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VOLUME XII, ARTICLE 2

THE ZOOPLANKTON OF THE UPPER WATERS OF THE BERMUDA AREA OF THE NORTH ATLANTIC

BY HILARY B. MOORE
Woods Hole Oceanographic Institution

Issued January, 1949
New Haven, Conn., U. S. A.

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By Hilary B. Moore

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CONTENTS

[1] Contribution No. 406 from the Woods Hole Oceanographic Institution.

INTRODUCTION

Studies of the oceanic zooplankton of the western North Atlantic have been limited in the past by the necessity of working from the materials obtained by such research vessels as the CHALLENGER, ATLANTIS, *et al.*, during transects and short cruises. It has not been possible to observe seasonal changes at any one spot, and the deductions attempted from comparison of the results of widespread stations and various cruises have proved far from satisfactory. Similarly, the discrepant figures quoted by different authors for the vertical distribution of even common species show the need for more extensive and detailed sampling with closing nets. Beebe's collections from the Bermuda area have provided very useful lists of species for some groups, but these are unsuitable for any quantitative comparisons.

The present paper comprises a survey of the zooplankton of the upper 300 metres in the Bermuda area, made under the auspices of the Royal Society in the period 1938–1940. The first part of the paper (pp. 2–6) describes the collecting methods, localities, etc. The second part (pp. 6–75) gives the available data on each species, while the third part (pp. 76–94) contains a general discussion of the results. It was considered preferable to include sufficient text figures to show the data obtained rather than to include extensive tables, but sets of the latter are on file at both the Royal Society in London and the Bingham Oceanographic Foundation at New Haven, Connecticut.

Throughout the text figures, the data on seasonal distribution are shown as numbers per ten cc. of plankton, and the types of hauls to which they refer are given on pp. 4–5. Data on vertical distribution are shown as percentages of the total for all hauls down to the lowest level indicated, and black circles indicate that none were taken. Diurnal migration data show numbers per haul.

MATERIAL, METHODS, COLLECTIONS AND DEFINITIONS

Most of the collections were made from the Royal Society's ketch CULVER, whose equipment is described by Kemp (1938). The medium silk closing nets used (70 cm. diameter) were of the Discovery N. 70 type described by Kemp, Hardy and Mackintosh (1929: 183). Catches were preserved immediately in 4% formaldehyde in sea water, neutralized with borax. The nets were lowered open and were closed by messenger before being raised. The use of nets which can be closed before hauling is considered essential in any quantitative work. The error introduced by lowering the nets open, at least to such depths as we were working, has been considered negligible (Kemp, Hardy and Mackintosh, 1929: 202). Our results confirm this, as shown by the following example. At Station 223, three successive tows were made, using in each case two nets 50 metres apart vertically. The nets were towed for half an hour, during which time they were raised obliquely through 50 metres. The nets towed at 0–50 and 50–100 metres caught respectively 880 and 11,920 *Clausocalanus* and 6,920 and 480 *Acartia*. These are two abundant and typically shallow forms. Two nets were later towed at 200–250 and 250–300 metres, the latter stopping for a few minutes in its descent while the other net was attached to the wire. Despite this pause in the rich shallow layer, the catches were respectively 0 and 20 *Clausocalanus* and 0 and 4 *Acartia*.

At all stations, except where otherwise indicated, the nets were lowered open to the maximum depth and towed for half an hour at an estimated speed of 2 knots.[2] The nets were raised ten metres vertically at the end of each five minutes so that when they were closed at the end of thirty minutes they had fished representatively through a vertical distance of 50 metres.

A wire angle indicator was used (Moore, 1941), and by watching this instrument the angle could be kept constant within about $\pm 2°$, and usually less in good weather. No depth gauge was available; depths are calculated on the assumption that the wire was straight. The error due to wire curvature is likely to be small at such shallow depths, and by maintaining the same arrangement of nets and weight the error should be constant throughout.

The volume of each sample was estimated by washing onto silk, draining for one minute, and then washing with a known quantity of water into a measuring cylinder. The method is somewhat crude but sufficiently accurate for comparison of volumes ranging as widely as these.

The sample was transferred to a glass dish and the larger forms picked out. Subsamples were then examined in detail and counted under a binocular dissecting microscope. After May 1940 the samples were decanted several times before subsampling. The heavy residues so obtained contained the bulk of the shelled pteropods and

[2] 1 knot = 1.85 km. per hour.

heteropods which were apt not to be adequately represented in dipped subsamples. No attempt was made to distinguish adult from immature specimens so long as the latter could be specifically identified. In all but the earliest samples the two generations of siphonophores and salps were counted separately.

As far as possible representative specimens were sent to specialists for identification. Acknowledgment of these is made under the species concerned, and to all of them I wish to express my indebtedness. Also, I wish to thank all those who have assisted in the collecting and helped with advice, particularly Dr. J. F. G. Wheeler, Dr. E. F. Thompson, Capt. E. Whitfield and the crew of the CULVER, and the staffs of the Plymouth Marine Laboratory and the Woods Hole Oceanographic Institution.

Certain groups, none of which bulked appreciably in the samples, are omitted here: Foraminifera on account of their small size and inadequate sampling; polychaetes, ostracods, amphipods and mysids on account of lack of available literature for identification; cephalopods and fishes which were too active to be adequately collected; decapod larvae which were passed on to Dr. Lebour and Dr. Gurney for incorporation in their studies.

The following series of collections were made:

Sept. 5–9, 1938. Day hauls in pairs at two depths at each of 17 stations forming a network round the islands. Owing to the depths not being consistent throughout, the results are of little use for determining horizontal distributions. The material served mainly for preliminary determination of species and for development of collecting and counting technique.

Nov. 10, 1938. A series of six day-hauls in pairs at 50-metre intervals down to 300 metres to obtain preliminary data on vertical distribution.

Dec. 2–12, 1938. A network of 17 stations round the islands, each consisting of a single day-haul obliquely from 150–100 metres. This depth was shown from the November 10 series to be the richest and most representative layer of the shallow plankton.

Feb. 3–4, 1939. Hauls using two nets at a time at six depths down to 250 metres. The upper pair hauled obliquely from 25–0 and 50–25 metres respectively and the remainder through 50 metres, spaced at 50-metre intervals.

May 10–18, 1939. Single day-hauls obliquely from 150–100 metres at a network of 23 stations round the islands. These were extended further from Bermuda than in the December cruise.

Jan.–April 1940. A series of night surface hauls made by the courtesy of the officers of a local ship at a time when the CULVER was out of commission. The hauls were made at 02.00–02.30 hours when it is estimated that the greatest quantity of plankton would be at the surface. As the speed of the ship could not be controlled accurately, the results are not quantitatively comparable with the others, and are simply expressed as numbers per 10 cc. of catch.

May–Dec. 1940. Owing to war conditions it was no longer possible to make long cruises, so it was decided to make repeated observations at one station which could be worked in a single day. Although this was closer to the land than might have been wished, results showed that it was quite comparable with more remote stations. Oblique hauls were made on ten occasions at 50-metre intervals down to 300 metres, and on two occasions to a greater depth. On July 9–12 two similar stations slightly further offshore were worked. This series yielded a large part of the seasonal distribution data as well as vertical distributions and their relation to illumination, etc.

In addition, by the courtesy of Mr. Iselin, samples were taken by the ATLANTIS in the Gulf Stream in October 1938 and February 1940, and these were used in the consideration of the general representativeness of the Bermuda material.

The following terms are used in describing the ecology of the various species:

Mean day-level. The depth above which 50% of those individuals occurring in the top 300 metres are found in the daytime. This is a mean value for all stations at which vertical distribution was determined and where numbers were adequate. Where the maximum level is close to or below 300 metres this figure is not used.

Spread. The difference in depth between the 25% and 75% day-levels obtained as above.

Day-night range. The difference between the 50% day- and night-levels as indicated by the diurnal migration series in February 1939.

Day : night ratio. The percentage ratio between the total day population of the top 250 metres and its increase at night. Thus 100 indicates no night increment from below 250 metres, and 0 indicates that the entire population retreats below 250 metres in the daytime.

Correlation of day-level with cloud. The correlation of the 50% levels on all days when vertical distribution data were obtained with the observed state of the sky. The latter was taken from the ship's deck log and classified as sunny, patchy or cloudy. Unfortunately, the more exact cloud observations made at the Meteorological Station were found to be inapplicable at a short distance out to sea.

Correlation of night surface abundance with moonlight. Based on the results of the night surface hauls in Jan.–April 1940. It should be noted that the nights at 15 and 20 days after new moon were somewhat overcast, and the illumination therefore reduced.

Horizontal distribution. The numerical distribution of each species is compared with that of the zooplankton as a whole (by volume) for each of the cruises on which a network of stations was made round the islands.

COELENTERATA

MEDUSAE

Bougainvillea niobe Mayer. Det. F. S. Russell

Numbers small, but apparently most abundant in upper 50–100 metres. This agrees with Bigelow (1938). Apparently a winter form (Fig. 1). Mayer (1910) records it in April from the Bahamas, but Bigelow (1938) gives summer records from Bermuda. Good correlation of horizontal distribution with that of rest of zooplankton on one cruise (Fig. 2).

Pandea sp.

Single specimens from 150–700 metres.

Heterotiara anonyma Maas. Det. F. S. Russell

One at 100–150 metres.

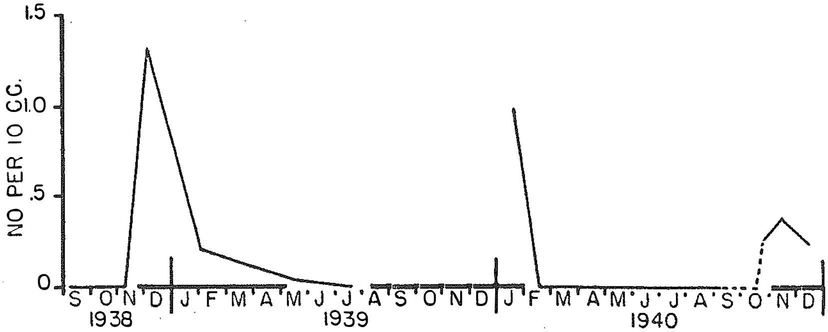
Dichotomia cannoides Brooks. Det. F. S. Russell

Two in the upper 50 metres.

Aequorea forskalea Péron and Lesueur. Det. F. S. Russell

One only.[3]

[3] Russell (personal cummunication) gives the following notes: "A young specimen. Diameter of umbrella 10 mm.; diameter of stomach 5 mm.; number of radial canals 30; number of mouth lips 16; number of fully developed tentacles 8. There were, in addition to the fully developed tentacles, 7 developingtentacular bulbs between every two tentacles, of which the centre one was fairly large, i. e. 8t + 56 developing = 64.



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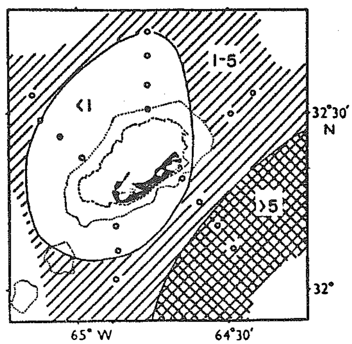

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Bougainvillea niobe. **Figure 1. Seasonal variation in numbers. In this and subsequent figures, numbers are quoted per ten cc. of plankton. The type of hauls to which they refer are given on pp. 4–5.**

Figure 2. Horizontal distribution in December 1938.

Rhopalonema velatum Gegenbaur. Det. F. S. Russell

The most abundant local medusa; maximum in late summer (Fig. 3); mean day-level 150 metres; spread 70 metres (Fig. 4). Generally described as typically a surface form (Bigelow, 1909; Mayer, 1910; Thiele, 1935). Its absence from Beebe's shallower Bermuda hauls described by Bigelow (1938) may be due to its having been missed on account of its small size. Numbers in diurnal migration hauls small, but these, with lack of correlation of night surface abundance and

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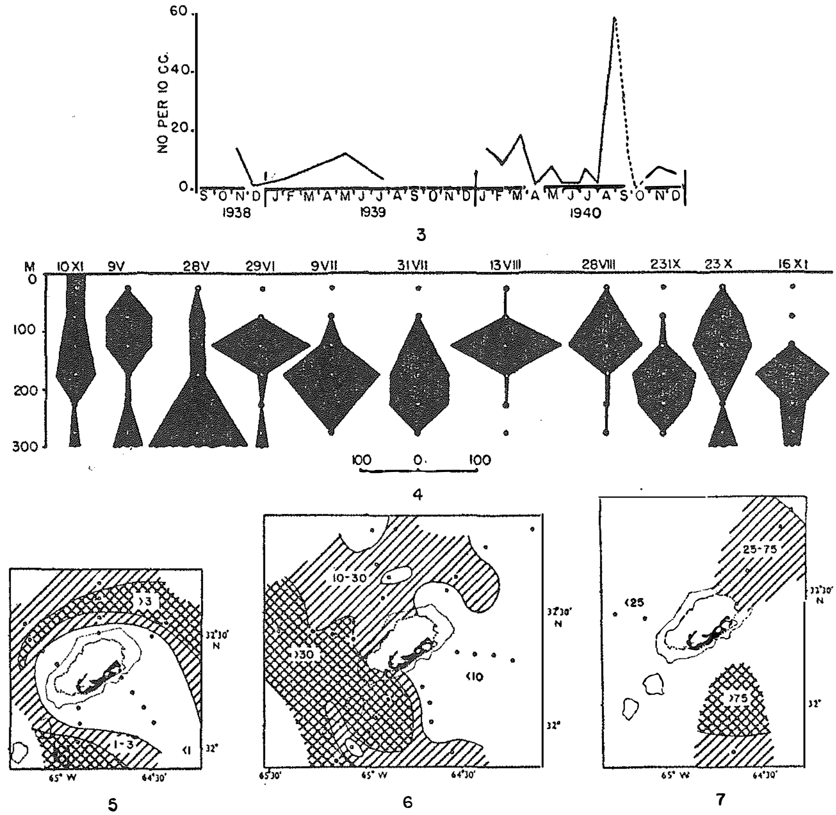
Half the radial canals were wider and half thinner, i. e. just developing. At first glance this might have been considered a young *Aequorea pusilis* var. *macrodactyla*, but there were no median spurs to the tentacle bases and the nematocysts were of the normal *A. forskalea* type, i. e. atrichous haplomeres were present. First record from Bermuda."

moonlight, suggest little or no diurnal migration. No correlation between day-level and cloud; good correlation of horizontal distribution with that of zooplankton on three cruises (Figs. 5–7).



Rhopalonema velatum. **Figure 3. Seasonal variation in numbers.**
Figure 4. Vertical distribution. In this and subsequent figures, quantities are shown as percentages of the total for all hauls down to the lowest level indicated. A black circle indicates that none were taken.
Figure 5. Horizontal distribution, December 1938.
Figure 6. Horizontal distribution, May 1939.
Figure 7. Horizontal distribution, July 1939.

Aglaura hemistoma Péron and Lesueur. Det. F. S. Russell

Present throughout the year, but owing to small size and ease with which it is crushed, is apt to be missed; this may account for its absence from Bigelow's (1938) list of Beebe's Bermuda material. Mean day-level 90 metres; spread 55 metres; Mayer (1910) states that it is common in surface tows in all warm seas, and Thiele (1935) gives its maximum as 0–50 metres.

Liriope tetraphyllum Chamisso and Eysenhardt. Det. F. S. Russell

A surface form; mean day-level about 30 metres (Fig. 8); maximum apparently in May (Fig. 9). Again the scarcity in Bigelow's (1938) records of Beebe's material may be due to small size. Some diurnal migration; day-night range 75 metres; day : night ratio 100, indicating no night increment from below 250 metres; good correlation between horizontal distribution and that of rest of zooplankton on one cruise (Fig. 10); no correlation of day-level with cloud.

Geryonia proboscidialis Forskål. Det. F. S. Russell

One only; Bigelow (1938) also records it from Bermuda.

? *Solmissus incisa* Fewkes. Det. F. S. Russell

Not well enough preserved to allow definite identification (see also Bigelow, 1938); a few; recorded also by Bigelow from Bermuda.

? *Aegina* sp.

Two; one of these was identified by Russell as ? *Aegina citrea* Eschscholtz. The latter is recorded by Bigelow (1918) from Bermuda as being a deep water form taken occasionally at the surface.

? *Carybdea* sp.

Three between 50 and 150 metres.

Periphylla hyacinthina Steenstrup. Det. F. S. Russell

One in a deep haul. Bigelow (1938) records it as common at Bermuda below 900 metres and rarely occurring above 600.

Nausithöe punctata Kölliker. Det. F. S. Russell

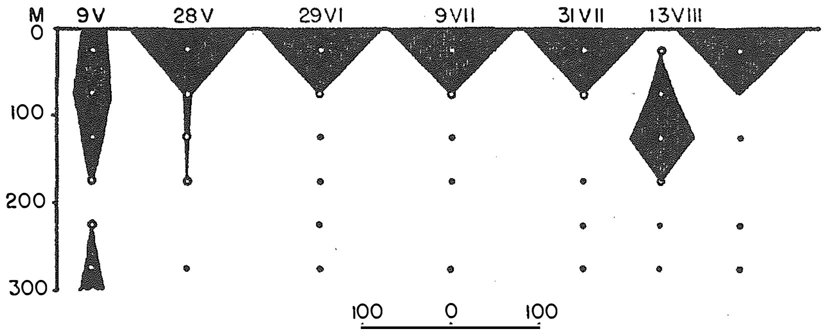
Occasionally in fair numbers. Bigelow (1938) records it in small numbers from Bermuda in summer, and in late autumn and winter in the Pacific (1909). Mayer (1910) records it as a summer surface form in the West Indies region.

Atolla wyvillei Haeckel (form *bairdii*). Det. F. S. Russell

One only. A form normally occurring deeper than our hauls (Bigelow, 1938).

Linuche unguiculata Schwartz. Det. F. S. Russell

Not found in outside hauls, but once in June in such numbers as to discolor the water in Ferry Reach. Mayer (1910) states that it is



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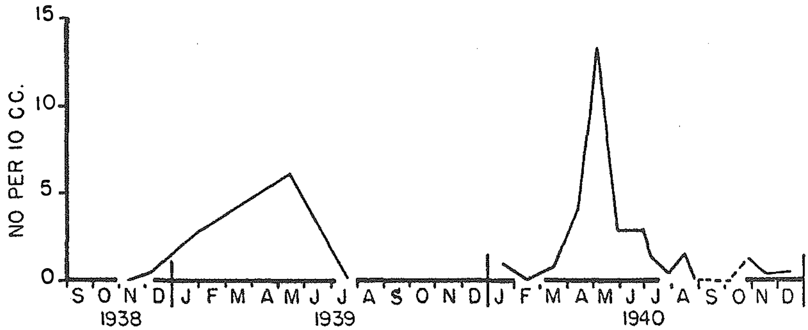

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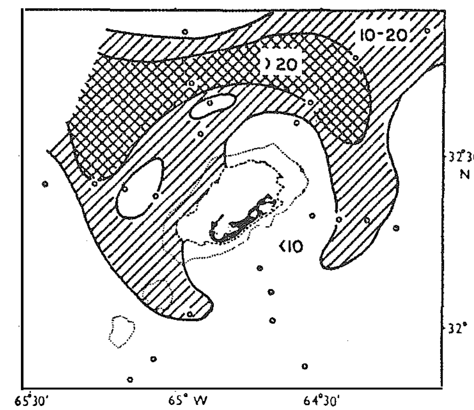

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Liriope tetraphyllum. **Figure 8. Vertical distribution.**
Figure 9. Seasonal variation in numbers.
Figure 10. Horizontal distribution, May 1939.

liberated in great numbers in the West Indies in Feb.–March, and disappears by mid-May.

Pelagia noctiluca Forskål. Det. F. S. Russell

Seen in considerable numbers, and sometimes taken in nets. Owing to large size, not included in estimates.

? *Mitrocoma* sp.

Single specimens in night surface hauls.

Discomedusa sp.

One in a night surface haul.

SIPHONOPHORA[4]

Amphicaryon acaule Chun. Det. A. K. Totton

Taken regularly, but never common. Totton (1936) records only one from Beebe's Bermuda material. Numbers vary seasonally

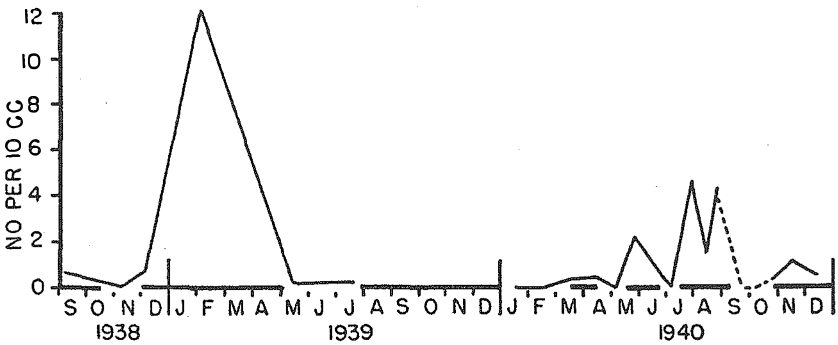


Figure 11. ***Amphicaryon acaule.*** **Seasonal variation in numbers.**

(Fig. 11), but maximum period doubtful. Mean day-level 80 metres; spread 75 metres. Indications of considerable diurnal migration, with day-night range 77 metres, and day : night ratio 83, but numbers inadequate. Indications of a correlation of day-level with cloud.

Nectodroma sp. Det. A. K. Totton

One damaged specimen.

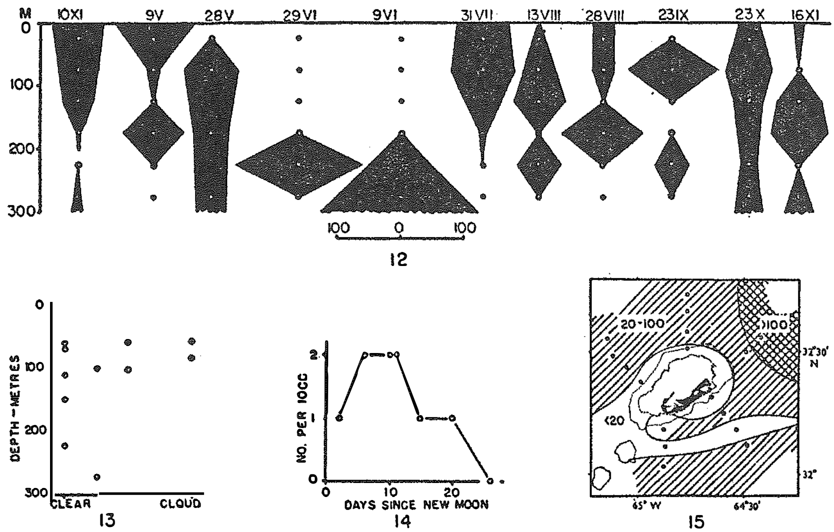
? *Praya* sp.

Several damaged specimens.

[4] Unless otherwise stated, numerical data refer to eudoxid and polygastric generations combined.

Hippopodius hippopus Forskål.[5] Det. A. K. Totton

Present in varying numbers throughout the year, but with no clear maximum. Mean day-level 140 metres (Fig. 12); spread 160 metres. Chun (1887) states that in the Mediterranean it is common at the surface from autumn to early spring, but that it retreats to deeper levels in summer. Leloup and Hentschel (1935) record it mainly from 0–800 metres. Good correlation between day-level and cloud (Fig. 13) and of night surface abundance with moonlight (Fig. 14).



***Hippopodius hippopus*. Figure 12. Vertical distribution.**
Figure 13. Relation of mean day-level to cloudiness of sky.
Figure 14. Relation of night surface abundance to phase of moon.
Figure 15. Horizontal distribution, December 1938.

Horizontal distribution agreed well with that of rest of zooplankton on one cruise (Fig. 15).

Abyla dentata Bigelow. Det. A. K. Totton

Single eudoxids twice, between 0 and 150 metres. Totton (1936) also records two from Bermuda.

[5] The nectophores of *Hippopodius* are readily detached in handling. Probably they may also become detached in the sea, since they are frequently taken in hauls which contain no colonies. From a series of counts, the figure of 13 free nectophores to one colony was obtained, and this conversion factor was applied throughout.

Abyla trigona Quoy and Gaimard. Det. A. K. Totton

Both generations regularly in small numbers; no definite seasonal maximum.

Abyla sagittata Quoy and Gaimard. Det. A. K. Totton

Both generations occasionally in small numbers; apparently no marked seasonal maximum. Leloup and Hentschel (1935) give range as 50–100 metres.

Abylopsis eschscholtzii Huxley. Det. A. K. Totton

Both generations fairly common; winter maximum (Fig. 16). Russell and Colman (1935) give maximum in spring (Aug.–Nov.) at the Great Barrier Reef, but they note that this may be a current effect. A fairly shallow form; mean day-level about 40 metres; spread 80 metres (Fig. 17). Leloup and Hentschel (1935) give range as 0–400 metres. Diurnal migration absent or slight, but numbers inadequate; horizontal distribution agreed well with that of rest of zooplankton on one cruise (Fig. 18); day-level not correlated with cloud. Proportion of two generations (Fig. 19) varying considerably but apparently not cyclically (see later), and about equal over a long period.

Abylopsis tetragona Otto. Det. A. K. Totton

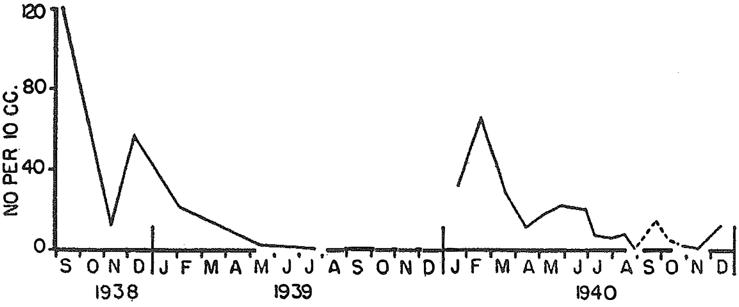
Considerably less common than *A. eschscholtzii;* possible winter maximum; mean day-level 55 metres; spread 25 metres. Leloup and Hentschel (1935) give range as 0–600 metres. A definite diurnal migration; day-night range 89 metres; day : night ratio 61. Proportion of generations varying, possibly cyclically and about equal over long period, but numbers inadequate.

Bassia bassensis (Quoy and Gaimard). Det. A. K. Totton

Mainly a winter or spring form (Fig. 20); mean day-level 50 metres; spread 40 metres. Leloup and Hentschel (1935) give range as 0–1,000 metres. Apparently no diurnal migration and no night increment from deep water, but numbers inadequate; little or no correlation between day-level and cloud. Eudoxid generation slightly more abundant than polygastric (Fig. 21), and a definite cyclic alternation indicating probably five cycles during the year.

Diphyes dispar Chamisso and Eysenhardt. Det. A. K. Totton

One of the less common diphyids round Bermuda; restricted almost entirely to the top 50 metres; mean day-level probably about 10



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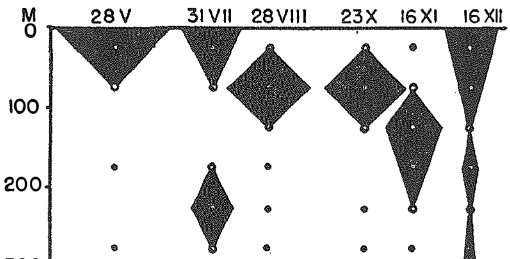

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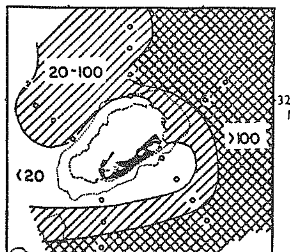

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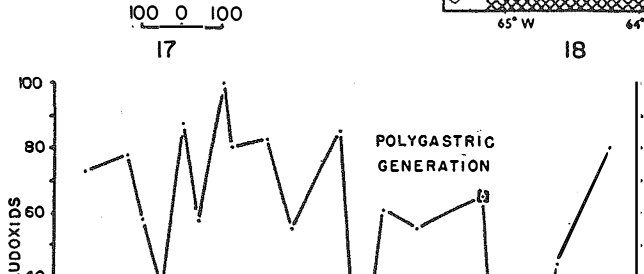

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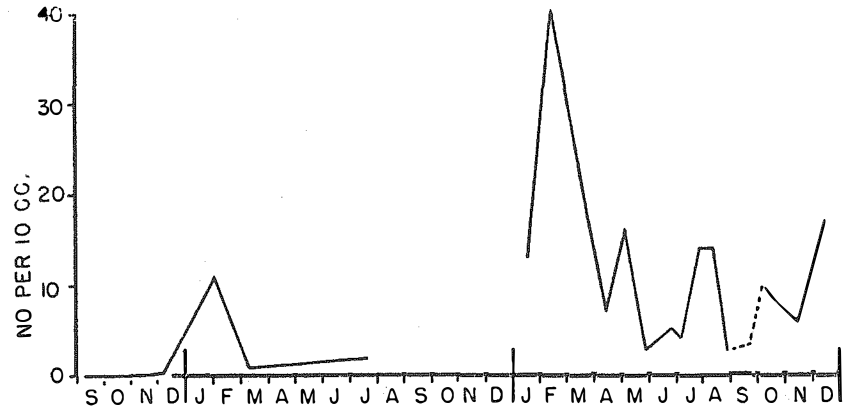
Abylopsis eschscholtzii. Figure 16. Seasonal variation in numbers.
Figure 17. Vertical distribution.
Figure 18. Horizontal distribution, December 1938.
Figure 19. Seasonal variation in the percentage ratio of the two generations.



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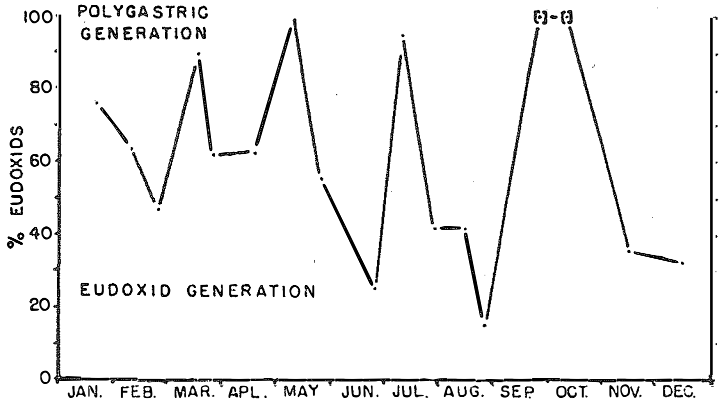

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Bassia bassensis. **Figure 20. Seasonal variation in numbers.**
Figure 21. Seasonal variation in the percentage ratio of the two generations.

metres; spread about the same. Leloup and Hentschel (1935) give range as 0–500 metres. Seasonal maximum doubtful. Day-level not correlated with cloud. Eudoxid generation very rare.

Diphyes bojani (Eschscholtz). Det. A. K. Totton

Moderately common; maximum in winter (Fig. 22). A shallow form; mean day-level 40 metres; spread 25 metres. Leloup and Hentschel (1935) give range as 0–600 metres. Probably either no diurnal migration or a slight downward movement at night, but numbers inadequate; no correlation between night surface abundance and moonlight. Horizontal distribution the reverse of that of rest of zooplankton on one cruise.

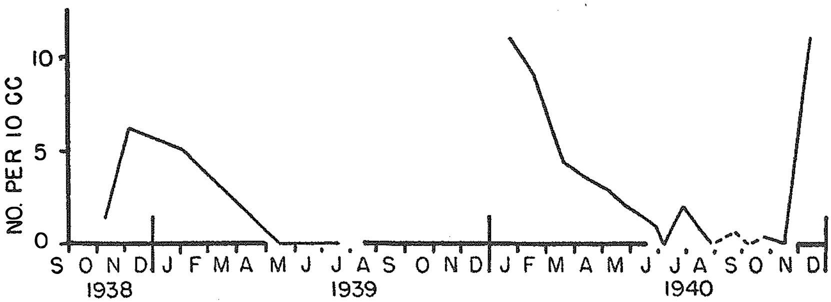
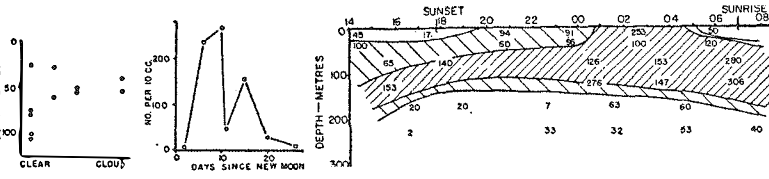


Figure 22. ***Diphyes bojani.*** **Seasonal variation in numbers.**

Eudoxoides spiralis (Bigelow). Det. A. K. Totton

A common form with a winter, or spring and autumn maximum. Leloup (1933) records it as most abundant in August, and Russell and Colman (1935), for the Great Barrier Reef, in spring. Mean day-level 65 metres (Fig. 23); spread 65 metres; no consistent difference in level in the two generations. A good correlation of day-level with cloud (Fig. 24) and of night surface abundance with moonlight (Fig. 25). A marked diurnal migration with some night increment from below 250 metres (Fig. 26); day-night range 47 metres; day : night ratio 60.



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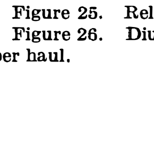

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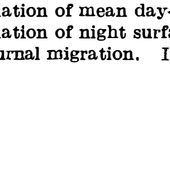

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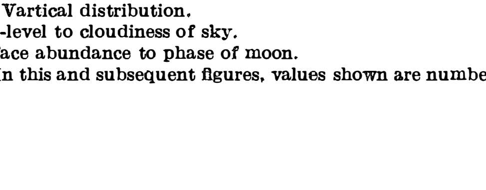

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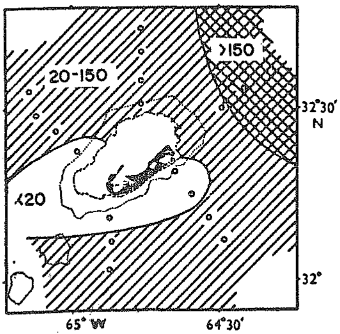
Eudoxoides spiralis. **Figure 23.** **Vartical distribution.**

Figure 24. **Relation of mean day-level to cloudiness of sky.**

Figure 25. **Relation of night surface abundance to phase of moon.**

Figure 26. **Diurnal migration. In this and subsequent figures, values shown are numbers per haul.**



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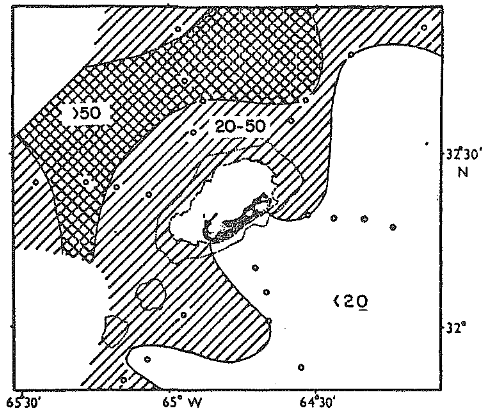

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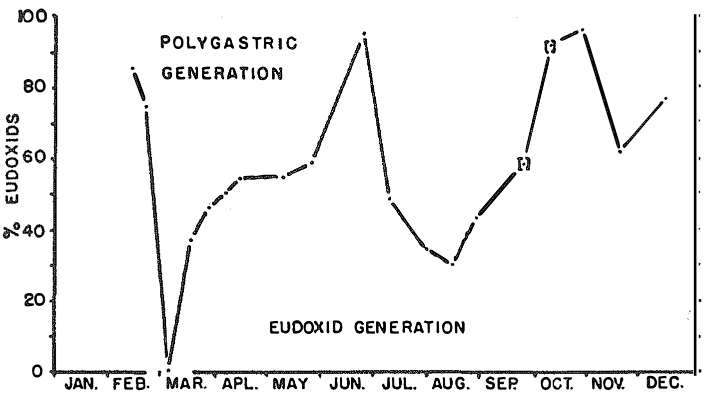

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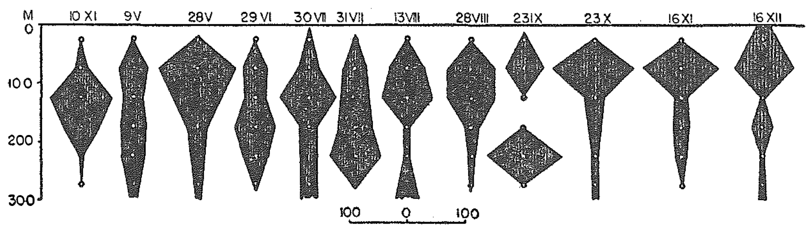
Eudoxoides spiralis. **Figure 27. Horizontal distribution, December 1938.**
Figure 28. Horizontal distribution, May 1939.
Figure 29. Seasonal variation in percentage ratio of the two generations.

Horizontal distribution agreed well with that of rest of zooplankton on two cruises (Figs. 27, 28). A clearly marked alternation in the proportion of the two generations, with three cycles during the year (Fig. 29). The polygastric generation appears to become dominant more suddenly, and to remain so for a shorter time than the eudoxid.

Eudoxoides mitra (Huxley). Det. A. K. Totton

One of the commonest Bermuda diphyids; no definite seasonal maximum; mean day-level 125 metres (Fig. 30); spread 105 metres; no difference in level in the two generations. Leloup (1933) records it as most abundant in Aug.–Sept., and chiefly at 500–1,000 metres. This does not agree with our results. No correlation of day-level with cloud; a good correlation of night surface abundance with moonlight (Fig. 31). Diurnal migration marked but not extensive (Fig. 32); day : night ratio 41, indicating considerable night increment from below 250 metres. Moderate to poor agreement of horizontal distribution with that of rest of zooplankton (Figs. 33–35). Apparently a cyclic alternation in proportions of two generations (Fig. 36), with five cycles during the year, but numbers rather inadequate.



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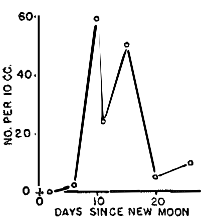

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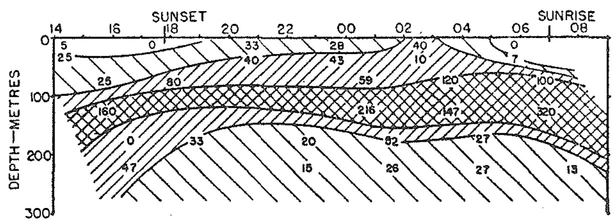

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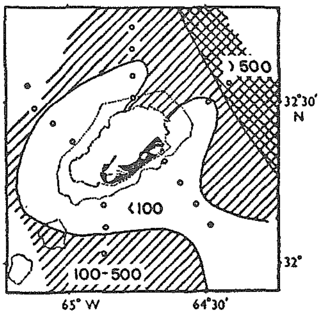
Eudoxoides mitra. Figure 30. Vertical distribution.
Figure 31. Relation of night surface abundance to phase of moon.
Figure 32. Diurnal migration.

Chelophyes appendiculata (Eschscholtz). Det. A. K. Totton

Fairly common; no definite seasonal maximum; mean day-level 75 metres, but variable (Fig. 37); spread 130 metres. Leloup (1933) states that it is most abundant in July–Aug., and has a very wide vertical range. Leloup and Hentschel (1935) give its range as 0–600 metres. Marked diurnal migration (Fig. 38); day-night range 87 metres; day : night ratio 78. Good correlation of night surface abundance with moonlight (Fig. 39). Horizontal distribution agreed only poorly with that of rest of zooplankton on one cruise (Fig. 40). Proportions of generations variable, with tendency for polygastric to be



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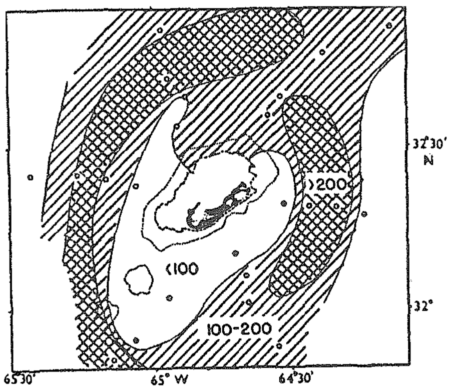

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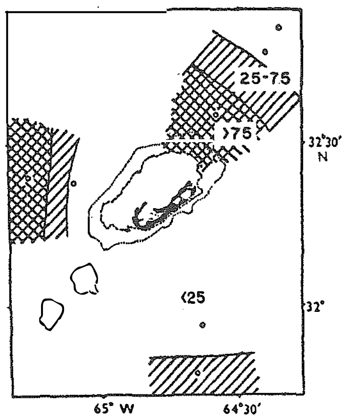

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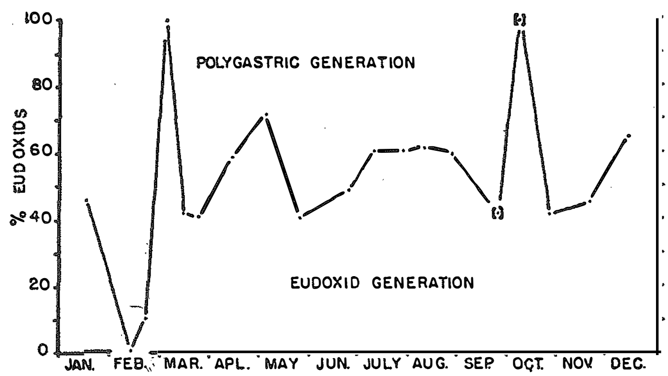

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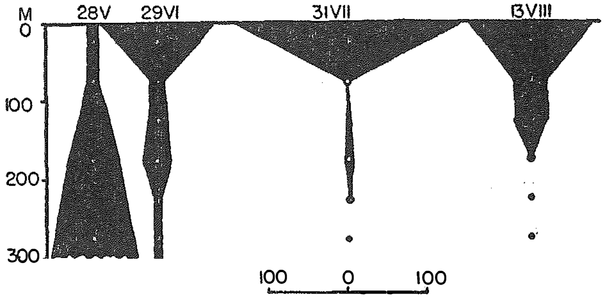
Eudoxoides mitra. Figure 33. Horizontal distribution, December 1938.
Figure 34. Horizontal distribution, May 1939.
Figure 35. Horizontal distribution, July 1939.
Figure 36. Seasonal variation in percentage ratio of the two generations.



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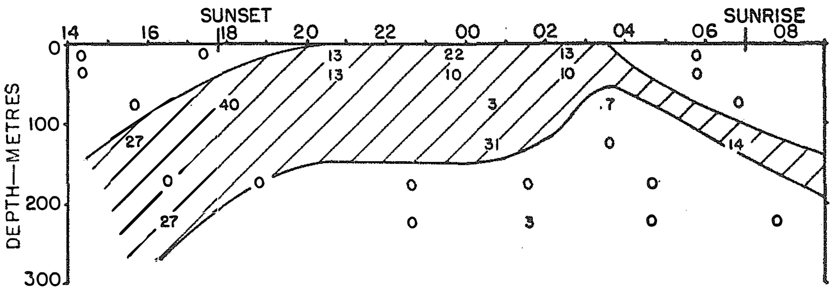

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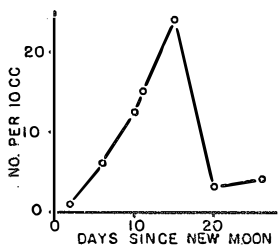

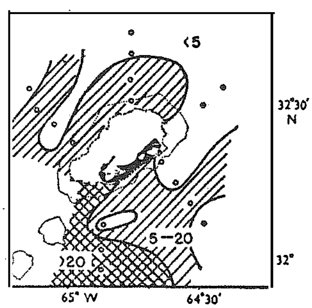

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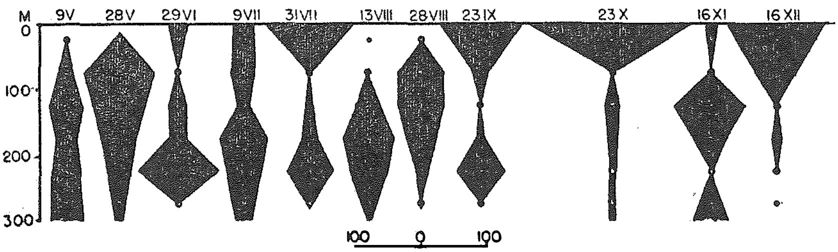
Chelophyes appendiculata. **Figure 37. Vertical distribution.**
Figure 38. Diurnal migration.
Figure 39. Relation of night surface abundance to phase of moon.
Figure 40. Horizontal distribution, December 1938.

more common, but numbers inadequate to show whether fluctuation is cyclic.

Lensia subtilis (Chun). Det. A. K. Totton

Common; maximum in summer; mean day-level 140 metres; spread 150 metres (Fig. 41). Leloup and Hentschel (1935) give range as 0–

800 metres. Diurnal migration slight, and chiefly affecting upper 25 metres. Horizontal distribution agreed well with that of rest of zooplankton on two cruises (Figs. 42, 43).



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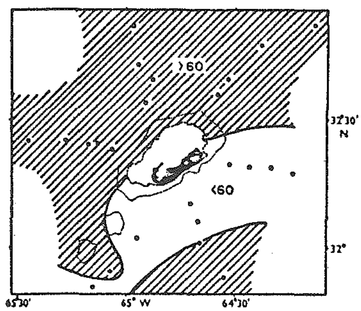

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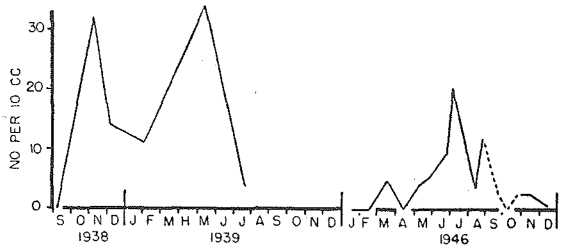
***Lensia subtilis*. Figure 41. Vertical distribution.**
Figure 42. Horizontal distribution, May 1939.
Figure 43. Horizontal distribution, July 1939.

Lensia fowleri (Bigelow). Det. A. K. Totton

Less common than *L. subtilis;* summer maximum (Fig. 44); mean day-level 165 metres; spread 70 metres (Fig. 45). Leloup and Hentschel (1935) give range as 0–800 metres. Day-level not correlated with cloud; horizontal distribution reverse of that of rest of zooplankton on two cruises, and doubtful on one (Figs. 46–48).

Lensia campanella (Moser). Det. A. K. Totton

About as common as *L. fowleri;* apparently an autumn maximum, but doubtful. Mean day-level 60 metres; spread 25 metres. Leloup and Hentschel (1935) give range as 0–400 metres. Slight correlation of day-level with cloud; horizontal distribution agreed moderately with that of rest of zooplankton on one cruise (Fig. 49).



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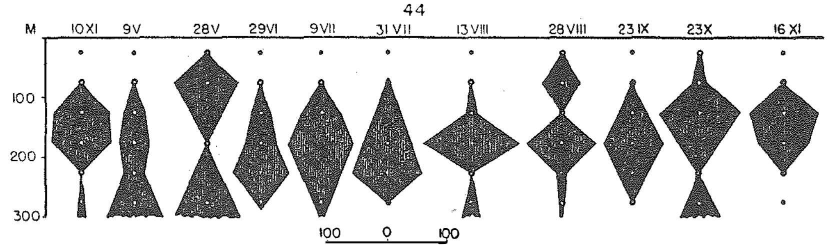

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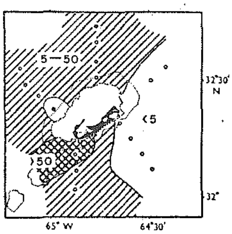

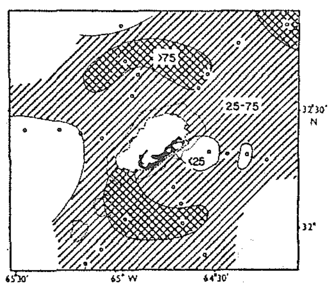

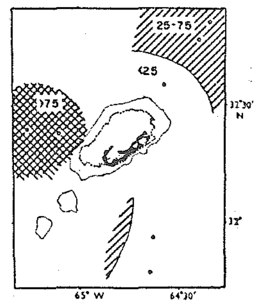

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***Lensia fowleri*. Figure 44. Seasonal variation in numbers.**
Figure 45. Vertical distribution.
Figure 46. Horizontal distribution, December 1938.
Figure 47. Horizontal distribution, May 1939.
Figure 48. Horizontal distribution, July 1939.

Lensia cossack Totton. Det. A. K. Totton [6]

Sporadically in small numbers.

Sulceolaria monoica (Chun). Det. A. K. Totton

Sporadically in small numbers; winter, or autumn and spring maximum (Fig. 50).

Sulceolaria quadridentata (Quoy and Gaimard). Det. A. K. Totton

Sporadically in small numbers; may be a winter form.

[6] Totton, 1941.

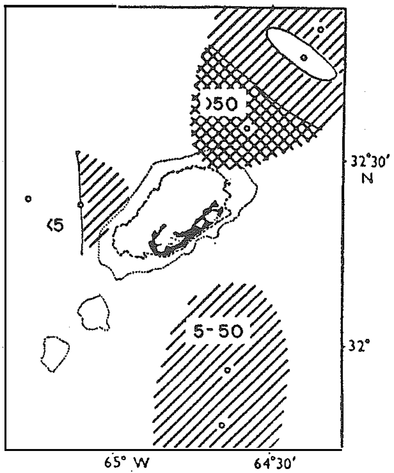


Figure 49. ***Lensia campanella.*** **Horizontal distribution, July 1939.**

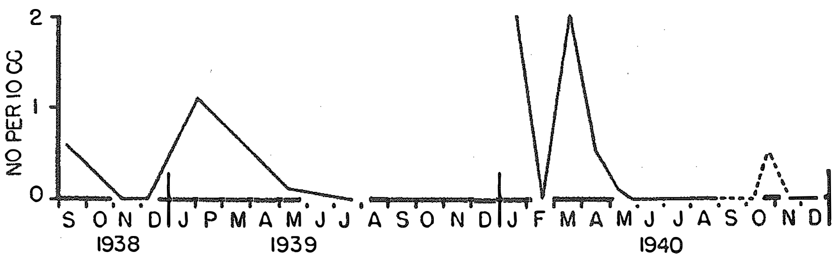


Figure 50. ***Sulceolaria monoica.*** **Seasonal variation in numbers.**

Galetta australis (Quoy and Gaimard). Det. A. K. Totton

Slightly more common than the previous two species; possible spring maximum.

Agalma elegans Sars

A few isolated nectophores.

Agalma okeni Eschscholtz. Det. A. K. Totton

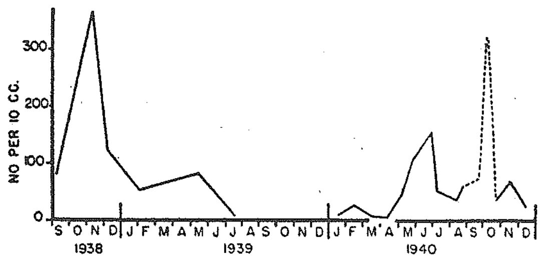
Occasional isolated nectophores and bracts.

CHAETOGNATHA

Sagitta hexaptera d'Orbigny. Det. F. S. Russell

Common throughout the year; maximum in summer or autumn (Fig. 51); mean day-level 95 metres (Fig. 52); spread 105 metres.

This level agrees with statement of most authors that the species is epiplanktonic (Ritter-Záhony, 1911, 1911a; Thiele, 1938; Michael, 1919), but Welsh, Chace and Nunnemacher (1937) record it in fair numbers at 400 metres, and Germain and Joubin (1916) give the maximum at 600–800 metres. Diurnal migration slight and chiefly affecting the top 25 metres; no night increment from below 250 metres. However, Welsh, *et al.* (1937) showed evidence of movement as deep as 400 metres. No correlation of day-level with cloud; good correlation of night surface abundance with moonlight; horizontal distribution agreed well with that of rest of zooplankton on two cruises (Figs. 53, 54).



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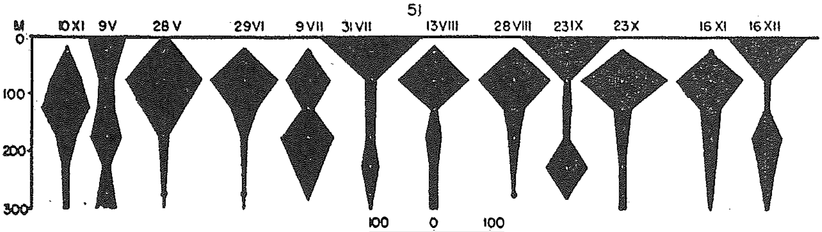

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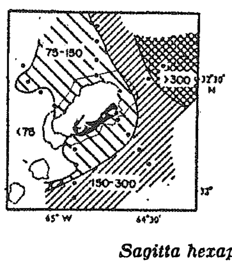

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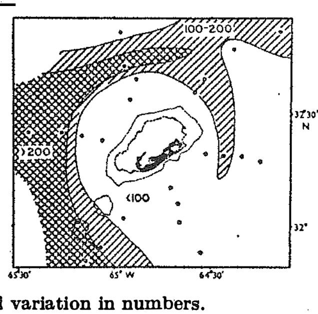

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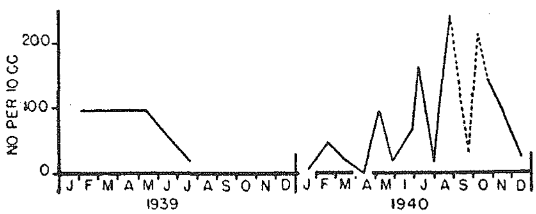
Sagitta hexaptera. **Figure 51. Seasonal variation in numbers.**
Figure 52. Vertical distribution.
Figure 53. Horizontal distribution, December 1938.
Figure 54. Horizontal distribution, May 1939.

Sagitta lyra Krohn. Det. F. S. Russell, J. W. S. Marr

Common, but somewhat less so than *S. hexaptera;* possible late summer maximum (Fig. 55). Mean day-level 120 metres; spread 85 metres (Fig. 56). Ritter-Záhony (1911a) records it at all levels from 100–200 metres down; Kuhl (1938) gives maximum at 100–600 metres; Michael (1911) gives the maximum at 400–600 metres and records it as rare above 25 metres, although moving upward somewhat at night; Germain and Joubin (1916) describe it as mesoplanktonic with a maximum at 360–540 metres, but reaching surface at night. No



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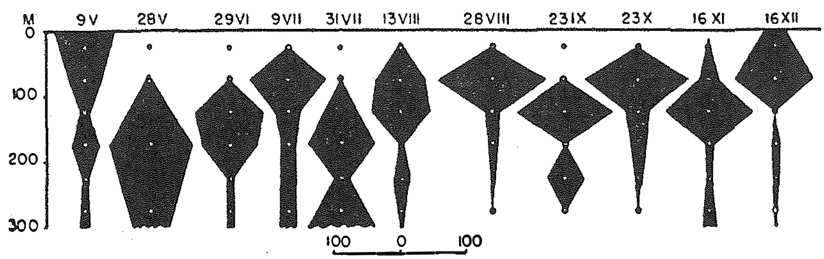

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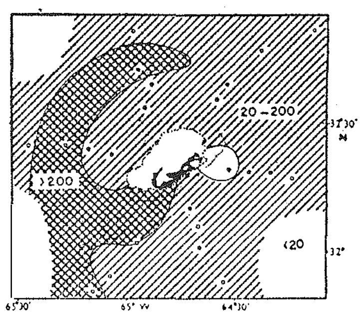

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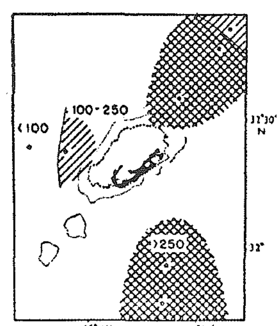


Sagitta lyra. **Figure 55. Seasonal variation in numbers.**
Figure 56. Vertical distribution.
Figure 57. Horizontal distribution, May 1939.
Figure 58. Horizontal distribution, July 1939.

correlation of day-level with cloud; diurnal migration slight and chiefly affecting top 25 metres; no night increment from below 250 metres; night surface abundance not correlated with moonlight. Horizontal distribution agreed well with that of rest of zooplankton (Figs. 57, 58).

Sagitta enflata Grassi. Det. F. S. Russell, J. W. S. Marr

Recorded only sporadically, although this may have been due in some cases to confusion with other species. Mean day-level 115 metres; spread 180 metres. Most authors describe it as epiplanktonic (Ritter-Záhony, 1911, 1911a; Michael, 1911, 1919; Thiele, 1938), but Germain and Joubin (1916) state that, although generally epiplanktonic, it may also be taken at considerable depths.

Sagitta bipunctata Quoy and Gaimard. Det. F. S. Russell, J. W. S. Marr, J. H. Fraser

This and *S. serratodentata* are the two abundant smaller chaetognaths in the area. Seasonal maximum doubtful, since apparent spring minimum is based on night hauls only. Mean day-level 95 metres; spread 105 metres (Fig. 59). Generally described as epiplanktonic (Ritter-Záhony 1911, 1911a; Thiele, 1938; Germain and Joubin, 1916); Michael (1911) gives day maximum at 80–150 metres, rising to 8–12 metres after sunset. Definite diurnal migration (Fig. 60); day-level not correlated with cloud; night surface abundance not correlated with moonlight. The latter is surprising in a species in which there is a marked downward scattering around midnight (Fig. 60; also Michael, 1911). Horizontal distribution agreed well with that of rest of zooplankton on one cruise, poorly on another and was reversed on a third (Figs. 61–63).

Sagitta robusta Doncaster. Det. F. S. Russell, J. W. S. Marr, J. H. Fraser

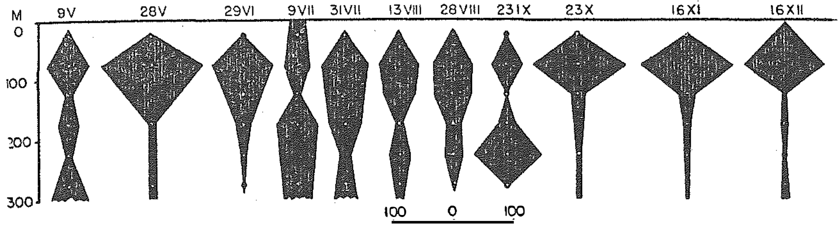
Abundant inside the reefs, but only occasionally as a stray in outside hauls.

Sagitta helenae Ritter-Záhony. Det. F. S. Russell, J. W. S. Marr

One only; Ritter-Záhony (1911) records it as an epiplanktonic species.

Sagitta serratodentata Krohn. Det. F. S. Russell

Common throughout the year, though slightly less so than *S. bipunctata;* summer, or summer and autumn maximum; mean day-



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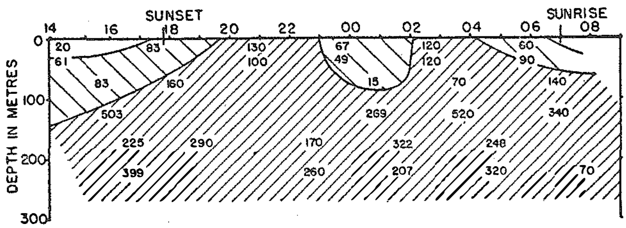

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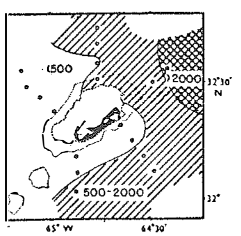

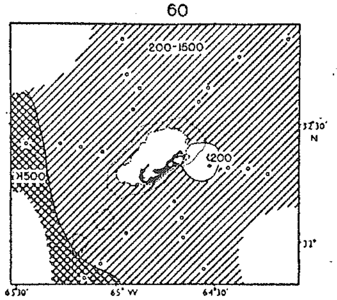

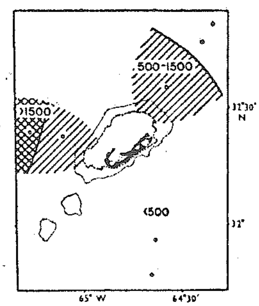

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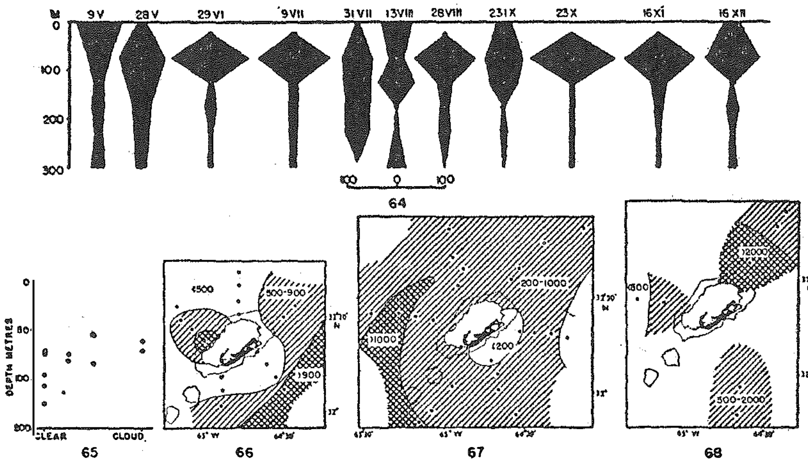
***Sagitta bipunctata*. Figure 59. Vertical distribution.**
Figure 60. Diurnal migration.
Figure 61. Horizontal distribution, December 1938.
Figure 62. Horizontal distribution, May 1939.
Figure 63. Horizontal distribution, July 1939.

level 75 metres; spread 70 metres (Fig. 64). Statements of other authors are conflicting. Ritter-Záhony (1911a) and Thiele (1938) give maximum near the surface. Michael (1911) gives day maximum at 400 metres, and Germain and Joubin (1916) at about 1,200 metres. Definite diurnal migration, but chiefly affecting top 50 metres. Good correlation of day-level with cloud (Fig. 65); night surface abundance not correlated with moonlight. Horizontal distribution agreed well with that of rest of zooplankton on three cruises (Figs. 66–68).

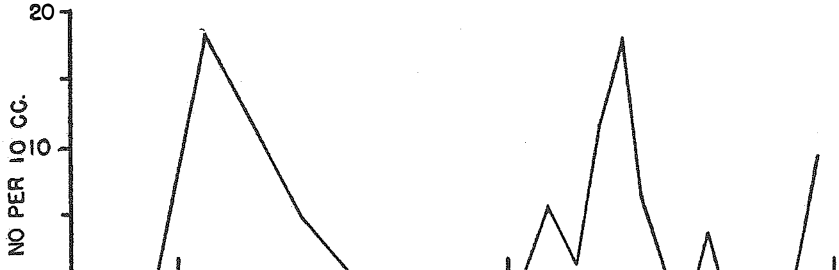


Sagitta serratodentata. **Figure 64. Vertical distribution.**
Figure 65. Relation of mean day-level to cloudiness of sky.
Figure 66. Horizontal distribution, December 1938.
Figure 67. Horizontal distribution, May 1939.
Figure 68. Horizontal distribution, July 1939.

Sagitta planktonis Steinhaus. Det. F. S. Russell, J. W. S. Marr

Not common; maximum in spring (Fig. 69); all our records show it as one of the most specifically surface forms in the area, ranking with *Diphyes dispar* and *Acartia negligens* (Fig. 70). This contradicts records of other authors. Ritter-Záhony (1911a) records it from the light limit down, although occurring higher in the antarctic. Hardy and Gunther (1935) give its maximum in the antarctic at 250–750 metres. Theile (1938) gives its maximum at 300 metres, and Michael (1911) at 600 metres. Germain and Joubin (1916) describe it as typically bathyplanktonic with maximum below 1,200 metres. It is difficult to reconcile these results with ours. Russell has described variations in level of *Sagitta* with age, but on a much smaller scale than this. Alternatively, there may be two species, one deep- and one shallow-living, which are at present combined as *S. planktonis.*

Diurnal migration figures small but suggest a downward movement at night and no night increment from deep water. Correlation of night surface abundance with moonlight the reverse of the usual, *S. planktonis* being most abundant at the surface on moonless nights (Fig. 71).



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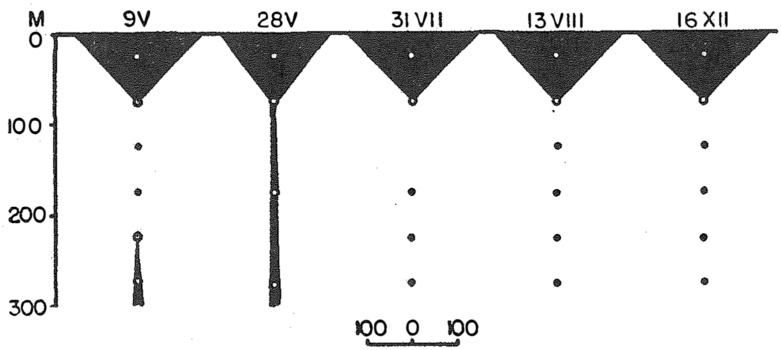

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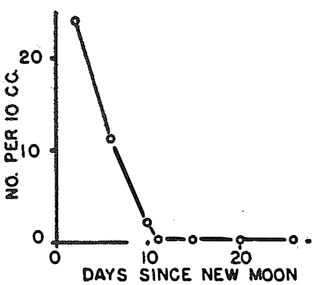

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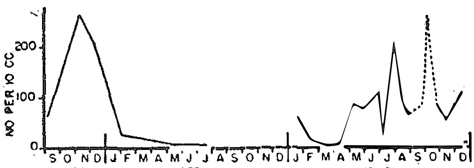
Sagitta planktonis. **Figure 69. Seasonal variation in numbers.**
Figure 70. Vertical distribution.
Figure 71. Relation of night surface abundance to phase of moon.

Pterosagitta draco (Krohn). Det. F. S. Russell

Fairly common; autumn maximum (Fig. 72); mean day-level 65 metres; spread 80 metres (Fig. 73). Level agrees with statements of other authors (Ritter-Záhony, 1911, 1911a; Thiele, 1938; Michael, 1919). Marked diurnal migration; day-night range 59 metres; considerable increment from deep water; day : night ratio 47. Slight correlation of day-level with cloud; slight correlation of night surface abundance with moonlight. Horizontal distribution agreed well and moderately well with that of rest of zooplankton on two cruises (Figs. 74, 75).



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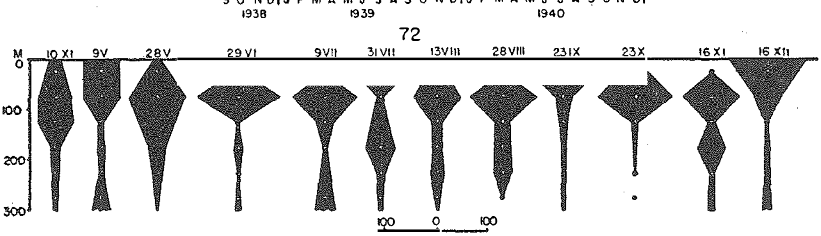

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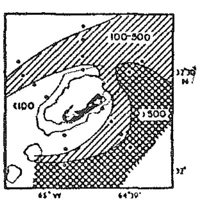

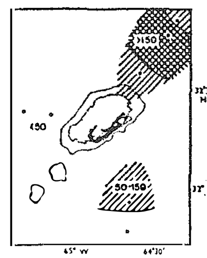

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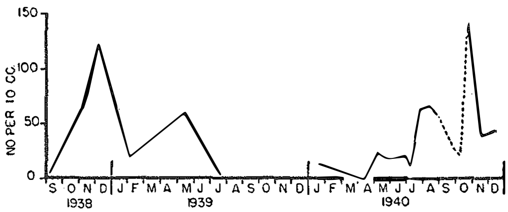
Pterosagitta draco. **Figure 72. Seasonal variation in numbers.**
Figure 73. Vertical distribution.
Figure 74. Horizontal distribution, December 1938.
Figure 75. Horizontal distribution, July 1939.

Eukrohnia ? fowleri Ritter-Záhony

Three poorly preserved specimens. A deep water form (Ritter-Záhony, 1911a; Thiele, 1938).

Krohnitta subtilis (Grassi). Det. F. S. Russell

Fairly common; autumn maximum (Fig. 76); mean day-level 135 metres; spread 95 metres (Fig. 77). Ritter-Záhony (1911a) describes it as a shallow form. Thiele (1938) gives maximum at 100 metres, and Michael (1911) at 400–500 metres. Germain and Joubin (1916) describe it as mesoplanktonic. Diurnal migration slight; some night increment from deep water; day : night ratio 75. Day-level not correlated with cloud; night surface abundance only slightly correlated with moonlight. Horizontal distribution agreed only poorly with that of rest of zooplankton (Figs. 78–80).



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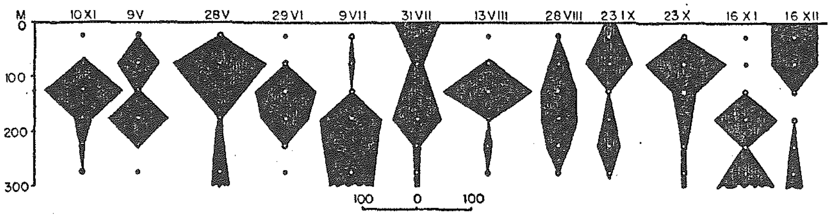

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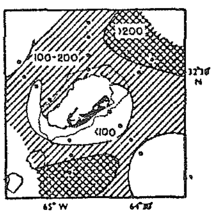
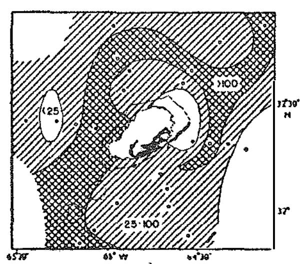
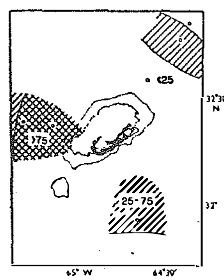
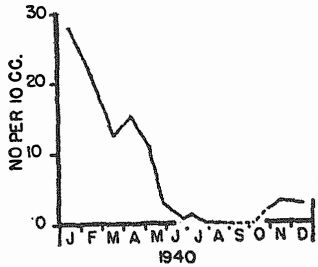






78 79 80

Krohnitta subtilis. **Figure 76. Seasonal variation in numbers.**
Figure 77. Vertical distribution.
Figure 78. Horizontal distribution, December 1938.
Figure 79. Horizontal distribution, May 1939.
Figure 80. Horizontal distribution, July 1939.



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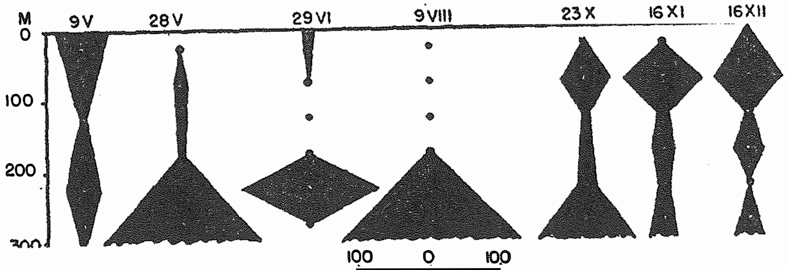

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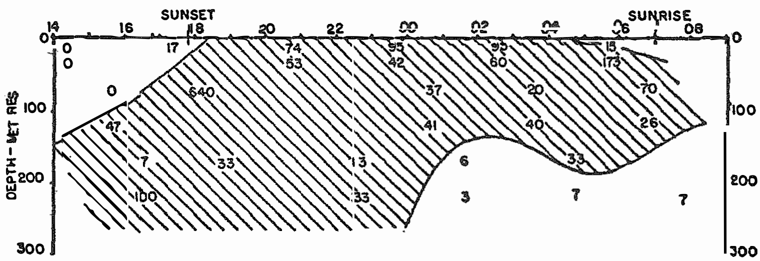

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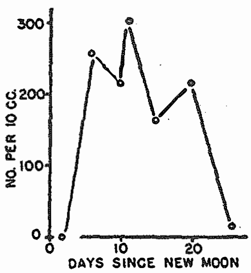


84

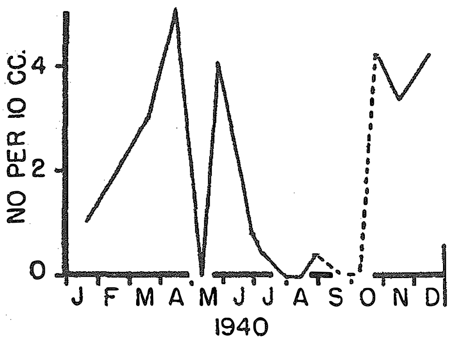
Limacina inflata. Figure 81. Seasonal variation in numbers.
Figure 82. Vertical distribution.
Figure 83. Diurnal migration.
Figure 84. Relation of night surface abundance to phase of moon.

MOLLUSCA

Pteropoda

Limacina inflata (d'Orbigny)

Far the commonest pteropod in the area. Owing to small size was probably underestimated in earlier samples before method of decanting was introduced. Marked maximum in winter or early spring (Fig. 81). Mean day-level probably somewhat below 300 metres, and spread more than 175 metres (Fig. 82). Very marked diurnal migration (Fig. 83); day-night range at least 195 metres; day : night ratio 67. Good correlation of night surface abundance with moonlight (Fig. 84).



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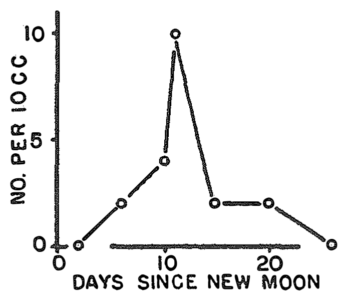


86

Limacina lesueurii. **Figure 85. Seasonal variation in numbers. Figure 86. Seasonal variation in numbers.**

Limacina lesueurii (d'Orbigny)

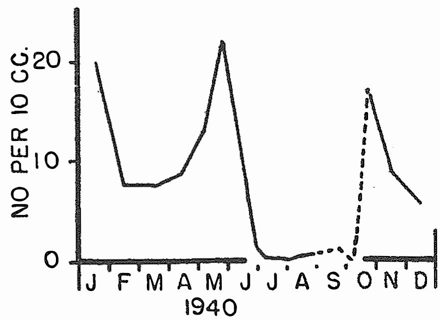
Much less common than *L. inflata;* winter, or spring and autumn maximum (Fig. 85); this species also may have been underestimated in earlier samples. Good correlation of night surface abundance with moonlight (Fig. 86).

Limacina trochiformis (d'Orbigny)

Single specimens occasionally.

Limacina bullimoides (d'Orbigny)

Slightly more abundant than *L. lesueurii;* seasonal maximum doubtful (Fig. 87); mean day-level 80 metres; spread 75 metres (Fig. 88). Bonnevie (1933) gives maximum at 0–100 metres. Good correlation of night surface abundance with moonlight (Fig. 89); horizontal distribution agreed only slightly with that of rest of zooplankton.



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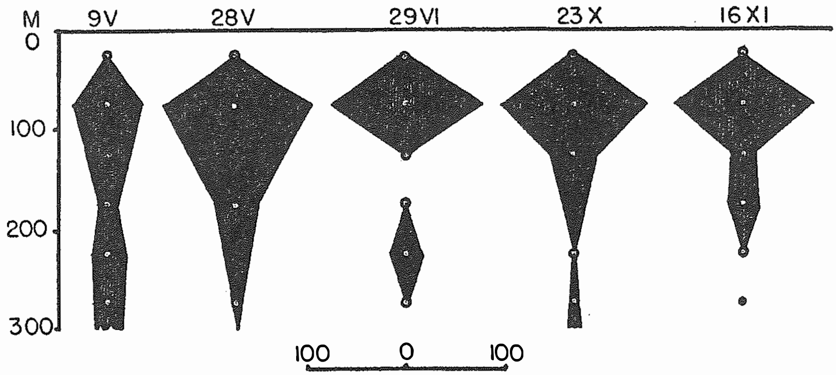

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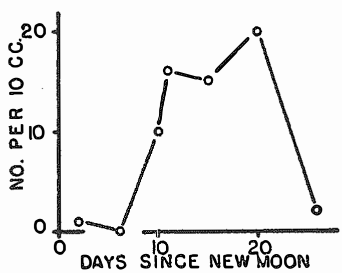

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***Limacina bulimoides*. Figure 87. Seasonal variation in numbers.**
Figure 88. Vertical distribution.
Figure 89. Relation of night surface abundance to phase of moon.

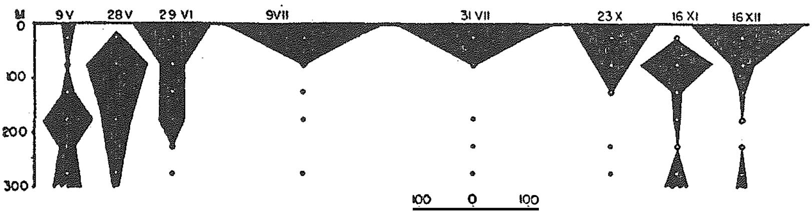
Creseis virgula Rang

Comparatively rare. According to Stubbings (1938) it is a surface form.

Creseis acicula Rang

More common than *C. virgula* but never abundant; winter, or autumn and spring maximum (Fig. 90); mean day-level 35 metres; spread 30 metres (Fig. 91). Bonnevie (1933) gives maximum at 0–50 metres, and Stubbings (1938) 250 metres in daytime and at surface at night. Day-level not correlated with cloud; night surface abundance not correlated with moonlight. Horizontal distribution agreed well with that of rest of zooplankton on one cruise.

90



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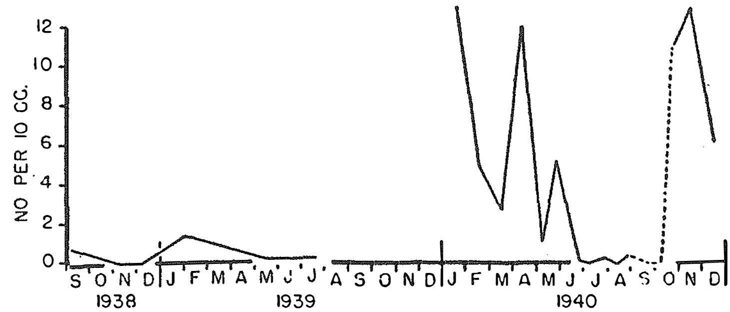
Creseis acicula. **Figure 90. Seasonal variation in numbers. Figure 91. Vertical distribution.**

Styliola subula (Quoy and Gaimard)

Fairly common; winter maximum (Fig. 92); mean day-level 60 metres; spread 35 metres (Fig. 93). Bonnevie (1933) gives maximum at 50–100 metres. Diurnal migration extensive (Fig. 94); day-night range at least 272 metres; considerable night increment from deep water. Good correlation of night surface abundance with moonlight (Fig. 95).

Hyalocylis striata (Rang)

Never common; winter maximum (Fig. 96); Bonnevie (1933) gives maximum level as 100–250 metres, and Stubbings (1938) as 200–500



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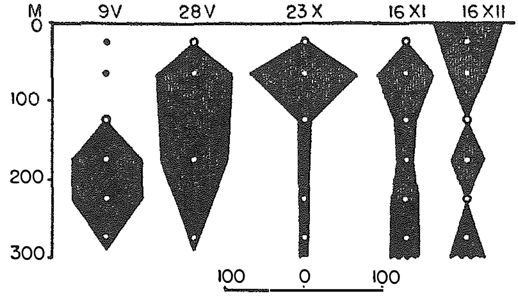

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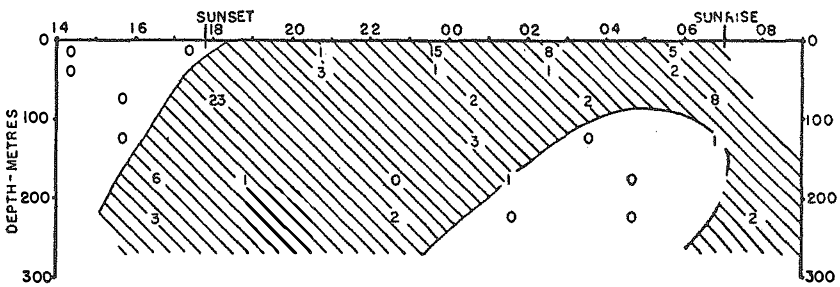

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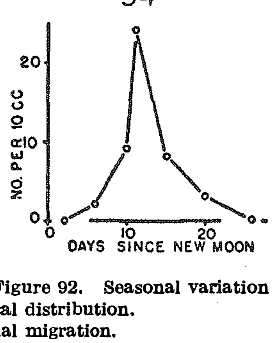

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Styliola subula. Figure 92. Seasonal variation in numbers.
Figure 93. Vertical distribution.
Figure 94. Diurnal migration.
Figure 95. Relation of night surface abundance to phase of moon.

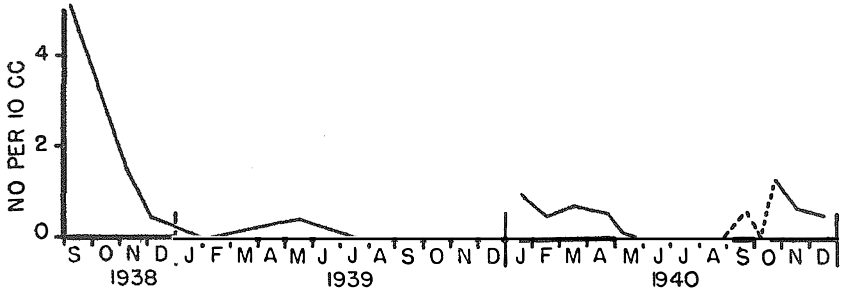
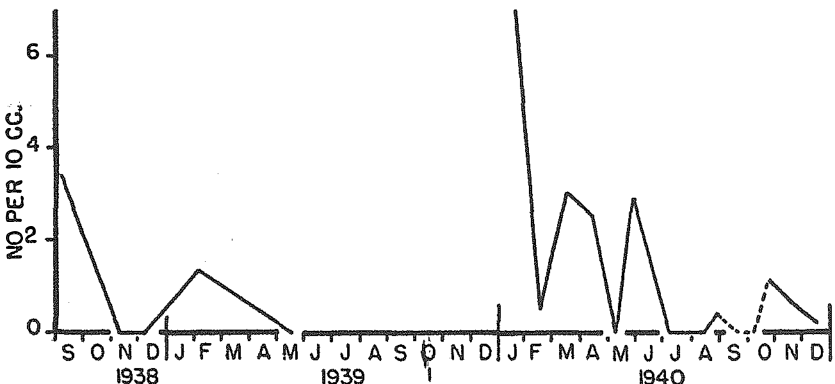


Figure 96. ***Hyalocylis striata.*** **Seasonal variation in numbers.**

metres in daytime, and surface at night. Good correlation of night surface abundance with moonlight.

Clio pyramidata Linné

Somewhat more common than *Hyalocylis;* winter maximum (Fig. 97); Bonnevie (1933) gives maximum at 50–250 metres, and Stubbings



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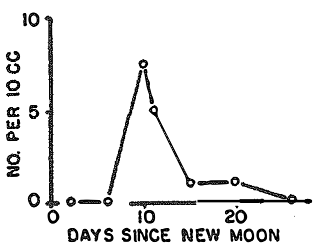


98

Clio pyramidata. **Figure 97. Seasonal variation in numbers.**
Figure 98. Relation of night surface abundance to phase of moon.

(1938) at 700 metres in daytime, and generally distributed down to 1,500 metres at night. Good correlation of night surface abundance with moonlight (Fig. 98).

Cuvierina columnella (Rang)

Not common; probably winter maximum, but numbers small (Fig. 99); Bonnevie (1933) gives maximum at 100–250 metres. Good correlation of night surface abundance with moonlight.

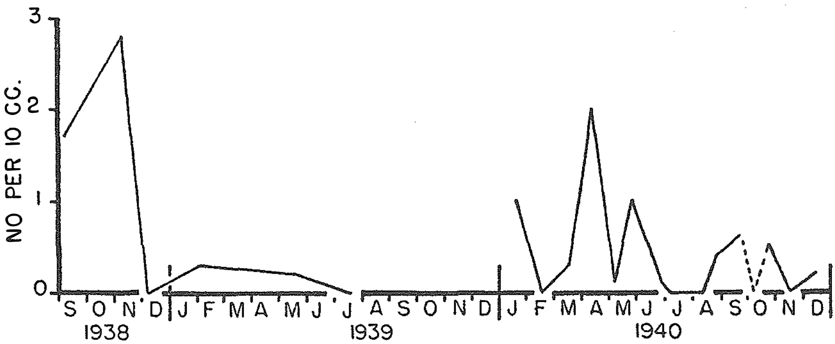


Figure 99. *Cuvierina columnella.* Seasonal variation in numbers.

Diacria trispinosa (Lesueur)

In small numbers; winter maximum (Fig. 100). Bonnevie (1933) gives maximum at 50–250 metres. Fairly good correlation of night surface abundance with moonlight.

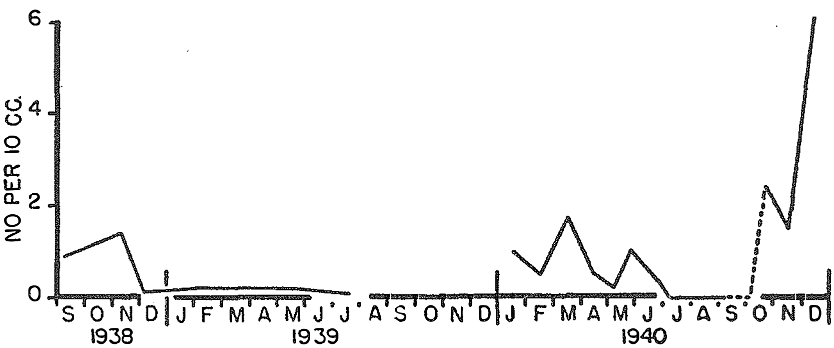


Figure 100. *Diacria trispinosa.* Seasonal variation in numbers.

Diacria quadridentata (Lesueur)

One in 1938–39, and in small numbers in 1940; winter or spring maximum (Fig. 101). Bonnevie (1933) gives maximum at 0–50 metres, and Stubbings (1938) as at the surface in the daytime, but deep at night.

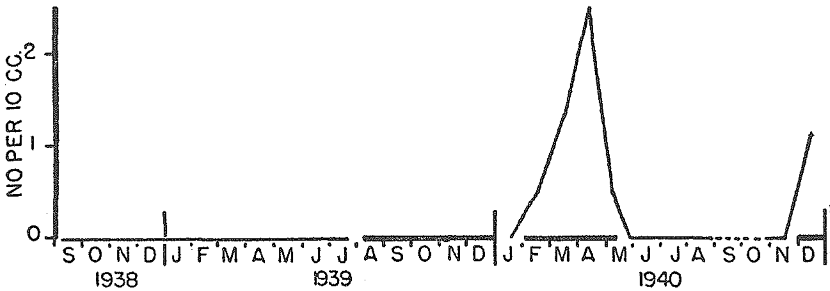


Figure 101. ***Diacria quadridentata.*** **Seasonal variation in numbers.**

Cavolinia longirostris (Lesueur)

In very small numbers only; winter maximum (Fig. 102). Russell and Colman (1935) give maximum on Great Barrier Reef in autumn. Bonnevie (1933) gives maximum at 0–50 metres, and Stubbings (1938) at 2,000 metres in daytime, and about 500 metres at night.

Figure 102. ***Cavolinia longirostris.*** **Seasonal variation in numbers.**

Cavolinia gibbosa (Rang)

Sporadically in small numbers. Bonnevie (1933) gives maximum at 100–250 metres. Good correlation of night surface abundance with moonlight (Fig. 103).

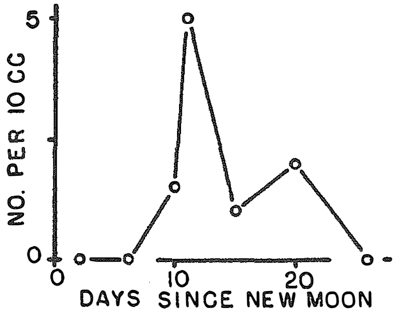


Figure 103. ***Cavolinia gibbosa.*** **Relation of night surface abundance to phase of moon.**

Cavolinia uncinata (Rang)

Two specimens.

Cavolinia tridentata (Forskål)

Two specimens.

Peracle reticulata (D'Orbigny)

Sporadically in small numbers throughout the year.

Peracle triacantha (Fischer)

One specimen.

Gleba cordata Forskål

Occasional damaged specimens.

PTEROPODA, Gymnosomata

Only a very few specimens were taken, and these too badly preserved for identification.

HETEROPODA

Carinaria sp.

Two specimens.

Cardiapoda richardi Vayssière

One specimen at 50–100 metres.

Firola hippocampus Philippi

One specimen in a night surface haul.

Firola gegenbauri Vayssière

Two specimens at 200–250 metres.

Firoloïda desmaresti Lesueur

Seven specimens in one haul at 0–50 metres.

Atlanta peroni Lesueur

Sporadically, and never in great numbers, throughout the year; mean day-level 60 metres; spread 60 metres (Fig. 104).

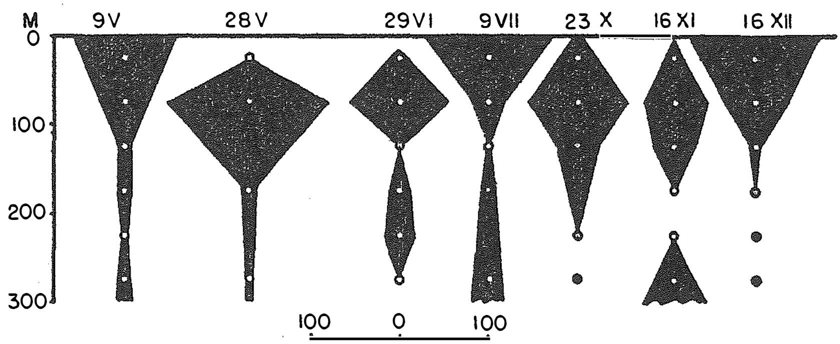


Figure 104. ***Atlanta peroni.*** **Vertical distribution.**

Atlanta inclinata Souleyer

In small numbers throughout the year, but much less common than *A. peroni.*

Phyllirhöidae

Cephalopyge sp.

One specimen at 50–100 metres.

Phyllirhöe atlantica Bergh

Two specimens.

Phyllirhöe bucephala Péron and Lesueur

Two specimens.

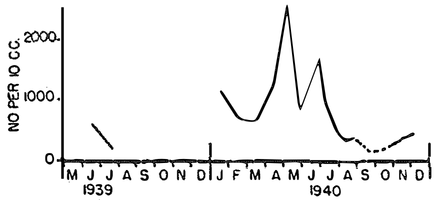
CRUSTACEA

Copepoda

Calanus minor (Claus). Det. G. P. Farran

Identifications in 1938–39 of doubtful value. Common; spring maximum (Fig. 105); mean day-level 85 metres; spread 95 metres

(Fig. 106). Good correlation of day-level with cloud (Fig. 107); good correlation of night surface abundance with moonlight. Horizontal distribution agreed well and moderately with that of rest of zooplankton on two cruises (Figs. 108, 109).



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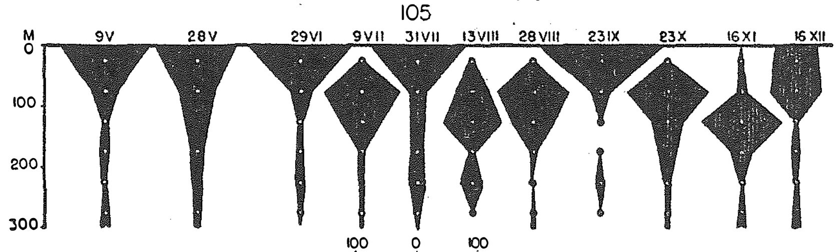

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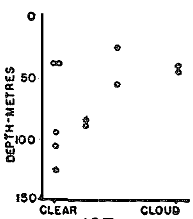

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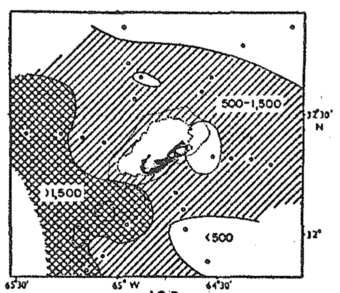

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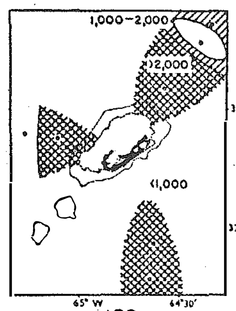
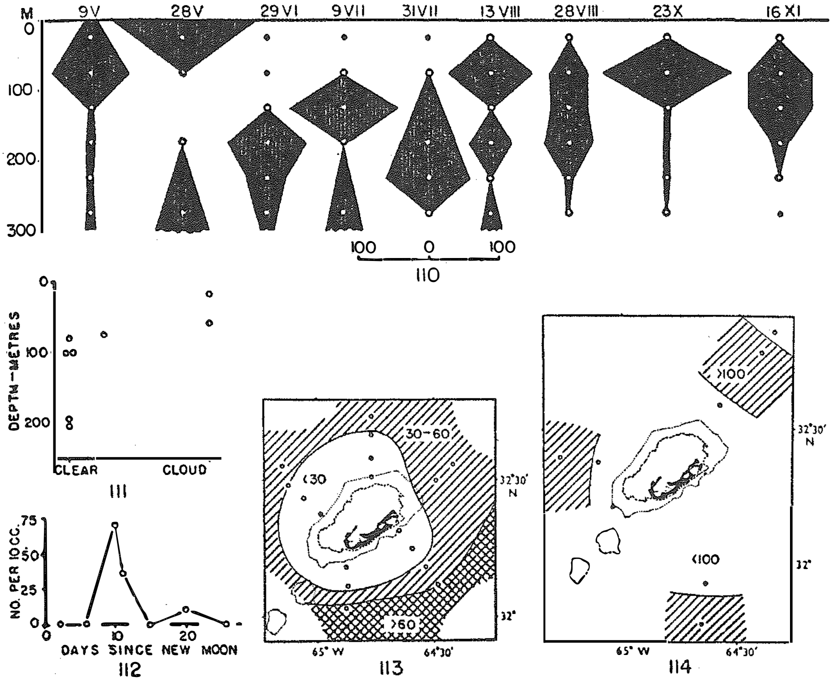


109

***Calanus minor*. Figure 105. Seasonal variation in numbers.**
Figure 106. Vertical distribution.
Figure 107. Relation of mean day-level to cloudiness of sky.
Figure 108. Horizontal distribution, May 1939.
Figure 109. Horizontal distribution, July 1939.

Neocalanus gracilis (Dana). Det. G. P. Farran, M. Sears

Present throughout the year in small numbers; may be an autumn maximum, but doubtful since minimum numbers were in night surface hauls. Mean day-level 130 metres; spread 115 metres (Fig. 110). Good correlation of day-level with cloud (Fig. 111) and an unusually large range of level; good correlation of night surface abundance with moonlight (Fig. 112); horizontal distribution agreed well and slightly with that of rest of zooplankton on two cruises (Figs. 113, 114).



Neocalanus gracilis. **Figure 110. Vertical distribution.**
Figure 111. Relation of mean day-level to cloudiness of sky.
Figure 112. Relation of night surface abundance to phase of moon.
Figure 113. Horizontal distribution, December 1938.
Figure 114. Horizontal distribution, July 1939.

Undinula vulgaris (Dana). Det. M. Sears

Sporadically in small numbers. Recorded as a shallow form (Farran, 1936; Rose, 1929).

Eucalanus attenuatus (Dana), and *E. mucronatus* Giesbrecht. Det. G. P. Farran

Owing to confusion of identification in counting, these two species must be considered together. Wilson (1932) records six species of *Eucalanus* from these waters, but the above two are the commonest. Present throughout the year in small numbers; good correlation of night surface abundance with moonlight (Fig. 115).

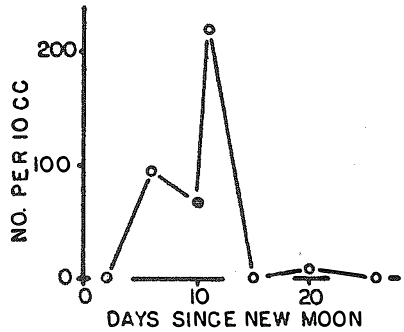
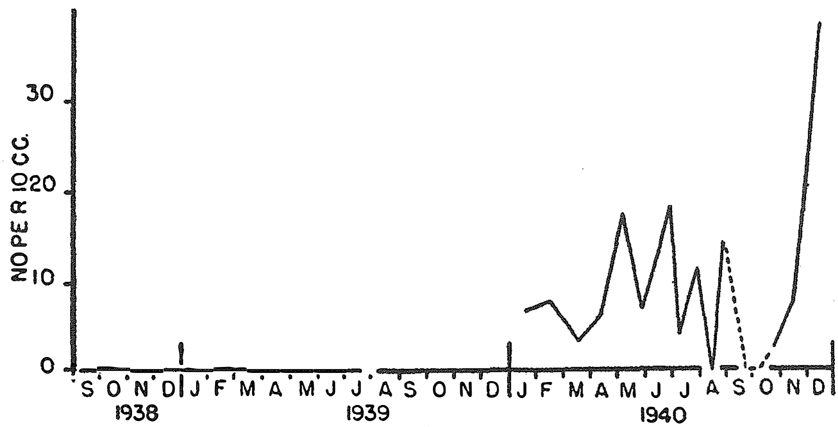


Figure 115. *Eucalanus attenuatus + E. mucronatus.* **Relation of night surface abundance to phase of moon.**



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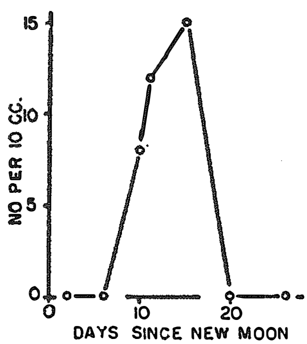

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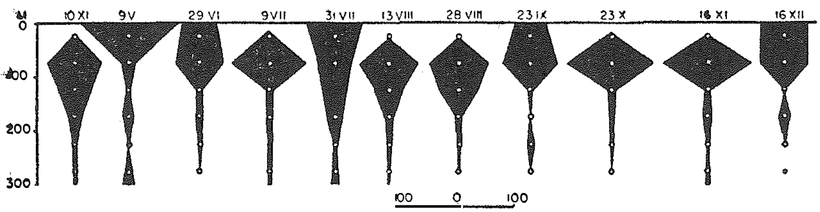
Rhincalanus cornutus. **Figure 116. Seasonal variation in numbers. Figure 117. Relation of night surface abundance to phase of moon.**

Rhincalanus cornutus Dana

Absent in 1938–39; present in small numbers throughout the year in 1940 (Fig. 116); numbers small, but appears to be a shallow form (*cf.* Sars, 1925; Farran, 1936; Steuer, 1937). Good correlation of night surface abundance with moonlight (Fig. 117).

Mecynocera clausi Thompson. Det. G. P. Farran, M. Sears

Common throughout the year; no apparent seasonal maximum; more abundant in 1940 than in 1938–39. Mean day-level 65 metres; spread 50 metres (Fig. 118). Definite, but small diurnal migration with little or no night increment from deep water. Good correlation of day-level with cloud; no correlation of night surface abundance with moonlight. Horizontal distribution agreed well with that of rest of zooplankton on two cruises and poorly on a third (Figs. 119–121).



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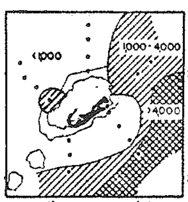

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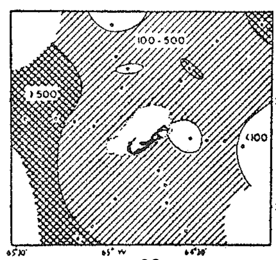

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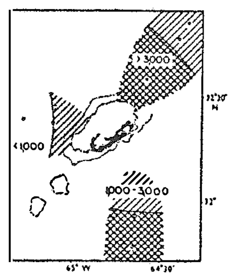


121

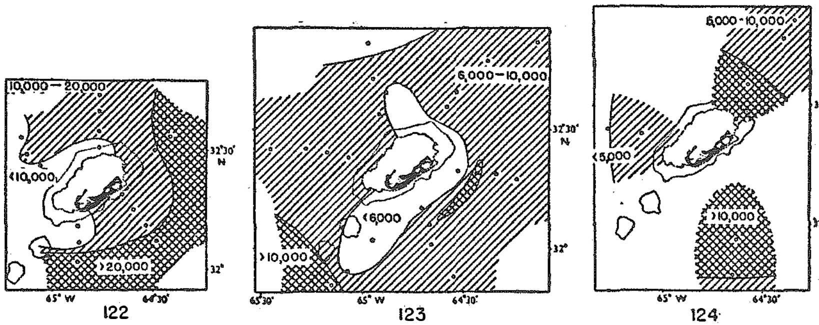
***Mecynocera clausi*. Figure 118. Vertical distribution.**
Figure 119. Horizontal distribution, December 1938.
Figure 120. Horizontal distribution, May 1939.
Figure 121. Horizontal distribution, July 1939.

Calocalanus pavo (Dana)

Single specimens occasionally; may be really more abundant owing to confusion with other forms; a shallow living form (Farran, 1936).

Clausocalanus arcuicornis (Dana). Det. G. P. Farran
C. furcatus (Brady). Det. G. P. Farran, M. Sears
C. ? *paululus* Farran. Det. G. P. Farran

These three species must be considered together owing to confusion of identification. Abundant throughout the year with no definite seasonal maximum. Mean day-level 85 metres; spread 105 metres. Generally described as shallow living (Sars, 1925; Rose, 1929; Farran, 1936). No correlation of day-level with cloud; only slight correlation of night surface abundance with moonlight. Horizontal distribution agreed well with that of rest of zooplankton (Figs. 122–124).



Clausocalanus spp. **Figure 122. Horizontal distribution, December 1938. Figure 123. Horizontal distribution, May 1939. Figure 124. Horizontal distribution, July 1939.**

Ctenocalanus vanus Giesbrecht. Det. G. P. Farran

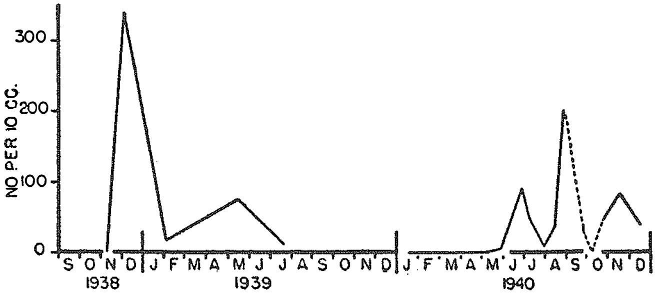
Present.

Aetidius armatus (Boeck). Det. G. P. Farran

Present in small numbers; seasonal maximum doubtful (Fig. 125). Mean day-level 145 metres, but one deep-haul series showed maximum at 400–500 metres, so may have been too deep to be representatively sampled (Fig. 126). Farran (1936) records it as an epiplanktonic species. Horizontal distribution agreed only moderately well with that of rest of zooplankton (Fig. 127).

Gaetanus miles Giesbrecht. Det. G. P. Farran

Small numbers below 300 metres in deep daytime hauls (Fig. 128) and at night at 150–250 metres. This suggests a diurnal migration. Farran (1936) records it as a deep water form.



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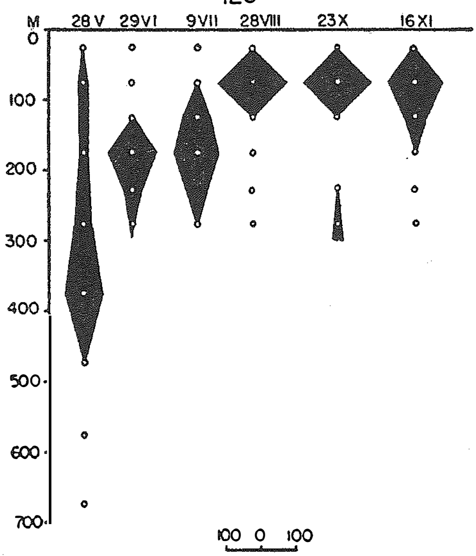

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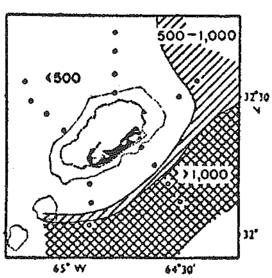

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Aetidius armatus. **Figure 125. Seasonal variation in numbers.**
Figure 126. Vertical distribution.
Figure 127. Horizontal distribution, December 1938.

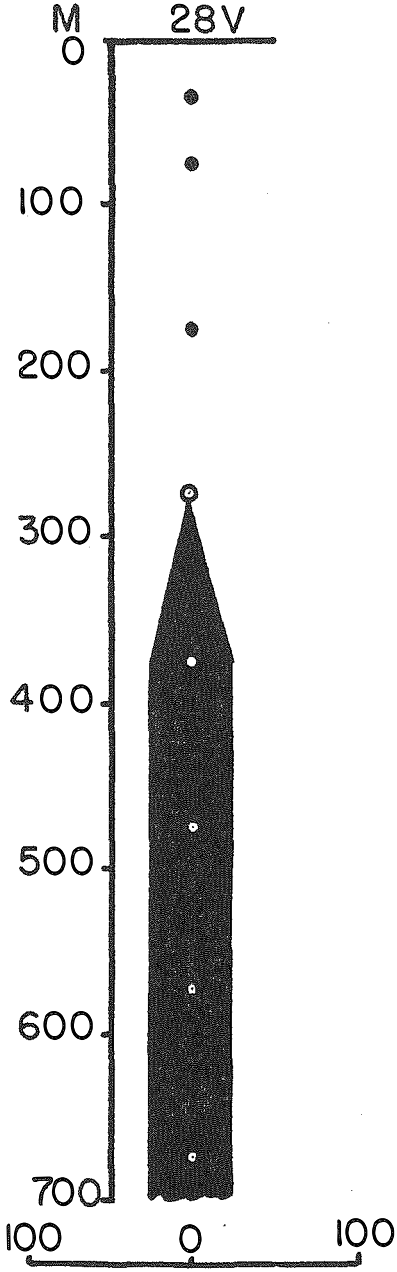


Figure 128. *Gaetanus miles.*
Vertical distribution.

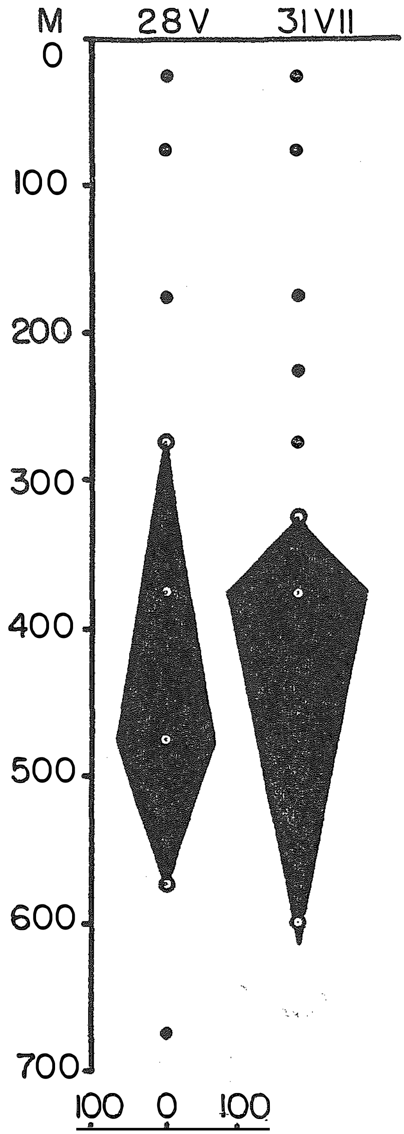


Figure 129. *Gaetanus minor.*
Vertical distribution.

Gaetanus minor Farran. Det. G. P. Farran

Rare; below 300 metres in daytime (Fig. 129) and below 200 metres at night; this suggests diurnal migration. Farran (1936) records it as a deep form.

Euchirella rostrata (Claus). Det. G. P. Farran

Present sporadically in small numbers. Rose (1929) describes it as a moderately deep form which reaches the surface at night, but we did not find it in any night surface hauls.

Euchirella messinensis (Claus). Det. G. P. Farran, M. Sears

Occasionally in small numbers below 300 metres. According to Rose (1929) it is a deep water form which may reach the surface at night.

Euchirella intermedia With. Det. G. P. Farran

Occasionally in small numbers.

Euchirella bitumida With

In small numbers in one night haul at 150–200 metres.

Undeuchaeta major Giesbrecht

Occasionally in small numbers.

Undeuchaeta minor Giesbrecht. Det. G. P. Farran, M. Sears

Present sporadically in small numbers in night surface hauls. Farran (1936) describes it as a deep form, but Rose (1929) states that it may be abundant at the surface at night.

Euchaeta spinosa Giesbrecht

One specimen.

Euchaeta media Giesbrecht. Det. G. P. Farran

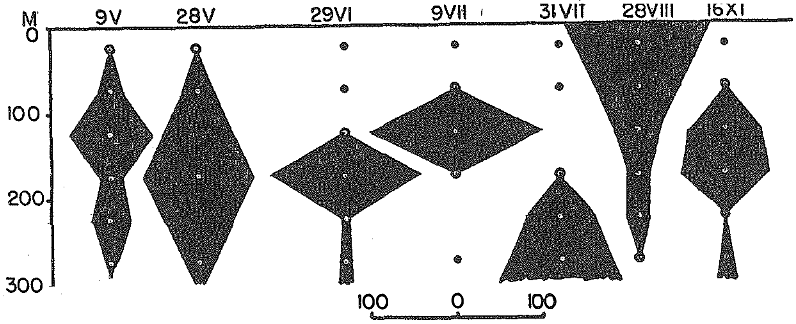
Sporadically in small numbers; no marked seasonal maximum. Mean day-level 155 metres; spread 80 metres (Fig. 130). Strong diurnal migration indicated, but numbers inadequate. Day-level not correlated with cloud; night surface abundance only slightly correlated with moonlight. Horizontal distribution agreed well and poorly with that of rest of zooplankton on two cruises (Figs. 131, 132).

Phaënna spinifera Claus. Det. G. P. Farran

Sporadically in small numbers throughout the year.

Scottocalanus persecans (Giesbrecht)

One specimen at 800 metres.



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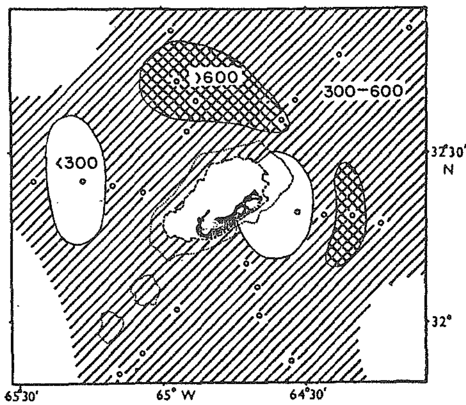
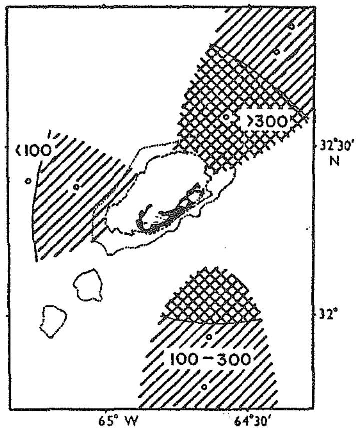




131 132

Euchaeta media. **Figure 130. Vertical distribution.**
Figure 131. Horizontal distribution, May 1939.
Figure 132. Horizontal distribution, July 1939.

Scolethrix danae (Lubbock). Det. G. P. Farran

Occasional; a shallow form according to most authors (Sars, 1925; Rose, 1929; Farran, 1936).

Scolethricella tenuiserrata (Giesbrecht). Det. G. P. Farran

Sporadically in small to moderate numbers; maximum usually about 125 metres; rarely above 50 metres in daytime; horizontal distribution agreed moderately well with that of rest of zooplankton on one cruise (Fig. 133).

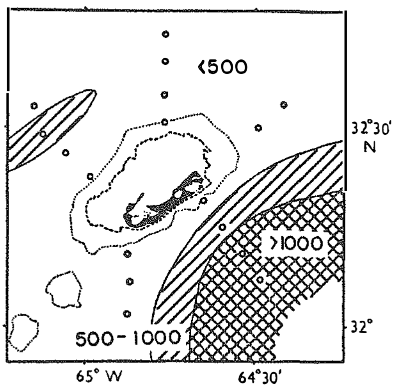


Figure 133. *Scolethricella tenuiserrata.* Horizonta distribution, December 1938.

Temora stylifera (Dana)

In small numbers on two occasions from 0–400 metres; according to Rose (1929) it is a surface and shallow form.

Metridia princeps Giesbrecht

In small numbers at 800 metres on one occasion.

Pleuromamma xiphias (Giesbrecht). Det. G. P. Farran

A deep form which, like other members of the genus, is known to have an extensive diurnal migration. Only occasionally above 300 metres in daytime (Fig. 134). Diurnal migration hauls showed rise from well below 250 to about 135 metres (Fig. 135). Taken only once at surface, and then at full noon. According to Rose (1929) it is abundant at surface at night.

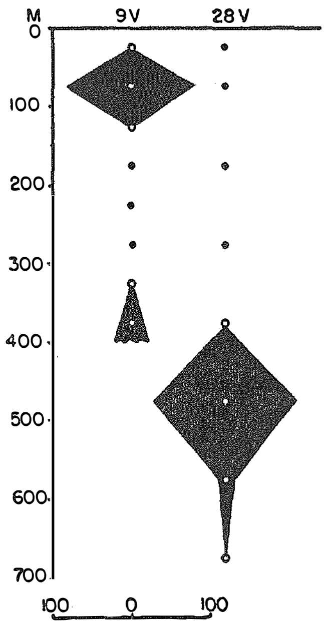
Pleuromamma abdominalis (Lubbock). Det. G. P. Farran

A slightly shallower form than *P. xiphias*, with day-level, judging from two series of hauls, at about 450 metres (Fig. 136). Diurnal migration very marked, with maximum at 100 metres, and considerable numbers reaching surface (Fig. 137). Taken at surface only at or near full moon.

Pleuromamma gracilis (Lubbock). Det. G. P. Farran

P. piseki Farran. Det. G. P. Farran

These two species have to be considered together owing to confusion of identification. In one sample sent to Dr. Farran, *P. piseki* was the more abundant of the two. Mean day-level at or below 300 metres, but occurring regularly above this level in the daytime (Fig. 138).



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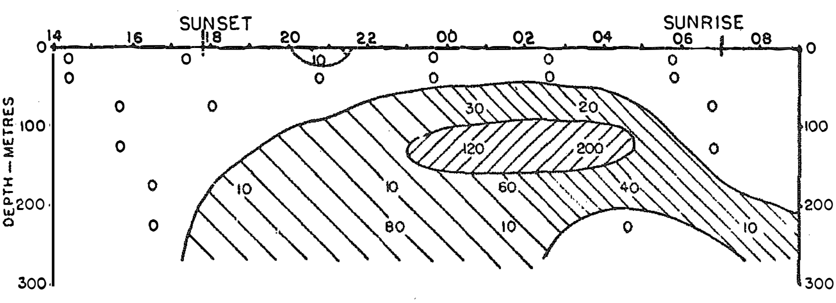

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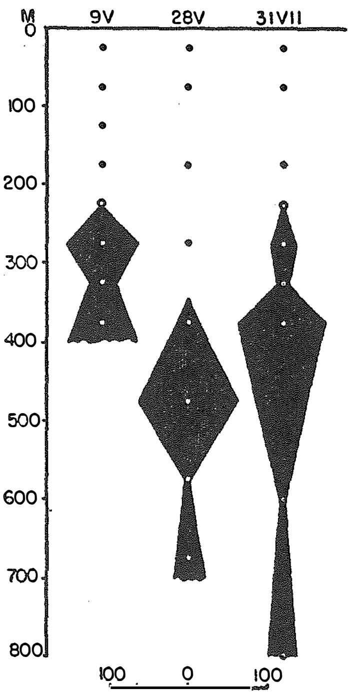
Pleuromamma xiphias. **Figure 134. Vertical distribution. Figure 135. Diurnal migration.**



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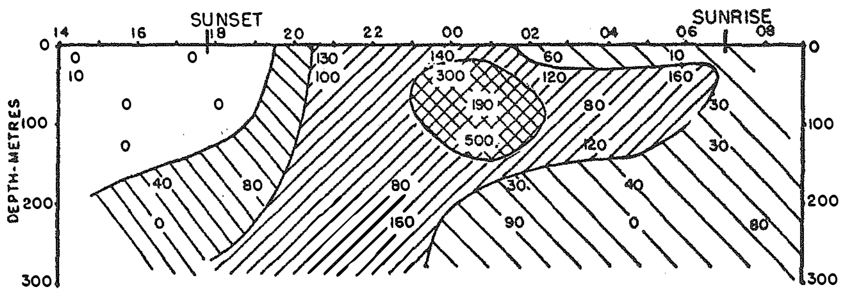

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Pleuromamma abdominalis. **Figure 136. Vertical distribution. Figure 137. Diurnal migration.**

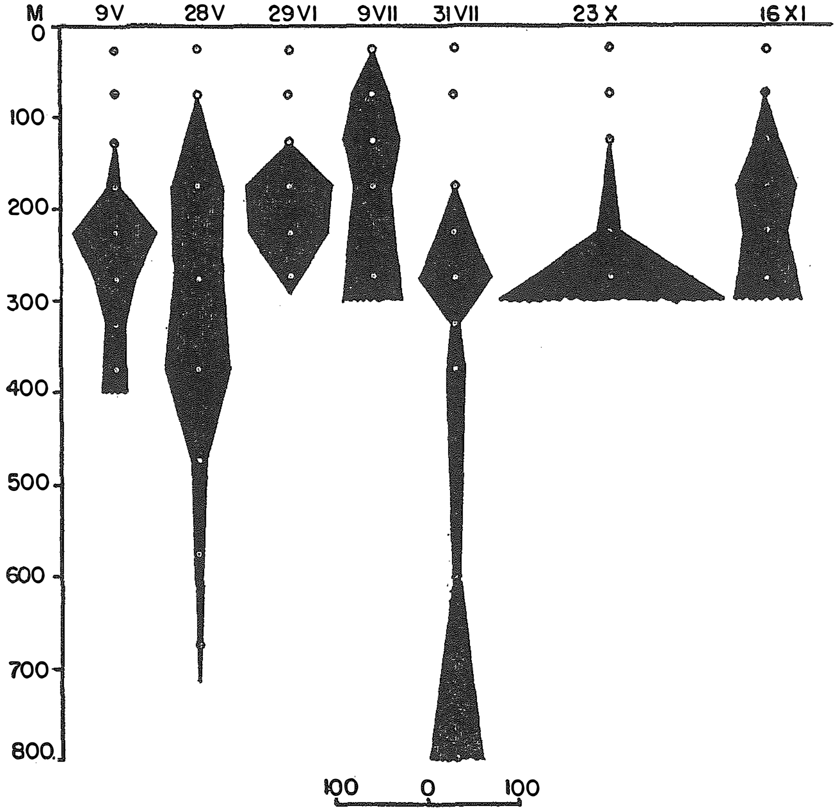
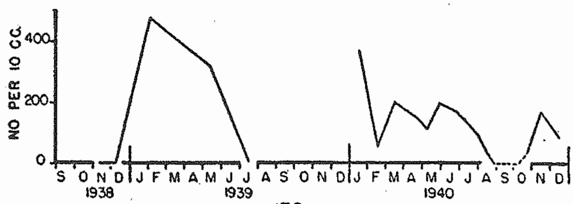


Figure 138. ***Pleuromamma gracilis* + *P. piseki*. Vertical distribution.**

Winter or spring maximum (Fig. 139). Decrease in summer not to be accounted for by shift to deeper levels during period of higher illumination, since no evidence of seasonal shift in level found. Diurnal migration marked with night maximum at 50–100 metres and considerable numbers at surface (Fig. 140); considerable migration from below 250 metres, the day : night ratio being 43. Good correlation of night surface abundance with moonlight (Fig. 141), and more surface records than in the two previous species. Good correlation of day-level with cloud. Horizontal distribution agreed only poorly with that of rest of zooplankton on two cruises (Figs. 142, 143).



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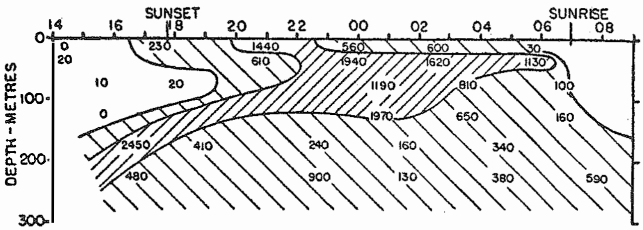

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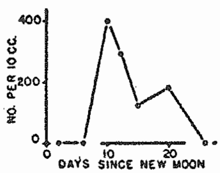

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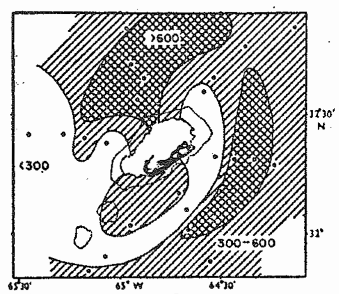

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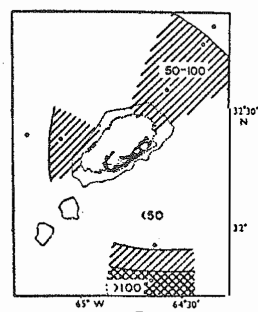

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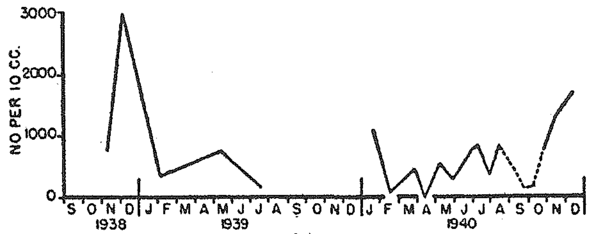
***Pleuromamma gracilis* + *P. piseki*. Figure 139. Seasonal variation in numbers.**
Figure 140. Diurnal migration.
Figure 141. Relation of night surface abundance to phase of moon.
Figure 142. Horizontal distribution, May 1939.
Figure 143. Horizontal distribution, July 1939.

Lucicutia flavicornis (Claus). Det. G. P. Farran

L. lucida Farran. Det. G. P. Farran

These two species must be considered together owing to confusion of identification. In considerable numbers throughout the year; winter maximum (Fig. 144); mean day-level 120 metres; spread 90



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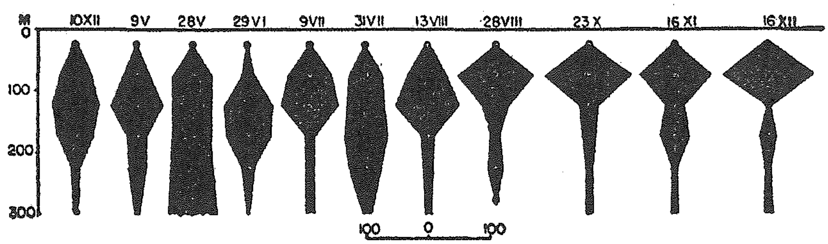

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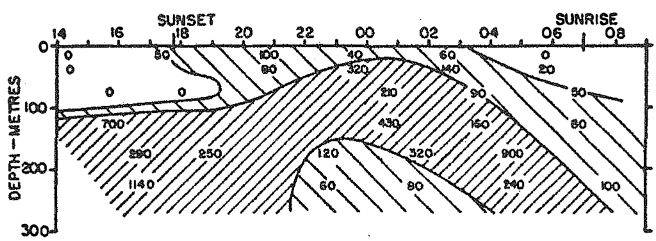

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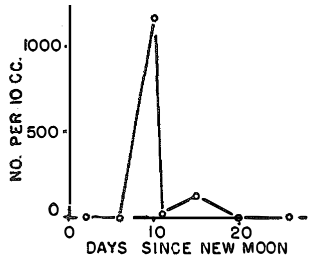
Lucicutia flavicornis **+ *L. lucida.*** **Figure 144. Seasonal variation in numbers.**
Figure 145. Vertical distribution.
Figure 146. Diurnal migration.

metres (Fig. 145). Marked diurnal migration (Fig. 146); day-night range 90 metres; day : night ratio 80. No correlation of day-level with cloud; moderate correlation of night surface abundance with moonlight (Fig. 147). Horizontal distribution agreed well with that of rest of zooplankton (Figs. 148–150).



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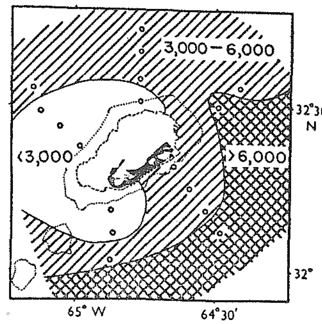

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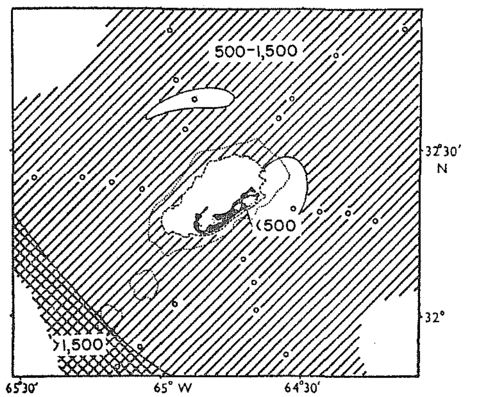

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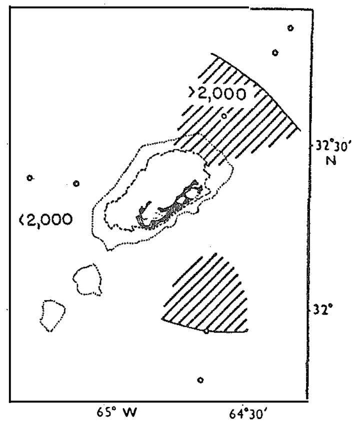

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***Lucicutia flavicornis* + *L. lucida*.** **Figure 147.** **Relation of night surface abundance to phase of moon.**

Figure 148. **Horizontal distribution, December 1938.**
Figure 149. **Horizontal distribution, May 1939.**
Figure 150. **Horizontal distribution, July 1939.**

Heterorhabdus spinifrons (Claus)

A few on one occasion at 50–100 metres. A deep form (Farran, 1936).

Heterorhabdus papilliger (Claus)

A few at 0–300 metres.

Mesorhabdus angustus Sars

One only.

Haloptilus longicornis (Claus). Det. G. P. Farran, M. Sears

Sporadic; mean day-level apparently 165 metres, but probably deeper (Fig. 151). Winter or spring maximum (Fig. 152). Diurnal migration indicated by day : night ratio of 43; day-level showed good negative correlation with cloud, *Haloptilus* being found nearer

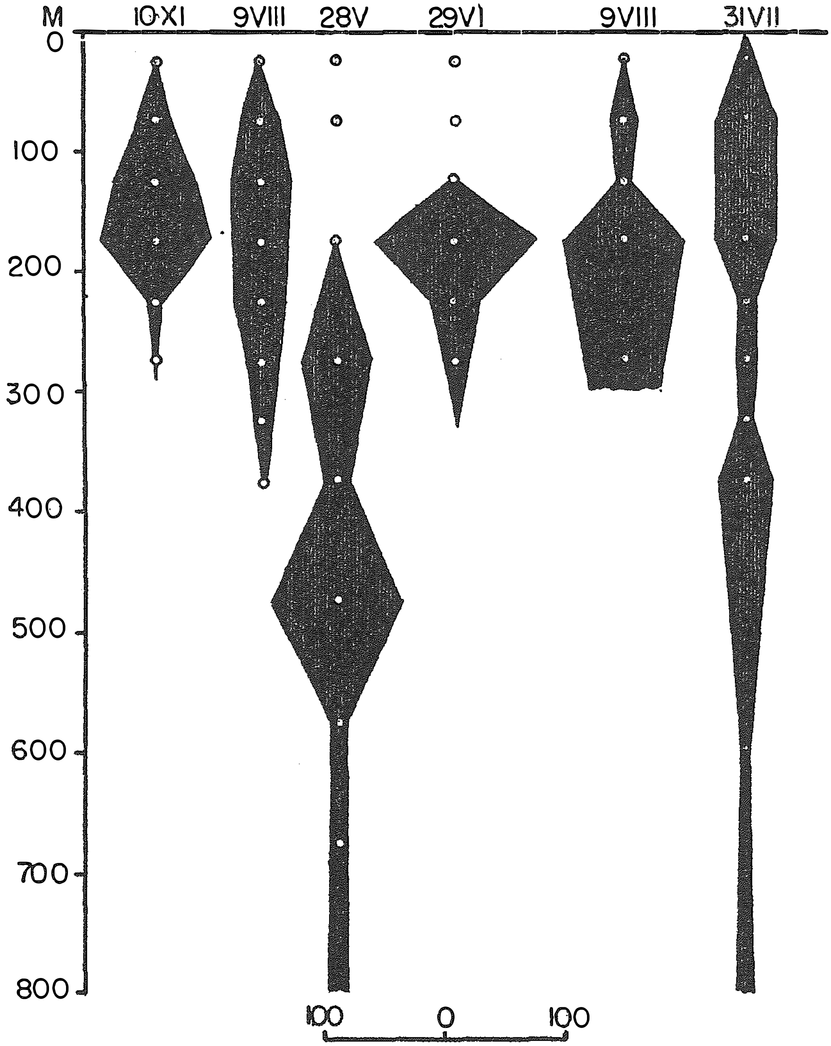
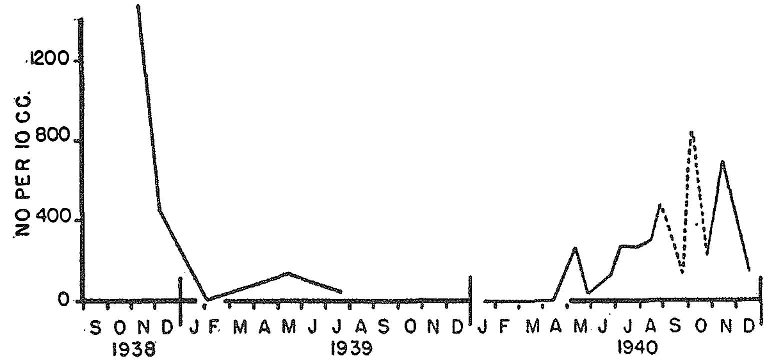


Figure 151. ***Haloptilus longicornis.*** **Vertical distribution.**



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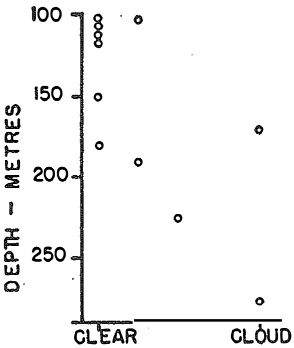

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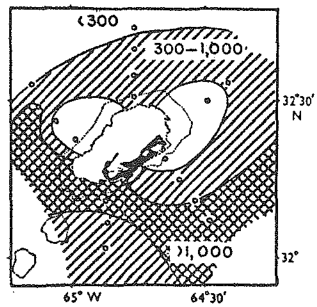

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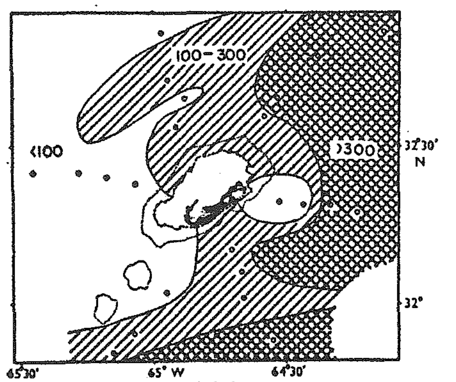

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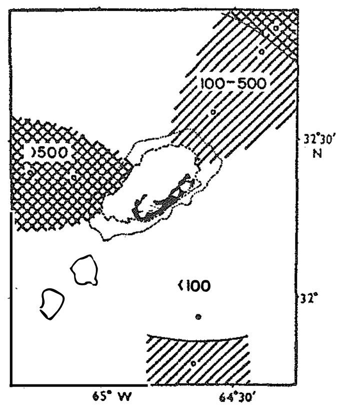

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Haloptilus longicornis. Figure 152. Seasonal variation in numbers.
Figure 153. Relation of mean day-level to cloudiness of sky.
Figure 154. Horizontal distribution, December 1938.
Figure 155. Horizontal distribution, May 1939.
Figure 156. Horizontal distribution, July 1939.

the surface on sunny days (Fig. 153). This is the only species in which such a reversed relationship was found. Little or no agreement of horizontal distribution with that of rest of zooplankton (Figs. 154–156).

Haloptilus spiniceps Giesbrecht
A few on one occasion at 0–50 metres.

Haloptilus oxycephalus Giesbrecht
Sporadically in small numbers at 100–300 metres.

Augaptilus spinifrons Sars
In small numbers on one occasion at 100–150 metres. A deep form (Farran, 1936).

Augaptilus ? *anceps* Farran
One at 100–150 metres.

Euaugaptilus hecticus (Giesbrecht). Det. G. P. Farran
Sporadically in small numbers.

Centraugaptilus sp.
One only.

Arietellus setosus Giesbrecht
Two at 100–250 metres. A deep form (Rose, 1929).

Phyllopus bidentatus Brady. Det. G. P. Farran
A few at night at 100–150 metres.

Candacia longimana (Claus). Det. G. P. Farran
A few at 200–250 metres at night. Epiplanktonic according to Farran (1936); deep according to Rose (1929).

Candacia aethiopica Dana. Det. M. Sears
Regularly in small numbers; autumn or winter maximum (Fig. 157). Mean day-level 105 metres. A shallow form (Farran, 1936), and occurring at the surface at night (Rose, 1929).

Candacia simplex (Giesbrecht)
Sporadically; mean day-level 85 metres; spread 120 metres. Epiplanktonic (Farran, 1936; Rose, 1929).

Candacia bispinosa (Claus). Det. G. P. Farran
Sporadically in small numbers. Epiplanktonic (Farran, 1936; Rose, 1929).

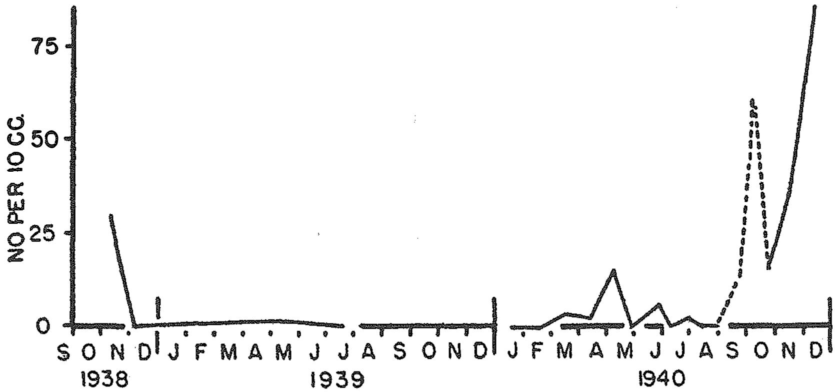


Figure 157. *Candacia aethiopica.* Seasonal variation in numbers.

Calanopia americana (Dahl). Det. M. Sears

The dominant copepod of the waters inside the reefs (Esterley, 1911; Clarke, 1934), but occurring only as an ocacasional straggler outside.

Pontella ? *atlantica* (Milne-Edwards)

In small numbers on one occasion in the top 50 metres.

Pontellopsis regalis Dana

One at 50–100 metres. A shallow form (Farran, 1936).

Pontellina plumosa Dana. Det. G. P. Farran

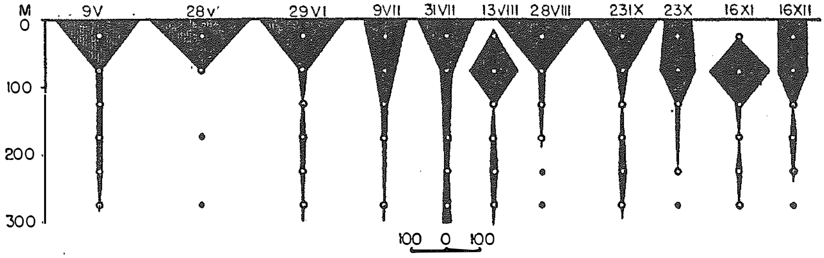
Single specimens throughout the year; 0–300 metres. Epiplanktonic (Farran, 1936).

Acartia negligens Dana. Det. G. P. Farran

The most specifically surface-living of the local copepods; mean day-level about 45 metres; spread 30 metres; frequently restricted to the top 50 metres (Fig. 158). Early autumn maximum (Fig. 159); good correlation of day-level with cloud, but over restricted range of depths. No diurnal migration of an order detectable by our hauls, and no night increment from deep water. No correlation of night surface abundance with moonlight. Horizontal distribution agreed moderately well with that of rest of zooplankton (Figs. 160–162).

Acartia spinata Esterley. Det. G. P. Farran, M. Sears

Present in moderate numbers on two occasions and may have been confused with *A. negligens* on others. Probably a straggler from inside



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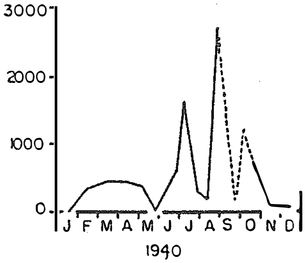

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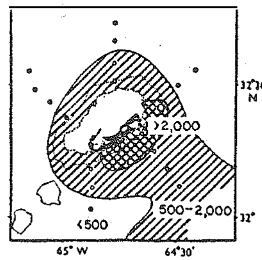

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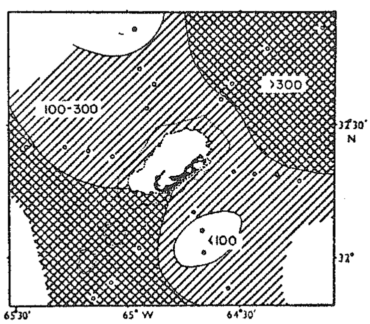

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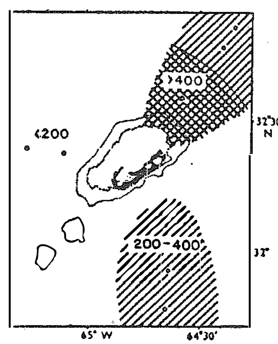

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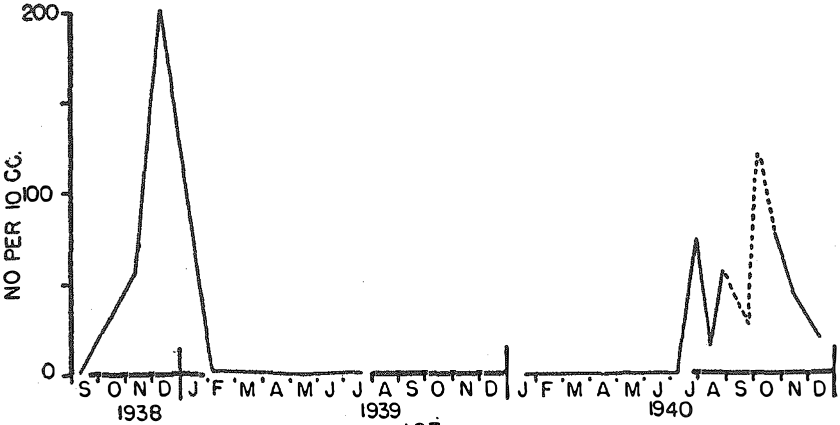
***Acartia negligens*. Figure 158. Vertical distribution.**
Figure 159. Seasonal variation in numbers.
Figure 160. Horizontal distribution, December 1938.
Figure 161. Horizontal distribution, May 1939.
Figure 162. Horizontal distribution, July 1939.

waters from which it was first described (Esterley, 1911; but see Clarke, 1934).

Macrosetella gracilis Dana. Det. G. P. Farran

In small numbers; autumn or winter maximum (Fig. 163); mean day-level 70 metres; spread 110 metres. Horizontal distribution agreed well with that of rest of zooplankton on one cruise (Fig. 164).



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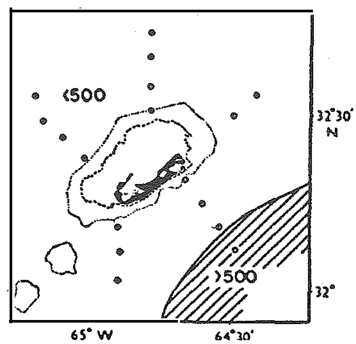


Macrosetella gracilis. **Figure 163. Seasonal variation in numbers. Figure 164. Horizontal distribution, December 1938.**

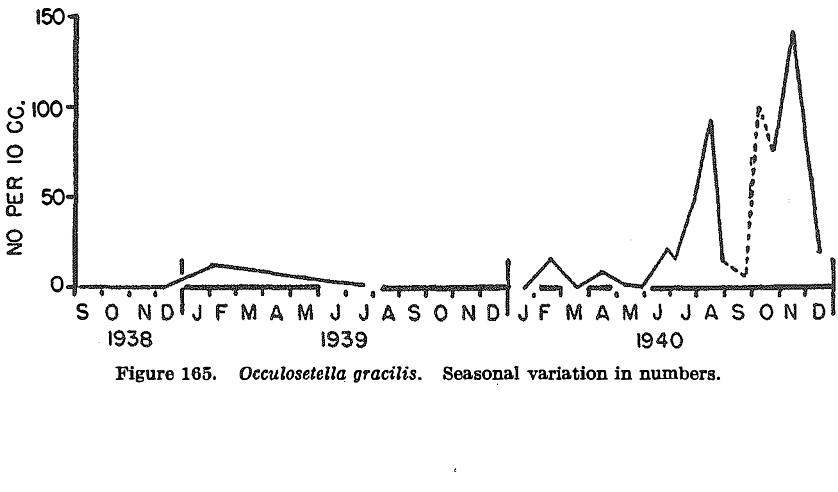


Figure 165. ***Occulosetella gracilis.*** **Seasonal variation in numbers.**

Occulosetella gracilis (Dana) [= *Setella occulata* G. O. Sars]. Det. G. P. Farran

Somewhat less common than the last species; autumn maximum (Fig. 165); mean day-level 100 metres; spread 110 metres.

Oithona spinifera Baird

Occasional single specimens; may have been confused sometimes with the abundant *O. setigera*.

Oithona robusta Giesbrecht. Det. G. P. Farran

A few on one occasion at 200–250 metres. Epiplanktonic (Farran, 1936).

Oithona setigera (Dana). Det. G. P. Farran[7]

One of the most abundant local copepods; no marked seasonal maximum, the apparent spring minimum being indicated only by night surface hauls. Mean day-level 95 meters; spread 130 metres (Fig. 166). Only slight diurnal migration. No correlation of day-level with cloud or of night surface abundance with moonlight. Horizontal distribution agreed only moderately well with that of rest of zooplankton (Figs. 167–169).

Lubbockia squillimana Claus

Sporadically in very small numbers.

Oncaea mediterranea Claus. Det. G. P. Farran

Corycaeus lautus Dana. Det. G. P. Farran

Corycella speciosus Dana. Det. G. P. Farran

Corycella rostrata (Claus). Det. G. P. Farran

Corycella concinna Dana. Det. G. P. Farran

The above were recorded as present, but owing to difficulties in identification, were not counted.

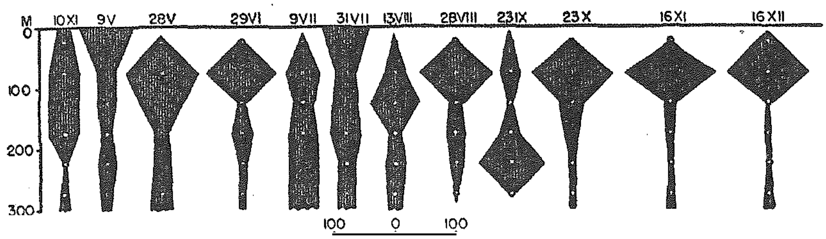
Sapphirina metallina Dana. Det. G. P. Farran

Sporadically in small numbers; mean day-level about 80 metres; spread 35 metres. Horizontal distribution agreed moderately well with that of rest of zooplankton on one cruise (Fig. 170).

Copilia mediterranea (Claus). Det. G. P. Farran

Present throughout the year in very small numbers.

[7] Farran (personal communication) makes the following notation on a sample: "smaller than the normal *O. setigera.* Two slender specimens seem to agree with Rosendorn's *forma linearis.*"



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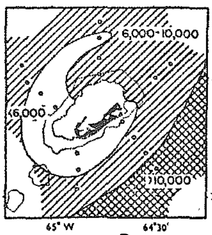

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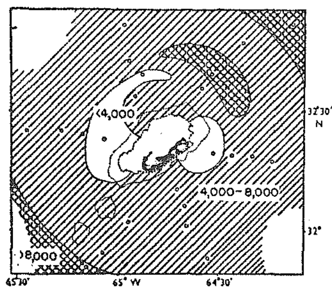

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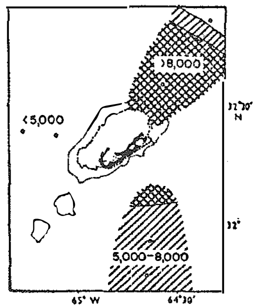

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Oithona setigera. Figure 166. Vertical distribution.
Figure 167. Horizontal distribution, December 1938.
Figure 168. Horizontal distribution, May 1939.
Figure 169. Horizontal distribution, July 1939.

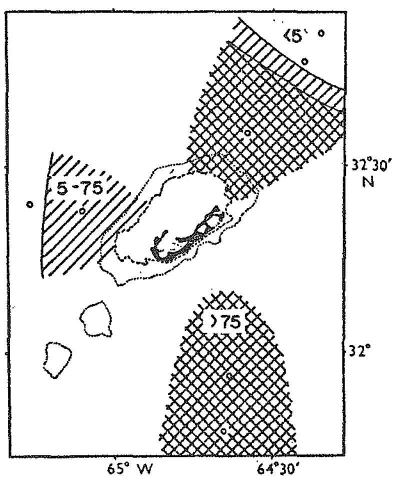


Figure 170. *Sapphirina metallina*. **Horizontal distribution, July 1939**

Euphausiacea

Thysanopoda aequalis Hansen

Sporadically in very small numbers, and mostly below 300 metres in the daytime. Tattersall (1926) gives its maximum at 100–200 metres; Ruud (1936) at 0–200 metres; Leavitt (1938) at 800 metres. Diurnal migration marked, with night maximum at about 50 metres (Fig. 171).

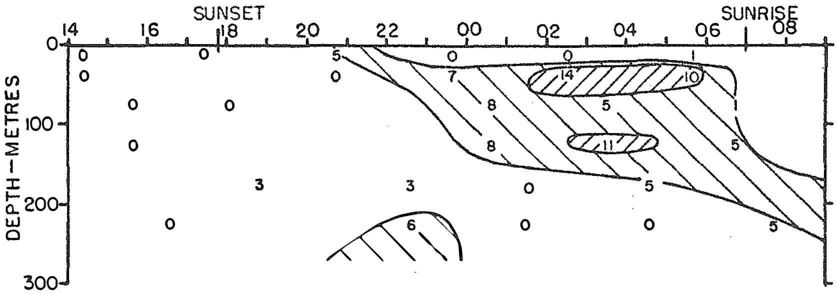


Figure 171. ***Thysanopoda aequalis.*** **Diurnal migration.**

Thysanopoda obtusifrons Sars

Taken on two occasions in very small numbers below 300 metres. Ruud (1936) gives maximum at 0–200 metres. Diurnal migration marked, but night maximum probably still below 300 metres.

Thysanopoda pectinata Ortmann

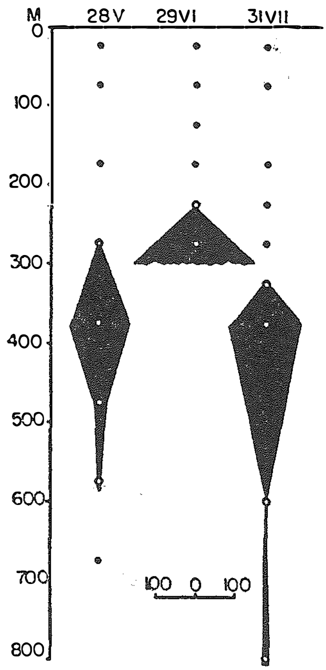
One at 350–400 metres. Ruud (1936) gives maximum at 0–200 metres and Leavitt (1938) at about 800 metres.

Euphausia americana Hansen

In small numbers, mostly below 300 metres. Tattersall (1926) gives maximum at 0–100 metres, and Leavitt (1938) at 800.

Euphausia brevis Hansen

The commonest local euphausid; rarely taken above 300 metres; maximum probably about 400 metres (Fig. 172). Tattersall (1926) gives maximum at 0–100 metres, Ruud (1936) at 0–200, and Leavitt (1938) at 200 metres or above. Marked diurnal migration up to a level of about 50 metres, most of the deep population apparently moving up into the top 250 metres (Fig. 173).



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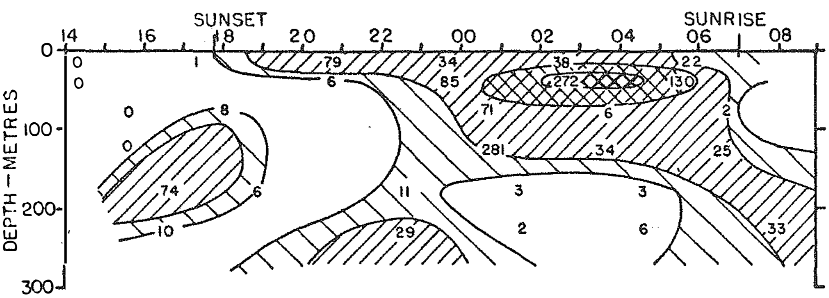


173

Euphausia brevis. **Figure 172. Vertical distribution.**
Figure 173. Diurnal migration.

Euphausia tenera Hansen

Sporadically, mostly below 300 metres. Tattersall (1926) gives maximum at 0–100 metres, and Leavitt (1938) 400–800. Diurnal migration to night-level of about 50 metres (Fig. 174), but numbers small.

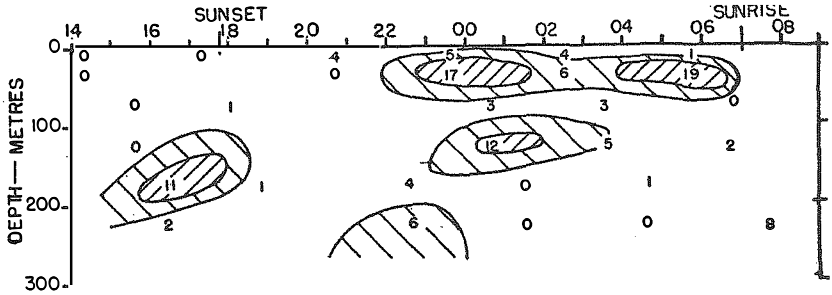
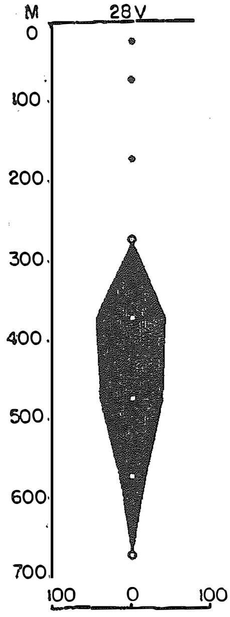


Figure 174. *Euphausia tenera.* **Diurnal migration.**



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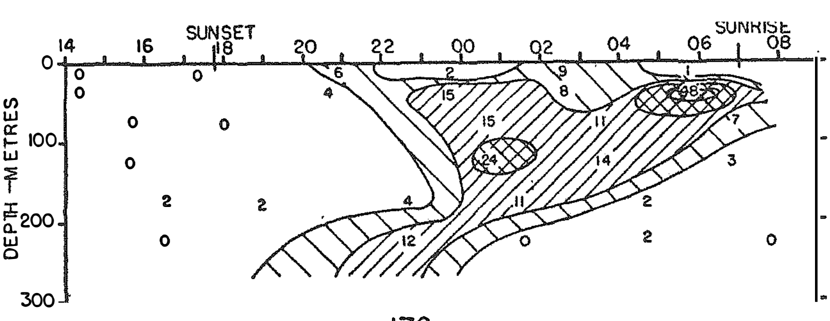

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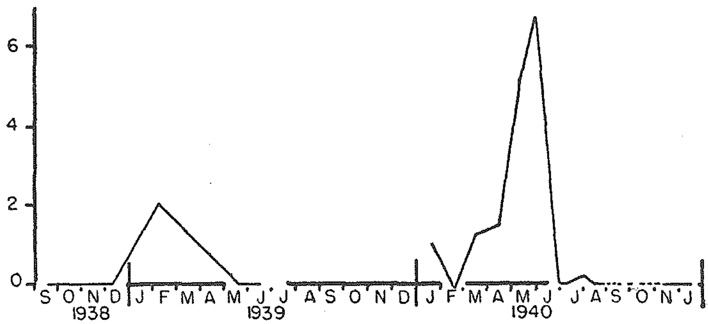
Euphausia hemigibba. **Figure 175. Vertical distribution.**
Figure 176. Diurnal migration.

Euphausia hemigibba Hansen

Maximum on one occasion below 400 metres (Fig. 175); Tattersall (1926) gives 0–100 metres, Ruud (1936) 0–200, and Leavitt (1938) 400. Shows diurnal migration to night level of about 50 metres (Fig. 176).

Thysanoessa gregaria Sars

Regularly in small numbers in upper 300 metres, but maximum deeper. Ruud (1936) gives 300 metres, Tattersall (1926) 200, and Leavitt (1938) 200 or less. Apparently a spring form (Fig. 177). Definite diurnal migration to night-level about 200 metres (Fig. 178), but few reach surface.



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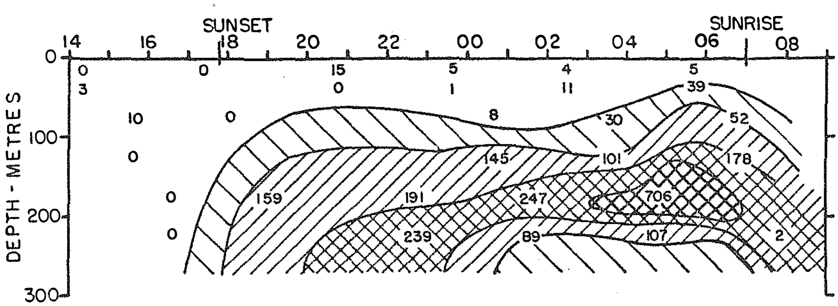

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Thysanoessa gregaria. Figure 177. Seasonal variation in numbers. Figure 178. Diurnal migration.

Nematoscelis microps Sars

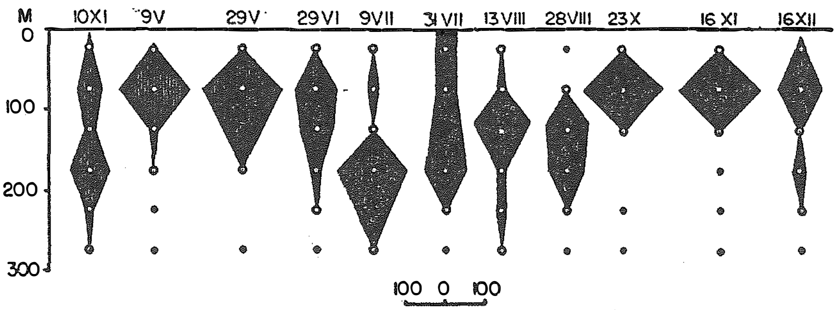
Occasionally in small numbers; maximum probably below 300 metres; Tattersall (1926) gives it at 100–200 metres, Ruud (1936) at 0–200, and Leavitt (1938) at 400–1,200.

Nematobrachion flexipes Ortmann

Occasionally in small numbers; Tattersall (1926) gives maximum at 100–200 metres, Ruud (1936) at 0–200, and Leavitt (1938) at 400–600.

Stylocheiron carinatum Sars

A shallower form; mean day-level 95 metres; spread 80 metres (Fig. 179). Most authors describe it as deeper than this. Tattersall (1926) gives maximum at 100–200 metres, Ruud (1936) at 0–200, and Leavitt (1938) at 400. Good correlation of day-level with cloud (Fig. 180). A possible winter maximum. Numbers inadequate to define diurnal migration.



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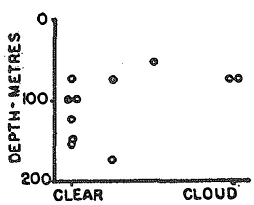

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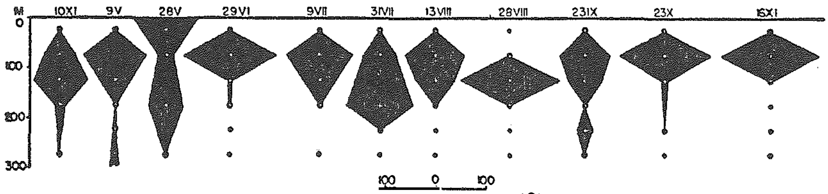
Stylocheiron carinatum. Figure 179. Vertical distribution. Figure 180. Relation of mean day-level to cloudiness of sky.

Stylocheiron suhmi Sars

A shallow form; mean day-level 95 metres; spread 45 metres (Fig. 181). Ruud (1936) gives maximum at 0–200 metres, and Tattersall (1926) at 100–200. Possible autumn maximum. Good correlation of day-level with cloud (Fig. 182).

Stylocheiron longicorne Sars

Mean day-level 195 metres; spread 55 metres (Fig. 183). Tattersall (1926) gives maximum as below 200 metres, Ruud (1936) as 0–200, and Leavitt (1938) as 200 or less. Possible summer maximum. Slight diurnal migration. No correlation of day-level with cloud.



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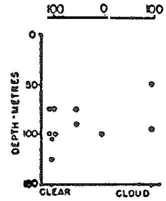

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Stylocheiron suhmi. Figure 181. Vertical distribution.
Figure 182. Relation of mean day-level to cloudiness of sky.

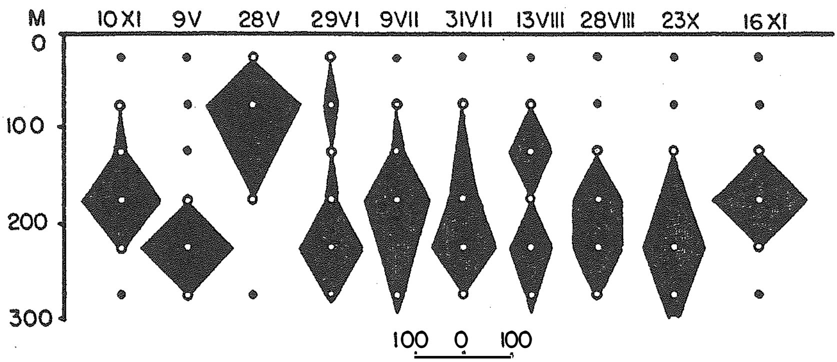


Figure 183. *Stylocheiron longicorne.* Vertical distribution.

Stylocheiron elongatum Sars

Comparatively scarce; mostly at 250–300 metres or below. Tattersall (1926) gives maximum below 200 metres, and Ruud (1936) below 300.

Stylocheiron ? maximum Hansen

A few specimens only. Tattersall (1926) gives maximum at below 200 metres, and Ruud (1936) below 300.

Stylocheiron abbreviatum Sars

In small numbers; autumn maximum; mean day-level 105 metres; spread 70 metres. Tattersall (1926) gives maximum below 200 metres, and Ruud (1936) below 300. No correlation of day-level with cloud. Indications of marked diurnal migration, but numbers inadequate.

CEPHALOCHORDA

Amphioxides pelagicus Gill[8]

Present throughout the year, with marked autumn or winter maximum (Fig. 184). Mean day-level 80 metres, spread 40 metres (Fig. 185); good correlation of day-level with cloud (Fig. 186). Definite diurnal migration with no night increment from deep water, but numbers small (Fig. 187). Good correlation of night surface abundance with moonlight (Fig. 188). Horizontal distribution variable in its agreement with that of rest of zooplankton on different cruises (Figs. 189–191).

TUNICATA

Pegea confederata (Forskål)

Occasional specimens of aggregate generation throughout the year; solitary generation not found.

Thalia democratica (Forskål)

The most abundant salp in the Bermuda area. Present throughout the year, but with a marked winter maximum (Fig. 192). There is a very marked cyclic variation in the proportion of the two generations, with three complete cycles during the year (Fig. 193).

Thetys vagina (Tileus) [= *Salpa tilesii* Cuvier]

Four specimens of the aggregate generation in a deep haul.

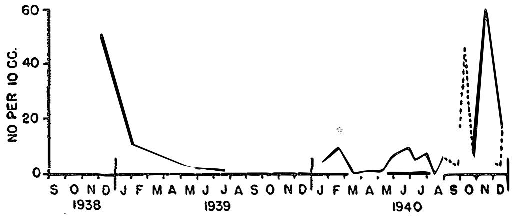
Salpa fusiformis Cuvier

In small numbers in winter and spring, and one very dense swarm in May. Two generations present in about equal porportions.

Salpa cylindrica Cuvier

A few specimens of the aggregate generation.

[8] Identification based on that of Goldschmidt (1933) for Bermuda material. He states that *A. pelagicus* is a larval form, but probably not that of either of the known local species, *Assymetron lucayanum* or *Branchiostoma bermudae.* It is probably the larva of a species which either is abyssmal or inhabits the slopes outside the reefs.



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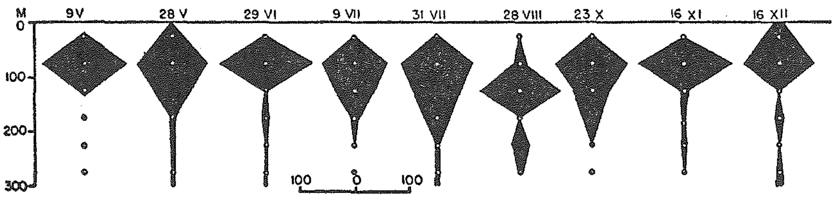

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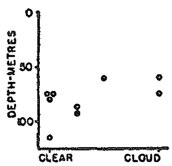

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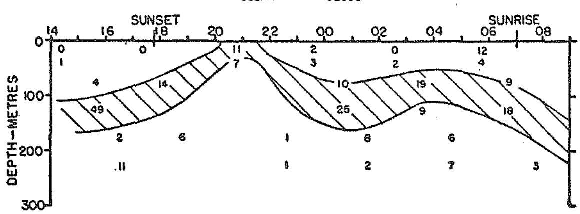

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Amphioxides pelagicus. **Figure 184. Seasonal variation in numbers.**
Figure 185. Vertical distribution.
Figure 186. Relation of mean day-level to cloudiness of sky.
Figure 187. Diurnal migration.

Salpa ? punctata Forskål

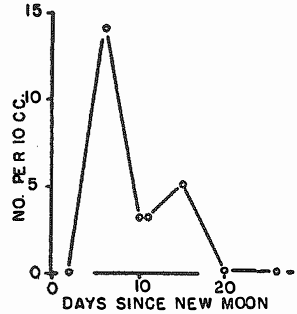
A few damaged specimens, of the aggregate generation, apparently of this species.

Iasis zonaria (Pallas)

A few specimens of the aggregate generation.

Traustedtia multitentaculata (Quoy and Gaimard)

A few specimens of the aggregate generation.



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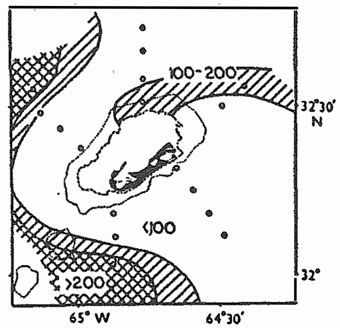

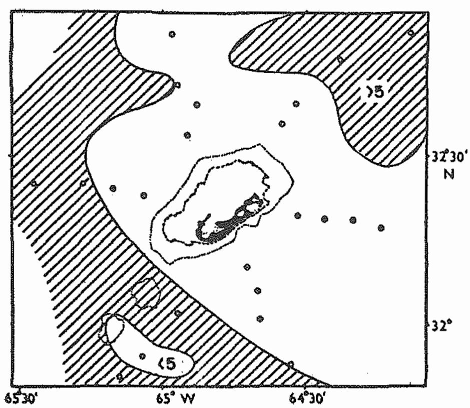

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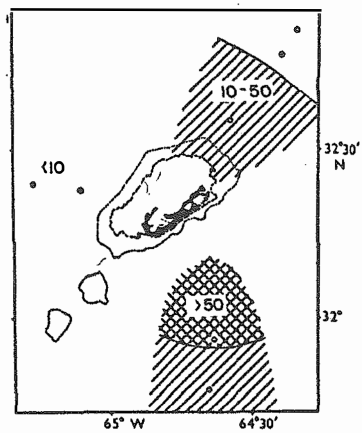

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Amphioxides pelagicus. **Figure 188. Relation of night surface abundance to phase of moon.**

Figure 189. Horizontal distribution, December 1938.
Figure 190. Horizontal distribution, May 1939.
Figure 191. Horizontal distribution, July 1939.

Pyrosoma sp.

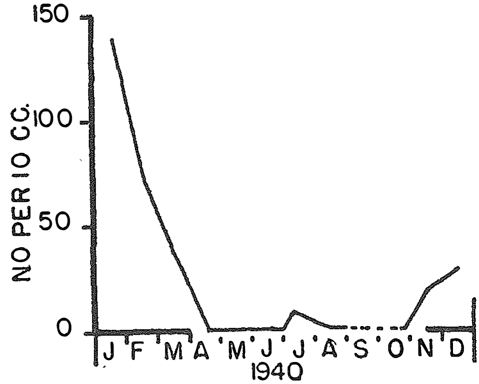
A few early colonies, but no large ones.

Doliolum sp.

Often abundant, but no identification made.

Appendicularia

Often common, but no identification made.



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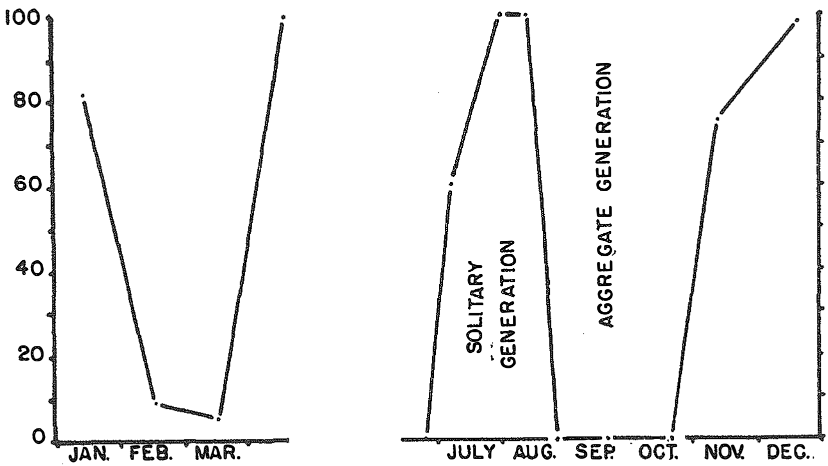

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Thalia democratica. **Figure 192. Seasonal variation in numbers.**
Figure 193. Seasonal variation in percentage ratio of the two generations.

DISCUSSION OF RESULTS

Seasonal Changes in Horizontal Distribution of the Zooplankton

The cruise in September 1938 was largely invalidated, so far as deductions as to horizontal distribution are concerned, since the hauls were not made at a consistent depth. Allowing for this, however, it is at least permissible to infer that there was an area of richer zooplankton somewhere to the east of the islands and a poor area to the west.

In the December cruise, the same condition was clearly shown (Fig. 194), the volumes of the catches from the rich area being about

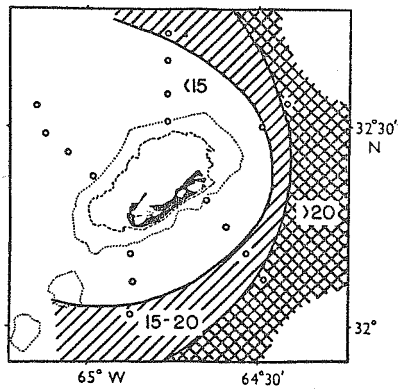


Figure 194. Horizonal distribution of the total zooplankton of the 100–150 metre level in December 1938. (Volumes in cc.)

three times those from the poor. Considered in detail, we find that the species present fell into two main groups. Of those species which were present in adequate numbers, all the copepods, two chaetognaths and one medusa had their richest area to the southeast, while two other chaetognaths and all but one of the siphonophores had their rich area to the northeast. Typical examples of these distributions are shown in Figs. 148 and 27. A small number of species showed a distribution which did not agree with that of the zooplankton as a whole.

On the cruise in May 1939, conditions were reversed, and the rich area now lay in a long loop centering to the northwest, with the poor area to the southeast (Fig. 195). Again the plankton of the rich area was about three times as abundant as that of the poor. In this cruise, stations were worked far enough out to get beyond the limits of the rich area at most points.

The cruise in July 1939 was unfortunately cut short by engine trouble, but sufficient stations were worked to show a return to conditions resembling those found the previous autumn, with a rich area somewhere to the east, and a poor one to the west of the islands (Fig. 196).

The question arises whether these rich and poor areas represent genuine changes in the total plankton content of the whole 0–300 metre layer, or whether they could be accounted for by local changes in the maximum level which resulted in less or more adequate sampling

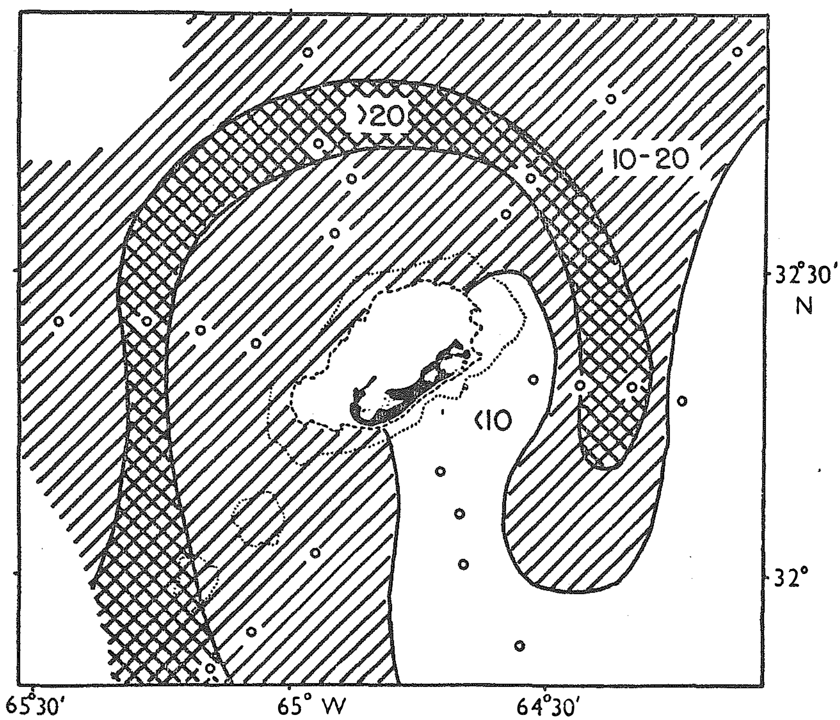


Figure 195. Horizontal distribution of the total zooplankton of 100–150 metre level in May 1939. (Volumes in cc.)

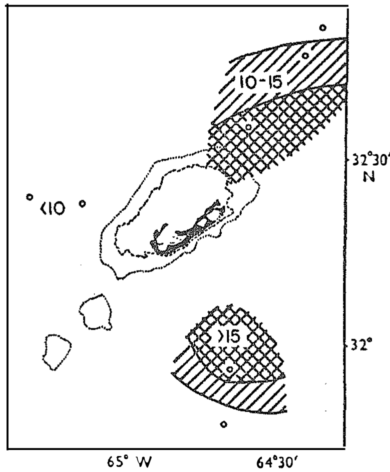


Figure 196. Horizontal distribution of the total zooplankton of the 100-150 metre level in July 1939. (Volumes in cc.)

by the hauls taken in the 100–150 metre layer. That the latter is unlikely is shown by the seasonal changes at a single station in the May–December 1949 series. At this station there was an equally marked seasonal cycle in the total volume of plankton in the top 300 metres, but there was no evidence of a seasonal change in maximum level. That the rich and poor areas were not the results of temporary shifts of level due to variation of illumination during the cruise is shown by the fact that no correlation was found between plankton abundance and either cloudiness of sky or time of day. The stations were worked in full daylight, and always at least two hours after sunrise or two hours before sunset. No appreciable seasonal change was found in the average amount of plankton for the area as a whole, the mean values per haul for the December, May and July cruises being 13.2, 14.6 and 13.9 cc. respectively.

The detailed comparison of the interrelations of the zoo- and phytoplankton must await Dr. Wheeler's account of the latter. However, since Hardy's exclusion mechanism seems unlikely to be operative in such relatively sparse plankton as this, we may look for some physical factor which could directly control the distribution of the zooplankton. An obvious suggestion is the possibility of an area of upwelling. If this were strong it would bring to the surface nutrient-enriched water which would produce a rich phytoplankton crop, and this in turn an enriched crop of zooplankton. Unfortunately our knowledge of the currents round Bermuda is still small, but it is unlikely that an upwelling, as marked as this would have to be, could have escaped detection. On the other hand one might suggest an upwelling on a very much smaller scale on one side of Bermuda, with a corresponding convergence on the opposite side. If these affected only the water of the top one or two hundred metres but did not extend as deep as the permanent thermocline, then the apparent physical effects would be much less while the inequalities in the plankton could be accounted for. Such an effect would tend to carry the shallow-living zooplankton away from the area of upwelling and to concentrate it somewhat in the area of convergence, and since the rate of vertical movement would be relatively small, the plankton would readily maintain their normal level. Should such a mechanism exist, it would follow that the shallower living species would be those most affected, while the deeper living forms would, if anything, tend to be concentrated in the areas of upwelling and so show a horizontal distribution the reverse of that of the shallower ones. Fig. 197 shows that just such an effect was in fact observed; those species whose horizontal distribution failed to agree with that of the main bulk of the zooplankton and those which showed a reversed distribution pattern were successively deeper-living forms.

Although the possibility of such areas of up- and down-welling is put forward as only a tentative hypothesis, with slight support from hydrographic observations,[9] it is in conformity with certain known facts. The Bermuda group consists of a chain of peaks running roughly southwest and northeast and rising abruptly from deep water (Fig. 198). Only a small portion of the chain is above water, the two peaks to the southwest reaching only to about 30 fathoms below the surface, and the peak to the northeast lying at about 745 fathoms below. Iselin (1936) shows an eddy on the northern edge of the Gulf Stream turning south towards Bermuda. Thompson (unpublished data) has found evidence of a seasonal change in the North Atlantic eddy system such that its northern edge moves northwards from about the beginning of May to the end of October, and southwards from about the beginning of November to the end of

[9] Some of Dr. E. F. Thompson's surface temperature observations appear to lend support to the hypothesis (personal communication).

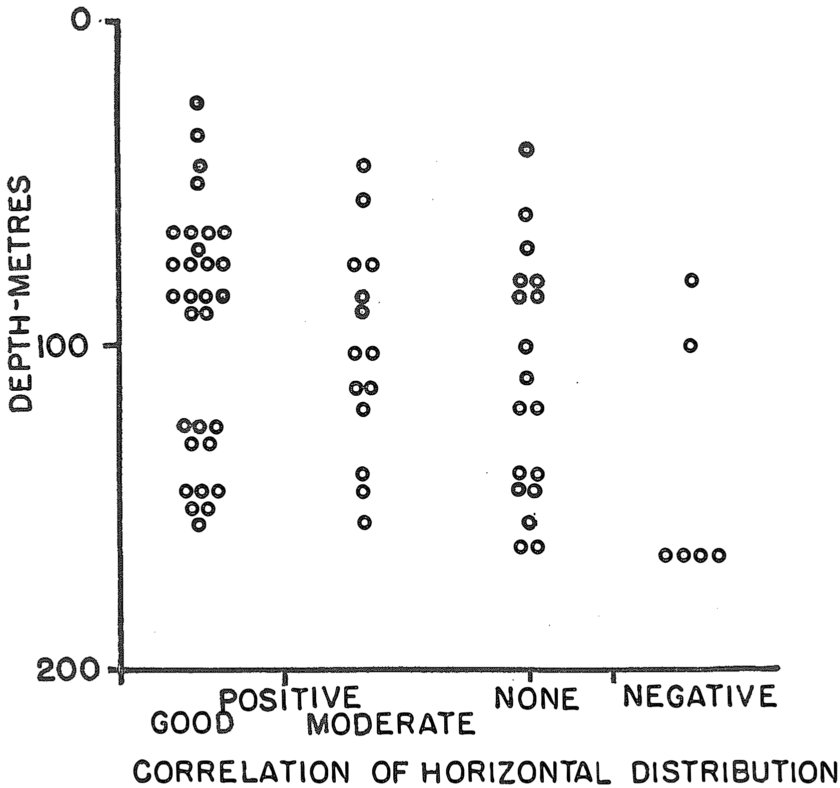


Figure 197. Scatter diagram showing, for all species present in sufficient numbers, the relation between their mean day-level and the degree to which their horizontal distribution agreed with that of the zooplankton as a whole.

April. This effect is reflected in changes in mean sea level at Bermuda. Local wind conditions, which might also influence currents, are summarized in Fig. 199. The residual wind, calculated over a five year period, changes from a strong westerly and southwesterly component in the winter through moderate south winds in summer to autumn winds whose direction is too variable to leave an appreciable residual mileage. If the currents affecting the shallow plankton tended to be from the northeast in summer, then we might expect the land mass to produce an area of upwelling somewhere to the west of the islands where the poor plankton area is found. Similarly a winter current from the southwest would give an upwelling somewhere to the east where the poor area occurs.

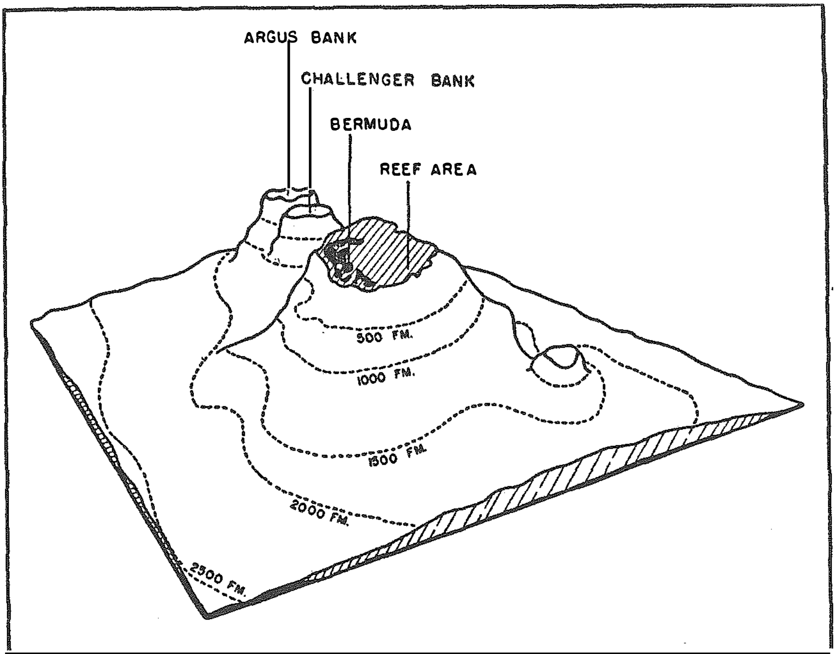


Figure 198. Perspective view of the Bermudas and the neighbouring sea bottom, seen from the northeast. The vertical scale is five times the horizontal scale, and the side in the right foreground is sixty-eight miles long.

An alternative to the theory of an area of convergence is suggested by the distribution shown in Fig. 195. If there were a rich area lying further from the shore than was reached by our sections, a pocket might be detached from there and trapped on one side of the islands. The May samples would suggest a stage where the rich area close to Bermuda was still connected with the rich offshore area. Varying current systems would produce shifts in the position of this pocket relative to the islands. However, the source of the hypothetical offshore rich area would still require explanation.

Returning to the plankton distributions found on the various cruises, that in September 1938 showed the summer condition well established with the rich area to the east. About the beginning of November we postulate a change in the direction of the current. The cruise early in December showed the rich area still to the east but with some species beginning to shift. Presumably a winter condi-

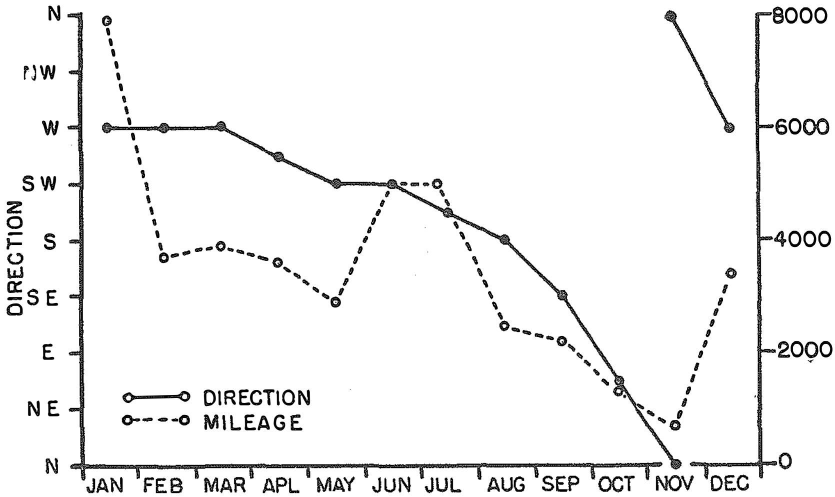


Figure 199. Direction and mileage of the residual winds for each month. Means for the years 1935, 1936, 1938, 1939, 1940.

tion became established with the rich area to the west. At the beginning of May we postulate a change of the current system back to the summer condition, and the cruise made only a few weeks later showed the plankton beginning to move back round the islands. Finally in the July cruise we find the plankton back in the summer condition with the rich area to the east.

That there are changes in the zooplankton in the autumn and spring is indicated by the individual species present and also by the results from the May–December 1940 series.

Fig. 200 gives the seasonal change in the quantity of zooplankton and in the total number of species taken in the top 300 metres from May to December; it also shows the autumn change clearly. Unfortunately the results from the cruises and other collections are not comparable with this series, so there is no opportunity of demonstrating the spring change. A striking point in Fig. 200 is the close correspondence between the fluctuations in number of species and size of catch. This suggests that the numbers of species recorded might be simply dependent on the amount of material examined. The exactness of the correspondence in even the minor fluctuations makes this possibility unlikely, and it is negated also by the results of individual

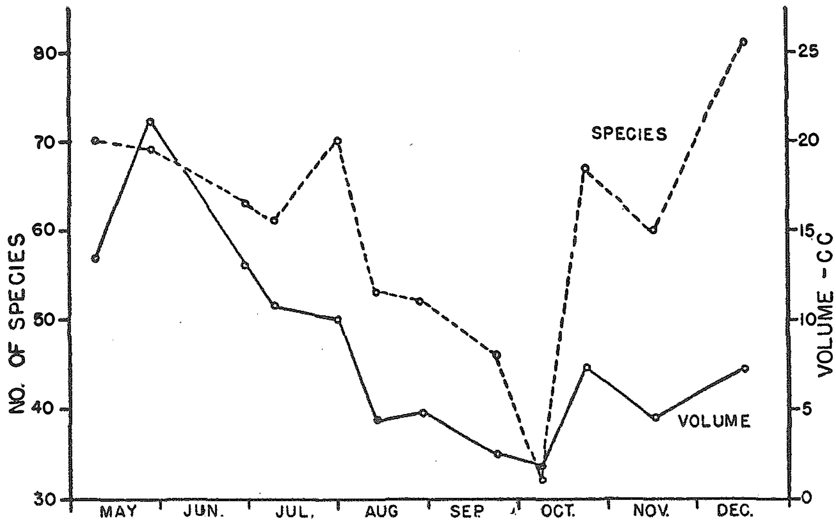


Figure 200. Seasonal variation in the number of species and the total volume (cc.) of the zooplankton at six levels between 0 and 300 metres at a single station.

cruises where, with no time factor entering, no correlation is found between number of species and size of catch. It is more likely that these minor fluctuations both in size of catch and in number of species represent short period variations in the local current system. Support for this is found in the fact that there is a considerable measure of correspondence between these small fluctuations and the variations in the wind from its normal direction for the times in question. The implication in these seasonal changes in fauna will be discussed more fully in a later paper.

Vertical Distribution and Vertical Migration

The data quoted for the mean day-levels of the various species have been obtained from a number of vertical distribution hauls taken at all seasons of the year. Since none of them showed any tendency for the maximum level to vary seasonally, it was possible to compare those taken under varying degrees of cloudiness and so obtain an indication of the specific response to changes in illumination. In the same way (Fig. 200A), by using the volumes of the catches, it is possible to show the influence of illumination on the plankton as a whole. Figs. 201–203 show the variations in level of the 25, 50 and

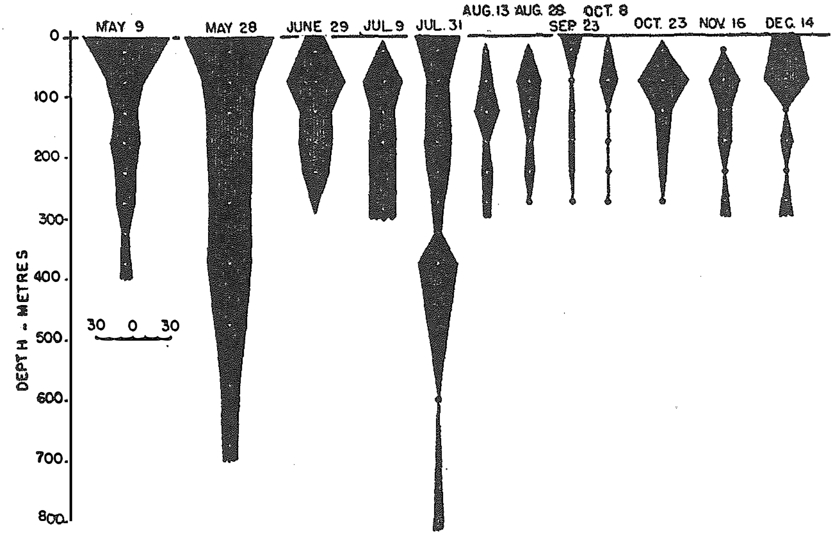
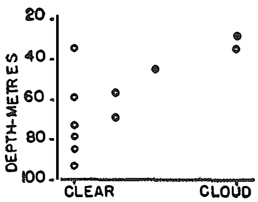


Figure 200[a]. Seasonal variation in the vertical distribution and total quantity of the zooplankton at a single station. (Volumes in cc.)



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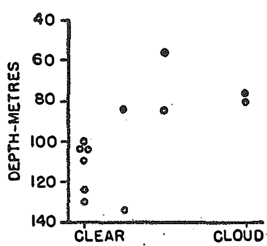

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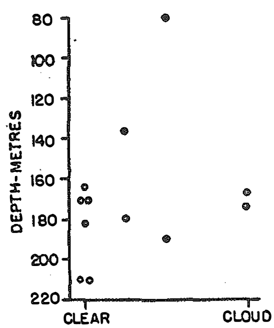

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Figure 201. Level above which 25% of the zooplankton of the top 300 metres occurs relative to the cloudiness of the sky.

Figure 202. Level above which 50% of the zooplankton of the top 300 metres occurs relative to the cloudiness of the sky.

Figure 203. Level above which 75% of the zooplankton of the top 300 metres occurs relative to the cloudiness of the sky.

75% levels of the plankton as a whole with cloud, and all show a definite correlation. The degree of correlation between day-level and cloud appears to be a specific characteristic and is not directly related with the depth at which the species normally lives. It does show, however, some positive correlation with extent of diurnal migration. In the following table a positive correlation implies that the species moves nearer to the surface on a cloudy day.

Table. I. Species Grouped According to the Correlation of Their Mean Day-Level with Illumination

Good positive correlation	Slight positive correlation	No correlation	Negative correlation
Hippopodius	*Bassia*	*Abylopsis*	*Haloptilus*
hippopus	*bassensis*	*eschscholtzii*	*longicornis*
Eudoxoides	*Amphicaryon*	*Chelophyes*	
spiralis	*acaule*	*appendiculata*	
Sagitta	*Lensia*	*Eudoxoides*	
serratodentata	*campanella*	*mitra*	
Neocalanus	*Pterosagitta*	*Lensia*	
gracilis	*draco*	*fowleri*	
Mecynocera		*subtilis*	
clausi		*Liriope*	
Acartia		*tetraphyllum*	
negligens		*Rhopalonema*	
Calanus		*velatum*	
minor		*Krohnitta*	
Stylocheiron		*subtilis*	
suhmi		*Sagitta*	
Amphioxides		*bipunctata*	
pelagicus		*lyra*	
		hexaptera	
		Creseis	
		acicula	
		Euchaeta	
		media	
		Pleuromamma	
		gracilis +	
		piseki[10]	
		Lucicutia	
		flavicornis	
		Oithona	
		setigera	
		Clausocalanus	
		spp.	
		Stylocheiron	
		abbreviatum	
		longicorne	

[10] See p. 51.

Spread (Fig. 204) shows a correlation with mean day-level, the deeper species tending to be more diffuse than the shallower ones.

Too much weight must not be placed on the diurnal migration characteristics given, since it was possible to work a single day only. As further work is in progress at present on this aspect, it will be best to present here the facts obtained and leave the discussion of the prob-

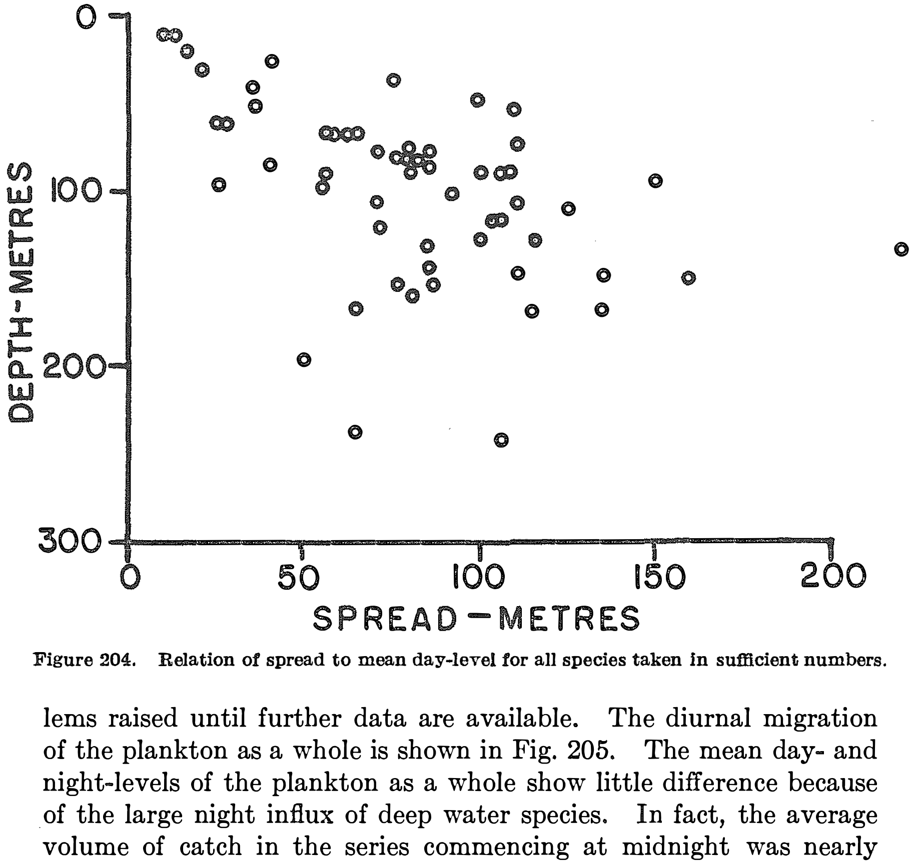

Figure 204. Relation of spread to mean day-level for all species taken in sufficient numbers.

lems raised until further data are available. The diurnal migration of the plankton as a whole is shown in Fig. 205. The mean day- and night-levels of the plankton as a whole show little difference because of the large night influx of deep water species. In fact, the average volume of catch in the series commencing at midnight was nearly double that at 15.00 hours.

The rate of ascent of many of the deeper forms such as *Pleuromamma abdominalis* (Fig. 137) must be very rapid, probably more than a metre per minute. It would appear that in some cases the rate of ascent is not sufficient to bring them to the highest level until well after midnight (Figs. 176, 178). The phenomenon of a temporary drop in level around midnight, followed by an ascent again before dawn, is shown by several species, i. e., *Sagitta bipunctata* (Fig. 60), *S. lyra*, etc. The same behaviour has been shown for pteropods and heteropods by Oberwimmer (1898) and for various forms by Russell. It has been suggested that the species concerned follow the level of optimum illumination to the surface at sunset, but scatter downwards again during the dark part of the night when there is insufficient illumination to attract them to the surface. They return to the surface again in the twilight before sunrise, and then sink during the day as the intensity of illumination rises. It is worth noting that in the

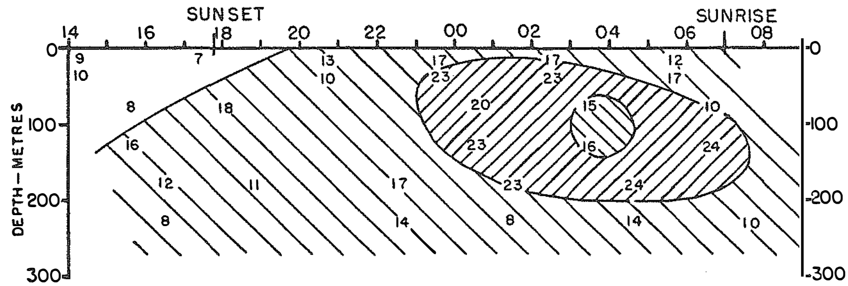

Figure 205. Diurnal migration of the total zooplankton of the top 250 metres. (Volumes in cc.).

present case this night drop occurred despite the fact that the moon was full.

The fact that the illumination from the moon is sufficient to have a marked effect on the surface plankton is shown by the numerous species in which a correlation was found between the catch at the surface and the phase of the moon. Some species even show a slight reduction in abundance on the nights 15 and 20 days after new moon, both of which were somewhat cloudy. The degree of correlation between night surface abundance and moonlight is a specific characteristic, but unlike the correlation of day-level with cloud, it is one which shows a marked correlation with both the depth at which the species lives in the daytime (Fig. 206) and the extent of its diurnal migration (Figs. 207). Deeper living forms, and ones having the greatest diurnal migration, tend most to concentrate at the surface at full moon. With the exception of the epitochous phase of a nereid worm, the only species which was more abundant at the surface at

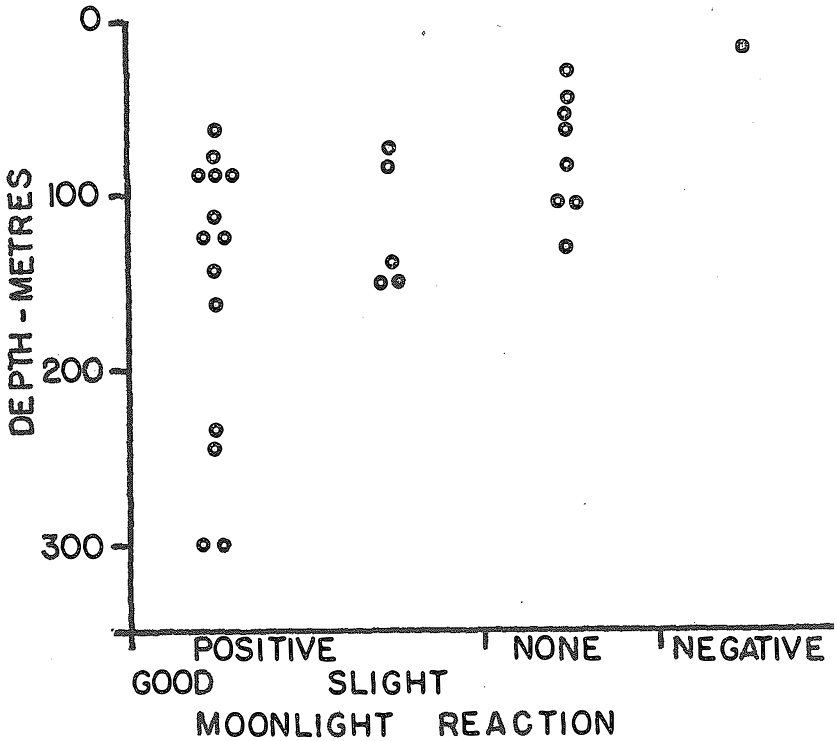

Figure 206. Relation, for all species present in sufficient numbers, between the degree to which they tend to occur at the surface at night at full moon and their mean day-level.

new than at full moon was the chaetognath *Sagitta planktonis* (Fig. 71). This has a day-level very close to the surface and possibly migrates downward at night.

The magnitude of diurnal migration cannot be accurately determined in the case of the deeper living forms, because a proportion of the population lies, in the daytime, below the level normally sampled. However, making such allowance as is possible for this fact, there appears to be some tendency for those species which make the greatest diurnal migration to show also the greatest difference in their level between sunny and cloudy days. There is also (Fig. 208) a correlation indicating, as might be expected, that deeper living forms tend to perform a more extensive diurnal migration than shallower ones. It seems possible too that some of the extreme surface forms actually move downwards at night.

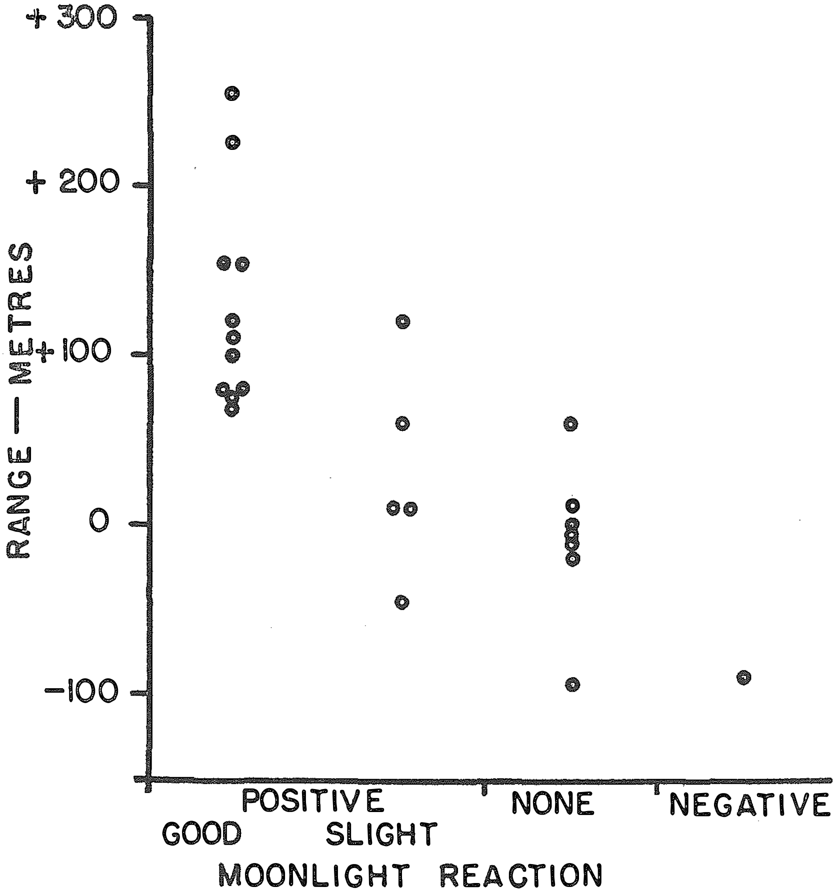

Figure 207. Relation, for all species present in sufficient numbers, between the degree to which they tend to occur at the surface at night at full moon and the extent of their diurnal migration (day-night range).

Cyclic Alternation of Generations

Data as to growth rates and length of life of plankton organisms are scanty. Further, they are restricted almost entirely to inhabitants of northern coastal waters. Since it has been suggested that the relative paucity of the standing crop of zooplankton in warmer waters may be compensated for to some extent by more rapid growth rates, any information on the latter is valuable. In a number of cases the Bermuda records indicate a cyclic change in the relative proportions

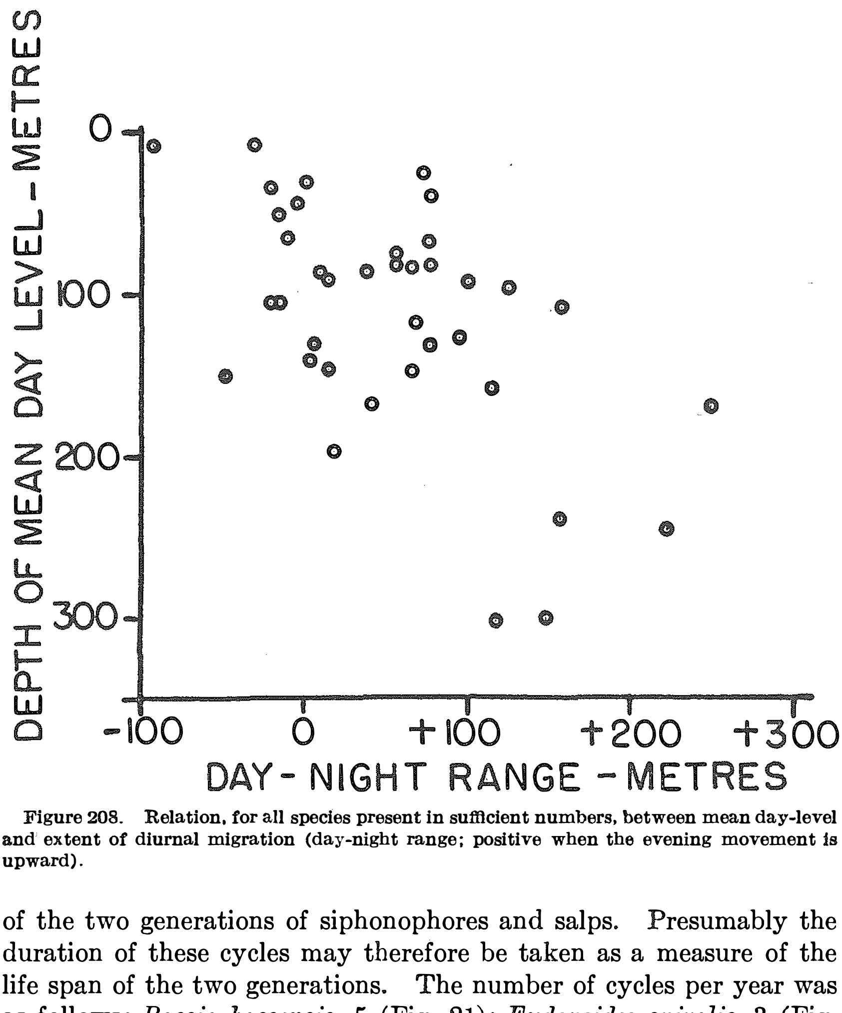

Figure 208. Relation, for all species present in sufficient numbers, between mean day-level and extent of diurnal migration (day-night range; positive when the evening movement is upward).

of the two generations of siphonophores and salps. Presumably the duration of these cycles may therefore be taken as a measure of the life span of the two generations. The number of cycles per year was as follows: *Bassia bassensis,* 5 (Fig. 21); *Eudoxoides spiralis,* 3 (Fig. 29); *Eudoxoides mitra,* 5 (Fig. 36); *Thalia democratica,* 3 (Fig. 193). In other species it appears that similar cycles might have been demonstrable had more material been available. Summer cycles appear to be slightly shorter than winter, but the difference, if significant, is small.

The Extent to Which Bermuda Results Are More Generally Applicable

The areas of rich and poor plankton and their seasonal movements are local phenomenona, and the cruises indicated no seasonal change in the total volume of plankton present in the area as a whole. The data presented on the vertical distribution and movement of both the individual species and the plankton as a whole, and on their seasonal changes, may be applicable to a considerable area of the western North Atlantic. In this connection, three points call for discussion.

The first point is the degree to which the islands contribute species of neritic origin to the zooplankton. As can be seen from the lists of species, most are obviously not of neritic origin. Bigelow (1938) has estimated the neritic fraction in the case of the medusae from Beebe's material, and his values may be expected to be higher than in most other groups. He states:

> In the case of the Hydromedusae, out of a total of 717 specimens, the number belonging to species that are either known to pass through an attached hydroid stage, or may reasonably be assumed to do so, does not exceed 17 . . . In the case of the Scyphomedusae, the situation was the reverse, if judged from the standpoint of total numbers only, for the number of neritic specimens was raised considerably above that of the holoplanktonic by one catch of several hundreds of juveniles of *Linuche* . . . And a second large catch (66) was also made of *Carybdea xaymacana* . . . However, if the neritic and holoplanktonic groups of Scyphomedusae be judged, not by numbers of specimens, but by the frequency of occurrence, the latter group ranks far in advance, for 252 hauls yielded representatives of genera certainly or probably holoplanktonic . . . While only 16 hauls and surface collections yielded genera which may safely be called neritic.

The next point is the extent to which the species found in the Bermuda catches are typical of a wider area. For this question we have two hauls made by the Atlantis in the Gulf Stream compared with hauls made as nearly as possible at the same time in Bermuda.

Table II. Comparison of Gulf Stream and Bermuda Zooplankton

	1938		1940	
	Gulf Stream	*Bermuda*	*Gulf Stream*	*Bermuda*
Bougainvillea niobe	+	−	+	−
Rhopalonema velatum	+	+	+	+
Liriope tetraphyllum	+	−	−	−
Aglaura hemistoma	+	+	+	+
Solmissus incisa	−	−	−	+

TABLE II. COMPARISON OF GULF STREAM AND BERMUDA ZOOPLANKTON (Cont.)

	1938 Gulf Stream	1938 Bermuda	1940 Gulf Stream	1940 Bermuda
Nausithöe punctata	−	+	−	−
Atolla sp.	−	−	+	−
Amphicaryon acaule	+	+	−	−
Praya sp.	+	−	−	−
Hippopodius hippopus	+	+	+	+
Abylopsis eschscholtzii	+	+	−	+
A. tetragona	+	−	+	+
Bassia bassensis	+	−	+	+
Diphyes dispar	+	+	−	−
D. bojani	+	+	+	+
Eudoxides spiralis	+	+	+	+
E. mitra	+	+	−	+
Chelophyes appendiculata	+	+	−	+
Lensia subtilis	−	−	−	+
L. campanella	−	−	−	+
Sulceolaria monoica	−	+	−	−
S. quadridentata	−	+	−	−
Agalma sp.	+	−	−	−
Sagitta hexaptera	+	+	+	+
S. lyra	−	+	−	+
S. bipunctata	+	+	+	+
S. serratodentata	−	+	−	+
S. planktonis	−	−	−	+
Pterosagitta draco	+	+	+	+
Krohnitta subtilis	+	+	−	+
Limacina inflata	−	?	+	+
L. lesueurii	+	?	+	+
L. bulimoides	−	?	−	+
Creseis virgula	+	−	+	−
C. acicula	+	+	+	+
Styliola subula	−	+	+	+
Hyalocylis striata	−	+	+	+
Clio pyramidata	−	+	+	+
Cuvierina columnella	−	+	+	+
Diacria trispinosa	−	+	−	+
D. quadridentata	−	−	+	+
Cavolinia longirostris	+	+	+	−
C. uncinata	−	−	+	−
C. tridentata	−	+	−	−
Atlanta sp.	+	+	−	−
Pterotrachea sp.	−	−	−	+

TABLE II. COMPARISON OF GULF STREAM AND BERMUDA ZOOPLANKTON (Cont.)

	1938		1940	
	Gulf Stream	*Bermuda*	*Gulf Stream*	*Bermuda*
Calanus minor	−	+	+	+
Neocalanus gracilis	+	+	+	−
Undinula vulgaris	+	−	+	−
Eucalanus spp.	+	+	+	+
Rhincalanus cornutus	−	−	+	+
Mecynocera clausi	−	+	−	+
Clausocalanus spp.	?	+	+	+
Aetidius armatus	−	+	−	−
Euchirella rostrata	−	+	−	−
Undeuchaeta minor	−	−	−	+
Euchaeta media	−	+	+	+
Scolethricella tenuiserrata	−	−	+	−
Pleuromamma gracilis + *P. piseki*	−	+	+	+
P. abdominalis	−	+	−	−
Lucicutia spp.	−	+	+	+
Haloptilus longicornis	+	+	−	−
Candacia aethiopica	+	+	+	−
Pontellina plumata	+	−	+	−
Acartia negligens	−	+	−	+
Macrosetella gracilis	−	−	+	−
Occulosetella gracilis	−	−	−	+
Oithona setigera	−	+	−	+
O. plumifera	−	−	+	−
Copilia sp.	−	−	+	−
Thysanopoda aequalis	−	+	−	+
Euphausia brevis	−	+	−	−
E. tenera	−	−	+	−
E. hemigibba	−	−	+	−
Nematoscelis microps	−	+	−	−
Stylocheiron carinatum	−	+	−	+
S. suhmi	−	+	−	−
Amphioxides pelagicus	+	+	−	+
Pegea confederata	−	+	−	−
Thalia democratica	−	?	−	+
Salpa fusiformis	−	?	+	+
Iasis zonaria	−	?	+	+

To summarize Table II, out of 84 species, 17 were found only in the Gulf Stream material, but all of these were found at some other time in the Bermuda area. Twenty-seven species were found in the Bermuda material but not from the Gulf Stream. This is not excessive, however, considering that we are comparing the results from two hauls in the Gulf Stream with all the hauls on one cruise together with a number of night surface hauls..

Quantitatively we have Jespersen's data (1923, 1935) which show that the amount of zooplankton in the shallower layers round Bermuda is somewhat greater than in the central area of the Sargasso Sea, much the same as that as far east as about Long. 40° W., and somewhat less than that in the Gulf Stream westnorthwest of Bermuda. These differences are much less than those between coastal and oceanic water. In general, then, the results obtained from Bermuda may be taken as probably typical of a much wider area.

A final point to be considered is whether or not the postulated different summer and winter current systems bring with them faunas characteristic of different areas of ocean. If they do so, the species present in the systems may prove to be useful indicators of the origin of the water masses. There is considerable evidence that this is the case, but a discussion of the results will be deferred until a later publication.

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