

Zooplankton of the southwest coast of India: abundance, composition, temporal and spatial variability in 1987

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Abstract - During early southwest and northeast monsoon periods of 1987, zooplankton standing stocks and abundances were high all along the west coast of India. Swarms of zooplankton were common in the shelf areas resulting in a low diversity - high biomass community. Paradoxically, this happened when nutrient concentrations and phytoplankton biomass were low. The zooplankton 'high' might have arisen from an earlier nutrient enrichment through land run-off and increased phytoplankton or through the microbial loop. Distinct coastal and offshore communities among copepods were discernible. Their distributions did not show much change among seasons indicating an ability to maintain their positions in the preferred niches. Niche-partitioning among congeners was indicated.

INTRODUCTION

The south and central west coasts of India (south of 20°N) are important areas in commercial fishery accounting for about 53% of the exploited catch from the country (calculated from CMFRI, 1986). Planktivorous fishes such as sardines, mackerels and anchovies form the mainstay of the pelagic fishery. Information on zooplankton from the area mainly comes from a couple of reports on standing stock (RAJ and RAMAMIRTHAM, 1981; JOHANNESSEN *et al*, 1987) and a few localised studies on composition (e.g. HARIDAS *et al*, 1980). Environmental and biological features of this region are strongly influenced by the monsoons and the scenario along the central west coast during late southwest monsoon has been outlined in a recent study (MADHUPRATAP *et al*, 1990). This paper examines the structure of the zooplankton community along the southwest coast (south of 15°N) during and after the summer monsoon.

MATERIALS AND METHODS

Zooplankton samples were collected on board ORV *Sagar Kanya* between 17 June and 10 July 1987 (early southwest monsoon period). Samples were collected from 37 stations (transects located perpendicular to the coast, Fig. 1) in vertical hauls using a WP-2 net (mesh width - 200 µm). Depth of sampling was 200 m in open waters and near bottom (varying from 40 to 110 m) in shelf area. Between 29 November and 19 December 1987 (early northeast monsoon period), sampling was repeated at these stations (except st.no. 36 and 37).

Immediately after each sampling, biomass was estimated as displacement volume and half of the sample (split by a Folsom Plankton Splitter) was dried to constant weight at 60°C in order to estimate the relation between wet volume and dry weight. The rest of the sample was preserved in 4% Formalin-sea water. Organisms were identified and enumerated from the entire sample or quantitative subsamples. Data were not separated for day/night differences.

In the ensuing account, coastal data refer to those collected from stations located near the coast and slope data those hugging the 200 m depth contour. Clustering of copepod genera/species was done by group-average sorting using Bray-Curtis measure after standardisation and then transforming the data using root-root method (FIELD *et al*, 1982). Data was reduced to exclude those genera/species which occurred in low numbers once or twice during each cruise.

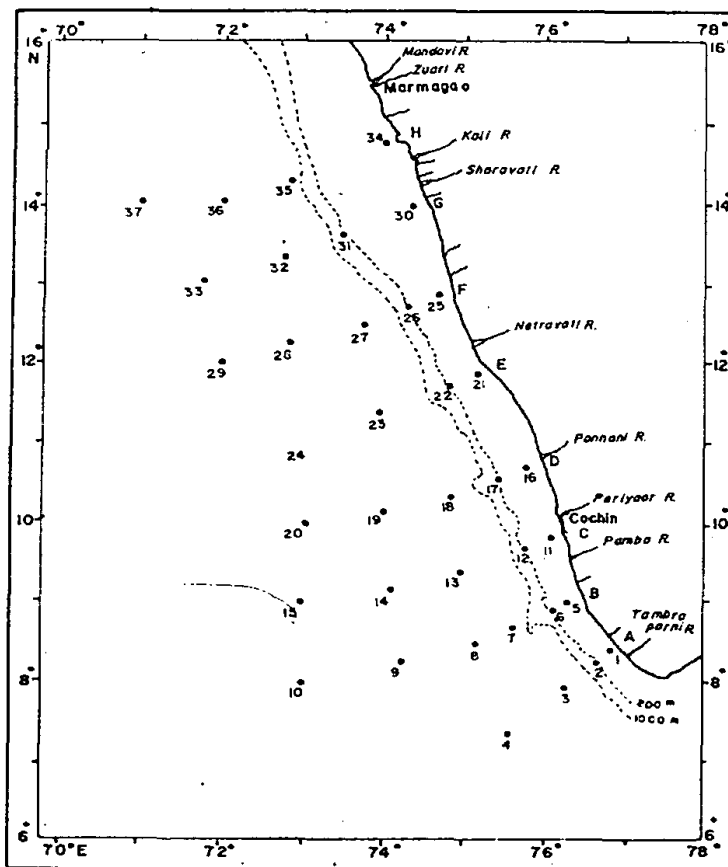


Fig. 1. Station locations

RESULTS

Environment

One of the major process which influences biological productivity along the west coast is coastal upwelling during the southwest monsoon period. Upwelling appears to begin earlier in the south compared to the northern areas (see MADHUPRATAP *et al*, 1990). Physical environment during the present study was described by SHETYE *et al*, (1990, 1991). In summary, during June-July 1987, upwelling occurred in the southernmost coastal area (section A, Fig. 1) indicated by lowering of nearshore surface temperature by about 2.5 °C. Near the coast, surface flow was equatorward (100 m deep and 150 km wide). Signatures of upwelling became obscure towards north. On the other hand, during November-December, downwelling occurred along the continental slope. Surface flow was poleward against the wind field. This flow, about 150 m deep and 400 km wide carrying low salinity Bay of Bengal/Equatorial water, appears to be driven by thermohaline forcing due to increase of density from south to north.

Rather surprisingly, during both periods of observation, nutrients (nitrate, phosphate and silicate) concentrations were very low - usually at undetectable levels in the upper 30 m - in coastal as well as offshore areas (segmented flow analysis using SKALAR Auto Analyser). Surface oxygen levels were uniform ranging from 400 to 417 $\mu\text{g at l}^{-1}$.

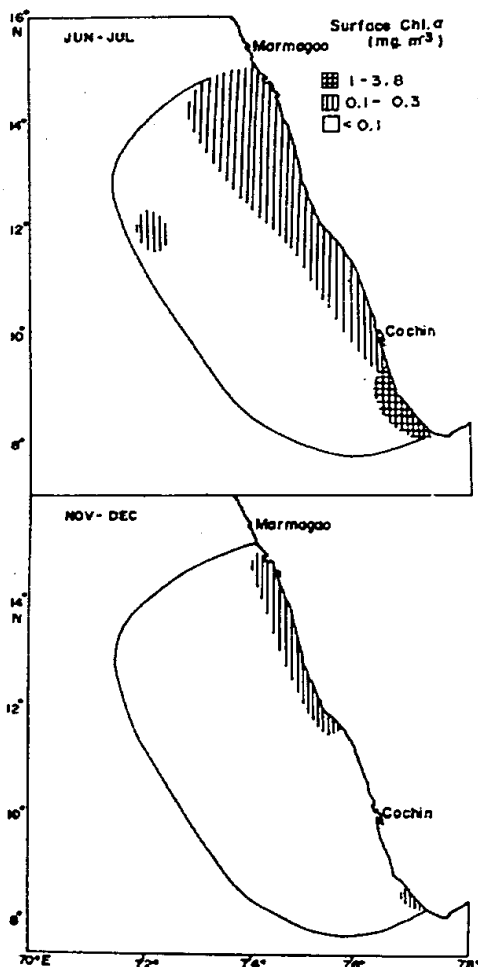


Fig. 2. Distribution of surface chlorophyll *a* in the study area during June-July (adapted from SUMITRA-VIJAYARAGHAVAN and KUMARI, 1989) and November- December (data courtesy J.P. ROYAN)

Phytoplankton biomass in surface layers was generally low during June-July except in the southernmost coastal area where upwelling was noticed (Fig.2). Plant biomass in the water column and primary production rates were also low (see SUMITRA-VIJAYARAGHAVAN and KUMARI, 1989). Values were still lower during northeast monsoon (data courtesy J.P. ROYAN). The chlorophyll *a* maximum occurred near surface in June-July while there was no trend in November-December.

Zooplankton standing stock and composition

Although the phytoplankton biomass was low, zooplankton standing stocks were high during both periods of observation (Fig. 3, Table 1). Higher standing stock occurred

Table 1. Averages of biomass (ml.m^{-3}) and abundances (no.m^{-3}) of major groups of zooplankton in June-July and November-December 1987 (values of the latter season in parentheses)

	Coast	Slope	Open Ocean
Biomass	1.9 (1.7)	0.4 (0.6)	0.2 (0.3)
Hydromedusae*	4 (2)	7 (0)	1 (0)
Siphonophora*	4 (30)	5 (17)	2 (3)
Ctenophora*	1 (16)	0 (0)	3 (0)
Polychaeta*	14 (9)	29 (1)	2 (1)
Chaetognatha*	20 (63)	15 (52)	12 (19)
Cladocera	244 (143)	9 (4)	1 (0)
Ostracoda	40 (60)	23 (30)	11 (11)
Amphipoda*	0 (3)	1 (1)	1 (1)
Decapod larvae	66 (8)	2 (5)	2 (3)
Sergestidae	248 (14)	2 (0)	1 (0)
Euphausiacea	9 (0)	0 (1)	5 (1)
Copepoda	411 (470)	645 (517)	374 (189)
Pteropoda	34 (24)	1 (22)	1 (1)
Thaliacea	35 (8)	1 (1)	1 (1)
Fish larvae*	2 (6)	1 (1)	1 (1)
Total	1136 (850)	750 (661)	417 (236)

*Groups considered carnivores in Table 3, trophic status of copepods according to genera, see text.

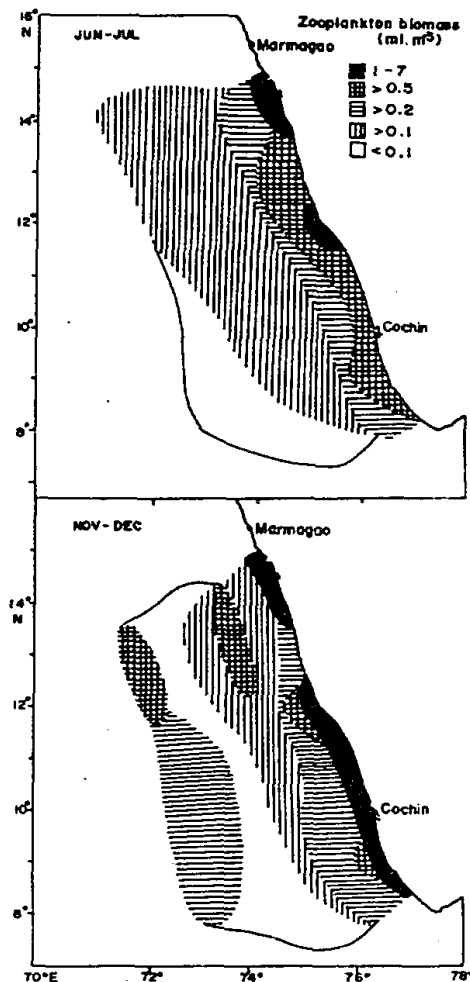


Fig.3. Distribution of zooplankton biomass during the two seasons

over the shelf area, but most of the offshore areas were also rich in zooplankton. This trend is clearer from zooplankton abundances (Fig. 4); the entire study area had populations well over 100 m^{-3} . On average, standing stock and zooplankton population were higher in June-July. Dry weight of zooplankton samples ranged from 40 to 263 mg ml^{-1} wet volume (mean $89.4 \pm 44 \text{ mg ml}^{-1}$, $n = 45$).

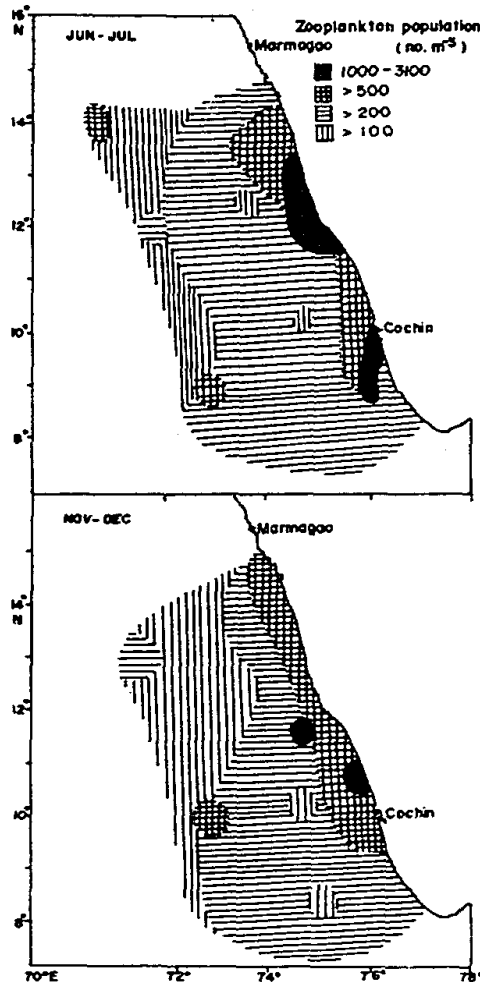


Fig. 4. Distribution of zooplankton population during the two seasons

Zooplankton swarms were common, especially in coastal areas (Fig. 5, numbers indicating swarms of organisms were arbitrarily chosen as above 100 m^{-3} , but aggregations above 50 m^{-3} of larger forms such as Thaliacea, Pteropoda, Euphausiacea, Chaetognatha and Siphonophora are also included). Filter or mucous feeders such as cladocerans, ostracods, sergestids, thaliaceans, pteropods and some copepods were common, but carnivores such as chaetognaths, siphonophores and the copepods *Oncaea* and *Corycaeus* also swarmed.

Average abundances of major groups of zooplankton in coastal, slope and oceanic waters are presented in Table 1. There was no significant difference ($p > 0.05$, t test) in total population between the two periods of observation in coastal and slope regions, but reduction was noticed during November-December ($p < 0.05$) in open waters.

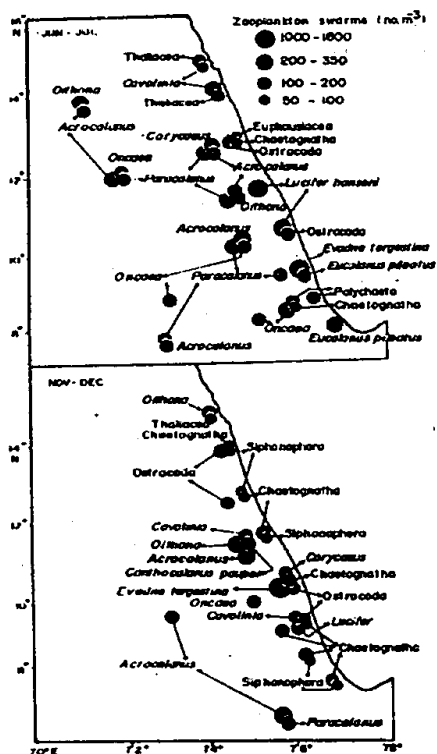


Fig. 5. Incidences of zooplankton swarms in the study area

Table 2. Diversity indices (D , MARGALEF, 1968) and equitability indices (E , HEIP, 1974) in the study area during June-July and November-December (values of the latter season in parentheses).

	D		E	
	Average	Range	Average	Range
Coast	3.68 (4.47)	2.3-5.3 (3.3-5.3)	0.29 (0.44)	0.13-0.55 (0.30-0.55)
Slope	4.37 (5.45)	3.3-5.8 (4.1-6.4)	0.43 (0.39)	0.36-0.55 (0.26-0.47)
Open ocean	5.36 (6.72)	4.2-6.8 (5.3-8.4)	0.40 (0.43)	0.17-0.64 (0.23-0.58)

Table 3. Percentage of composition of different trophic groups during June-July and November-December (values of the latter season in parentheses)

	Coast	Slope	Open ocean
Carnivores	8.9 (32.0)	23.6 (38.0)	30.2 (36.6)
Herbivores	85.0 (53.4)	44.9 (48.6)	51.1 (50.7)
Omnivores	6.1 (14.6)	31.5 (13.4)	18.7 (12.7)

Copepods were most abundant, forming 50% and 67% respectively of the zooplankton population during the two seasons. In coastal waters cladocerans and sergestids comprised 21% each during June-July while the former contributed about 17% during November-December. While Table 1 gives the overall averages, it must be appreciated that some organisms such as polychaetes, pteropods and chaetognaths were dominant in certain areas (as indicated in Fig. 5). It can also be seen that although a few groups or species tended to be more abundant, none of them dominated large areas.

These trends are reflected in the diversity indices (Table 2). During June-July, coastal waters showed low diversity and equitability and there was an increase offshore. In November-December, the trend was similar, but diversity increased in all areas.

Herbivores dominated the coastal areas during June-July (Table 3, classification of trophic status of copepods based on Timonin, 1971, other groups of carnivores as indicated in Table 1). A few organisms such as ostracods, pteropods, the cladoceran *Evadne tergestina*, the sergestid *Lucifer hansenii* and some copepods *Eucalanus pileatus*, *E. crassus*, *Paracalanus* spp., *Acrocalanus* spp. and *Canthocalanus pauper* mainly accounted for this. On the other hand, copepods such as *Temora turbinata* and *Centropages tenuiremis* which are also known to reach very high abundances during upwelling season along the Indian west coast (MADHUPRATAP *et al*, 1990) were poorly represented. Although herbivores were also abundant in offshore waters, the importance of omnivores and carnivores increased in these areas. By November-December, carnivores formed a sizeable part of the zooplankton community in the entire region. This was due to the increase of populations of siphonophores, ctenophores, chaetognaths and some cyclopoid and poecilostomatoid copepods.

Distribution of copepods

In all, 59 and 64 copepod genera/species were identified from samples collected in June-July and November-December respectively. Calanoids were dominant especially in coastal waters during June-July (Table 4). Cyclopoids and the carnivorous poecilostomatoids were the other important orders.

Table 4. Relative abundances (%) of various orders of copepods during June-July and November-December (values of the latter season in parentheses).

	Coast	Slope	Open ocean
Calanoida	89 (59)	58 (63)	54 (62)
Cyclopoida	4 (20)	10 (16)	13 (16)
Poecilostomatoida	6 (20)	25 (20)	28 (20)
Harpacticoida	1 (1)	6 (1)	4 (1)
Mormonilloida	0 (0)	1 (0)	1 (1)

Among calanoids, the genera *Paracalanus* and *Acrocalanus* were uniformly abundant in all areas and both seasons (16 to 36% of the total copepod population). In coastal waters, during June-July, species of families Eucalanidae (23.5%), Acartiidae (10.5%), Calanidae (10%), and Centropagidae (4%) were other dominant members of the community. During November-December, Acartiidae (10.5%), Centropagidae (9.5%), Eucalanidae (8%), Temoridae (6%) and Calanidae (4%) were well represented. During June-July, dominance of the aforementioned families (except Paracalanidae) declined

in slope waters and open waters further offshore forming 0.6 to 2.8% of the total copepods). However, species belonging to other families such as Calocalanidae, Clausocalanidae, Euchaetidae, Scolecithricidae, Lucicutiidae, Heterorhabdidae, Candaciidae and Pontellidae were more or less equally represented (0.5 to 3.4%). During November-December the trend was identical except that calanids, eucalanids and clausocalanids occurred in greater numbers in offshore areas as well (4 to 8.3%).

Species composition of the epipelagic forms during the two seasons was quite similar. Notable exceptions were the absence of *Nanocalanus minor* and *Mesocalanus tenuicornis* in June-July. A few other species such as *Calocalanus tenuis* and coastal forms such as *Metacalanus aurivilli*, *Centropages orsinii* and *Labidocera pectinata* which occurred in November-December albeit scantily were also not recorded in this season. Conversely, *Calocalanus pubes*, *Candacia pachydactyla* and the estuarine species *Pseudodiaptomus compactus* recorded in June-July were not captured in November-December. Other differences in composition were caused by occasional occurrences of deep water forms in either season.

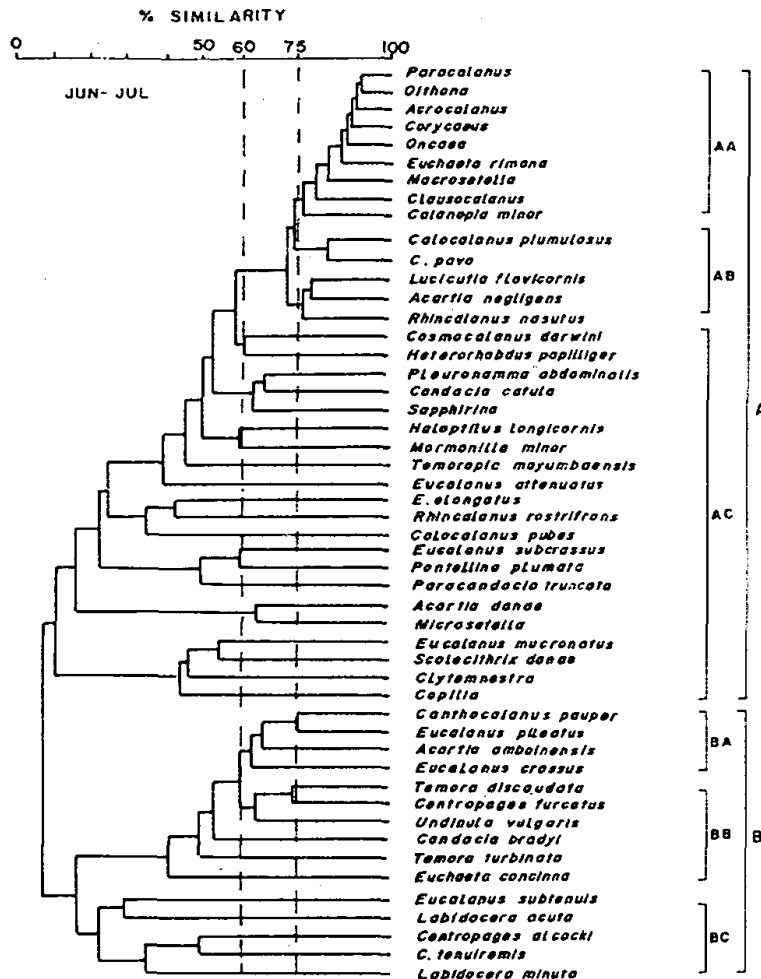
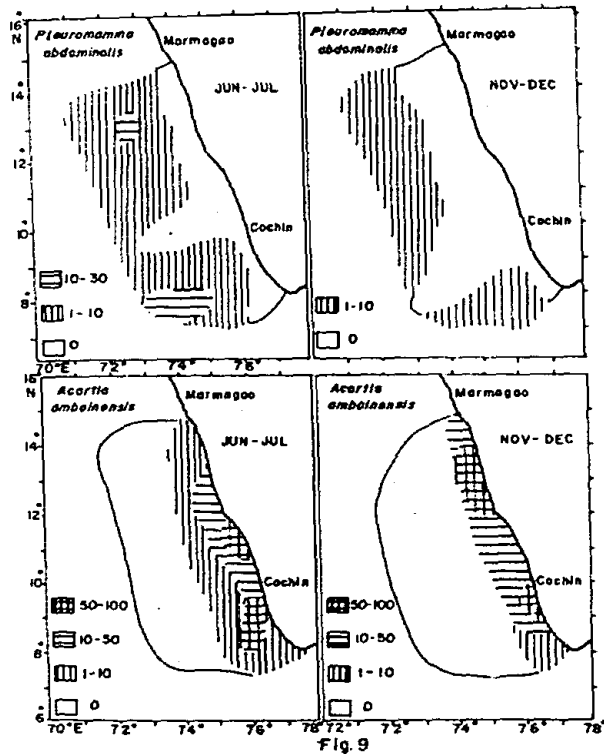
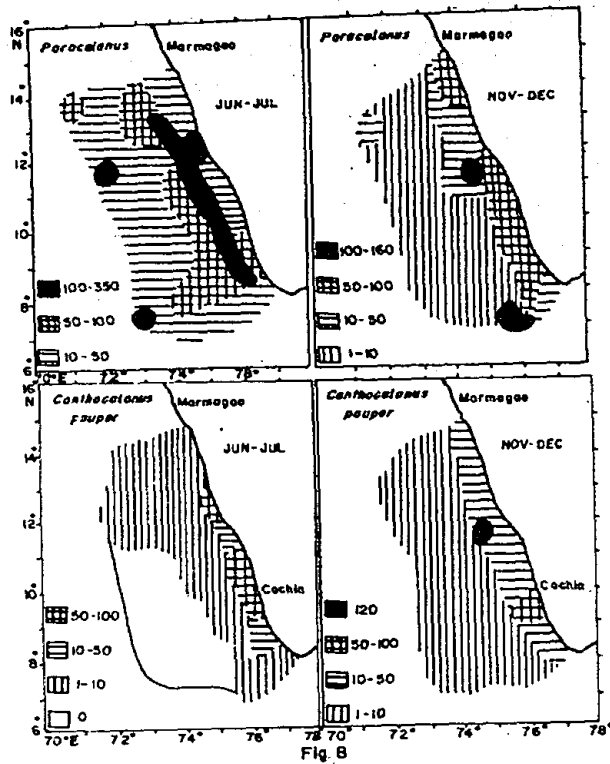


Fig. 6. Results of cluster analysis showing affinities of copepod genera/species during June-July. See text for explanation of groups



Figs. 8 & 9. Typical distributions of representative species from the clusters during the two seasons. Data are in numbers per cubic meter

Cluster AA in November-December consists of slope species of June-July which were now more or less evenly distributed in both slope and coastal waters (e.g. *Paracalanus*, Fig. 8). Two other species which were predominantly coastal in the earlier season, viz. *Canthocalanus pauper* and *Eucalanus pileatus*, joined this group (Fig. 8). Other coastal species (cluster AD) had similar distributions as in the previous season. AB and AC species primarily occurred in the slope waters and AC occurred in lower numbers. BA and BB species were generally absent in coastal waters, BB having lesser abundances.

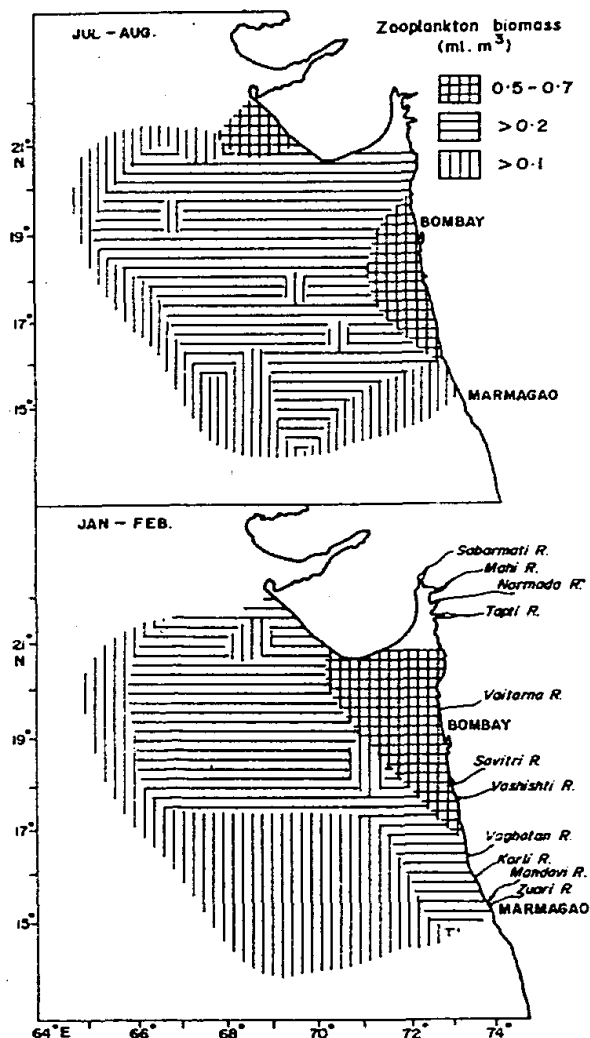


Fig. 10. Distribution of zooplankton biomass in northern areas during southwest and northeast monsoon seasons (data courtesy S.R.S. NAIR and G. PADMAVATI)

On the whole, distribution patterns of species between the two seasons did not differ much except that a few calanoids such as *Calocalanus pavo*, *C. plumulosus* and *Acartia negligens* occurred in coastal waters as well during November-December. Maximum number of species occurred away from the coast in slope and open ocean waters and were generally present in both seasons. Maximum abundances were

recorded in coastal/slope species and they were somewhat less abundant during the northeast monsoon season. The most abundant copepod species in coastal, slope and oceanic areas were those belonging to clusters BA, AA and AB respectively during June-July and clusters AA, AB and BA respectively during November-December. Congeners were generally weakly linked. Distributions of representative species are given in Figs. 8 and 9.

DISCUSSION

Two long-term studies conducted during 1963-69 and 1971-75 (RAJ and RAMAMIRTHAM, 1981; JOHANNESSEN *et al*, 1987) show that zooplankton standing stock is quite high along the southwest coast of India during summer monsoon period. High zooplankton biomass, especially in coastal waters, develops by June-July, persists until September- October and shows a general decrease thereafter. There is some interannual variability, the duration of the 'high' may be curtailed or prolonged.

The present data show that in 1987, the south west coast had the 'high' from June through December. The paradox is that while biomass of zooplankton was high, nutrient concentrations and phytoplankton biomass were low and upwelling was confined to the southern most part of the coast during June-July. Furthermore, during summer monsoon period of 1987, the 'high' was not confined to the southwest coast alone but extended to northern regions as well (Fig. 10, July-August data courtesy S.R.S. NAIR) where upwelling does not occur. By January-February 1988, there was a slight reduction of standing stock in this area (data courtesy G. PADMAVATI). In this northern area also, nutrient concentrations and standing stock of phytoplankton were low. Even considering that the observations were only data points in a continuum, the coincidence in both seasons is intriguing.

Table 5. Rainfall data (mm) along the south west coast during 1987 (Data courtesy Indian Metereological Department)

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
8° 30' N	116	196	176	48	353	162	414	198	333
10° N	70	125	634	227	596	131	329	251	32
12° N	0	48	983	219	681	98	238	147	2

One obvious explanation for the low biomass of phytoplankton is the grazing pressure by herbivorous zooplankton. If so, it follows that an earlier increase of phytoplankton must have occurred to favour such an increase of zooplankton and that the earlier bloom used up the nutrients in the area. Note that the phytoplankton biomass was high in the southern area where upwelling was operative. The low nutrient levels in this area might have resulted from active uptake.

But what was the source of nutrients to initialise the increase of phytoplankton all along the coast? The southwest coast has no major river systems, but there are several smaller rivers all along (Fig. 1). Further north, two major river systems- the Narmada and Indus, apart from other smaller rivers - are present. Could it be that the river and land run-off brought in the nutrients into the coastal waters? Rain fall data for 1987 along the southwest coast (Table 5) suggests such a possibility. Although uneven, rains were distributed from May to November. This would have episodically brought nutrients into the coastal environment. A further possibility is that during the northeast monsoon, the northward surface flow bringing low salinity water from

the Bay of Bengal may be nutrient rich. There are several major river systems along the east coast and during early northeast monsoon period (October-November), heavy rains occur in this area. Fairly high percentages of carnivores in fringe areas during June-July and even in coastal waters during November-December suggest that some time has elapsed between enrichment and observations.

There is yet another way the paradox can be explained. It is now becoming increasingly evident that the so called herbivorous zooplankton actively or even selectively feed on microzooplankton such as ciliates (e.g. WAIDNYANA and RASSOUL-ZADEGAN, 1989). The microzooplankton, in turn, ingest bacteria keeping bacterial concentrations low (SHERR and SHERR, 1987). Although we do not have quantitative data on microzooplankton, ciliates were observed in large numbers in water samples collected from coastal waters (MADHUPRATAP, unpublished data). Total counts of bacteria in the coastal waters during southwest monsoon were low, averaging $2.2 \times 10^5 \text{ ml}^{-1}$ (S. NAIR, personal communication). Thus a short-circuit in the microbial loop might have led to the high zooplankton population. A simulation model by PARSONS and KESSLER (1986) shows that the initial presence of zooflagellates (microzooplankton) during the introduction of freshwater plumes (as would have happened in the coastal waters during rainy season) can enhance zooplankton production by several hundred percent.

Southwest monsoon of 1987 is generally regarded as a poor season. Usually still heavier rains occur during this period. Thus there is a distinct possibility that increased biological productivity happens each year during this season from run-off either through enrichment or the microbial loop. Of course, during the later part of the southwest monsoon (July-September), progression of upwelling to the northern areas influences the productivity of the entire south and central west coast of India (see MADHUPRATAP *et al*, 1990).

The low diversity indices in the coastal waters resulted from a few organisms swarming to contribute the large biomass. Such swarms appear to be a recurring feature along the west coast during the southwest monsoon (NAIR *et al*, 1991). The fact that most of them are filter/mucous feeders also point out the availability of sufficient primary food. Organisms living in inshore waters seem to be adapted to high food concentrations and unable to thrive in offshore areas where food levels are low (cf. PAFFENHOFER and STEARNS, 1988). Increase of diversity and evenness in offshore communities of low biomass is common (cf. MADHUPRATAP, 1987).

The fact that species composition and distribution patterns of copepods did not change much over the two sets of observation shows that the species are highly adapted to their niches. Further, they are able to maintain their populations in a particular area (Fig. 9). Weak associations between congeners indicate niche partitioning. Along the southwest coast of India, increase of population of coastal and slope species along with coastal enrichment has been observed earlier also (HARIDAS *et al*, 1980). Coastal and slope populations reach still higher abundances in response to upwelling signals (MADHUPRATAP *et al*, 1990). In conclusion, the present data and earlier studies show that the southwest and early northeast monsoon seasons favour high biological productivity along the west coast of India. Apart from upwelling, inputs from freshwater run-off appear to be an important mechanism leading to this in coastal waters.

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