DOE/NBM-2015781
(DE82015781)

DIEL DISTRIBUTION OF ZOOPLANKTON AT THE MOBIL OTEC SITE (29°N 88°W) IN THE NORTHERN GULF OF MEXICO

By
John P. Steen, Jr.
Gordon Gunter
Eric O. Hartwig

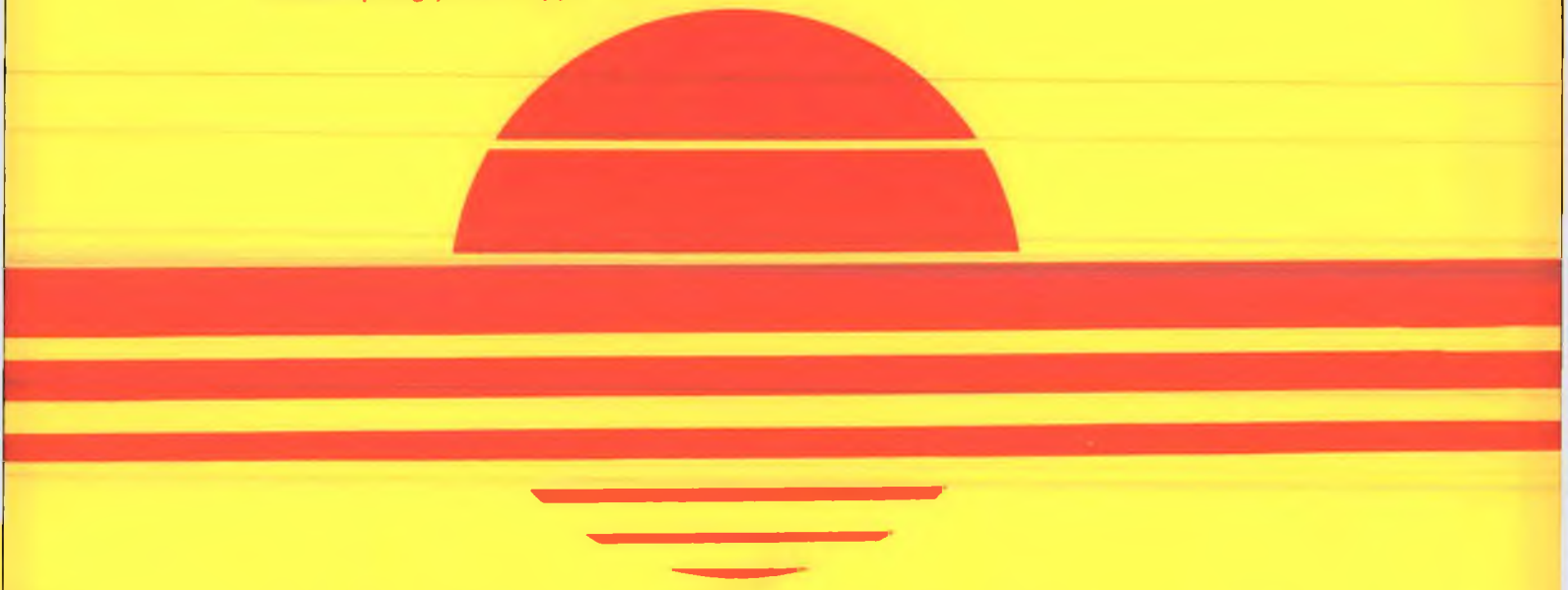
January 1982

Work Performed Under Contract No. W-7405-ENG-48

University of California
Lawrence Berkeley Laboratory
Berkeley, California

and

Gulf Coast Research Laboratory
Ocean Springs, Mississippi



U.S. Department of Energy

Solar Energy

DISCLAIMER

DISCLAIMER

DOE/NBM-2015781
(DE82015781)
Distribution Category UC-64

Diel Distribution of Zooplankton at the Mobil OTEC Site (29°N 88°W) in the Northern Gulf of Mexico

John P. Steen, Jr.[1]
Gordon Gunter[1]
and
Eric O. Hartwig[2]

[1] Gulf Coast Research Laboratory
Ocean Springs, MS 39564

[2] Marine Sciences Group
Lawrence Berkeley Laboratory
Berkeley, CA 94720

January, 1982

This work was done under a subcontract (LBL 4714602) with the Lawrence Berkeley Laboratory. The Lawrence Berkeley Laboratory is operated by the University of California for the U.S. Department of Energy under Contract DE-AC03-76SF00098.

Diel Distribution of Zooplankton at the Mobile OTEC Site ($29^{o}N$ $88^{o}W$) in the Northern Gulf of Mexico

ABSTRACT

In the study 128 copepod species and 43 other zooplankton taxa were identified from four depth strata (0-50m, 50-100m, 100-300m and 300-500m). Duplicate step-oblique tows at six hour intervals over 24 hours were taken at a site in the Gulf of Mexico. The distribution of zooplankton numbers and sizes, and species diversity, richness and evenness through a diel period are described.

INTRODUCTION

The operation of an OTEC plant will redistribute large volumes of water. Also, the use of biofouling control agents and working fluids may alter zooplankton behavior and mortality rates (Venkataramiah, et al., 1981) and therefore their distributions.

Many zooplankton species migrate vertically through the water column on a diel cycle. Recognition of this phenomenon dates back to the last century (Cuvier, 1817; Loeb, 1839). The somewhat scanty information available in this field has been reviewed by Russell (1927), Cushing (1951), Banse (1964) and Pearre (1979). However, the mechanism affecting the vertical migration of zooplankton remains incompletely understood (Clark, 1934; Moore, 1955, 1965; Moore and O'Berry, 1957; Rudjakov, 1970; and Pearre, 1973). It is still unknown whether some life stages and species of zooplankton migrate at all (Roe, 1972; Zaret and Suffern, 1976) and the problems of actually determining vertical migrations through conventional sampling methods are extensive (Pearre, 1979).

It was the purpose of this study to collect and analyze data on the vertical movement of zooplankton at the Mobile OTEC site in the northern Gulf of Mexico. Comparatively little work has been done on the vertical distributions of oceanic zooplankton based upon systematic sampling with closing nets. Several studies describing the vertical distribution of

zooplankton have been conducted in the Gulf of Mexico and Caribbean (Owre and Foyo, 1964, 1967; Roehr and Moore, 1965; Michel and Foyo, 1976; and Park, 1970).

ACKNOWLEDGEMENTS

This work was done under subcontract to the Lawrence Berkeley Laboratory (LBL 4714602) for the Assistant Secretary for Conservation & Renewable Energy, Office of Solar Applications, Division of Ocean Energy Systems, Department of Energy, contract # DE-AC03-76SF00098.

METHODS

Zooplankton were sampled at approximately six hour intervals over a 24 hour period on November 1-2, 1978, at depths of 0m-50m, 50m-100m, 100m-300m and 300m-500m with duplicate samples taken at all depths during the 0915-1415 CST (day) time period. Step-oblique tows were made with metered 0.75, 5 to 1 ratio, 202μ mesh conical nets fished in tandem pairs. The nets were fished in tandem pairs so that simultaneous samples could be taken at 0m-50m and 50m-100m and again at 100m-300m and 300m-500m. Both nets were equipped with opening and closing devices. Total water depth was approximately 1200m.

Sampling depth was determined by measuring the length of wire that was let out and adjusting the ship speed so that a wire angle of 45^{o} was maintained throughout the tow. An electronic wire angle indication device facilitated the wire angle maintenance within a range of $\pm 3^{o}$.

Step-oblique zooplankton tows from 0m-50m and 50m-100m strata were divided into depth intervals of 10 meters. The net was opened at the bottom of the water stratum, fished for approximately 4.5 minutes at each 10m depth interval, moved up the the next depth interval within 30

seconds and closed at the top of the water stratum. The entire tow was completed within 25 minutes. The 100m-300m and 300m-500m step-oblique zooplankton samples were taken in like manner but with depth intervals of 40m. At each 40m depth interval the net was fished four minutes and movement of the net through the interval between depths was done within one minute.

All net tows were 25 minutes long with the exception of samples 52, 53, 54 and 55 which were reduced to 15 minutes. Problems with the hydrowinch made it impossible to take tows 52 through 55 in the same manner as all the others. Rather than step-oblique tows with the ship underway, tows 52 through 55 were vertical hauls through their respective water depths. The change in methodology resulted in reduced water volume filtered for these tows as compared to those true step-oblique tows (Table 1). The water volume for each tow was determined from flow meter data.

Zooplankton identifications and counts were made from sub-samples containing a minimum of 300 copepods. Sub-samples were taken with a Folsom plankton splitter. Copepods were identified to species and other zooplankters were identified to order or family. All counts were reported as numbers per m^3.

RESULTS

Distribution of total zooplankton at four depths over diel cycle.

One hundred and twenty-eight copepod species were identified from the zooplankton sampled during the diel migration study. Other non-copepod invertebrates along with larval and juvenile fish comprised another 43 zooplankton taxa (Table 2).

Zooplankton density was an order of magnitude higher in the 0m-100m water stratum than in the water between 100m and 500m. The largest total zooplankton density (4939 m^{-3}) occurred in the 50m-100m stratum at night, while the lowest density was also found at night at 100m-300m ($32m^{-3}$). A dominant shift in zooplankon density occurred over a diel cycle within the 0m-100m stratum of the water column. Zooplankton densities within the upper 50m were highest during day and early evening hours and fell to lows during night and morning hours (Figure 1). The 50m-100m zooplankton distributional pattern was inverse to that of the surface (Figure 1).

Diel zooplankton distribution patterns in the 100-300m and 300m-500m strata showed that zooplankton may have moved vertically within this water mass but the sharp increase of zooplankton between 100m-300m during the day indicated that zooplankton moved into these strata from areas of the water column above and below the 100m-300m depth (Figure 1).

Copepods composed 73% of the total numbers of zooplankton during this study. The influence of copepod distribution on the distribution of total zooplankton is seen in Figure 2. Copepod distributional curves from each depth are congruent with the total zooplankton curves from the respective depth.

Changes in the zooplankton over time and depth

Species diversity, richness and evenness indices (Odum, 1971) were calculated for each sample that was taken during this zooplankton diel distribution study. Results are seen in Figure 3. Richness values

plotted over depth for each of the four time periods show a pattern of relative species change over a diel cycle. In this pattern, species richness during the evening (1740-1930) and day (0915-1415) was lowest in the 0m-50m stratum and increased linearly with depth to 500 meters. At night (2230-2415 hrs) there was an increase in species richness within the 0m-50m and 100m-300m strata and a decrease in the 0m-50m and 300m-500m strata. In the morning (0325-0515) hours, the richness in the 0m-50m water stratum had decreased slightly from the level that occurred at night. At 50m-100m, the morning species richness remained unchanged from that which occurred at night. The species richness within the 100m-300m stratum dropped sharply from the night level, but remained essentially unchanged within the 300m-500m stratum. Most of the changes in diel distribution of species richness occurred in the water column above 300m. In comparing the curve for species diversity and richness, it cannot be shown that changes in numbers of species (richness) was a dominant force in determining diversity changes.

The curve that resulted from plotting evenness values over depth for each sampling time was more similar to the species diversity curve than was the richness curve, therefore, within this series of samples the change in distribution of zooplankton individuals among the species was the major cause for changes in zooplankton diversity (Figure 3).

Taxonomic distribution of copepods within the water column over time

The diel distribution of copepod species was different from the distribution of total numbers of copepods. The greatest number of species (63) occurred at 50m-100m in early evening but this number

decreased sharply during the night and morning hours to 40 species (Figure 4). During the following day, however, the number of species increased to 47 species. In the 0m-50m region of the water column the species number peaked at 52 during the night, decreased to a low of 40 species during the morning, and began to increase again during the day and evening. The copepod diel distributional pattern within the 300m-500m stratum was similar to that of the 0m-50m stratum with the exception of three less species occurring in the deeper water than in near surface water during the night and morning and seven less species occurring during the day.

Within the 100m-300m stratum of the water column the number of species reached a low of 36 at night. This was the time that species numbers were high at the other depths (Figure 4). The largest number of species (52) occurred at this depth during the morning hours and then decreased to 49 in the day samples. The pattern of species distribution at the 100m-300m stratum was opposite to that shown at the other depths.

Size distribution of zooplankton within the water column over a diel cycle

Approximately 45% of individual zooplankters collected during this diel zooplankton distribution study were within the 1.0mm-1.9mm size range (Table 3). Thirty-nine percent of the zooplankters were included in size class 2 (0.5mm-0.9mm) and another 10% were evenly divided between size classes one (<0.5mm) and four (2.0mm-2.9mm). Ninety-four percent of the total net zooplankton collected from the water column above 500m was smaller than 3mm (Table 3).

The smallest zooplankton size class was composed of species which were less than 0.5mm. Individuals smaller than 0.2mm were not quantitatively sampled by the net used in this study. Examples of size class 1 zooplankton are foraminifera, radiolaria, some thecostomes and echinoderm larve. The greatest density of size class 1 zooplankton in near surface water occurred in the day samples. Their greatest densities within the water column occurred in the 50m-100m water stratum during night sampling (Fig. 5).

Zooplankton within the size range of class 2 (0.5mm-0.9mm) included calanoid copepod copepodites, some adult calanoids, most cyclopoid and harpacticoid adults and all nauplii. Size class 2 zooplankton occurred in large numbers in the 0m-50m waters during the day and early evening but the greatest concentration of these size zooplankters occurred at night in the 50m-100m depths (Fig. 5).

Size class 3 zooplankton (1.0mm-1.9mm) included most calanoid copepod adults, decapod zoea, amphipods, ostracods and siphonophore bracts. This size group had the same vertical diel distribution as the previous groups. Their densities were higher in the 0m-50m stratum during periods of light than during periods of dark while the opposite pattern occurred in the 50m-100m depths. The densities in the deeper waters were generally greater for zooplankton of size classes 1 and 4 than for size classes 2 and 3. The greatest zooplankton density in the deep waters occurred during the day within the 100m-300m stratum, but a diel distribution pattern for zooplankton within the 100m-500m strata was not apparent. The zooplankton density within the 100m-300m water

stratum increased from $200m^{-3}$ in the morning samples to more than $400m^{-3}$ in the day samples (Figure 1).

Size class 4 zooplankton included adults of some large size calanoid copepods, chaetognaths, larvaceans and salps. This size class of zooplankton had high densities in the 0m-50m water stratum during the day and in the 50m-100m stratum at night. A greater percentage of size class 4 zooplankton occurred at 100m-300m during the day than at night. This same phenomenon also occurred, to a lesser extent, within the 300m-500m stratum. Since there was not a large decrease in size class 4 zooplankton during the day in the 0m-100m depths, the increase within the deeper strata (300m-500m) probably result from the upward migration of zooplankton from below 500m in addition to the day time sinking of zooplankton from above 100m.

Size classes 5 through 16 contained zooplankton species that either occurred on an infrequent basis or were not adequately sampled by the gear type that was used in this study. Euphausiids, chaetognaths, siphonophores, polychaetes and fish were some zooplankters that were in these larger size classes. The diel distribution of size classes 5, 6, 7 and 8 zooplankton within the upper 100m was similar to the distribution of smaller zooplankton. Densities were high in the upper 50m stratum during the day and evening (0915-1930) and low during the night and morning (2230-0515), while concomitant zooplankton densities at 50m-100m were high in night and morning samples and low in day samples. Density values within the 100m-500m depth for these size classes were small and distribution patterns are difficult to discern.

Data for the temporal and vertical distribution of zooplankton in size classes 9 through 16 are shown in Figure 5. Low population densities among these zooplankton groups makes the determination of diel distribution patterns difficult.

Analysis of zooplankton among sample replicates

During the day (0915-1415 hrs) sampling period three samples were taken from both the 0m-50m and 50m-100m depths and two were taken at the 100m-300m and 300m-500m depths. The 0m to 500m depth range represented the upper half of the 1000m water column at the Mobile OTEC site in the northern Gulf of Mexico.

Zooplankton variation among replicate samples was more influenced by changes in the total number of zooplankters rather than by changes in number of species. Within each set of replicates the coefficient of variation (c.v.) was consistently higher for total zooplankton than for numbers of species (Table 4).

Species diversity along with its component values of species richness and evenness were calculated for replicates from each of the aforementioned depths (Table 4). Evenness values varied directly with diversity while the relationship of species richness with diversity was not consistently positive or negative. These data indicate that zooplankton diversity among replicates from each depth was strongly influenced by changes in the distribution of individual zooplankters among species (evenness), while the changes in species composition among replicates (richness) had little effect on diversity. This data set is limited and any conclusions

concerning the cause and effect of changes in zooplankton diversity among sample replicates should be made with caution.

There was less variation among replicates from 0m-50m and 50m-100m than from 100m-300m and 300m-500m. Relative variation (c.v.) values for zooplankton individuals from the 0m-50m and 50m-100m replicates were within the $\pm$50% range (Table 4). A c.v. of 106% from the 100m-300m replicates and 62% from the 300m-500m replicates indicates a highly variable community. Further work should be done to determine the amount of variation among a greater number of replicates over a longer time period. No data on the size of zooplankton patches have been reported for the northern Gulf of Mexico.

Analysis of net performance

Water volume data from nets towed as tandem pairs were subjected to statistical analysis using the paired t test. A t-value of 1.60182 with 10df showed that there was no significant difference in the volumes of water filtered by the tandem paired nets at a = 0.05 (Table 5).

Table 1

Sample Data from Mobile OTEC Diel Zooplankton Study

Sample No.	Depth	Time (GMT)	Time (CST-local)	Date	Volume Water Filtered (m^3)	Portion of Sample used for Numerical Analysis	No. Zooplankton m^{-3}	No. Copepods m^{-3}
34	0-50m	2340	1740	11-1-78	537.4	1/4096	3069.6	2552.1
35	50-100m	2340	1740	"	653.8	1/512	451.2	258.5
36	100-300m	0130	1930	"	529.2	1/128	70.5	50.3
37	300-500m	0130	1930	"	638.3	1/64	42.9	34.6
39	0-50m	0430	2230	"	706.2	1/512	250.1	160.5
38	50-100m	0430	2230	"	615.8	1/4096	4938.6	3562.8
41	100-300m	0615	2415	11-2-78	587.6	1/64	32.5	27.2
40	300-500m	0615	2415	"	669.8	1/128	97.3	63.5
43	0-50m	0925	0325	"	694.2	1/512	262.9	170.7
42	50-100m	0925	0325	"	600.3	1/4096	2543.0	1847.7
45	100-300m	1115	0515	"	718.1	1/256	172.4	117.3
44	300-500m	1115	0515	"	809.2	1/128	49.8	43.6
47	0-50m	1515	0915	"	609.6	1/2048	1813.8	1274.0
49	0-50m	1630	1030	"	635.7	1/4096	2554.3	1981.7
51	0-50m	1745	1145	"	704.5	1/4096	2131.3	1504.2
46	50-100m	1515	0915	"	752.3	1/512	359.8	211.5
48	50-100m	1630	1030	"	468.7	1/256	197.6	147.2
50	50-100m	1745	1145	"	784.5	1/1024	458.1	304.6
53	100-300m	1900	1300	"	124.5	1/256	720.5	486.9
55	100-300m	2015	1415	"	142.9	1/32	101.5	75.6
52	300-500m	1900	1300	"	400.9	1/128	117.8	99.5
54	300-500m	2015	1415	"	266.5	1/32	46.1	38.7

Table 2

Zooplankton Species List for OTEC Vertical Migration Study

COPEPODS

Code Number	Genus-Species	Family
001	Calanus tenuicornis	CALANIDAE
002	Nannocalanus minor	
003	Neocalanus gracilis	
004	Undinula vulgaris	
005	Eucalanus sp.	EUCALANIDAE
006	E. elongatus	
007	E. mucronatus	
008	E. attenuatus	
009	E. pileatus	
010	E. subtenuis	
011	Rhincalanus cornutus	
012	Acrocalanus longicornis	PARACALANIDAE
013	Paracalanus sp.	
014	Calocalanus pavo	
015	C. pavoninus	
016	Ishnocalanus plumulosus	
017	Mecynocera clausii	
018	Clausocalanus sp.	PSEUDOCALANIDAE
019	Microcalanus sp.	
020	Monacilla typica	SPINOCALANIDAE
021	Spinocalanus sp.	
022	Aetideus sp.	AETIDEIDAE
023	A. armatus	
024	Euaetideus giesbrechti	
025	Chiridius poppei	
026	Gaetanus sp.	
027	G. minor	
028	Euchirella sp.	
029	Chirundina streetsi	
030	Undinopsis similis	
031	Undeuchaeta major	
032	Valdiviella sp.	
033	Euchaeta sp.	EUCHAETIDAE
034	E. marina	
035	E. calva	
036	E. media	
037	E. paraconcinna	
038	E. pubera	
039	Phaenna spinifera	PHAENNIDAE
040	Xanthocalanus sp.	
041	Scolecithrix bradyi	SCOLECITHRICIDAE
042	S. danae	
043	Scolecithricella sp.	
044	S. dentata	
045	S. ctenopus	

Table 2 (continued)

Code Number	Genus-Species	Family
046	S. vittata	
047	S. tenuiserrata	
048	Scottocalanus sp.	
049	Scaphocalanus sp.	
050	Lophothrix laticeps	
051	Amallothrix sp.	
052	Stephos sp.	STEPHIDAE
053	Undinella sp.	THARYBIDAE
054	Temora turbinata	TEMORIDAE
055	T. stylifera	
056	Temoropia mayumbaensis	
057	Metridia sp.	METRIDIIDAE
058	M. brevicauda	
059	M. venusta	
060	Pleuromamma sp.	
061	P. abdominalis	
062	P. gracilis	
063	P. piseki	
064	P. xiphias	
065	Centropages furcatus	CENTROPAGIDAE
066	Lucicutia spp.	LUCICUTIDAE
067	Heterorhabdus sp.	HETERORHABDIDAE
068	H. papilliger	
069	H. spinifrons	
070	Heterostylites longicornis	
071	Hemirhabdus sp.	
072	Haloptilus longicornis	AUGAPTILLIDAE
073	H. oxycephalus	
074	H. ornatus	
075	H. spiniceps	
076	Euaugaptilus hectus	
077	E. laticeps	
078	Phyllopus sp.	ARIETELLIDAE
079	Candacia sp.	CANDACIIDAE
080	C. curta	
081	C. varicans	
082	C. pachydactyla	
083	Paracandacia simplex	
084	P. bispinosa	
085	Calanopia americana	PONTELLIDAE
086	Pontella sp.	
087	Labidocera sp.	
088	Pontellina plumata	
089	Acartia sp.	ACARTIIDAE
090	A. danae	
091	Mormonilla minor	MORMONILLIDAE
092	M. plasma	
093	Aegisthus aculeatus	AEGISTHIDAE
094	A. mucronatus	

Table 2 (continued)

Code Number	Genus-Species	Family
095	A. dubius	
096	Microstella norvegica	ECTINOSOMIDAE
097	Clytemnestra scutellata	CLYTEMNESTRIDAE
098	Miracina minor	
099	Macrostella gracilis	MACROSTELLIDAE
100	Euterpina acuifrons	TACHYDIIDAE
101	Oithona spp.	OITHONIDAE
102	Ratania atlantica	
103	Oncaea conifera	ONCAEIDAE
104	O. venusta	
105	O. mediterranea	
106	O. notopus	
107	Conaea gracilis	
108	Lubbockia squillimana	
109	L. aculeata	
110	Pachos punctatum	
111	Sapphirina sp.	SAPPHIRINIDAE
112	Vettoria granulosa	
113	Corissa parva	
114	Copilia quadrata	
115	C. mirabilis	
116	Corycaeus sp.	CORYCAEIDAE
117	C. amazonicus	
118	C. americanus	
119	C. catus	
120	C. clausi	
121	C. flaccus	
122	C. latus	
123	C. lautus	
124	C. typicus	
125	C. speciosus	
126	C. limbatus	
127	Farranula gracilis	
128	F. rostrata	
129	Unidentified Calanoids	
130	Unidentified Cyclopoids	
NON-COPEPOD ZOOPLANKTERS		
131	Amphipoda - Hyperiids	
132	Gammarids	
133	Barnacle cypris	
134	Branchiopods larvae	
135	Cephalopod larvae	
136	Chaetognatha	
137	Cladocera - Evadne sp.	
138	- Penilia sp.	
139	- Podon sp.	

Table 2 (continued)

Code Number	Genus-Species	Family
140	Decapod - protozoea	
141	- zoea	
142	- Caridean shrimp	
143	- Sergestid shrimp	
144	Dinoflagellida (Gymnodinium sp. - Pyrocystis sp.)	
145	Echinodermata - bipinnaria	
146	- pluteus	
147	- Juv. Brittle Star	
148	Euphausiacea	
149	Fish - larval	
150	- juvenile	
151	Foraminifera	
152	Gnathostoma - Cephalochordata	
153	Heteropoda	
154	Hydromedusae	
155	Isopoda	
156	Larvacea - Appendicularia sp.	
157	- Fritillaria sp.	
158	- Oikopleura sp.	
159	Nauplius	
160	Ostracoda	
161	Pelecypoda	
162	Polychaeta	
163	Radiolaria	
164	Siphonophores	
165	Stomatopod larvae	
166	THALIACEA - Doliolidae	
167	- Salpidae	
168	Thecostomata - Cavolina sp.	
169	- Creseis sp.	
170	- Diacria sp.	
171	- Euclio sp.	
172	- Limacina sp.	
173	- Peraclis sp.	
174	LEPTOCEPHALUS - (Larval Eel)	

Table 3

Size Distribution of Zooplankton from the Diel Migration Study

Class	Size	Percent Composition (Individuals m^{-3})
1	<0.5mm	5.6
2	0.5mm-0.9mm	38.6
3	1.0mm-1.9mm	44.8
4	2.0mm-2.9mm	5.0
5	3.0mm-3.9mm	1.9
6	4.0mm-4.9mm	1.5
7	5.0mm-5.9mm	0.6
8	6.0mm-6.9mm	0.9
9	7.0mm-7.9mm	0.2
10	8.0mm-8.9mm	0.1
11	9.0mm-9.0mm	0.2
12	10.0mm-19.9mm	0.6
13	20.0mm-29.9mm	0.0005
14	30.0mm-39.9mm	0.001
15	40.0mm-49.9mm	-
16	>50.0mm	0.003

Table 4

Diversity and Variation Within Replicate Samples

	Diversity	Richness	Eveness	Number of species in subsample	Coefficient of variation for species	Numbers of individuals (m^{-3})	Coefficient of variation for individuals
0-50m	1.29964	1.15053	0.76893	49	4.5%	1813.8	17.1%
	1.29380	0.89038	0.78259	45		2554.3	
	1.25587	0.99640	0.75529	46		2131.3	
50-100m	1.37971	2.74140	0.80402	52	22.2%	359.8	38.9%
	1.17139	2.41871	0.76487	34		197.6	
	1.35861	2.38281	0.79563	51		458.1	
100-300m	1.36509	1.89999	0.79943	51	24.3%	720.5	106.5%
	1.23575	4.86365	0.73113	36		101.5	
300-500m	1.20574	4.05396	0.73366	44	14.1%	117.8	61.9%
	1.03760	5.30215	0.66671	36		46.1	

Table 5

Analysis of Tandem Net Water Volume Data

Sample No.	Depth (m)	Volume water filtered (M^3)	Paired t-value	d.f.	ρ=0.05 significance level
34	0-50	537.4	1.60182	10	2.228
35	50-100	653.8			
36	100-300	529.2			
37	300-500	638.3			
39	0-50	706.2			
38	50-100	615.8			
41	100-300	587.6			
40	300-500	669.8			
43	0-50	694.2			
42	50-100	600.3			
45	100-300	718.7			
44	300-500	809.2			
47	0-50	609.6			
46	50-100	752.3			
49	0-50	635.7			
48	50-100	468.7			
51	0-50	704.5			
50	50-100	784.5			
53	100-300	124.5			
52	300-500	400.9			
55	100-300	142.9			
54	300-500	266.5			

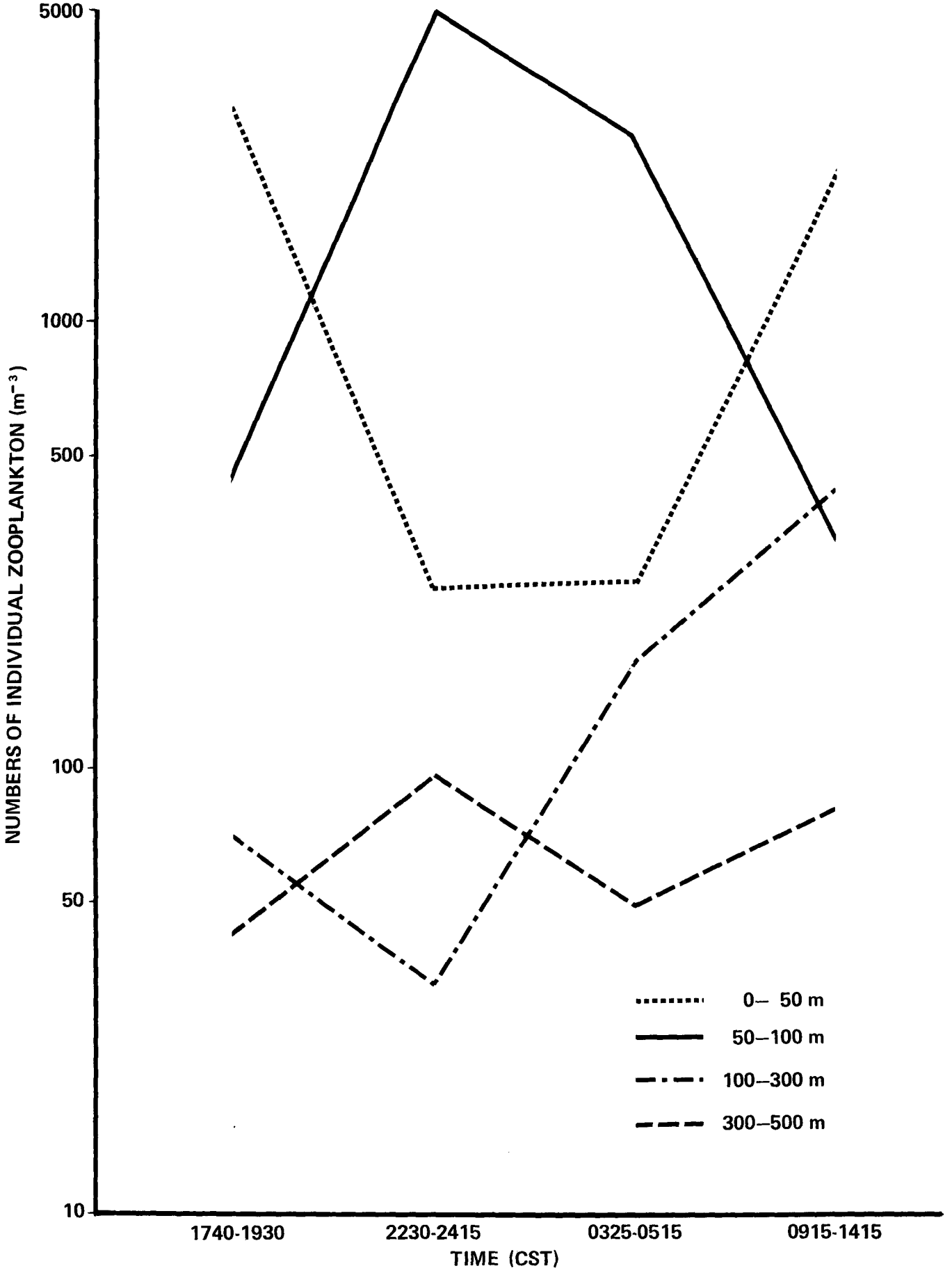


Figure 1. Distribution of total zooplankton over time and depth.

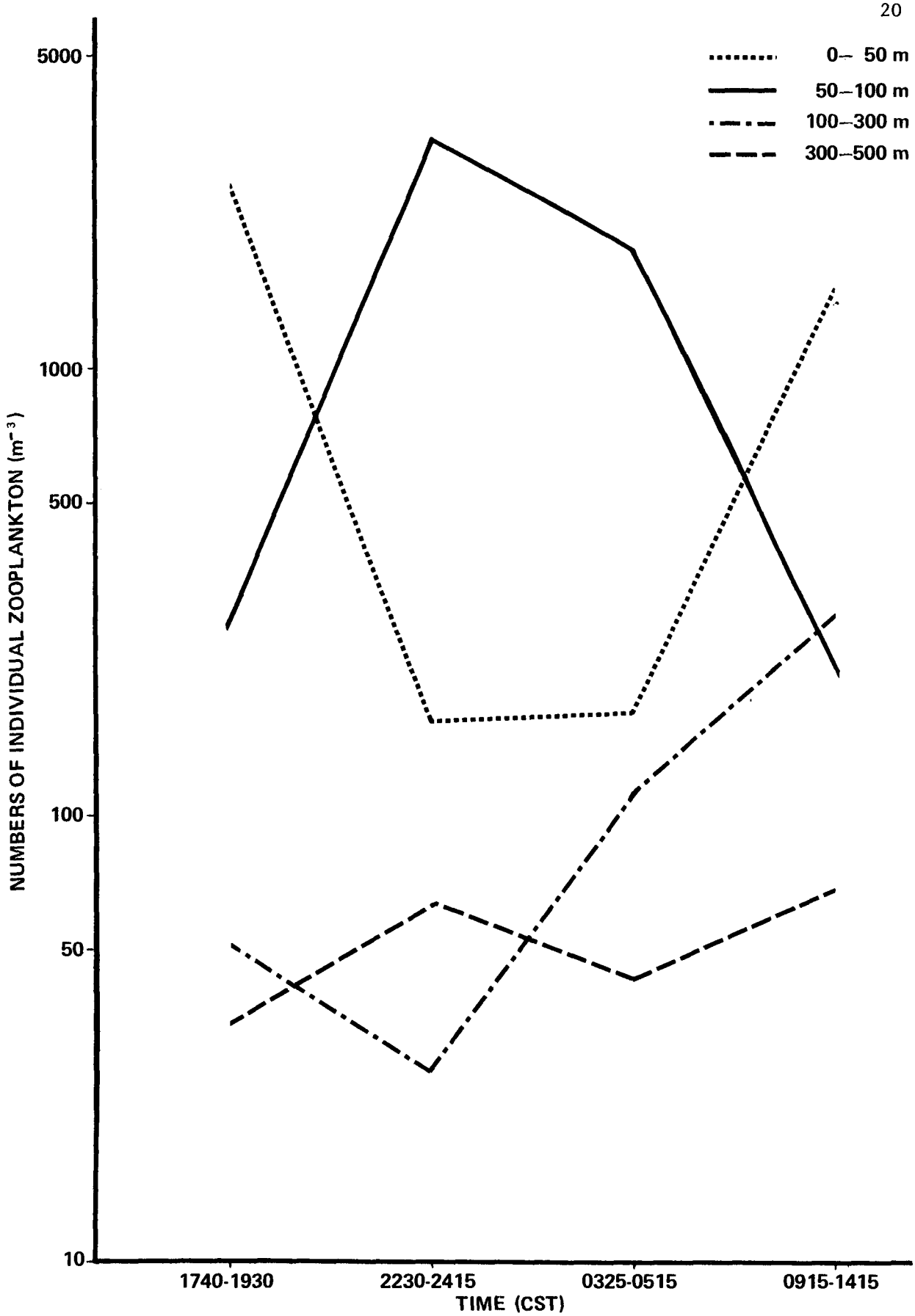


Figure 2. Distribution of copepods over time and depth.

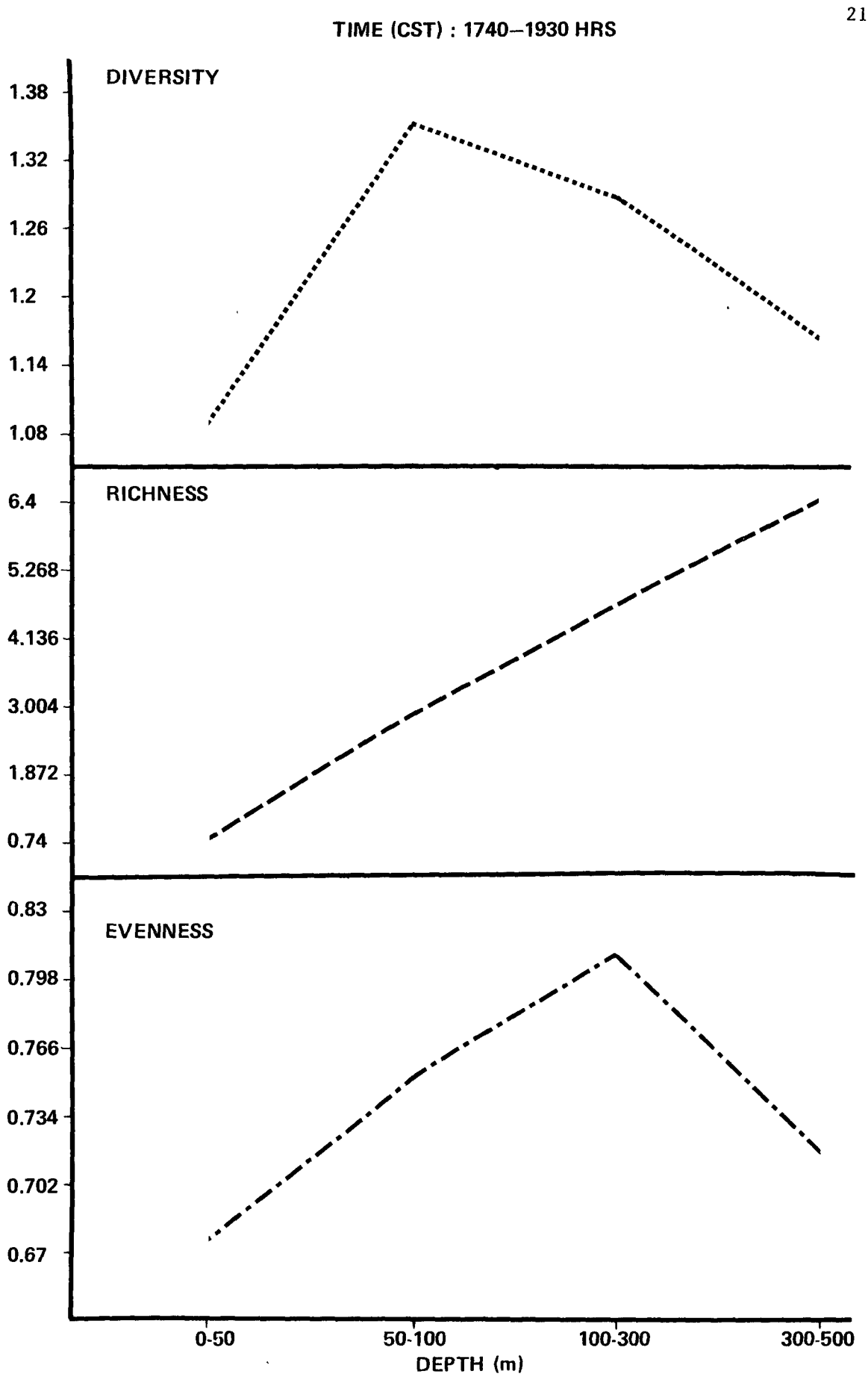


Figure 3. Distribution of species diversity, richness and evenness values over depth for each of four time periods.

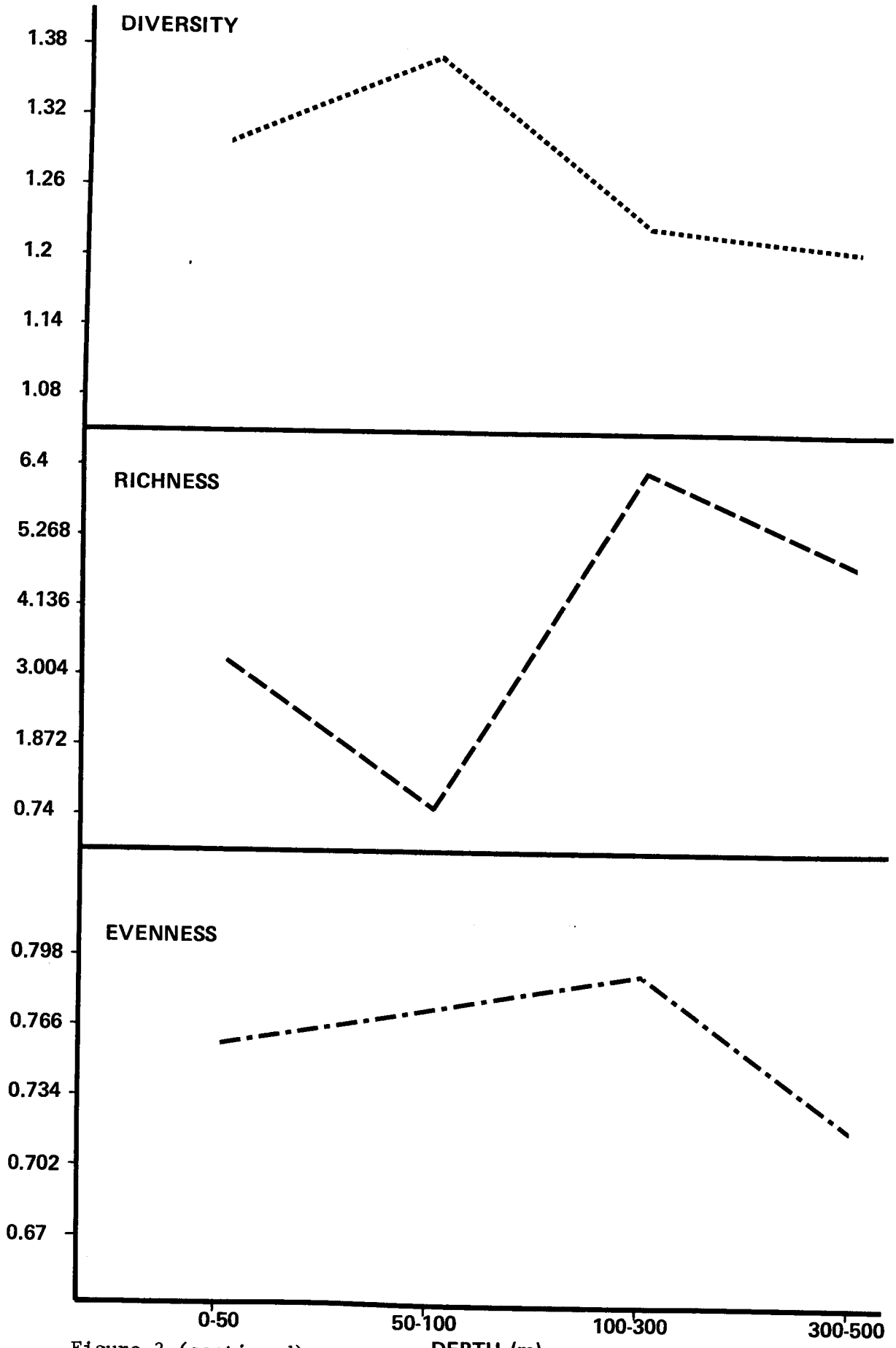


Figure 3 (continued).

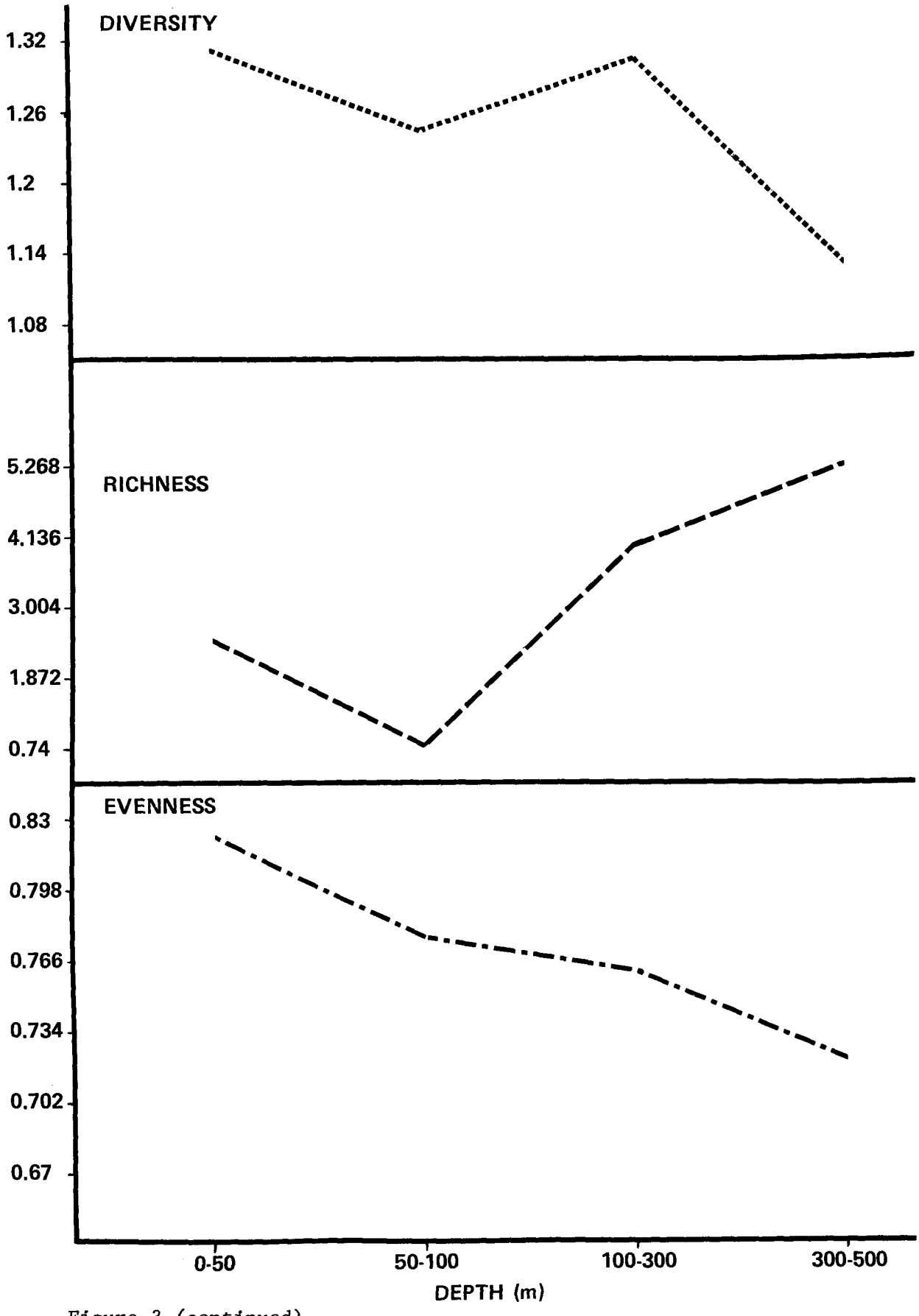


Figure 3 (continued).

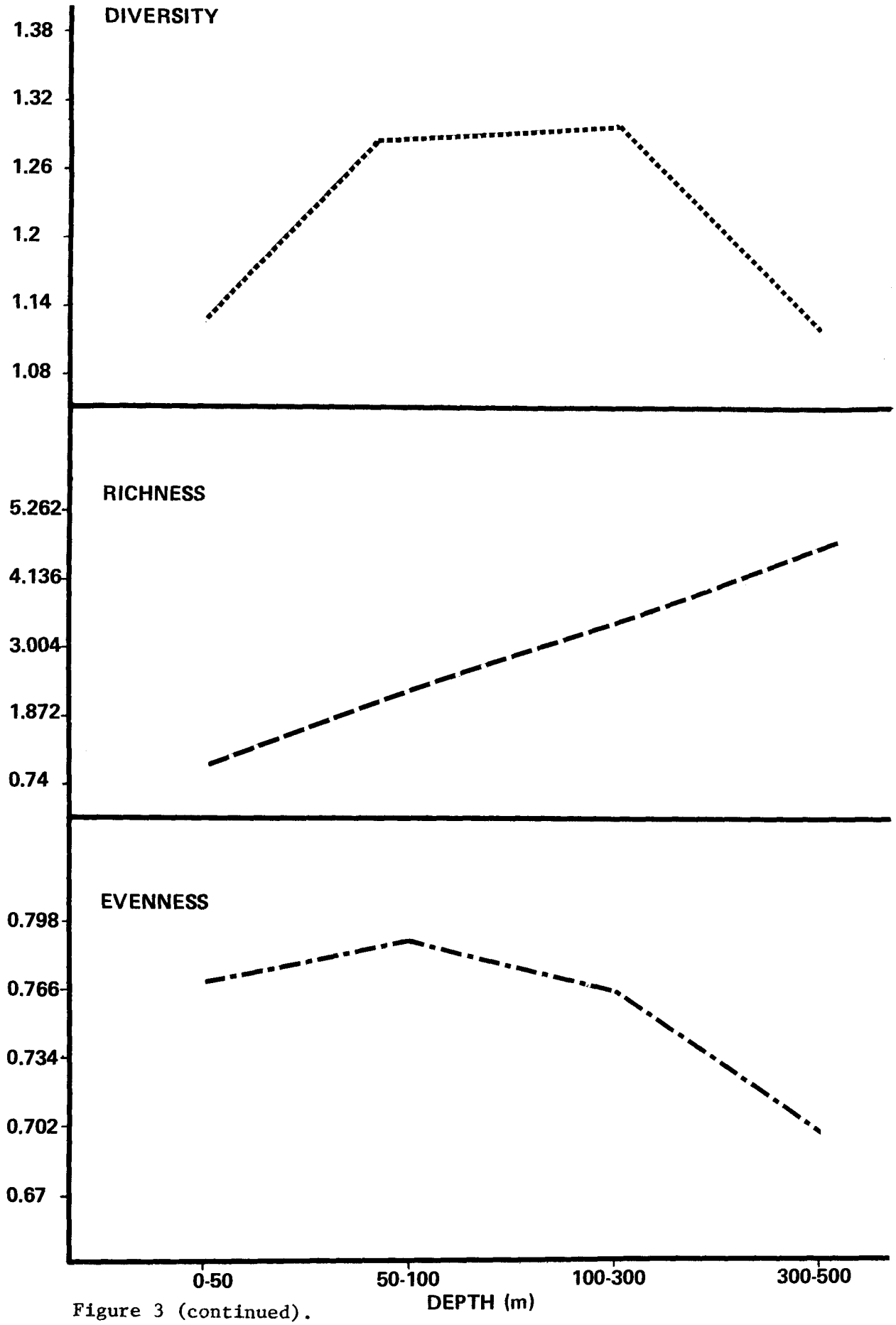


Figure 3 (continued).

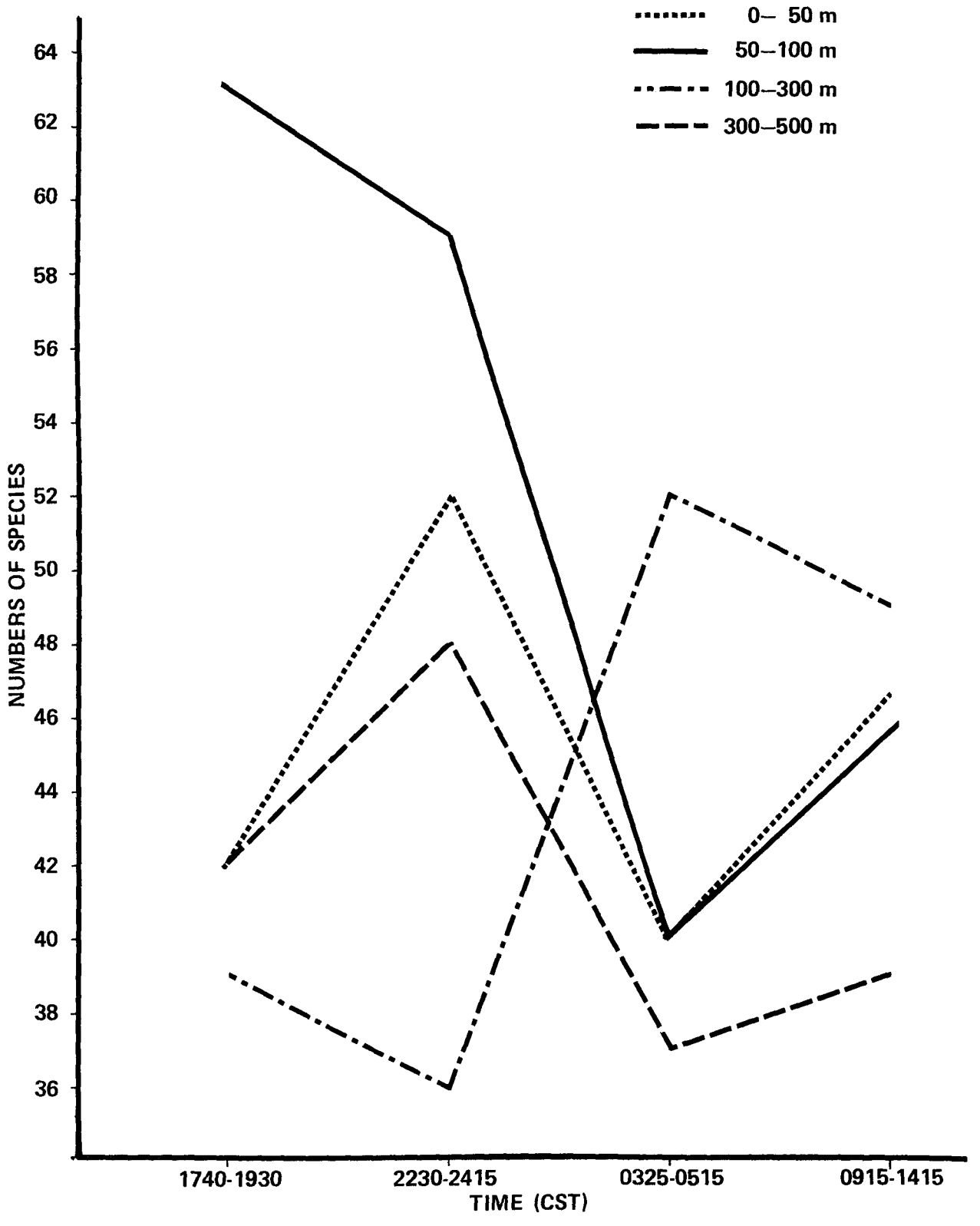


Figure 4. Changes in copepod species composition at four depths over a diel cycle.

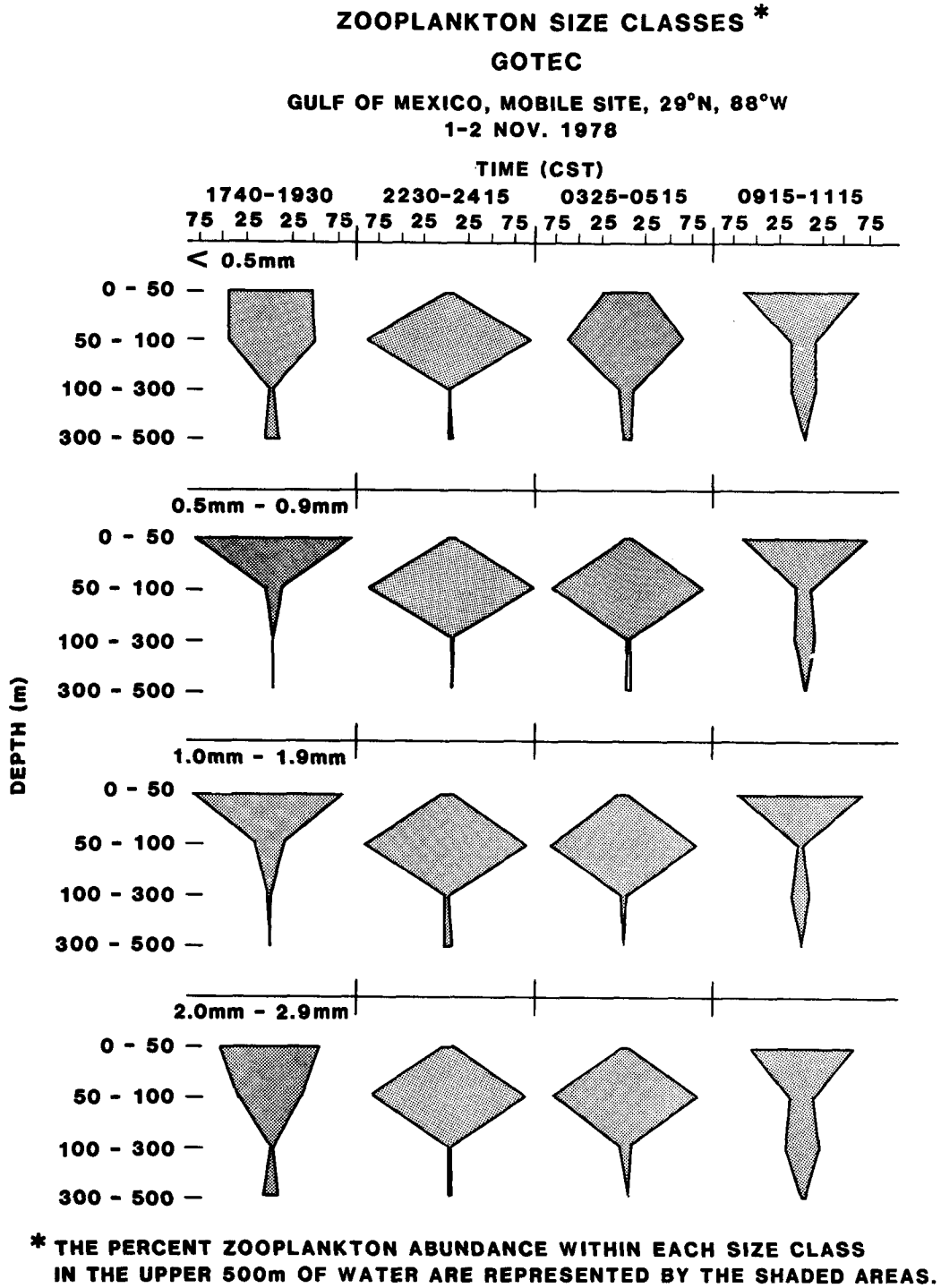
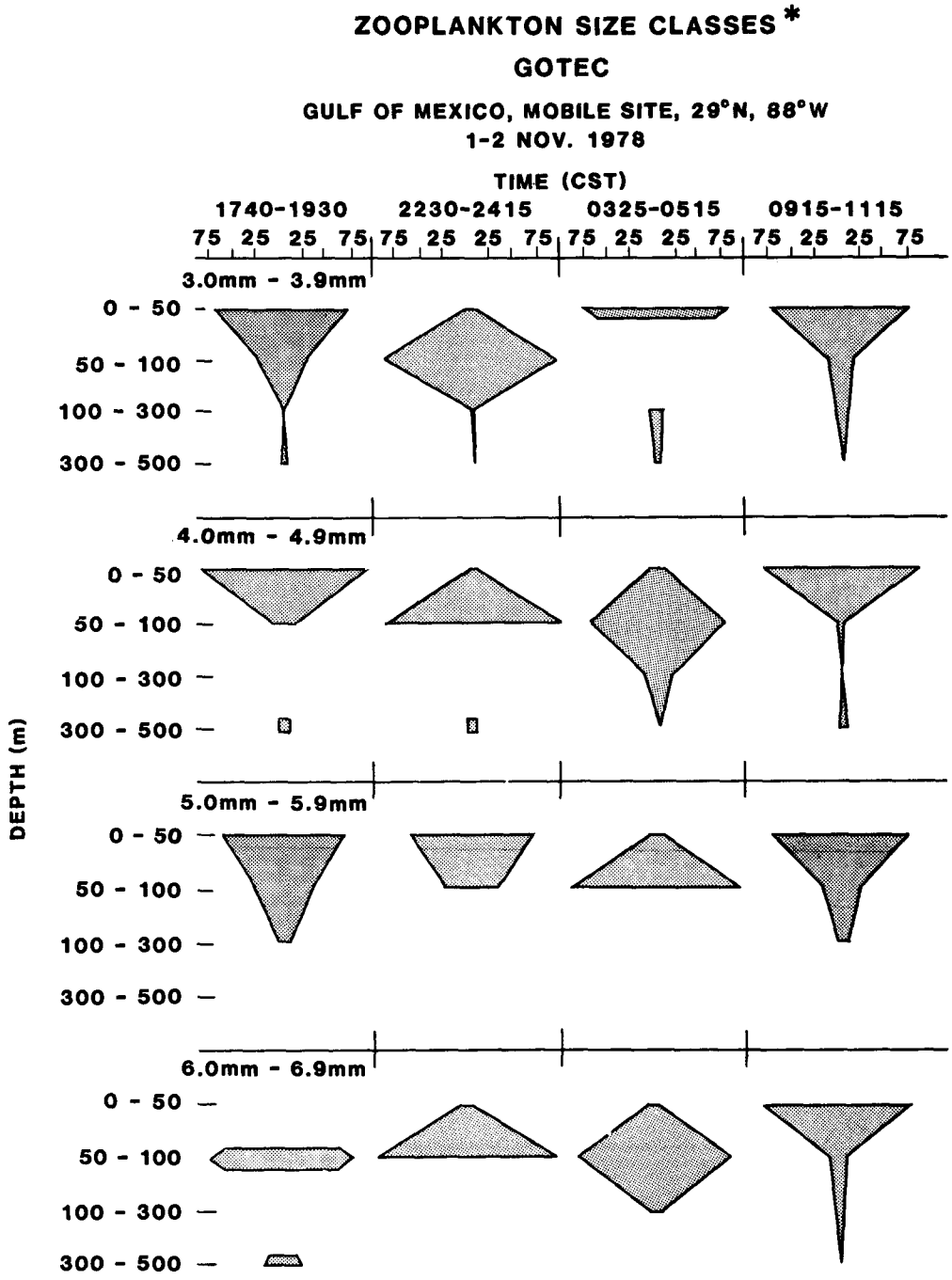


Fig. 5 Zooplankton size classes and diel vertical distribution. The percent composition for numbers of zooplankton of each size class within each depth sampled in the upper 500m of water are represented by the shaded areas.



XBL 8012-13182

Fig. 5 (cont.) Zooplankton size classes and diel vertical distribution. The percent composition for numbers of zooplankton of each size class within each depth sampled in the upper 500m of water are represented by the shaded areas.

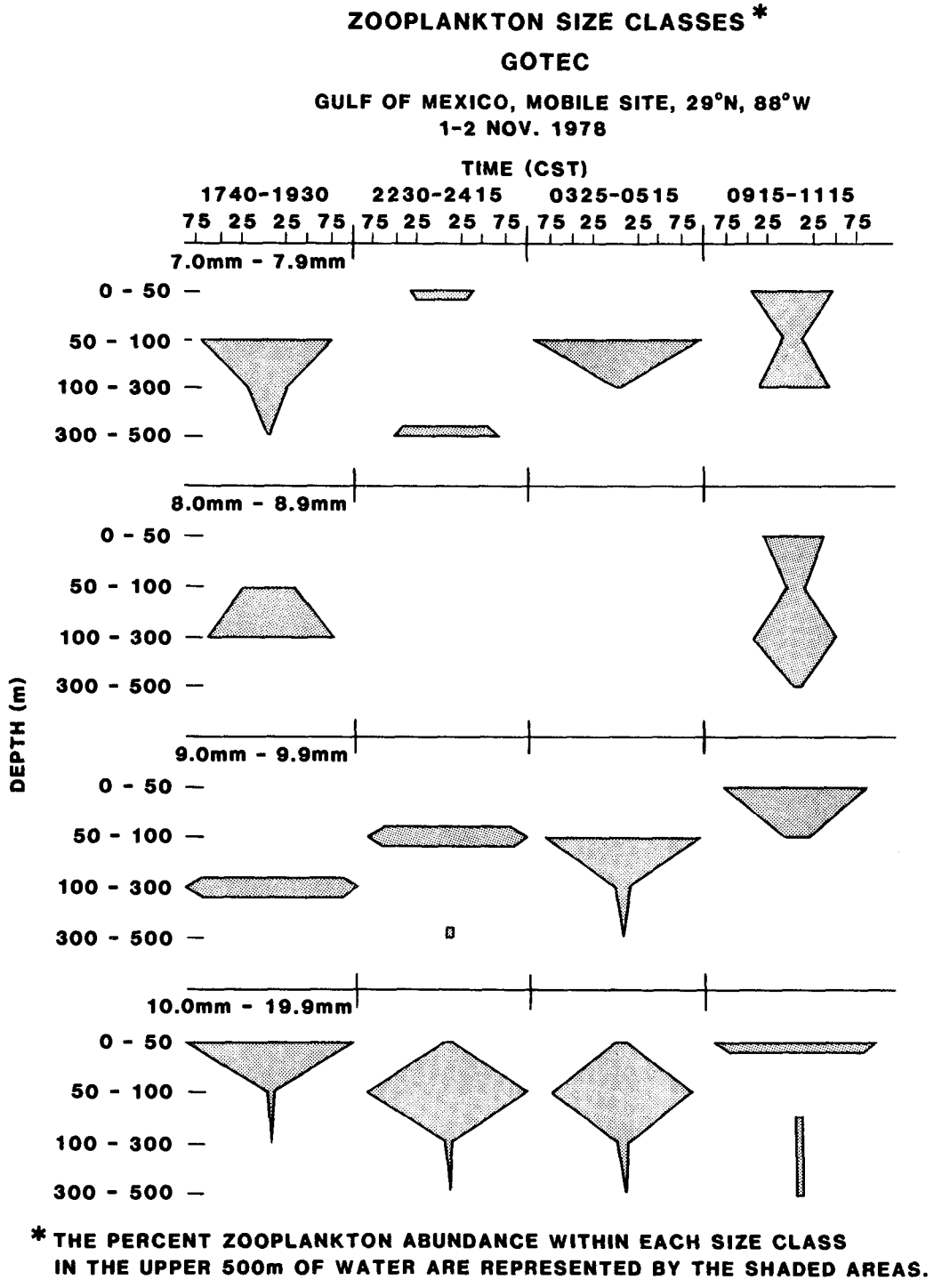
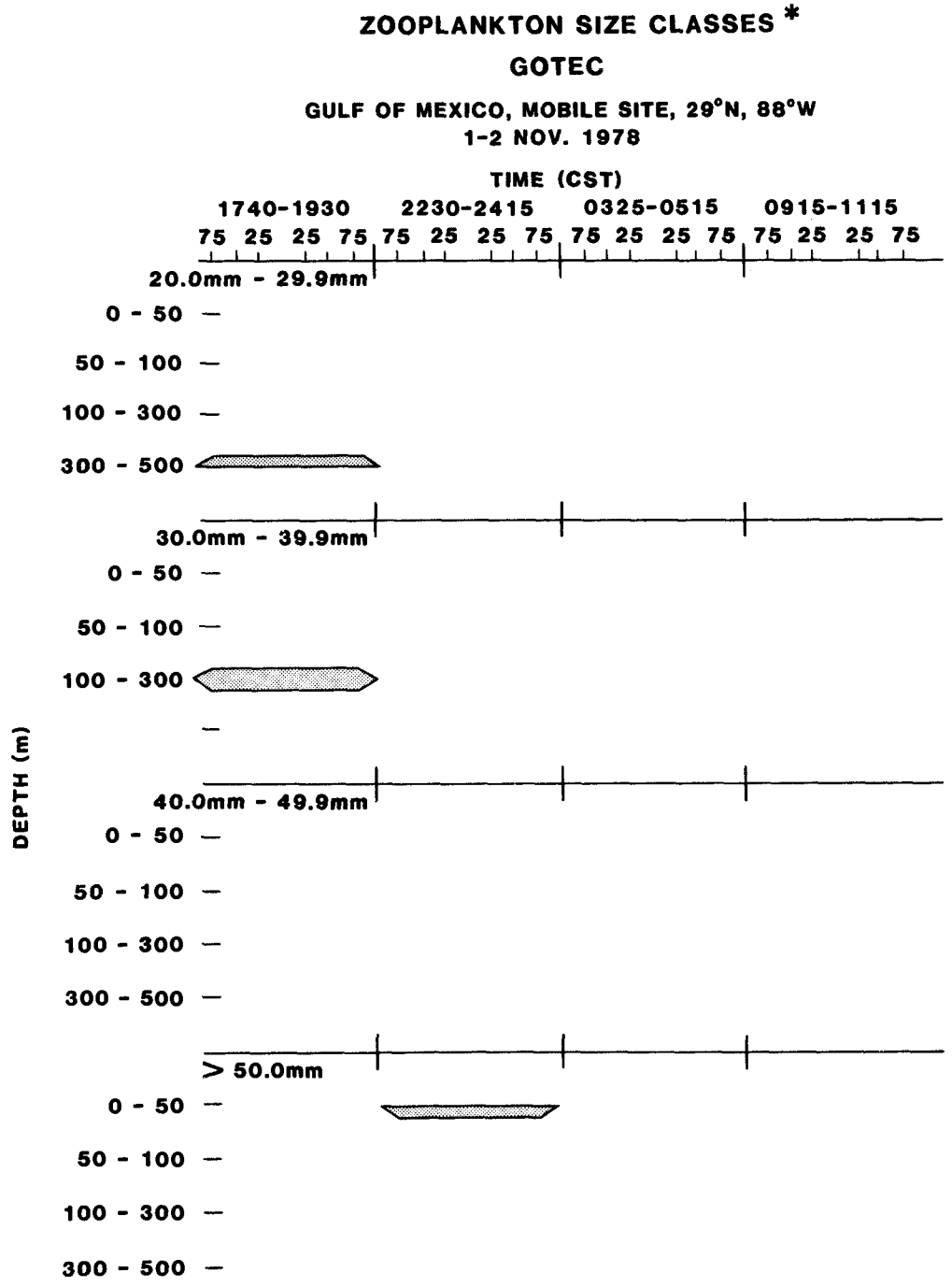


Fig. 5 (cont.) Zooplankton size classes and diel vertical distribution. The percent composition for numbers of zooplankton of each size class within each depth sampled in the upper 500m of water are represented by the shaded areas.



XBL 8012-13184

Fig. 5 (cont.) Zooplankton size classes and diel vertical distribution. The percent composition for numbers of zooplankton of each size class within each depth sampled in the upper 500m of water are represented by the shaded areas.

LITERATURE CITED

Banse, K. (1964) On the vertical distribution of zooplankton in the sea. Progress in Oceanography, 2, 53-125.

Clarke, G. L. (1934) Factors affecting the vertical distribution of copepods. Ecological Monographs, 4, 530-540.

Cushing, D. H. (1951) The vertical migration of planktonic crustacea. Biological Reviews, 26, 158-192.

Cuvier, le Baron (1817) La règne animale. Paris.

Loeb, J. (1893) On the influence of light on the periodical depth-migrations of pelagic animals. Bulletin of the U.S. Fish Commission, 13, 65-68.

Michel, H. B. and M. Foyo (1976) Caribbean Zooplankton. Part , Siphonophora, Heteropoda, Copepods, Euphausiacea, Chaetognatha and Salpidae. Office of Naval Research, Department of the Navy, pp. 549.

Moore, H. B. (1955) Variations in temperature and light response within a plankton population. Biological Bulletin, 108, 175-181.

Moore, H. B. (1967) Intra-and interspecific relations of the factors and muls which regulate the vertical distribution of zooplankton. Bulletin of Marine Science, 17, 914-934.

Moore, H. B. and L. D. O'Berry (1957) Plankton of the Florida current IV. Factors influencing the vertical distribution of some common copepods. Bulletin of Marine Science of the Gulf and Caribbean, 7, 297-315.

Odum, E. P. (1971) Fundamentals of ecology. W. B. Saunders Co. Philadelphia, PA.

Owre, H. B. and M. Foyo (1964) Report on a collection of Copepoda from the Caribbean Sea. Bulletin of Marine Science of the Gulf and Caribbean, 14, 359-372.

Owre, H. B. and M. Foyo (1967) Copepods of the Florida Current. Fauna Caribaea, No. 1, Crustacea, Pt. 1: Copepoda, pp. 1-137.

Park, T. S. (1970) Calanoid copepods from the Caribbean Sea and Gulf of Mexico. 2. New species and new records from plankton samples. Bulletin of Marine Science, 20, 472-576.

Pearre, S., Jr. (1973) Vertical migration and feeding in Sagitta elegans Verrill. Ecology, 54, 300-314.

Pearre, S., Jr. (1979) Problems of detection and interpretation of vertical migration. Journal of Plankton Research, 1, 29-44.

Roe, M. S. J. (1972) The vertical distribution and diurnal migration of calanoid copepods collected on the SOUND Cruise, 1965. I. The total population and general discussion. Journal of the Marine Biological Association of the United Kingdom, 52, 277-314.

Roehr, M. G. and H. B. Moore (1965) The vertical distribution of some common copepods in the Straits of Florida. Bulletin of Marine Science, 15, 565-570.

Rudjakov, J. A. (1970) The possible causes of diel vertical migrations of planktonic animals. Marine Biology, 6, 98-105.

Russell, F. S. (1927) The vertical distribution of plankton in the sea. Biological Reviews, 2, 213-261.

Venkataramiah, A., G. J. Lakshmi, C. Best, G. Gunter, Eric Hartwig and Pat Wilde (1981) Studies on toxicity of OTEC plant components on Eucalanus sp. from the Gulf of Mexico. Annual report to Lawrence Berkeley Laboratory by the Gulf Coast Research Laboratory, Ocean Springs, MS 39564. Subcontract 4714620, pp. 52.

Zaret, T. M. and J. S. Suffern (1976) Vertical migration in zooplankton as a predator avoidance mechanism. Limnology and Oceanography, 21, 804-813.

APPENDIX A

Spatial and Temporal Distribution of Frequently Occurring Copepod Species from the Mobile OTEC Site on November 1-2, 1978

Values reported are numbers of individuals per m^3

Species	Depth in Meters	Time (Central Standard) 1740-1930	2230-2415	0325-0515	0915-1115
Undinula vulgaris					
Adult copepods	0-50	7.6			10.2
	50-100		19.9		
Copepodites	0-50				19.4
	100-300				2.0
Eucalanus sp.					
Adult copepods	100-300	0.4			
Copepodites	0-50		0.7	1.4	
	100-300	0.9			
	300-500	3.9			
Eucalanus elongatus					
Adult copepods	100-300		0.2		
	300-500	0.1			
Eucalanus pileatus					
Adult copepods	0-50				8.3
	50-100			6.8	
	300-500		0.3		
Copepodites	0-50		0.7		14.0
	50-100		6.6	6.8	
	100-300				0.1
	300-500		0.1		
Eucalanus subtenuis					
Adult copepods	100-300		2.4	0.7	1.2
	300-500			0.6	0.7
Copepodites	50-100				0.4
	100-300		2.6	1.0	2.6
	300-500			5.0	6.5
Rhincalanus cornutus					
Adult copepods	0-50		0.7		
	100-300		0.3		1.0
	300-500	0.3	0.3	0.7	0.5
Copepodites	100-300		0.1	0.3	0.1
	300-500	0.2		0.3	

APPENDIX A (continued)

Species	Depth in Meters	Time (Central Standard) 1740-1930	2230-2415	0325-0515	0915-1115
Acrocalanus longicornis					
Adult copepods	0-50	7.6		0.7	18.3
Copepodites	0-50			2.2	16.9
Paracalanus sp.					
Adult copepods	0-50	22.8			10.8
	50-100		19.9		1.3
Copepodites	0-50	15.2			22.0
	50-100				0.2
Calocalanus pavo					
Adult copepods	0-50	15.2		0.7	12.0
	50-100	0.7	26.6	13.6	
	100-300				1.0
Copepodites	0-50				8.2
	50-100	3.9	6.6	13.6	
	100-300				3.2
Calocalanus pavoninus					
Adult copepods	0-50	38.1	0.7	0.7	1.1
	50-100	0.7	46.5	47.7	0.9
	100-300			1.7	1.0
	300-500		0.5	0.1	
Copepodites	0-50		2.1		6.7
	50-100	1.5			0.4
	100-300				3.0
Mecynocera clausii					
Adult copepods	0-50		2.1	4.4	5.2
	50-100	0.7	19.9		1.5
	100-300				1.1
Copepodites	0-50			0.7	
	100-300				1.0
Clausocalanus sp.					
Adult copepods	0-50	228.6	5.0	10.2	123.0
	50-100	20.3	119.6	191.0	15.2
	100-300	1.1		1.3	16.4
	300-500		2.2	0.1	0.3
Copepodites	0-50	251.5	5.0	5.8	157.0
	50-100	12.5	345.8	95.5	8.6
	100-300	1.2			19.0
	300-500		0.3		

APPENDIX A (continued)

Species	Depth in Meters	Time (Central Standard) 1740-1930	2230-2415	0325-0515	0915-1115
Temora stylifera					
Adult copepods	0-50	30.4			17.1
	50-100		13.2	13.6	
	100-300				0.1
Copepodites	0-50	38.1			3.0
	50-100		13.2	6.8	
	100-300	0.2			3.0
Temoropia mayumbaensis					
Adult copepods	0-50		0.7	3.6	
	50-100	0.7	6.6		
	100-300		1.3	2.1	1.2
	300-500	0.4	1.1	0.7	0.3
Copepodites	100-300		0.2	0.7	0.4
	300-500			0.9	0.4
Metridia venusta					
Adult copepods	100-300		0.1		
	300-500			0.1	
Copepodites	300-500			0.3	
Pleuromamma abdominalis					
Adult copepods	0-50		0.7		
	50-100	4.6	6.6		
	100-300			0.7	0.1
	300-500	0.1	0.2		0.2
Copepodites	50-100	2.3			
	300-500		0.3	0.4	
Pleuromamma gracilis					
Adult copepods	100-300			1.0	0.2
Copepodites	100-300			1.4	0.1
Pleuromamma xiphias					
Adult copepods	100-300			0.7	
	300-500			0.1	0.5
Copepodites	50-100	0.7			
	100-300			0.3	
	300-500	0.1		0.1	0.1
Lucicutia sp.					
Adult copepods	0-50	22.8	0.7	2.9	8.4
	50-100	3.8	26.5	27.2	5.6

APPENDIX A (continued)

Species	Depth in Meters	Time (Central Standard) 1740-1930	2230-2415	0325-0515	0915-1115
Lucicutia sp. (cont.)					
	100-300	0.9		3.9	2.5
	300-500	0.1	0.3		0.5
Copepodites	0-50	7.6	6.5	4.4	5.8
	50-100	13.3	19.9		7.7
	100-300	2.6		2.4	8.1
	300-500	0.1	0.7	0.1	0.1
Haloptilus longicornis					
Adult copepods	0-50		1.4	4.4	1.9
	50-100	5.4		6.8	0.8
	100-300	0.6		1.7	
	300-500		1.1	0.1	0.4
Copepodites	0-50		2.8	3.6	
	50-100	5.4			2.4
	100-300	2.6		6.4	4.0
	300-500		3.2		0.3
Mormonilla minor					
Adult copepods	100-300	4.1	3.0	1.7	1.4
	300-500	1.0	4.5	2.3	3.4
Copepodites	100-300		0.1	4.2	
	300-500	1.9		5.3	0.1
Aegisthus aculeatus					
Adult copepods	300-500	0.2			
Aegisthus mucronatus					
Adult copepods	100-300	0.2	0.1		
	300-500	0.2		0.4	0.1
Copepodites	300-500			0.1	0.3
Macrostella gracilis					
Adult copepods	0-50	22.8		1.4	3.2
	50-100	0.7	39.8		0.2
	100-300				2.0
Oithona sp.					
Adult copepods	0-50	60.9	13.7	13.2	44.3
	50-100	28.1	126.3	68.2	27.1
	100-300	5.2	4.3	13.9	20.2
	300-500	3.4	10.7	0.7	13.1

APPENDIX A (continued)

Species	Depth in Meters	Time (Central Standard) 1740-1930	2230-2415	0325-0515	0915-1115
Copepodites	0-50	22.8	28.9	22.8	30.6
	50-100	39.9	33.2		23.6
	100-300	5.5		22.4	23.3
	300-500	3.7	5.9	2.3	6.1
Oncaea conifera					
Adult copepods	0-50	7.6		0.7	
	50-100	4.6	538.7	6.8	2.6
Oncaea conifera (cont.)					
	100-300		1.5	1.7	
	300-500	1.1	0.3	2.3	0.5
Copepodites	100-300		0.2		1.0
Oncaea venusta					
Adult copepods	0-50	1059.5	2.8	13.1	500.7
	50-100	2.3	685.1	552.6	9.6
	100-300	1.4	0.4	1.7	59.2
	300-500	1.2	0.7	0.6	3.3
Copepodites	0-50	38.1		2.2	24.4
	50-100		33.2	13.6	3.5
	100-300			1.4	2.5
	300-500	3.8		10.4	8.3
Oncaea mediterranea					
Adult copepods	0-50	91.4	18.7	22.4	44.1
	50-100	17.1	179.5	61.0	15.1
	100-300	2.1	1.5	1.7	14.1
	300-500	0.5	7.9		4.4
Copepodites	0-50	15.2	5.0	4.4	16.6
	50-100	3.9	19.9	34.1	7.5
	100-300	5.0		5.3	8.6
	300-500		7.2		0.1
Oncaea notopus					
Adult copepods	0-50	38.1			
	100-300	2.4	0.3		
Copepodites	100-300	0.9	0.4		
Conaea gracilis					
Adult copepods	100-300	0.4	1.9		0.2
	300-500	3.7	0.1	2.7	2.5

APPENDIX A (continued)

Species	Depth in Meters	Time (Central Standard) 1740-1930	2230-2415	0325-0515	0915-1115
Copepodites	300-500	1.0		0.6	0.7
Lubbockia aculeata					
Adult copepods	50-100				0.2
	100-300			0.6	
	300-500	0.1	0.1	0.1	0.1
Copepodites	50-100				0.6
	300-500	0.1			0.6
Corycaeus sp.	0-50	22.8			
	50-100		6.6		6.5
	100-300	0.9		2.4	0.1
	300-500		0.3		0.1
Copepodites	0-50	7.6	2.1	6.6	19.8
	50-100	7.0	33.2		6.3
	100-300			2.4	4.1
	300-500				0.1
Corycaeus catus					
Adult copepods	0-50	7.6			17.3
	50-100	2.3			1.0
	100-300				1.0
Copepodites	50-100	0.7			
Corycaeus latus					
Adult copepods	0-50	7.6		1.4	16.7
	50-100		106.4	75.0	1.8
	100-300				1.4
Copepodites	50-100			6.8	0.1
Corycaeus lautus	0-50		0.7		
	50-100	3.9	39.9		0.6
	100-300			1.7	
	300-500		1.3		0.1
Copepodites	50-100	32.8			0.2
Corycaeus limbatus					
Adult copepods	0-50		1.4	1.4	8.3
	50-100	2.3			3.1
	100-300			2.0	1.0
	300-500		0.8		0.4

APPENDIX A (continued)

Species	Depth in Meters	Time (Central Standard) 1740-1930	2230-2415	0325-0515	0915-1115
Copepodites	50-100				0.3
Farranula gracilis					
Adult copepods	0-50	121.9		2.9	74.6
	50-100	0.7	126.3	122.7	0.4
	100-300			1.0	7.1
	300-500				0.1
Farranula rostrata					
Adult copepods	0-50		2.8		
	50-100	4.6			1.1

APPENDIX B

Diel Distribution of Zooplankton Size Classes Over Depth

Numbers represent individuals per m^3

	Depth in Meters	Time (Central Standard)					
		1740-1930	2230-2415	0325-0515	0325-0515		
Size Class 1 <0.5mm	0-50	60.8	12.1	35.1	147.6	51.5	145.2
					Avg. 114.8		
	50-100	60.0	365.6	102.2	24.9	9.1	41.6
					Avg. 25.2		
	100-300	3.3	1.5	14.4	49.1	2.7	
					Avg. 25.9		
	300-500	5.9	6.9	4.2	3.4	4.7	
					Avg. 4.0		
Size Class 2 0.5-0.9mm	0-50	1241.8	76.1	73.0	862.4	978.1	778.3
					Avg. 872.9		
	50-100	110.0	1907.9	974.9	136.9	80.2	149.7
					Avg. 122.3		
	100-300	19.6	12.9	59.1	256.2	38.5	
					Avg. 147.3		
	300-500	19.2	27.9	26.2	56.0	25.0	
					Avg. 40.5		
Size Class 3 1.0-1.9mm	0-50	1614.7	115.5	127.9	609.9	1222.4	940.9
					Ave. 924.4		
	50-100	219.6	2047.5	1240.9	142.1	90.0	197.8
					Avg. 143.3		
	100-300	38.4	10.1	73.9	309.1	43.5	
					Avg. 176.3		
	300-500	11.9	48.8	14.8	35.3	10.3	
					Avg. 22.8		
Size Class 4 2.0-2.9mm	0-50	38.0	21.4	6.5	66.4	115.5	162.5
					Avg. 114.8		
	50-100	28.2	258.9	115.8	26.5	6.1	48.1
					Avg. 26.9		

APPENDIX B (continued)

	Depth in Meters	Time (Central Standard) 1740-1930	2230-2415	0325-0515	0325-0515		
	100-300	2.8	7.1	11.3	75.7	4.5	
					Avg.	40.1	
	300-500	4.7	7.3	2.7	13.7	4.6	
					Avg.	9.1	
Size Class 5 3.0-3.9mm	0-50	53.3	2.1	12.4	50.1	45.0	87.1
					Avg.	60.7	
	50-100	19.0	59.6	0.0	16.7	3.7	9.1
					Avg.	9.8	
	100-300	0.4	0.5	1.3	12.1	5.2	
					Avg.	8.6	
	300-500	0.7	1.0	1.0	0.6	1.2	
					Avg.	0.9	
Size Class 6 4.0-4.9mm	0-50	22.8	2.8	5.8	30.0	51.4	5.8
					Avg.	29.1	
	50-100	3.0	119.5	40.9	0.0	3.2	1.3
					Avg.	1.5	
	100-300	0.0	0.1	8.1	0.0	1.2	
					Avg.	0.6	
	300-500	0.1	1.2	0.4	5.6	0.3	
					Avg.	2.9	
Size Class 7 5.0-5.9mm	0-50	7.6	13.7	0.7	16.7	38.6	0.0
					Avg.	18.4	
	50.100	3.9	6.6	20.4	6.0	1.6	6.5
					Avg.	4.7	
	100-300	0.2	0.0	0.0	2.0	1.5	
					Avg.	1.7	
	300-500	0.0	0.0	0.0	0.0	0.0	
					Avg.	0.0	
Size Class 8	0-50	0.0	1.4	0.7	6.6	19.3	5.8
					Avg.	10.6	
	50-100	0.7	119.7	13.6	2.6	1.0	0.0
					Avg.	1.2	

APPENDIX B (continued)

	Depth in Meters	Time (Central Standard)					
		1740-1930	2230-2415	0325-0515	0325-0515		
	100-300	0.0	0.0	2.1	2.0	0.0	
					Avg.	1.0	
	300-500	0.2	0.0	0.0	0.3	0.0	
					Avg.	0.1	
Size Class 9 7.0-7.9mm	0-50	0.0	2.1	0.0	10.0	0.0	0.0
					Avg.	3.3	
	50-100	3.8	0.0	13.6	0.0	0.0	2.6
					Avg.	0.9	
	100-300	1.2	0.0	0.3	6.1	0.0	
					Avg.	3.0	
	300-500	0.1	3.4	0.0	0.0	0.0	
					Avg.	0.0	
Size Class 10 8.0-8.9	0-50	0.0	0.0	0.0	3.3	6.4	0.0
	50-100	1.5	0.0	0.0	3.0	1.5	0.0
					Avg.	1.5	
	100-300	3.8	0.0	0.0	8.2	0.8	
					Avg.	4.5	
	300-500	0.0	0.0	0.0	0.6	0.0	
					Avg.	0.3	
Size Class 11 9.0-9.99mm	0-50	0.0	0.0	0.0	0.0	6.4	5.8
					Avg.	4.1	
	50-100	0.0	6.6	13.6	0.6	0.5	1.3
					Avg.	0.8	
	100-300	0.2	0.0	1.3	0.0	0.0	
					Avg.	0.0	
	300-500	0.0	0.1	0.1	0.0	0.0	
					Avg.	0.0	
Size Class 12 10.0-19.9mm	0-50	30.4	2.1	0.7	10.0	19.2	0.0
					Avg.	9.7	
	50-100	0.7	46.4	6.8	0.0	0.0	0.0
					Avg.	0.0	

APPENDIX B (continued)

	Depth in Meters	Time (Central Standard) 1740-1930	2230-2415	0325-0515		0325-0515
	100-300	0.4	0.2	0.7	0.0	0.2
					Avg.	0.1
	300-500	0.0	0.1	0.2	0.3	0.0
					Avg.	0.1
Size Class 13 20.0-29.9mm	300-500	0.1	0.0	0.0	0.0	0.0
					Avg.	0.0
Size Class 14 30.0-39.9mm	100-300	0.2	0.0	0.0	0.0	0.0
					Avg.	0.0
Size Class 16 >50.0mm	0-50	0.0	0.7	0.0	0.0	0.0
					Avg.	0.0

☆U.S. GOVERNMENT PRINTING OFFICE: 1982-546-085/3191