

Microdistribution of zooplankton in the neustonic realm of the eastern Arabian Sea during southwest monsoon

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Abstract— During the southwest monsoon season of 1987, the zooplankton distributions in the neustonic realm (upper 50 cm) of the eastern Arabian Sea were studied and compared with those in the water column. The upper microlayer (upper 15 cm) had generally poor biomass and densities during day-time as compared to the lower microlayer (30-45 cm below). Diel variations were discernible in biomass and numerical abundance. There was nocturnal increase in biomass and density in both layers suggesting diel vertical migration, but the increase was relatively more in the upper layer than the layer below. Ostracods, amphipods, pteropods, mysids and megalopa larvae were significantly more abundant in the upper layer during night-time. Northern areas of west coast of India had higher biomass and population density. Zooplankton abundance was more in the coastal belt as compared to the offshore waters. Neuston biomass and population densities were lower than those in the water column. Only pontellid copepods showed significantly higher density in the neuston layer. High sea surface temperature and escapism from predators may be responsible for lower abundances in the neustonic realm during day-time. Most of the zooplankters dwelling the neuston layer of tropical waters are either facultative or pseudoneustonic forms.

INTRODUCTION

Organisms inhabiting the uppermost layer of the seas (neuston) have received some attention in recent years. The first extensive study of marine neuston was made by ZAITSEV (1970). This was followed by a review of neuston of the subtropical and boreal North-eastern Atlantic Ocean by HEMPEL and WEIKERT (1972). They redefined the ecological categories of marine neuston into 3 main groups: euneuston (maximum abundance in the immediate vicinity of surface), facultative neuston (concentrate at the surface mostly during night) and pseudoneuston (deep water forms which appear at the surface layer during certain time). Subsequently, HOLDWAY and MADDOCK (1983) made a comparative study of the marine neuston from west of Fiji to the Bay of Biscay and identified the geographical and temporal distribution patterns. The importance of pleuston in the marine food web and the need to consider them as a distinct ecological entity rather than a constituent of neuston was emphasised by CHENG (1975). However, neuston of the Indian waters is limited to the studies of DANIEL and JOTHINAYAGAM (1976) and NAIR *et al.* (1989), both from the Arabian Sea. During the southwest monsoon season of 1987, we made extensive surveys in the eastern Arabian Sea, in order to study the distribution of zooplankton in the neustonic realm. The questions we addressed were, 1) are there major differences between the neustonic distribution and vertical distribution of zooplankton? 2) are there any euneustonic forms? and 3) what would favour/prevent such distributions?

MATERIALS AND METHODS

Forty stations, along 12 transects approximately perpendicular to the coast (B-M, Fig. 1), were sampled during 2 consecutive cruises of ORV *Sagar Kanya* between June and

August 1987. This study covered a vast area of the eastern Arabian Sea ($8-22^{\circ}$ N, $65-73^{\circ}$ E). Sixteen stations lying within the shelf zone (< 200 m depth) were designated as coastal stations and the remaining, beyond the shelf were designated as offshore stations. Twenty stations were sampled during night (1800-0600 hrs) and the rest during day-time (0600-1800 hrs).

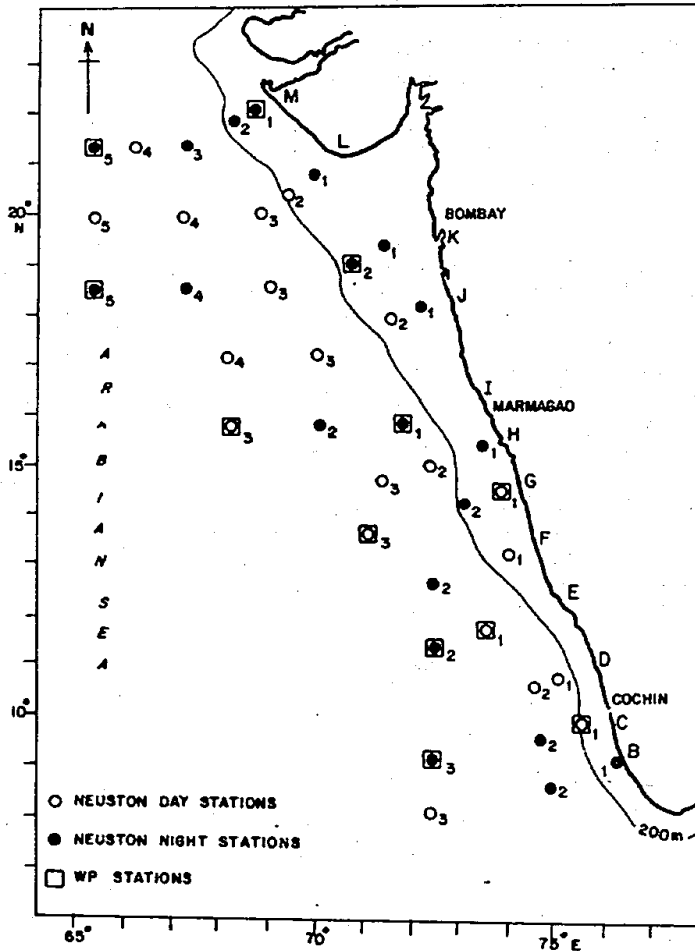


Fig.1. Location of stations.

A David-Hempel neuston net (Model 200, 30 X 15 cm net bag, 200 μ m mesh width) was hauled for 20 minutes at 2 knots speed. The upper net filtered the uppermost 15 cm of the water column and the lower net filtered 30-45 cm layer below this. Displacement volume was determined on board and the samples were preserved in 5% sea water-Formalin. Depending on the quantity, either entire samples or aliquots were analysed. Copepods and decapods were identified to families, chaetognaths and ostracods to species and others as taxonomical groups. Biomass and numerical abundances were computed to unit volume from the tow speed, duration of haul and mouth area of nets.

Vertical hauls of zooplankton were also made from these stations using a WP-2 net (200 μ m mesh width), either from 200 m depth or near bottom. Analyses of 12 of these samples from representative areas (Fig. 1) were carried out to compare depth distributions of organisms in neuston samples. Biomass and density values were converted to unit volume from depth of haul and mouth area of net.

Classification of neuston was adopted from HEMPEL and WEIKERT (1972). For microdistribution studies, samples of upper and lower nets were treated separately. For other comparative studies, average values of upper and lower nets of each station were considered. A *t* test was performed in order to differentiate significant variations (SOKAL and ROHLF, 1981).

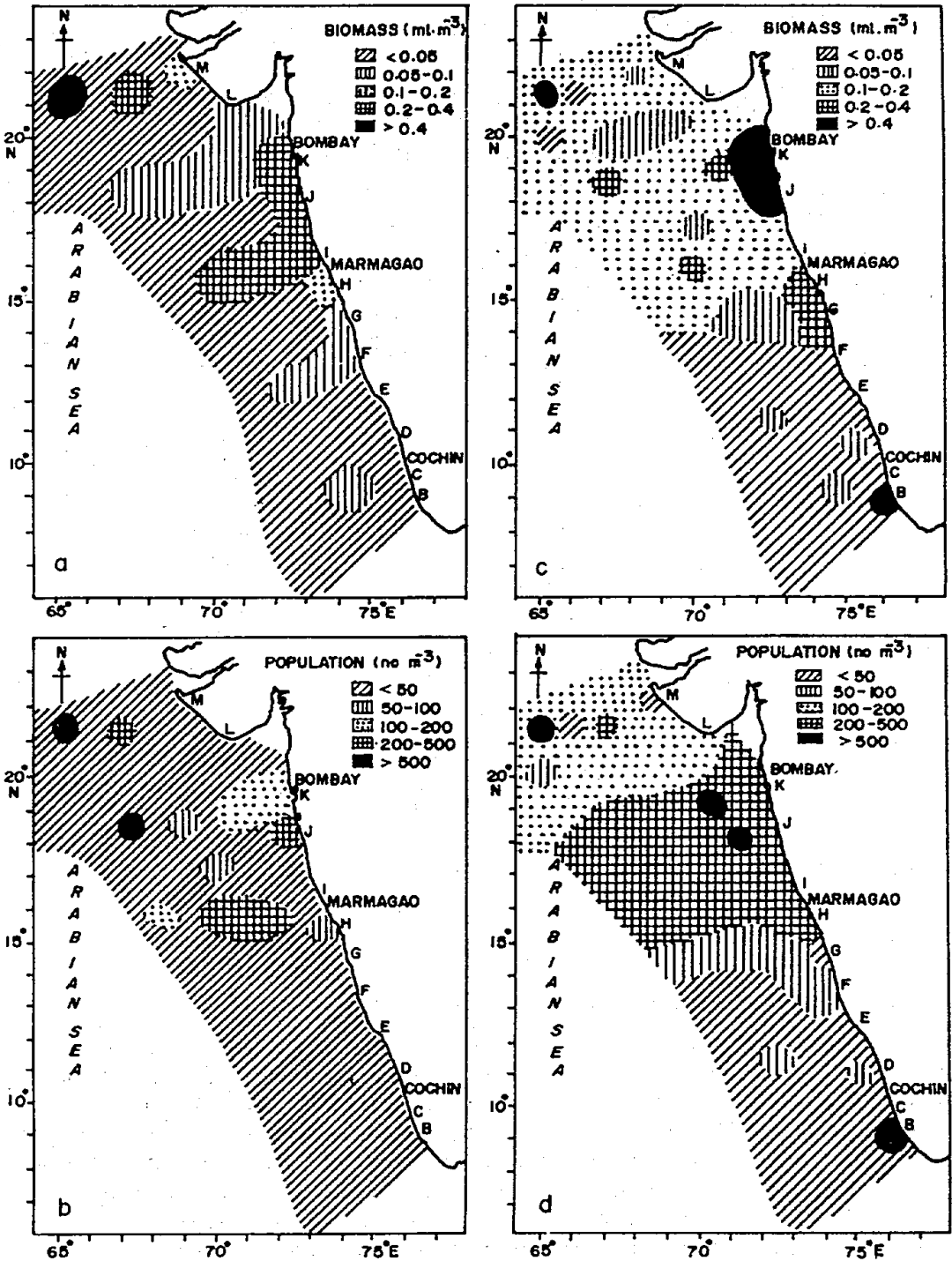


Fig.2. Distribution of zooplankton biomass (a) in the upper microlayer (c) in the lower microlayer and population density (b) in the upper microlayer and (d) in the lower microlayer.

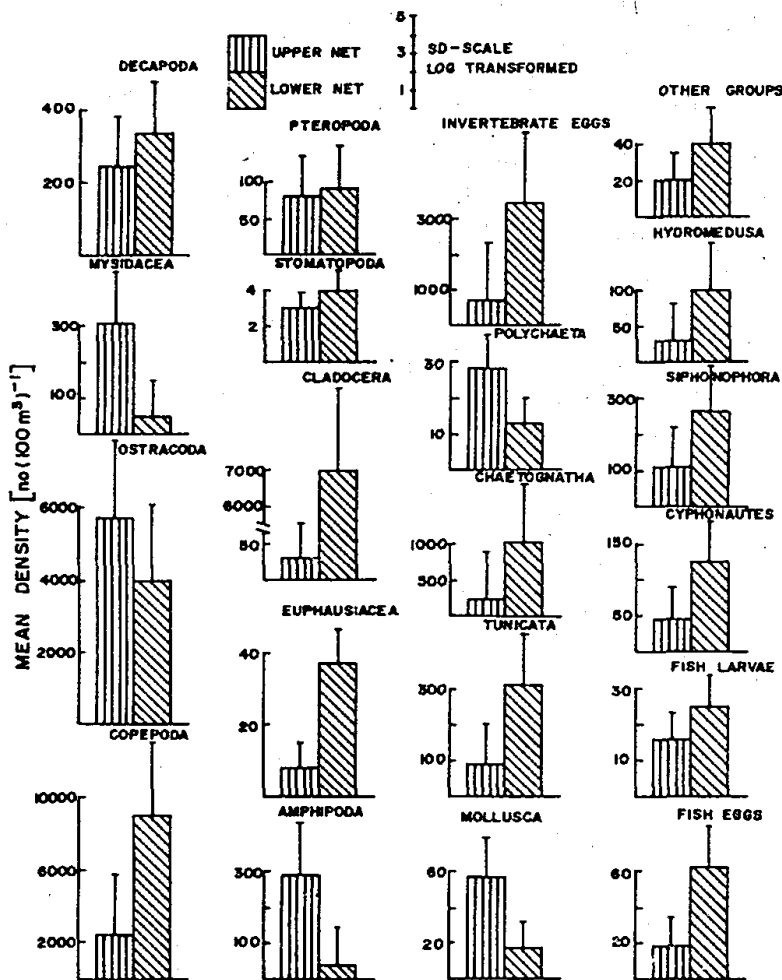


Fig.3. Mean densities of various zooplankton groups in the upper and lower microlayers.

RESULTS

Microdistribution of biomass and population densities

The surface microlayer (upper 15 cm) was generally poor in biomass ($<0.05 \text{ ml m}^{-3}$, Fig. 2a). However, along coastal belts, particularly between $15\text{-}20^{\circ}\text{N}$, relatively higher biomass was observed. A similar trend was noticed in the densities of organisms (Fig. 2b). Except for a few isolated patches of higher abundances, mostly in the northern region, they were less than 50 m^{-3} . In the lower layer (30-45 cm) also, biomass showed difference between south (generally $<0.05 \text{ ml m}^{-3}$) and north (generally $0.1\text{-}0.2 \text{ ml m}^{-3}$, Fig. 2c). Trends in abundances were also similar (Fig. 2d), the southern region had lower densities ($<50 \text{ m}^{-3}$) and the area between $15\text{-}20^{\circ}\text{N}$ registered higher densities ($200\text{-}500 \text{ m}^{-3}$). Biomass and numerical abundance in the lower layer (av. 0.14 ml m^{-3} and 264 m^{-3}) were 1.2 and 2.5 times higher than the upper layer (av. 0.11 ml m^{-3} and 103 m^{-3}). However, these variations were not statistically significant ($p > 0.05$).

Microdistribution of taxa

Nineteen major taxa were identified from the samples (Fig. 3). Ostracoda was the predominant group (mean, $5709 (100\text{m}^3)^{-1}$, 55.2%) in the upper microlayer followed by copepoda (mean, $2534 (100\text{m}^3)^{-1}$, 22.8%) and invertebrate eggs (mean, $674 (100\text{m}^3)^{-1}$, 6.5%). Other important groups were Amphipoda, Mysidacea, Decapoda, Chaetognatha, and Siphonophora. Copepods generally dominated in the southern region (40-90% of the total counts), but higher abundances of ostracods in the northern region (often exceeding 50% of total counts) masked this in the overall picture.

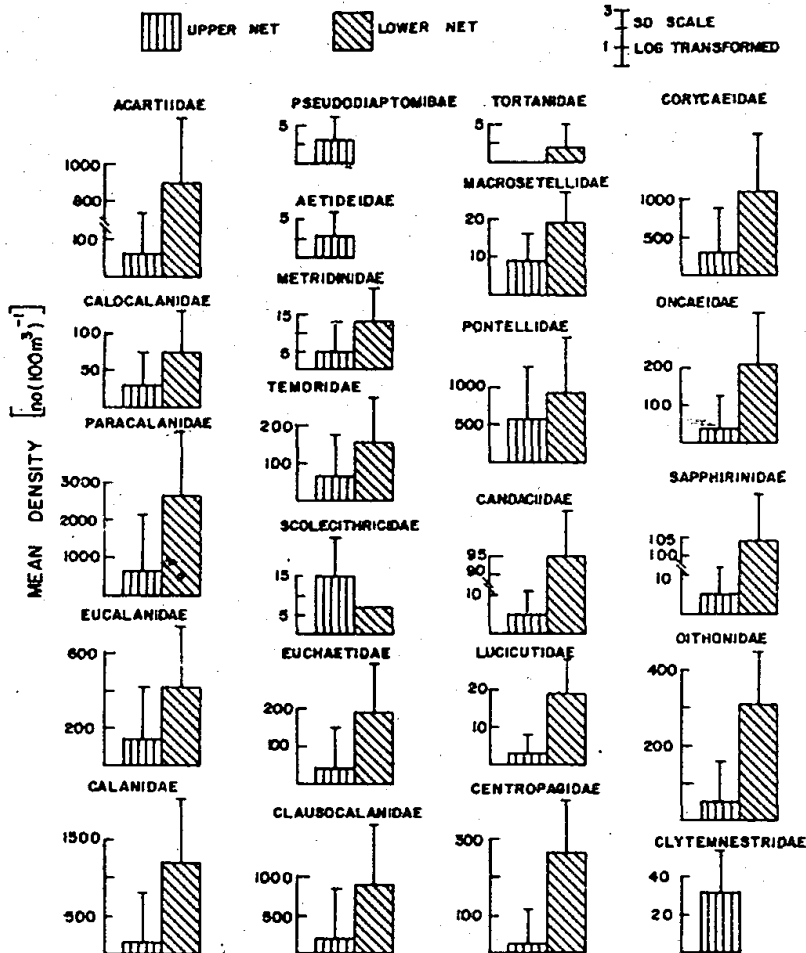


Fig. 4. Mean densities of copepod families in the upper and lower microlayers.

In the lower microlayer, Copepoda dominated (mean, $9039 (100\text{m}^3)^{-1}$, 34.6%) followed by Cladocera (mean, $6982 (100\text{m}^3)^{-1}$, 26.7%), Ostracoda (mean, $4007 (100\text{m}^3)^{-1}$, 15.4%) and invertebrate eggs (mean, $3433 (100\text{m}^3)^{-1}$, 13.2%). Higher percentage of Cladocera was due to a swarm at st. B1. Chaetognatha, Decapoda and Tunicata were other common forms. Abundances of amphipods and mysids were relatively less compared to the upper layer.

Copepods were represented by 23 families in the neuston layer (Fig. 4) and calanoids dominated. Members of families such as Paracalanidae, Pontellidae,

Clausocalanidae, Calanidae, Acartiidae and Corycaeidae were more common and abundant in both the layers. Among these, Paracalanidae and Pontellidae were more important, the former constituting 23.1 and 28.6% and the latter 26.2 and 10.3% of the total copepods, respectively in the upper and lower layers.

Among decapod crustaceans collected from the neuston layer (Fig. 5a), sergestids were most abundant (54.1 and 62.4% of decapods in the upper and lower layers, respectively) and were constituted mainly by adult and larval stages of *Lucifer* spp. Brachyuran zoeae were the next abundant component. Members of other families were sporadic and formed a small fraction of total decapods.

Eleven species of chaetognaths occurred in the neuston (Fig. 6a). Among them, *S. enflata* formed 43.7 and 46.7% of the chaetognath population in the upper and lower layers. Species such as *S. bipunctata*, *S. pacifica*, *S. bedoti*, *S. robusta*, *S. neglecta*, *S. regularis* and *S. ferox* individually shared 4-9% of the total chaetognaths.

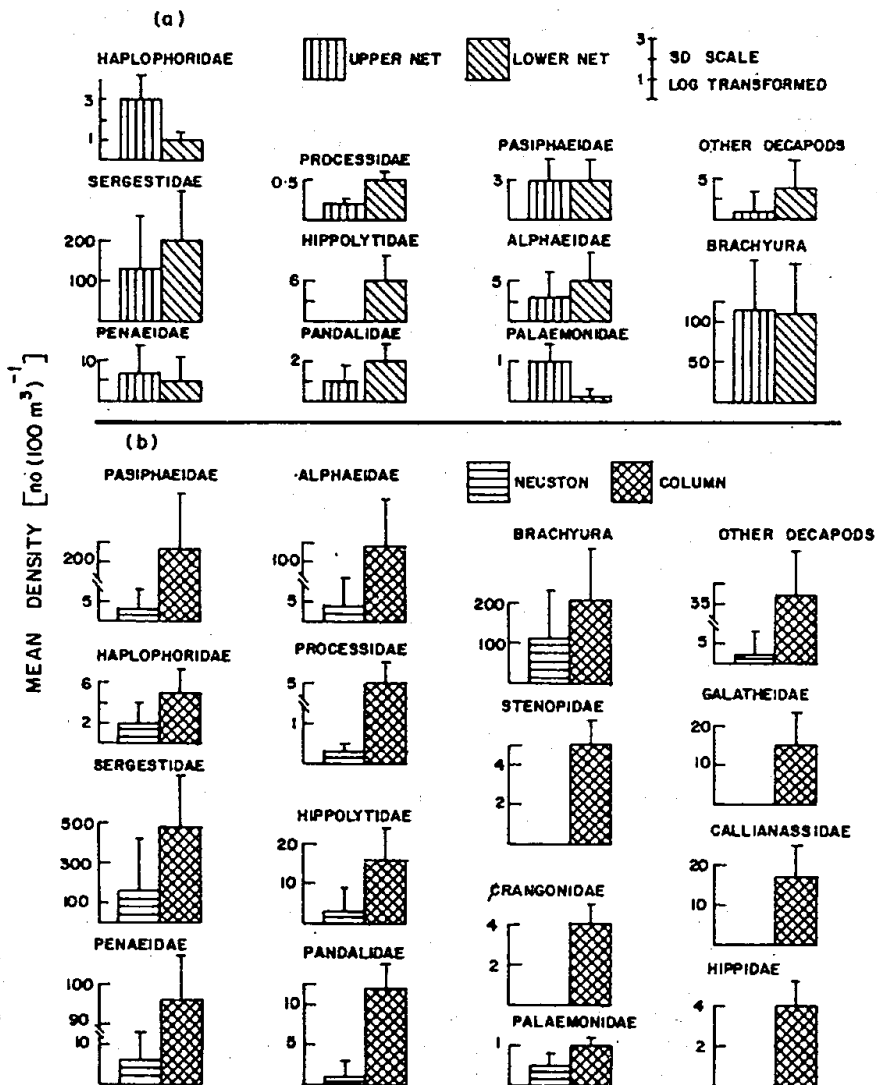


Fig.5. Mean densities of decapod families (a) in the upper and lower microlayers (b) in the neuston layer and water column.

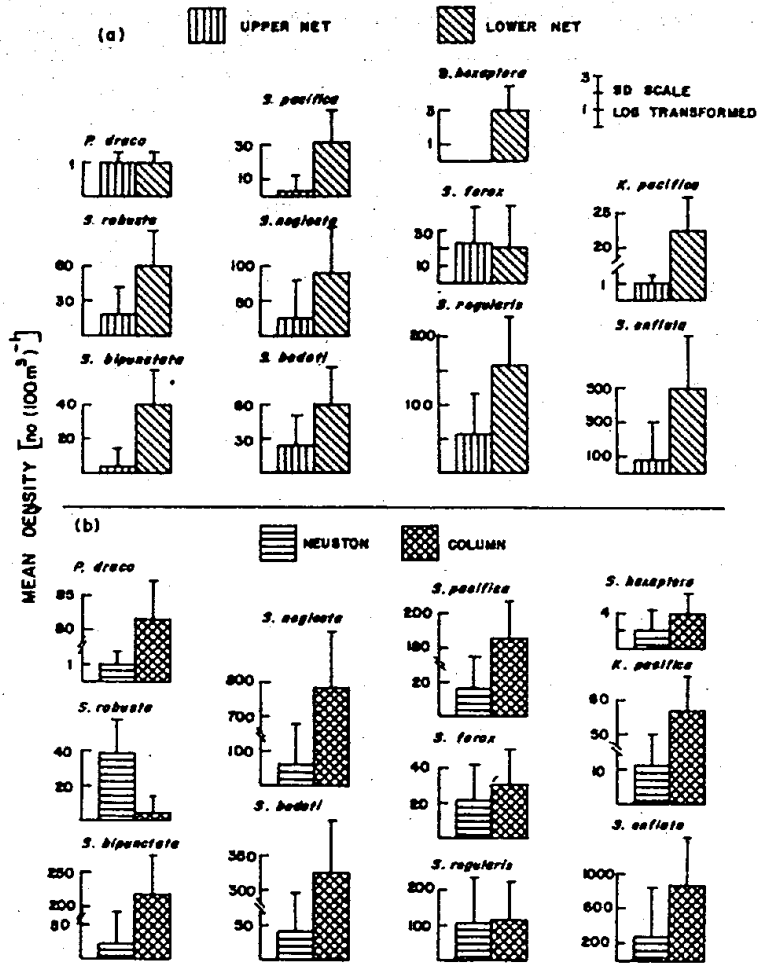


Fig. 6. Mean densities of chaetognath species (a) in the upper and lower microlayers (b) in the neuston layer and water column.

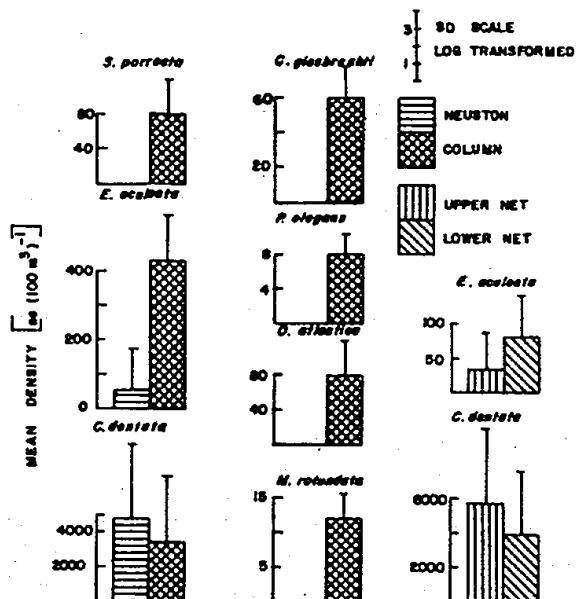


Fig. 7. Mean densities of ostracod species in the upper and lower microlayers and neuston layer and water column.

Table 1. Diel variation between upper and lower microlayers.

GROUPS	Day		Night	
	upper	lower	upper	lower
Siphonophora	70	222	150	309
Copepoda	1556	7978	3143	10101
Ostracoda	16	99	11402	7915
Amphipoda	11	8	562	68
Euphausiacea	11	48	10	42
Mysidacea	20	13	597	91
Decapoda	37	138	-	-
Polychaeta	49	11	-	-
Pteropoda	22	105	135	79
Mollusca	92	23	-	-
Chaetognatha	282	929	189	1135
Tunicata	91	258	89	366
Fish eggs	13	54	-	-
Cyphonautes larva	48	130	36	105
Invertebrate eggs	698	3814	645	3052
COPEPODA				
Calanidae	76	474	202	1895
Eucalanidae	29	105	243	724
Paracalanidae	396	1908	939	3352
Calocalanidae	24	49	33	103
Clausocalanidae	151	1330	262	461
Euchaetidae	17	175	61	200
Temoridae	41	85	88	223
Centropagiidae	27	44	24	482
Candaciidae	9	77	2	113
Pontellidae	362	930	-	-
Acartiidae	27	623	97	1077
Oithonidae	64	429	42	187
Oncaeiidae	28	115	39	303
Corycaeidae	306	1521	241	654
DECAPODA				
<i>Lucifer</i> spp	35	110	-	-
Acetes larvae	-	-	13	29
<i>Brachyura</i> zoeae	1	19	41	123
Megalopa larvae	-	-	187	78
CHAETOGNATHA				
<i>S. enflata</i>	88	292	84	697
<i>S. bipunctata</i>	5	32	-	-
<i>S. pacifica</i>	4	49	3	12
<i>S. bedoti</i>	5	17	44	102
<i>S. robusta</i>	23	74	13	43
<i>S. regularis</i>	79	212	35	104
<i>S. ferox</i>	36	15	10	26
OSTRACODA				
<i>C. dentata</i>	14	66	11336	7790
<i>E. aculeata</i>	1	32	62	129

(Significantly different groups/families/species only are given. Mean values are in 100m³)

Only 2 species of ostracods, viz. *Cypridina dentata* and *Euconchoecia aculeata* occurred in the neuston layer, (Fig. 7) the former forming > 97% of the total ostracods in both layers.

Some groups such as siphonophores, copepods, amphipods, euphausiids, mysids, chaetognaths, cyphonautes larvae and invertebrate eggs showed significant difference in their abundances between the layers. Among these only amphipods and mysids were more abundant in the upper layer. It was of interest to note that some forms such as *Physalia*, *Verella*, *Porpita*, *Halobates*, etc. which are known to be surface dwellers were very rare in our collections.

Spatial variations

Since biomass and numerical abundances showed spatial differences, the data were separately treated for areas south and north of 15°N. Biomass and total counts (av. 0.09 ml m⁻³ and 127 m⁻³ in southern area; 0.15 ml m⁻³ and 229 m⁻³ in northern area) did not show significant variations ($p > 0.05$). However, certain groups like siphonophores, copepods, ostracods, mysids, tunicates, cyphonautes larvae and invertebrate eggs had significantly higher abundances ($p < 0.05$) in the northern region. Similarly, variations in biomass and population densities between coastal and offshore waters (av. 0.17 and 0.1 ml m⁻³; 253 and 143 m⁻³, respectively) were not statistically significant, but population of copepods and decapods were consistently higher in the coastal waters.

Diel variations

Separate treatment of day and night samples showed that the day-time biomass and population density in the lower layer (av. 0.07 ml m⁻³ and 148 m⁻³) were significantly higher than those in the upper layer (av. 0.05 ml m⁻³ and 33 m⁻³), but the differences were not significant during night (av. 0.2 ml m⁻³ and 380 m⁻³; 0.17 ml m⁻³ and 173 m⁻³, respectively).

Most taxa, except a few like mysids, polychaetes and juvenile molluscs, had higher day-time abundances in the lower layer. Significant increase in populations of ostracods, amphipods, pteropods and megalopa larvae, besides mysids, occurred in the upper layer during night (Table 1). Nocturnal abundances of most groups in the upper layer were relatively more than those in the lower layer. The same was true for most families/species of Copepoda, Decapoda, Chaetognatha and Ostracoda (Table 1). Increase in abundances of the ostracod *C. dentata*, amphipods, mysids and megalopa larvae were particularly noteworthy.

Distribution in the water column

Mean zooplankton biomass (0.58 ml m⁻³) and abundance (768 m⁻³) in the water column were 4.6 and 4.2 times higher than those in the neuston layer (0.13 ml m⁻³ and 184 m⁻³). Copepods, on an average, constituted 67.8% (52288 (100m³)⁻¹) of the total population. This was followed by invertebrate eggs (13420 (100m³)⁻¹) and ostracods (4095 (100m³)⁻¹). Chaetognaths, decapods and tunicates were next in the order of abundance (Fig. 8).

Paracalanids dominated (11836 (100m³)⁻¹) the copepod composition (Fig. 9). Other important calanoid families were Clausocalanidae, Eucalanidae, Calocalanidae and Acartiidae. Cyclopoid *Oithona* and poecilostomatoids such as *Oncaea* and *Corycaeus* were also fairly abundant.

As in neuston layer, sergestids were the dominant decapod (52.8% of the total decapods and > 96% *Lucifer* spp.) distributed in the water column. Brachyuran zoeae followed next (12.4%). Penaeidae, Pasiphaeidae, Pandalidae and Alphaeidae were the other common families (Fig. 5b). Except *S. robusta*, all the chaetognath species encountered in the surface layer were more abundant in the column (Fig. 6b). Among them, *S. enflata* (864 (100m³)⁻¹, 35.1%) and *S. neglecta* (786 (100m³)⁻¹, 20%) were the major contributors.

Seven species of ostracods occurred in the water column (Fig. 7) as against 2 in the neuston layer. However, as in the latter, *C. dentata* (3447 (100m³)⁻¹, 59.2%) and *E. aculeata* (429 (100m³)⁻¹, 25.2%) were more abundant.

Variations between neuston layer and water column

Only a few groups like hydromedusae, ostracods, mysids, amphipods, cladocerans and fish eggs showed slightly higher abundance in the neuston layer compared to the

water column (Fig. 8), but these were not statistically significant. On the other hand, most of the other groups - particularly copepods, chaetognaths, decapods and invertebrate eggs - were significantly more abundant in the column. Among copepods (Fig. 9), pontellids alone showed higher abundance in the neuston layer ($p < 0.05$). Members of all decapod families occurred more abundantly in the water column and those of Callianassidae, Galatheidae, Crangonidae, Stenopidae and Hippidae were not collected from the neuston zone (Fig. 5b). Among ostracods, species such as *Conchoecetta giesbrechti*, *Spinoecia porrecta*, *Orthoconchoecia atlantica*, *Metaconchoecia rotundata* and *Paraconchoecia elegans*, which were fairly abundant in the column did not occur in the neuston layer (Fig. 7). Eventhough, *C. dentata* had higher density in the neuston layer, it was not significant.

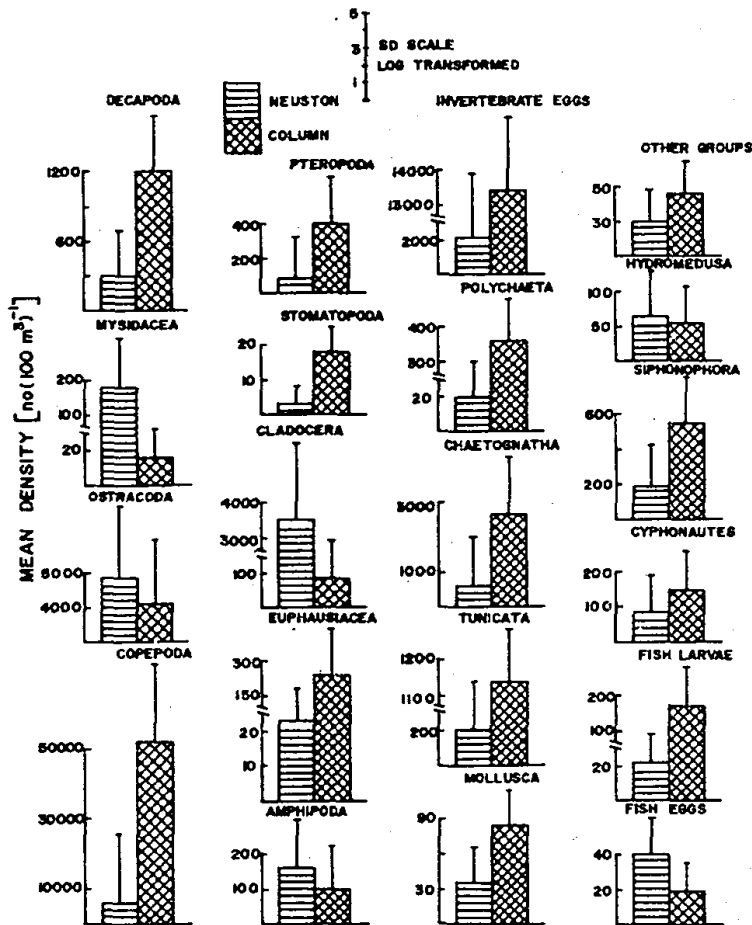


Fig.8. Mean densities of various zooplankton groups in the neuston layer and water column.

DISCUSSION

Microstratification of zooplankton during day-time, resulting in higher abundances in the lower microlayer, as observed in this study, has been reported particularly on bright days from the subtropical and boreal north-eastern Atlantic (HEMPEL and WEIKERT, 1972). Intense solar radiation and consequent increase in surface temperature

during day-time are attributed as factors restricting the distribution of organisms to the sub-surface microlayer. The upper microlayer had low day-time biomass and numerical abundances almost throughout the eastern Arabian Sea compared to the layer beneath. The cloud cover prevailing during this season probably reduced the intensity of solar radiation to some extent, but did not have any appreciable effect on sea surface temperature, which was around 28°C both during day and night, except in the southern most coastal belt where upwelling was observed (SHETYE *et al.*, 1990).

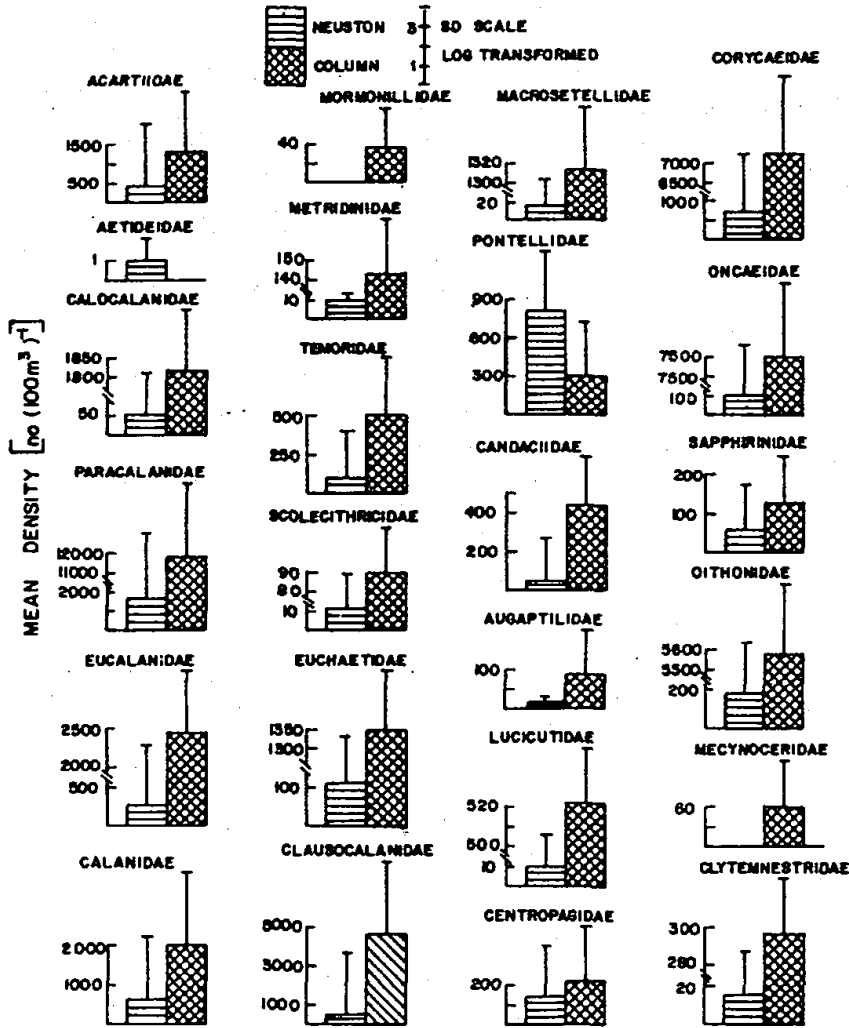


Fig.9. Mean densities of copepod families in the neuston layer and water column.

Low phytoplankton production in the upper microlayer is thought to be another factor responsible for poor zooplankton abundances in the surface layer (HEMPEL and WEIKERT, 1972; HOLDWAY and MADDOCK, 1983). However, the chlorophyll maxima during the present study was at or near the surface (SUMITRA-VIJAYARAGHAVAN and KUMARI, 1989; ROYAN, unpublished data). We feel that the avoidance of the upper microlayer by zooplankton during day-time is mainly due to the high visibility and is a typical escapist behaviour to avoid predators.

This is supported by the fact that significant increase occurs in this layer during night when the organisms migrate to this layer for foraging although there is no real decrease in the sea surface temperature. Hence, the contentions that avoidance of surface microlayer by zooplankton may be because of high temperature and/or poor availability of food may not be tenable especially for tropical zooplankton.

Some similarities were observed in zooplankton abundance in the neuston layer of subtropical and tropical waters. In the subtropical Atlantic, zooplankton in the lower layer, on an average, was twice more abundant than the upper layer (HEMPEL and WEIKERT, 1972). In our study also, it was around 2.5 times higher. Another similarity observed was the overwhelming abundance of crustacean components, dominated by copepods (also see NAIR *et al.*, 1989). Crustaceans formed the major component in the present study also, but the dominance of copepods (av. ca 30%) was overshadowed due to the abundance of ostracods (av. 27%) in the northern region and cladocerans (av. 19%) in the southern region. Nonetheless, wherever ostracods or cladocerans were not very abundant, copepods exceeded 50% of zooplankton population. HOLDWAY and MADDOCK (1983) have reported the dominance of taxa such as coelenterates, tunicates and molluscs in the lower latitudes. These, however, formed minor components in our study.

Nocturnal upward migration of many zooplankters enriches the neuston layer (DAVID, 1965; ZAITSEV, 1970; HEMPEL and WEIKERT, 1972; HOLDWAY and MADDOCK, 1983). During night-time, there was considerable increase in biomass and numerical abundances in both upper and lower layers (Table 1). This was mainly due to the vertical migration of many facultative and pseudoneustonic forms. Thus, during the night, no significant difference in microdistribution was discernible between the two layers. This obviously was due to a relatively higher increase in the upper layer than lower layer compared to respective day-time values. More or less a similar trend was observed for most of the taxa, families and species. This implies that a large number of zooplankton which normally dwell in the deeper layers during the day migrate to the neustonic realm during the night. However, some forms (such as calanoid copepod families Metridinidae and Augaptilidae) were very rare and it appears that they have the core population in much deeper waters, and thus qualify to become the pseudoneuston. But others, particularly ostracods (*C. dentata*), amphipods, mysids, pteropods, megalopa etc., which had a nocturnal dominance in the upper microlayer are essentially the facultative neuston. It is noteworthy that nocturnal increase of some of these groups also occurred in the Mediterranean and Atlantic during autumn when the day and night periods were similar to those in the tropics (HOLDWAY and MADDOCK, 1983). Very low biomass and abundances observed in the upper microlayer during day-time indicate the downward movement and aggregation of zooplankton in the lower microlayer.

Our data support the observation of HEMPEL and WEIKERT (1972) that zooplankton dwelling in the neuston biotope is not distinctly different from that of the water column. Almost all groups, families and species recognised in the neuston layer were more abundant in the column. Some groups (such as hydromedusae, ostracods, amphipods, mysids, cladocera, and fish eggs) were relatively more in the neuston, but the differences were not significantly different from those in the water column. The only exception was pontellid copepods, which were consistently more abundant in the neuston layer and thus appear to be euneustonic forms. Several species of pontellids have been recognised as permanent inhabitants of the surface layers (SHERMAN, 1963, 1964; ZAITSEV, 1970; RAYMONT, 1983). Thus it could be generally concluded that in the tropics, most of the

zooplankton dwelling the neuston layer are essentially those which are distributed in the water column and that neustonic zooplankton increases considerably during night as a result of vertical migration of column population.

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