VERTICAL MIGRATION PATTERNS OF COMMON COPEPODS OVER THE PUERTO RICO TRENCH

A Thesis

Presented to

the Faculty of the Department of Biology

East Carolina University

In Partial Fulfillment

of the Requirements for the Degree

Masters of Science in Biology

by

Dane Clay Herring

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"O what endlesse worke have I in hand
To count the seas abundant progeny,
Whose fruitful seede farre passeth those in land."

--E. Spenser
"Faerie Queene"

ABSTRACT

Dane Clay Herring. VERTICAL MIGRATION PATTERNS OF COMMON COPEPODS OVER THE PUERTO RICO TRENCH. (Under the direction of Edward P. Ryan and Robert Y. George) Department of Biology, April 1978.

Copepods caught in day and night series of quantitative horizontal plankton tows at depths between 0 and 150m over the Puerto Rico Trench (20°N 66°W) have been examined. Twelve species representing three major copepod orders (Calanoida, Cyclopoida, Harpacticoida) were sufficiently abundant for detailed analysis of their depth distribution and vertical migration patterns.

Three patterns of vertical migration were observed. Seven species exhibited the usual pattern involving an upward movement to or toward the surface during the night and a descent to deeper depths during the day. The second migratory pattern, observed in only one species (*Oncaea venusta*), appeared as a reverse migration (i.e. moved downward at night and upward during the day). A third pattern was seen in two calanoids (*Mecynocera clausii* and *Calocalanus pavo*) as a bidirectional movement during the night in which a portion of the population moved toward the surface and another portion moved downward to deeper depths. A lack of migratory behavior was seen in two species, *Haloptilus longicornis* and *Macrosetella gracilis*.

Calanoids emerged as the most diverse and abundant group. At the species level, cyclopoid (*Oithona plumifera* and *Oncaea venusta*) and harpacticoid (*Macrosetella gracilis*) species were more abundant than any calanoid species.

VERTICAL MIGRATION

PATTERNS OF COMMON COPEPODS

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by

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INTRODUCTION

Copepods are highly significant zooplankters which exhibit more or less extensive vertical migrations that are of vital importance in the ecology of pelagic communities. These migrations, or movements, typically involve a disappearance from the surface in the daytime and a return toward the surface at night; however, the reverse of this pattern has been observed among some copepod species and some species do not appear to migrate.

Accurate knowledge of distributional patterns for copepods in planktonic communities is an important requisite for understanding oceanic ecosystem dynamics. Systematic sampling by use of opening-closing nets at various times and depths during the day and night should reveal patterns of vertical distribution and diurnal migration. This study is an examination of the diurnal migratory patterns of the most common species in the copepod orders, Calanoida, Harpacticoida, and Cyclopoida, found in a tropical oceanic regime that has been poorly investigated.

Literature Review

Vertical Distribution and Diurnal Migration

Vertical distribution and diurnal migration in copepods were first described in some detail by Brady (1883) in his treatment of the material taken during the Challenger expedition. Subsequently, numerous authors have made observations concerning this phenomenon which is known to occur among many zooplankton species. Vertical migration and its relationship to a variety of environmental factors such as light, temperature, pressure, etc., have been discussed by Russell (1926), Cushing (1951), Moore *et. al.*, (1953), Moore and Corwin (1956), Moore and O'Berry (1957), Moore and Bauer (1960), and Moore and Foyo (1963). McLaren (1962) proposed an interesting theory concerning the adaptive value of vertical migration with the suggestion that migrators, which feed nearer the surface in warmer waters and "rest" in cooler waters, gain an "energy bonus" that may result in greater ultimate fecundity. Vinogradov (1968) advanced a similar theory in a disucssion emphasizing the biological advantages of vertical migration. These advantages include protection from predation, maintenance and preservation of horizontal and vertical range, and escape from unfavorable surface conditions such as crowding and competition. His hypothesis on the unique adaptations of migrators implies that migrating species gain an energy advantage by feeding in warm surface waters and descending "to a colder environment where energy expenditure for growth and development takes place more economically." Most investigators point out that light must have some influence on vertical migration, in as much as the migrations are in one way or another synchronized with the coming and going of daylight (photoperiodic reactions). However, this phenomenon cannot be explained as a simple case of phototaxis because it appears that vertical migration is a result of complex interactions induced by the synchrony of many environmental factors.

Endogenous diurnal rhythyms have been observed in some copepods and other zooplankters. The copepods, *Acartia tonsa* and *A. clausi*, when kept under laboratory conditions in the dark will make regular upward and downward movement for 2 to 3 days after capture (Easterly, 1917, cited in Vinogradov, 1968). These rhythms may serve as a mechanism for genetic communication among the majority of the population.

Although the reports on vertical distribution are numerous, Roe (1972a) states that "comparatively little work has been done on vertical distribution of oceanic copepods based on systematic sampling with closing nets." Closing nets facilitate taking plankton from narrow depth strata by horizontal tows, which produce typically large samples, rather than by methods using vertical or oblique tows which sample usually wide depth ranges and yield relatively small samples. Since Damas and Koefoed (1909), who were among the first to use closing nets, several investigations on the vertical distribution of copepods have been conducted in the Atlantic. Grice and Hulsemann (1965) discussed the taxonomy, abundance, and vertical distribution of calanoid copepods between 30^{o} and 60^{o}N. They found that tows taken to 5000m yielded larger numbers of copepods above 1000m than below this depth and that the maximum concentration of adults was found between 50m and the surface. In the vicinity of the Canary Islands, Roe (1972a,b,c,d) identified 212 species of calanoid copepods from a series of day and night tows between 40 and 960m. From a review of previous works and his own findings Roe (1972a) concluded that ". . . in most of the Atlantic Ocean the maximum numbers of calanoid copepods are in the upper 100m both day and night and there are often secondary midwater maxima by both day and night."

During the early sixties Owre and Foyo began a comprehensive survey of vertical and spatial distributions of zooplankton in the Florida Current and Caribbean. The impacts of Caribbean tropical water masses and the influence of the Florida Current were possibly two important elements that lead to such a long term study (1964-1976). The taxonomy and vertical distribution of a large number of copepod species were presented in their monograph, Copepods of the Florida Current (Owre and Foyo, 1967), which included a summary of the data on copepod distributions in the western Atlantic. Their most recent report, Caribbean Zooplankton (Michel* and Foyo, 1976), contains a discussion of the hydrographic characteristics and water structure of the Caribbean, and an excellent review of previous studies in the Atlantic. They did not attempt a complete taxonomic analysis of the copepods; "instead 20 common, frequently caught, and readily identified species with broad vertical ranges were selected as representatives of Caribbean copepods." Species were included from the three groups of free-living copepods, namely the calanoids, cyclopoids, and harpacticoids. The number of calanoid and harpacticoid species was found to increase with distance from land while that of the cyclopoids decreased. Although calanoids far outnumbered the cyclopoids in total numbers of species, the cyclopoids (45.4%) almost equalled the calanoids (49.4%) in abundance of individuals. Two cyclopoid species, *Oithona plumifera* and *Farranula gracilis*, were the most numerous of the 20 common copepod species and a harpacticoid species, *Microstella rosea*, was more abundant than the most common calanoid. These investigations also confirmed that copepod populations are concentrated in the upper 250-300m with the majority of specimens being caught in shallower tows in the upper 100m. Therefore, it can be concluded that in the tropics, at least, the greatest abundance of copepods occur at relatively shallow depths and cyclopoids and harpacticoids certainly should be included in studies of biomass and biology.

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* nee Owre

Puerto Rico Trench Studies

The emphasis of previous studies in this tropical Atlantic trench has been on geological, physical, and hydrographical aspects (Pollak, 1950; Wust, 1964; Emery and Uchupi, 1972). Biological studies have been few, usually directed toward sampling deep-sea benthos (Nybelin, 1957; Staiger, 1972; George and Higgins, 1977). Pérês (1965) explored the Puerto Rico Trench in ten dives with the French bathyscape, Archimède. Two of these dives were devoted to biological observations which revealed a virtual absence of plankton below 2900m. During a recent oceanographic cruise, Michel and Foyo (1976) sampled the zooplankton of the Puerto Rico Trench (Brownson Deep). "However, no attempt was made during the Caribbean survey to determine non-migration or diurnal migration of copepod species."

Since migratory patterns of oceanic copepods, especially over the Puerto Rico Trench, remain poorly understood, the present study will examine the patterns of diurnal migrations of calanoid, harpacticoid, and cyclopoid species in the upper 150m in this tropical oceanic environment.

MATERIALS AND METHODS

Study Area

The Institute of Marine Biomedical Research (IMBR) at Wilmington, North Carolina has established a permanent station in the tropical Atlantic over the Puerto Rico Trench (George and Higgins, 1977). This area has been sampled periodically since 1976. Their study constitutes a long term investigation which is concerned with the biology of the Puerto Rico Trench. These study sites are located above the trench in an area bounded by the northern coast of Puerto Rico and 20^{o}N latitude and 66^{o} and 67^{o}W longitude (Figure 1). Within this area I chose six plankton sampling stations for obtaining quantitative samples to evaluate the migrational patterns of the copepods in this geographic area. These six plankton stations were sampled during my participation in IMBR sponsored biological oceanographic cruises in July 1976 (GILLISS cruise no. 7607) and June 1977 (GILLISS cruise no. 7704). Specific locations for the plankton stations were plotted from the ship's track, which was computed from Loran C and periodic SATNAV (Satellite Navigation) fixes. The stations lie along a northerly transect 10-160 km from the north coast of Puerto Rico (Figure 1).

Sampling Strategy

Patterns of vertical migration for copepods can be determined by sampling the plankton at several depths through the water column with opening-closing nets. In July 1976 and June 1977, a series of horizontal plankton tows were taken during day and night periods at six stations in a tropical oceanic environment directly north of the island of Puerto Rico.

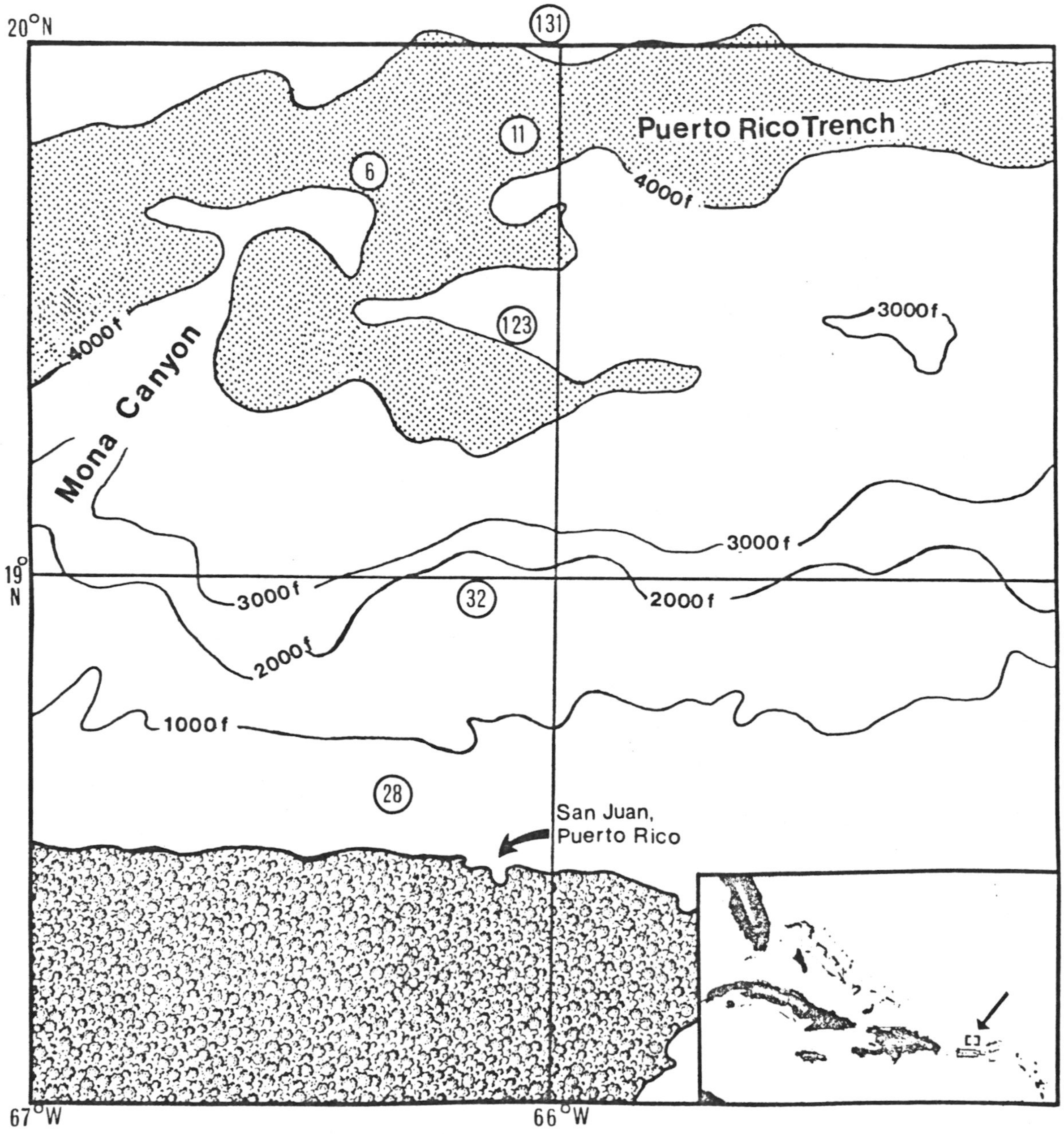

Figure 1. Map of study area showing the six plankton stations over the Puerto Rico Trench north of San Juan. (Contour lines in fathoms are converted to metric as: 1000f = 1828m, 2000f = 3656m, 3000f = 5484m, 4000f = 7312m).

At each station, the water column was sampled at 50m intervals from the surface to 150m (Table 1). This depth range included the major portion

Table 1. Date, time, and location of vertical series (0-150m) of zooplankton collections.

RV GILLISS Station No.	Time	Date	Position Latitude (N)	Longitude (W)
6	1142	13 July 76	19°46.7'	66°22.5'
11	2220	14 July 76	19°50.0'	66°04.9'
28	0304	20 July 76	18°35.7'	66°18.9'
32	1638	20 July 76	18°57.7'	66°09.8'
123	0523	19 June 77	19°27.0'	66°06.1'
131	1510	22 June 77	20°02.0'	66°02.9'

of the photic zone where the greatest abundance of plankton exists. Deep tows (1000-4000m) and random surface tows were also taken but used only for taxonomic purposes and shipboard observations of tolerances of selected copepod species to hydrostatic pressure.

Sampling Equipment

Equipment and methods employed in the present study are similar to that described in Owre and Low (1969). All sampling was conducted from the University of Miami oceanographic research vessel GILLISS. In July, 1976, two 75 cm (mouth diameter) opening-closing "Discovery" nets were used for sampling at four stations (Table 1). Each net consisted of three sizes of nylon mesh, located in segments as shown in Figure 2 (0.110 mm, 1.6 mm, and 3.2 mm). A PVC ring threaded to receive a straight-sided plastic jar was fitted into the cod-end (10 cm diameter) and held in place with a stainless steel hose clamp.

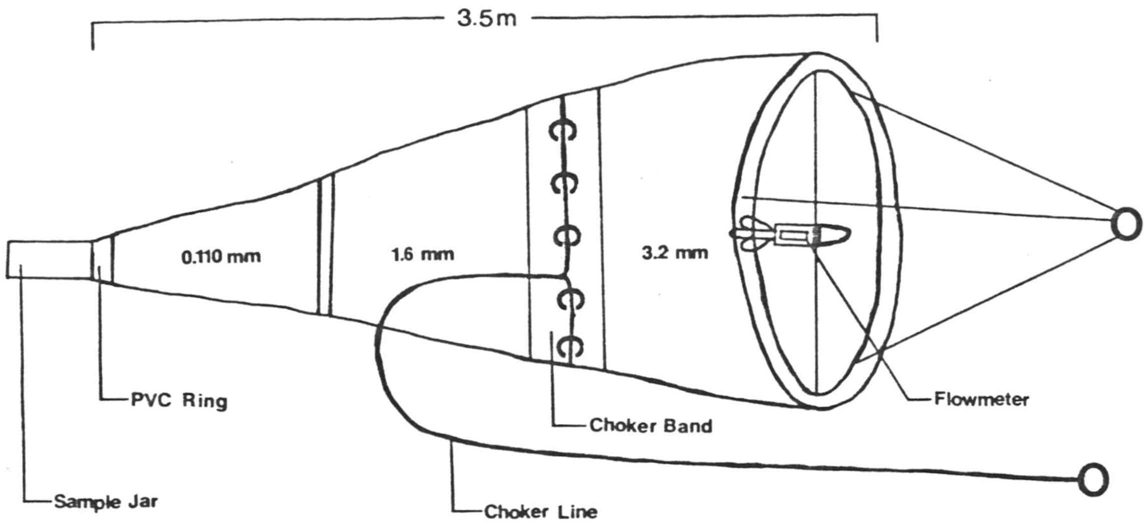

Figure 2. "Discovery" type plankton net used during the 1976 GILLISS cruise (mesh sizes noted).

The "Discovery" nets were not available for the 1977 GILLISS cruise. Dr. Harding B. Michel (Rosenstiel School of Marine and Atmospheric Sciences) recommended using simular nets available from Ernest Case, Inc. The overall dimensions were the same as those of the "Discovery" nets (including mouth diameter, cod-end, and total length) except a single mesh size of 0.110 mm nylon was used throughout the length of each net.

A General Oceanics flowmeter (Model No. 2030-R) was mounted in the mouth of one of the two nets, providing quantification of towing distance, volume, and speed. Formulae for these calculations were provided in the instruction manual that accompanied each meter. An average towing speed of 2.8 km/hr was maintained.

Each net was rolled (closed), attached to a double trip mechanism (General Oceanics Model No. 4020), positioned on the hydrowire by a wire stop, and lowered to the desired sampling depth, which was determined by applying the wire angle measured by an inclinometer to a known amount of out. The nets were positioned at sampling depths, opened by mechanical messenger, fished for 30 minutes, and closed at depth by mechanical messenger (Figure 3).

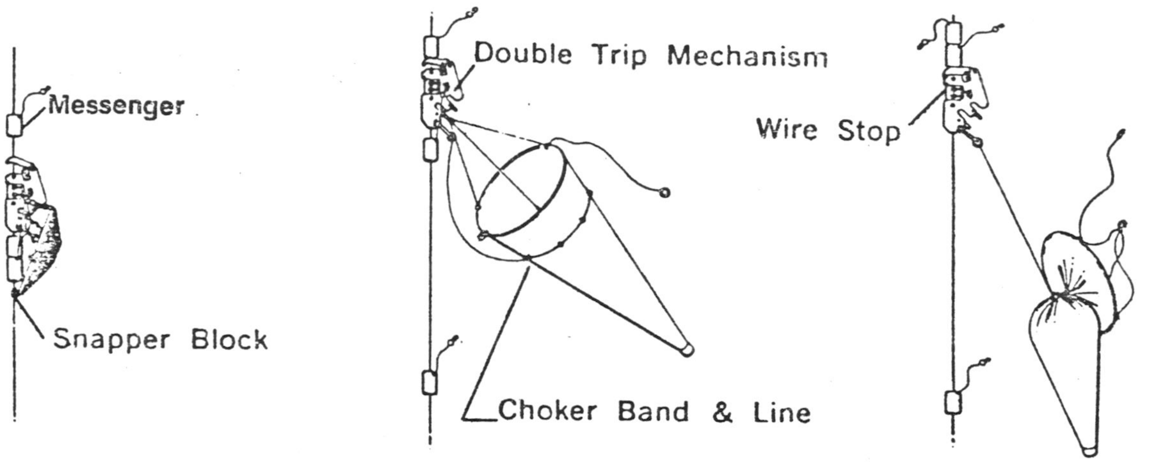

Figure 3. Opening-closing procedure for closing plankton nets.

Upon retrieval, the nets were washed with sea water to remove organisms adhering to the netting. Excess sea water was strained through the netting and the concentrated plankton sample was transferred to a labeled glass jar for preservation in 10% formaldehyde buffered with sea water.

Sample Treatment

Due to the large amount of material caught by horizontal net hauls, the samples had to be fractioned in a plankton splitter (Burrell, Jr., et. al., 1974). The whole sample was first split into two subsamples with subsequent splitting of one of these halves into successive subsamples. This process was repeated two (1/4) to ten (1/1024) times depending on the biovolume of each sample. The adult copepods and some copepodites that could be accurately and readily identified were separated, sorted to species, and counted using Wild M5 and M40 microscopes. Owre and Foyo (1967) was the principal reference for species identifications. Reference specimens of twenty species were sent to Drs. Thomas

Bowman and Frank Ferrari of the U. S. National Museum who verified the identifications. This data is included herein as Appendix A.

Abundance estimates were converted to No./100m^3. Estimates for the more frequently encountered copepod species, those occurring in one-half or more of the available samples, were used to compute the percentage of each sampled species ranging in depth from 0 to 150m meters. These percentages were plotted graphically to show day and night distributions.

Hydrographic Data

Detailed hydrographic measurements were not within the limits of this plankton program; however, salinity and temperature measurements were taken at the surface during each plankton tow with a Goldberg refractometer (A. O. Model No. 10419) and mercury thermometer ($\pm$ 0.5°C). Additional hydrographic data were provided by the cast of a Bisset-Berman STD probe (Model No. 9006) which recorded salinity and temperature readings from 10 to 850m.

RESULTS AND DISCUSSION

Hydrography of Study Area

The upper 200m over the Puerto Rico Trench appears to belong to a warm water layer and is obviously a part of Tropical Surface Water (TSW) (Worthington, 1971). This layer (TSW) is characterized in the eastern Caribbean as the uppermost 50 to 100m in which highly variable salinity (33 $^{o}/oo$ to 37 $^{o}/oo$) and temperature (22^{o} to 28^{o}C) are found (Michel and Foyo, 1976). The subsurface water between 50 and 200m over the Puerto Rico Trench area seems to be somewhat stable both in thermal and salinity characteristics as evidenced from the comparisons of the present study with earlier data. Perhaps a thermocline separating TSW from deeper layers is present between 100 and 200m and could therefore explain the apparent similarity and consistency of subsurface salinity and temperature measurements reported from this area.

The salinity and temperature data for the upper 200m over the Puerto Rico Trench are presented in Figure 4. Salinity increased from 34.0 (surface) to 36.6 $^{o}/oo$ (200m) and temperature decreased from 27.4 (surface) to 21.0^{o}C (200m). A prominent thermocline is not evident in the profile shown here; however, Bjornberg (1971) noted the presence of a thermocline at 100 to 200m in the caribbean and Gulf of Mexico. Possibly the presence or absence of a thermocline in tropical waters is dependent on intrusion of water masses of varying thermal value.

Wust (1964) stated that due to the westerly flowing Antilles Current, salinities in the Puerto Rico Trench region were controlled by the dispersal of higher salinity water (37.2 $^{o}/oo$) from a point source at 21-32^{o}N. His salinity measurements (36.5-37.0 $^{o}/oo$) from the upper 200m over the

Puerto Rico Trench were higher at the surface than those of the present study. Michel and Foyo (1976) recorded salinities between 34.44 and 36.69 ^{o}/oo in the upper 200m over the Puerto Rico Trench (Brownson Deep). Bjornberg (1971) reported salinity between 36.5 and 35.2 ^{o}/oo in the subsurface water (50-200m) of the Caribbean Sea and pointed out that

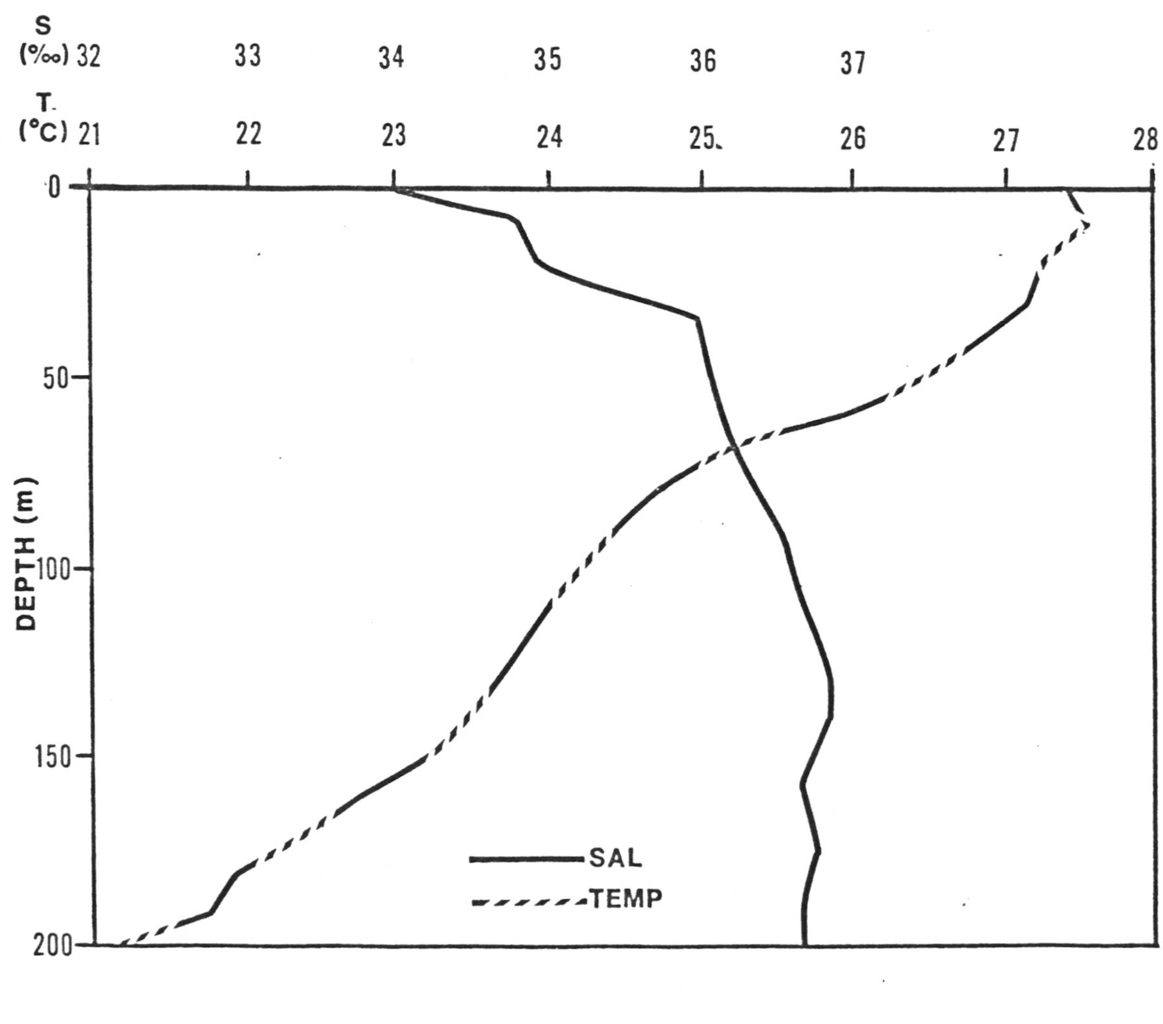

Figure 4. Hydrographic profile over Puerto Rico Trench at 19°49.3'N, 66°21.5'W on 16 July 1976. Temperature and salinity are based upon an STD cast except surface points (0 m) that were obtained with the use of a thermometer and refractometer.

surface water (0-50m) was quite variable with regards to salinity and temperature. Surface water (0-50m) temperature varied between 26.0 (Wust, 1964) and 28.8°C (Michel and Foyo, 1976). In subsurface water (50-200m) temperature was centered around 20.0°C (Wust, 1964) and 19.75°C (Michel and Foyo, 1976) at 200m.

Composition of Copepod Fauna

This systemmatic survey revealed a total of 83 copepod species; although, a complete taxonomic analysis was not within the limits of this plankton study. The majority of species (63) came from twenty-two samples taken at depths between 0 and 150m over the Puerto Rico Trench. The remaining 20 species were identified during preliminary taxonomic analysis of qualitative surface tows and deep tows (1000-4000m). The total of 83 species encountered north of Puerto Rico represents less than 25% of the total known number of copepod species in the Caribbean which approaches 450 species with more to be found in tows from deeper than 500m.

Distribution of these species among the three major free-living orders of copepods can be found in Table 2. As is generally the case in oceanic environments, the greatest number of species (50) belonged to the order Calanoida. Cyclopoida was the second largest order with 26 species.

Table 2. Phylogenetic distribution of copepod species.

ORDER	FAMILIES	GENERA	SPECIES
Calanoida	18	32	50
Harpacticoida	5	6	7
Cyclopoida	4	9	26
TOTALS	27	47	83

It is generally known that cyclopoids exhibit greater diversity in near-shore waters. The harpacticoids, represented here by only 7 species, are usually benthic; however, a few species have adapted to a planktonic existence. Bjornberg (1965) described such an adaptation for the harpacticoid, Macrosetella gracilis. Adults and larval stages of this species apparently cling to filaments of the blue-green alga, Trichodesmium, which serve as a mechanism of support enabling it to live, reproduce, and develop in the plankton. Trichodesmium commonly occurs in the typically nitrogen-poor tropical Atlantic surface waters and was encountered in high concentration in the surface and 50m plankton tows in this study.

The species encountered in this investigation are listed in phylogenetic order in Table 3.

Table 3. Species list of the copepods from the 1976 and 1977 GILLISS cruise. Species marked (*) will be described in detail elsewhere with reference to its migratory pattern.

CALANOIDA

Calanidae

1. Calanus tenuicornis (Dana, 1849)
2. C. minor (Claus, 1863)
3. Neocalanus robustior (Giesbrecht, 1888)
4. Undinula vulgaris (Dana, 1852)*

Eucalanidae

5. Eucalanus attenuatus (Dana, 1849)
6. E. subtenuis (Giesbrecht, 1888)
7. Eucalanus sp.
8. Rhincalanus cornutus forma atlantica (Dana, 1852)

Paracalanidae

9. *Acrocalanus longicornis* (Giesbrecht, 1888)

10. *Paracalanus aculeatus* (Giesbrecht, 1888)

11. *Paracalanus* sp.

Calocalanidae

12. *Calocalanus pavo* (Dana, 1852)*

13. *Calocalanus* sp.

14. *Ischnocalanus plumulosus* (Claus, 1863)

15. *Mecynocera clausii* (Thompson, 1888)*

Pseudocalanidae

16. *Clausocalanus arcuicornis* (Dana, 1852)

17. *C. furcatus* (Brady, 1883)*

Aetideidae

18. *Aetideus armatus* (Boeck, 1872)

19. *Euaetideus giesbrechti* (Cleve, 1904)

20. *Euchirella* sp.

21. *Undeuchaeta plumosa* (Lubbock, 1856)

Phaennidae

22. *Phaenna spinifera* (Claus, 1863)

Euchaetidae

23. *Euchaeta marina* (Prestandrea, 1883)

24. *Euchaeta* sp.

Scolecithricidae

25. *Scolecithrix danae* (Lubbock, 1856)

Temoridae

26. *Temora stylifera* (Dana, 1852)

27. *T. turbinata* (Dana, 1852)

Metridiidae

28. *Metridia venusta* (Giesbrecht, 1889)

29. *Pleuromamma abdominalis* (Lubbock, 1856)

30. *P. xiphias* (Giesbrecht, 1889)

Centropagidae

31. *Centropages violaceus* (Claus, 1863)

32. *Centropages* sp.

Lucicutiidae

33. *Lucicutia flavicornis* (Claus, 1863)*

34. *L. gemma* (Claus, 1863)

Heterorhabdidae

35. *Heterorhabdus* sp.

Augaptilidae

36. *Haloptilus longicornis* (Claus, 1863)*

37. *H. mucronatus* (Claus, 1863)

38. *Haloptilus* sp.

39. *Arietellus plumifera* (Sars, 1905b)

Candaciidae

40. *Candacia cuta* (Dana, 1852)

41. *C. pachydactyla* (Dana, 1852)

42. *C. aethiopica*

43. *Paracandacia bispinosa* (Claus, 1863)

Pontellidae

44. *Labidocera nerii* (Kroger, 1849)

45. *Labidocera* sp.

46. *Pontellina plumata* (Dana, 1852)

Acartiidae

47. *Acartia negligens* (Dana, 1852)

48. *A.spinata* (Esterly, 1911a)

49. *Acartia* sp.

Mormonillidae

50. *Mormonilla phasma* (Giesbrecht, 1891a)

HARPACTICOIDA

Aegisthidae

51. *Aegisthus aculeatus* (Giesbrecht, 1891a)

Ectinosomidae

52. *Microsetella rosea* (Dana, 1848)*

Clytemnestridae

53. *Clytemnestra scutellata* (Dana, 1848)

Miraciidae

54. *Miracia efferata* (Dana, 1852)

55. *M. minor* (T. Scott, 1894)

Macrosetellidae

56. *Macrosetella gracilis* (Dana, 1848)*

57. *Oculosetella gracilis* (Dana, 1852)

CYCLOPOIDA

Oithonidae

58. *Oithona plumifera* (W. Baird, 1843)*

59. *Oithona* sp.

Oncaeidae

60. *Oncaea conifera* (Giesbrecht, 1891a)

61. *O. curta* (Sars, 1916)

62. *O. venusta* (Philippi, 1843)*

63. *Conaea gracilis* (Dana, 1853)

64. *Lubbockia squillimana* (Claus, 1863)*

65. *Pachos punctatum* (Claus, 1863)

Sapphirinidae

66. *Sapphirina auronitens* (Claus, 1863)

67. *S. metallina* (Dana, 1852)

68. *S. nigromaculata* (Claus, 1863)

69. *S. opalina* (Dana, 1852)

70. *S. setellata* (Giesbrecht, 1891a)

71. *Copilia mirabilis* (Dana, 1852)

72. *C. quadrata* (Dana, 1852)

73. *C. vitrea* (Haeckel, 1864)

Corycaeidae

74. *Corycaeus speciosus* (Dana, 1852)

75. *C.* (*Agetus*) *flaccus* (Giesbrecht, 1891a)

76. *C.* (*A.*) *limbatus* (G. Brady, 1883)

77. *C.* (*A.*) *typicus* (Kroger, 1849)

78. *C.* (*Urocorycaeus*) *lautus* (Dana, 1852)

79. *C.* (*Onychocorycaeus*) *latus* (Dana, 1852)

80. *C.* sp.

81. *Farranula carinata* (Giesbrecht, 1891a)

82. *F.* *gracilis* (Dana, 1853)*

83. *Farranula* sp.

Numerical Abundance of Copepods

Abundance estimates are based on data from twenty-two (22) quantitative tows at six stations over the Puerto Rico Trench. Results by station and depth can be found in Appendix A. A summarization of these data with reference to the percentage distribution for copepod orders and species appears in Table 4.

Table 4. Percentage distribution of copepod species within their order and in relation to total copepod numbers.

ORDER	SPECIES	% WITHIN ORDER	TOTAL %
Calanoida			52.8
	Clausocalanus furcatus	9.3	4.9
	Mecynocera clausii	5.7	3.0
	Undinula vulgaris	5.0	2.6
	Others (including copepodites)	80.0	42.3
Harpacticoida			10.5
	Microsetella rosea	93.1	9.8
	Others (including copepodites)	6.9	0.7
Cyclopoida			36.7
	Oithona plumifera	42.2	15.5
	Oncaea venusta	27.6	10.1
	Others (including copepodites)	30.2	11.1

Density Distribution Among Copepod Orders

Calanoids were the most numerically abundant order with 52.8% of the total number of individuals (Table 4). Cyclopoids were second with 36.7% and harpacticoids were the least abundant with 10.5% of the total individuals. It is of interest to note that these percentages are comparable to those found throughout the Caribbean by Michel and Foyo (1976).

They reported abundance estimates of 49.4% for the calanoids, 45.4% for the cyclopoids, and 5.2% for the harpacticoids. The higher cyclopoid percentage may be the result of their sampling in neritic areas whereas the present study only sampled an oceanic regime. The lower percentage for the harpacticoids could be a reflection of their sampling over a greater depth range than the comparatively shallow depth range (0-150m) of the present study.

Species Abundance

Among calanoids, three species, namely Clausocalanus furcatus, Mecynocera clausii, and Undinula vulgaris (Table 4, Figure 5), showed the highest abundance. However, their numerical abundance was not as high as that of the dominant cyclopoid and harpacticoid species. Furthermore, the numerical abundance of these three species combined, only represented 20% of the total calanoid numbers. The majority of the total calanoid numbers were represented by forty or more species listed as "Other Calanoids." This is a reflection of the large numbers of species typically found in this copepod order.

The most dominant copepod species in the upper 150m over the Puerto Rico Trench were two cyclopoids, Oithona plumifera (15.5% of the total population) and Oncaea venusta (10.1%). These two species, represented 69% of the total cyclopoid density. Microsetella rosea (9.8%), the third most abundant copepod species, was undoubtedly the most dominant harpacticoid as it alone accounted for over 90% of the total harpacticoid density. These three most abundant copepod species are illustrated in Figure 6.

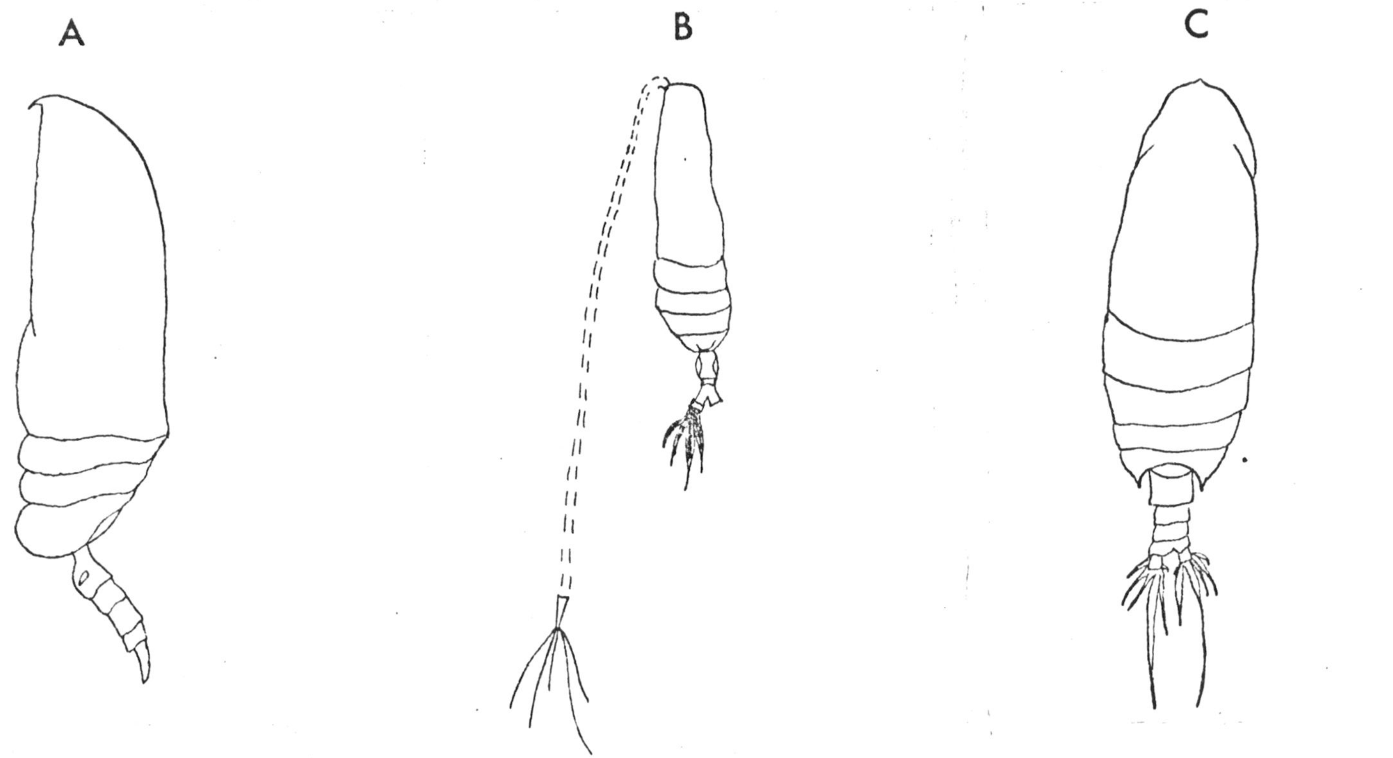

Figure 5. Dominant calanoid copepods from upper waters (0-150m) over Puerto Rico Trench. (A) Clausocalanus furcatus, (B) Mecynocera clausii, and (C) Undinula vulgaris.

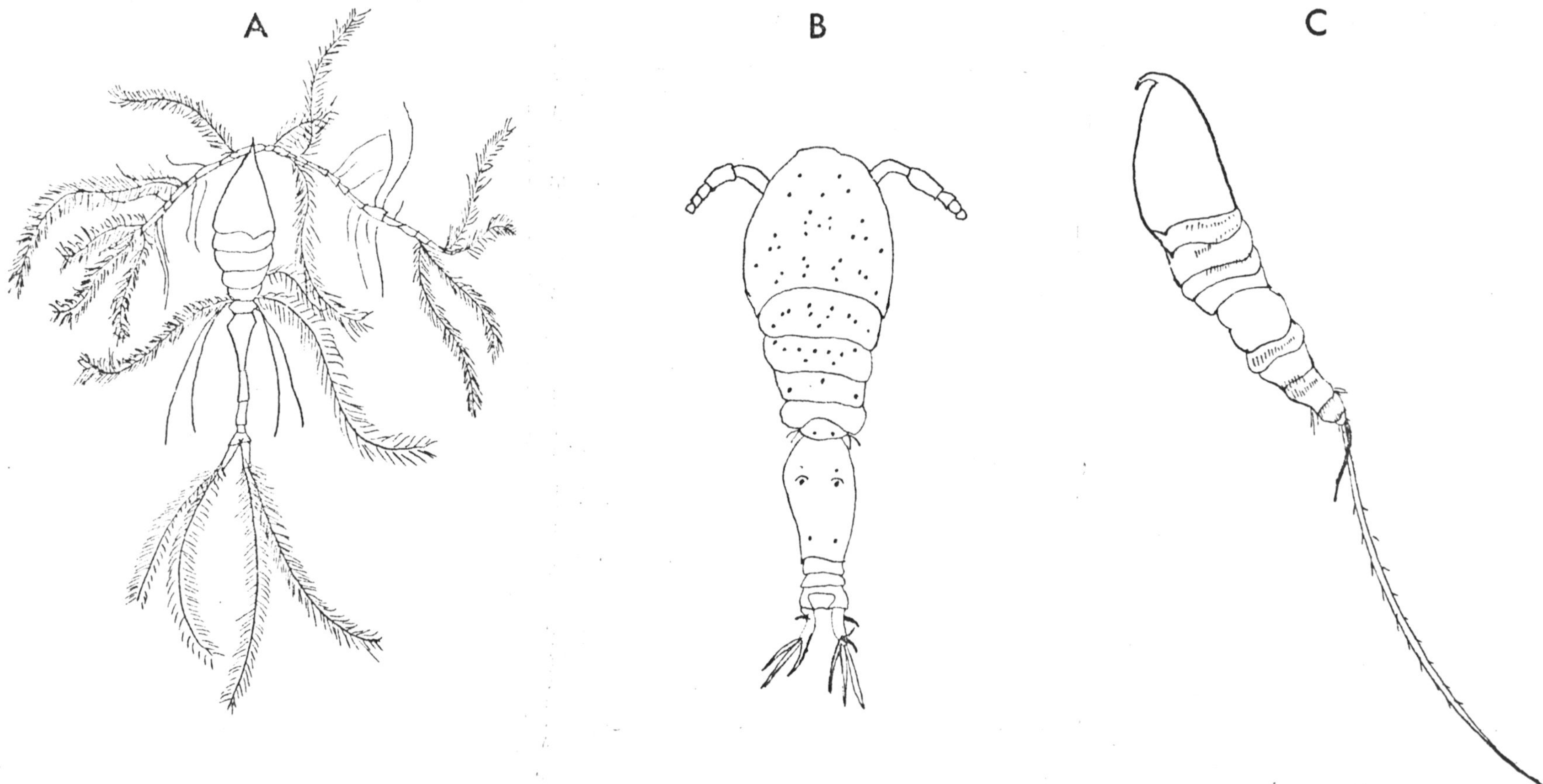

Figure 6. Most numerous copepod species counted in samples from Puerto Rico Trench study area. (A) Oithona plumifera, (B) Oncaea venusta, and (C) Microsetella rosea.

The relative abundance of certain copepod species in the Puerto Rico Trench area appears to reveal some similarity to the Caribbean species described by Michel and Foyo (1976). As in the present study, they reported the cyclopoid, O. plumifera, as the most abundant copepod of the species quantitatively investigated. However, they reported another cyclopoid, Farranula carinata, as the second most abundant species, whereas in this study Oncaea venusta showed the second highest density. Farranula carinata was rarely encountered in the present study. Perhaps it is confined to the Caribbean Sea and does not inhabit the Antilles Current in large numbers. Oncaea venusta was reported as sixth in overall abundance by Michel and Foyo (1976). Microsetella rosea, was found by both surveys to rank third in overall abundance and C. furcatus emerged as the most abundant calanoid in both studies. Apparently, cyclopoids and harpacticoids are important constituents of the copepod fauna in the tropical Atlantic and should not be neglected when studying the biology of the plankton community in this region.

Vertical Migration Patterns of Copepod Species

Twelve (12) copepod species were selected for analysis of diurnal migration on the basis of their abundance and frequency (i.e. presence in 50% more than of the twenty-two (22) plankton samples). Data on the time-density distributions for these species appear in Table 5. In order to demonstrate obvious patterns in density shifts, graphic illustrations depicting day and night differences are presented in Figures 7 and 8. These illustrations were computed from the total abundance of each species at a particular depth during the diurnal and nocturnal periods.

Table 5. Relative abundance estimates (No./100m^3) of copepod species from vertical profiles (0-150m) at six stations over the Puerto Rico Trench.

Species or Order	No. of Samples			Total Numbers		
	Day	Night	Total	Day	Night	Total
Clausocalanus furcatus	8	8	16	3,342	16,129	19,471
Mecynocera clausii	5	8	13	5,495	6,532	12,027
Undinula vulgaris	6	6	12	5,670	4,739	10,409
Calocalanus pavo	6	7	13	4,574	4,874	9,448
Lucicutia flavicornis	6	10	16	3,881	4,521	8,402
Haloptilus longicornis	5	7	12	2,592	2,509	5,101
Other Calanoids (including copepodites)	11	8	19	59,146	85,268	144,414
Microsetella rosea	11	9	20	10,484	28,247	38,731
Macrosetella gracilis	9	8	17	831	1,471	2,302
Other Harpacticoids (including copepodites)	5	4	9	328	263	591
Oithona plumifera	12	10	22	26,817	34,642	61,459
Oncaea venusta	12	10	22	14,409	25,807	40,216
Farranula gracilis	8	7	15	19,292	10,354	29,646
Lubbockia squillimana	5	6	11	451	1,288	1,739
Other Cyclopoids (including copepodites)	11	9	20	4,222	8,287	12,509

Calanoid Species

Clausocalanus furcatus (Figure 7A) occurred predominantly in the upper 100m where 99% of its population was collected. This calanoid was caught in far greater numbers at night than during the day (Table 5). The greatest diurnal concentration (62.5%) occurred at 50m while 87% of the nocturnal catch was distributed at the surface. As seen in Figure 7A, *C. furcatus* exhibited a marked upward migration to the surface at night.

In the Caribbean Sea, Owre and Foyo (1964) and Michel and Foyo (1976) also found *C. furcatus* confined to the upper 100m with less than 1% caught below this depth. These authors did not attempt to describe the migratory pattern for this or any other species. However, from their Florida Current investigations, they (1967) concluded that *C. furcatus* was a diurnal migrator and moved toward the surface at night. The results of the present study support the findings of their Florida Current study.

Mecynocera clausii (Figure 7B) was also distributed in greatest abundance (92%) within the upper 100m. Numerical maxima were found at 50m (97%) by day and 100m (44%) by night. This species was not collected at the surface during the day, but a small portion (19%) of the nocturnal population occurred at the surface. These data do not indicate a pronounced upward migration as evidenced in the distribution of *C. furcatus*. Instead, there is apparently a movement in both directions at night from the diurnal concentration at 50m.

Other literature concerning the distribution or migrational tendencies for *M. clausii* is lacking. Owre and Foyo (1964) reported it

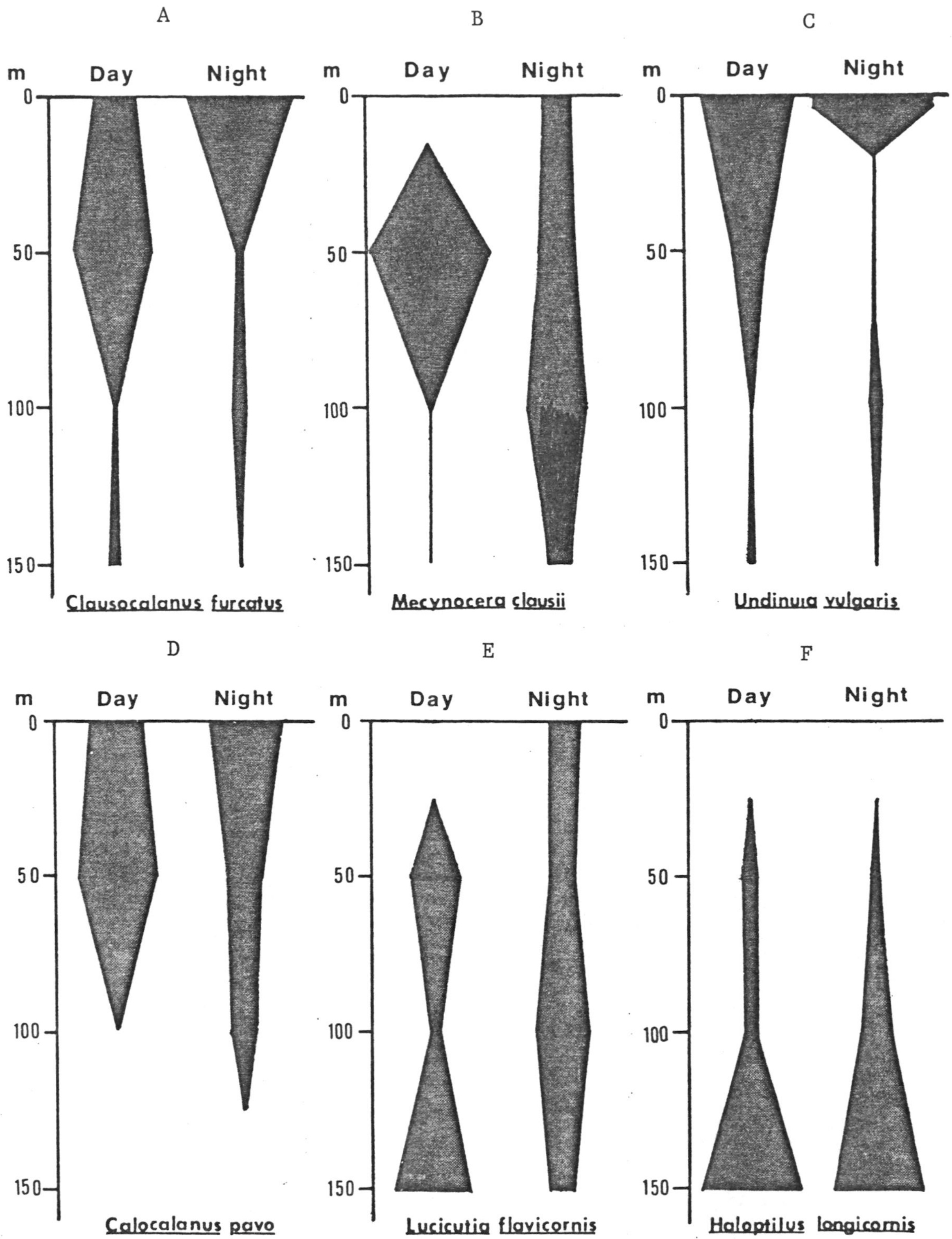

Figure 7. Day and night distributions of calanoid species listed in order of numerical abundance. Interpolation of population to midpoint between depths when data is not available as in B (Day), C (Night), D (Night), E (Day), and F (Day and Night).

as rare in the Caribbean with a few females at 100, 170, and 877m. From sparse data, they (1967) concluded that M. clausii was an inhabitant of the upper 200m in the Florida Current. Roe (1972a) found a small number of this species at 40m; however, he did not sample above this depth and did not record its occurrence in deeper strata. Since it was the second most abundant calanoid in the Puerto Rico Trench samples, this may be an area in which M. clausii occurs in sufficient abundance to provide conclusive data concerning its migrational behavior.

Undinula vulgaris (Figure 7C) was concentrated in the upper 50m where 97% of the population existed by day and night. Despite a slightly lower density at night (Table 5), this calanoid occurred with a greater abundance (97%) at the surface at night than during the day when 73% occurred at the surface. This indicates an upward migration to the surface at night; however, most of the population appeared to exist at or very near the surface regardless of time.

Owre and Foyo (1964) found 97% of this calanoid's population in the upper 50m in the Caribbean. Michel and Foyo (1976) noted that this species was abundant in shallow subtropical oceanic waters and stated that it swarmed in hugh numbers near the surface even during the day. Moore and O'Berry (1957) reported the diurnal migration of this species as moderately extensive showing a definite movement away from the surface in the daytime. Roehr and Moore (1965) found a shift toward the surface from a day level at 134m to night level at 85m. Michel and Foyo(1976) also reported this same pattern for U. vulgaris in the Caribbean. There is little disagreement as to the migrational behavior of this species in the tropical Atlantic.

In light of the fact that 89% of the population occurred in the upper 50m, Calocalanus pavo (Figure 7D) appeared to be a shallow water inhabitant as were all the previously mentioned calanoids. Total night numbers were only slightly higher than those during the day (Table 5). By night 57% occurred at the surface indicating an upward migration at night; however, a noticeable increase occurred at 100m during the nocturnal period implying that part of the population moved away from the diurnal maximum at 50m to deeper depths. Evidently portions of the population move in both directions from the daytime concentration as seen in M. clausii.

C. pavo was reported by Owre and Foyo (1964) as extremely abundant in the Caribbean with 71% of the population concentrated in the upper 50m. Roe (1972a) encountered this species at 40m only; however, he did not sample above this depth. The migration pattern for this species is not clear. Moore and O'Berry (1957) and Roehr and Moore (1965) concluded that C. pavo performed a reverse migration by moving downward at night. The data from the present study points out for the first time that during the night C. pavo has a tendency to move upward and downward from midwater depths (50m by day).

As seen in most of the other calanoids, Lucicutia flavicornis (Figure 7E) was captured in greater abundance during the night. In view of the fact that 87% of the day and night totals were found below 50m, L. flavicornis appeared to inhabit deeper and broader depth ranges than the aforementioned species. It avoided the surface during the day when the population was concentrated at 50m (36%) and 150m (60%). At night numerical maxima occurred at 100m (43%) and the surface (21%). This pattern suggests an upward migration of both daytime maxima toward the surface (Figure 7E).

Michel and Foyo (1976) reported a very broad vertical range (0-4350m) for this species in the Caribbean. They did not encounter L. flavicornis in surface tows during the day and only 6% of the specimens were captured at the surface at night. In earlier Caribbean studies, they (1964) found the greatest concentration (82%) between 50 and 146m. Roehr and Moore (1965) and Michel and Foyo (1976) reported an upward migration at night for this calanoid. Data from the present study confirms the upward nightly migration pattern observed by these investigators in the Caribbean and the Straits of Florida.

Haloptilus longicornis (Figure 7F) occurred with almost equal day and night concentrations which were the lowest estimates recorded for the calanoids quantitatively treated by the present study. This low abundance may be a reflection of its deeper distribution which was apparently concentrated below the sampling range of this study. H. longicornis was not collected at the surface by day or night and the bulk (77%) of the total population occurred at 150m regardless of collection time (diurnal and nocturnal). Diurnal (82%) and nocturnal (72%) maxima were also found at 150m. It is somewhat evident from Figure 7F that the population density increased slightly from 150 to 100m at night. Nevertheless, the data from this study did not indicate a well-defined migrational pattern. It is assumed that, at least in the upper 150m over the Puerto Rico Trench, H. longicornis does not migrate.

Owre and Foyo (1964) reported this species as common in the Caribbean where 92% of its population occurred between 100 and 292m. The same authors (1967) found it most abundant between 50 and 250m in the Florida Current. *H. longicornis* has been reported as exhibiting a reverse migration (Roehr and Moore, 1965) and a distinct upward migration (Roe, 1972d). Data from this study does not support the two cited conflicting views about the migratory behavior of this species.

Harpacticoid Species

Microsetella rosea (Figure 8A) was present throughout the upper 150m, especially at night when the total catch was three times that caught during the day (Table 5). The bulk (90%) of its population occurred above 100m, day and night. The diurnal distribution revealed a maximum concentration (84%) at 50m. During the nocturnal period maximum numbers (57%) occurred at the surface while the remainder of the population was distributed almost evenly between 50 and 150m. The shift of the daytime concentration toward the surface at night is interpreted as an upward migration.

Owre and Foyo (1967) summarized the few known records of this species from the western North Atlantic, the Florida Straits, and the Gulf of Mexico; however, they made no mention of vertical distribution or diurnal migration. Michel and Foyo (1976) described *M. rosea* as "one of the most interesting species counted, especially as so little is known about it in the Caribbean area and, indeed, in the North Atlantic." They recorded maximum numbers (93%) in the upper 115m regardless of collection time. The data presented in this study clearly indicate an upward migration at night, and constitute the only record on the migratory activity of this interesting species.

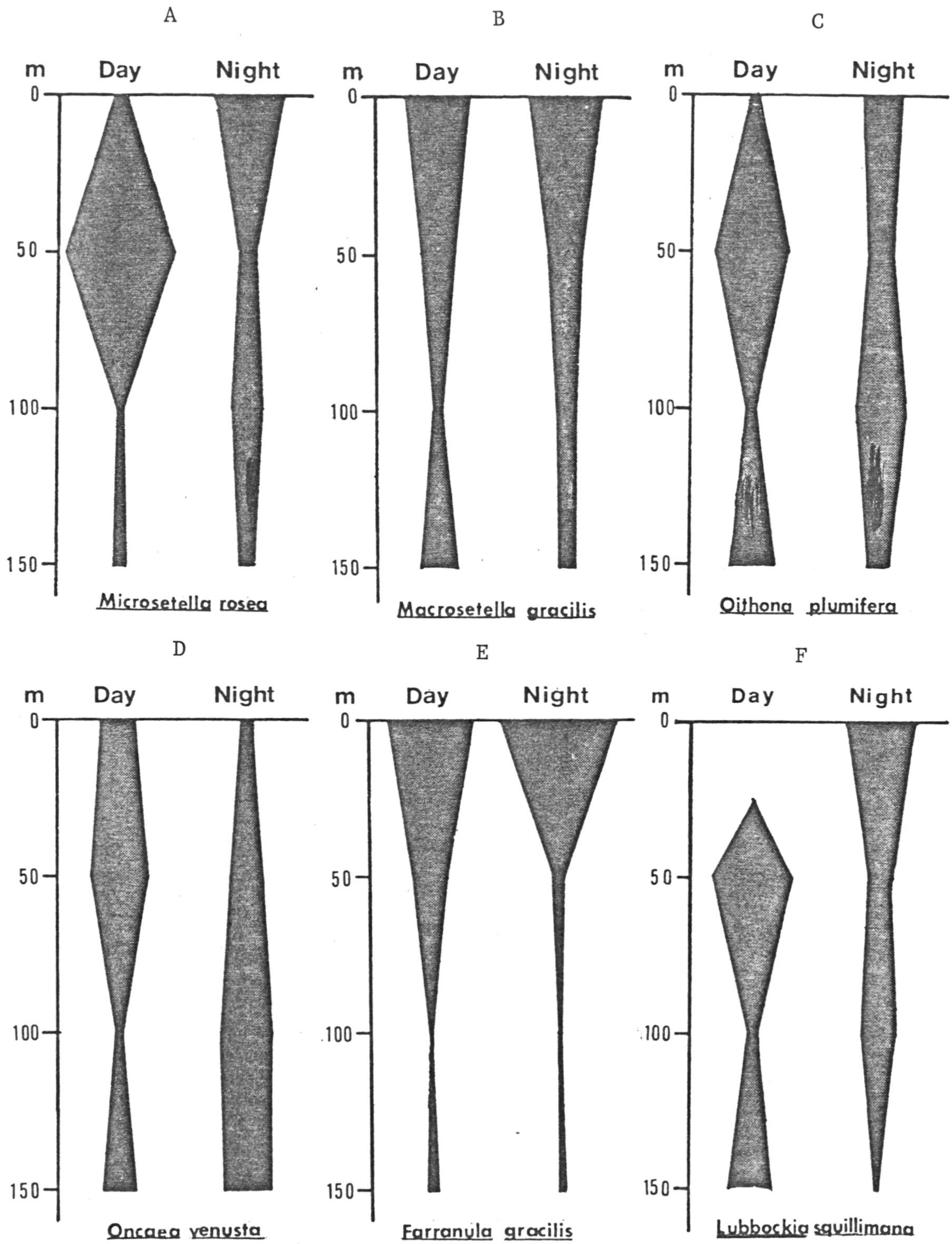

Figure 8. Day and night distributions of harpacticoid (A-B) and cyclopoid (C-F) species. Population distribution interpolated to the midpoint between depths at which a species was not recorded.

Macrosetella gracilis (Figure 8B) was broadly distributed throughout the 150m sampling range with the majority (75%) of the population occurring in the upper 50m by day or night. Numerical maxima were found at the surface by day (48%) and night (55%). This finding suggests that this harpacticoid inhabits the surface waters in highest concentrations. The present data did not provide evidence to show an upward or downward migration. *M. gracilis* is probably a non-migrator with a broad vertical range.

Moore and O'Berry (1957) referred to this harpacticoid as a deep-living form and their illustrations indicated that the bulk of the population occurred between 300 and 600m. They reported it as showing a very small diurnal migration. Roehr and Moore (1965) also considered *M. gracilis* to be deep-living and stated that it was "aberrant in showing no migration." Michel and Foyo (1976) found numerical maxima (87%) in the upper 115m regardless of time of day. With reference to its migration they speculated that, "if *M. gracilis* does migrate diurnally, the migration takes place on a very small scale compared with the vertical range of the species." In view of the fact that this species has a vertical range greater than 600m, it is not possible to arrive at any generalization of the migratory pattern of the species.

Cyclopoid Species

Oithona plumifera (Figure 8C) was the most numerous of all species and occurred in tows at all stations and depths. As in most of the other species, greater numbers were found at night than during the day (Table 5). By day, two maxima were descernable, one at 50m (55%) and another at 150m (36%). By night, these maxima appeared to move toward the surface. These data suggest that O. plumifera performs an upward migration during the night that is similar to the migratory pattern of the calanoid, L. flavicornis.

Maximum numbers of O. plumifera were found in the upper 50 to 150m in the tropical Atlantic by Owre and Foyo (1964), Michel and Foyo (1976) and Boxshall (1977). The latter author found the bulk of the population between 10 and 100m but observed no marked difference in vertical distributions between day and night. In the tropical Pacific, Zalkina (1970a) found the greatest part of the population in the upper 100 to 150m during the 24-hour collecting period. He listed O. plumifera as a non-migratory species. From observations of a Florida Current population, Moore and O'Berry (1957) described this cyclopoid as showing a definite movement away from the surface during the day and a "moderately extensive diurnal migration." Perhaps the data from this present study is indicative of the typical migrational pattern in that daytime numerical maxima at 50 to 150m appear to move upward at night.

Oncaea venusta (Figure 8D) was the second most abundant species. It was caught in considerably larger numbers at night (Table 5), but was prevalent throughout the 150m sampling range with nearly 70% found at or above 100m by day or night. During the day, the main mass (44% of the total day catch) occurred at 50m with a sizable number (24%) at the surface. At night the majority of the population was found at lower depths where 41% was concentrated at 100m and 33% at 150m. The obvious difference between day and night distribution is indicative of a reverse migration showing a movement away from the surface at night.

Several investigators (Owre and Foyo, 1964, 1967, 1972; Zalkina, 1970a; Michel and Foyo, 1976, Boxshall, 1977) have reported this species with its greatest abundance in the upper 150m. Zalkina (1970a) listed O. venusta as a non-migrator in the tropical Pacific, but Boxshall (1977) reported a marked upward migration at night from his investigations in the tropical Atlantic near the Cape Verde Islands. The results of the present study are not in agreement with these earlier reports. Conversely, the migrational pattern of O. venusta during my investigation showed a movement away from the surface at night in the Puerto Rico Trench area.

Unlike most of the aforementioned species, Farranula gracilis (Figure 8E)was found in greater abundance during the day than at night. This species was generally concentrated in the upper 50m with a greater maximum (91%) at the surface by night than by day (69%). These data indicate an upward migration toward the surface during the nocturnal period.

Owre and Foyo (1964) reported 92% of this species from the upper 50m in the Caribbean. Michel and Foyo (1976) stated that "swarms of males and females live just beneath the surface" and noted its apparent potential as an indicator of conditions in surface waters in the equatorial regions of the Atlantic Ocean. Boxshall (1977) found about 60% of the F. gracilis population in the upper 100m by day and nearly 90% between 10 and 60m at night. Although this appeared to show an upward migration at night, he reported some difficulty in interpreting his data because of unreliable results due to inadequate sampling of this small species. The data from the present study are apparently one of the few describing the migrational pattern for this species.

Lubbockia squillimana (Figure 8F)was frequently encountered in low numbers. Nearly 91% of its abundance occurred in the upper 100m. During the day, this species avoided the surface and the maximum concentration (62% of night total) occurred at 50m. At night the greatest numbers (55% of the day total) occurred at the surface. L. squillimana apparently exhibits a marked upward migration at night.

Owre and Foyo (1964) found 91% of the L. squillimana population between 50 and 146m in the Caribbean. Boxshall (1977) reported the bulk of its occurrence between 55 and 100m during the day and 25 and 100m at night. He interpreted this as an indication of upward migration by part of the population. Lubbockia squillimana populating the waters over the Puerto Rico Trench appeared to follow this common type of migratory pattern.

General Patterns of Vertical Migration

Analysis of these twelve species revealed three basic patterns of vertical migration. The most prevalent migrational pattern, to which seven species conformed, involved a movement away from the surface during the day and an ascent to or toward the surface at night. This is the typical pattern of vertical migration, exhibited by most epipelagic species. Five of the seven species that show a well-defined upward migration during the night include C. furcatus, U. vulgaris, M. rosea, F. gracilis, and L. squillimana. Two species tend to fall under a special category typifying a two-step upward migration of the population from 150m to 100m and 100m or 50m to the surface during the night. These two species are L. flavicornis and O. plumifera.

The second migratory pattern involves a movement toward the surface during the day and away from it at night. Such a pattern was observed in only one species, Oncaea venusta. It is of interest to point out that this downward movement during the night as revealed in the present study is contrary to the opinions held by earlier investigators.

The third type of vertical migration included populations showing a shift at night in both directions from a daytime concentration. Two species, Mecynocera clausii and Calocalanus pavo, exhibited this pattern of vertical migration. In the case of M. clausii, this bidirectional movement was very pronounced since this species was totally absent at the surface and poorly distributed in the lower layers during the day.

In addition to the above three modes of diurnal migration, this study revealed the presence of two species that apparently lacked any migratory activity during the day or night. The two non-migratory species were Haloptilus longicornis and Macrosetella gracilis. Haloptilus longicornis was a deep dwelling species and was not found at the surface. On the contrary, Macrosetella gracilis appeared to have a wide range without any marked population changes during the day or night.

All species discussed in detail were primarily inhabitants of the epipelagic zone, which is more or less equivalent to the photic zone (0-200m). From a zoogeographic viewpoint, the species dealt with in this study are typical Caribbean or tropical Atlantic fauna. Details of the horizontal and geographical distributional patterns of these twelve species were not within the focus of this study.

SUMMARY

1. In the Puerto Rico Trench surface copepod fauna, the calanoids existed in the greatest diversity and abundance.

2. At the species level, cyclopoid and harpacticoid species were more numerous than the most abundant calanoid species.

3. The vertical distribution of twelve frequently encountered species revealed that all except two calanoid species, *Lucicutia flavicornis* and *Haloptilus longicornis*, were concentrated above 100m in the oceanic environment over the Puerto Rico Trench.

4. From the analysis of twelve copepod species in relation to their depth-density distributions in the upper 150m over the Puerto Rico Trench, three patterns of vertical migration were observed.

5. The most prevalent migrational pattern to which seven species conformed, involved a descent to deeper depths during the day and a return or ascent toward the surface at night.

6. The second migratory pattern appeared as an upward movement during the day and a downward movement at night (i.e. a reverse migration). The cyclopoid, *Oncaea venusta*, was the only species exhibiting this migratory trend.

7. The third migratory pattern showed a bidirectional movement, upward and downward, at night of portions of the population from daytime concentrations at 50m. Two calanoids, *Mecynocera clausii* and *Calocalanus pavo*, exhibited this pattern.

8. A lack of migratory behavior was also seen in this study. The non-migratory species were *Haloptilus longicornis* and *Macrosetella gracilis*.

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APPENDIX A

ZOOPLANKTON LAB DATA

Station No: 6 Depth: 0 m Time: 1145 Date: 13 July 1976 Subsample Size: 1/8

Flowmeter: 40817 rev. Water Volume Sample: 485 m^3 Towing Speed: 2.3 km/hr Towing Distance: 1097 m

Remarks: Very dense *Trichodesmium* bloom.

CALANOIDS				HARPACTICOIDS				CYCLOPOIDS			
Species	No/ Count	Total No.	No/ 100 m^3	Species	No/ Count	Total No.	No/ 100 m^3	Species	No/ Count	Total No	No/ 100 m^3
Clausocalanus furcatus	8	64	13	*Macrosetella gracilis*	23	184	38	*Farranula gracilis*	19	152	31
Undinula vulgaris	3	24	5					*F.* spp.	10	80	16
Euchaeta marina	1	8	2					*Oithona plumifera*	11	88	18
Others	42	336	69					*Oncaea venusta*	2	16	3

ZOOPLANKTON LAB DATA

Station No: 6 Depth: 50 m Time: 1145 Date: 13 July 1976 Subsample Size: 1/128

Flowmeter: 40817 rev. Water Volume Sample: 485 m^3 Towing Speed: 2.3 km/hr Towing Distance: 1097 m

Remarks: Trichodesmium bloom not evident.

CALANOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Eucalanus subtenuis	47	6016	1240
Undinula vulgaris	39	4992	1029
Mecynocera clausii	33	4224	871
Clausocalanus furcatus	23	2944	607
Calanus minor	19	2432	501
Scolecithrix danae	14	1792	369
Euchaeta marina	13	1664	343
Calocalanus pavo	3	384	79
Candacia pachydactula	3	384	79
Haloptilus mucronatus	1	128	26
Temora stylifera	1	128	26
Others	35	4480	924

HARPACTICOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Microsetella rosea	15	1920	396
Oculosetella spp.	1	128	26

CYCLOPOIDS

Species	No/ Count	Total No	No/ 100 m^3
Oithona plumifera	168	21504	4434
Oncaea venusta	45	5760	1188
Farranula gracilis	9	1152	238
Corycaeus spp.	1	128	26

ZOOPLANKTON LAB DATA

Station No: 6 Depth: 100 m Time: 1245 Date: 13 July 1976 Subsample Size: 1 /32

Flowmeter: 37026 rev. Water Volume Sample: 440 m^3 Towing Speed: 2.1 km/hr Towing Distance: 996 m

Remarks: Trichodesmium sparse.

CALANOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Calanus tenuicornis	76	2432	553
Haloptilus longicornis	24	768	175
H. spp.	3	96	22
Mecynoceri clausii	8	256	38
Eucalanus spp.	1	32	7
Lucicutia flavicornis	1	32	7
Euaetidus giesbrechti	1	32	7
Others	10	320	73

HARPACTICOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Microsetella rosea	11	352	80
Clytemnestra scutellata	1	32	7

CYCLOPOIDS

Species	No/ Count	Total No	No/ 100 m^3
Oithona plumifera	140	4480	1018
Oncaea venusta	2	64	15
Corycaeus speciosus	1	32	7
C. spp.	2	64	15

ZOOPLANKTON LAB DATA

Station No: 6 Depth: 150 m Time: 1245 Date: 13 July 1976 Subsample Size: 1/28

Flowmeter: 37026 rev. Water Volume Sample: 440 m^3 Towing Speed: 2.1 km/hr Towing Distance: 996 m

Remarks: No *Trichodesmium* evident.

CALANOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Haloptilus longicornis	45	5760	1309
Lucicutia flavicornis	32	4096	931
Euchaeta spp.	22	2816	640
Neocalanus robustior	7	896	204
Centropages spp.	1	128	29
Scolecithrix danae	1	128	29
Mormonilla phasma	1	128	29
Others	69	8832	2007

HARPACTICOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Microsetella rosea	5	640	145
Miracia minor	1	128	29

CYCLOPOIDS

Species	No/ Count	Total No	No/ 100 m^3
Oithona plumifera	81	10368	2356
Oncaea venusta	43	5504	1251
O. conifera	1	128	29
Corycaeus spp.	4	512	116
Lubbockia squillimana	2	256	58
Farranula spp.	1	128	29
Others	14	1792	407

ZOOPLANKTON LAB DATA

Station No: 11 Depth: 0 m Time: 2220 Date: 14 July 1976 Subsample Size: 1/128

Flowmeter: 37517 rev. Water Volume Sample: 445 m^3 Towing Speed: 2.1 km/hr Towing Distance: 1008 m

Remarks: Dense *Trichodesmium* bloom with particulate matter (?).

CALANOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Undinula vulgaris	59	7552	1697
Calanus minor	18	2304	518
Paracalanus aculeatus	15	1920	431
Acrocalanus longicornis	13	1664	374
Calocalanus pavo	9	1152	259
Clausocalanus furcatus	6	768	173
Temora stylifera	3	384	86
Lucicutia flavivornis	2	256	58
Others (copepodites)	45	5760	1294

HARPACTICOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Microsetella rosea	6	768	173
Macrosetella gracilis	2	256	58

CYCLOPOIDS

Species	No/ Count	Total No	No/ 100 m^3
Farranula gracilis	18	2304	517
F. spp.	14	1792	403
Corycaeus spp.	11	1408	316
Oithona plumifera	8	1024	230
Oncaea venusta	5	640	144

ZOOPLANKTON LAB DATA

Station No: 11 Depth: 100 m Time: 2315 Date: 14 July 1976 Subsample Size: 1 /128

Flowmeter: 17982 rev. Water Volume Sample: 213 m^3 Towing Speed: 1.1 km/hr Towing Distance: 482 m

Remarks: Trichodesmium filaments present.

CALANOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Calanus tenuicornis	24	3072	1442
Lucicutia flavicornis	16	2048	962
Mecynocera clausii	15	1920	901
Clausocalanus furcatus	15	1920	901
Paracalanus aculeatus	9	1152	541
Haloptilus longicornis	6	768	361
Paracandacia bispinosa	4	512	240
Heterorhabdus spp.	3	384	180
Calocalanus pavo	1	256	120
Scolecithrix danae	2	128	60
Pleuromamma xiphias	1	128	60

HARPACTICOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Microsetella rosea	9	1152	541
Oculosetella gracilis	1	128	60

CYCLOPOIDS

Species	No/ Count	Total No	No/ 100 m^3
Oithona plumifera	59	7552	3546
Oncaea venusta	11	1408	661
Corycaeus spp.	11	1408	661
Lubbockia squillimana	3	384	180
Copilia mirabilis	2	256	120

ZOOPLANKTON LAB DATA

Station No: 11 Depth: 150 m Time: 2315 Date: 14 July 1976 Subsample Size: 1/8

Flowmeter: 17982 rev. Water Volume Sample: 213 m^3 Towing Speed: 1.1 km/hr Towing Distance: 482 m

Remarks: Trichodesmium abundant.

CALANOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Calanus tenuicornis (?)	24	192	90
C. minor	4	32	15
Temora turbinata	11	88	41
Clausocalanus furcatus	7	56	26
Undinula vulgaris	4	32	15
Acrocalanus lorgicornis	3	24	11
Acartia negligens	2	16	8
Others	9	72	34

HARPACTICOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Macrosetella gracilis	3	24	11
Microsetella rosea	2	16	8
Miracia minor	1	8	4

CYCLOPOIDS

Species	No/ Count	Total No	No/ 100 m^3
Oncaea venusta	6	48	23
Farranula gracilis	3	24	11
Oithona plumifera	2	16	8
Lubbockia squillimana	2	16	8

ZOOPLANKTON LAB DATA

Station No: 28 Depth: 0 m Time: 0300 Date: 20 July 1976 Subsample Size: 1/256

Flowmeter: 55813 rev. Water Volume Sample: 663 m^3 Towing Speed: 3.2 km/hr Towing Distance: 1500 m

Remarks: Very dense *Trichodesmium* bloom.

CALANOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Clausocalanus furcatus	19	4864	733
Paracalanus aculeatus	11	2816	425
Calocalanus pavo	6	1536	232
Undinula vulgaris	5	1280	193
Eucalanus subtenuis	4	1024	154
Centropages violaceus	2	512	77
Temora stylifera	2	512	77
Mecynocera clausii	2	512	77
Euchaeta marina	2	512	77
Acartia spp.	1	256	39
Lucicutia flavicornis	1	256	39
Labidocera spp.	1	256	39
Calanoids	56	14336	2162

HARPACTICOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Microsetella rosea	5	1280	193
Macrosetella gracilis	1	256	39

CYCLOPOIDS

Species	No/ Count	Total No	No/ 100 m^3
Oithona plumifera	31	7936	1197
Oncaea venusta	20	5120	772
Farranula gracilis	3	768	116
F. spp.	1	256	39
Corycaeus spp.	2	512	77

ZOOPLANKTON LAB DATA

Station No: 28 Depth: 100 m Time: 0400 Date: 20 July 1976 Subsample Size: 1/256

Flowmeter: 98021 rev. Water Volume Sample: 1164 m^3 Towing Speed: 5.3 km/hr Towing Distance: 2634 m

Remarks: Trichodesmium absent.

CALANOIDS Species	No/ Count	Total No.	No/ 100 m^3	HARPACTICOIDS Species	No/ Count	Total No.	No/ 100 m^3	CYCLOPOIDS Species	No/ Count	Total No	No/ 100 m^3
Clausocalanus furcatus	15	3840	330	Microsetella rosea	8	2048	176	Oithona plumifera	55	14080	1210
Calanus tenuicornis	11	2816	242					Oncaea venusta	47	12032	1034
Mecynocera clausii	4	1024	88					Corycaeus speciosus	5	1280	110
Lucicatia flavicornis	2	512	44					C. spp.	1	256	22
Heterorhabdus spp.	2	512	44					Sapphirina stellata (?)	1	256	22
Haloptilus longicornis	1	256	22								
Others	36	9216	792								

ZOOPLANKTON LAB DATA

Station No: 28 Depth: 150 m Time: 0400 Date: 20 July 1976 Subsample Size: 1/32

Flowmeter: 34110 rev. Water Volume Sample: 1164 m^3 Towing Speed: 5.3 km/hr Towing Distance: 2634 m

Remarks: Trichidesmium absent.

CALANOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Haloptilus longicornis	110	3520	302
Lucicutia flavicornis	13	416	36
Euchaeta spp.	5	160	14
Calocalanus spp.	3	96	8
Neocalanus robustior	3	96	8
Candacia pachydactula (?)	2	64	5
Mormonilla phasma	1	32	3
Pleuromamma abdominalis	1	32	3
Pleuromamma xiphias	1	32	3
Others	34	1088	93

HARPACTICOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Macrosetella gracilis	1	32	3

CYCLOPOIDS

Species	No/ Count	Total No	No/ 100 m^3
Oithona plumifera	164	5248	451
Oncaea venusta	19	608	52
O. conifer	3	96	8
Corycaeus speciosus	4	128	11
Corycaeus spp.	5	160	14
Lubbockia squillimana	3	96	8
Farranula spp.	1	32	13

ZOOPLANKTON LAB DATA

Station No: 32 Depth: 0 m Time: 1640 Date: 20 July 1976 Subsample Size: 1/256

Flowmeter: 50872 rev. Water Volume Sample: 603 m^3 Towing Speed: 2.8 km/hr Towing Distance: 1366 m

Remarks: Very dense *Trichodesmium* bloom.

CALANOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Paracalanus aculeatus	136	34816	5774
Undinula vulgaris	38	9728	1613
Clausocalanus furcatus	24	6144	1019
Euchaeta marina	24	6144	1019
Calocalanus pavo	16	4096	679
Eucalanus subtenuis	5	1280	212
Acrocalanus longicornis	4	1024	170
Temora stylifera	4	1024	170
Others	53	13568	2250

HARPACTICOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Microsetella rosea	4	1024	170
Macrosetella gracilis	2	512	85

CYCLOPOIDS

Species	No/ Count	Total No	No/ 100 m^3
Oncaea venusta	72	18432	3056
Farranula gracilis	18	4608	764
F. app.	2	512	85
Oithona plumifera	14	3584	594
Corycaeus spp.	5	1280	212

ZOOPLANKTON LAB DATA

Station No: 32 Depth: 50 m Time: 1640 Date: 20 July 1976 Subsample Size: 1/64

Flowmeter: 50872 rev. Water Volume Sample: 603 m^3 Towing Speed: 2.8 km/hr Towing Distance: 1366 m

Remarks: Abundant *Trichodesmium* filaments.

CALANOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Eucalanus subtenuis	49	3136	520
Undinula vulgaris	38	2432	403
Scolecithrix danae	23	1472	244
Euchaeta marina	15	960	159
Calocalanus pavo	14	896	149
Mecynocera clausii	11	704	117
Calanus minor	10	640	106
Calanus tenuicornis (?)	1	64	11
Calanus spp.	1	64	11
Temora stylifera	8	512	85
Centropages pachydactula	2	128	21

HARPACTICOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Macrosetella gracilis	3	192	32
Microsetella rosea	2	128	21

CYCLOPOIDS

Species	No/ Count	Total No	No/ 100 m^3
Oithona plumifera	57	3648	605
Oncaea venusta	20	1280	212
Others	3	192	32

ZOOPLANKTON LAB DATA

Station No: 32 Depth: 100 m Time: 1730 Date: 20 July 1976 Subsample Size: 1 /32

Flowmeter: 34110 rev. Water Volume Sample: 405 m^3 Towing Speed: 1.9 km/hr Towing Distance: 917 m

Remarks: Moderately dense *Trichodesmium* bloom.

CALANOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Pleuromamma xiphias	16	512	126
Lucicutia flavicornis	12	384	95
Calanus tenuicornis	5	160	40
Euchaeta marina	2	64	16
Aetideus armatus	2	64	16
Calocalanus pavo	1	32	8
Clausocalanus furcatus	1	32	8
Paracalanus aculeatus	1	32	8
Haloptilus spp.	1	32	8
Others	13	416	103

HARPACTICOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Macrosetella gracilis	2	64	16
Microsetella rosea	1	32	8

CYCLOPOIDS

Species	No/ Count	Total No	No/ 100 m^3
Oithona plumifera	29	928	229
Oncaea venusta	27	864	213
Farranula gracilis	2	64	16

ZOOPLANKTON LAB DATA

Station No: 32 Depth: 150 m Time: 1730 Date: 20 July 1976 Subsample Size: 1/128

Flowmeter: 34110 rev. Water Volume Sample: 405 m^3 Towing Speed: 1.9 km/hr Towing Distance: 917 m

Remarks: A few Trichodesmium filaments present.

CALANOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Haloptilus longicornis	14	1792	442
Neocalanus robustior	7	896	212
Eucalanus subtenuis	4	512	126
Euchaeta spp.	4	512	126
Undinula vulgaris	3	384	95
Calocalanus spp.	2	256	63
Mecynocera clausii	2	256	63
Scolecithrix danae	1	128	32
Acartia negligens	1	128	32
Lucicutia flavicornis	1	128	32
Others	57	7296	1801

HARPACTICOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Microsetella rosea	3	384	95
Macrosetella gracilis	1	128	32

CYCLOPOIDS

Species	No/ Count	Total No	No/ 100 m^3
Oithona plumifera	164	30992	5183
Oncaea venusta	9	1152	284
Farranula carinata	1	128	32
F. spp.	1	128	32
Lubbockia squillimana	1	128	32
Sapphirina metallina	1	128	32

ZOOPLANKTON LAB DATA

Station No: 123 Depth: 0 m Time: 0530 Date: 19 June 1977 Subsample Size: 1/1024

Flowmeter: 60670 rev. Water Volume Sample: 720 m^3 Towing Speed: 3.4 km/hr Towing Distance: 1630 m

Remarks: Trichodesmium absent. Copepods in poor condition.

CALANOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Clausocalanus furcatus	90	92160	12800
Acartia negligens	34	34816	4835
Undinula vulgaris	19	19456	2702
Calocalanus pavo	16	16384	2276
Mecynocera clausii	8	8192	1138
Lucicutia flavicornis	6	6144	853
Euchaeta marina	4	4096	539
Labidocera spp.	2	2048	284
Calanus minor	1	1024	142
Eucalanus attenuatus	1	1024	142
Others	425	435200	60444

HARPACTICOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Microsetella rosea	111	113664	15787
Macrosetella gracilis	5	5120	711

CYCLOPOIDS

Species	No/ Count	Total No	No/ 100 m^3
Farranula gracilis	62	63488	8818
Oithona plumifera	60	61440	8533
Corycaeus spp.	19	19456	2702
Lubbockia squillimana	5	5120	711
Oncaea venusta	4	4096	539
Others	4	4096	539

ZOOPLANKTON LAB DATA

Station No: 123 Depth: 50 m Time: 0530 Date: 19 June 1977 Subsample Size: 1/128

Flowmeter: 60670 rev. Water Volume Sample: 720 m^3 Towing Speed: 3.4 km/hr Towing Distance: 1630 m

Remarks: Very low concentration of Trichodesmium.

CALANOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Mecynocera clausii	88	11264	1564
Calocalanus pavo	63	8064	1120
Lucicutia flavicornis	46	5888	818
Clausocalanus furcatus	36	4608	640
C. arcuicornis	1	128	18
Temora stylifera	7	896	124
Haloptilus longicornis	5	640	89
H. mucronatus	3	384	53
Euchaeta marina	3	384	53
Eucalanus attenuatus	2	256	36
Centropages spp.	1	128	18

HARPACTICOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Microsetella rosea	162	20736	2880
Macrosetella gracilis	18	2304	320
Oculosetella gracilis	2	256	36

CYCLOPOIDS

Species	No/ Count	Total No	No/ 100 m^3
Oithona plumifera	340	43520	6042
Oncaea venusta	293	37504	5209
Farranula gracilis	28	3584	498
F. spp.	3	384	53
Corycaeus limbatus	20	2560	356
C. flaccus	6	768	107
C. lautus	4	512	71
C. speciosus	3	384	53
C. spp.	11	1408	196
Lubbockia squillimana	14	1792	249
Copilia mirabilis	4	512	71
C. quadrata	1	128	18
Sapphirina spp.	2	256	36
Others	48	6144	853

ZOOPLANKTON LAB DATA

Station No: 123 Depth: 100 m Time: 0615 Date: 19 June 1977 Subsample Size: 1 /512

Flowmeter: 65550 rev. Water Volume Sample: 778 m^3 Towing Speed: 3.6 km/hr Towing Distance: 1762 m

Remarks: Sparse Trichodesmium filaments.

CALANOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Mecynocera clausii	29	14848	1908
Calocalanus pavo	15	7680	987
Lucicutia flavicornis	14	7168	921
Acartia negligens	14	7168	921
Clausocalanus furcatus	8	4096	526
Haloptilus longicornis	3	1536	197
Undinula vulgaris	2	1024	132
Euchaeta spp.	2	1024	132
Candacia spp.	1	512	66
Neocalanus robustior	1	512	66
Others	164	83968	108

HARPACTICOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Microsetella rosea	82	41984	5396
Macrosetella gracilis	3	1536	197

CYCLOPOIDS

Species	No/ Count	Total No	No/ 100 m^3
Oncaea venusta	135	69120	8884
Oithona plumifera	130	66560	8555
Corycaeus spp.	7	3584	461
Farranula gracilis	3	1536	197
Lubbockia squillimana	2	1024	132

ZOOPLANKTON LAB DATA

Station No: 123 Depth: 150 m Time: 0615 Date: 19 June 1977 Subsample Size: 1/512

Flowmeter: 65550 rev. Water Volume Sample: 778 m^3 Towing Speed: 3.6 km/hr Towing Distance: 1762 m

Remarks: No *Trichodesmium* filaments.

CALANOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Haloptilus longicornis	23	11776	1514
Mecynocera clausii	13	6656	856
Lucicutia flavicornis	12	6144	790
Acartia app.	3	1536	197
Euchaeta attenuatus	1	512	66
Others	118	60416	7766

HARPACTICOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Microsetella rosea	47	24064	3093
Miracia spp.	4	2048	263
Macrosetella gracilis	2	1024	132

CYCLOPOIDS

Species	No/ Count	Total No	No/ 100 m^3
Oncaea venusta	129	66048	8489
Oithona plumifera	74	37888	4870
Corycaeus spp.	10	5120	658
Farranula gracilis	3	1536	197
Others	4	2048	263

ZOOPLANKTON LAB DATA

Station No: 131 Depth: 0 m Time: 1510 Date: 22 June 1977 Subsample Size: 1/512

Flowmeter: 46477 rev. Water Volume Sample: 552 m^3 Towing Speed: 2.6 km/hr Towing Distance: 1249 m

Remarks: Trichodesmium absent.

CALANOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Undinula vulgaris	27	13824	2504
Calocalanus pavo	13	6656	1200
Acartia negligens	5	2560	463
Euchaeta marina	1	512	93
Clausocalanus furcatus	1	512	93
Others	84	43008	7791

HARPACTICOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Microsetella rosea	5	2560	463
Macrosetella gracilis	3	1536	278
Miracia efferata	1	512	93

CYCLOPOIDS

Species	No/ Count	Total No	No/ 100 m^3
Farranula gracilis	134	68608	12428
F. spp.	1	512	93
Oncaea venusta	5	2560	463
Corycaeus spp.	3	1536	278
Oithona plumifera	2	1024	185
Copilia mirabilis	1	512	93
Sapphirina spp.	1	512	93

ZOOPLANKTON LAB DATA

Station No: 131 Depth: 50 m Time: 1510 Date: 22 June 1977 Subsample Size: 1 / 512

Flowmeter: 46477 rev. Water Volume Sample: 552 m^3 Towing Speed: 2.6 km/hr Towing Distance: 1249 m

Remarks: Trichodesmium absent.

CALANOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Paracalanus aculeatus	55	28160	5101
Mecynocera clausii	47	24064	4359
Calocalanus pavo	27	13824	2504
Clausocalanus furcatus	16	8192	1484
Lucicutia flavicornis	15	7680	1391
Acrocalanus longicornis	7	3584	649
Haloptilus longicornis	3	1536	278
H. mucronatus	1	512	93
Euchaeta marina	2	1024	186
Others	215	110080	19942

HARPACTICOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Microsetella rosea	91	46592	8440
Macrosetella gracilis	2	1024	186

CYCLOPOIDS

Species	No/ Count	Total No	No/ 100 m^3
Oithona plumifera	105	53760	9739
Farranula gracilis	54	27648	5008
Oncaea venusta	54	27648	5008
Corycaeus spp.	16	8192	1484
Lubbockia squillimana	3	1536	278
Copilia mirabilis	1	512	93

ZOOPLANKTON LAB DATA

Station No: 131 Depth: 100 m Time: 1600 Date: 22 June 1977 Subsample Size: 1/ 32

Flowmeter: 70643 rev. Water Volume Sample: 932 m^3 Towing Speed: 3.9 km/hr Towing Distance: 2110 m

Remarks: No *Trichodesmium*.

CALANOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Lucicutia flavicornis	15	480	52
Calocalanus pavo	10	320	34
Mecynocera clausii	8	256	27
Undinula vulgaris	6	192	21
Clausocalanus furcatus	4	128	14
Candacia pachydactula	3	96	10
Euchaeta spp.	2	64	7
Haloptilus longicornis	1	32	3
Calanus minor	1	32	3
Temora stylifera	1	32	3
Others	74	2368	254

HARPACTICOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Microsetella rosea	50	1600	172
Macrosetella gracilis	3	96	10

CYCLOPOIDS

Species	No/ Count	Total No	No/ 100 m^3
Oncaea venusta	103	3296	354
Oithona plumifera	94	3008	323
Corycaeus spp.	14	448	48
Farranula gracilis	11	352	38
Lubbockia squillimana	8	256	27
Copilia mirabilis	1	32	3
Others	2	64	7

ZOOPLANKTON LAB DATA

Station No: 131 Depth: 150 m Time: 1600 Date: 22 June 1977 Subsample Size: 1/512

Flowmeter: 70643 rev. Water Volume Sample: 932 m^3 Towing Speed: 3.9 km/hr Towing Distance: 2110 m

Remarks: No *Trichodesmium*.

CALANOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Lucicutia flavicornis	20	12800	1373
Haloptilus longicornis	7	3584	385
Neocalanus robustior	3	1536	165
Clausocalanus furcatus	3	1536	165
Calocalanus spp.	2	1024	110
Acartia negligens	2	1024	110
Heterorhabdus spp.	1	512	56
Euchaeta spp.	1	512	56
Others	63	32256	3461

HARPACTICOIDS

Species	No/ Count	Total No.	No/ 100 m^3
Microsetella rosea	9	4608	494
Miracia efferata	4	2048	220
Macrosetella gracilis	3	1536	165

CYCLOPOIDS

Species	No/ Count	Total No	No/ 100 m^3
Oithona plumifera	44	22528	2417
Oncaea venusta	43	22016	2362
Farranula gracilis	14	7168	769
F. carinata	3	1536	165
F. spp.	4	2048	220
Corycaeus spp.	11	5632	604
Lubbockia squillimana	1	512	56
Copilia mirabilis	1	512	56