27 Emery K O & Rittenberg S C, *Bull Am Ass Petrol Geol*, **36** (1952) 735.
28 Eisma D, Das H A, Haede D, Van Raaphorst J G & Zonderhuis J, *Neth J Sea Res*, 3 (1966) 68.
29 Qasim S Z & Sankaranarayanan V N, *Mar Biol*, **15** (1972) 193.
30 Holm Hansem O, *Mem Inst Ital Idrobiol*, **29** (Suppl.) (1972) 37.
31 Qasim S Z, Wellershaus S, Bhattathiri P M A & Abidi S A H, *Proc Indian Acad Sci*, **69B** (1969) 51.

Organic Carbon Content of Tropical Zooplankton

VIJAYALAKSHMI R NAIR
National Institute of Oceanography, Dona Paula, Goa 403 004

Received 13 *August* 1979; *revised received* 31 *October* 1979

In the Zuari and Mandovi estuaries variations in organic carbon of zooplankton are 26.4-38.8 and 24-39.9% of dry weight respectively. Maximum carbon content of estuarine zooplankton is observed in November. Organic carbon in nearshore and oceanic zooplankton is 34.5 and 41% of dry weight respectively. Variation in the carbon content of zooplankton is attributed to its composition. Diversity of zooplankton increases from estuarine to oceanic realm with a concomitant rise in the value of organic carbon. The average dry weight for 1 ml of nearshore and oceanic zooplankton is 61.9 and 81.7 mg respectively.

To estimate secondary production in an ecosystem the zooplankton biomass needs to be converted into a more general unit like weight of organic carbon. Some information[1-6] on the organic content of zooplankton dealing mainly with temperate waters is available. Organic carbon content of tropical zooplankton is lower than that from higher latitudes[4,6]. In the present study carbon contents of estuarine and nearshore zooplankton from Goa waters and oceanic zooplankton from the southwest coast of India are estimated. Seasonal variations in the carbon content of zooplankton in the Mandovi-Zuari estuarine system of Goa also form part of this communication.

From the estuaries and nearshore waters of Goa vertical zooplankton samples, 5 m to the surface, were collected (Fig. 1) using a HT net (mouth area 0.25 m^2; mesh size 0.3 mm). A few vertical collections from the Arabian Sea were taken with an IOS net (0.33 mm mesh size)[7]. As the mesh size of both the nets are almost same zooplankton organisms caught in the 2 sets of collections are comparable. The samples were frozen and 20% of each sample was preserved in 5% formalin for analysing the different taxa and the rest was used for carbon estimation. Samples were washed thoroughly with distilled water and dried in an oven at 60°C until a constant weight was attained. Organic carbon in a 10 mg sample was estimated by the wet oxidation method[8]. For each sample triple estimates were done and the mean value was considered.

Data from 3 sets of samples were used for the present study. (1) Fortnightly or monthly collections from the mouths of Mandovi (st 1) and Zuari (st 2) were taken from January to December 1978. During September and October, which represent monsoon and postmonsoon periods respectively, sampling could not be done. Data are, however, available for 3 remaining months of respective monsoon periods and hence a general trend in organic carbon can be surmised. (2) Fortnightly samples were taken from the nearshore waters of Goa at 20 m (st 3) during January to May 1978. The period and area of collection coincided with the *Trichodesmium* bloom[9]. Due to navigational difficulties sampling could not be done from June to December. (3) During the 31st cruise (March 1978) of *RV Gaveshani* 12 vertical zooplankton samples from 60-200 m to surface were taken. Stations were located between 9° 16′N-12° 40′N and 72°-75° 44′E in the Arabian Sea.

Estuarine zooplankton—Variations in the carbon content of zooplankton in the Zuari and Mandovi estuaries are given in Table 1. Maximum values of organic carbon was obtained at the beginning of the postmonsoon period. At both the estuaries biomass and percentage of organic carbon did not show any correlation. Often low biomass was associated with relatively higher carbon values or vice versa.

Nearshore zooplankton—The organic carbon content indicated an increasing trend from January to May (Table 1). In 1979, *Trichodesmium* bloom was observed from January to April[9] and maximum carbon value was recorded in May. The lowest value observed in March corresponds to similar values

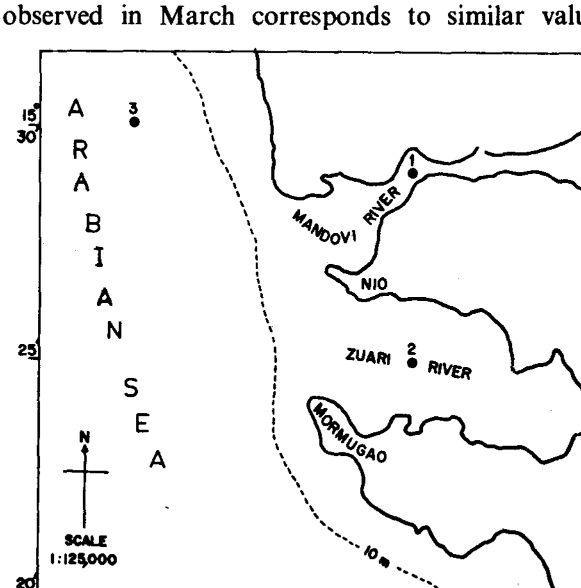

Fig. 1—Locations of stations in the Mandovi, Zuari and nearshore waters of Goa

Table 1—Variations in Organic Carbon Content of Zooplankton in Estuarine and Nearshore Waters during 1978
[Values are expressed in: biomass, dry wt mg/m^3 and organic carbon, % dry wt]

	Mandovi		Zuari		Nearshore	
	Biomass	Organic carbon	Biomass	Organic carbon	Biomass	Organic carbon
Jan.	15.5	24.0	19.3	26.8	8.3	33.6
Feb.	30.9	25.2	29.9	31.5	41.5	32.6
March	36.9	26.0	26.7	26.4	18.9	29.4
April	34.8	31.2	43.6	28.2	78.7	38.0
May	24.8	26.4	32.7	29.4	26.2	39.0
June	11.2	31.8	6.0	30.8	—	—
July	23.1	30.2	22.9	27.3	—	—
Aug.	11.2	34.2	52.5	34.9	—	—
Nov.	113.0	39.9	78.7	38.8	—	—
Dec.	16.8	31.5	17.5	33.1	—	—
Mean	31.8	30.1	33.0	30.7	34.7	34.5

obtained at sts 1 and 2. Higher per cent organic carbon was not always associated with a corresponding high biomass value. Compared to the estuarine zooplankton, carbon values were higher in the nearshore zooplankton during January to May.

Oceanic zooplankton—The estimated carbon values ranged from 36.6 to 45% (av. 41%) of zooplankton dry weight. Low values were found in samples where an appreciable part of the biomass was contributed by gelatinous organisms like siphonophores, medusae and salps. When crustaceans dominated, the value was always high. Relation between dry weight and carbon content of oceanic zooplankton can be expressed by the equation below:

Organic carbon/m^3 (mg) $= 5.53 + 0.396$ dry wt/m^3 (mg).

Relation between volume and dry weight—For calculating secondary production the biomass usually measured in terms of displacement volume has to be converted to dry weight. So for all the samples volumes and equivalent dry weight were found out for obtaining conversion factors. Dry weight for 1 ml of estuarine and nearshore zooplankton varied between 26 and 97.7 mg and the factor 1 ml = 61.9 mg could be used for conversion. For oceanic zooplankton dry weight of 1 ml ranged between 44.4 and 127.8 mg. The conversion factor for oceanic zooplankton would work out to be 1 ml = 81.7 mg.

Organic matter present in zooplankton can theoretically yield information about the energy content of the secondary producers, thereby giving a direct index to energy flow in marine ecosystem. Hence the carbon content of the zooplankton can be used as a reliable indicator of the energy equivalent for any season[5]. Very high biomass obtained from a particular sample need not necessarily give high percentage of carbon values (Table 1). The organic content of zooplankton is dependant on the quantitative variations in the constituent groups.

Off Cochin, Gupta[6] found marked seasonal variations in the organic content of zooplankton. In the present study, variations in the carbon content of estuarine zooplankton were relatively less. Variations in energy equivalent of zooplankton is attributed to changing species composition[1,2] and to changing age distribution within species[3]. In the estuaries soon after the monsoon very high populations of copepods, cladocerans, lucifers, other decapods and veligers were noted. Possibly, such congregations of certain groups of zooplankton in the postmonsoon period must have contributed to the high carbon values. The amount of food available was reported to influence the carbon content of zooplankton[4]. The carbon content of *Calanus cristatus* was maximum soon after the spring bloom of phytoplankton[4]. In the nearshore waters of Goa *Trichodesmium* bloom occurs every year from February to April/May[9]. The present samples from the nearshore waters were from the bloom area and herbivores and omnivores formed the major part of zooplankton[10]. The maximum carbon content in the nearshore zooplankton was obtained in May, immediately after the bloom season of 1978, possibly supporting the earlier observation[4].

Average carbon content of oceanic zooplankton amounts to 60% of the total zooplankton dry weight[11] which appears to be a very high value. Curl[1] obtained a value ranging from 6.6 to 46.8%. Omori[4] considered the average carbon content of zooplankton in the North Pacific as 45.6% of dry weight. Gupta[6] reported a range of 13 to 42.3% for the offshore waters of Cochin. Compared to these reports the present estimate of carbon comprising 36.6 to 45% (mean 41%) of dry weight of oceanic zooplankton is close to Omori's[4] value. However, the slightly lower value of organic carbon in the present collection indicates that the latitudinal difference may also influence the carbon content of zooplankton.

Estuarine, nearshore and oceanic zooplankton have their own characteristic composition, diversity and abundance. In the estuarine habitat, the fauna is constituted of relatively fewer groups and species. In the nearshore waters the number of representative groups and species are more than in the estuary. The diversity is maximum in oceanic waters where many taxonomic groups are represented. This progressive change in the composition of zooplankton appears to be reflected in the organic content of these organisms. The variations might be a cumulative effect of the available food, species composition of zooplankton and physiological state of the constituent organisms.

The author is thankful to Dr S.Z. Qasim, Director, and Dr T.S.S. Rao, Head, BOD for their comments. Thanks are also due to Shri V.P. Devasy and Shri C.T. Achuthankutty for help in the collection of samples.

References

1 Curl H J R, *J Mar Res*, **20** (1962) 181.
2 Beers J R, *Limnol Oceanogr*, **11** (1966) 520.
3 Comita G W, Marshall S M & Orr A P, *J mar Biol Ass U K*, **46** (1966) 1.
4 Omori M, *Mar Biol*, 3 (1969) 4.
5 Platt T, Brawn V M & Irwin B, *J Fish Res Bd Can*, **26** (1969) 2345.
6 Gupta T R C, *Proceedings symposium on warm water Zooplankton* (Spl, Publ, NIO, Goa) 1977, 511.
7 Currie R I, *Deep Sea Res*, **10** (1963) 27.
8 EL Wakeel S K & Riley J P, *J Cons Perm int Explor Mer*, **22** (1957) 180.
9 Devassy V P, Bhattathiri P M A & Qasim S Z, *Indian J mar Sci*, **7** (1978) 168.
10 Nair V R, Devassy V P & Qasim S Z, *Indian J mar Sci*, **9** (1980) 1.
11 Cushing D H, Humphrey G F, Banse K & Laevastu T, *Rapp Pv Reun Cons perm int Explor Mer*, **144** (1958) 15.

Production & Associations of Zooplankton in Estuarine & Nearshore Waters of Goa

VIJAYALAKSHMI R NAIR
National Institute of Oceanography, Dona Paula, Goa 403 004

Received 28 *August* 1979; *revised received* 10 *December* 1979

Zooplankton production in the Zuari and Mandovi estuaries indicated 2 peaks-one in November and another in March/April. In the nearshore waters very high value of zooplankton biomass was observed in April associated with *Trichodesmium* bloom. Mean rate of production in Mandovi, Zuari and nearshore waters was 51, 69 and 136 mgC/m^2/day respectively. Crustaceans contributed to the major part of the phytophagous and euryphagous populations while chaetognaths and coelenterates formed an appreciable part of the predators. In the estuaries higher diversity of zooplankton was associated with predominance of carnivores. In the nearshore waters community at the initial stages was dominated by filter feeders and omnivores and later by a high ratio of predators.

Ecology of zooplankton in the nearshore waters of Goa has been investigated[1-6]. Secondary production[7] and variations in organic carbon content of zooplankton[8] in the Mandovi-Zuari estuarine system have been estimated. In an estuarine habitat mostly herbivores and omnivores predominate with a relatively low percentage of predators. However, carnivores play an important role in maintaining ecological balance in any environment. Plankton associations of the tropical region differ from higher latitudes in an increase in the relative biomass of predators[9]. In this study structure of trophic interrelations within the zooplankton community is assessed quantitatively. Rate of secondary production in Mandovi and Zuari estuaries and nearshore waters is also estimated and compared with earlier reports.

Two sets of Zooplankton samples were collected in vertical hauls (5 m to surface) using methods described earlier[8], from Mandovi (15°29′N and 73°49′E) and Zuari (15°25′N and 73°49′E) estuaries during Jan. to Dec. 1978 and from nearshore waters (15°30′N and 73°42′E) during Jan. to May 1978. The depths for estuarine and nearshore areas ranged from 6 to 8 m and 12 to 15 m respectively.

For estimation of secondary production mean biomass value for each month was considered and rate of production estimated[7] based on organic carbon values[8] for the same set of samples. Each sample (20%) was analysed for the enumeration of different taxa. Dry weight estimates were made separately for herbivores/omnivores and predators. Predatory copepods formed a negligible part of total copepods and hence were not separately treated.

Zooplankton production—Production of zooplankton in Zuari, Mandovi and nearshore waters for different months are given in Table 1 and Fig. 1. Zooplankton biomass in the Zuari estuary ranged between 6 and 78.7 mg dry wt/m^3/day with a mean value of 33 mg dry wt/m^3/day. In Mandovi estuary,

Table 1—Rate of Secondary Production in Mandovi, Zuari and Nearshore Regions during 1978

[Values expressed in mgC/m^2/day]

	Mandovi	Zuari	Nearshore
Jan.	18.35	33.71	30.69
Feb.	38.77	61.42	148.83
March	47.18	45.9	61.05
April	53.38	80.2	329.01
May	32.28	62.72	112.42
June	17.47	12	—
July	34.34	40.68	—
Aug.	18.79	199.38	—
Nov.	221.89	119.12	—
Dec.	26.03	27.82	—
Mean	50.85	69.3	136.4