bolin, 1959; Nafpaktitis and Nafpaktitis, 1969) only a few times in the northeast equatorial Indian Ocean. Since neither species is uncommon and both are circumglobal in distribution, it appears that our results do not reflect the actual distributions of all midwater fish species; presumably the same may be said of invertebrates.

In some cases, our horizontal distribution data may be explained by the differential depths of hauls. For example, the four members of the genus *Cyclothone* taken by us certainly occur at more localities than indicated by Table 2. Known depth distributions for the four species indicate that *Cyclothone alba* is the shallowest of the four in vertical distribution, followed by *C. pseudopallida*, then by *C. acclinidens*, with the deepest being *C. pallida* (personal communication, B. N. Kobayashi). Thus, nets that did not fish deeper than 250 to 300 m during the daytime did not catch *Cyclothone alba*, and nets generally had to reach about 400-m depths to catch the other three species. Although diel migrations are described for the genus *Cyclothone* (Grey, 1964), the four species we encountered were never taken in the upper 200 m, either day or night.

Lack of nighttime collections in the southwestern Indian Ocean (Fig. 2) probably accounts for the absence from hauls 182 to 189 of such a common lanternfish as *Ceratoscopelus warmingi*. The large proportion of deep daytime hauls in that area, however, probably accounts for our having netted more organisms with deep daytime distributions from the southwestern equatorial Indian Ocean than from the northeastern portion.

VERTICAL DISTRIBUTION, MIGRATION, AND RELATIONSHIP OF ANIMALS TO THE DSL[6]

Because neither closing nets nor depth recorders were employed in the sampling program during the cruise, results of analyses for vertical distributions are fairly crude estimates. Nevertheless, our methods did show diel changes in vertical distributions of some species that suggest relationship with the main DSL.

To make analyses of vertical distributions, a basic diagram was drawn up that showed a generalized main DSL and combined layer such as reproduced in Figures 12 to 16, with a vertical scale in meters that relates to the scattering pattern. For the sake of simplicity, all other scattering features are omitted. The effective fishing range for each haul (vertical stippled bars) was superimposed on the scattering pattern, but the top and/or bottom of each bar was adjusted to the generalized DSL pattern rather than to the depth scale, as follows. For hauls taken below the main DSL or combined layer (Sta. 182, 183, 184, 189, 190, 193, 203), the effective fishing range was adjusted upward or downward so that for each haul the distance between the top of the effective fishing range and the bottom of the main DSL or combined layer was the same as prevailed at the time the haul was actually taken. (See Table 1 or Fig. 2 for actual effective fishing

[4] Although we identified our material soon after the cruise was finished as *Lepidophanes pyrsobolus*, a recent paper by Nafpaktitis and Nafpaktitis (1969) shows that one more species of this genus occurs in the area we had sampled than we had considered; our material will have to be re-examined in the light of their work.

[5] Bolin (1959) indicated that *Hygophum reinhardti* is a name that should be used to designate an Atlantic population but did not name the Indian Ocean populations of this genus. The recent work of Nafpaktitis and Nafpaktitis (1969) indicates that our material may represent *Hygophum proximum* Becker.

[6] Only the following groups are included in this discussion: siphonophores, gastropods, euphausiids, penaeids, carideans, tunicates, and fishes.

ranges.) For hauls taken in the main DSL (Sta. 185, 188, 191, 194, 202), the effective fishing range was adjusted so that the top and bottom of the fishing range bore the same relationship to the top and bottom of the main DSL as actually prevailed at the time the haul was taken. For hauls taken between the bottom of the surface layer and the top of the main DSL (Sta. 187, 195, 201), the top and bottom of the effective fishing range were adjusted to conform to the actual distances from the bottom of the surface layer and the top of the main DSL, respectively, that prevailed at the time the hauls were made. For hauls taken in the daytime surface layer or nighttime combined layer (Sta. 192, 196, 197, 198, 199, 200), the bottom of the effective fishing range was adjusted to be the same distance above the bottom of the surface layer or combined layer as actually prevailed when the haul was made. Haul 186 required considerable adjustment to fit the generalized scattering diagram; it was clearly made in the combined layer (Fig. 4), but the combined layer extended downward unusually far that day (23 November). For the purposes of the generalized diagram, the effective fishing range was adjusted upward so its lower limit coincided with the bottom of the combined layer on the diagram.

With the diagram prepared as described above, a graph was prepared for every species, showing the number of specimens for every haul in which the species was taken. The results of graphing were best for species that were taken at one half or more of the localities and in relatively large numbers and suggested the following distribution patterns relative to the main DSL.

1. Species taken primarily at main DSL depths and below in the daytime, and in the combined layer at night.
2. Species taken primarily below the main DSL in daytime, and in the combined layer at night.
3. Species taken primarily at main DSL depths and below both day and night.
4. Species taken from below the main DSL in daytime and below the combined layer at night.
5. Species taken primarily above 200 m day and night.
6. Species taken primarily above 500 m day and night.

Species taken primarily at main DSL depths and below in the daytime, and in the combined layer at night. Figure 12a shows three species that were taken in large numbers during the cruise; *Ablyopsis tetragona* (a siphonophore), *Cymbulia* sp. (a pteropod), and *Thysanopoda* sp. (a euphausiid). There is a dramatic difference between the number of these organisms taken from the combined layer at night and those taken in the surface layer in daytime, with many fewer taken in the surface layer in daytime. The largest numbers in the daytime catches were from the main DSL, although all three species were taken in hauls below the main DSL. No hauls were made below 500 m at night, so we have no information about the distribution of these forms below 500 m at night, but our data suggest that these three species have wide bathymetric ranges in daytime, from 300 m to about 1000 m, with their centers of distribution in the main DSL (except for *Cymbulia* sp., a total of 90 once being taken in a haul that fished above the main DSL). At night, their distribution is heavily centered above 100 m. The pattern indicates that these animals migrate toward the surface at night and return to depths during the daytime; they may be among the organisms chiefly responsible for sound scattering at main DSL and DSL curtain depths.

Although taken in fewer numbers, three additional species show a similar distribution pattern; these three are *Nematobrachion* sp. (a euphausiid), *Vinciguerria nimbaria* (a stomiatoid fish), and *Notolychnus valdiviae* (a myctophid fish), Figure 12b. Of these, none were taken from layers

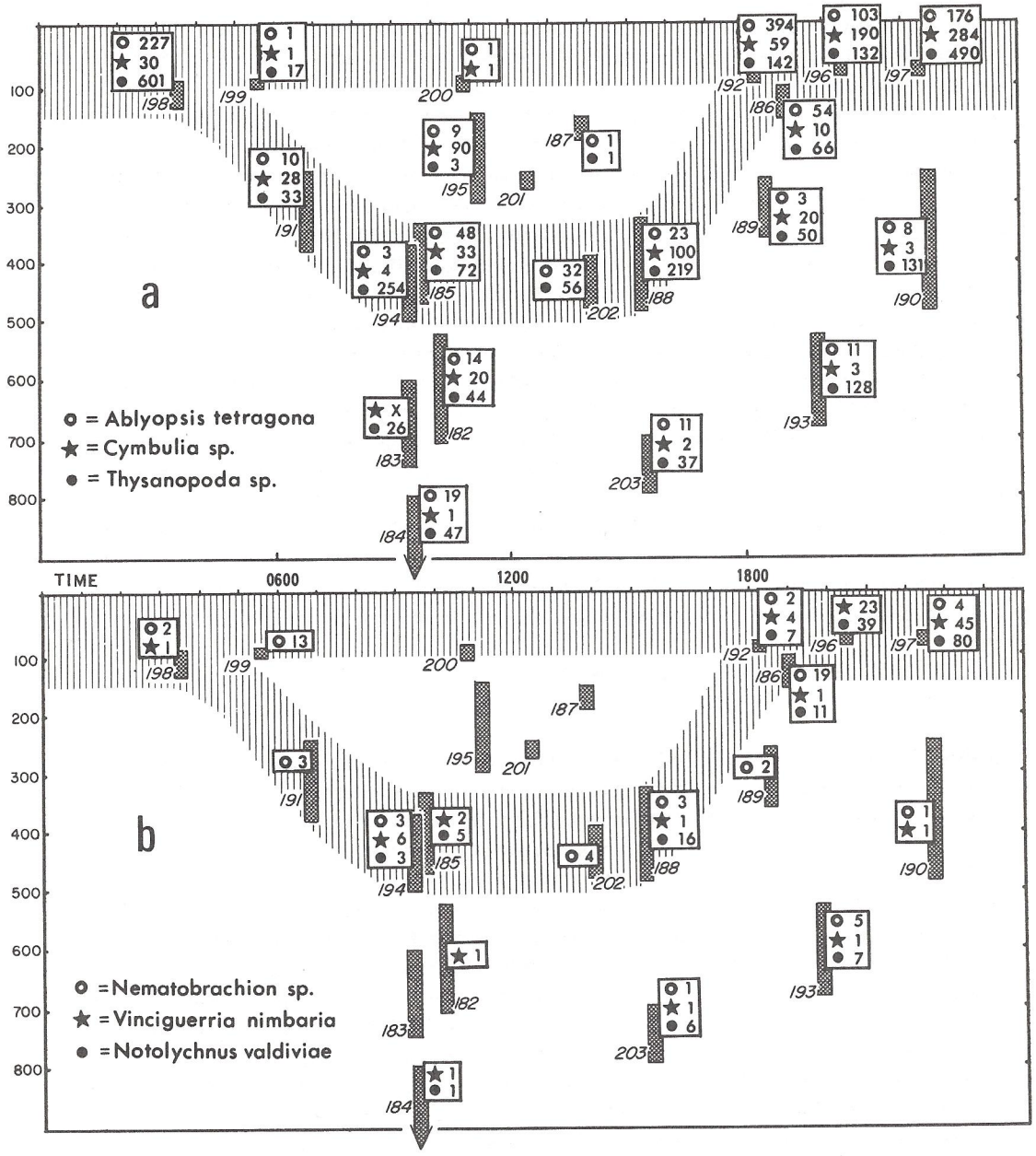

Figure 12. Six species taken primarily at main DSL depths and below in daytime and in the combined layer at night. Numbers of individuals are given beside symbols for each species.

above the main DSL in daytime, although all were taken above 100 m at night. None show special affinity for the main DSL, although all were taken in it in at least three of the five hauls made in the main DSL.

It is possible that at least some of the fishes can avoid slowly moving nets in lighted shallower waters in daytime. Pearcy and Laurs (1966) have analyzed vertical distributions of four dominant mesopelagic fish species in the eastern Pacific off Oregon. They found that the largest catches in daytime were made in the 150 to 500 m (intermediate) range, but at night the largest catches were made in the 0 to 150 m (surface) range. However, they found that the increase from day to night in fishes per unit volume in the surface range was always greater than the increase from night to day in the intermediate range. In other words, if migrations were really taking place and fishes were retiring to the intermediate range in daytime, one might expect that the numbers of fishes captured in the intermediate range in daytime would represent about the same increase over nighttime captures in the intermediate range as occurs in reverse at the surface, where the numbers of fishes captured in the surface range at night were greater than in daytime; in fact, results showed that fewer fishes were taken in the intermediate range in daytime than could probably be accounted for by the migration hypothesis. Pearcy and Laurs (1966) reasoned that the difference might result from net avoidance by fishes in the upper 500 m in daytime, and they estimated that diel differences in catches probably were in part the effect of net avoidance for three of the four species with which they worked. Their chief criterion for showing vertical migration, therefore, would be the diel differences in catches in the intermediate range while allowing for net avoidance rather than diel differences in the surface range. Our data for *Vinciguerria nimbaria* and *Notolychnus valdiviae* are meager and our localities were widely separated, but the two species of fishes were taken in larger numbers below 250 m in daytime than they were from below 250 m at night (Fig. 12b), suggesting they do in fact disappear from below 250 m at night by migrating up. The increase from day to night of numbers taken in the upper 250 m is so much greater than is the increase from night to day below 250 m that net avoidance may be involved.

During Cruise 6 of the R/V *Anton Brunn* in the Indian Ocean, collections of *Notolychnus valdiviae* at stations closest to the equator (Sta. 333B, 337A, and 342A) show that the species was present in hauls made from the surface to 250 to 400 m at night but not in deeper hauls made at the same localities on the same nights (Nafpaktitis and Nafpaktitis, 1969), showing some agreement with our data. Both *Vinciguerria nimbaria* and *Notolychnus valdiviae* have been previously thought to make diel vertical migrations (Marshall, 1960). In fact, like many other myctophids, *Notolychnus valdiviae* has been taken at the very surface at night by dip-netting (Beebe and Vander Pyl, 1944). However, *Vinciguerria nimbaria,* although frequently taken in the upper several hundred meters at night, is not taken at the very surface; moreover, smaller specimens, not adults, are generally recorded as being taken in upper layers at night (Marshall, 1960, p. 88), a generalization that is made for numerous stomiatoids (Morrow, 1964a). Thus, it will probably eventually be necessary to define vertical migration patterns for young stages separately from those for adults, as has been the case for some pelagic crustaceans such as *Euphausia pacifica* in Monterey Bay, California (Barham, 1957). Both *Vinciguerria nimbaria* and *Notolychnus valdiviae* have gas-filled swimbladders that would serve as scattering targets (Marshall, 1960), so both species may be implicated as contributing to scattering in the main DSL.

Additionally, although they were not taken frequently or in large numbers, there were one pteropod, two crustaceans, and four fishes with vertical distribution patterns that suggested that they, too, normally inhabit depths in or below the main DSL in daytime and migrate upwards at night. These are *Euclio pyramidata* (a pteropod), *Nematoscelis* sp. (a euphausiid), *Oplophorus gracilirostris* (a caridean), *Diaphus mollis* and *Benthosema fibulatum* (myctophid fishes), and

Chauliodus pammelas and *Chauliodus sloani* (stomiatoid fishes) (Table 2). We captured the pteropod *Euclio pyramidata* only in the western Indian Ocean, where it occurred in all three hauls below the main DSL in morning (182 to 184) and in the main DSL in afternoon (188); because no hauls were made in the upper 100 m at night in the western Indian Ocean, it is impossible to tell whether this form occurs there at night, but its presence in hauls 186 (above 240 m) and 189 (above 375 m) just after dark suggests that it moves near the surface at night. We took 11 specimens of *Benthosema fibulatum,* but as its range is restricted to the northern Indian Ocean north of about 4°N (Nafpaktitis and Nafpaktitis, 1969), we may say that we captured it at 3 out of a possible 7 localities, once in the main DSL in daytime and twice in the upper 100 m at night. Similarly, *Chauliodus pammelas* has a northerly distribution (Gibbs and Hurwitz, 1967) and was taken by us at 3 out of a possible 7 localities; of a total of 10 specimens,[7] 5 were taken in the main DSL, 2 in the upper 100 m at night, and 3 below 500 m at night. Species of *Chauliodus* are all thought to perform extensive diel vertical migrations, with the distributions of adults centered at greater depths than those of juveniles (Morrow, 1964b). They do not have swimbladders (Marshall, 1960), and it is doubtful that they are sound-scattering targets. Data for *Diaphus mollis* shows that the form was taken at 7 localities, 13 specimens from 3 hauls in and below the main DSL, 15 specimens from 3 hauls above 240 m at night, and 1 specimen in a haul below 450 m at night, indicating that it is a vertical migrator. Unfortunately, we did not check the swimbladder of this form, but it has apparently never been recorded as lacking a swimbladder and may be hypothesized as contributing to sound scattering.

Species taken primarily below the main DSL in daytime and in the combined layer at night. Vertical distributions for the following species are shown in Figure 13a and b: *Stylocheiron* sp. L (a euphausiid), *Sergestes robustus* (a penaeid), *Thalassocaris lucida* (a caridean), and the fishes *Diogenichthys panurgus, Diaphus regani,* and *Diaphus lutkeni* (all myctophids). These species almost never occurred in hauls through the main DSL save for haul 191, which was made shortly after sunrise while the main DSL was descending. Thus, while these species probably are migrators, they probably are not constituents of the main DSL. All six species were taken in largest numbers at night in the combined layer. The crustaceans were all taken in larger numbers between 265 and 600 m at night than they were in daytime, suggesting that either they avoid the net at these intermediate depths in daytime, or their daytime center of distribution is below these intermediate depths in daytime. Data for the fishes are equivocal, as samples are few and small.

The vertical distributions of three other species resemble the above distributions. These species are *Parapandalus zurstrasseni* (a caridean), *Stomias nebulosus* (a stomiatoid fish), and *Lampanyctus nobilis* (a myctophid fish) (Table 2). *Stomias nebulosus* was taken once above 240 m (haul 186) and once above 375 m (haul 189) at night but not in the upper 100 m at night, a finding that agrees with the known distribution, for, although small specimens of other species of *Stomias* frequently have been taken in surface waters at night, *Stomias nebulosus* has not (Marshall, 1960). The species, like others of its family, lacks a swimbladder, so perhaps may be discounted as a sound-scattering target.

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[7] The total may have been slightly higher, because the record for one station is incomplete for this species.

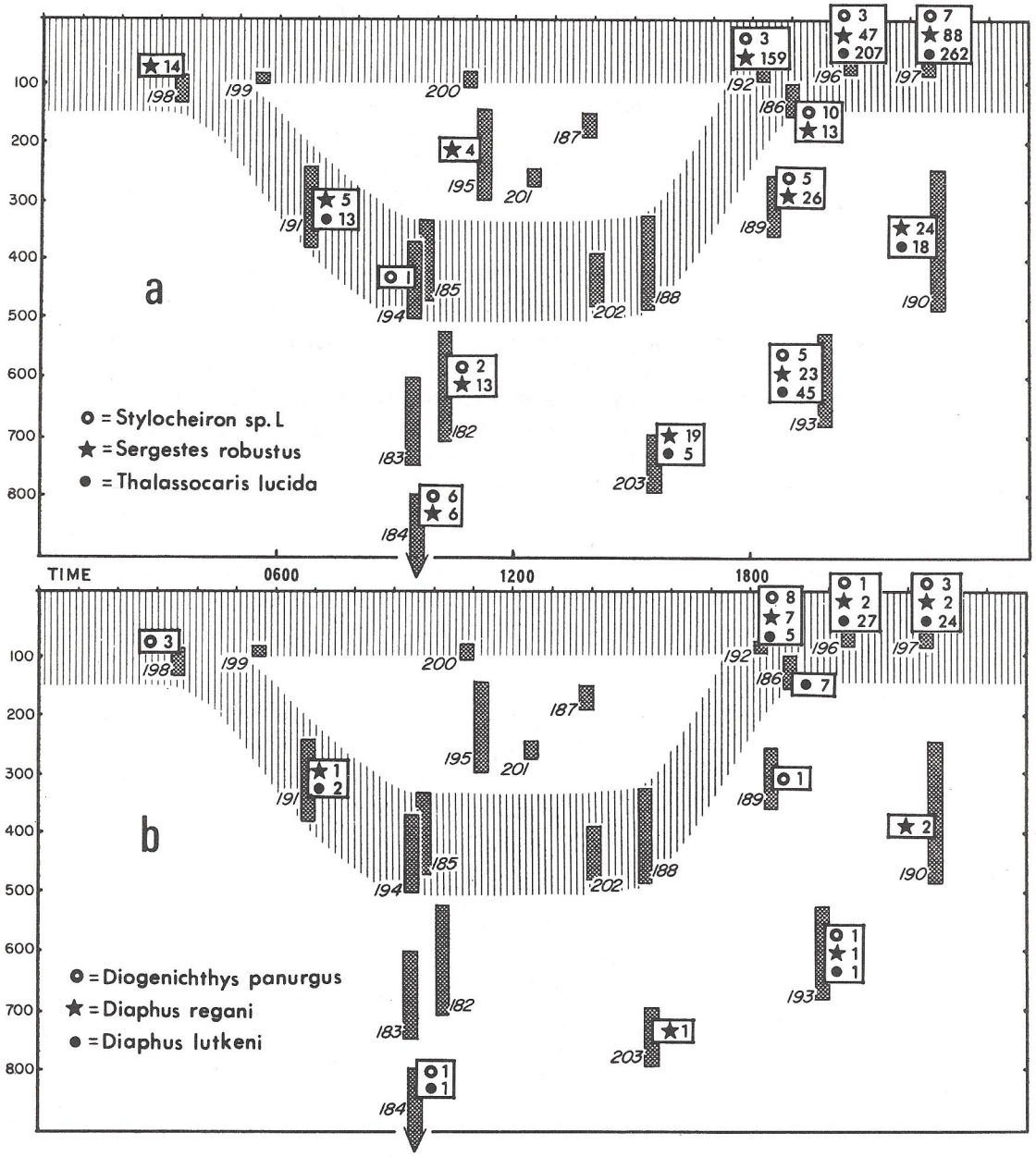

Figure 13. Six species taken primarily below the main DSL in daytime and in the combined layer at night. Numbers of individuals are given beside symbols for each species.

Species taken primarily at main DSL depths and below both night and day. The vertical distributions of two stomiatoid fishes that were nearly always taken below 275 m, day and night, are shown in Figure 14a. Of the two, *Cyclothone alba* had the greater depth range, occurring in all hauls in which the net fished below 300 m except haul 189. Species of *Cyclothone* have been known to undergo vertical migrations, but Grey (1964, p. 187) writes, "The vertical distribution of these fishes is complicated, as some undergo daily vertical migrations during at least part of their lives, they inhabit shallower depths in cold seas than in tropical and temperate waters, and older specimens live in deeper water." Our data do not show a pattern of migration. Depth distributions of species of *Cyclothone* are known to be stratified in some localities (Grey, 1964; B. N. Kobayashi, personal communication), with the pale-colored *C. alba* having a shallow distribution; of the species of *Cyclothone* we captured, *C. alba* had the shallowest range and was the only species of *Cyclothone* to occur in the main DSL. Swimbladders are present in adults of *Cyclothone*, although regressed in size from the premetamorphosis size (Marshall, 1960). Because so many specimens of *Cyclothone alba* were taken during Cruise 5 at depths from which no sound scattering was recorded, it is doubtful that this form contributes to strong sound scattering in the main DSL even though a substantial portion of the population occurs there in daytime.

Members of the stomiatoid genus *Argyropelecus* have been called partial migrators by Marshall (1960, p. 88), meaning that nighttime populations are centered higher than daytime populations, but the nighttime distribution does not reach much above 150 m. Our data for *Argyropelecus lychnus sladeni* agree with those observations. However, although previous records indicate that the species has been taken below 600 m in the Indian Ocean (Schultz, 1961), none of our specimens were taken below that depth. In fact, of a total of 23 specimens belonging to at least three species of *Argyropelecus* (Table 2), 21 were taken in the main DSL. All of the 13 taken at night were captured between 150 and 600 m. These forms have gas-filled swimbladders (Marshall, 1960) and are probably sound scatterers.

Like *Argyropelecus,* two other stomiatoids, *Valenciennellus tripunctulatus* and *Ichthyococcus ovatus,* and the myctophid *Diaphus kendalli* were taken only in the main DSL in daytime, although the data for these forms are extremely meagre (Table 2). *Diaphus kendalli* may be one of the exceptions to the generalization that most myctophids make extensive vertical migrations to the surface at night, for we never took this form in the hauls in shallow depths at night in which myctophids were normally relatively numerous.

Species taken from below the main DSL in daytime and below the combined layer at night. In general, hauls at depths below scattering features were not as productive as hauls in shallower depths, so that distribution patterns of the animals there are not so easily discernible. Six species were taken by us in sufficient numbers to suggest patterns; these were *Hemipenaeus crassipes* and *Aristeus* sp. (penaeids), *Lampanyctus niger* (a myctophid fish), and *Cyclothone pallida, C. pseudopallida,* and *C. acclinidens* (stomiatoid fishes). Vertical distributions for the two penaeids (Fig. 14b) show their daytime distributions to be well below the main DSL. Nighttime hauls show these forms present from below 100 m to 500 or 600 m, suggesting that they migrate up at night but stop short of the upper 100 m. Previous authors have suggested that vertical migrators that cease their upward migration below the surface mixed layer are stopped by the thermocline (Marshall, 1960), a possible explanation for our data, because the region of the thermocline during Cruise 5 was 30 to 120 m (Fig. 3). The myctophid *Lampanyctus niger* may fall into this category (Table 2), as may the migrators mentioned previously as not having occurred in the upper 100 m, such as *Stomias nebulosus, Argyropelecus* spp., *Diaphus kendalli,* etc.

Three species of *Cyclothone, C. pallida, C. pseudopallida,* and *C. acclinidens* (Table 2), were regularly taken below the main DSL in daytime except for *C. pallida,* which was once taken in

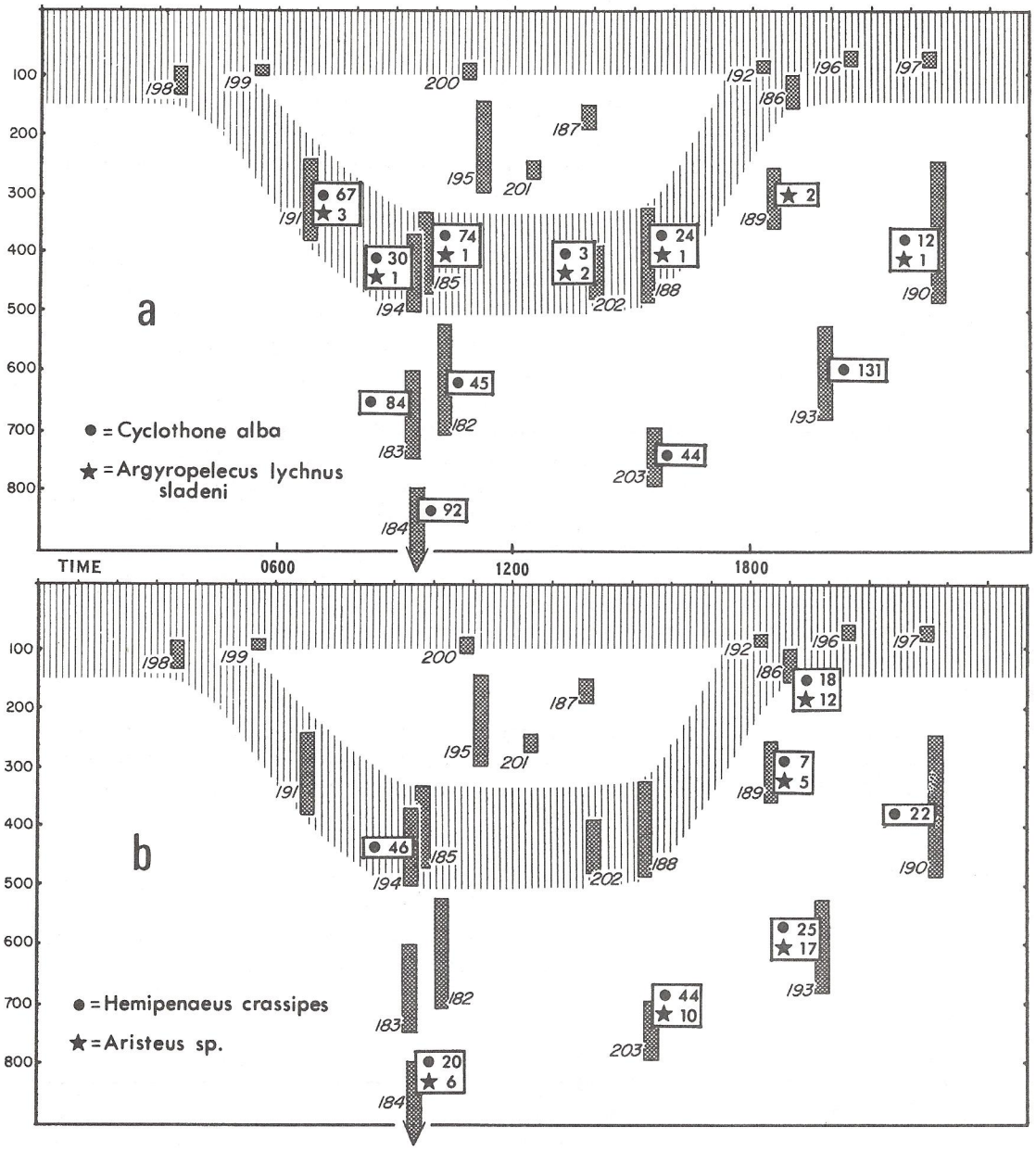

Figure 14. (a) Two species taken primarily at main DSL depths and below both night and day. (b) two species taken from below the main DSL in daytime and below the combined layer at night. Numbers of individuals are given beside symbols for each species.

the main DSL (haul 194). Their absence from depths above 600 m at night indicates that none of them make extensive vertical migrations in this range (it is possible, of course, that they perform migrations below these depths).

Species taken primarily above 200 m day and night. The vertical distributions for two crustaceans whose center of distribution was in surface layers day and night are shown in Figure 15; these are *Stylocheiron* sp. s (a euphausiid) and *Leucifer acestra* (a penaeid). Both were taken in the main DSL and below in daytime, but generally not in numbers as great as were taken nearer the surface. Heteropods of the genus *Atlanta* (our collections probably consisted of more than one species) had similar concentrations near the surface (data for *Atlanta* given in Table 2); their vertical distribution varied somewhat from those of the crustaceans in that they were absent (with one exception) from depths below the main DSL. The distributions for the crustaceans and heteropods indicate that they may be involved as agents of sound scattering at the surface and daytime intermediate layers but that they are probably not involved in the diel changes in the main DSL.

Species taken primarily above 500 m day and night. A pteropod and a number of siphonophores and tunicates were widely distributed throughout the upper 500 m day and night; none appeared to have any affinity for the main DSL, although they sometimes were captured in hauls through it. The siphonophore *Diphyes dispar* did not appear in hauls below about 150 m at night (Figure 16a). This fact suggested that it congregates near the surface at night. Another siphonophore, *Diphyes bojani*, and the tunicate *Cyclosalpa virgula* may have a similar distribution pattern (Figure 16a), but we took them in fewer hauls and the picture for them is unclear. Two other forms, the pteropod *Cavolinia longirostris* and the siphonophore *Agalma okeni* (Figure 16b), had distributions showing their tendency to leave the upper 100 m in daytime; that is, they

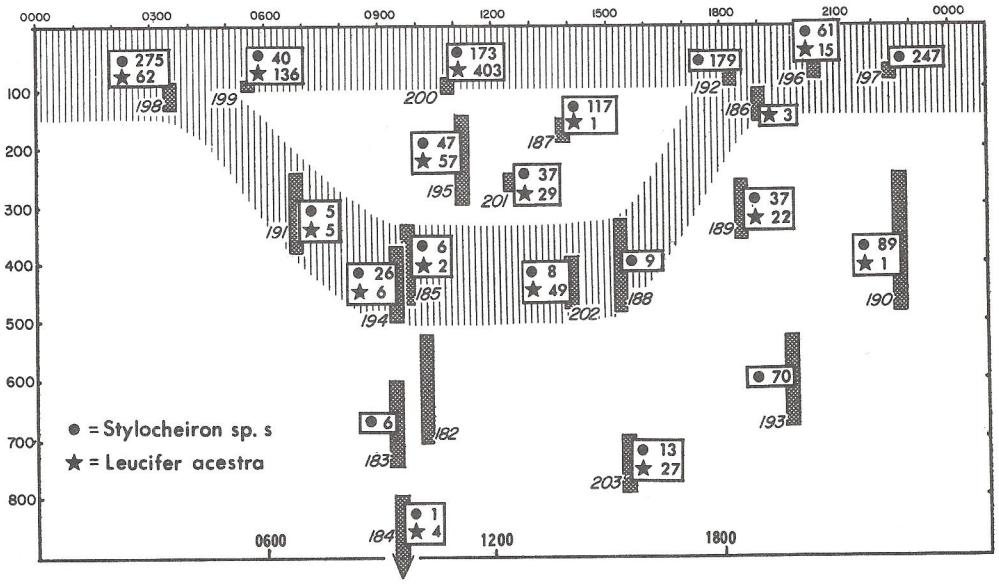

Figure 15. Two species taken primarily above 200 m day and night. Numbers of individuals are given beside symbols for each species.

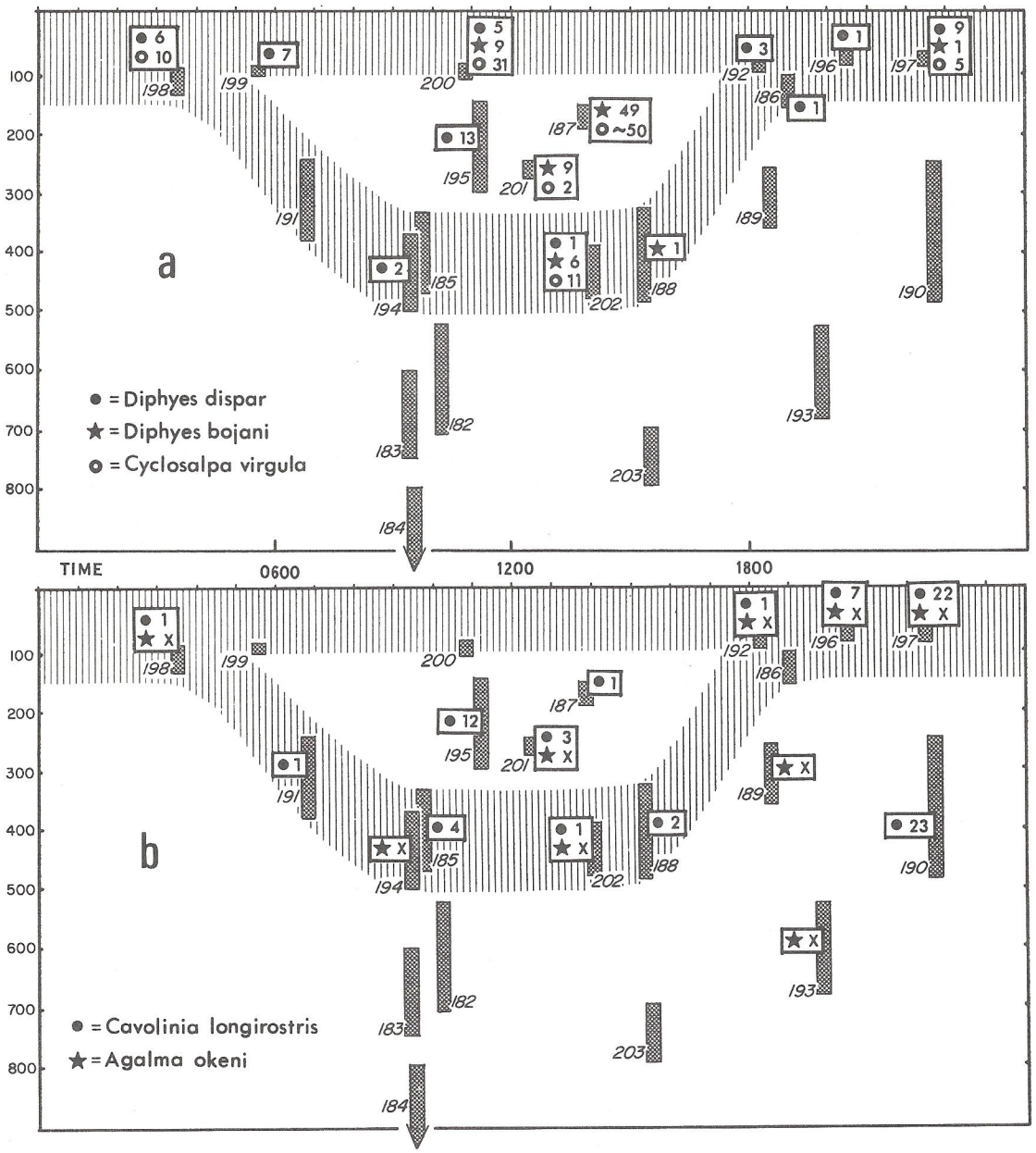

Figure 16. Five species taken primarily above 500 m day and night. Numbers of individuals are given beside symbols for each species except *Agalma okeni*, which is scored as present or absent in hauls by the presence or absence of the symbol X.

occurred in haul 198 (75 to 120 m) before daybreak but not in haul 199 (75 to 90 m) just after daybreak on the same day, and they occurred in hauls 201 and 202 (225 to 475 m) but not in haul 200 (80 to 85 m) earlier the same day.

Three tunicates were taken above 500 m night and day, but their distributions show no special patterns: they are *Salpa fusiformis, Pegea confoederata,* and *Dolioletta gegenbauri* (Table 2).

By this method of analysis, we are left with a number of invertebrates that occurred variously in moderate to large numbers from the surface to below 700 m, some of which were patchy in distribution but none of which show any particular affinities for any particular depths. These were the siphonophores *Abyla trigona, Hippopodius hippopus, Chelophyes appendiculata, Chelophyes contorta,* and *Eudoxoides mitra;* the pteropods *Diacria quadridentata* (two subspecies) and *Creseis* sp.; the euphausiid *Thysanoessa* sp.; and the tunicates *Thalia democratica, Iasis zonaria,* and *Pyrosoma atlanticum* (Table 2).

The pitfalls of plotting distributions and making inferences from them about dynamics of population movements probably are numerous, but the following example is especially instructive. Nafpaktitis and Nafpaktitis (1969) report that the myctophid fish *Ceratoscopelus warmingi* has a broad distribution from the Atlantic Ocean through the Indian Ocean, probably to the South Pacific; they write concerning collections from *Anton Brunn* Cruises 3 and 6 in the western Indian Ocean, "*C. warmingi* seems to be common in the Indian Ocean. The 386 specimens were taken almost uninterruptedly from about 12°N to 44°S." Yet during *Te Vega* Cruise 5, this species was taken only at four localities (Table 2), none of which were in the western Indian Ocean. Also, the species was taken only in nighttime hauls during *Te Vega* Cruise 5, with 16 of the 17 specimens taken in hauls from 0 to 120 m, but *Anton Brunn* Cruises 3 and 6 took the species in daytime in 15 hauls that sampled the upper 1000 m. (Of a total of 80 *Anton Brunn* hauls that captured *C. warmingi,* 15 were made during daylight hours and 38 during the night, while 27 could not be scored as either day or night hauls; the latter hauls were evidently made partly by day and partly by night in at least some cases.) Thus it is plain that our data are insufficient to show the relationship of *Ceratoscopelus warmingi* to the main DSL, even though other workers have found the fish to be common in the Indian Ocean and have taken it at various depths. The same is undoubtedly true for other species we attempted to treat, but the case of *C. warmingi* is especially provocative because schools of one of its congeners, *C. maderensis,* were recently identified with a deep scattering layer composed of discrete hyperbolic echo sequences off the continental slope of the northeastern United States (Backus et al., 1968).

To summarize, for the species for which we could discern migration patterns, there were six that appear to perform extensive migrations and one that is a partial migrator, any or all of which may be important sound scatterers in the main DSL in the equatorial Indian Ocean in October and November. Best evidence for association with the main DSL was obtained for *Ablyopsis tetragona* (a siphonophore), *Cymbulia* sp. (a pteropod), and *Thysanopoda* sp. (a euphausiid). Lesser evidence was obtained for *Nematobrachion* sp. (a euphausiid), *Vinciguerria nimbaria* (a stomiatoid fish), *Notolychnus valdiviae* (a myctophid fish), and the partial migrator *Argyropelecus lychnus sladeni* (a stomiatoid fish).

NOTES ON FOOD RELATIONSHIPS

Although time and facilities did not permit an extensive study of food relationships among organisms occurring in the vicinity of the DSL, qualitative examinations of stomach contents were made on selected species. For some of these species it was possible to examine specimens collected at several different times of day and night. Several prominent species were never taken

with recognizable food remains in the gut, a situation not uncommonly encountered among zooplankton (Raymont, 1963, p. 502). Our methods did not permit decisions as to whether this might be the result of regurgitation upon capture or preservation; rapid digestion and elimination; ingestion only of soft parts or soft-bodied organisms; feeding on organic matter in the form of fine detritus, organic aggregates, or dissolved organic matter (Riley, 1963); or other factors. Fragmentary as our data are, they are deemed worth tabulating in view of the lack of detailed information on the food habits of most zooplankters (Raymont, 1963).

In Table 3, the feeders (left hand margin) and the foods found in their stomachs (top) are arranged in such an order that the herbivores and microphagous feeders are grouped in the upper part of the table, omnivores fall near the middle, and carnivores are clustered in the lower part. A number of forms were noted in which the stomachs contained both microscopic and macroscopic foods. In some cases, both may have been selectively ingested. In other cases, such as the euphausiids *Stylocheiron* and *Thysanopoda,* the caridean shrimp *Acanthephyra,* and perhaps the penaeid prawns (see Hall, 1962), some of the microscopic forms reported in the gut may represent organisms that were present in the stomachs of ingested animals.

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SUMMARY

Twenty-two stations were occupied at 14 localities in the equatorial Indian Ocean between Mombasa, Kenya, and the Nicobar Islands to secure organisms from deep scattering layers (DSL) and vicinity by midwater trawling and to determine the behavior of the DSL by echogram analysis.

Prominent scattering features of the equatorial Indian Ocean are described and named. Main layers observed were (1) a daytime *surface layer* (outgoing signal plus any surface scattering) in the top 60 to 150 m; (2) a daytime *main DSL,* 50 m or more thick, sometimes recorded as a double layer, with a top at 300 to 350 m; (3) a daytime *intermediate layer,* not always present, centering at about 200 m; and (4) a nighttime *combined layer* in the upper 150 to 250 m,

Table 3. Gut Contents of Selected Animals

Pelagic animals analyzed for gut contents	Number containing food	Number examined	Unicellular Algae	Filamentous Algae	Flagellates	Dinoflagellates	Coccolithophores	Silicoflagellates	Diatoms	Foraminiferans	Radiolarians	Tintinnids	Planula Larvae	Echinoderm Larvae	Nemertean Larvae	Annelid Larvae	Gastropods	Pteropods	Crustacean parts	Crustacean Larvae	Crustacean Eggs	Ostracods	Copepods	Amphipods	Mysidacea	Stomatopod Larvae	Euphausiacea	Penaeidae	Tunicata	Fish Parts & Scales	Fish Larvae
TUNICATA																															
*Iasis zonaria**	1	1				X	X		X	X	X																				
Pegea confoederata	1	1	X				X		X	X																					
Pyrosoma, soft form	1	1				X	X		X																						
Pyrosoma, berry	2	2				X	X	X	X																						
Pyrosoma, large colony	1	1					X																								
Salpa sp.	1	1				X	X		X	X	X																				
Salpa fusiformis	1	1	X				X		X	X																					
MOLLUSCA																															
Cavolinia longirostris	4	4	X						X	X	X	X					X		X	X											
Euclio pyramidata	6	6	X			X	X	X	X	X		X																			
ARTHROPODA																															
Copepoda	8	40							X		X								X												
Stylocheiron (euphausid)	6	10							X		X								X												
Thysanoessa (euphausid)	2	6																	X				X								
Thysanopoda (euphausid)	17	31	X	X	X	X			X	X	X	X							X				X	X							
Anchylomera (amphipod)	4	11																	X												
Cystosoma (amphipod)	2	3	X																X												
Phronima (amphipod)	4	5																	X												
Platyscelid (amphipod)	4	8																	X												
Rhabdosoma (amphipod)	1	12									X																				
Penaeidae																															
Hemipenaeus crassipes	6	6				X										X														X	
Sergestes robustus	5	12	X			X			X	X									X												
Aristeus	10	10									X	X	X						X				X	X							
Caridea																															
Acanthephyra sanguinea	6	7							X									X	X		X		X								
Species E	12	19													X	X	X		X			X					X				
CHAETOGNATHA																															
Sagitta ferox	2	?												X									X								
Sagitta hexaptera	2	?																			X		X								
Sagitta sp.	9	?															X		X	X			X				X			X	
COELENTERATA, Siphonophora																															
Unident. feeding polyp	1	1																									X				
Ablyopsis tetragona	4	4																					X								
Agalma okeni	1	1																					X				X				
PISCES																															
Cyclothone	3	11																	X						X						
Ichthyococcus ovatus	2	2																											X		
Vinciguerria nimbaria	5	5															X					X	X	X							
Argyropelecus lychnus	3	4															X		X				X	X							
Myctophidae																															
Species 1	10	10																X	X		X		X	X			X	X	X		
Species 2	10	11																X	X			X	X	X	X		X	X	X		
Species 3	3	3															X		X				X	X					X		X
Species 4	2	2																	X				X						X		
Species 5	2	3																	X				X	X		X	X	X	X	X	
Species 6	2	8																	X			X		X				X			
Gadoidei																															
Bregmaceros macclellandi	1	1																	X												

*X = materials present in the gut

formed by merging of the surface layer with the main DSL. Scattering layers of the Indian Ocean are compared with those from other oceans.

Geographical distribution data are presented for the 161 species of animals that were identified; of these there were 16 siphonophores, 14 pteropods, 10 heteropods, 3 mysids, 7 euphausiids, 19 shrimps, 8 pelagic tunicates, and 79 fishes. Distribution of amphipod genera is given; chaetognaths, medusae, annelids, copepods, and other groups taken were generally not identified; collections of these as well as of the identified species are available for study.

Vertical distributions for 56 genera and species are discussed with special reference to migration patterns. Best evidence for association with the main DSL was obtained for the vertical migrators *Ablyopsis tetragona* (a siphonophore), *Cymbulia* sp. (a pteropod), and *Thysanopoda* sp. (a euphausiid), with lesser evidence for *Nematobrachion* sp. (a euphausiid), *Vinciguerria nimbaria* (a stomiatoid fish), and *Notolychnus valdiviae* (a myctophid fish), and the partial migrator *Argyropelecus lynchnus sladeni* (a stomiatoid fish).

A small amount of information on gut contents is presented for 39 species.

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