

Zooplankton ecology in the Mandovi-Zuari estuarine system of Goa, west coast of India

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Seasonal variability in the physico-chemical features, zooplankton standing stock (biomass) and faunal composition in the Mandovi-Zuari estuarine system of Goa during January to December 1990 were studied. Hydrobiological characteristics were influenced by the southwest monsoon. Salinity fluctuations were drastic (0.1 to 36.6×10^{-3}). This appeared to cause variations in plankton production and heterogeneity of various taxa. Zooplankton biomass and total numerical counts varied significantly between seasons and estuaries. Highest biomass values (1.9 ml/m^3) were recorded in the Zuari estuary but the maximum counts ($25700/\text{m}^3$) were obtained in the Mandovi estuary. Crustaceans particularly copepods predominated (54.9 to 70.6%). Invertebrate larvae, luciferid shrimps, cladocerans and chaetognaths were the other common zooplankton groups. Distribution and abundance of majority of constituent groups and species were influenced by various hydrographical characteristics of the environment.

The Mandovi-Zuari estuarine system consists of the Mandovi-Zuari rivers, their tributaries and the man-made channel, the Cumbarjua canal. These two large rivers, their perennial connections with the Arabian Sea, mixed semi-diurnal tides and strong tidal currents make this ecosystem one of the most variable environments for the study of trophic relationship. Zooplankton play an important role in the marine food chain as intermediate link between phytoplankton and fish. Plankton studies in the estuarine system of Goa have been carried out¹. However, information on the seasonal distribution of major zooplankton taxa and common species is lacking. The present paper gives a detailed account of seasonal variability in zooplankton biomass, faunal composition and species distribution in relation to prevailing physico-chemical features in the Mandovi-Zuari estuarine system of Goa, west coast of India during 1990.

Materials and Methods

Monthly zooplankton samples were collected simultaneously at 7 stations (Fig. 1) for 12 months (January to December 1990). Three stations each were located in the Mandovi (M1-M3) and Zuari (Z1-Z3) estuaries (representing the lower, middle and the upper reaches of the estuaries) and one in the interconnecting Cumbarjua canal (st. C1). The

depth of water column at high tide at the station varied between 7 to 12 m. Zooplankton samples were taken during high tide using a modified HT net (mouth area, 0.25 m^2 and mesh width of $330 \mu\text{m}$) fitted with a calibrated flow meter. The samples were preserved in 5% formaldehyde. Aliquots (5 to 10%) of the samples were examined for enumeration of different organisms. Number was calculated for the whole sample (no/m^3). Surface and bottom water samples were taken at each station. Environmental parameters were determined using standard procedures².

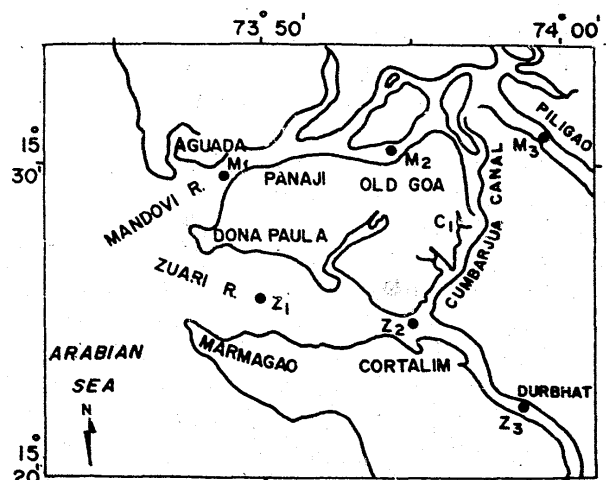


Fig. 1—Station locations

Results and Discussion

Physico-chemical parameters

Annual range of physico-chemical parameters in the surface and bottom waters at stations in the Mandovi-Zuari estuarine complex has been tabulated (Table 1). The temperature varied from 24° to 33°C. The seasonal fluctuations in temperature were reported to be 5 to 6°C in the Mandovi-Zuari estuarine system³. Salinity variations were drastic (0.1 to 36.6×10⁻³). With the onset of southwest monsoon in June, almost freshwater conditions were recorded at stations in the Mandovi estuary and Cumbarjua canal. Higher saline conditions were recorded at stations in the Zuari estuary owing to its wider mouth area and lower number of the tributaries. The dissolved oxygen values varied between 1.1 to 5.9 ml/l with higher values during the monsoon months. De Souza & Sengupta⁴ observed that during the monsoon period the Mandovi and Zuari estuaries were well mixed with uniform dissolved oxygen concentration from surface to bottom layers. The pH values in surface and bottom layers varied from 6.9 to 8.2.

Zooplankton biomass and density

Seasonal fluctuations in values of zooplankton biomass (ml/m³) and total numerical counts (no/m³) at different stations have been tabulated (Table 2). Maximum biomass values were recorded in the estuaries in September (0.9 ml/m³ at st. M1 and 1.9 ml/m³ at st. Z3) but in the Cumbarjua canal (st. C1) it was in December (0.3 ml/m³). Highest zooplankton

counts in the Mandovi and Zuari estuaries and Cumbarjua canal were obtained in December (25700/m³ at st. M3, 10500/m³ at st. Z3 and 9600/m³ at st. C1). However, the counts and peak

biomass values were not always correlated. This was due to the occurrence of large organisms viz. medusae, ctenophores and decapods resulting in high biomass but small forms such as copepods and cladocerans accounted for most of the numerical counts. Monthly values of total counts at different stations have been shown (Figs 2 and 3). The biomass values and total counts varied significantly between seasons and estuaries. The values were usually high during dry high saline premonsoon season. The biomass and counts were poor in the Mandovi estuary and Cumbarjua canal during monsoon period (June-Sept.) when almost fresh water conditions prevailed there. Low zooplankton production in the Mandovi-Zuari estuarine system during monsoon compared to premonsoon season (Feb.-May) were reported^{1,5}. The present investigation has shown that salinity is the key factor influencing distribution and biomass of zooplankton. Other factors such as ambient temperature, oxygen content and pH are of secondary importance.

Faunal composition

Eighteen taxa of both holoplankton and meroplankton invariably occurred in the samples. Besides these, some groups such as the Cephalochordata (*Amphioxus* sp), water insects (*Halobates* sp.) and some crustacean nauplii were observed sporadically and in small numbers (0.5%). The rare groups have

Table 1—Annual range of physico-chemical parameters at stations in the Mandovi-Zuari estuarine system of Goa during January-December, 1990

St. no.	Type of haul	Temp. (°C)	pH	Diss. O ₂ (ml/l)	Sal. (×10 ⁻³)
M1	Surface	24.5-30.5	7.2-8.0	3.0-5.1	3.9-34.8
	Bottom	24.0-30.3	7.5-8.1	2.7-4.9	18.4-35.0
M2	Surface	25.0-32.0	7.0-7.5	3.6-5.5	0.1-32.2
	Bottom	25.0-32.0	6.9-7.8	3.6-5.9	0.1-32.1
M3	Surface	25.0-32.5	6.8-7.8	4.0-5.3	0.1-28.3
	Bottom	25.0-32.5	6.8-7.7	3.4-5.6	0.1-28.8
C1	Surface	26.0-33.0	6.9-8.0	3.4-5.3	0.27-34.4
	Bottom	26.0-32.8	6.9-8.0	3.4-5.0	0.28-35.0
Z1	Surface	25.0-32.0	7.5-8.2	3.4-5.0	12.0-36.4
	Bottom	25.0-31.0	7.7-8.2	1.1-4.8	12.6-36.6
Z2	Surface	24.5-31.5	7.4-8.2	3.6-4.9	0.2-34.2
	Bottom	24.5-31.3	7.5-8.1	3.1-4.9	0.2-34.7
Z3	Surface	24.0-32.0	6.9-7.9	3.8-5.1	0.1-33.4
	Bottom	24.0-32.0	6.9-7.9	3.4-5.1	0.1-34.3

been put together and considered as 'miscellaneous' assemblage. Average numerical counts and percentage composition of various taxa have been tabulated (Table 3). Crustacea particularly Copepoda dominated the zooplankton population in the estuaries constituting 66.2% of the total annual counts. Decapod larvae were next in the order of abundance (17.2%) followed by Cirriped larvae (5.7%), Sergestidae (4.3%), Cladocera (1.8%), Fish eggs (1.7%), Chaetognatha and Copelata (1.4%), Gastropod larvae (1%), Hydromedusae and fish larvae (0.4% each), Cumacea (0.3%) and Amphipoda (0.1%). In the Cumbarjua canal Copepoda formed (54.9%) followed by Decapoda (18.2%), Sergestidae (2.2%), Cirriped larvae (2%), Cladocera, Mysidacea and Cumacea (0.2% each), Amphipoda and Copelata (0.1% each) of zooplankton population.

Species distribution

Hydromedusae, Siphonophores, Ctenophores and Chaetognaths were the carnivores usually occurring in the Mandovi-Zuari estuarine environment during high temperature and saline period. The hydrome-

dusae were represented by 3 species viz. *Eutima commensalis*, *Eirene menoni* and *Blackfordia virginica*. The last two were most abundant and together accounted for 82%, 79% and 74% of numerical counts of hydromedusae in the Mandovi and Zuari estuaries and in the Cumbarjua canal respectively. The hydromedusae were recorded largely at the lower reaches of the estuaries during post and premonsoon seasons. However, by April they were present right up to the head (sts M3 & Z3) and Cumbarjua canal (st. C1). Peak densities ($21/m^3$ at st. M3, $15/m^3$ at st. Z3 and $14/m^3$ at st. C1) were in the month of March. On the basis of population density, the Mandovi estuary appeared to be a better environment for hydromedusae. Siphonophores were stragglers and occurred in small numbers. Highest count ($7/m^3$) was obtained at the mouth of Zuari estuary in June. Chaetognaths were abundant during late postmonsoon and premonsoon seasons ($370/m^3$ at st. Z3 in March, $290/m^3$ at st. C1 in December and $190/m^3$ at st. M1 in January) indicating their influx along with saline waters. *Sagitta bedoti* and *S. enflata* were the common species, the former

Table 2—Zooplankton biomass (ml/m^3) and population (no/m^3 in parentheses) at stations in the Mandovi Zuari estuarine system of Goa during January-December, 1990

Months (1990)	Stations						
	M1	M2	M3	C1	Z1	Z2	Z3
Jan.	0.03 (160)	0.4 (4000)	0.1 (660)	0.1 (570)	0.1 (400)	0.1 (340)	0.04 (150)
Feb.	0.1 (160)	0.03 (200)	0.04 (110)	0.1 (160)	0.1 (670)	0.03 (200)	0.03 (520)
March	0.2 (1300)	0.4 (830)	0.1 (530)	0.1 (440)	0.1 (1000)	0.5 (5100)	1.0 (5600)
April	0.4 (520)	0.2 (590)	0.1 (520)	0.1 (650)	0.5 (560)	0.3 (1000)	0.1 (850)
May	0.1 (240)	0.3 (1800)	0.1 (870)	0.1 (520)	0.6 (1700)	0.2 (720)	0.1 (710)
June	0.2 (980)	0.02 (230)	0.02 (290)	0.1 (670)	0.2 (700)	0.03 (310)	0.1 (410)
July	0.1 (220)	0.01 (10)	0.03 (22)	0.1 (10)	0.1 (910)	0.03 (370)	0.1 (90)
Aug.	0.1 (170)	0.01 (40)	0.02 (110)	0.03 (60)	0.02 (180)	0.1 (1400)	0.1 (110)
Sept.	0.9 (3200)	0.01 (20)	0.02 (30)	0.04 (80)	0.2 (2900)	0.02 (50)	1.9 (40)
Oct.	0.02 (490)	0.1 (2100)	0.1 (650)	0.1 (680)	0.1 (430)	0.3 (3400)	0.2 (2500)
Nov.	0.01 (70)	0.01 (170)	0.01 (130)	0.1 (330)	0.02 (130)	0.1 (300)	0.4 (1600)
Dec.	0.04 (2100)	0.2 (7300)	0.5 (25700)	0.3 (9600)	0.1 (1800)	0.1 (4600)	0.1 (10500)

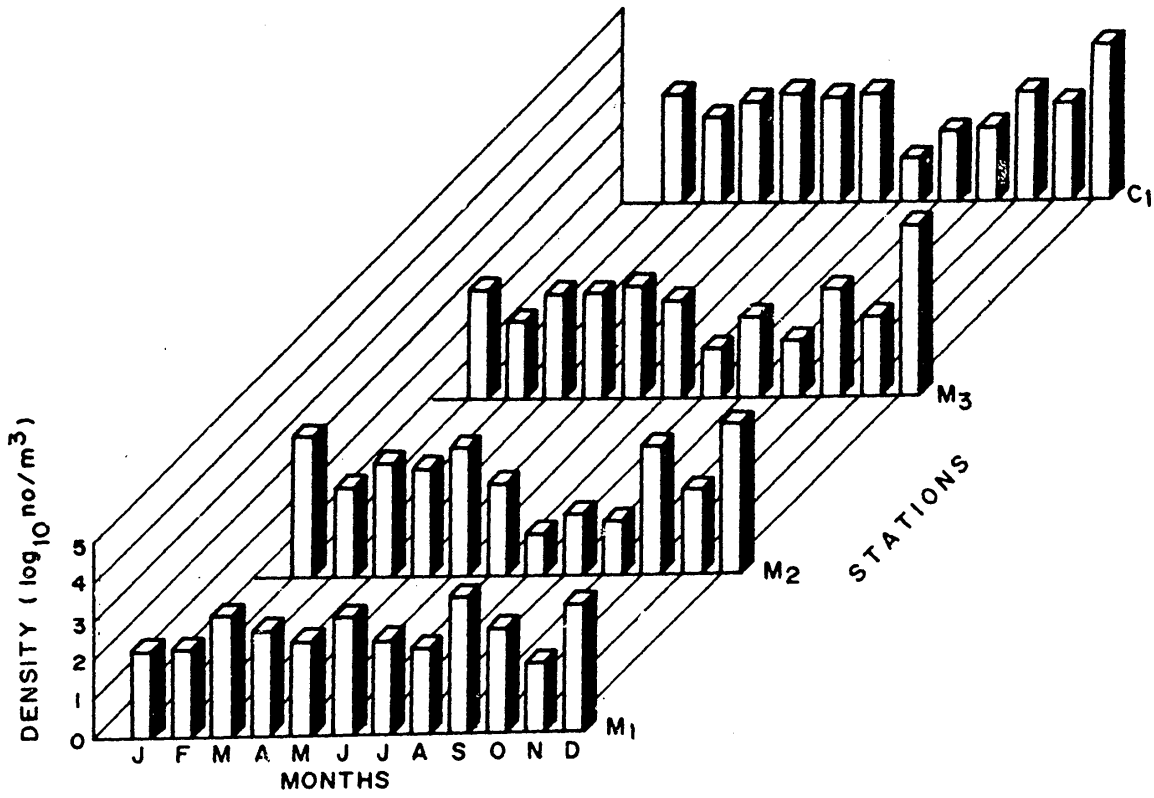


Fig. 2—Monthly distribution of total zooplankton counts at stations in the Mandovi estuary and Cumbarjua canal during the period of observation

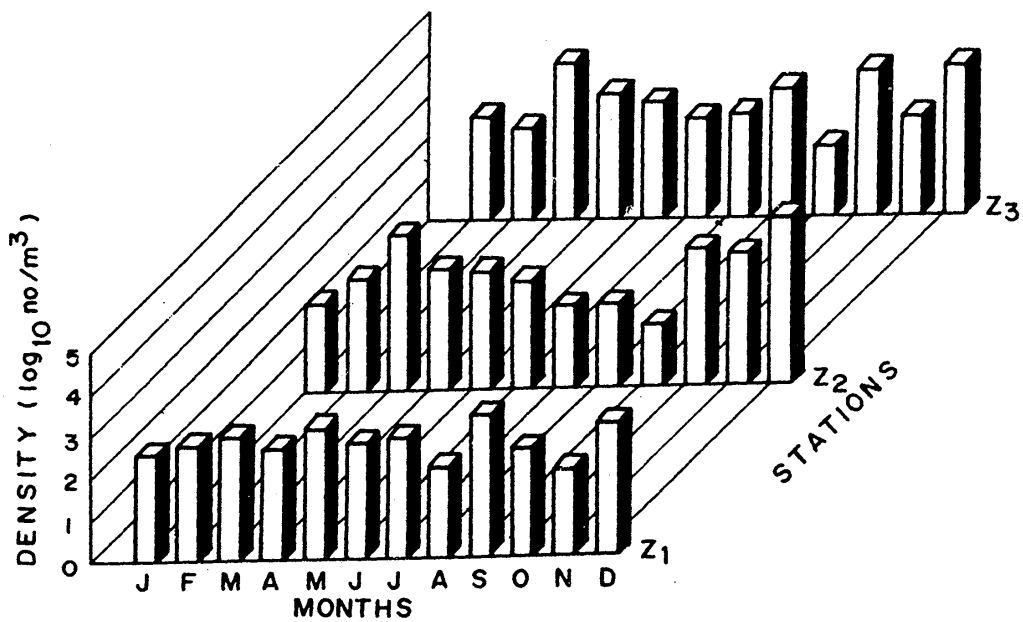


Fig. 3—Monthly distribution of total zooplankton counts at stations in the Zuari estuary during the period of observation

Table 3—Average of numerical counts (no/m³) and percentage composition (in parentheses) of major groups of zooplankton in the Mandovi-Zuari estuarine system of Goa

Zooplankton Groups	Mandovi	Zuari	C. canal
Hydromedusae	2.5 (0.15)	1.2 (0.08)	2.3 (0.3)
Siphonophora	0.01 (0.00)	0.5 (0.03)	0.0 (0.0)
Ctenophora	0.1 (0.01)	1.4 (0.09)	0.1 (0.01)
Chaetognatha	10.6 (0.67)	21.1 (1.43)	28.3 (3.31)
Cladocera	4.1 (0.26)	10.4 (0.73)	0.3 (0.03)
Ostracoda	0.0 (0.0)	0.2 (0.01)	0.01 (0.00)
Copepoda	1354 (86.11)	1242 (84.35)	696 (81.39)
Amphipoda	0.2 (0.01)	0.1 (0.01)	0.2 (0.02)
Lucifers	33.3 (2.12)	43.4 (2.95)	13.5 (1.57)
Mysidacea	1.1 (0.06)	2.5 (0.16)	0.7 (0.08)
Cumacea	0.2 (0.01)	0.5 (0.03)	0.3 (0.03)
Invertebr. eggs	0.5 (0.03)	0.9 (0.06)	0.1 (0.01)
Invertebr. larvae	154.3 (9.81)	131.6 (8.93)	109.8 (12.83)
Pteropoda	0.0 (0.0)	0.1 (0.0)	0.0 (0.0)
Copelata	4.5 (0.29)	9.7 (0.65)	0.8 (0.09)
Fish eggs	4.0 (0.25)	4.7 (0.32)	0.04 (0.0)
Fish larvae	2.8 (0.19)	2.0 (0.13)	2.7 (0.31)
Miscellaneous	0.1 (0.01)	0.1 (0.01)	0.1 (0.01)

dominating. These species were abundant when the salinity was higher. However, they occurred albeit scantily in salinities as low as 17.8, 9.5 and 13.2×10^{-3} at stations in the Mandovi and Zuari estuary and Cumbarjua canal respectively. Nair & Selvakumar⁶ recorded 6 chaetognath species in the estuarine system of Goa with maximum species diversity during the period of relatively high salinity. Ctenophores occurred more in the Zuari estuary. Their peak abundance was at st. Z1 in April ($40/m^3$). *Pleurobrachia globosa* was the common species.

Occurrence of cladocans was discontinuous both in space and time. *Evadne tergestina* and *Penilia avirostris* represented cladoceran population. This group was usually observed during the monsoon and postmonsoon months. Maximum density of *E. tergestina* was recorded at st. Z1 ($220/m^3$) in July followed by $56/m^3$ at st. M1 in October. Maximum density ($35/m^3$) of *P. avirostris* was observed at Z1 in October. In general, the cladocerans were abundant during the period when the temperature and salinity values were low but dissolved oxygen was more in the environment. The occurrence of cladoceran species was reported to be discontinuous both

in space and time in the Mandovi-Zuari estuarine system⁷.

Ostracods were not observed in samples from the Mandovi estuary and Cumbarjua canal. They occurred in small numbers ($3/m^3$) at the mouth of Zuari estuary in March. Copepods were dominant component of zooplankton population from the estuarine system. The copepod species consisted of euryhaline and stenohaline and marine and fresh water species. Copepods of families Acartiidae, Pseudodiaptomidae and Paracalanidae formed the bulk of copepod population. Maximum species diversity was observed at the mouth of the estuaries. However, most of copepod species penetrated further up the estuaries along with the incursion of seawater during high saline premonsoon season. *Acartia centrura*, *A. spinicauda*, *A. tropica*, *Pseudodiaptomus bowmani*, *P. sewelli*, *Paracalanus* sp., *Acrocalanus* sp. and *Oithona* sp. formed the bulk of the copepod population with the maximum numerical counts when the temperature and salinity were high in the environment. *Pseudodiaptomus binghami malayalus*, *P. tollingeriae*, *P. annandalei*, *Acartiella keralensis*, *A. graveleyi*, *Heliodyptomus cinctus* and *H. contortus* occurred in small numbers during the low saline period. The amphipods were constituted by individuals of the family Gammariidae and a few specimens of Hyperiididae. Maximum density ($2/m^3$) was recorded in March at the middle reaches of Mandovi estuary. *Lucifer hanseni* was the common sergestid occurring almost throughout the year in the estuarine system. This species was reported to form the major part of the decapods (40 to 93%) in the Zuari estuary⁸. Maximum number ($73/m^3$) in the Cumbarjua canal was in April. Mysids being the benthic forms, their occurrence in the plankton samples was sporadic. The individuals of this group were present more in the Zuari estuary ($79/m^3$ at st. Z3) compared to the Mandovi estuary ($28/m^3$ at st. M3). The cumaceans, another benthic group were obtained occasionally and in small numbers. At the mouth and middle reaches of Zuari estuary (sts. Z1, Z2) they were observed only once during the pre- and post-monsoon seasons. Their maximum abundance was observed in the upper reaches of the Zuari estuary during the peak of monsoon season ($6/m^3$). The highest abundance in the Mandovi estuary was in March ($4/m^3$). They were absent in the Cumbarjua canal. Invertebrate

larvae constituted an important component of zooplankton population. The decapod larvae were common and were next to the copepods in their contribution to the total zooplankton in these estuaries (17.2%). They formed 36.5% of the total count at Cumbarjua canal followed by Mandovi (21.4%) and Zuari (13.1%) estuaries. Zoea larvae of Brachyura were abundant and occurred almost throughout the year with peaks during the premonsoon months except at the sts M1, Z2 and Z3 where maximum density was observed in December ($220/m^3$), August ($130/m^3$) and June ($220/m^3$) respectively. Megalopa larvae were rare in the plankton samples. The different larval stages (protozoeca, mysis and postlarvae) of penaeid and caridean decapods were always present, in abundance during the pre- and post-monsoon seasons with maximum density ($190/m^3$) recorded at Z2 in March. Larvae of penaeid prawn species were more abundant and enjoyed a wider distribution in Zuari estuary than Mandovi⁹. *Squilla* larvae occurred in small numbers during the period of higher temperature and salinity. Cirriped larvae were observed almost throughout the year in the Zuari estuary while in the Mandovi estuary they were present only during the pre- and post-monsoon months. Maximum number ($350/m^3$) was obtained at the mouth of Zuari (st. Z1) during February. However, annual average densities were greater in Mandovi ($23/m^3$) than in Zuari ($19/m^3$) and Cumbarjua canal ($17/m^3$). Polychaete and isopod larvae occurred in the estuaries and Cumbarjua canal in small numbers. Gastropod larvae of Mollusca were quite well represented in the collections. Their peak abundance in the Mandovi estuary and Cumbarjua canal was in December ($360/m^3$ at st. M3 and $96/m^3$ at st. C1). Pluteus larvae of Echinodermata were obtained only from the mouth of Zuari estuary during February. The lingula larvae of Brachiopoda were recorded in a few collections from the estuaries and were absent in the plankton samples from the Cumbarjua canal.

Fish eggs and larvae were abundant in the lower reaches while the fish larvae were common at the upper reaches of the estuaries. The fish eggs were more during the post- and premonsoon seasons. Highest abundance of fish eggs was in the Zuari

($70/m^3$) in October and in Mandovi ($33/m^3$) in September. They were poorly distributed in the Cumbarjua canal. Fish larvae constituted 1.4% in Mandovi, 0.4% in Zuari and 0.2% in Cumbarjua canal of the total zooplankton counts. Their peak abundance was at the upper reaches of the Mandovi estuary in October ($24/m^3$).

Larvaceans occurred in the environment during high temperature and salinity conditions. They were present mostly at the mouth of the estuaries. The composition varied from 0.1 to 0.8% in the Cumbarjua canal and the estuaries. Salps and doliolids were not observed in the Mandovi-Zuari estuarine system.

The present study has shown that salinity is an important factor influencing distribution of zooplankton in the Mandovi-Zuari estuarine system. The zooplankton is rich and varied with the incursion of carnivorous forms during dry high saline premonsoon season. In tropical waters high species and trophic diversity were reported to be associated with predominance of predators in the ecosystem¹⁰.

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