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An ecological reconnaissance of the deep scattering layers in the eastern tropical Pacific

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THESIS

AN ECOLOGICAL RECONNAISSANCE OF THE DEEP SCATTERING LAYERS IN THE EASTERN TROPICAL PACIFIC

by

Calvin Ray Dunlap, III

June 1968

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Thesis
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AN ECOLOGICAL RECONNAISSANCE OF THE DEEP SCATTERING LAYERS IN THE EASTERN TROPICAL PACIFIC

by

Calvin Ray Dunlap, III
Lieutenant, United States Navy
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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OCEANOGRAPHY

from the

NAVAL POSTGRADUATE SCHOOL
June 1968

Signature of Author ______________________________

Approved by ______________________________
Thesis Advisor

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Chairman, Department of Meteorology and
Oceanography

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Academic Dean

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ABSTRACT

This reconnaissance is the first ecological study of the deep scattering layers (DSL) in the eastern tropical Pacific. It was made during two three month cruises of the R/V TE VEGA, one of which was predominantly in the Gulf of California. The reconnaissance is based on over 100 fathometer echograms and 100 trawls which fished for a period of one hour with an opening and closing Tucker midwater trawl. Echograms of two fathometer frequencies (30 Kc and 11 Kc) indicated that two latitudinal scattering zones may exist. Temperature, oxygen, light intensity, faunal composition, and swimbladder morphology were investigated with relation to the DSL. The oxyclines associated with the eastern Pacific oxygen minimum zone seemed to have little effect on the DSL. Possible further evidence for the migration of DSL organisms for feeding purposes was apparent as the maximum night surface scattering was observed at the depth of maximum Chlorophyll *a* or phytoplankton. Frequency comparisons indicated a possible gradient of the size of organisms in the DSL with smaller organisms toward the top of the layer. A twenty-four hour continuous observation of an equatorial Pacific DSL diurnal cycle and an evaluation of possible scattering organisms are included.

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I also offer my thanks to Dr. Donald Thompson of the University of Arizona and Dr. Richard Barber of Woods Hole Institute of Oceanography, the senior scientists aboard TE VEGA, as well as to the other members of the scientific party and the technicians of the respective cruises. There were long hours of strenuous net handling into the night and to each "Tucker trawler" my deepest gratitude.

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My final and greatest thanks are to my advisor, Dr. Eugene C. Haderlie, who inspired me with a naturalist's approach to biology and to my wife, Elizabeth, who typed many long hours and patiently supported a husband who was at sea for six months of a two year "shore" tour.

INTRODUCTION

Since their discovery in the early 1940's the deep scattering layers (DSL) and their diurnal migrations have been studied throughout the world. The present era of the deep submersible (Barham, 1966), scattering coefficient studies (Anderson, 1967) and more reliable trawling techniques (Davies and Barham, unpublished manuscript) has provided new tools in the study of the ecology of the DSL. A pattern of the broad aspects of the DSL is emerging, but its composition and complete predictability have not yet been firmly established.

Organisms suspected of causing the DSL migrate through the upper 1000 meters of the ocean, an area which contains the largest gradients of light, temperature, oxygen, and greatest number of organisms in the marine realm. The DSL involves very complex and important problems of deep-sea ecology. The DSL is particularly important in the solution of biologic energy budgets in marine ecology and reverberation levels in the study of ocean acoustics.

The eastern tropical Pacific and the Gulf of California provide an excellent ecosystem for scattering layer studies since an oxygen minimum zone exists, cloud cover is minimal, a rich and diverse faunal development occurs in areas of upwelling, and calm seas usually prevail. Since the Gulf is the only major evaporation basin in the Pacific, many parameters such as temperature and salinity are accentuated. This is particularly apparent in the northern part, and above the thermocline in the southern part of the Gulf. A continental effect provides interesting data for comparison of the Gulf with other Pacific scattering models such as Monterey Bay, California (Barham, 1957) and Saanich Inlet, British Columbia (Bary, 1962, 1966).

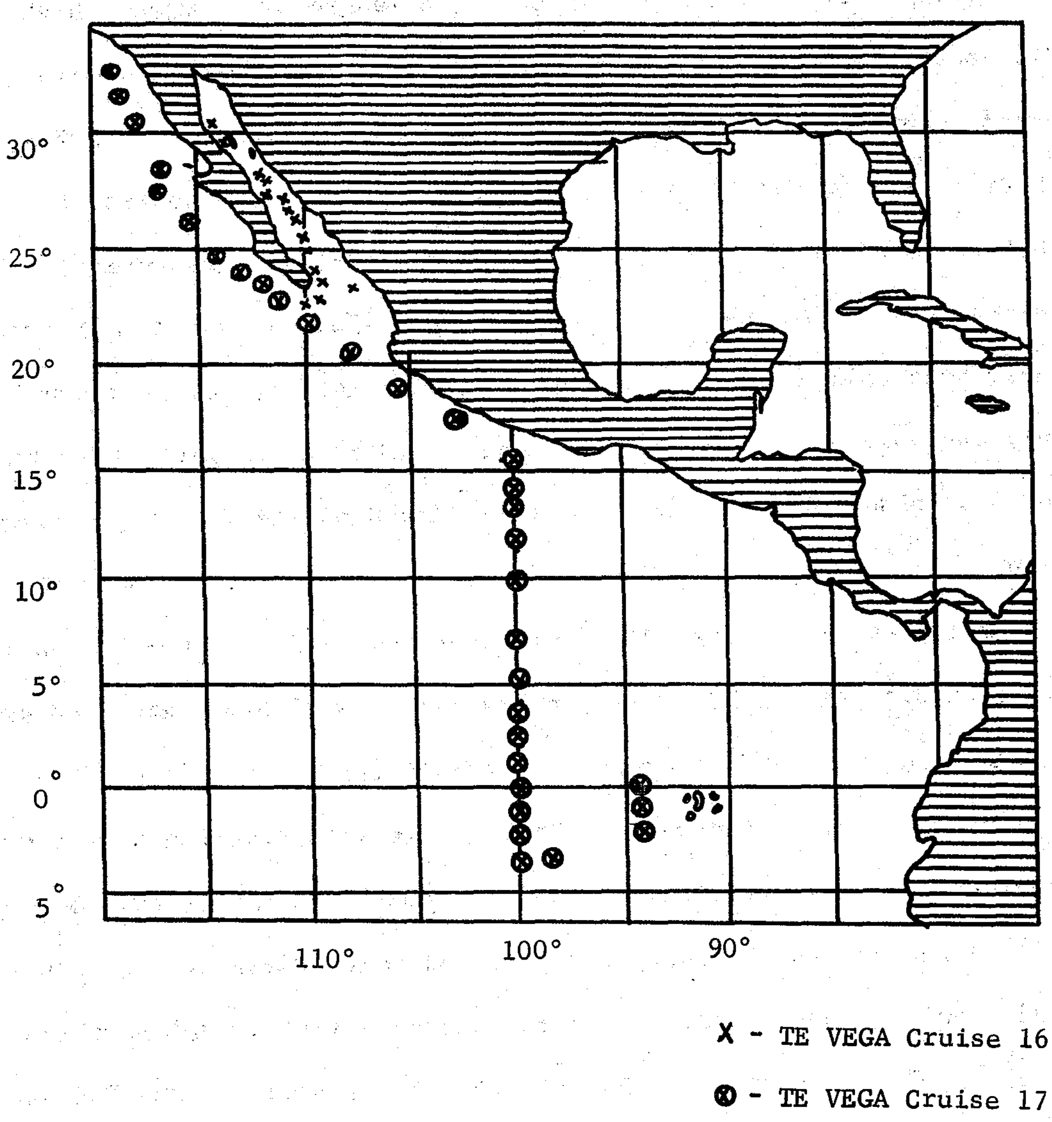
Recently the circulation and water mass structure of the eastern tropical Pacific has been studied by numerous investigators (Wyrtki, 1967).

The position and movements of the scattering layers appear to be mainly functions of light intensity (Kampa and Boden, 1954; Clarke and Backus, 1965) and of the frequency of the investigating sound source (Hersey, Backus and Hellwig, 1962; Anderson, 1967). Other less well defined parameters include temperature (Moore, 1958; Hersey and Backus, 1962), oxygen (Bary, 1966), trophic relationships (Tucker, 1951), and species composition (Barham, 1957). The suspected scattering organisms are: bathypelagic fishes (Marshall, 1951; Tucker, 1951; Hersey and Backus, 1954; Andreeva, 1964), euphausiids (Boden,1950; Moore, 1950), squid (Lyman, 1948), shrimps (Barham, 1957), heteropods (Blackburn, 1956), and certain siphonophores (Barham, 1963).

Andreeva (1965) suggests that many statistical gaps in the study of the DSL can be filled by wide geographical investigations using different frequencies with similar standard trawling procedures. This investigation provides information for an equatorial area that has been almost totally neglected with regard to DSL studies (Dietz, 1948). However, some studies have been made off of Baja California on the edge of the Equatorial water mass (Barham, 1966).

The objective of this investigation, conducted during Cruises 16 and 17 of the R/V TE VEGA, was to provide a reconnaissance of the DSL in the eastern tropical Pacific including the Gulf of California. These cruises include the periods, September 22 - November 14, 1967 and January 3 - February 15, 1968. The parameters previously mentioned have been examined in the geographical area of Figure 1. Fishes larger than 10 cm and

FIGURE 1. Geographical Distribution of Deep Scattering Layer Observations and Data



plankton less than about 5 mm were not considered in this study although they may be of importance in describing the behavior of the DSL.

MATERIALS AND METHODS

A 30 Kc Simrad Sonar Model 540-4 (Simonsen Radio A.S., Oslo) provided the majority of DSL sound profiles. This sonar was used in the fathometer mode with a predominate pulse length of 11 msec. High gain dial settings of 8-10 (of a maximum reading of 10) provided deep layer bands. Low to medium gain dial settings (1-7) allowed discrimination of multiple layers and provided mean layer depths. Gain control is an art in that improper gain control can mask and distort layer widths. This instrument is limited for use in the upper 1500 m. An 11 Kc Simrad Fathometer Model 513-1 provided comparative information, but unfortunately was only operable during the second cruise. TE VEGA'S engines were secured for most observations since they masked much of the fathometer information.

A review of the literature provides the basic weakness of current trawl studies of the DSL. It appears that few highly controlled studies of the efficiency and dependability of the large mesh mid-water sampling nets have been made (Andreeva, 1965). This investigation relies on a previous catching efficiency study of a similar Tucker trawl (Barham, 1957). Another recent study has proposed that trawls such as the Issac - Kidd trawl are not reliable with regards to effective DSL sampling (Aaron et al, 1967). However, the Issac - Kidd trawl study of the DSL used minimal sampling times. Patchiness must be always considered in any trawling study.

A modified Tucker net (Tucker, 1951) was used with a special opening and closing device constructed by the Naval Undersea Warfare Center

(Davies and Barham, unpublished manuscript). Two depressors were used, one on each end of the bottom frame bar to increase the diving and stabilization efficiency of the trawl (see Figure 2). The net sampled only the macroplankton and micronekton since it had a one-quarter inch mesh at the cod end. Total biomass displacement volumes were made using all invertebrates less than about three cm in length. Dominance by volume was established by measuring the wet volumes of the component organisms. All fishes and larger invertebrates were counted and standard length measurements made.

"Dominant" in this study means that: (1) for small invertebrates, the particular organism had the greatest component of biomass displacement volume for a particular trawl, or (2) for large invertebrates, the organism was the most numerous large invertebrate, or (3) for fishes, the fish was the most numerous fish in the trawl. "Subdominant" means that the organism was present with the second greatest component volume or the second most numerous depending whether it was a small or large invertebrate or a fish. "Present" means that the organism was not dominant or subdominant but was present in the catch.

Bathypelagic fishes were identified by R. H. Loomis and B. H. Robison, members of the TE VEGA Cruise 16, and by S. Peterson and M. Anctil, members of the TE VEGA Cruise 17. Decapods of TE VEGA Cruise 17 were identified by L. Barr, a member of that cruise.

Wire angle indications were marginal for accurate continuous depth control. This problem had been anticipated and an attempt was made on the first cruise to continuously monitor the net's position by placing a Hydro Products Model 3-1045c 11 Kc Pinger on the trawl. The active sonar transducer was trained aft but the engine noise in the baffle area appeared

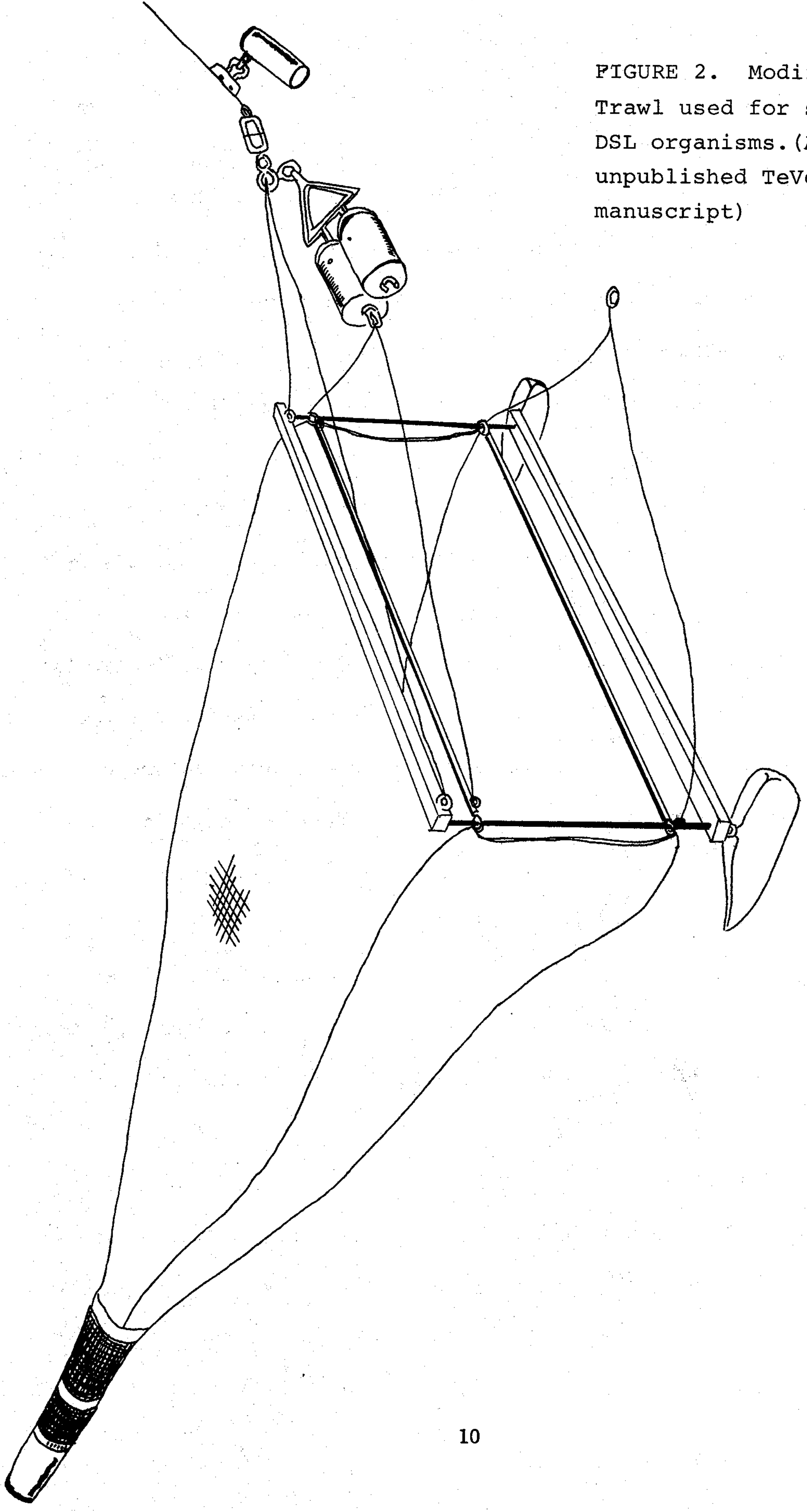


FIGURE 2. Modified Tucker Trawl used for sampling DSL organisms. (After Robison, unpublished TeVega Cruise 16 manuscript)

to mask any possible signal. Other problems such as correct frequency matching are inherent in this method. It appears that an instantaneous telemetering system is needed for precise DSL studies.

A continuous depth-time recorder attached to the trawl provided the actual trawl-depth range. The depth distribution of Tucker trawls is shown in Figure 3. Each trawl used as much as three hours of ship time and the net was fishing open for one hour at a selected depth. The net was towed at two knots and thus, patchiness would not seem to significantly alter the results except when trawling in the early morning or late afternoon during the diurnal migrations of organisms. Trawl times were scheduled during non-migration periods. On Cruise 17, trawl data was corrected to a standard two nautical-mile tow when ship speed varied from two knots. This was possible by towing a speed log astern. Attempts to measure net flow rates were unsuccessful. Displacement volumes and counts of larger organisms must be interpreted with the consideration that occasionally different amounts of water may have been filtered due to subsurface currents.

Standard hydrocasts to at least 1000m and bathythermograph stations were made. A separate series of euphotic zone hydrocasts were made on Cruise 16 in the upper 100 m for Chlorophyll a analysis using a Turner Fluorometer, Model 111 (Yentsch and Menzel, 1963; Lorenzen, 1965).

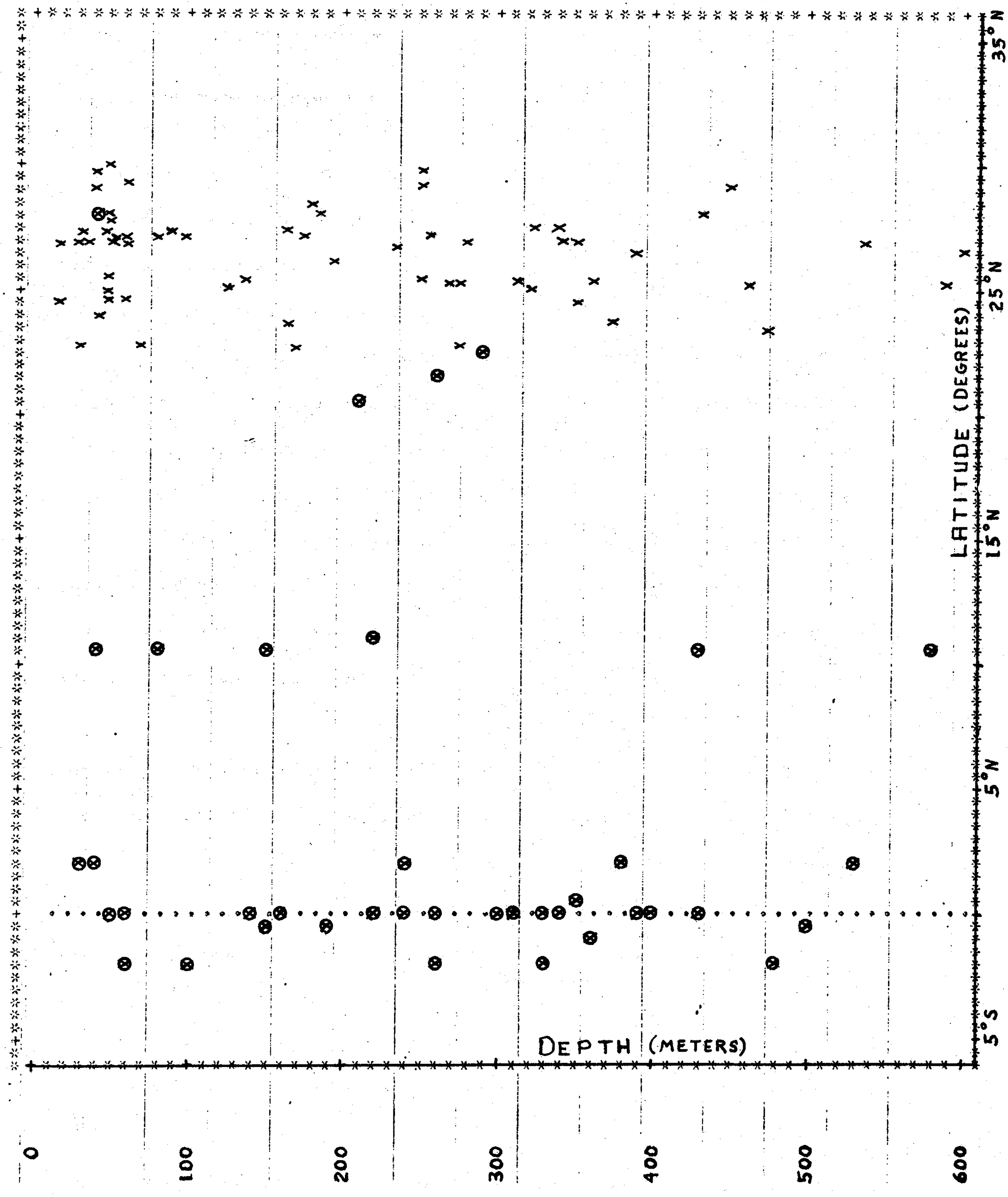
Oxygen determinations were made using the Winkler technique. Light intensities were recorded continuously by a pyrheliometer and light penetration was measured with a photometer.

Swimbladder morphology of several midwater fish was investigated. Measurements of major and minor axises were taken with a caliper. Calculation of swimbladder volumes were based on the equation for the volume

Figure 3. Depth distribution of Tucker trawls on a latitudinal transect

X - TeVega Cruise 16

⊗ - TeVega Cruise 17



of a prolate spheroid (Capen, 1967):

$$V = 4/3\,\pi\,ab^2$$

V - volume (mm^3)
a - major axis (mm)
b - minor axis (mm)

Direct measurements of swimbladder volume of fresh specimens were also made by injecting water from a calibrated syringe into the swimbladder until the last bubble of gas escaped from around the tip of the syringe.

Resonance curves were constructed using the following equations (Capen, 1967):

$$r_{rs} = \frac{(d + 10)^{\frac{1}{2}}}{f}$$

$$V_{rs} = 4/3\,\pi\,r_{rs}^{3}$$

r_{rs} - radius of resonating sphere (mm)
d - depth (m)
f - frequency (Kc)
V_{rs} - Volume of resonating sphere.

OBSERVATIONS AND RESULTS

THE DSL DIURNAL CYCLE

On 28 and 29 January 1968, a twenty-four hour observation of the DSL was made at the equator on the 100°W meridian. TE VEGA drifted with all engines secured throughout the observation. Figure 4 illustrates the typical migration pattern with the corresponding sunlight intensities plotted for comparison. The DSL appear to reach their maximum day depths between 0930 and 1000 hours. At that time the sunlight intensity (56 cal/cm^2/hr.) is about 66% of the maximum daytime intensity. The DSL start their upward migration at about 1500 hours when the intensity is again about 55 cal/cm^2/hr. The time rate of change of intensity is about 15-20 cal/cm^2/hr. per hour at the 0930 and 1500 observations. There appear

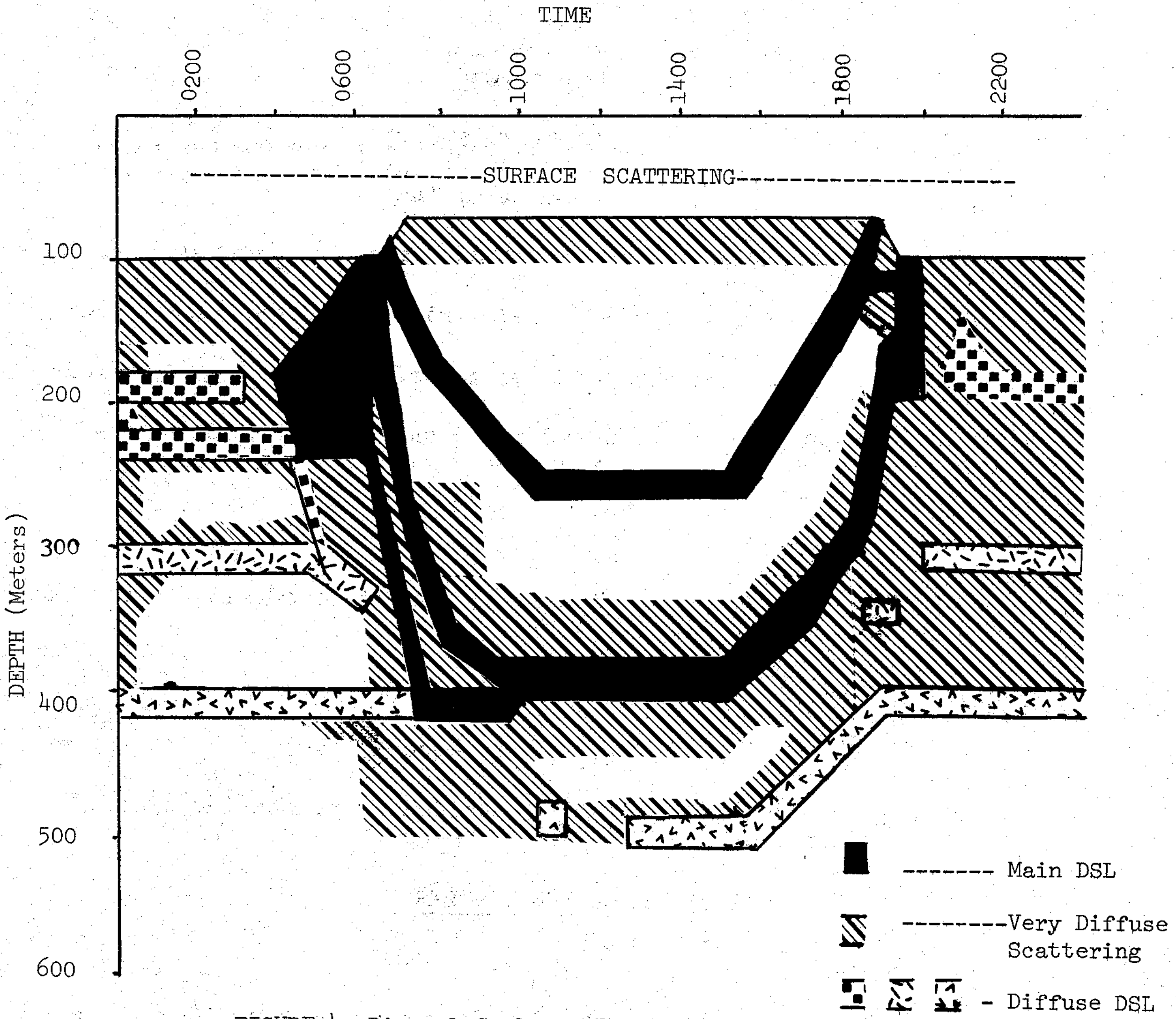
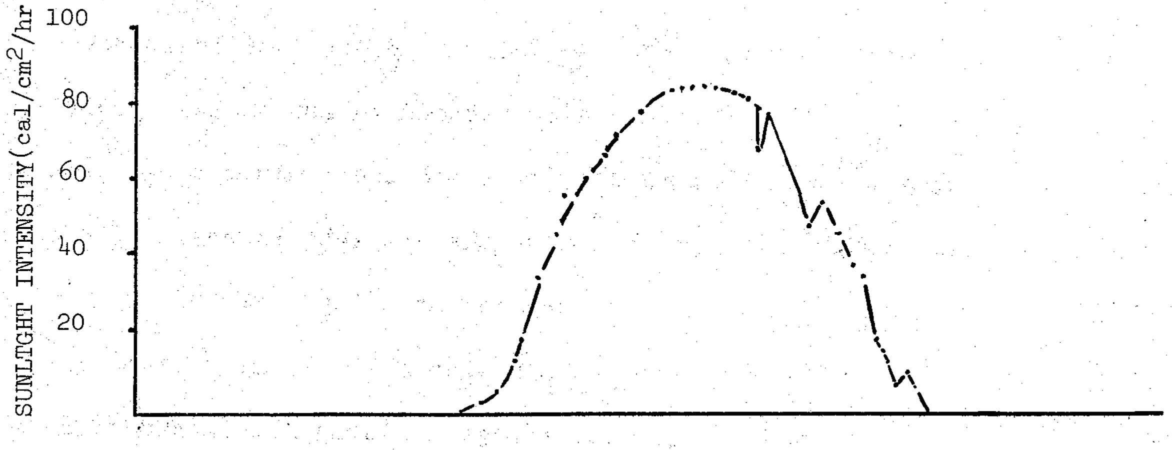


FIGURE 4. Diurnal Cycle of Equatorial Scattering Zone DSL and Corresponding Sunlight Intensities.



to be two major migrating DSL which have a maximum mean day depth of 260 m and 390 m. Another scattering layer appears at about 500 m but its evening migration takes it to about 410 m for the mean night residence depth. Diffuse DSL are also found at 310, 230 and 190 m during the night while their day positions are not clear.

GEOGRAPHICAL DSL ZONATION

Figure 5 summarizes the 30 Kc, mean scattering layer depths on a 2200-mile latitudinal transect. Three distinct intervals seem apparent.

The first interval of latitude is from 4°S to 7°N, hereafter referred to as the "equatorial scattering zone." In the equatorial scattering zone the day mean layer depths are about 250, 390 and 500 m. Sunlight maximum intensities ranged from 84 to 90 cal/cm^2/hr. in this zone.

The second interval of latitude is from about 8°N to about 24°N, hereafter referred to as the "tropical scattering zone." Sunlight daily maximum intensities ranged from about 70 to 83 cal/cm^2/hr. for this zone. The tropical scattering zone usually has a deep scattering layer with a mean day depth between 100-200 m, but it is most clearly identified by a second layer with a mean depth of about 300 m. DSL at about 400 and 500 m are also common in the tropical scattering zone.

Data from Cruise 16 of TE VEGA reveals that most of the Gulf of California is probably also a part of the 30 Kc tropical scattering zone for at least the months of September through November. During that period the maximum daily light intensities varied from 72 to 84 cal/cm^2/hr. in the Gulf. A comparison of cruises 16 and 17 data on Figure 5 reveals the similarities of the mean layer depths in the Gulf of California and the more southerly tropical scattering zone of the open ocean.

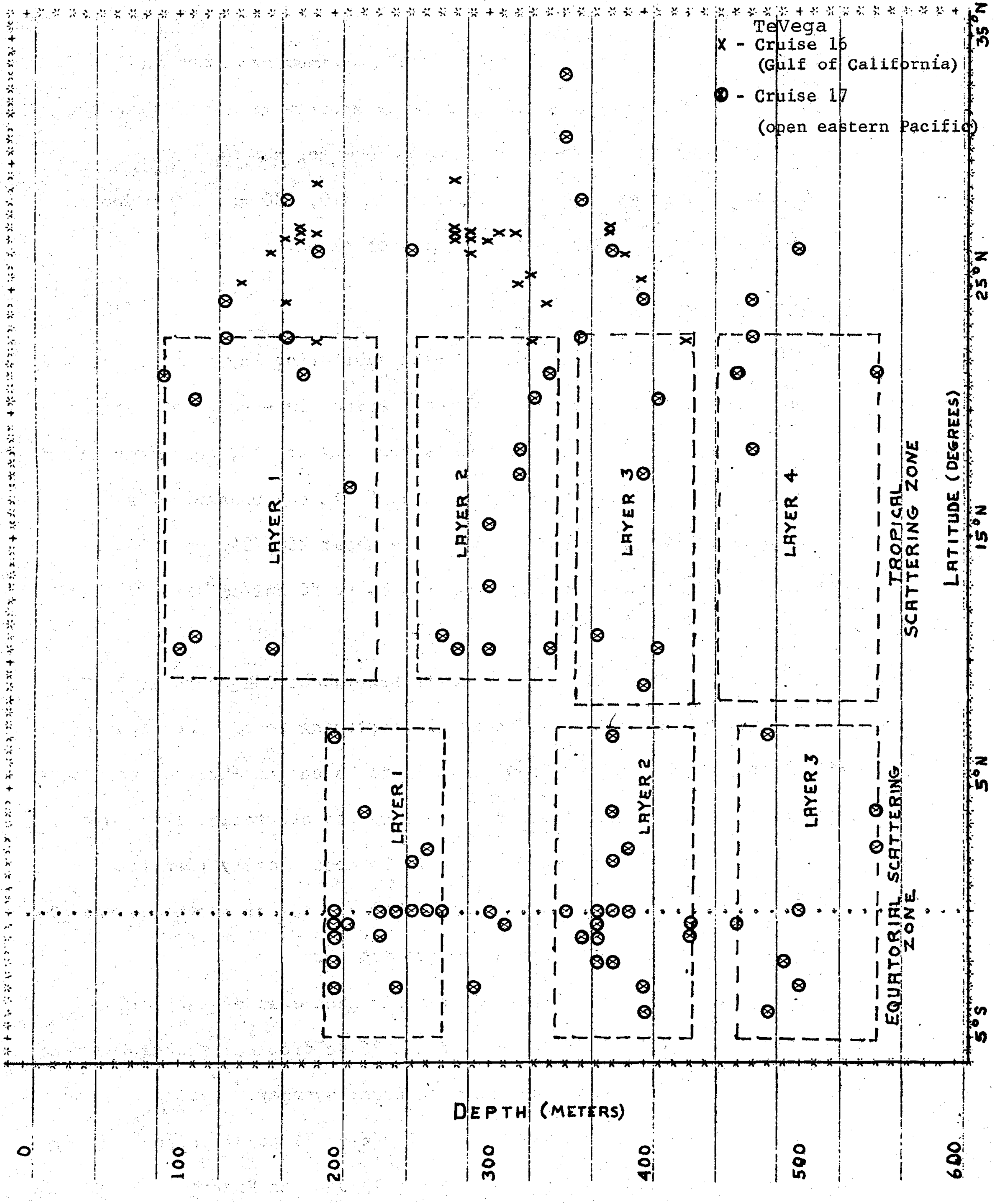


Figure 5. Distribution of mean day DSL depths and zones on a latitudinal transect

The third interval of latitude represents the data from 24°N to 33°N which might be defined as a "transition scattering zone." Few observations were made in this zone during this investigation. DSL were most commonly found with mean depths of 350-400 m. Light intensities varied from 54 to 70 $cal/cm^2/hr$.

GULF OF CALIFORNIA DAY SCATTERING OBSERVATIONS

Midday (0900-1500) mean scattering layer depths in the Gulf of California were usually found at average depths of 175, 300 and 400 meters. The layer at 400 m was not present as often as the first two layers. A 500 m layer was also observed at three stations. Figure 6 illustrates the relationship of these three layers to hydrographical data along a transect of the Gulf as well as to major bathymetric features.

It is evident that the midday layer depths are homogeneous for most of the entire Gulf although hydrographic parameters change. The 400 meter layer is an exception in that it does not appear to occur in the 800 m water of the northern basin or trench. Midday layer depths do not correlate significantly with the depth of the water (over a range of 600-2400 m water depth). In nine of ten observations the first mean layer depth (175 m) is found between the 13° and 14° isotherm. Isotherms and oxygen isopleths indicate the presence of internal waves south of the northern sill (Figure 6).

Maximum sunlight intensities and length of sunlight are plotted with time in Figure 7. The maximum sunlight intensity ($cal/cm^2/hr.$) is obtained from the pyrheliometer's daily graphical output after correcting for any obvious servo-mechanism errors. The length of sunlight index is the distance between the intersections of the morning and evening zero light intensity readings and corresponds roughly to the number of daily hours

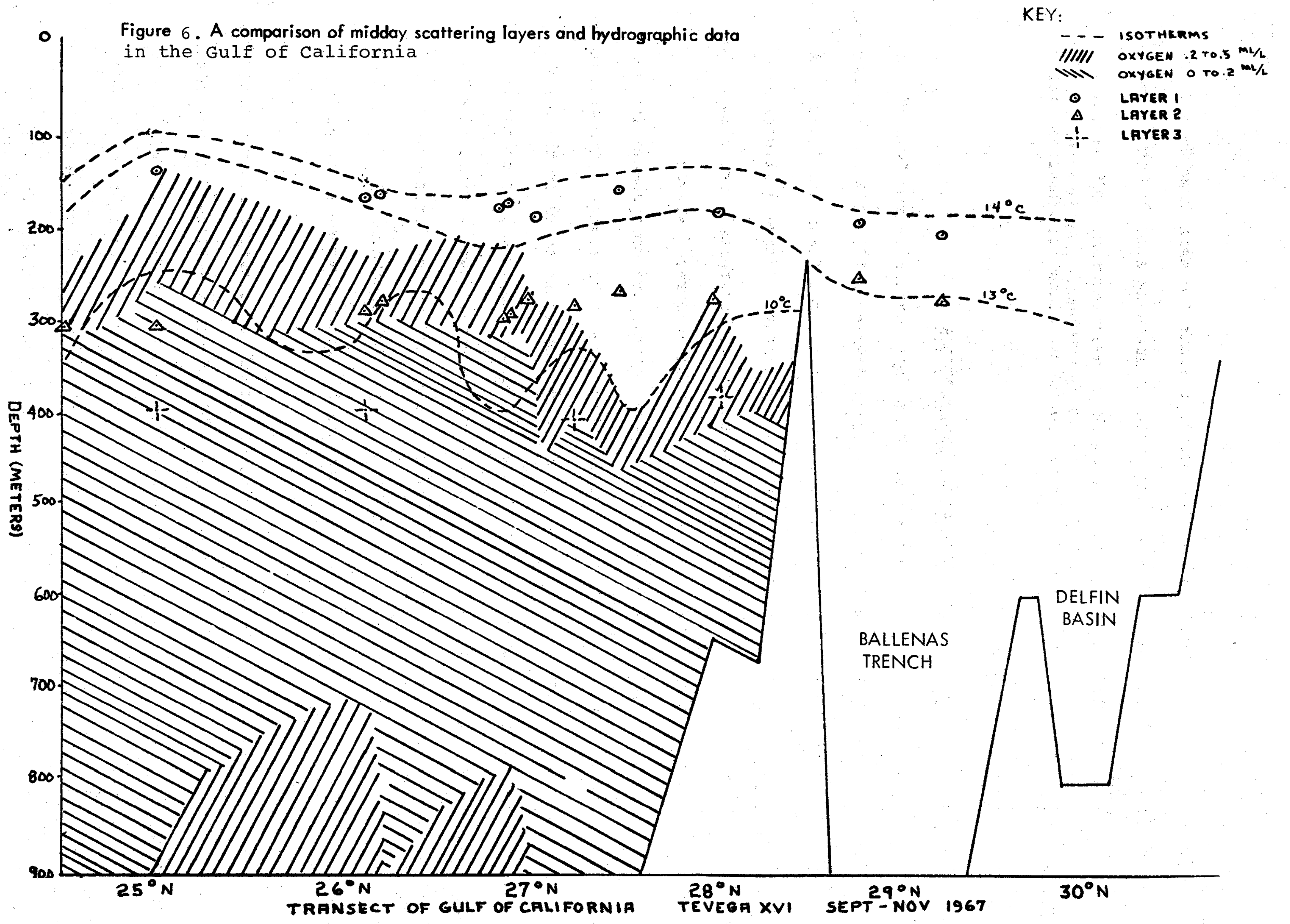


Figure 6. A comparison of midday scattering layers and hydrographic data in the Gulf of California

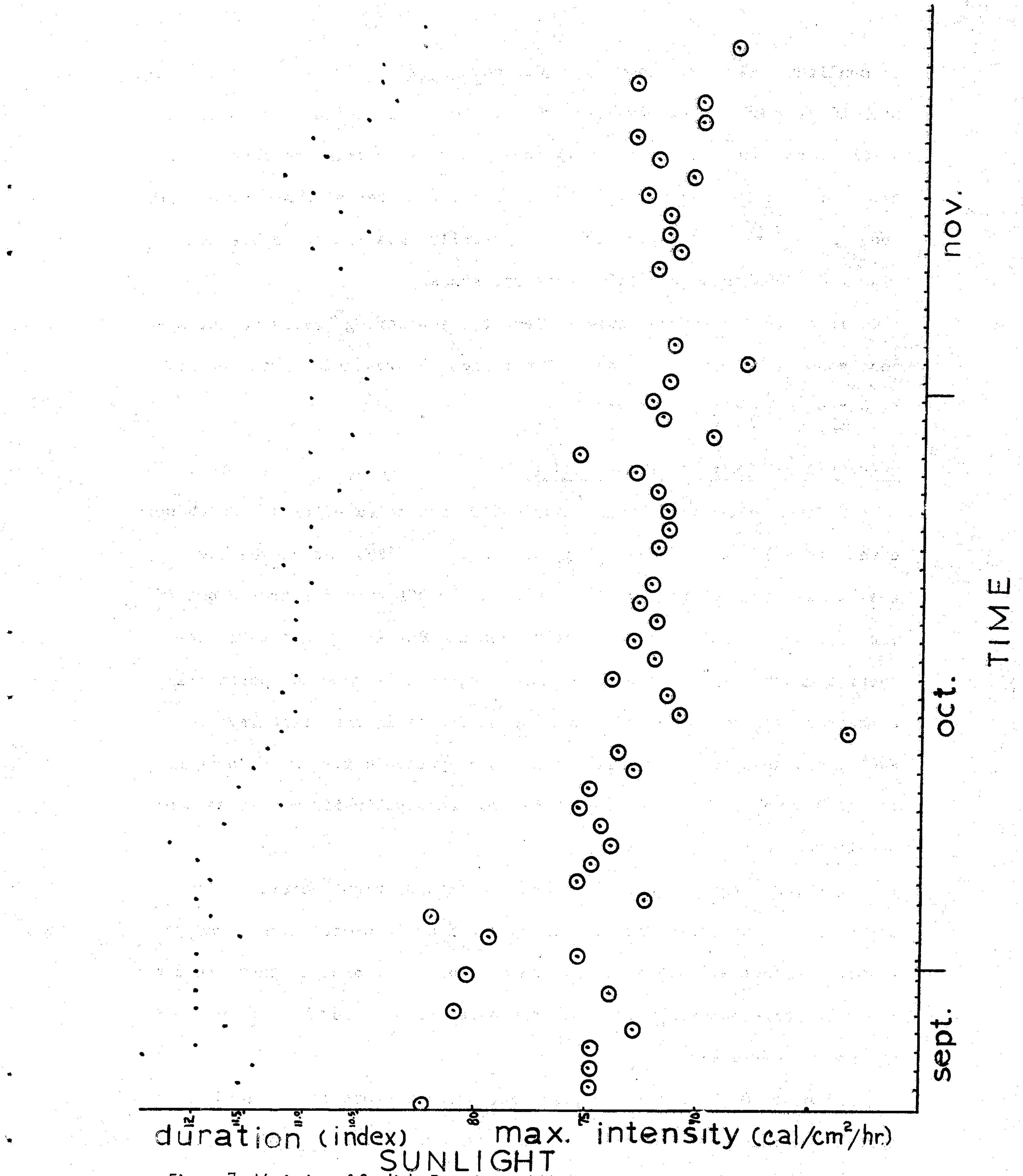


Figure 7. Variation of Sunlight Duration and Maximum Intensity with Time

of sunlight. The one cloudy day (October 13, 1967) is plainly contrasted with 50 days of relatively clear skies. Seasonal declines of sunlight are also obvious. Latitude variations due to ship position changes are also a factor in this figure. Layer migration rates at dusk varied from about 2 to 7 m/min. Major migrations usually appeared to be between sunrise and 0900 hours, and 1500 hours and sunset.

In twelve of fifteen observations the scattering layers do not appear associated with oxyclines. Two typical hydrostation profiles are illustrated in Figures 8a and 8b.

GULF OF CALIFORNIA DAY TRAWL RESULTS

Table 1 summarizes biomass evaluation for selected trawls which were either totally in the layer (1A), or out of it (1B). As can be seen, the biomass is much higher for trawls in the DSL than for trawls out of the layers. Table 1 also indicates that the day layers are more productive as the depth increases. According to this data the potential scatterers appear to be squid and larval fishes in the first layer. Squid, euphausiids, large crustaceans and myctophid fish were dominant in the second layer. Squid, euphausiids, and myctophids were also dominant in the third layer.

Figures 9 through 17 illustrate the day and night vertical distribution of the potential scatterers as based on information obtained in 70 trawls. Figure 9 combined with data of Table 1C indicates that squid are found in large numbers throughout the water column and are probably not the major scatterers.

Figures 10 through 17 suggest that equally probable potential scatterers for the first layer (175 m) are the myctophids Diogenichthys laternatus, and Triphoturus mexicanus, and the gonostomid Vinceguerria

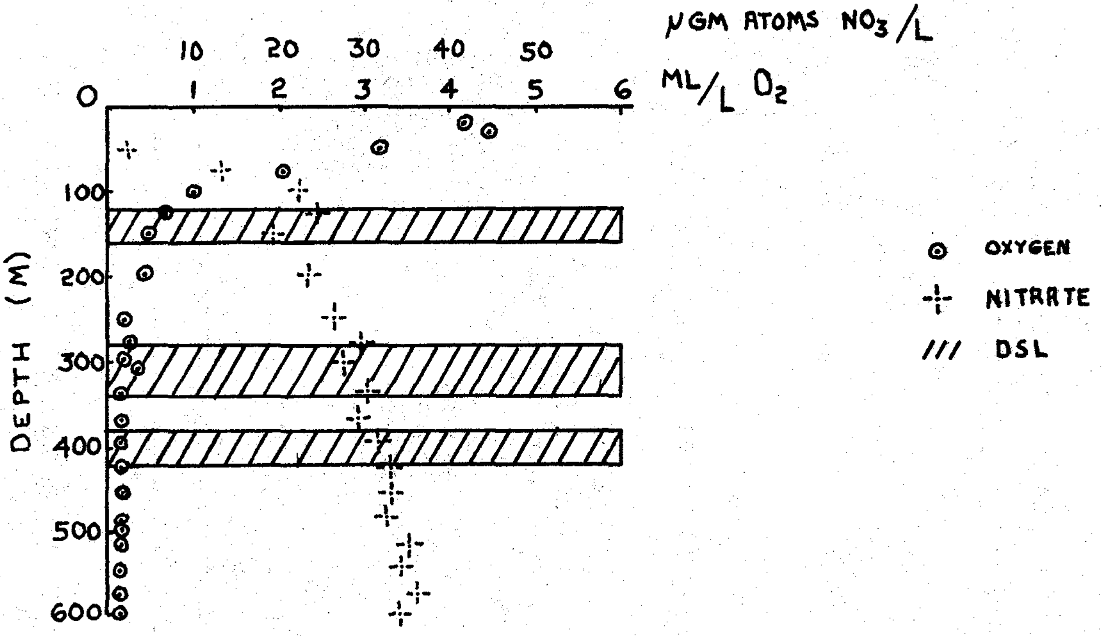


Figure 8a. STATION 164

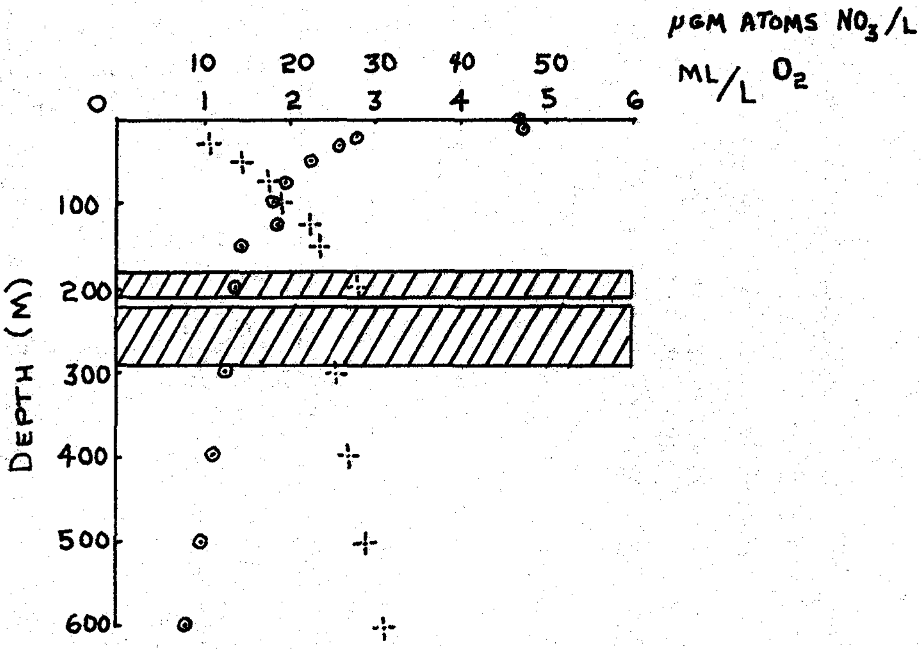


Figure 8b. STATION 75

Figure 8 Typical Hydrostation Profiles and DSL Locations in Gulf of California

TABLE 1

BIO-MASS SUMMARY OF DAY TUCKER TRAWLS

A. SELECTED TRAWLS WHICH TRAWLED EXCLUSIVELY IN THE DSL

STATION	NUMBER OF LARGE INVERTEBRATES	SMALL INVERTEBRATE DISPLACEMENT VOLUME (ml)	TOTAL NUMBER OF FISH	TRAWL DEPTH (M)	LAYER NUMBER	TIME
35	28	25	146	355	3	1102/1202
121	18	50	12	175	1	0945/1045
135	21	22	72	290-345	2	1035/1135
145	33	40	1626	390	3	1250/1350
161	20	40	185	250-300	2	0950/1050
163	2	15	82	130-145	1	1405/1505
AVERAGE	20	34	354			

B. SELECTED TRAWLS WHICH TRAWLED EXCLUSIVELY OUT OF THE DSL

STATION	NUMBER OF LARGE INVERTEBRATES	SMALL INVERTEBRATE DISPLACEMENT VOLUME (ml)	TOTAL NUMBER N OF FISH	TRAWL DEPTH (M)	TIME
64	4	5	33	425-445	1500/1600
112	21	25	27	850	1335/1435
122	9	50	124	235	1200/1300
123	3	25	22	540-650	1420/1520
136	138	0	154	320-360	1237/1337
144	2	25	136	525-560	1029/1129
184	64	7	47	360-390	1520/1620
191	1	2	8	170-175	0604/0704
192	2	0	5	770-830	0845/1045
193	20	1	0	275	1235/1335
AVERAGE	26.4	14.0	55.6		

C. SUMMARY OF DATA BY LAYERS (FROM "A")

LAYER NUMBER	AVERAGE NUMBER OF LARGE INVERTEBRATES	AVERAGE SMALL INVERTEBRATE DISPLACEMENT VOLUME (ml)	AVERAGE NUMBER OF FISH	DOMINATE INVERTEBRATES	DOMINATE FISH
1	10	32	47	Squid	Larval Fish
2	20	31	128	Squid/Euphausiid/Lg Decapods	*Triphoturus mexicanus*
3	30	32	886	Squid/Euphausiid	" "

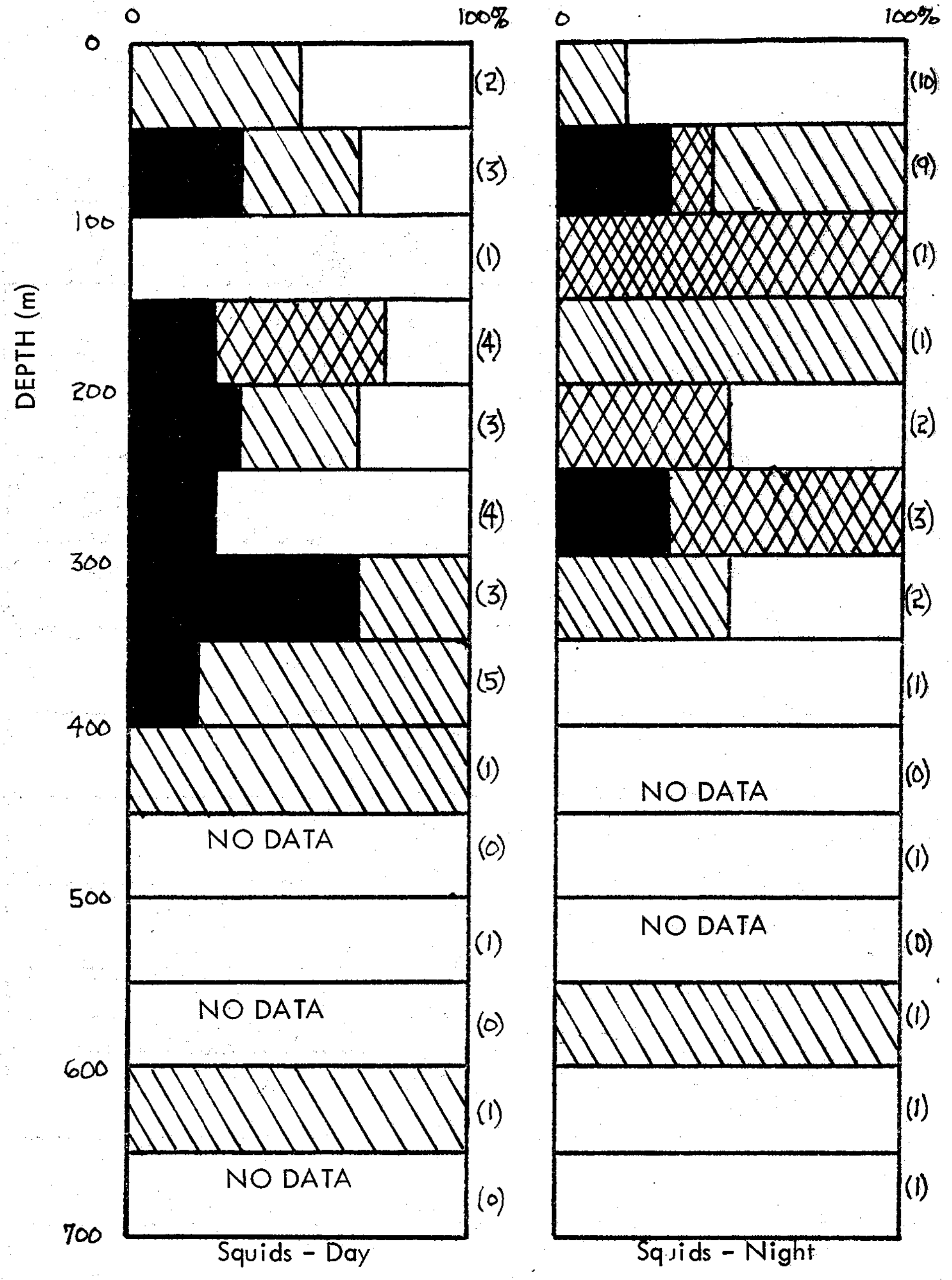


FIGURE 9. Diurnal Vertical Distribution of Squids by Percentage of Dominance

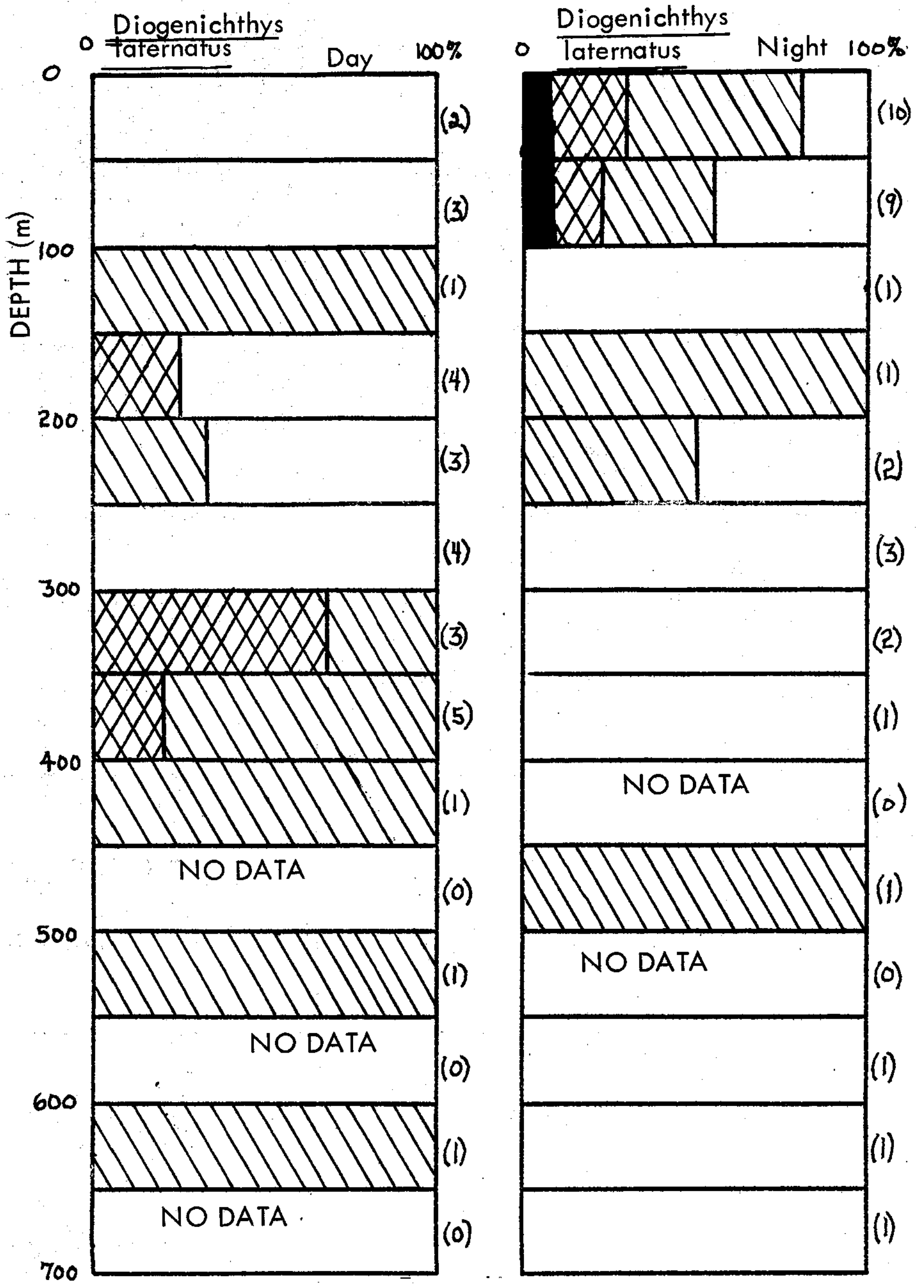


FIGURE 10. Diurnal Vertical Distribution of *Diogenichthys laternatus* by Percentage of Dominance

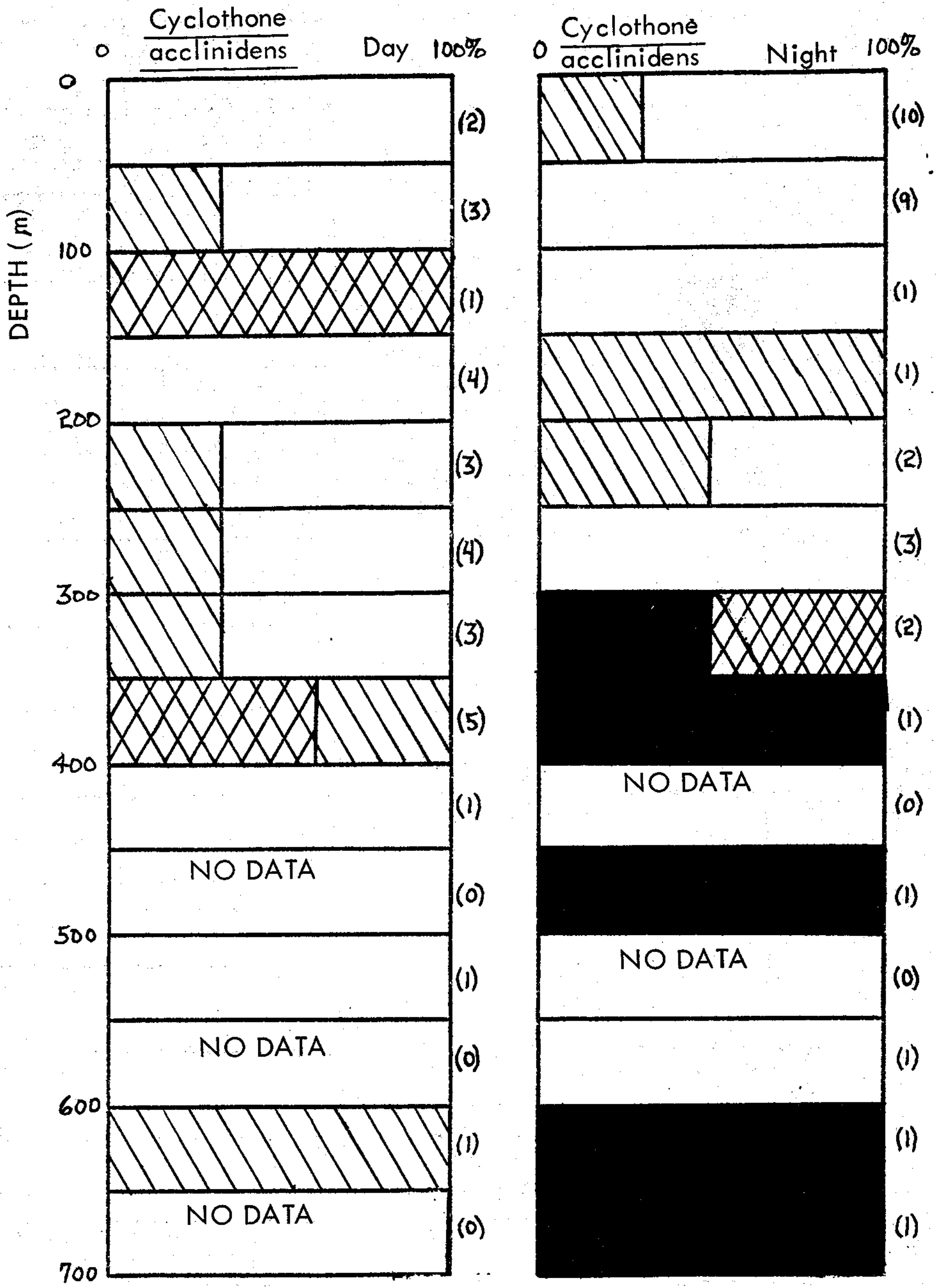


FIGURE 11. Diurnal Vertical Distribution of Cyclothone acclinidens by Percentage of Dominance

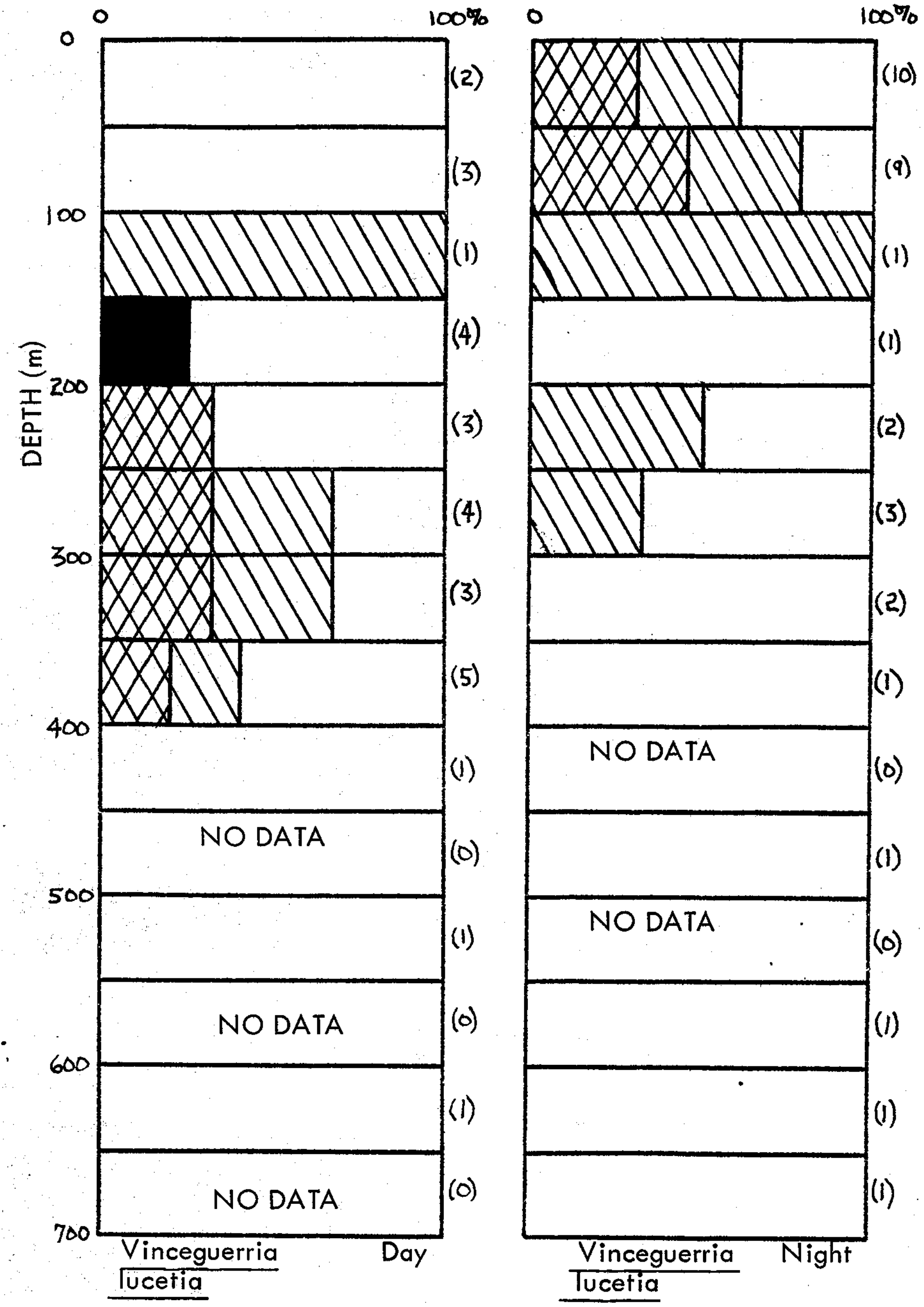


FIGURE 12. Diurnal Vertical Distribution of *Vinceguerria lucetia* by Percentage of Dominance

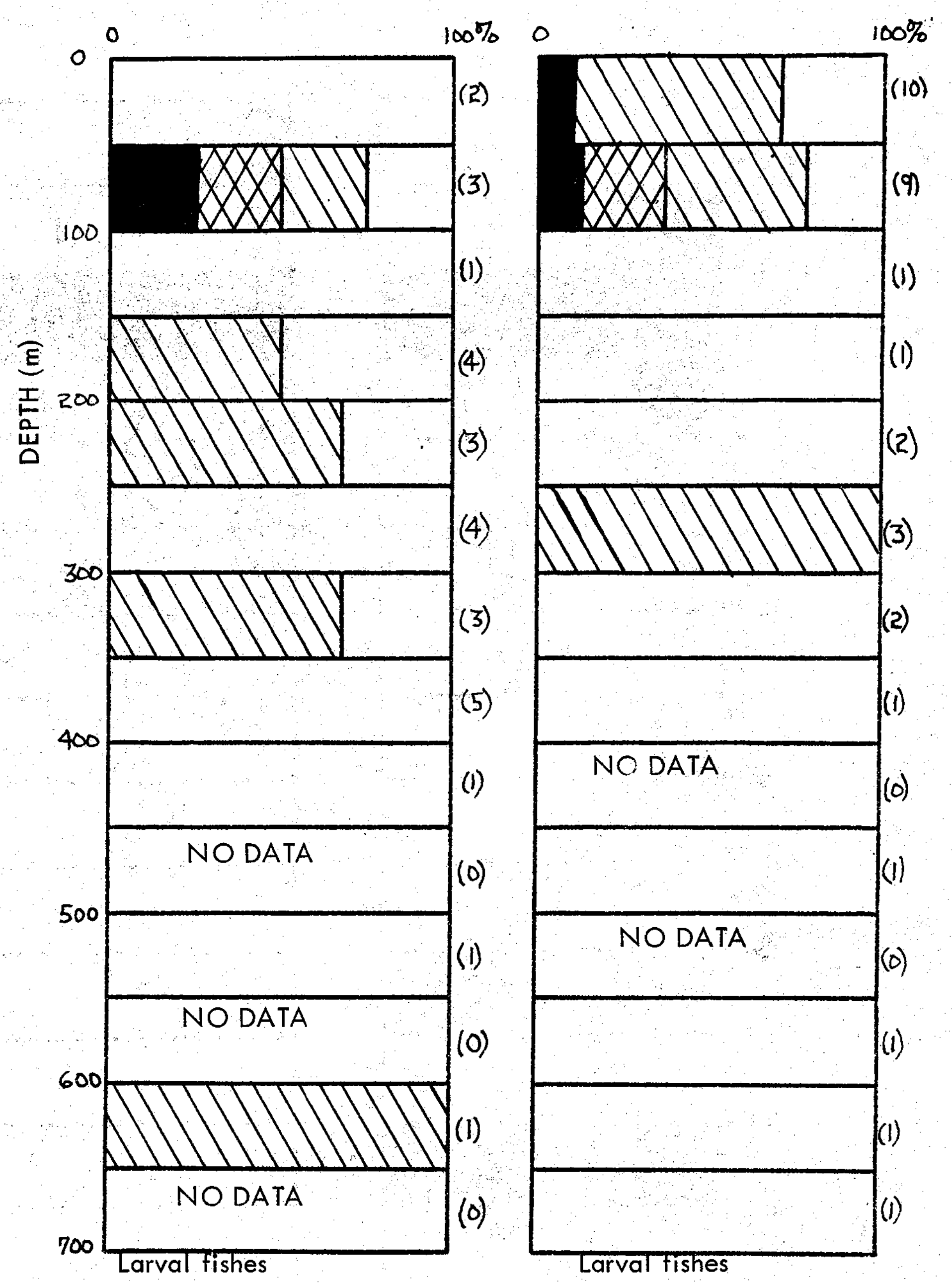


FIGURE 13. Diurnal Vertical Distribution of Larval Fishes by Percentage of Dominance

■ Dominant
▩ Sub-dominant
▨ Present
( ) no. of trawls

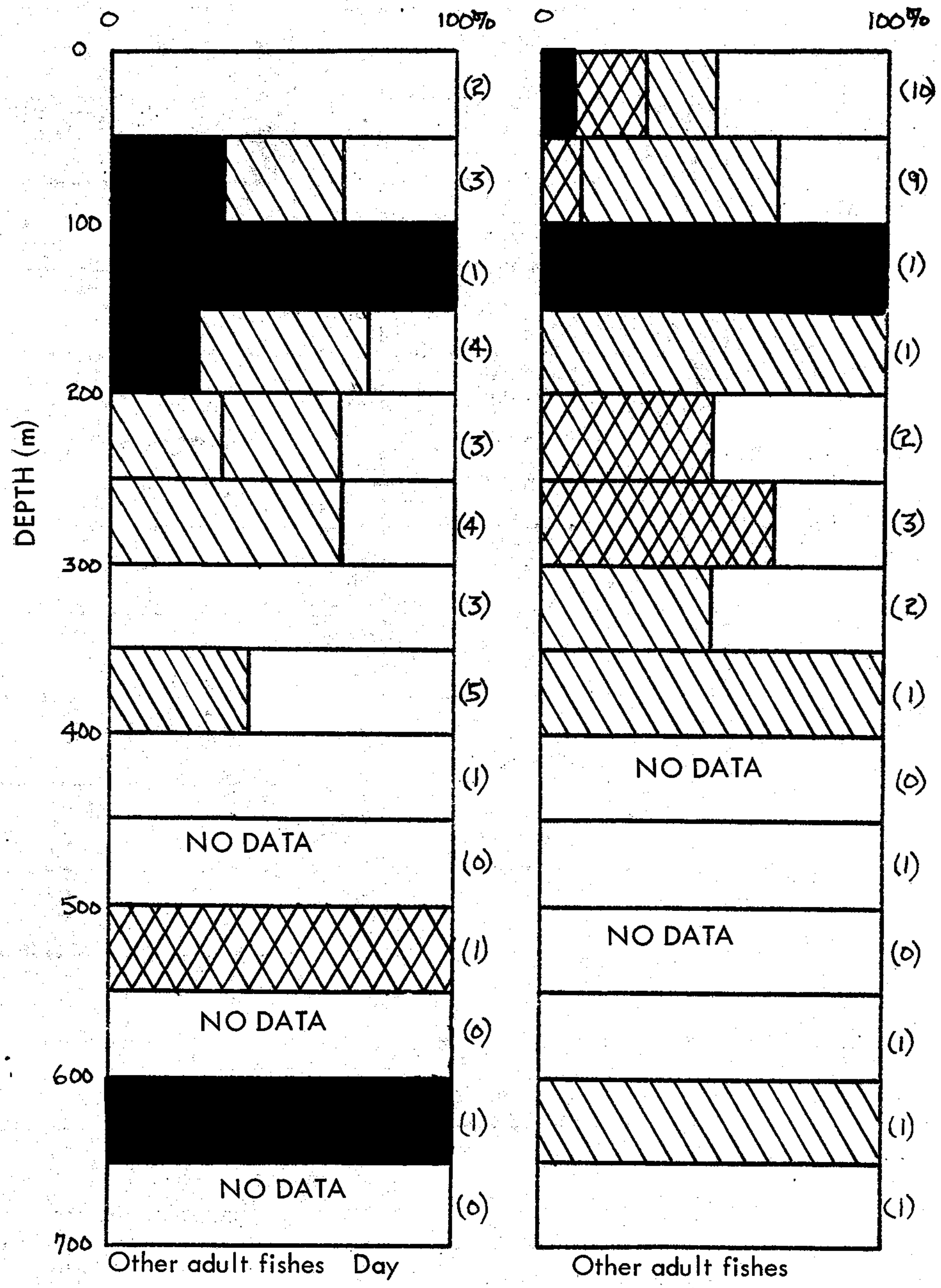


FIGURE 14. Diurnal Vertical Distribution of Other Adult Fishes by Percentage of Dominance

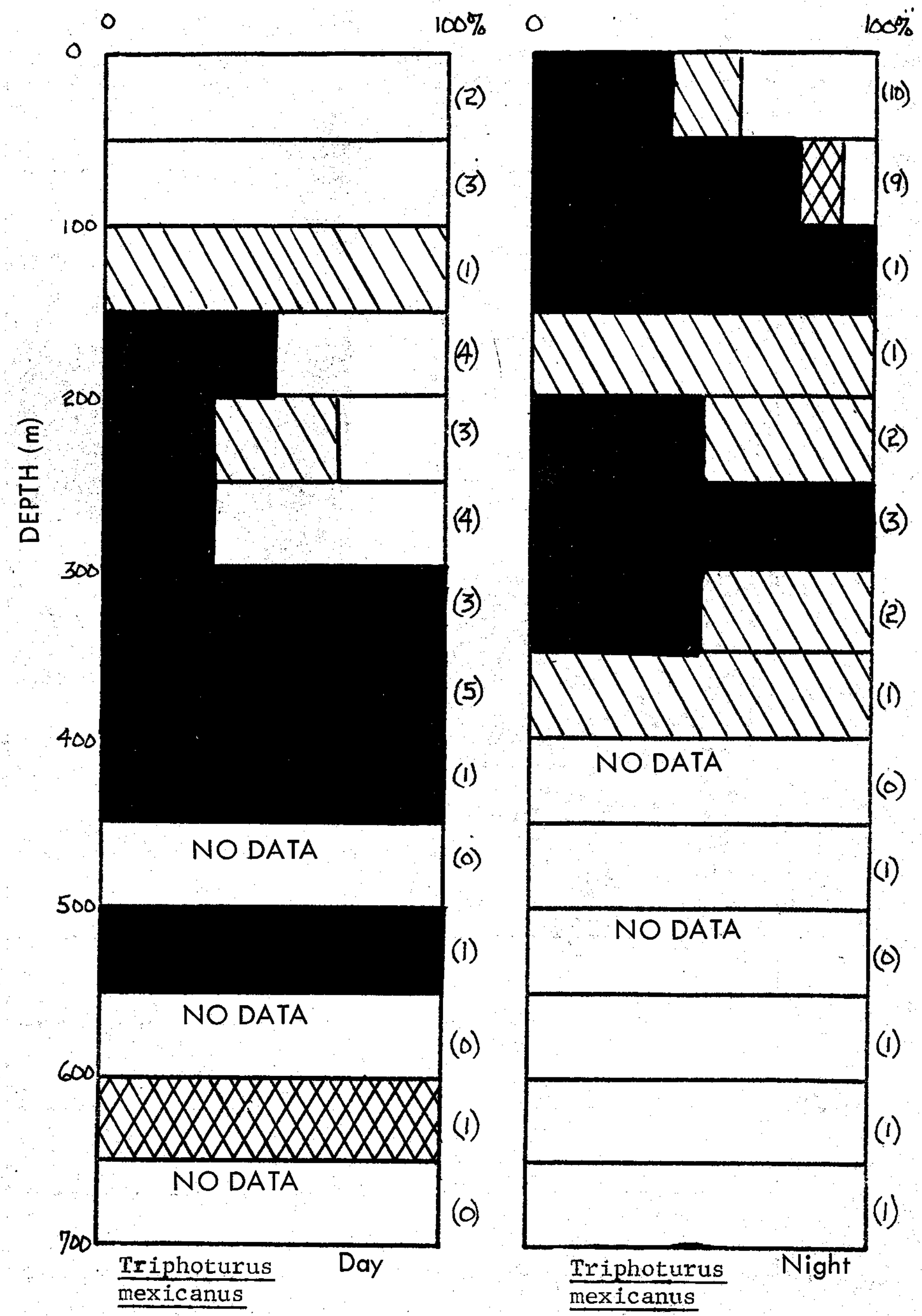


FIGURE 15. Diurnal Vertical Distribution of Triphoturus mexicanus by Percentage of Dominance

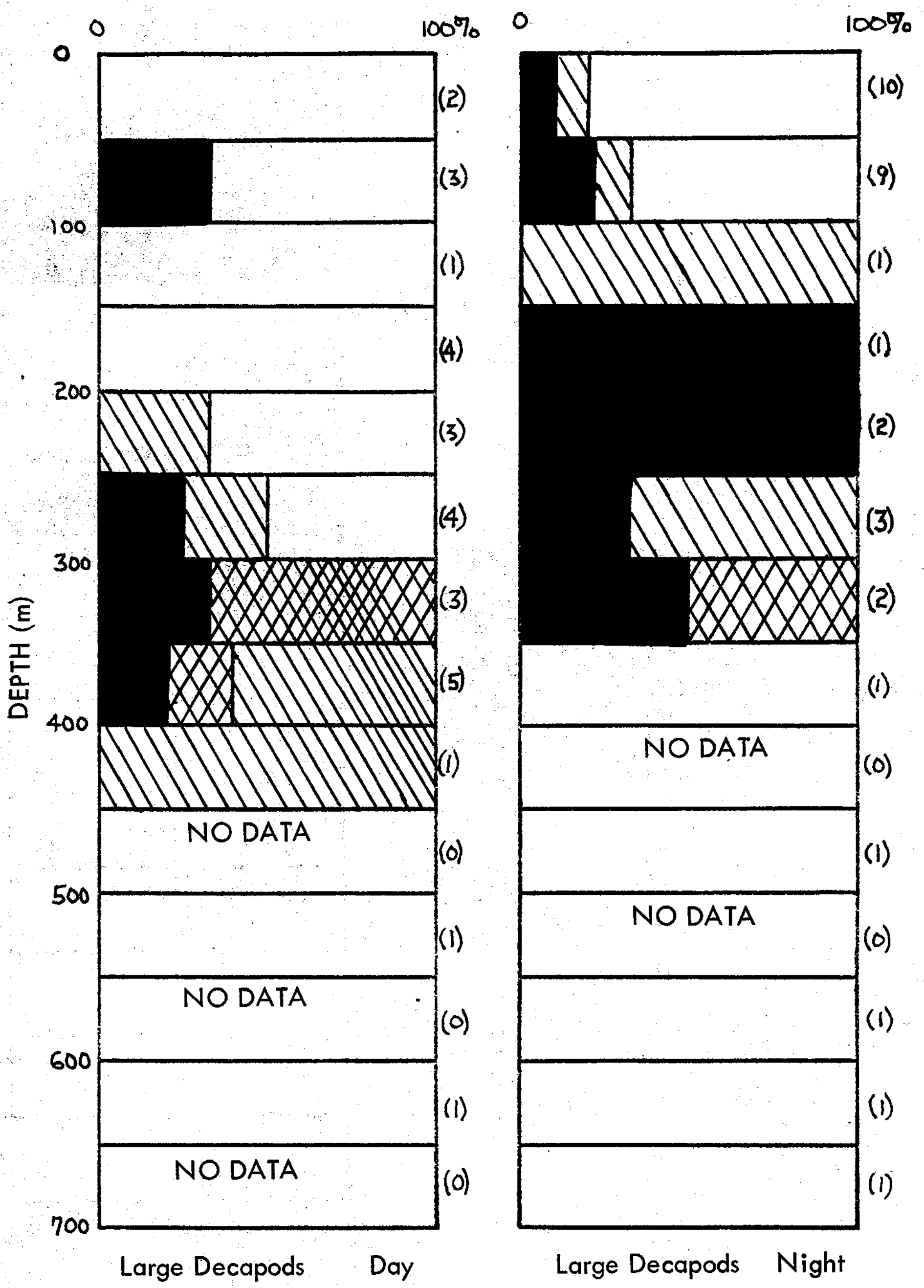


FIGURE 16. Diurnal Vertical Distribution of Large Decapods by Percentage of Dominance

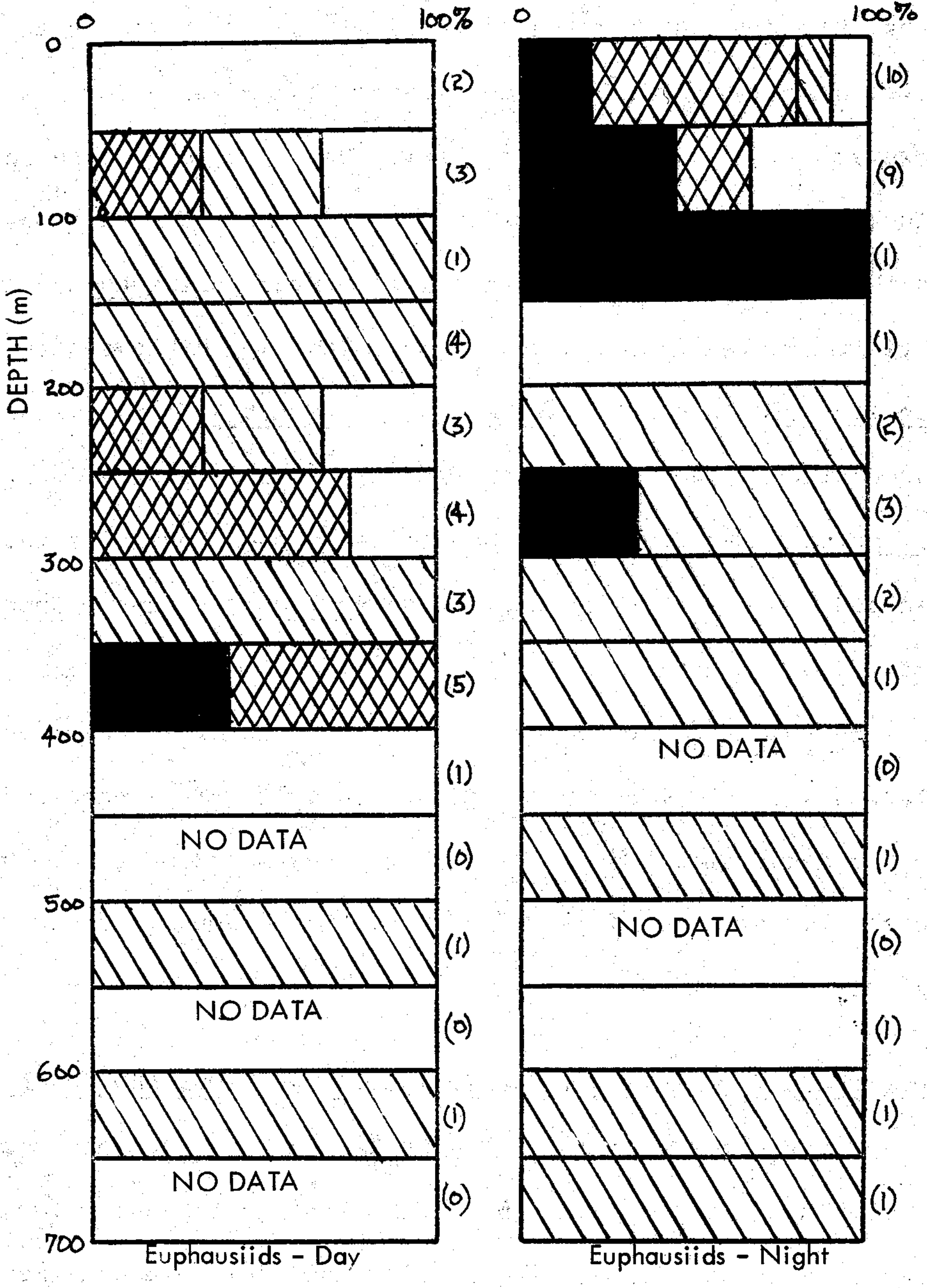


FIGURE 17. Diurnal Vertical Distribution of Euphausiids by Percentage of Dominance

lucetia, and a variety of other fishes, including larval forms. However, the absolute numbers of these specimens at the depth of the first layer are so small that no conclusions can be made for the first layer. However, small numbers of organisms could possibly cause scattering (Tucker, 1951). The figures further suggest the most probable scatterers in the second layer (300 m) are *Triphoturus mexicanus* and large (over three cm in length) decapod prawns. Other possible scatterers include *Vinceguerria lucetia*, *Diogenichthys laternatus*, larval fishes, and euphausiids. The third layer (400 m) probable scatterers would be *Triphoturus mexicanus* and euphausiids. Other possibles include large decapods, the gonostomid *Cyclothone acclinidens*, and *Diogenichthys laternatus*.

Physonectid siphonophores were found at midday near the surface at station 130 in the central part of the Gulf. They appeared to be present in large numbers. The pneumataphores contained an air bubble approximately 1.2 mm by 0.35 mm. They were also caught in three Tucker trawls, all at 60 m depths.

GULF OF CALIFORNIA NIGHT SCATTERING OBSERVATIONS AND TRAWL RESULTS

The average biomass of Tables 2A and 2B illustrate the mass migration of many organisms through the thermocline to the upper 100 meters at night. Stations 94/95, 124/126/127, and 138/139 emphasize the striking migration of fishes. They also generally support the evening rise of smaller (less than three cm in length) invertebrates to the upper hundred meters of the Gulf. The larger invertebrates seem to have the least migration into the upper 100 m at night.

Moonlight intensity was not such that it could be reliably recorded on the pyrheliometer. It may be a factor in nighttime scattering layer depths (Moore, 1958).

TABLE 1

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	15	336	[illegible]	0157/0257
59	170	5	150	50-55	2035/2135
67	40	10	67	35-45	2205/2305
88	40	15	0	35-50	2117/2217
90	30	36	24	60-65	0034/0134
95	25	0	39	60	2033/2133
102	40	9	12	40-45	2342/0042
113	120	0	33	35	2127/2227
114	110	112	190	65-90	2322/0022
119	65	6	44	55-65	2029/2129
126	70	3	290	55-60	2157/2257
127	240	6	70	90	2336/0036
131	300	6	201	50-65	1940/2040
139	400	0	305	45-55	1837/1937
159	120	12	5	70-75	2222/2322
160	[illegible]	[illegible]	0	530	0352/0452
SUM	[illegible]	[illegible]	[illegible]		
AVERAGE	[illegible]	[illegible]	[illegible]		

In nine of ten observations the depth of maximum Chlorophyll *a* was at about 40 m and the most intense scatterers migrated to within 10 m of it. This relationship is illustrated in Table 3. The acid factors at the maximum Chlorophyll *a* depth indicate that chlorophyll from living cells is present. These factors suggest that conditions similar to inshore high phytoplankton crops occur at about 40 m in most of the locations sampled (Lorenzen, 1965). The scatterers also seem to be 10-20 m below the depth of maximum oxygen concentration.

Figures 9-17 illustrate the night depths of the dominant organisms. Figure 15 shows that *Triphoturus mexicanus* is found at both the surface layers and in the 300 m layer at night.

EASTERN PACIFIC EQUATORIAL SCATTERING OBSERVATIONS AND TRAWL RESULTS

Reference isotherms and maximum sunlight intensities are provided in Figure 18. The first layer of the equatorial scattering zone was usually found between 12° and 13° C when at midday depth. The second layer was usually slightly deeper than the 10° C isotherm.

Figures 19a through 19d compare the 30 Kc DSL while at day depth, with the oxygen profiles at various stations along the latitudinal transect of Cruise 17. The transect cuts through the major portion of the eastern Pacific oxygen-minimum zone. Scattering layers do not seem associated with a steep oxycline when a 30 Kc sound source is used.

Approximately 50% of the Cruise 17 trawls were made during the day and of this about half were made in the DSL. Tables 4A and 4B compare trawls which were in scattering layers with trawls out of the layers. The dominant invertebrate in the main layer (390 m) of the equatorial scattering zone is the euphausiid while the dominant fishes are the gonostomids (larval forms and *Vinceguerria lucetia*) and the hatchet fishes

TABLE 3

NIGHT SURFACE SCATTERING INTENSITIES AND OTHER PARAMETERS

STATION	DEPTH MAX INTENSITY NIGHT SURFACE SCATTERING (M)	DEPTH OF MAX O_2 CONCENTRATION (M)	DEPTH OF MAX CHLOROPHYL A (M)	ACID FACTOR AT CHLOROPHYL A MAX	POSITION OF CHLOROPHYLL MAX IN RELATION TO THERMOCLINE
102	29-37	20-25	--	--	--
113	40 Secondary at 25M	20	40	1.6	Top
119	30-50	20	40	1.6	Top
127	22-30	20	40	1.4	Top
132	25-37	30-40	--	--	--
139	30-58	30-40	40	1.8	Top
140	30-42	30-40	40	1.8	Top
148	40	10	40	1.9	Top
156	40 Secondary at 20-22M	30	40	1.45	Top
164	--	30-40	40	1.65	Top
179	40 Secondary at 65M	0-40	--	--	--
187	33	0-40	40	1.58	Top

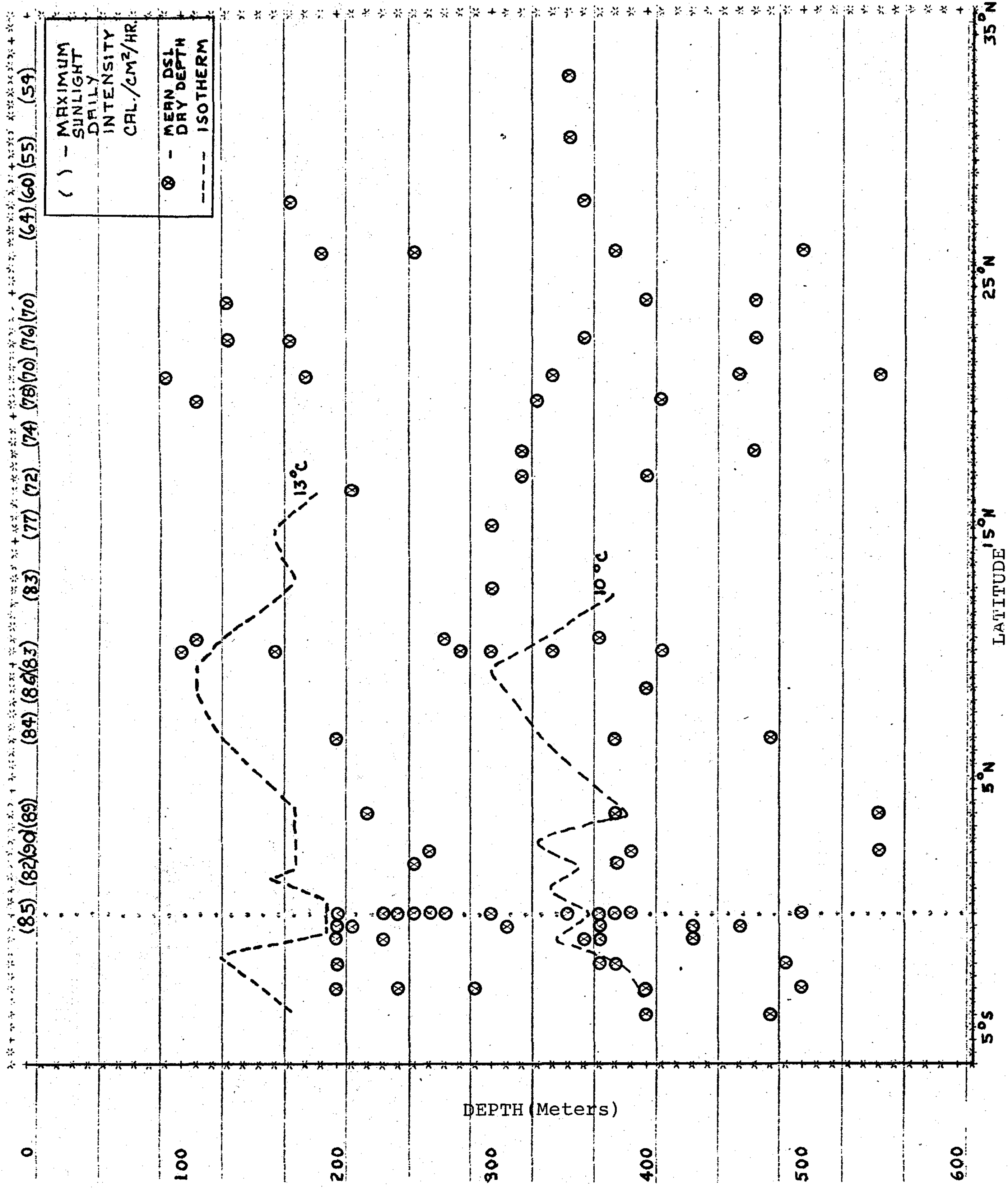


Figure 18. A comparison of day DSL depths, isotherms and sunlight intensity on a latitudinal transect

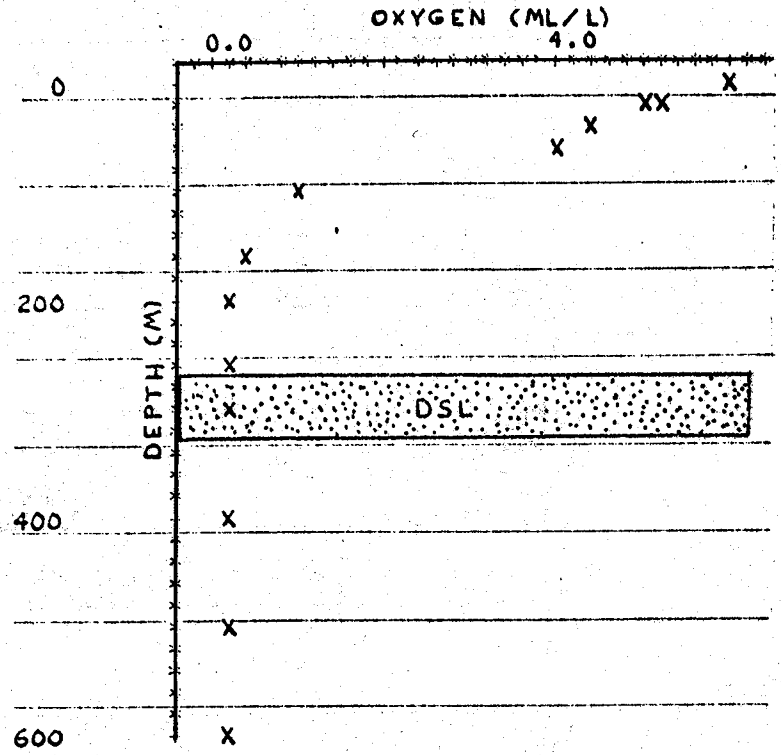


Figure 19a. Oxygen profile at 13°N, 100°W

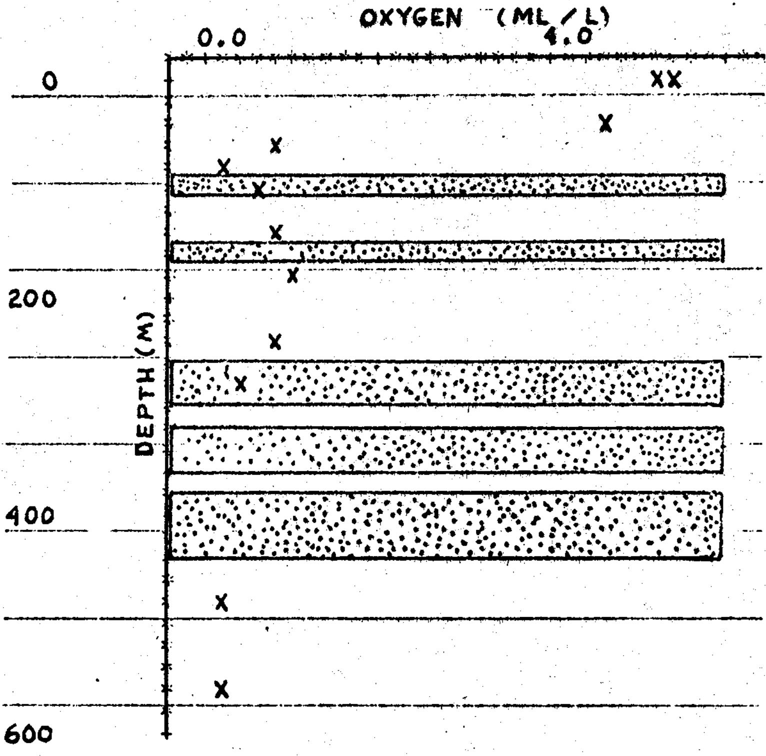


Figure 19b. Oxygen profile at 10°N, 100°W

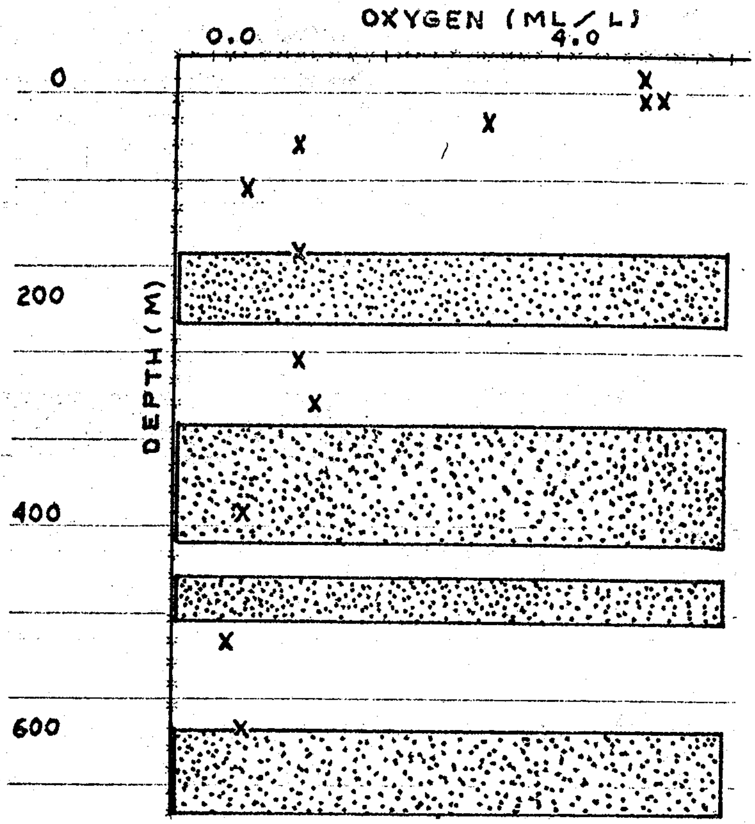


Figure 19c. Oxygen profile at 6°N, 100°W

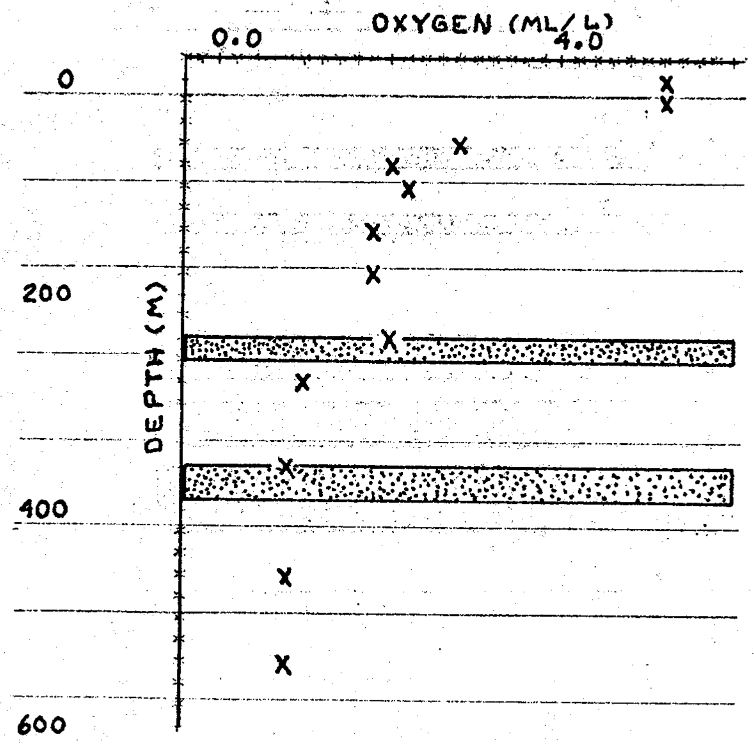


Figure 19d. Oxygen profile at 2°N, 100°W

TABLE 4

BIO-MASS SUMMARY OF DAY TUCKER TRAWLS

A. SELECTED TRAWLS WHICH TRAWLED EXCLUSIVELY IN THE DSL

TE VEGA STATION	NUMBER OF LARGE INVERTEBRATES	SMALL INVERTEBRATE DISPLACEMENT VOLUME (ml)	TOTAL NUMBER OF FISH	TIME	TRAWL DEPTH (M)	LAYER NUMBER	"SCATTERING LAYER" ZONE
17	3	8	122	1400/1500	385-481	3	Tropical
31	0	43	2	1303/1403	200-270	1	Equatorial
32	12	62	219	1520/1620	355-410	2	Equatorial
42	0	743	51	1358/1458	390-400	2	Equatorial
47	65	166	36	1000/1100	250-400	2	Equatorial
49	23	43	200*	1505/1605	450-500	3	Equatorial
57	73	412	117	0935/1035	350-378	2	Equatorial
60**	7	43	15	1625/1655	140-160	1	Equatorial
66	19	430	99	1435/1535	300-350	2	Equatorial
AVERAGE	22	216	96				

B. SELECTED TRAWLS WHICH TRAWLED EXCLUSIVELY OUT OF THE DSL

TE VEGA STATION	NUMBER OF LARGE INVERTEBRATES	SMALL INVERTEBRATE DISPLACEMENT VOLUME (ml)	TOTAL NUMBER OF FISH	TIME	TRAWL DEPTH (M)	LAYER NUMBER	"SCATTERING LAYER" ZONE
8	8	45	33	1244/1344	235-277		Tropical
10	0	8	5	1155/1255	185-225		Tropical
15	3	43	9	0931/1031	200-246		Tropical
16	1	12	0	1139/1239	60-90		Tropical
40	6	64	1	0937/1037	210-230		Equatorial
41	-	27	3	1122/1222	215-227		Equatorial
48	18	39	9	1230/1330	185-335		Equatorial
58	13	26	6	1135/1235	160-210		Equatorial
69	11	210	24	0900/1000	290-310		Equatorial
70	21	167	-	1040/1140	250-265		Equatorial
AVERAGE	9	64	10				

C. SUMMARY OF DATA BY LAYERS (FROM "A") FOR EQUATORIAL SCATTERING ZONE

LAYER NUMBER	MEAN LAYER DEPTH (M)	AVERAGE NUMBER OF LARGE INVERTEBRATES	AVERAGE SMALL INVERTEBRATE DISPLACEMENT VOLUME (ml)	AVERAGE NUMBER OF FISH	DOMINANT INVERTEBRATES	DOMINANT FISH
1	250	3	43	8	Tunicates, Siphonophores	Larval Leptocephalus
2	390	34	362	104	Euphausiids	Gonostomids and Hatchet Fish
3	500	23	43	200	Sergestid Shrimp	Myctophids and Gonostomids

* Estimated Number

** Data Corrected to Standard Day Trawl.

(*Argyropelecus pacificus* and *Argyropelecus lynchnus*). All the trawls in Table 4B are shallower than 335 m and the averages of Table 4A are greater probably not only because of the presence of DSL but because Table 4A includes data from a deeper depth range.

A numerical model or measure of the association between various organisms and scattering at different depths is desirable. It would appear that a depth class interval of 50 m would be a reasonable interval for such a numerical measure. Since many suspected organisms are found over large depth ranges, a ranking by dominance and a comparison of trawls in and out of layers for each depth class interval could provide an index of association of organism "X" with scattering, $P(X_s)$. The organism could be placed into one of four occurrence categories for each trawl: *absent*, *subdominant* (implies also present), *dominant* (implies also present), and *present* (implies also not dominant nor subdominant). These categories of occurrence could be ranked by the following weights: present (+1); subdominant (+2); dominant (+3); and, absent (-1). The following mathematical statements define the index of association with scattering of organism X, $P(X_s)$:

$$P(X|Y_s) = P(X_P|Y_s) + 2P(X_{SD}|Y_s) + 3P(X_D|Y_s) - 1P(X_A|Y_s)$$
$$P(X|Y_{NS}) = P(X_P|Y_{NS}) + 2P(X_{SD}|Y_{NS}) + 3P(X_D|Y_{NS}) - 1P(X_A|Y_{NS})$$
$$P(X_s) = P(X|Y_s) - P(X|Y_{NS})$$

X --Organism X occurs in Trawl
Y_s --Depth Interval *DOES* contain Scattering Layer
Y_{NS}--Depth Interval *DOES* *NOT* contain Scattering Layer
X_P--% (Either all Scattering or all Nonscattering) Trawls in which X "PRESENT"
X_{SD}-% (Either all Scattering or all Nonscattering) Trawls in which X "SUBDOMINANT"
X_D--% (Either all Scattering or all Nonscattering) Trawls in which X "DOMINANT"
X_A--% (Either all Scattering or all Nonscattering) Trawls in which X "ABSENT"

The results of this approach are plotted in Figure 20 for the equatorial scattering zone. A negative value of $P(X_s)$ means that the organism was generally found out of the layers and not in the layers. Perhaps some value of $P(X_s)$ is the threshold for nonresonant scattering. The model might be refined by an analysis of the volumes of organisms obtained. Euphausiids and tunicates were the only two invertebrates that were collected in large quantities and perhaps values of $P(X_s)$ around +300 are meaningful in causing scattering. In any event, the index indicates that tunicates (mainly _Iasis zonaria_) are associated with layer 1 and that euphausiids are associated with layer 2.

The micronekton results of 27 trawls in the equatorial scattering zone are found in Figures 21-27. _Triphoturus mexicanus_ does not appear above 350 m in the daytime but at night is quite dominant in the upper 250 m. _Diogenichthys laternatus_ was present at depths below 300 m in day and is possibly an "early riser" to the surface in the evening as a few specimens were found at about 150 m at about 1700. This would be ahead of the first layer's migration. _D. laternatus_ was found only in the 50-150 m depth interval at night.

Vinceguerria lucetia was present during the day throughout most of the scattering depths but most dominant in the 300-400 m interval. At night it was only found in the upper 100 m. _Cyclothone_ spp. were not as dominant as _Vinceguerria_ and were mainly found below 250 m in the daytime. _Cyclothone_ spp. were found to be dominant both in the upper 50 m and at deeper depths of 300 and 500 m at night.

The hatchet fishes, _Argyropelecus_ spp. were found dominantly from 250 - 400 m in the day and from 100 - 200 m and 300 - 350 m at night.

Two prawns of the tribe Peneides were found in large numbers.

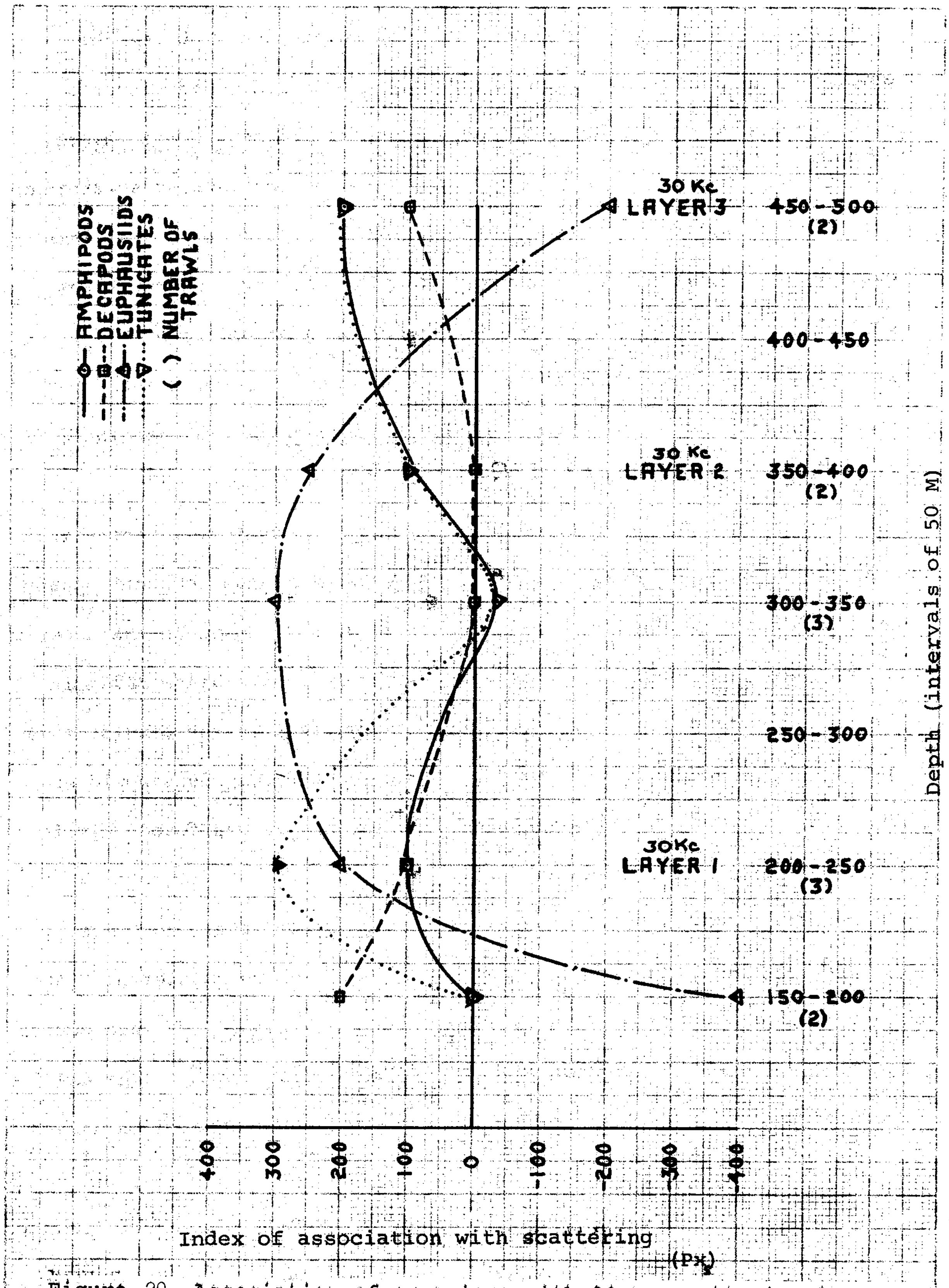


Figure 20. Association of organisms with 30 Kc scattering layers in the equatorial scattering zone

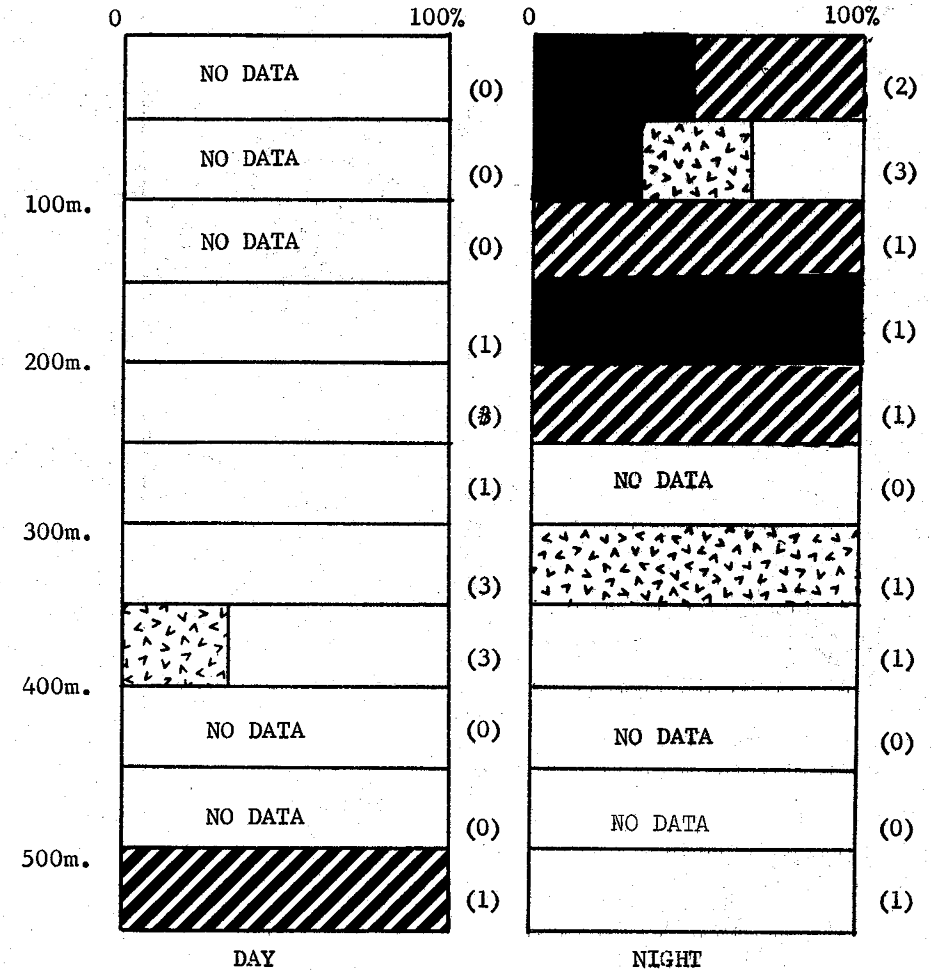


FIGURE 21. Diurnal VerticalDistribution of Triphoturus mexicanus by Percentage of Dominance

KEY : Dominant - ■
Subdominant - ▨
Present - ▩
Absent - □
No. of trawls- ( )

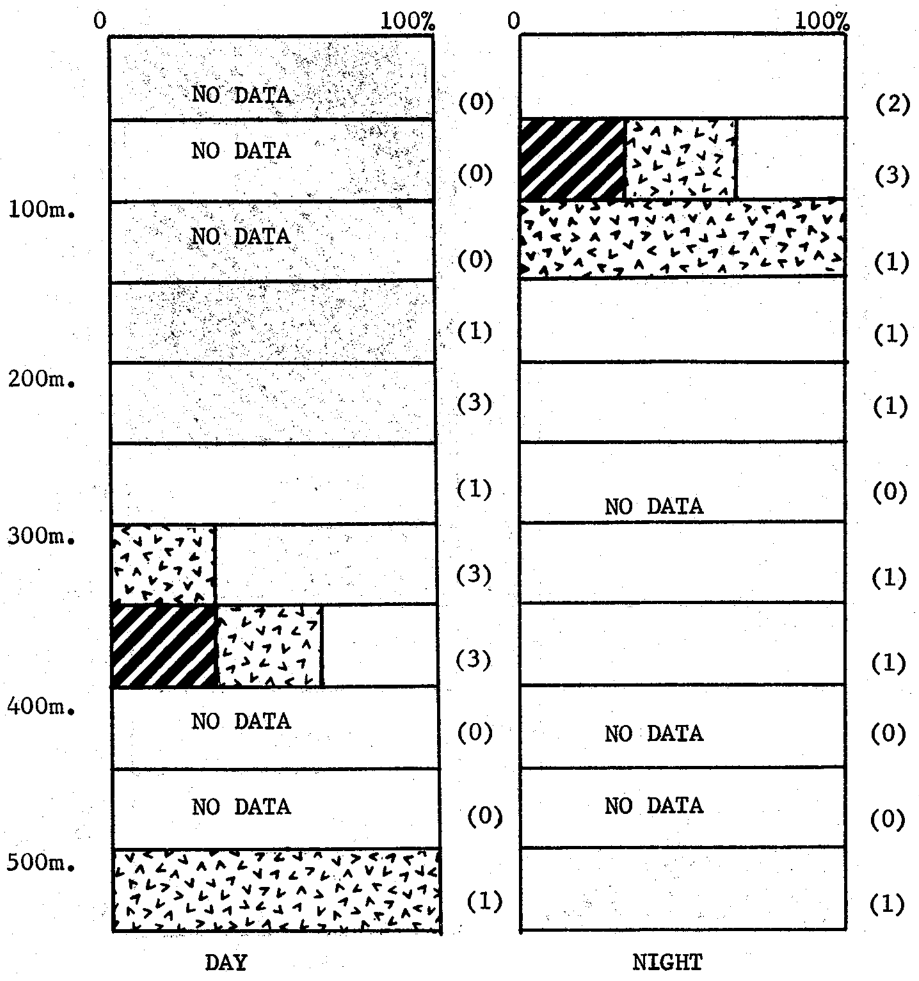


FIGURE 22. Diurnal Vertical Distribution of Diogenichthys laternatus by Percentage of Dominance

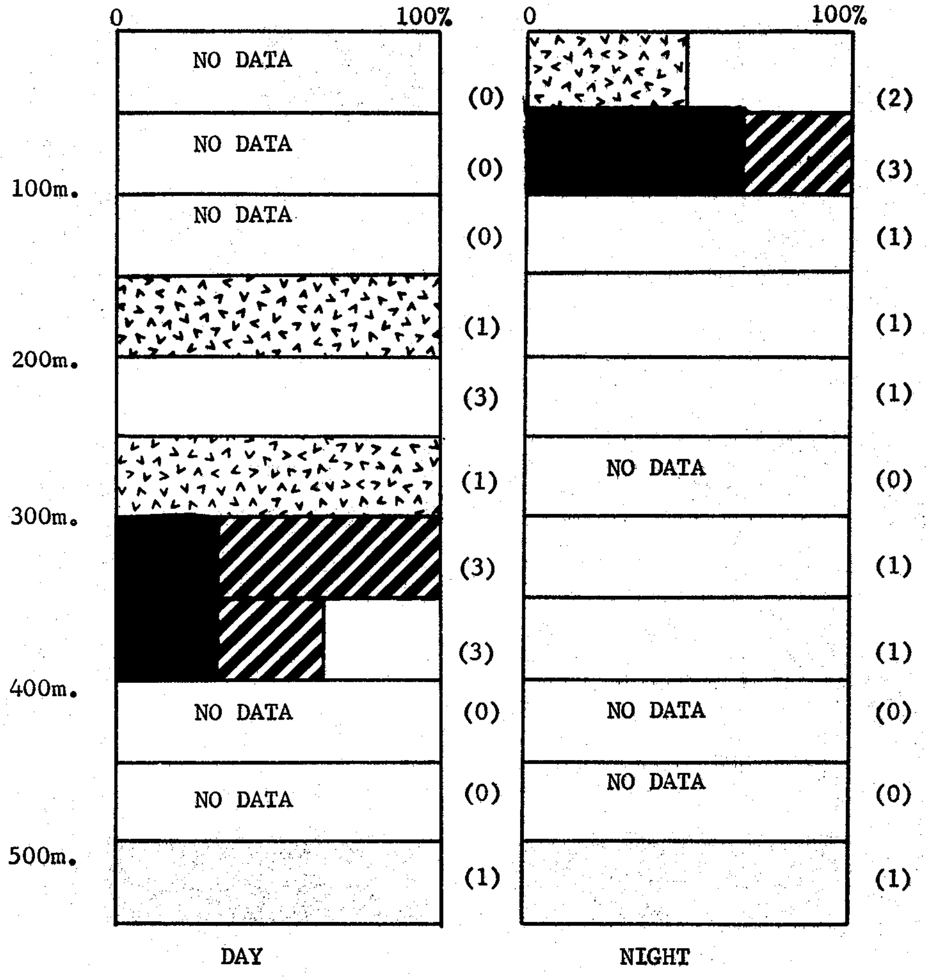


FIGURE 23. Diurnal Vertical Distribution of *Vinceguerria lucetia* by Percentage of Dominance

Dominant --- ■
Subdominant- ▨
Present----- ▩
Absent-------☐
No. of trawls ------( )

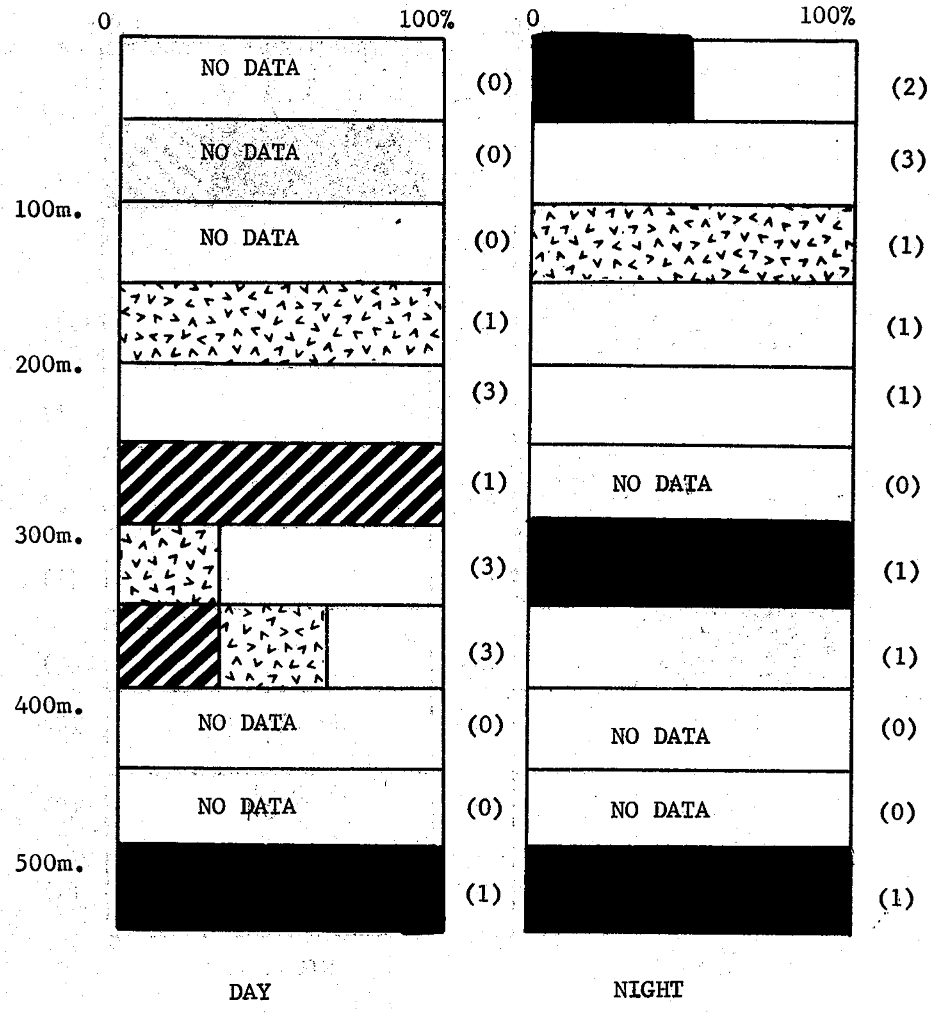


FIGURE 24. Diurnal Vertical Distribution of <u>Cyclothone</u> sp. by Percentage of Dominance

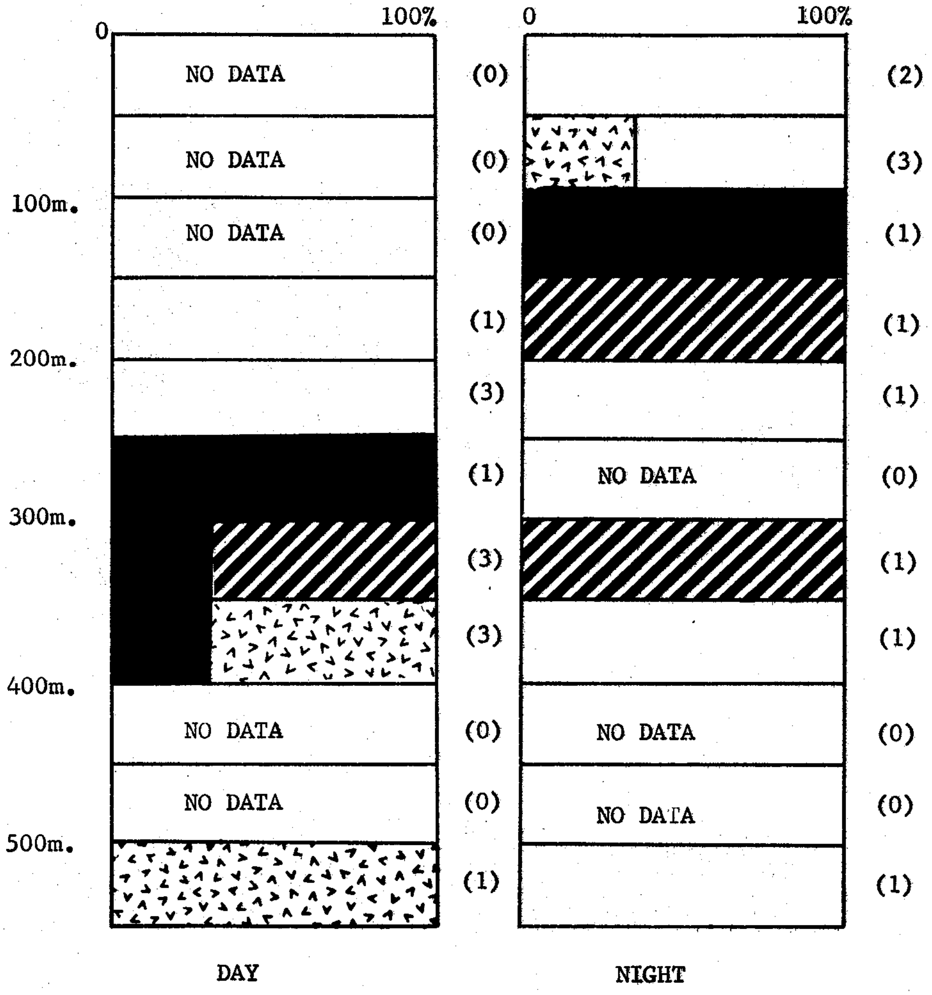


FIGURE 25. Diurnal Vertical Distribution of _Argyropelecus_ spp. by Percentage of Dominance

Dominant --- ■
Subdominant- ▨
Present----- ⁘
Absent------ □
No. of trawls------ ( )

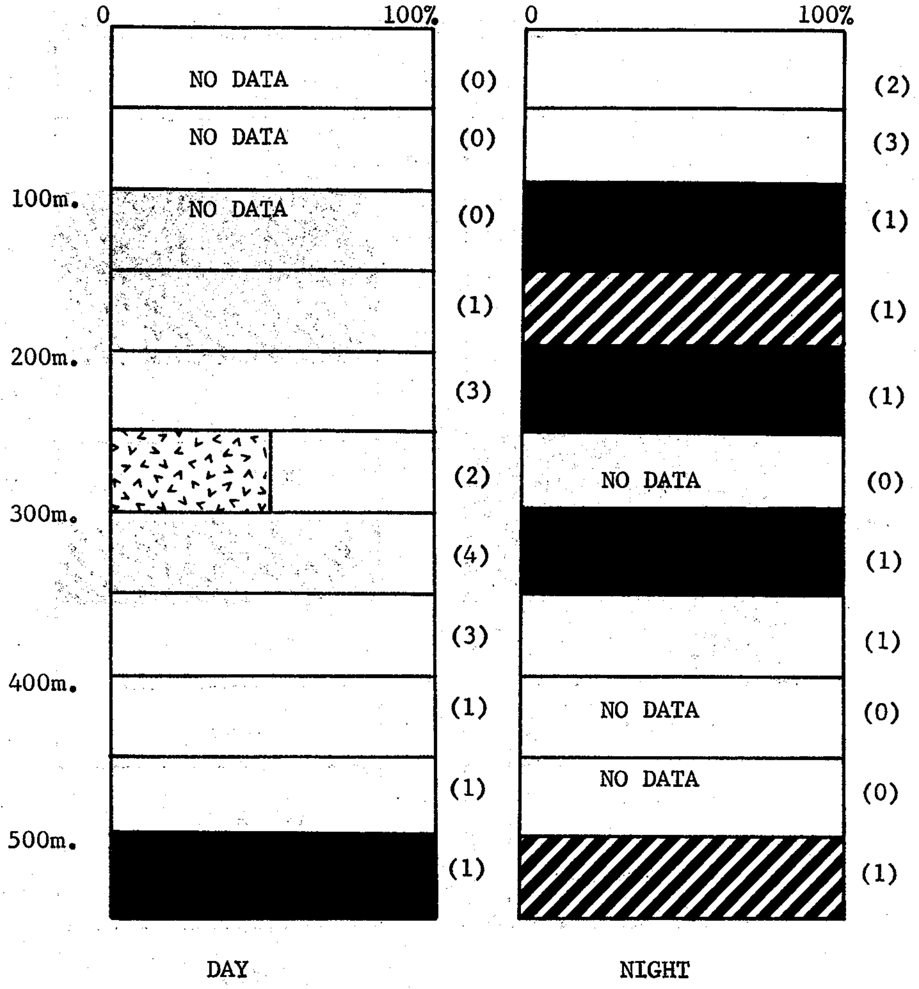


FIGURE 26. Diurnal Vertical Distribution of Gennadas sp. by Percentage of Dominance

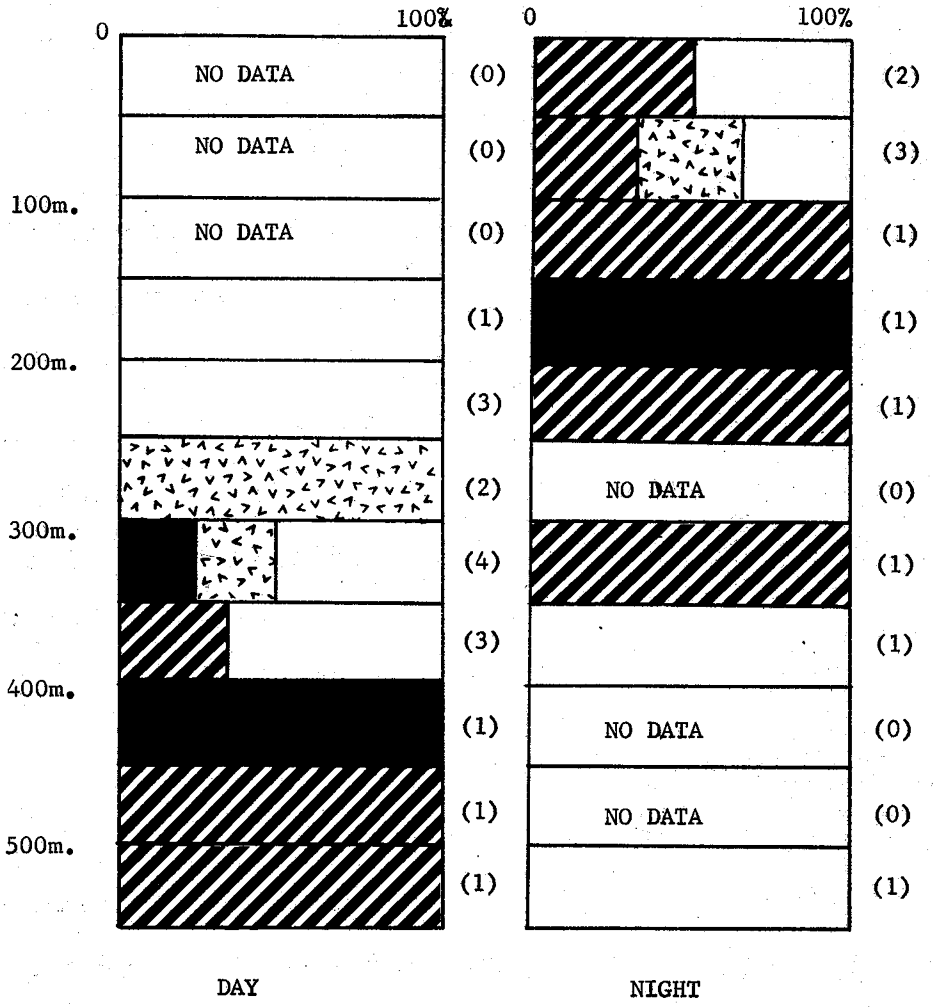


FIGURE 27. Diurnal Vertical Distribution of Sergestes sp.

by Percentage of Dominance

Dominant --- ■
Subdominant-- ▨
Present------ ⁂
Absent------- ☐
No. of trawls------- ( )

Gennadas sp. was found as the dominant large invertebrate between 500 - 550 m in the daytime and sometimes present between 250 - 300 m. At night it was particularly dominant between 100 - 350 m. Sergestes sp. was more dominant than Gennadas sp. between 250 and 500 m in the daytime. At night Sergestes sp. was usually the subdominant large invertebrate in the upper 350 m.

A comparison of these trawl results for large fish and invertebrates suggests that hardly any micronekton fish or invertebrates are associated with equatorial layer 1. Layer 2 appears to have a combination of micronekton associated with it. These include Vinceguerria lucetia, Argyropelecus spp., and Sergestes sp. The third layer suggests mainly Cyclothone spp., Triphoturus mexicanus, Gennadas sp. and Sergestes sp. Diogenichthys laternatus is also a possible scatterer in the second and third layers since it also is present at these depths.

FREQUENCY EFFECTS ON SCATTERING LAYER OBSERVATIONS

Table 5 is a summary of thirty-eight comparisons of DSL simultaneous observations using frequencies of 11 Kc and 30 Kc. The mean DSL depths for the two frequencies were rarely at the same depth and the 30 Kc mean depth was most always above the 11 Kc mean depth for the same layer. At the deeper depths (450 - 500 m) at least 50% of the time only the 30 Kc DSL would be found.

Figure 28 demonstrates the effects of frequency on resonance scattering. The standard lengths of eleven specimens of the myctophid Myctophum affine are plotted both against calculated volumes and directly measured volumes of their swimbladders. This species has a gas-filled swimbladder and volumes measured directly were much smaller than calculated volumes. Only juvenile specimens of Myctophum affine less than about 15

TABLE 5

A COMPARISON OF 30 Kc AND 11 Kc MEAN DSL DEPTHS

Layer #	Depth Interval (M)	30 Kc DSL Above 11 Kc DSL (% OBS)	11 Kc DSL Above 30 Kc DSL (% OBS)	Both Freq. DSL Same Depth (% OBS)	Only 30 Kc DSL (% OBS)	Only 11 Kc DSL (% OBS)	Number of OBS.
1T, 1E	100-250	61.5	0	0	30.5	8.0	13
2T	250-350	14.3	14.3	0	42.8	28.6	7
2E, 3T	350-450	40.0	0	20.0	30.0	10.0	10
3E, 4T	450-550	25.0	12.5	12.5	50.0	0	8
ALL	100-550	39.5	5.25	8.0	36.75	10.5	38

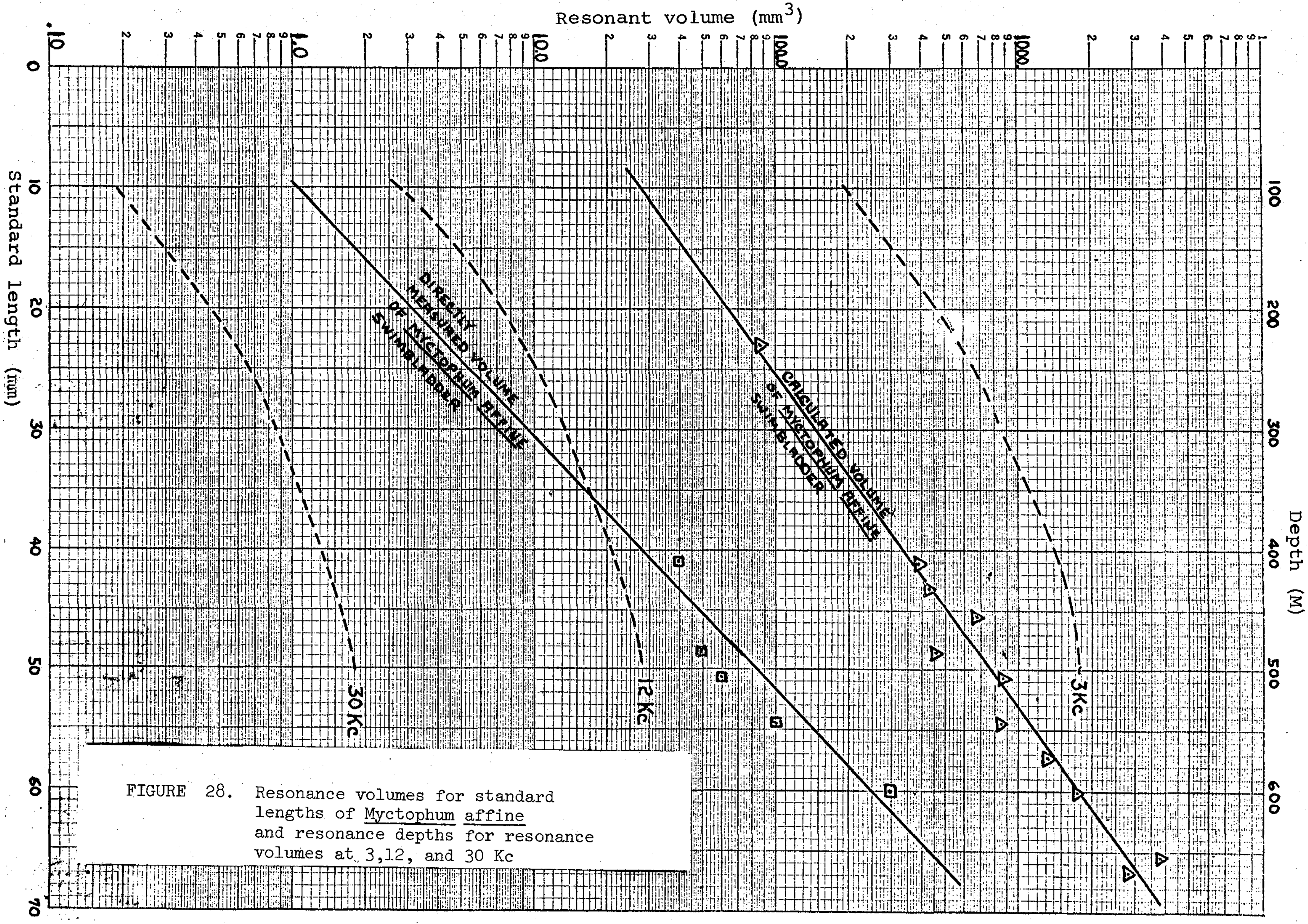


FIGURE 28. Resonance volumes for standard lengths of Myctophum affine and resonance depths for resonance volumes at 3,12, and 30 Kc

mm in standard length would resonate above a depth of 500 m if a fathometer frequency of 30 Kc is used. At 12 Kc, specimens of this species with standard lengths up to about 40 mm would resonate above 500 m.

Table 6 is a summary of the actual number of the major midwater fishes caught in the Tucker Trawl for Cruises 16 and 17.

DISCUSSION

North Atlantic DSL midday depths usually average 240 m and 500 m (Hersey and Backus, 1962). Pacific DSL average depths off California are between 280 and 510 m (Dietz, 1962). Hersey and Backus (1962) report DSL depths of 260 m and 420 m for off northern Chile. Thus, DSL depths are somewhat different for various parts of the world ocean. This study uses over 100 echogram observations and over 100 trawls to describe basically one water mass, the Pacific Equatorial water.

A comparison of this study with the DSL of other equatorial regions provides interesting results. TE VEGA had previously investigated the DSL in the equatorial Indian Ocean (Abbott, et. al., unpublished TE VEGA Cruise 5 manuscript). The 24 hour DSL cycle observed in the Indian Ocean by Abbott and the Pacific diurnal cycle of this study are strikingly similar. A main layer at about 400 m and an intermediate layer at about 250 m are found in both studies. Tunicates (Iasis zonaria and Pyrosoma sp.) and euphausiids were closely associated with 30 Kc scattering layers in both studies. "Association" in this study does not necessarily mean a cause and effect relationship. For example pelagic tunicates do not theoretically have good acoustic scattering qualities.

TABLE 6

SUMMARY OF MAJOR MIDWATER FISH

	CRUISE 16*		CRUISE 17**	
	Number of Trawls	Number of Fish	Number of Trawls	Number of Fish
Triphoturus mexicanus	56	5457	9	327
Diogenichthys laternatus	52	335	8	105
Vinceguerria lucetia	39	392	11	302
Cyclothone acclinidens	30	421	1	139
Cylothone sp.	--	--	7	274
Aethophora lucida	--	--	2	111
Lampanyctus regalis	--	--	2	102

*Based on 70 trawls
**Based on 29 trawls

Dietz (1948) found the DSL of the tropical Pacific to be deeper than off San Diego when an 18 Kc sound pulse was used. However, a detailed reconnaissance of the DSL in the eastern tropical Pacific has not been made prior to the present study.

The particular division of latitudinal scattering zones for 30 Kc in this report could be explained by a number of factors, including oceanographic conditions, light conditions, and patchiness.

The oceanographic conditions are somewhat different in the tropical scattering zone. The oxygen minimum zone, the thermal equator upwelling at about 10°N and the Northern Pacific Equatorial Current are the dominant factors in this zone. The equatorial scattering zone is dominated by the Equatorial Counter Current, the Cromwell Current and equatorial upwelling. Wyrtki (1967) also distinguishes between equatorial surface water and tropical surface water.

Light conditions were a possible source of the latitudinal variations. Incident sunlight intensities are not usually thought to vary the depth of the scattering layer by more than about 50 m (Moore, 1958). If this is the explanation it would seem that, given similar turbidity, the tropical scattering zone mean depth values could shift seasonally. However, previous TE VEGA data obtained in a different season seemed to indicate that the mean layer depth pattern was very constant (Levenson, unpublished TE VEGA Cruise 15 manuscript). It is doubtful that the equatorial scattering zone depths would shift much due to light, since seasonal light changes appear to be less than 6 cal/cm^2/hr. (Moore, 1958).

The possibility of patchiness in observations in the oceans almost always exists. Three observations in the 30 Kc equatorial scattering zone at 300 m fit the pattern of the tropical zone. It must be recognized that these patterns might be fortuitous to this set of observations since vast areas of ocean are being considered.

The overall patterns still seem more likely to be more permanent than in the northern Pacific DSL where seasonal variations have been definitely observed at 17 - 18 Kc (Barham, 1957).

Much of this investigation was carried out in the Gulf of California. The Gulf is an extremely interesting model for DSL studies due to the bottom topography which provides a distinct boundary between Pacific Equatorial water and Gulf water. In the Gulf of California, Pacific Equatorial water is generally beneath the thermocline and south of the northern sill. Gulf water is found above the thermocline in the south and at all depths north of the sill (Roden and Groves, 1959). This condition is broken at the depths of most scattering layers by sizeable internal waves. Monk (1941) demonstrated that a dominant internal wave with a period of seven days and an amplitude of approximately 200 m is present in the Gulf. This weekly internal wave effect must be considered when analyzing parameters such as the distributions of temperature, nutrients, salinity and currents. The mean depths of the layers appeared to be independent of internal waves. Consistent layers at 175, 300 and 400 meters were observed during the two month sampling period.

The apparent lack of deeper DSL (400 - 600 m) in the Ballenas Trench and the Delfin Basin in the northern part of the Gulf provides an interesting situation. The conditions are such that the water is relatively warm (above 10°C), well oxygenated (above 1.0 ml/O_2) and of relatively higher salinity (above 34.8‰). The small number of observations for the northern Gulf can not be used to make any definite conclusions. However, the data indicates that deep layers may be related to these oceanographic parameters. The data of trawls in the northern Gulf again is sparse although there are indications of a different faunal development and in particular a scarcity of some of the most suspected scatterers such as Triphoturus mexicanus, Vinceguerria lucetia, Diogenichthys laternatus, and Cyclothone acclinidens.

This study suggests that scattering layers do not appear to be related to oxyclines or oxygen concentration. Bary (1966) suggested that day layer depths in Saanich Inlet might be determined by an oxycline. In the Gulf of California the oxycline is above a similar oxygen minimum. Due to the similarities of the two areas, this study would suggest that the scattering layers of Saanich Inlet are in the oxycline by coincidence or that they could possibly be there by necessity due to the shallow depths of the inlet. Oxygen gradients also seemed to have little predictive association with DSL in the open ocean portion of this study.

Temperature gradients or certain absolute values of temperature may have acted as a brake in the downward migration of the DSL because usually the layers were at maximum depth several hours before the maximum sunlight intensity would occur. However, the rate of increase of sunlight intensity varies slightly about the time the layers reach maximum day depth. Thus rate change of light might not only start the migration but also brake it. Moore (1958) mentions the possibility of the "thermal brake" but Hersey and Backus (1962) assert that there is no correlation between midday depth and temperature. The midday DSL "association" with isotherms such as at 14°, 13°, and 10° in this study indicates that isotherms have predictive value and may or may not have a cause - effect relationship.

Light has been briefly discussed but its effects on vertical migration are complex. In this study not all organisms of the same species (e.g., Triphorurus mexicanus) migrate to the surface layers at night.

Thus not all migrating organisms are light followers. This is contrary to a previous study of myctophid distribution off Southern California (Paxton, 1967).

Organisms might migrate to feed in an environment where it would be easier to find food (Marshall, 1954). In this study scattering layers were observed to migrate to the maximum Chlorophyll a or phytoplankton level at a depth of about 40 m. This may be another explanation for Paxton's (1967) night critical depth of 50 m. Longhurst (1967) found that the greatest zooplankton biomass that migrated to the surface was at the depth of maximum Chlorophyll a. Other factors such as the depth of the mixed layer and higher temperatures could also limit this upward migration (Hersey and Backus, 1962; Paxton, 1967).

The feeding habits and behavioral patterns of many suspected scattering organisms still appear to be unresolved. Miles (unpublished TE VEGA Cruise 15 manuscript) showed by stomach investigations that Triphoturus mexicanus was a nocturnal feeder and that the main item in the diet of the larger of the specimens was euphausiids. However Paxton (1967) suggested that myctophid fishes were continuous feeders throughout the day and night. The present study shows that euphausiids and some T. mexicanus move to the surface layers, that both are highly probable scatterers, and that some scattering layers move to the maximum phytoplankton level. Thus it is probable that some scattering organisms migrate in order to feed. Light probably triggers and controls this migration (Clarke and Backus, 1965).

Most studies do not cite trawl sampling efficiencies since efficiency studies are so complex. This study relies on a relative efficiency approach used in a previous Tucker trawl study of the DSL (Barham, 1957). There were several differences between the two Tucker trawl procedures. The present study used a towing speed of about 2 kts. compared with Barham's average speed of 1.22 kts. The present study also used a heavier rig since an opening and closing device and larger depressors were used. These differences should not alter the selectivity of the trawl very much. Barham compared results of the Tucker trawl with that of a meter net at the same depth. He found that the Tucker trawl was good for the micronekton while the meter net was better for the macroplankton. The present study has used only the Tucker trawl for quantitative sampling and this selectivity must be considered in the evaluation of the data.

Andreeva (1965) points out that the catching capacity of DSL trawl equipment must be determined and that numerical decibel measurement of the intensity levels of scattering layers are urgently needed. TE VEGA equipment could be altered to provide this information but this study has not had the benefits of numerical variation of scattering intensities with depth. While it is not as helpful in acoustic work, an alternative approach is to analyze for mean layer depths and non-parametric rankings such as presence, dominance, absence, etc. This approach was used sucessfully although the statistical reliability of the sampling methods can not be determined as readily.

When evaluating the organisms which might cause the DSL, it is necessary to investigate which animals are found in the layers. Next, these organisms are compared with the fauna which is found throughout the water column. In this way it is possible to eliminate organisms which have no physical scattering mechanism and which are found at all depths. Using this approach the most probable major scatterers for the second layer (300 m) in the Gulf of California are the myctophid <u>Triphoturus mexicanus</u>

and large decapod prawns (mainly Sergestes sp.). Triphoturus mexicanus and euphausiids are the suspected scatterers in the third layer (400 m). Other organisms such as the myctophid Diogenichthys laternatus and the gonostomids Vinceguerria lucetia and Cyclothone acclinidens seem to have a smaller effect. It was not possible to evaluate the first layer since so few specimens were obtained at that depth during TE VEGA Cruise 16.

The same method used in the equatorial scattering zone produced interesting comparative data. Again the first layer (250 m) did not provide enough organisms to warrant a conclusion of their association with scattering. Pearcy and Laurs (1966) off Oregon explain a similar problem with a shallow layer by net avoidance. Taylor (1968) recently used a much larger net off British Columbia and for a similar undefined shallow layer rejected net avoidance and proposed smaller euphausiids which would pass through a larger net mesh. In the present study even macroplankton such as euphausiids seem ruled out on the basis of trawl catch data. Something fragile such as siphonophores could agree with such requirements, as it would break up and pass through the net. However, recent findings (Pickwell et al, 1968) report that siphonophores probably do not migrate diurnally as a total population as previously suggested. Thus, it would appear that net avoidance or some other explanation may be involved in the determination of the faunal composition of the first DSL of the tropical and equatorial eastern Pacific. This question will probably remain unanswered until it can be clearly determined how many organisms are actually required to indicate a DSL.

The DSL faunal composition scheme of Figure 20 provides some additional information. It suggests pelagic tunicates are associated with the first layer. While the data is insufficient for statistical confidence, it provides a numerical approach to the situation. Of particular interest in this model is the close association of tunicates and amphipods in the mesopelagic zone. A possible verification of the model can be physically observed in the association of the amphipod *Phronima* which resides inside the dead skin of the tunicate *Pyrosoma*.

While the first layer may be quite undefined, the second or main layer (390 m) of the equatorial scattering zone seems to contain the micronekton *Vinceguerria lucetia*, *Argyropelecus* sp., and the large decapod prawns *Sergestes* sp. The hatchet fish *Argyropelecus* does not appear to make the entire migration to the surface at night. It has been suggested as one of the major causes of the non-migratory night DSL off California (Pickwell et al, 1968). This may explain one or more of the diffuse night layers of Figure 4.

In the third layer of the equatorial scattering zone *Triphoturus mexicanus* again appears. It may be significant that this myctophid was found at greater depths in the equatorial area than in the Gulf of California. *T. mexicanus* appears to be one of the most dominant myctophids of eastern Pacific Equatorial water mass and thus this major change in depth distribution is of interest. There may be a relation between *T. mexicanus* and the deeper DSL pattern in the eastern Equatorial Pacific. Off California the swimbladders of the adult *T. mexicanus* are fat invested, while the juveniles have gas filled swimbladders (Capen, 1967). Thus the juveniles are theoretically good resonant scatterers for the frequencies of this investigation.

T. mexicanus and *Diogenichthys laternatus* have been associated specifically with the eastern Pacific Equatorial water mass (Paxton, 1967). The distribution of T. mexicanus has been also thought to vary seasonally in the northern part of this water mass (Paxton, 1967). It would seem that seasonal changes would be minimal in the region of this present study and that T. mexicanus is probably associated with scattering in the Pacific Equatorial water mass.

This study suggests Cyclothone spp., Gennadas sp. and Sergestes sp. as possible scatterers in the third layer of the equatorial scattering zone. Deep submersible observations have shown similar concentrations of physonect siphonophores, Cyclothone spp., and sergestid prawns in the daytime DSL off southern California and Baja California (Pickwell et al, 1968). The same previous observations linked Cyclothone spp. with the night non-migratory scattering layers and the distributional data of this report agrees with this finding.

Physonect siphonophores are not mentioned as probable DSL organisms due to the lack of specimens collected in water deeper than 60 m. Kincaid (unpublished TE VEGA Cruise 15 manuscript) found siphonophores to be distributed predominantly in the upper 100 m in the Gulf of California.

Barham (1966) observed siphonophores at DSL depth just outside of the Gulf of California. They are difficult to sample effectively due to break-up and loss through the Tucker trawl net.

It would appear that the Tucker trawl does sample the water column fairly well since much of the distributional data of this study is generally very similar to that described by some of the recent deep submersible aquanauts of the sea (Barham, 1966; Pickwell et al, 1968).

One of the major strengths of this study was the availability of two frequencies for use in determining the depths of the DSL. Perhaps the reason that the 30 Kc mean DSL depth was usually above that of the 11 Kc observation was that there may be a gradient of smaller organisms to that of larger organisms with depth in some of the scattering layers.

Some scattering occurs when the organism is about equal to or less than the wave length of the sound pulse. This wave-length scattering would occur for specimens less than five cm in length for 30 Kc. The effects of wave-length scattering are quite small when compared with resonance scattering. Figure 28 illustrates the volume of a bubble required for resonance scattering at the TE VEGA frequencies. These frequencies seem to require very small mesopelagic fish with swimbladders or some small invertebrate macroplankter with some sort of gas bubble inside.

The swimbladder analysis was based on selected specimens from the early evening equatorial surface waters. Many specimens still had all their scales present when dip netted. It would seem that the volumes of the swimbladders would be at their maximum inflation since they had just arrived from deeper waters. The volume of gas in the swimbladder encountered in this study was greater on a calculated and direct measurement basis than most Pacific myctophids (Capen, 1967). Myctophum affine seemed to be similar to the Pacific hake in its possible resonant scattering range (Capen, 1967). Thus, Myctophum affine could also resonate at lower frequencies as well as 30 or 11 Kc.

CONCLUSIONS

1. Scattering layers appearing at 30 Kc in the Pacific Equatorial water mass may possibly be divided into different latitudinal zones. These may consist of an equatorial scattering zone from 4°S to about 7°N which consists of day mean layer depths of about

250, 390 and 500 m. The second possible latitudinal interval is the tropical scattering zone from about 8 °N to about 24°N with layer depths of about 150, 300, 400 and 500 m.

2. The Pacific equatorial scattering zone appears similar to the same latitudinal zone in the Indian Ocean where the main layer depth has been reported to be at about 400 m with an intermediate layer at about 250 m.
3. The 30 Kc scattering layers of the Gulf of California appear to be an integral northern extension of the open Pacific tropical scattering zone. However the 400 and 500 m DSL do not usually occur in the northern basin and trench of the Gulf of California.
4. Mean layer depths above 300 m seem to be mainly related to maximum daily sunlight intensities and generally to water mass conditions. The relationship to light intensity may include not only the daily maximum intensity value but also the time rate of change of light intensity. Layer depths at 30 Kc did not appear related to oxyclines.
5. Trawl data suggests that tunicates, siphonophores, euphausiids, amphipods and decapods are associated with scattering in the first equatorial scattering zone layer. However the numbers of these organisms are so small in the first layer that they may only have predictive value with little cause and effect relation to scattering. Euphausiids, small gonostomid fishes and hatchet fishes were associated with the main layer at about 400 m. Tunicates, amphipods, decapods, gonostomid fishes and myctophid fishes are associated with the deep 500 m layer.

6. In the Gulf of California the probable scattering organisms are undetermined for the first layer, myctophid fishes and large decapod prawns in the second layer, and myctophid fishes and euphausiids in the third layer.

7. Some of the species most associated with scattering in the Pacific Equatorial water mass were: the myctophid fishes, Triphoturus mexicanus and Diogenichthys laternatus; the hatchet fishes, Argyropelecus lynchnus and Argyropelecus pacificus; the prawns, Sergestes sp. and Gennadas sp; and the tunicate, Iasis zonaria.

8. Based on indirect evidence some deep scattering layers appear to migrate to the surface waters to feed. Some layers appeared to migrate to the depth of maximum Chlorophyll *a* or phytoplankton which was normally about 40 meters in the Gulf of California. However, it must be recognized that higher temperatures at the top of the thermocline could also explain this limit in the upward night migration.

9. For resonance scattering using 11 and 30 Kc frequencies, the volume of a resonating swimbladder would be .02 to 28 mm^3 for depths between 100 and 500 m. Data for Myctophum affine indicates that typical standard lengths of equatorial zone myctophids for resonance might be between 0 and 40 mm.

10. Comparison of frequency data suggests there may be a gradient of the size of organisms in the DSL with the smaller organisms at the top of the layer.

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13. ABSTRACT

This reconnaissance is the first ecological study of the deep scattering layers (DSL) in the eastern tropical Pacific. It was made during two three month cruises of the R/V TE VEGA, one of which was predominantly in the Gulf of California. The reconnaissance is based on over 100 fathometer echograms and 100 trawls which fished for a period of one hour with an opening and closing Tucker midwater trawl. Echograms of two fathometer frequencies (30 Kc and 11 Kc) indicated that two latitudinal scattering zones may exist. Temperature, oxygen, light intensity, faunal composition, and swimbladder morphology were investigated with relation to the DSL. The oxyclines associated with the eastern Pacific oxygen minimum zone seemed to have little effect on the DSL. Possible further evidence for the migration of DSL organisms for feeding purposes was apparent as the maximum night surface scattering was observed at the depth of maximum chlorophyll a or phytoplankton. Frequency comparisons indicated a possible gradient of the size of organisms in the DSL with smaller organisms toward the top of the layer. A twenty-four hour continuous observation of an equatorial Pacific DSL diurnal cycle and an evaluation of possible scattering organisms are included.

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