

Zooplankton production, composition and diversity in the coastal waters of Goa

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Spatial and temporal variability in zooplankton production, composition and diversity in the coastal waters of Goa were studied. Zooplankton production was bimodal with primary peak during September-October and secondary peak during March-April. Secondary production computed from the zooplankton biomass values fluctuated between 24.7 and $87.2 \text{ mgC.m}^{-2}.\text{d}^{-1}$. Herbivores dominated the zooplankton community and copepods were most abundant. Cladocerans, pteropods and decapod larvae, sergestids, siphonophores, chaetognaths and fish eggs were the other common taxa. Zooplankton population was never dominated by a single group. Swarms of copepods (*Temora turbinata*), cladocerans (*Evadne tergestina*), and pteropods (*Creseis acicula*) occurred in the nutrient enriched environment during early postmonsoon months (October-November). Swarming of these zooplanktonic forms resulted in high biomass but low diversity community. Faunal and species diversity were enhanced with increase of carnivores in the ecosystem. An inverse relationship between zooplankton biomass and species diversity was the general trend. A total of 58 species of pelagic copepods belonging to calanoids(42), cyclopoids(12) and harpacticoids(4) were identified. Their occurrence and abundance were influenced by seasons, depth of sampling station and prevailing hydrographic conditions. Niche partitioning among congeners was evident.

Zooplankton are small heterotrophic animals, inhabiting the oceans at all depths and occupy almost every type of ecological environment. They are considered as the chief index of utilization of aquatic biotope at the secondary trophic level. A general account of zooplankton distribution in the nearshore waters of Goa, mostly till 10 m depth zone, was given earlier^{1,2}. The present communication deals with zooplankton production, temporal and spatial variability in common groups and their species, and diversity indices in the coastal waters of Goa up to 50 m depth contour.

Materials and Methods

Monthly zooplankton samples were collected at 4 stations located along a perpendicular transect off Aguada. The sampling stations were located at 5, 10, 25 and 50 m depth zones (Fig. 1). Zooplankton samples were collected by surface hauls (10 m) using Heron-Tranter net (mouth area 0.25 m^2 , mesh size $300 \mu\text{m}$) fitted with a calibrated flowmeter. The sampling was carried out between 0600 to 1200 hrs during September 1986 to May '87. Zooplankton samples were preserved in 5% buffered formaldehyde and analysed for determination of biomass, occurrence and abundance of major taxa and their common species. An aliquot (5 to 10% of total sample) was examined for enumeration of organisms.

The number was calculated for the whole sample. Secondary production was estimated from zooplankton biomass values³ and zooplankton diversity as per method of Margalef⁴. Physico-chemical parameters were measured⁵ in water samples taken simultaneously along with the zooplankton collections.

Results and Discussion

Spatial and temporal variations in the physico-chemical features at 4 stations have been tabulated (Table 1). Surface water temperature varied from 26.8° to 31.5°C . The temperature was low

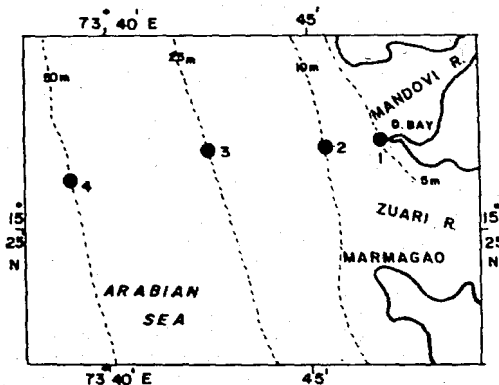


Fig. 1—Station position

in September obviously because of strong landsea breeze and precipitation. The value increased slightly during October-November but decreased steadily from December to February before rising to a peak in May (Table 1). The salinity values fluctuated between 34.1 and 35.8×10^{-3} . In general, salinity showed an exponential increase with depth of sampling stations. The dissolved oxygen evinced the reverse pattern with the maximum and minimum average values recorded at 5 and 50 m depth contours respectively. Higher inorganic phosphate-phosphorus content (1.4 to $2.3 \mu\text{g-at.l}^{-1}$) was obtained during September-October.

Secondary production values fluctuated between 24.7 and $87.2 \text{ mg C.m}^{-2}.\text{d}^{-1}$. Production was high during September-October. There was gradual decrease till February and the values increased again during March-April. Higher secondary production values obtained during September-October were due to swarming of planktonic organisms. Swarms of cladocerans (*Evadne tergestina*) and pteropods (*Cresis acicula*) were common in the ecosystem. The regular occurrence of swarms of pteropods (*C. acicula*) in the coastal waters of Goa in October, from

1976 to 1980 was observed⁶. Synchronization in the occurrence of bloom of blue green algae (*Trichodesmium* spp) and swarming of pteropods (*C. acicula*) and cladocerans (*Penilia avirostris*) in the area off Cochin was reported⁷. The secondary production peak during March-April was mainly due to the abundance of carnivores such as siphonophores (*Lensia* sp. and *Diphyes* sp.) and chaetognaths (*Sagitta* spp). There was no significant relationship between zooplankton production, water temperature and salinity as higher production values were recorded during the period when the ambient temperature and salinity values were low as well as high in the environment (Table 1). The dissolved oxygen values did not vary much during the period of study. There was significant relationship (1% level) between the zooplankton production and inorganic phosphate. The phosphate-phosphorus value ($2.3 \mu\text{g-at.l}^{-1}$) was obtained during October when zooplankton biomass values were high. The nutrient enrichment due to land run off resulted in phytoplankton abundance. Maximum counts of diatoms ($162.5 \times 10^3.\text{l}^{-1}$) and occurrence of diatom, (*Flagillaria oceanica*) in October in nearshore waters

Table 1—Surface water temperature, salinity, dissolved oxygen and phosphate-phosphorous at 4 stations in the coastal waters off Goa

St no.	1986				1987					Monthly av.
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	
Temperature (°C)										
1	27.0	28.0	28.0	27.8	27.5	27.6	28.8	30.1	31.0	28.4
2	26.8	28.2	28.2	27.8	27.2	27.8	28.9	30.4	31.2	28.5
3	26.9	28.1	28.2	27.9	27.3	28.0	29.2	30.6	31.4	28.6
4	26.9	28.1	28.3	28.0	27.3	28.0	29.4	30.8	31.5	28.7
Salinity ($\times 10^{-3}$)										
1	34.1	34.7	35.1	35.0	35.2	35.2	35.3	35.5	35.7	35.1
2	34.2	34.8	35.3	35.1	35.2	35.2	35.5	35.6	35.6	35.2
3	34.2	34.9	35.3	35.2	35.3	35.4	35.6	35.6	35.8	35.2
4	34.2	34.9	35.4	35.2	35.3	35.4	35.6	35.8	35.8	35.3
Dissolved oxygen (ml.l ⁻¹)										
1	5.9	4.2	4.1	5.1	4.9	4.4	4.0	3.8	3.6	4.4
2	5.6	4.1	4.0	5.1	4.8	4.2	3.9	3.6	3.5	4.3
3	5.4	4.4	3.9	5.0	4.6	3.9	3.8	3.5	3.2	4.2
4	5.4	4.0	3.8	4.9	4.7	3.7	3.6	3.5	3.4	4.1
Phosphate-phosphorous ($\mu\text{g-at.l}^{-1}$)										
1	2.3	1.4	0.9	0.5	0.3	0.8	1.1	1.6	0.9	1.1
2	1.9	1.4	0.8	0.4	0.3	0.7	1.3	1.6	0.8	1.0
3	2.0	1.5	0.8	0.4	0.2	0.7	1.0	1.5	0.7	1.0
4	1.9	1.4	0.7	0.4	0.2	0.7	1.0	1.4	0.7	0.9

of Goa was reported⁸. Abundance of diatoms in environment resulted in higher population density of herbivores during early postmonsoon months. Spatial variability in secondary production was discernible with the maximum and the minimum values recorded at 10m and 50m depth contours (Table 2). The average value of secondary production ($48.9 \text{ mg C.m}^{-2} \cdot \text{d}^{-1}$) obtained during the present study was higher than the secondary production values for coastal waters of Goa ($38.2 \text{ mg C.m}^{-2} \cdot \text{d}^{-1}$) and coastal belt between Vengurla to Malpe ($26.2 \text{ mg C.m}^{-2} \cdot \text{d}^{-1}$) given earlier^{2,9}.

Twentyfour zooplankton groups were present in the samples collected at 4 stations. Of these 20 taxa were common. Based on total counts, their percentage occurrence were copepods(55.2%), cladocerans(11.6%), pteropods(6.5%), decapod larvae(4.7%), sergestids(3.1%), siphonophores(2.8%), chaetognaths(2.5%), fish eggs(2.4%), amphipods(1.8%), cirriped larvae(1.6%), appendicularians(1.4%), hydromedusae(1.3%), polychaete larvae(1.2%), ctenophores(1.2%), gastropod larvae(0.6%), fish larvae(0.5%), euphausiids(0.4%), mysids(0.4%), stomatopod larvae(0.3%) and salps(0.2%). The remaining groups viz., ostracods, isopods and echinoderm larvae occurred sporadically and in small number. These together constituted <0.5% of the total population. Distribution of common groups has been shown in Fig. 2. The zooplankton community can be segregated into herbivores, omnivores and carnivores or predators. Herbivores dominated the community but no single group maintained the dominance throughout the period of observation. The distribution of taxa was influenced by the prevailing hydrographic conditions. The herbivores/omnivores were abundant in the environment when the water temperature and salinity values were low. The carnivores such as hydromedusae, siphonophores, chaetognaths and fish larvae were usually more during the period when the values of these environmental parameters were high. Herbivores were reported to dominate the

coastal areas during June-July¹⁰. Copepods were dominant from December onwards with peak population density in February. Maximum($689 \text{ copepods.m}^{-3}$) and minimum($81 \text{ copepods.m}^{-3}$) counts were obtained at 25m and 5m depth stations respectively. Maximum number of 782 and 657 copepods. m^{-3} were recorded from the west¹¹ and southwest¹² coast of India. A total of 58 species of pelagic copepods belonging to 29 genera were identified. Calanoids constituted bulk of copepod species(72.4%) followed by cyclopoids(20.7) and harpacticoids(6.9). Herbivore/omnivore copepod species of genera *Undinula*, *Eucalanus*, *Cosmocalanus*, *Centropages* and *Temora* were abundant in surface layer after the southwest monsoon. The carnivore or predatory forms of calanoids(*Euchaeta*, *Labidocera*, *Pontellopsis* and *Tortanus*), cyclopoids(*Oithona*) and poecilostomatoids(*Corycaeus* and *Oncaea*) were common prior to the advent of southwest monsoon. Depending upon their occurrence and abundance the copepod species identified can be grouped into 3 categories. In the first category were those species which occurred invariably throughout the period of study. These species were *Undinula darwini*, *Eucalanus subcrassus*, *E. crassus*, *Paracalanus parvus*, *P. aculeatus*, *Acrocalanus gracilis*, *A. gibber*, *Centropages orsinii*, *C. tenuiremis*, *Temora turbinata*, *Scolecithrix danae*, *Euchaeta marina*, *E. wolfendeni*, *Candacia bradyi*, *Labidocera pectinata*, *L. minuta*, *Pontella danae*, *Oithona rigida*, *O. brevicornis* and *Oncaea venusta*. These species were recorded in greater numbers and formed bulk of copepod population. *Temora turbinata* was very common ($750 \text{ individuals.m}^{-3}$) in the environment during September. This species was stated to be an opportunistic, occurring in large numbers during the period of abundance of phytoplankton and other particulate matter¹³. Swarming of *T. turbinata* had been reported from west coast associated with monsoon¹⁴. *Canthocalanus pauper*, *Clausocalanus arcuicornis*, *Calocalanus pavo*, *Eucalanus pileatus*, *Eucalanus* spp, *Temora discaudata*, *Centropages*

Table 2—Secondary production values ($\text{mg C.m}^{-2} \cdot \text{d}^{-1}$) obtained at 4 stations in the coastal waters off Goa

St. no.	1986				1987					Av.
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	
1	78.5	68.4	40.3	32.9	34.6	30.2	48.2	59.6	55.2	49.8
2	87.2	85.9	56.3	40.2	38.9	36.3	55.3	53.4	80.2	62.6
3	64.5	60.2	38.2	28.6	30.2	28.8	40.9	50.2	46.1	43.0
4	62.3	65.2	33.6	29.6	26.8	24.7	28.6	48.2	40.9	39.9
Av.	73.1	70.0	42.1	32.8	32.6	29.9	43.2	60.3	55.6	48.8

species were *Nannocalanus minor*, *Centropages trispinosus*, *Acartia danae*, *Candacia aethiopica*, *Labidocera acuta*, *Labidocera* spp., *Calanopia elliptica*, *Pontellopsis scotti*, *P. herdmanni*, *Pontellopsis* spp., *Tortanus forcipatus*, *Corycaeus* spp., *Sapphirina* spp. and *Copilia* spp. These species were observed usually when the ambient temperature and salinity were high. *Nannocalanus minor*, *Cosmocalanus darwini*, *Euchaeta marina* and *E. wolfendeni* were reported to show preference to high saline waters (35×10^{-3}) along the west coast of India¹⁵. Maximum and minimum number of species were recorded during the premonsoon and postmonsoon seasons respectively. Occurrence and abundance of common copepod species at different sampling stations were tabulated (Table 3). The number of copepod species usually increased with depth but number of individuals of each species decreased. Based on spatial extent of distribution of pelagic copepods, 3 groups viz., oceanic, neritic and intermediate were described¹⁰.

Cladocerans were represented by *Evadne tergestina* and *Penilia avirostris*. Both the species occurred throughout the period of observation (Table 4). Based on total number, the former was abundant (52.9%) than the latter (47.1%) as was observed earlier in the coastal waters of Goa² and along the west coast of India from Vengurla to Malpe¹¹. Temporal variations in their occurrence were noticed. *E. tergestina* was more during the postmonsoon season (66.6%) while *P. avirostris* during premonsoon period (69.4%). *E. tergestina* was reported to occur discontinuously throughout the year in the coastal waters with peak in November and *P. avirostris* showed bimodal distribution with abundance during November-December and March-May¹⁶. Niche-partition among the two spe-

cies was evident. Maximum population of *E. tergestina* was obtained at 5m depth zone and density decreased with increase in depth of the sampling station. The distribution trend was reversed for *P. avirostris*. Percentage occurrence at 5, 10, 25 and 50m depth stations of *Evadne* were 67.1, 55.6, 49.2 and 39.7 and of *Penilia* were 32.9, 44.4, 50.8 and 60.3 respectively. The ambient temperature and salinity appeared to influence distribution and abundance of these species. *E. tergestina* peak in the environment was in September when the temperature and salinity values were low while *P. avirostris* peak was in May when the values for both the parameters were high in the ecosystem (Table 1).

Species of genera *Sagitta* and *Pterosagitta* were the common representatives of chaetognaths. *S. enflata* was the dominant species with maximum abundance (83.5%) in November at 10m station (Table 5). *S. bedoti* was common in 5m depth zone with maximum percentage (80.30) in September. The population of this species gradually decreased till May. *S. enflata* showed reverse pattern of distribution at 5 and 10m depth stations. *Sagitta* spp. were more in samples taken at 25 and 50m depth in May. *P. draco* occurred in small number during premonsoon months. Maximum abundance (2.1%) was recorded at 50m station in May when temperature and salinity were high. The species was not present in samples from 5 and 10m depth. *P. draco* was stated to be a stenohaline and oceanic species found in abundance in offshore areas of the west coast of India¹⁷. However, the species was recorded from the mouth of Mandovi estuary, Goa during April-May when salinity was high¹⁸. Hydromedusae, siphonophores and ctenophores were the other carnivores. *Diphyes chamissonis* and *Lensia* sp. were the common species of siphonophores. *Pleurobrachia* sp. was the

Table 3—Occurrence of common copepod species at different stations in the coastal waters of Goa

St.1	St.2	St.3	St.4
<i>Paracalanus parvus</i> , <i>P. aculeatus</i> , <i>Acrocalanus gracilis</i> , <i>Eucalanus subcrassus</i> , <i>Centropages tenuiremis</i> , <i>Labidocera pectinata</i> , and <i>Oithona rigida</i> ,	✓ <i>Acrocalanus gibber</i> , ✓ <i>Eucalanus crassus</i> , ✓ <i>Centropages orsinii</i> , ✓ <i>Temora turbinata</i> , ✓ <i>Labidocera minuta</i> , ✓ <i>Acartia centrura</i> , ✓ <i>A. spinicauda</i> , ✓ <i>Euchaeta wolfendeni</i> , ✓ <i>Oithona brevicornis</i> , ✓ <i>Oithona</i> sp., ✓ <i>Euterpina acutifrons</i> , and ✓ <i>Microsetella rosea</i>	<i>Undinula darwini</i> , <i>Calocalanus pavo</i> , <i>Euchaeta marina</i> , <i>Eucalanus pileatus</i> , <i>Eucalanus</i> spp., <i>Candacia bradyi</i> , <i>C. pachydactyla</i> , <i>Centropages furcatus</i> , <i>Temora discaudata</i> , <i>Calanopia minor</i> , <i>Oncaea venusta</i> , <i>O. confier</i> and <i>Corycaeus</i> spp.	<i>Canthocalanus pauper</i> , <i>Nannocalanus minor</i> , <i>Cosmocalanus darwini</i> , <i>Pontella securifer</i> , <i>Calanopia elliptica</i> , <i>Labidocera acuta</i> , <i>Candacia aethiopica</i> , <i>Pontellopsis scotti</i> , <i>Pontellopsis</i> spp., <i>Corycaeus gibbulus</i> , and <i>Copilia</i> spp.

dominant ctenophores. Pteropods were represented by *Creseis acicula* and *Cavolina* sp. The former species was most abundant in the environment during September-October as observed earlier⁶. Decapod larval population decreased with increase in depth of the sampling station. Palaemonids, alpheidids, hippolytids, porcellanids, brachyurans and anomurans were the non-penaeid prawn larvae in the samples. Brachyurans were most numerous (31.5 m⁻³) in April at 5m depth station. A few specimens of genus *Alpheus* representing the alpheidids were recorded at 50m. The specimens belonging to different groups were invariably present in collections albeit in small numbers. Penaeid prawn larvae occurred mostly at depths between 10 and 25m which is the traditional fishing area. An account of distribution of penaeid prawn larvae upto 50m depth zone was given earlier¹⁹. Sergestids were abundant and represented by *Lucifer hansenii* and *L. typus*. Among the 2 species larvae of *L. hansenii* were dominant. Stray specimens of *L. typus* were obtained at 50m depth. *L. hansenii* was reported to be a

dominant species in the Arabian Sea²⁰. The gammarids (*Atylus* spp) were the common amphipods. *Lopadorhynchus* sp. and *Pelagobia* sp. were represented by polychaete larval population. Euphausiids occurred in small numbers at 50m depth zone. Species of genera *Euphausia* and *Stylocheiron* were present. *Cypridina dentata* was the common ostracod species. Appendicularians were represented by *Oikopleura* and salps by *Thalia democratica*. These taxa were common during April-May (Fig. 2).

The species diversity (D) values ranged between 2.9 to 5.7. Minimum value was obtained during September/October when swarms of herbivore zooplankers were common. This resulted in low diversity but high biomass community. The carnivores succeeding the herbivores and omnivores resulted in trophic and species diversity in the ecosystem. The diversity value was reported to vary from 1.5 to 3.7 in the inshore waters off Trivandrum, southwest coast of India²¹. High diversity values obtained during the present investigation indicate

Table 4—Percentage occurrence of cladoceran species at different stations in the coastal waters of Goa

St. no.	Species	1986				1987				
		Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May
1	<i>Evadne tergestina</i>	96.5	94.16	88.06	93.2	71.33	53.12	45.20	32.26	30.0
	<i>Penilia avirostris</i>	3.5	5.84	11.94	6.8	28.67	46.88	54.8	67.74	70.0
2	<i>E. tergestina</i>	91.3	79.32	59.92	67.99	57.3	43.19	47.02	35.71	19.01
	<i>P. avirostris</i>	8.7	20.68	40.08	32.01	42.7	56.81	52.98	64.29	80.99
3	<i>E. tergestina</i>	84.04	78.27	64.62	56.75	54.5	42.23	29.54	18.12	14.88
	<i>P. avirostris</i>	15.96	21.73	35.38	43.25	45.5	57.77	70.46	81.88	85.12
4	<i>E. tergestina</i>	77.9	62.6	52.24	45.56	39.62	22.55	26.41	20.96	9.23
	<i>P. avirostris</i>	22.1	37.4	47.76	54.44	60.38	77.45	73.59	79.04	90.77

Table 5—Distribution of chaetognath species(no.m⁻³) at different stations

St. no.	Species	1986				1987				
		Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May
1	<i>Sagitta bedoti</i>	80.3	75.6	65.3	60.8	57.6	53.3	51.4	47.1	37.4
	<i>S. enflata</i>	19.7	24.4	33.5	37.0	38.5	43.0	44.1	45.8	52.5
	<i>Sagitta</i> spp.	0.0	0.0	1.2	2.2	3.9	3.7	4.5	7.1	10.1
2	<i>S. bedoti</i>	30.9	13.1	11.2	17.1	12.3	6.6	5.9	2.8	3.0
	<i>S. enflata</i>	66.7	82.4	86.5	76.6	67.0	73.4	78.3	73.7	71.4
	<i>Sagitta</i> spp.	2.4	4.5	2.3	6.3	20.7	20.0	15.8	23.5	25.6
3	<i>S. bedoti</i>	14.6	10.7	6.3	8.1	4.1	4.2	0.4	0.0	0.0
	<i>S. enflata</i>	82.0	83.3	80.0	72.6	81.1	78.3	73.6	76.9	73.1
	<i>Sagitta</i> spp.	3.4	6.0	13.7	19.3	14.8	17.5	26.0	23.1	26.9
4	<i>S. bedoti</i>	3.8	1.2	0.2	0.0	0.0	0.3	0.4	0.0	0.0
	<i>S. enflata</i>	78.8	78.1	81.4	72.6	68.6	70.2	65.3	59.1	51.6
	<i>Sagitta</i> spp.	17.4	20.7	18.4	27.4	31.4	29.5	34.3	40.9	48.4

that the study area is rich in species under various zooplankton taxa.

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