

Studies on *Limacina inflata* d'Orbigny (Thecosomata, Gastropoda) in the Indian Ocean

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This paper deals with the seasonal and diurnal variations in spatial abundance, the annual variations along 78° E, latitudinal and seasonal variations along 110° E and also the distribution in relation to the thermocline. This study is based on the identification of the sorted fractions of Euthecosomata from 1927 zooplankton collections of the IIOE and 180 collections of the seasonal biological cruises of the Division of Fisheries and Oceanography CSIRO Australia. Because of remarkable diurnal changes of *Limacina inflata* only night collections were taken into consideration for studying seasonal variations.

I. Present Observation on Geographical Abundance

Out of 1927 samples, *Limacina inflata* was present in 1040, of which 438 were day hauls, and 602 night hauls. The day distribution (Fig. 1) shows that a large number of stations in the central water mass of the southern Indian Ocean and the areas which fall away from the zones of upwelling and divergence either caught none of this species or very few (<10 per haul). This species has been caught in moderate numbers in the areas where coastal upwelling or divergence is reported, for example, the coasts of Kenya and Somalia, the Gulf of Aden, the south Arabian coast, the SW coast of India, a part of the western Bay of Bengal, near Andaman, off Sumatra, off Java and in isolated areas in the equatorial zone. The areas of greater abundance are restricted to small areas off the Kenya and Somali coast, off Goa, off Cochin and off Madras. The night distribution (Fig. 2) shows that the range B (10–100 per haul) covers about $\frac{3}{4}$ of the area of the Indian Ocean, whereas the same range of abundance was found mainly in the North Indian Ocean during the day. Except in a few coastal areas (West Australian coast, Malaya and Burmese coast, NE coast of India) and a large area off South Africa, Gulf of Oman, the eastern Bay of Bengal, east of Ceylon, a few areas in the equatorial zone and the area near West Java, *Limacina inflata* is more common at night in the entire area of the Indian Ocean. The area of greater abundance (range C, 100–1 000 per haul Fig. 2) is comparatively many times larger than during the day; it covers almost the entire western half of the Indian Ocean from Madagascar to the south Arabian coast, off Goa, off Cochin, a meridional zone along 78° E, specified areas in the equatorial zone, off Madras, a part of the northern Bay of Bengal, Andaman Sea and off Java. The areas of highest abundance (range D, > 1 000 per haul) were noted in the form of patches off the Somali coast, near Socotra, off Goa, off Madras and near the Equator at 82° E. The average number of organisms in the day hauls is 39 and night hauls 105.

The distinct variation in spatial abundance of *Limacina inflata* clearly indicates that

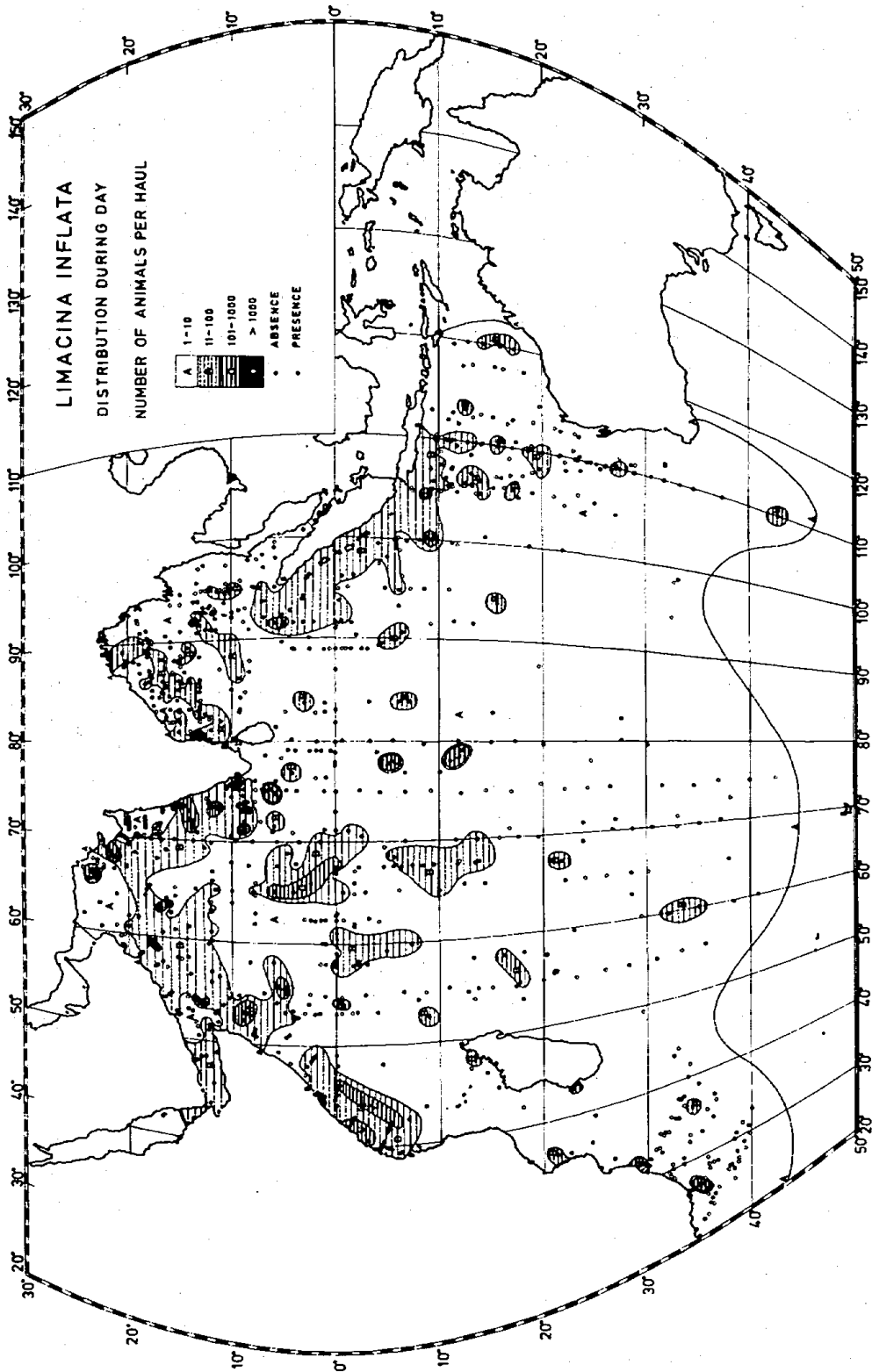


Fig. 1. The day distribution of *Limacina inflata*

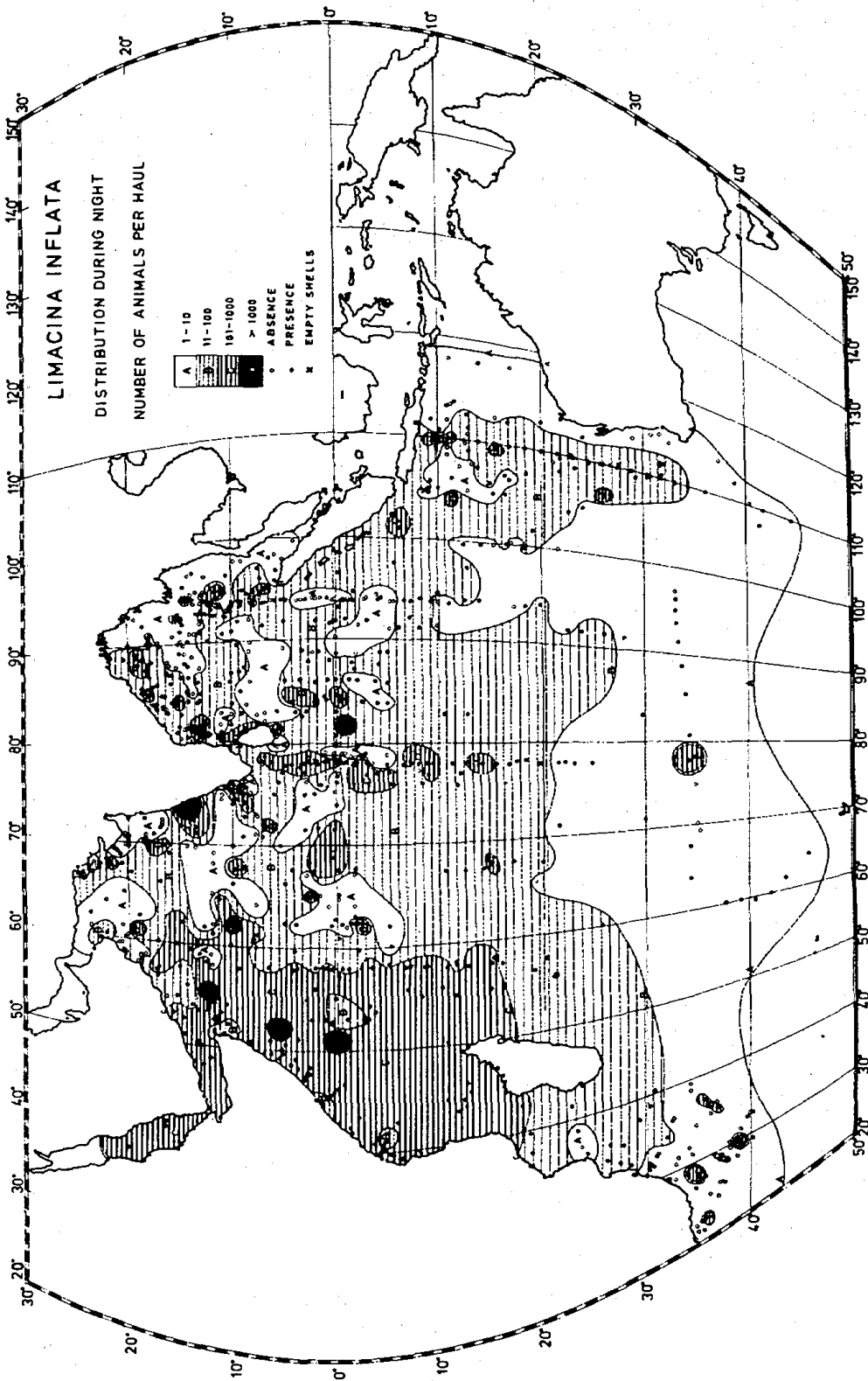


Fig. 2. The night distribution of *Limacina inflata*

it undergoes vertical migration and avoids surface waters during the day. The mean level of this species might be around 200 m in the areas of coastal upwelling and divergence where, in general, light penetration is less. In clear waters where light penetrates deeply, this species lives mainly below 200 m. This is evident from its occurrence in the night hours in the central water mass of the South Indian Ocean where it is absent in the daytime. The ascending migration at night is for the purpose of feeding on phytoplankton, generally most abundant at 75 m (HUMPHREY and KERR, 1969). The areas of greater abundance of *Limacina inflata* are approximately the areas of the vertical extension of monsoonal effects, as reported by DÜING (1970). As this result almost coincides with the similar finding of MCGOWAN (1960) in the North Pacific, *Limacina inflata* could be considered an indicator of environments where the nutrient-rich, deep water is brought up, in the form of upwelling, divergence or other vertical mixing processes.

II. Seasonal Variation in Spatial Abundance

From mid-April to mid-October, a large area in the western Indian Ocean between Madagascar and the south Arabian coast and a large area in the eastern Indian Ocean, especially the western Bay of Bengal, the Andaman Sea, the areas around Ceylon, off Sumatra and the areas between Java and Australia, show abundance (range B) of *Limacina inflata* (Fig. 3). The areas of greater abundance (range C) are found off Kenya, NE of Madagascar, the Somali coast, the south Arabian coast.

The highest abundance (range D) was seen only in the area off the Somali coast. A large area off South Africa, part of the central and eastern Bay of Bengal including the Malacca Strait, a few areas in the equatorial zone and a large area in the southern Indian Ocean are poorly populated. From mid-October to mid-April (Fig. 4), the areas of abundance (range B) are seen off Kenya and Somali coast, the Gulf of Aden, the west coast of India, a meridional zone along 78° E, the areas around Ceylon, a part of western Bay of Bengal, a few areas in the equatorial zone and the NW Australian Sea. The areas of greater abundance (range C) are found in the areas off the Kenya and Somali coast, near Socotra, the Gulf of Aden, off Kathiawar, the SW coast of India, a meridional zone along 78° E, off Madras and off Java. The highest abundance (range D) is noted in the area near Socotra, off Goa, off Madras, and a patch near the Equator at 82° E. The area off South Africa, the Gulf of Oman, the central and southern Arabian Sea, the eastern Bay of Bengal, the west coast of Australia and a large area in the western half of the Indian Ocean are poorly populated by *Limacina inflata*. The fact that the period from mid-April to mid-October which is dominated by the SW monsoon shows greater abundance than that from mid-October to mid-April; that might be due to the different intensities and duration of the SW and NE monsoons which bring about a number of changes in the properties of the environment according to the vertical extension.

The finding of a large number of well-preserved empty shells of *Limacina inflata* off the eastern part of the Somali coast (Table 1 and Fig. 2) could indicate mass mortality of this species, due to the toxic effects of phytoplankton blooms or other unknown environmental factors. The subsurface O₂ minimum is also recorded.

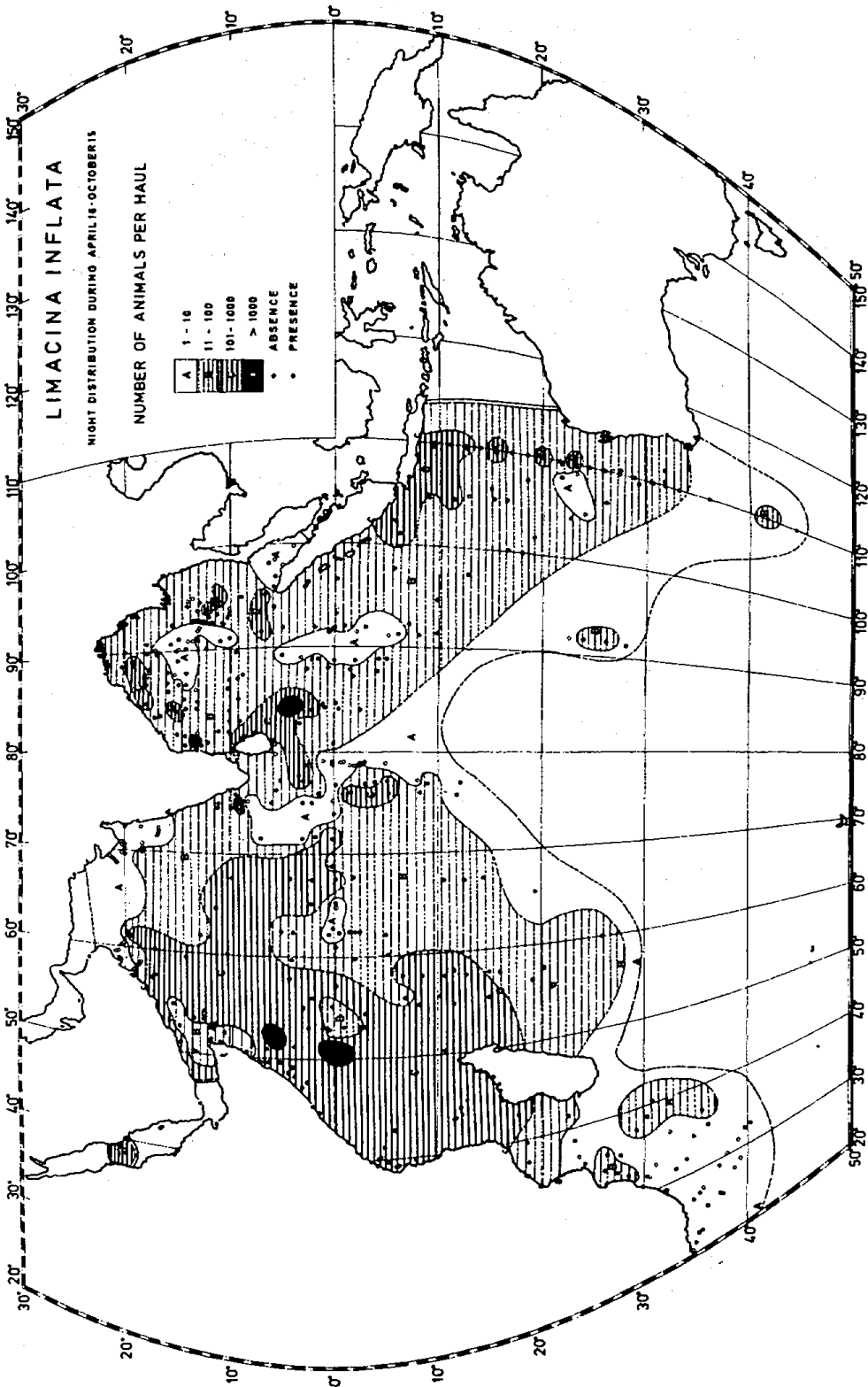


Fig. 3. The distribution of *Limacina inflata* from mid-April to mid-October

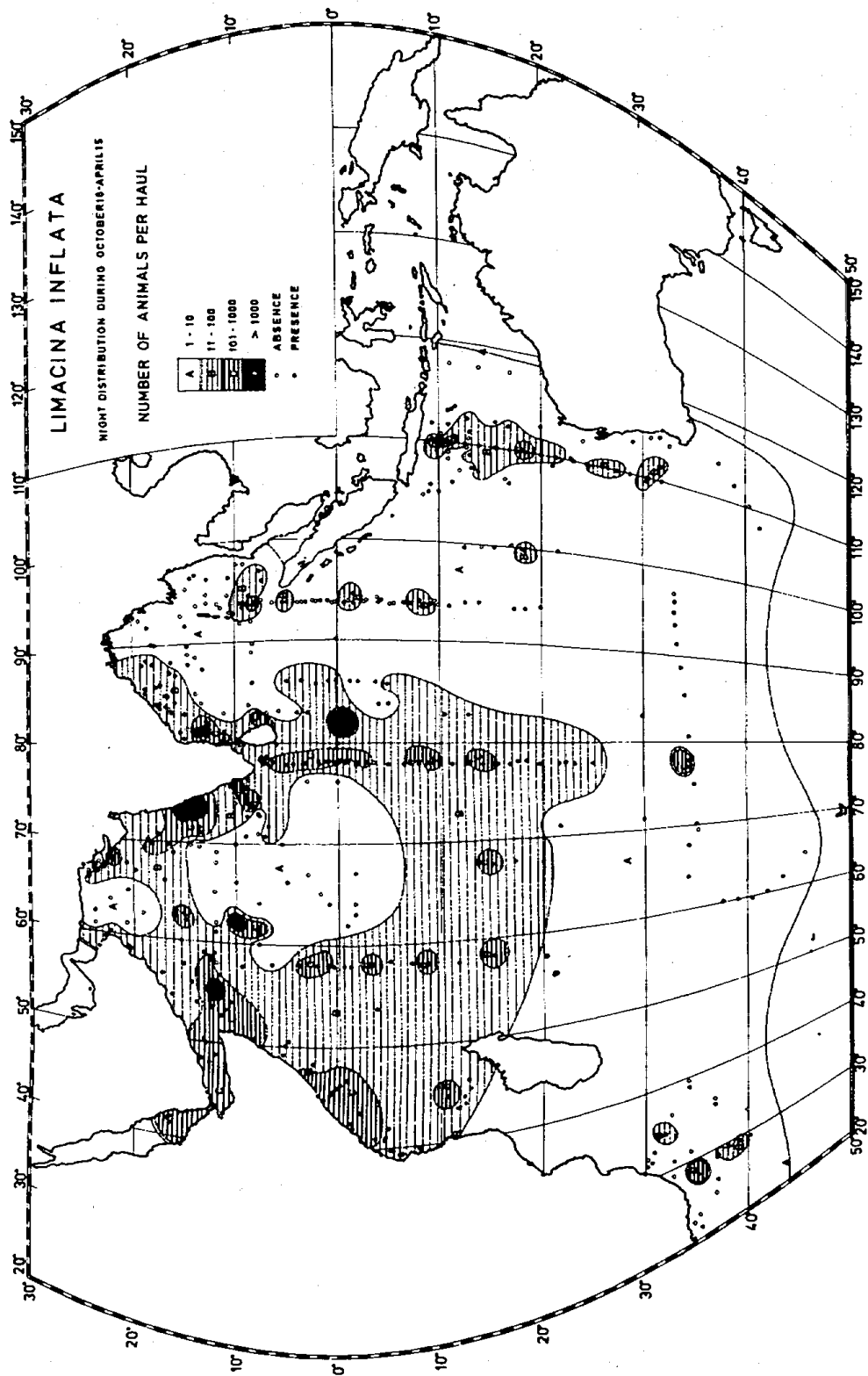


Fig. 4. The distribution of *Limacina inflata* from mid-October to mid-April

Table 1. Hydrographic details of stations where a large number of empty shells of *Limacina inflata* were found

Ship	Cruise	Station	Date	Gear	Position	O ₂ range 200 m layer (ml l ⁻¹)	Temperature range 200 m layer (° C)	Salinity range 200 m layer (‰)	No. of <i>L. inflata</i> 200 m layer
INS "Kistna"	2	78	9. 11. 62	Organdie	12°00' N 55°00' E	0.32-4.47	15.52-27.5°	35.43-36.31	3195
INS "Kistna"	3	95	2. 12. 62	Organdie	08°00' N 60°00' E	1.95-4.31	14.05-27.8	35.21-36.22	522
INS "Kistna"	3	96	2. 12. 62	Organdie	10°00' N 62°03' E	2.06-4.74	15.72-27.4	35.40-35.96	2126

III. Annual Variation of *Limacina inflata* along 78° E

“Umitaka Maru” and “Kagoshima Maru”, 2 Japanese research vessels, during the IIOE took a series of collections along the meridian 78° E during December to January 1962–1963 and December to January 1963–1964. Twenty zooplankton collections during the first year and 23 during the second year were made along the track between

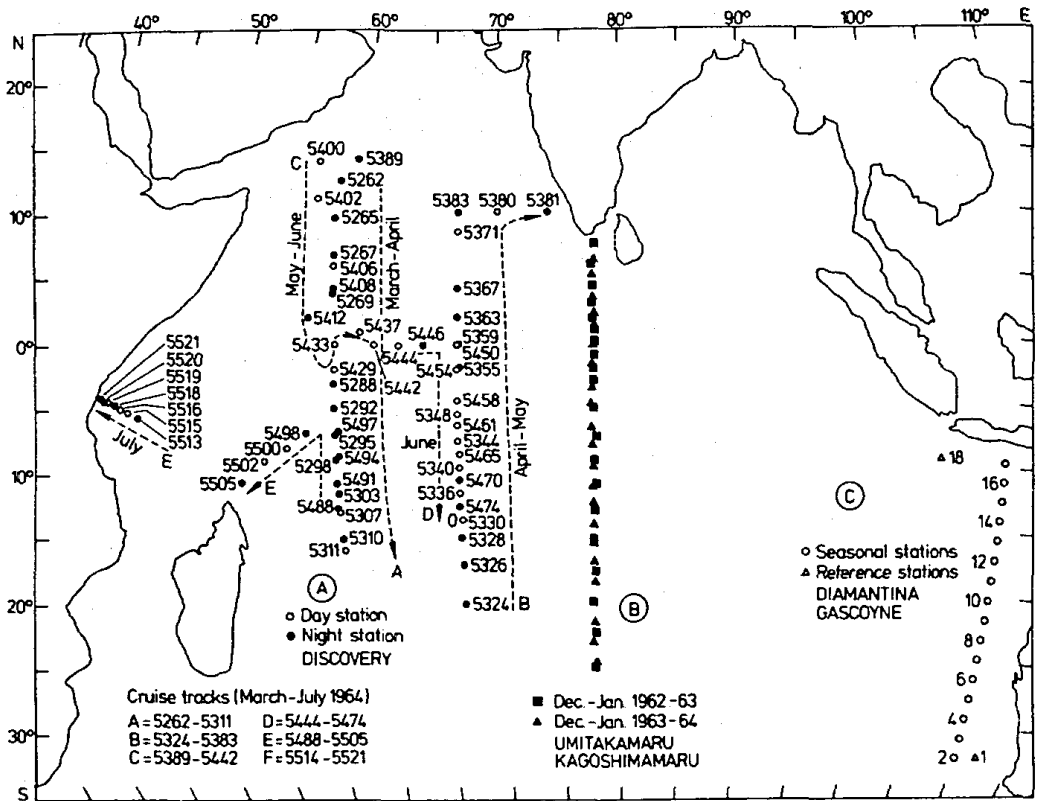


Fig. 5. Stations for special observations, A Distribution in relation to the thermocline, B Annual variation, C Seasonal variation

8°N and 25°S, almost all between 1900 and 2400 h, the majority between 2000 and 2100 h. The position of these stations is given in Fig. 5 B. The data collected from these stations for chlorophyll *a*, zooplankton displacement volume and numbers of *Limacina inflata* are plotted with temperature (Figs. 6 and 7). The station list and sampling details are given in the IOBC Handbook (1969). On the basis of vertical temperature gradients approximately 3 zones were selected for latitudinal comparison. The vertical temperature gradient in the upper 100 m was very narrow at the Equator during both years. From 15°S to 25°S temperatures at 0 m, 75 m and 100 m were falling and the temperature at 200 m was rising (Fig. 6). The stations up to the Equator were taken as track A, stations between the Equator and 15° S as track B, and the stations between 15° S and 25° S as track C. The data collected from each zone in the form of mean values for chlorophyll *a*,

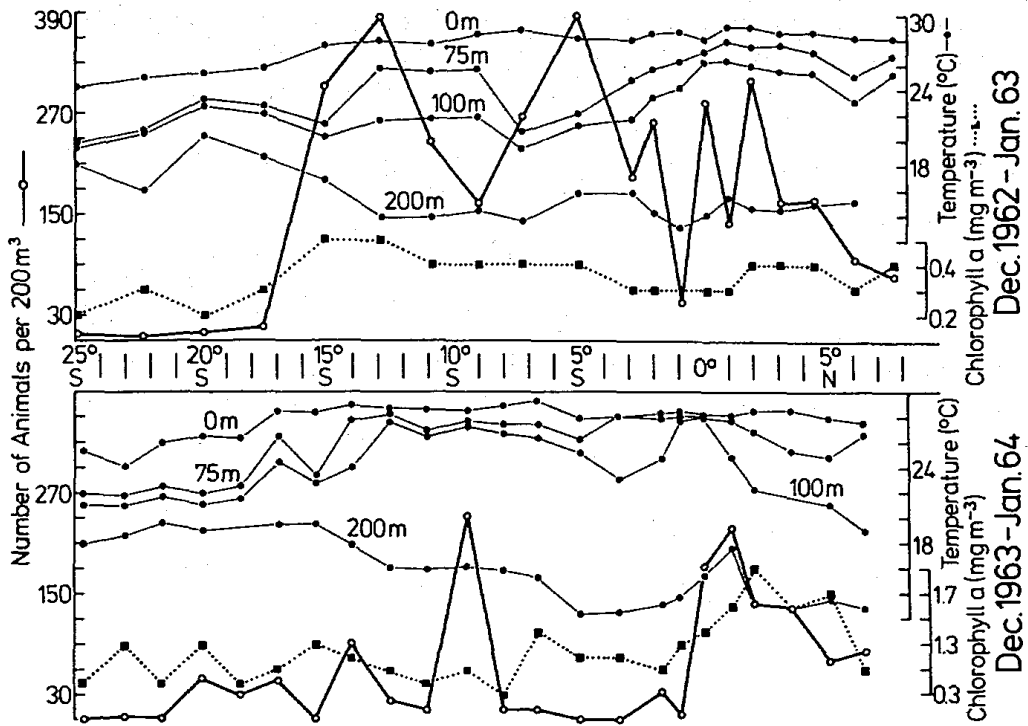


Fig. 6. Annual variation of *Limacina inflata* along 78° E with chlorophyll *a* and temperature

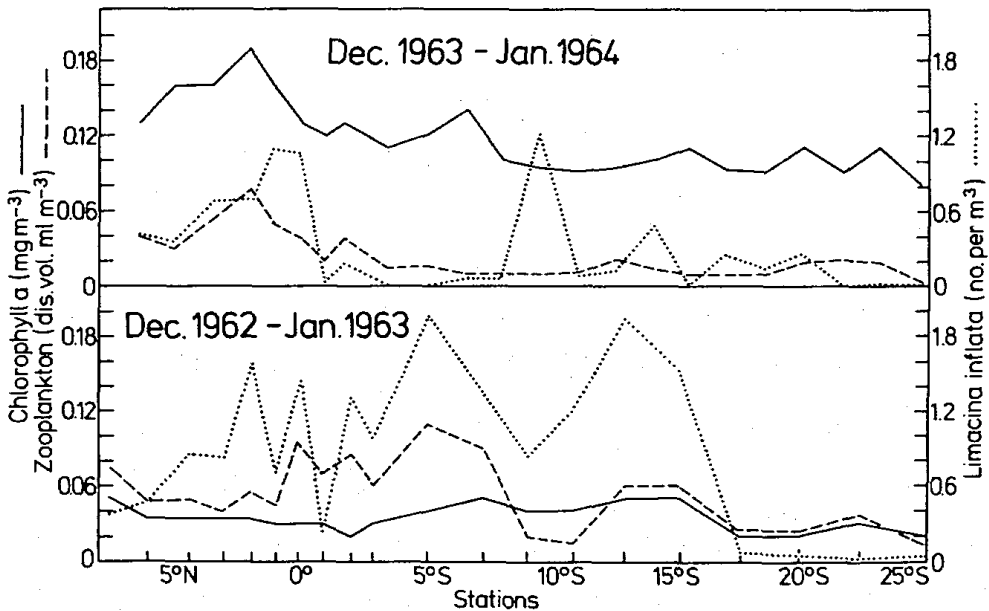


Fig. 7. Annual variation of *Limacina inflata* in comparison with chlorophyll *a* and zooplankton displacement volume along 78° E

zooplankton displacement volume and *Limacina inflata* are given in Fig. 8. The mean annual variation is given in Table 2.

Table 2. Mean annual variation in chlorophyll *a*, zooplankton displacement volume and *Limacina inflata* along 78° E

Year	Mean chlorophyll <i>a</i> mg m ⁻³	Mean zooplankton displacement volume ml m ⁻³	Mean number of <i>Limacina inflata</i> No m ⁻³
Dec. 1962 – Jan. 63	0.034	0.053	0.85
Dec. 1963 – Jan. 64	0.118	0.025	0.32

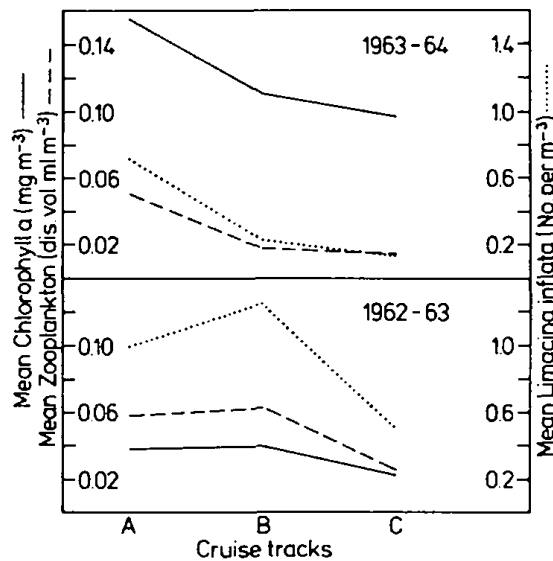


Fig. 8. Mean annual variation of *Limacina inflata*, chlorophyll *a* and zooplankton displacement volume in 3 selected tracks along 78° E.

From Table 2 it is clear that chlorophyll *a* is low in the first year, but zooplankton and numbers of *Limacina inflata* are high. In the second year, chlorophyll *a* is more than 3 times as abundant, zooplankton is less than half as abundant and *Limacina inflata* about 3 times less abundant when compared to the mean values of the first year. In the first year, track B shows high abundance in all 3 values while track A shows slightly less abundance and track C poor abundance (Fig. 8). Whereas in the second year, all the 3 mean values are high along track A with a decrease along track B and C, the decrease in chlorophyll *a* in the first year and increase in zooplankton and *Limacina inflata* suggests that the secondary producers have established themselves after a long period of grazing. In the second year, primary producers are abundant and secondary producers are less abundant, giving an impression that the secondary producers have just started

grazing, following the bloom of phytoplankton. As *Limacina inflata* is predominantly a herbivore, this follows closely the general trend of increase or decrease of zooplankton. This year-to-year change in the cyclic changes of the ecosystem might probably have been introduced by the earlier or later setting in of the NE monsoon.

IV. Latitudinal, Seasonal and Diurnal Variations of *Limacina inflata* along 110° E

In 1962–63 the Division of Fisheries and Oceanography, CSIRO Cronulla, with the collaboration of the oceanographic laboratory, ORSTOM New Caledonia, undertook 6 seasonal biological cruises, at 2-month intervals along 110° E meridian between 32° and 9° S. The aim of these cruises and other details have been published by ROCHFORD (1969 and TRANTER (1973) this volume).

Duplicate collections from these cruises were sent to IOBC and utilized for comparison. The data collected for the identification of thecosomes are being worked out; only the species *Limacina inflata* is presented here. The number of *Limacina inflata* from each collection was converted to log 10 and a contour was drawn at different grades of density; figures were prepared for day and night (Fig. 9 a, b).

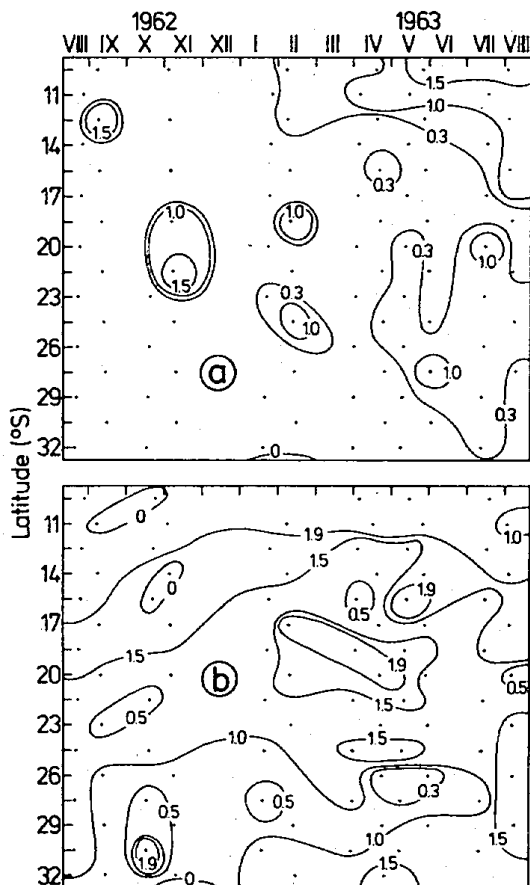


Fig. 9. Latitudinal, diurnal and seasonal variations of *Limacina inflata* along 110° E Contours: log of individuals per 200 m³ a Day b Night

Limacina inflata is abundant in the northern latitudes (between 9 and 12° S) almost throughout the year (Fig. 9b). The area of abundance extends spatially up to 20° S between August and November in 1962 and May to August in 1963. The central latitudes between 15° and 26° S show less abundance and southern latitudes in general between 26° and 32° S are poor. This follows the results on the latitudinal variation of biomass well (TRANter, 1969). The absence of *Limacina inflata* in many collections in the southern latitudes and periodical occurrence in certain months might be due to the scarcity of this

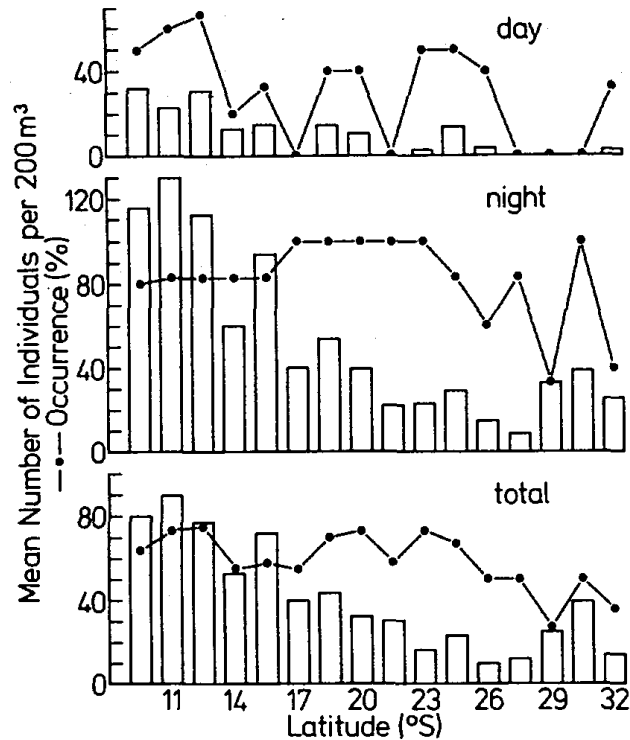


Fig. 10. Latitudinal variation in the mean number of *Limacina inflata* with % of occurrence

species in an area where water conditions are stable. The central latitudes in general show less abundance but in the period of summer divergence, as reported by ROCHFORD (1969), *Limacina inflata* undergoes a significant increase, as in northern latitudes. As a whole this species is in maximum abundance during August, following the peak period of chlorophyll, reported as maximum during June to August (HUMPHREY and KERR, 1969). The maximum abundance of *Limacina inflata* in the northern latitudes might be due to the upwelling during the SE monsoon as described by WYRTKI (1962) followed by high biological productivity. The absence of this species in 4 of the collections in the northern latitudes during September – October 1962 might be due to the different type of gear used. Out of 18 night tows using the Clarke-Bumpus Sampler (CBS) during September and November *Limacina inflata* was present in only 8 samples, whereas this species was

present in all 12 Indian Ocean Standard Net (IOSN) night tows in August and October. As CBS and IOSN samples were not available from the same station, no definite conclusion can be drawn as to the efficiency of the gear. However, in the southern latitudes IOSN samples, too, lack this species.

The diurnal variation of this species is remarkable (Fig. 9a). There are a few records of small numbers of specimens, especially during April–August, but most of the day collections do not contain this species, whatever the latitude and season. Only collections

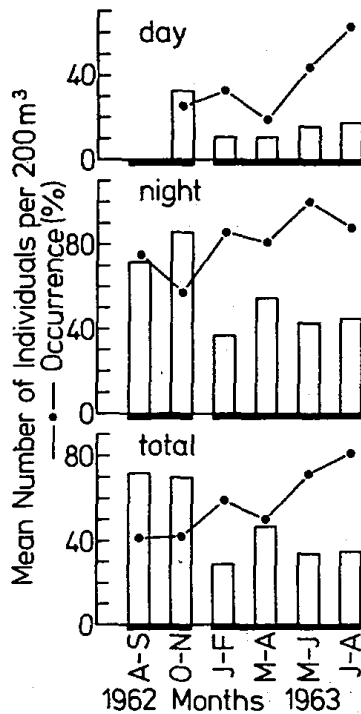


Fig. 11. Seasonal variation in the mean number of *Limacina inflata* with % of occurrence

from the northern latitudes between 9° and 13° S and another at 21° S show greater abundance. This shows that *Limacina inflata* for most of the year lives below 200 m during the day in many stations along 110° E.

The mean number of *Limacina inflata* and its percentage of occurrence with respect to latitude and month are shown in Figs. 10 and 11, day and night values being shown separately. In determining the average, either for each latitude or each cruise, single records of occurrence were omitted in day values, but included in the total. Of all the latitudes between 9° and 32° S, the maximum number of this species was found at 11° S and minimum at 26° S. Of all 6 cruises, the highest percentage was found in July–August 1963, the highest mean number in August–September 1962 and the lowest in January–February 1963 (Fig. 11).

V. The Distribution of *Limacina inflata* in Relation to Thermocline

During the IIOE RRS "Discovery" collected zooplankton samples from 62 stations in the area of the western half of the Indian Ocean for the study on distribution of plankton in relation to the thermocline (Fig. 5 A). Fig. 12 shows that *Limacina inflata* is abundant at night above and below the thermocline in the 200 m water column. During the day the population of this species is very poor above the thermocline and less abundant below the thermocline (Fig. 12). The mean number of organisms above and below the thermocline in terms of unit haul and in terms of number per m^3 are given in Table 3.

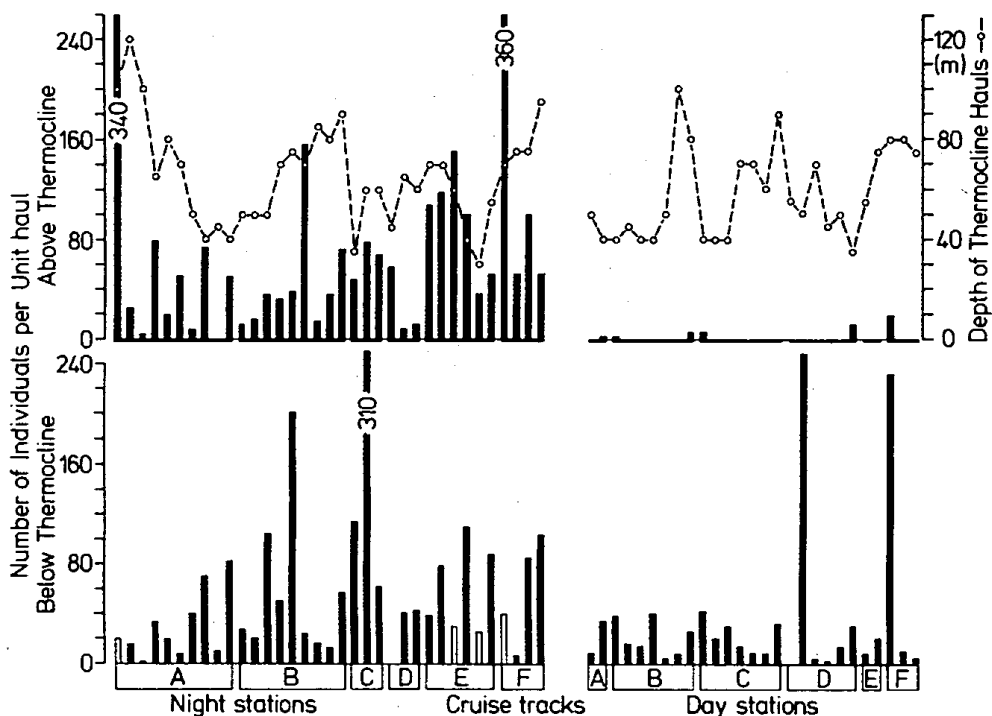


Fig. 12. The distribution of *Limacina inflata* in relation to the thermocline (in terms of unit haul).
For cruise tracks see Fig. 5

Table 3. Diurnal variation in the mean number of *Limacina inflata* in relation to the depth of thermocline in terms of unit haul and number m^{-3}

<i>Limacina inflata</i>	Day		Night	
	Thermocl. -0 m	200 m - Thermocl.	Thermocl. -0 m	200 m - Thermocl.
Mean number per unit haul	3.83	34.96	72.17	+ 52.06
Mean number per m^3	0.07	0.16	1.12	-0.55

Of the 6 cruise tracks, tracks C, E and F show relatively high abundance of *Limacina inflata* which perhaps might be due to the influence of the SW monsoon during June and

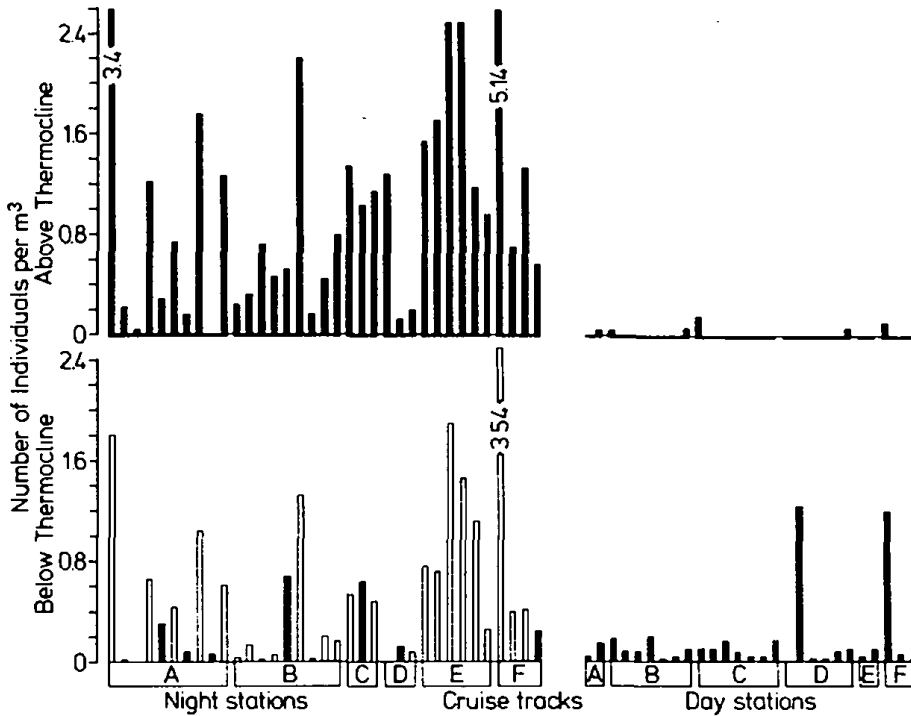


Fig. 13. The distribution of *Limacina inflata* in relation to the thermocline (in terms of number per m^3)

July. As *Limacina inflata* is an eurythermic form inhabiting tropical to polar waters, the temperature may not act as a barrier to the up and down migration of this species. As diurnal variation is remarkable, light may be the major factor in the vertical distribution of *Limacina inflata*.

Even though no correction factor was applied to the varying depth of thermocline hauls (30–120 m), the occurrence and abundance of *Limacina inflata* above and below the thermocline show more or less the expected vertical distribution. When the data were converted in terms of number per m^3 (Fig. 13), 28 of the 35 night stations below the thermocline show negative values, giving the impression that no organisms are present. This might be due to the non-random distribution of the organisms, the population of *Limacina inflata* being more dense above than below the thermocline at night, or it might be an artefact of the method used.