Indian Journal of Marine Sciences
Vol. 2, June 1973, pp. 38-46

Copepod Component of Zooplankton in a Tropical Estuary

P. PARAMESWARAN PILLAI, S. Z. QASIM & A. K. KESAVAN NAIR
Central Marine Fisheries Research Institute, Cochin 682018

Received 29 *January* 1973

Copepods constitute the most predominant portion of zooplankton biomass in the Cochin Backwater throughout the year. Their population largely includes omnivores, although carnivores become abundant during the premonsoon months and herbivores during the monsoon months. Seasonal differences in temperature of the estuary are of the order of 5°C, while the changes in salinity are considerable. Phytoplankton production does not have a definite seasonal rhythm and shows only twofold increase from the average value in some months. Characteristics of copepod population are investigated by using the diversity indices α, H(s) and ε. An inverse relationship is found between diversity and copepod biomass during the year which indicates that the copepod population is heterogeneous when the biomass is low and homogeneous when the biomass is high. The values of α decrease as the copepod number increases, whereas the H(s) and ε values are sensitive to changes in species composition. Species number has little influence on the diversity indices. Similarly zooplankton biomass has no definite relation with the diversity. The relationships between the environmental factors (temperature, salinity and food supply) and the abundance of copepods have been determined from the simple, partial and multiple correlation coefficients. Changes in temperature are linked with those of salinity and these two produce highly unstable conditions in the estuary which induce seasonal variations in the species and in the total abundance of copepods. Food supply seldom acts as a limiting factor in the estuary and does not seem to govern the seasonal abundance of copepods. Six major families of copepods exhibit varying degrees of coexistence among themselves in the environment.

THE environmental features including productivity and foodchain of a tropical estuary, commonly known as the Cochin Backwater, have been reported[1-5]. The main purpose of these studies was to determine the extent to which the widely fluctuating environmental factors (hydrographic features) would influence the abundance of plants and animals in the estuary. The influence of some of the singled out environmental factors such as salinity, light and nutrients on the photosynthesis of phytoplankton by species and their abundance in the estuary have been discussed[6-8]. In this paper some features associated with the abundance and diversity of copepod population in the estuary are reported.

Seasonal changes in the zooplankton population have been studied by George[9] and more recently by Nair and Tranter[10] and Menon *et al.*[11]. Specific groups such as copepods, chaetognaths and hydromedusae have been studied by several authors[12-15]. The relative proportion of the various groups seems to vary with the monsoon cycle which makes the year divisible into three seasons, each of four months: (i) Premonsoon (February to May), (ii) monsoon (June to September), and (iii) postmonsoon (October to January).

Copepods constitute the most dominant portion of zooplankton and occur throughout the year[11]. They thus form a very interesting group to study their relationship with the environment. Nine species of Acartiidae have recently been reported to form the most predominant component of copepods[16].

Materials and Methods

Zooplankton samples were collected at weekly intervals from one station[12] in the Cochin Backwater for a period of 2 yr (January 1969 to December 1970). Horizontal surface tows were made for 10 min and the speed of the boat in each tow was kept at 1 knot. The conical net used had a diameter of 0·5 m with nylon gauze of 0·33 mm mesh width and an open area ratio of 5. The volume of water filtered was determined by a 'TSK 487' flow meter attached to the net. The samples were preserved in 5% buffered formaldehyde in sea water. The copepod components of the samples were identified, sorted out and counted up to the species. Measurements of temperature and salinity were made from the same station along with the zooplankton samples.

Results

Copepods and zooplankton biomass — Table 1 gives the counts of different species of copepods in various months of the years 1969 and 1970. Thirty-one species were present at the station in 1969; but during the subsequent year, only 28 species could be seen. The absence of three species (*Labidocera pavo, L. minuta* and *Temora discaudata*) from the collections was well-marked. However, in 1969, at no time of the year, the total number of species exceeded 15, with a minimum of 8 species in October. In 1970, the maximum number of species recorded was 16 in January and May and the minimum of 5 in July and August.

TABLE 1 — MONTHLY COUNTS OF DIFFERENT SPECIES OF COPEPODS IN THE COCHIN BACKWATER FOR A PERIOD OF TWO YEARS TOGETHER WITH OTHER SEASONAL DATA ON ZOOPLANKTON BIOMASS, TOTAL COPEPOD COUNTS AND SPECIES NUMBER

1969

	J	F	M	A	M	J	Jy	A	S	O	N	D
Number of samples	3	3	3	4	3	3	3	3	4	1	4	3
Av. copepod counts/m³	96	471	160	50	65	36	10	15	70	53	19	72
Total number of species	13	15	13	15	10	9	9	11	12	8	12	14
Av. zooplankton biomass/m³	0·185	0·319	0·152	0·195	0·352	0·138	0·090	0·161	0·109	0·228	0·095	0·176
Total copepods in sample	2006	9896	3355	1058	1374	762	208	307	1468	1114	400	1508
Species counts:												
Acartia spinicauda	432	1549	976	554	354	143	17	152	28	4	117	272
A. centrura	340	5170	888	306	333	104	1	30	—	—	25	182
A. erythraea	448	1200	310	28	378	—	—	10	—	7	42	269
A. plumosa	—	—	—	—	—	72	44	—	—	—	17	—
Acartiella gravelyi	—	—	—	—	—	—	15	4	197	4	2	—
A. keralensis	—	—	—	—	—	19	30	—	21	—	—	10
A. biloba	—	—	—	—	—	76	—	—	601	—	—	—
Centropages furcatus	12	81	98	8	144	—	—	—	—	22	3	88
C. trispinosus	470	1036	44	10	—	—	—	—	—	—	30	244
C. alcockii	136	—	26	16	—	—	—	35	30	—	—	—
C. orsinii	—	—	6	—	19	—	—	—	—	917	2	28
C. tenuiremis	—	—	—	—	—	—	—	50	—	44	—	—
Pseudodiaptomus serricaudatus	62	353	70	26	—	—	—	—	50	40	72	79
P. jonesi	—	149	212	18	8	—	—	—	1	—	8	—
P. mertoni	4	2	660	36	38	48	—	16	95	—	—	—
P. binghami malayalus	—	—	—	—	—	—	—	5	104	—	—	—
P. tollingerae	—	—	—	—	—	8	3	—	—	—	—	—
P. annandalei	10	96	14	14	88	280	83	—	300	—	20	4
Diaptomus mirabilipes	—	—	—	—	—	—	10	—	14	—	—	—
D. cinctus	—	—	—	—	—	—	5	2	27	—	—	—
Labidocera pectinata	40	200	26	9	—	—	—	—	—	—	—	—
L. kroyeri	10	28	—	4	—	—	—	—	—	—	—	—
L. pavo	—	6	—	—	—	—	—	—	—	—	—	—
L. minuta	40	4	—	—	—	—	—	—	—	—	—	—
Temora turbinata	—	—	25	5	8	—	—	2	—	76	62	109
T. discaudata	—	2	—	—	—	—	—	—	—	—	—	—
Candacia bradyi	—	20	—	—	—	—	—	—	—	—	—	12
Paracalanus crassirostris	—	—	—	—	—	2	—	1	—	—	-	—
Eucalanus subcrassus	—	—	—	—	4	—	—	—	—	—	—	180
Acrocalanus similis	—	—	—	20	—	—	—	—	—	—	—	26
Tortanus gracilis	2	—	—	4	—	—	—	—	—	—	—	5

1970

	J	F	M	A	M	J	Jy	A	S	O	N	D
Number of samples	4	1	1	3	4	4	2	3	3	1	3	3
Av. copepod counts/m³	267	203	406	280	106	36	7	6	32	10	11	12
Total number of species	16	10	9	15	16	11	5	5	14	6	14	12
Av. zooplankton biomass/m³	0·233	0·333	1·738	1·533	0·290	0·128	0·086	0·114	0·842	0·228	0·114	0·096
Total copepods in sample	5600	4258	8528	5877	2228	752	125	108	665	195	216	244
Species counts:												
Acartia spinicauda	745	836	2640	1303	695	26	—	—	8	—	19	61
A. centrura	747	1896	2120	1499	917	25	—	—	132	—	43	57
A. erythraea	633	—	—	714	208	—	—	—	—	—	—	10
A. plumosa	—	—	—	—	—	385	—	—	83	148	20	6
Acartiella gravelyi	—	—	—	—	—	41	63	25	46	4	—	—
A. keralensis	—	—	—	—	—	106	—	1	36	5	—	—
A. biloba	—	—	—	4	—	—	—	—	—	—	—	—
Centropages furcatus	210	254	328	386	18	—	—	—	—	—	17	9
C. trispinosus	932	456	—	—	9	—	—	—	—	—	—	64

TABLE 1 — MONTHLY COUNTS OF DIFFERENT SPECIES OF COPEPODS IN THE COCHIN BACKWATER FOR A PERIOD OF TWO YEARS TOGETHER WITH OTHER SEASONAL DATA ON ZOOPLANKTON BIOMASS, TOTAL COPEPOD COUNTS AND SPECIES NUMBER (*Contd*)

	1970											
	J	F	M	A	M	J	Jy	A	S	O	N	D
C. alcockii	45	56	64	256	4	23	—	—	10	—	3	11
C. orsinii	42	—	—	—	2	—	—	—	4	—	23	2
C. tenuiremis	—	—	—	—	2	—	—	—	24	10	15	—
Pseudodiaptomus serricaudatus	1165	436	200	134	3	—	—	—	—	—	39	5
P. jonesi	513	72	—	56	84	1	—	—	—	—	—	—
P. mertoni	—	—	880	403	194	—	—	—	—	—	—	—
P. binghami malayalus	—	—	—	—	—	16	40	1	57	16	2	—
P. tollingerae	—	—	—	—	—	—	—	—	2	—	—	—
P. annandalei	37	36	—	72	8	100	3	—	231	12	8	—
Diaptomus mirabilipes	—	—	—	—	—	4	8	63	—	—	—	—
D. cinctus	—	—	—	—	—	25	14	14	—	—	—	—
Labidocera pectinata	251	204	2264	642	52	—	—	—	—	—	2	5
L. kroyeri	—	12	8	320	4	—	—	—	—	—	1	4
L. pavo	—	—	—	—	—	—	—	—	—	—	—	—
L. minuta	—	—	—	—	—	—	—	—	—	—	—	—
Temora turbinata	148	—	24	32	—	—	—	—	24	—	16	10
T. discaudata	—	—	—	—	—	—	—	—	—	—	—	—
Candacia bradyi	60	—	—	—	—	—	—	—	—	—	—	—
Paracalanus crassirosris	—	—	—	—	—	—	—	—	4	—	8	—
Eucalanus subcrassus	22	—	—	24	—	—	—	—	4	—	—	—
Acrocalanus similis	32	—	—	—	16	—	—	—	—	—	—	—
Tortanus gracilis	18	—	—	32	12	—	—	—	—	—	—	—

There is a direct correlation between the number of species and the total counts, i.e., when the species number was large the counts were also greater (Table 1). This, however, was not true between the number of species and biomass. Three species of Acartiidae were found to be most predominant. Tranter and Abraham[16] recorded the copepod counts in the Cochin Backwater many times greater than those of ours. This may be because they used a finer 'Heron-Tranter Net' of 0·2 mm mesh width which could possibly retain smaller copepods and larval forms. They report the occurrence of 11 species of Acartiidae, of which, 9 were relatively common. We could record only 7 species of Acartiidae at our station which was typically estuarine. The species absent were *Acartia southwellii* and *A. negligens*. Tranter and Abraham[16] report that *A. southwellii* died out during the low salinity regime, although this species is a well-known estuarine form. Kasthurirangan[17], however, has pointed out that *A. southwellii* is found as 'sole zooplankton element' when the salinity is lowest and when the other zooplankton organisms are absent. More recent observations of ours have confirmed the occurrence of *A. southwellii* in predominantly fresh water sections of the Backwater and not in the areas which become predominantly marine in certain seasons. *A. negligens*, on the other hand, is a typically oceanic form and hence its absence at the estuarine station is explained.

Monthly variations in the zooplankton biomass for the years 1969 and 1970 have been shown in Fig. 1A. In both the years, the zooplankton biomass was high from January to May and low from June to September. Copepods formed the

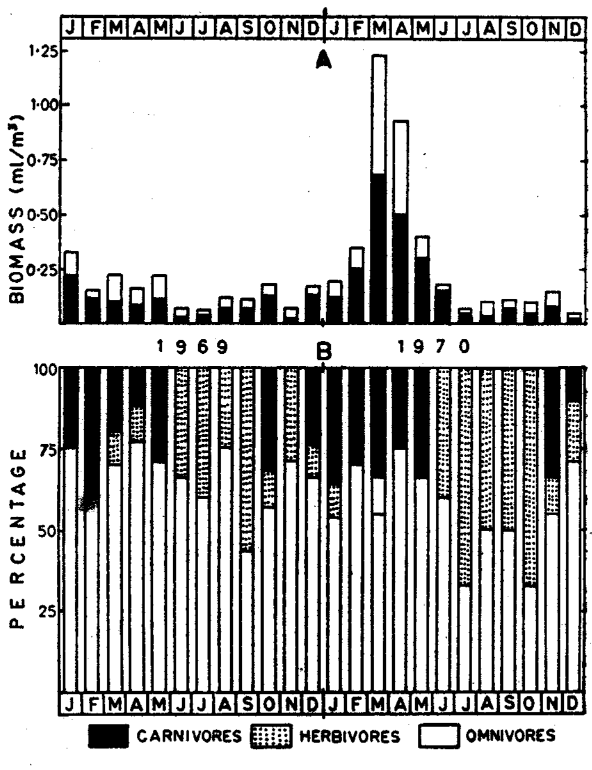

Fig. 1 —(A) Seasonal variation in the total quantity of zooplankton in the Cochin Backwater for a period of 2 years [Shaded portions indicate contributions of copepods in the total zooplankton biomass], and (B) Percentage composition of 3 different categories of copepods [carnivores, herbivores and omnivores in the monthly samples as determined from their mouth parts]

major component of zooplankton at all times of the year and contributed nearly 50% or more of the total biomass. From June to August, the composition of copepods in the zooplankton was nearly 80-90%. The overall picture of zooplankton biomass obtained for the year 1970 was entirely different from that of the preceding year (Fig. 1A). During 1970, the biomass was many times greater in March, April and May than in the corresponding period of the previous year, with copepods once again contributing the bulk. Minimum values in both the years were obtained during June, July and August. The coefficient of variation of zooplankton was 47% in 1969 and 113% in 1970.

An examination of the mouth parts of the different species of copepods showed that most of the species could be classified as omnivores, carnivores and herbivores. This classification was based on the morphological peculiarities of the appendages as given by Anraku and Omori[18] and Gauld[19], for the planktonic copepods. The omnivores included many species belonging to the neritic genera *Pseudodiaptomus*, *Centropages* and *Acartia*; herbivores from the genera *Acartia*, *Diaptomus* and *Paracalanus* and carnivores from four families — Acartiidae, Candaciidae, Pontellidae and Tortanidae. The percentage composition of these three categories of copepods has been shown in Fig. 1B for both the years. Despite the marked differences in the biomass values during the two years, the three categories of copepods showed little change in their percentage composition. Omnivores dominated in practically all the months. Herbivores appeared during the monsoon and postmonsoon months, but the carnivores were largely confined to the premonsoon period (Fig. 1B).

Environmental features and copepod abundance — Seasonal changes in the surface temperature and salinity during the 2 yr have been shown in Fig. 2. Salinity varied considerably each year, from virtually fresh water to typically marine conditions. Equally well pronounced were the other properties in the estuary such as dissolved oxygen, alkalinity, nutrients and the rate of flushing associated with the rainfall[4,20]. From the changes in temperature and salinity, it is evident that the copepods found at the surface of this station will be subjected to an annual temperature variation from 26·2° to 31·9°C and salinity from 0·8 to 34·6°/$_{oo}$. At present, only little is known about the ability of various species to withstand such wide fluctuations in salinity and practically nothing on the mechanism involved. Species such as *Pseudodiaptomus mertoni*, *P. binghami malayalus*, *Acartia plumosa*, *A. spinicauda*, *Acartiella gravelyi* and *A. keralensis* occurred in the Cochin Backwater during the period of very low salinity. The appearance and succession of some of the common species of copepods in response to changes in salinity have been discussed earlier[12]. When the backwater is sea water dominated, about 16 species are recorded; but with a gradual influx of fresh water during the monsoon months, the number gets progressively reduced, and when the system becomes fresh water dominated, only 5-9 species remain in the estuary.

Monthly values of gross and net primary production, as given by Qasim *et al.*[3], has been shown in Fig. 3. The coefficient of variation in the primary production was found to be 40% for gross and 37% for net primary production. These data have been included here to indicate the general trend in the production rates in the estuary during the year and not as absolute values for the various months.

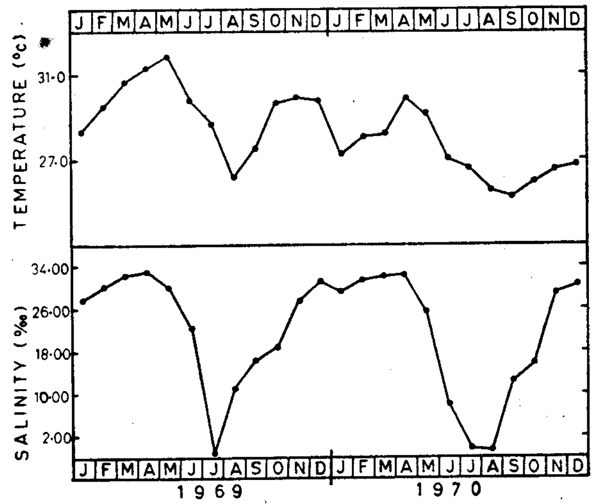

Fig. 2 — Seasonal variation in temperature and salinity in the Cochin Backwater at the station from where zooplankton collections were made

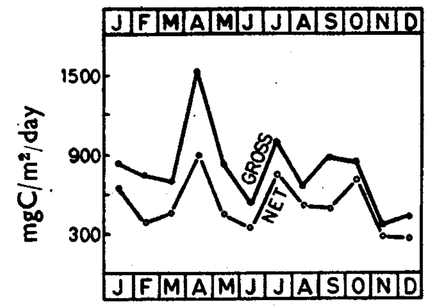

Fig. 3 — Seasonal cycle in the rate of gross and net primary production in the Cochin Backwater at the station from where zooplankton samples were collected [The production values refer to 1965-66]

Species diversity — Species diversity is defined as the absolute number of species present in an environment. Fisher *et al*[21]. have expressed the diversity by the following equation:

$$S = \alpha \log_e (1+N/\alpha) \quad \ldots(1)$$

where S is the number of species in the sample, N is the number of specimens in the sample and α is the index of diversity. Margalef[22] used a simple diversity index (d) expressed by the formula

$$d = \frac{S-1}{\log_e N} \quad \ldots(2)$$

where S is the number of species and N is the number of individuals. Sutcliffe[23], while correlating the diversity of the species of copepods with the zooplankton biomass, found that the diversity index (α) of Fisher *et al.*[21] has a greater stability than that of Margalef's index. In the present analysis α values were calculated by the method of iteration for the copepod population. Table 2 gives the α values for the different months together with their standard errors. Relevant data on other features have also

TABLE 2 — MAXIMUM NUMBER OF SPECIES OF COPEPODS PRESENT IN THE COCHIN BACKWATER IN RELATION TO THE DATE OF COLLECTION IN EACH MONTH

[Data on the number of specimens, biomass, temperature and salinity refer to the dates on which collections were made. Calculated values of diversity indices α, $H(s)$ and ε are also given]

Date of collection	No. of species	Copepod counts/m³	Biomass ml/m³	Salinity ‰	Temp. °C	α values	SE of α	$H(s)$ values	ε values
21 January	8	189	0·333	29·9	28·2	1·7	0·29	2·2410	0·794
18 February	10	721	0·152	32·3	29·4	1·6	0·20	2·2805	0·655
24 March	10	200	0·224	34·3	30·6	2·2	0·34	2·3815	0·706
16 April	9	77	0·166	34·6	31·2	2·7	0·56	1·6895	0·458
13 May	7	79	0·224	32·3	31·9	1·9	0·41	1·6952	0·591
3 June	6	37	0·076	24·2	29·9	2·0	0·54	2·0254	0·897
1 July	5	10	0·062	0·8	28·7	4·0	2·17	2·0566	1·102
19 August	8	22	0·124	9·1	26·2	4·5	1·52	1·7171	0·527
5 September	9	200	0·114	19·2	27·5	1·9	0·30	1·9679	0·570
31 October	8	53	0·186	20·8	29·7	2·2	0·53	1·0371	0·351
28 November	7	33	0·071	29·2	29·9	2·7	0·75	2·1038	0·816
12 December	9	94	0·176	33·0	29·8	2·4	0·45	2·6150	0·932
16 January	11	257	0·195	34·0	29·2	2·3	0·33	2·8549	0·918
12 February	10	203	0·352	32·8	30·0	2·2	0·34	2·5383	0·795
13 March	9	406	1·286	33·7	30·1	1·6	0·23	2·2629	0·718
24 April	8	362	0·938	33·9	31·8	1·4	0·21	2·2253	0·784
23 May	9	146	0·409	27·5	31·1	2·1	0·36	1·5673	0·417
5 June	5	54	0·181	10·1	29·0	1·3	0·32	1·6151	0·778
17 July	3	4	0·071	1·6	29·1	5·4	5·92	1·5573	1·240
18 August	4	7	0·100	1·4	27·5	3·9	2·66	1·4331	0·843
11 September	8	49	0·109	14·3	27·3	2·7	0·64	2·4443	0·927
2 October	6	12	0·100	17·6	28·0	4·8	2·37	1·3158	0·508
27 November	9	13	0·152	31·4	28·6	13·0	7·39	2·3356	0·758
18 December	7	12	0·052	32·6	28·8	7·0	3·64	1·2803	0·423

been included in the Table. For calculating the different indices of diversity, the maximum number of species found in a particular month in respect of the date of collection has been used rather than the total number of species recorded in that month as shown in Table 1. As an example, if four collections were made in a particular month and in these collections the total numbers of species were 8, 3(7), 2(6), 2(5) = 15 [figures in parentheses indicate common species inclusive of the additional species — the latter not in brackets — present in each collection]; but the maximum number in one collection was 8, this value in respect of that date has been taken. Thus the values of the number of specimens, zooplankton biomass, temperature and salinity given in Table 2 are specific to the dates on which the collections were made. As seen from Table 2, α values ranged from 1·6 to 4·5 in 1969 and from 1·3 to 13·0 in 1970. The small number of species present in relation to the density of copepods in the backwater gives rise to low values of α. In 1970, the greater range in the value signifies a larger variation in the number of specimens in relation to the number of species. The copepod population in the Atlantic has been found to exhibit the least diversity in coastal waters and the greatest diversity in oceanic waters[24].

Another approach of diversity is by determining the equitability, which is defined as the extent to which the species occur in numbers. Thus the equitability is greatest when the specimens of different species composing a sample are in equal numbers and minimal when the specimens are most unequally divided among species. Margalef[22] called it heterogeneity.

Making use of the Shannon-Wiener function, the diversity is expressed as

$$H(s) = -\sum_{r=1}^{s} p_r \log_2 p_r \qquad ...(3)$$

where $p_r = n_r/N$ is the probability of an individual belonging to the rth species, n_r is the number of individuals in the rth species and N is the total number of individuals. For the relative ease in calculation the equation can be rewritten as

$$H(s) = C\{\log_{10} N - \frac{1}{N} \sum_{r=1}^{s} n_r \log_{10} n_r\} \qquad ...(4)$$

where $C = 3{\cdot}321928$ used as the conversion factor to change the base of logarithms from 10 to 2[25].

Lloyd and Ghelardi[25] gave ε as the measure of equitability component which was expressed as

$$\epsilon = S'/S \qquad ...(5)$$

where S is the observed number of species and S' is the number of hypothetical 'equitably distributed' species, which would be needed to produce species diversity equivalent to $H(s)$. When MacArthur's distribution is perfectly obeyed, ε will have a maximum value of 1·0. Thus the equitability component gives a direct comparison between the number of species and the evenness of their relative abundance. Sanders[26] has discussed the characteristics of these different diversity indices with reference to benthic forms.

Table 2 also includes the values of $H(s)$ and ε for the different months of the years 1969 and 1970. For computing the values of S' the table of Lloyd and Ghelardi[25] was used.

Seasonal variations in the values of α, $H(s)$ and ε have been graphically shown in Fig. 4 in relation to the copepod biomass values. Diversity is inversely correlated with the biomass, which would mean that the copepod population is more homogeneous (less diverse) when the biomass is maximum and more heterogeneous (diverse) when the biomass is low. During the premonsoon period, when marine conditions prevail in the estuary, the biomass is maximum. Both temperature and salinity conditions during this period are maximum. The monsoon period is characterized by stratification of the water column, with fresh water at the top and sea water at the bottom. The quantity of copepods present during the monsoon is small and the evenness in their relative abundance is greater (Table 1). The ϵ values for both the years are maximum in July whereas the α values attain peak in April and November. These seem to be dependent on the total number of specimens, and the number of species, whereas the equitability value $H(s)$ and ϵ, in addition to the number of specimens, also depend on the species composition. Some species disappear altogether during the monsoon months, but the total number of species still present in relation to the biomass remains large. This would also mean that a fairly large number of species is adapted to a wide range of environmental features of the estuary. The species diversity of Acartiidae in the Cochin Backwater was studied by Tranter and Abraham[16]. They found that diversity was greater during the high salinity regime at a typically estuarine station (Aroor) than that during the low salinity period. However, from their data pertaining to the mouth of the estuary, which is close to our station, it is clear that diversity is maximum in June and July which are the months of decreasing salinity.

To determine the effectiveness of the different indices of diversity and equitability, the values of α, $H(s)$ and ϵ were plotted against the number of individuals (N). The number of individuals is an expression of population density. Fig. 5 shows this relationship from which it is evident that the diversity index (α) decreases rapidly as the copepod number increases. However, when the copepod density becomes sufficiently large, this index attains uniformity (Fig. 5a). The values of $H(s)$ and ϵ as a function of copepod density give a wide scatter at low population density (Figs. 5b and c). As both $H(s)$ and ϵ are dependent upon the species composition, the scatter indicates that the species composition in the Cochin Backwater keeps changing, but when the population density becomes high, the changes in the species composition do not remain so well marked.

Figs. 6a, b and c give the indices of diversity as a function of species number. The inconsistency in their relationship, as is evident from all the 3 figures, indicates that the species number does not affect the diversity as much as the population density does.

The relationship between the diversity indices and zooplankton biomass has been shown in Fig. 7a, b and c. The curve for α as a function of zooplankton biomass is similar to that of population density. Since 50-80% of the zooplankton biomass is contributed by the copepods, the size of the biomass is largely dependent on the population density. For low values of biomass, the α values

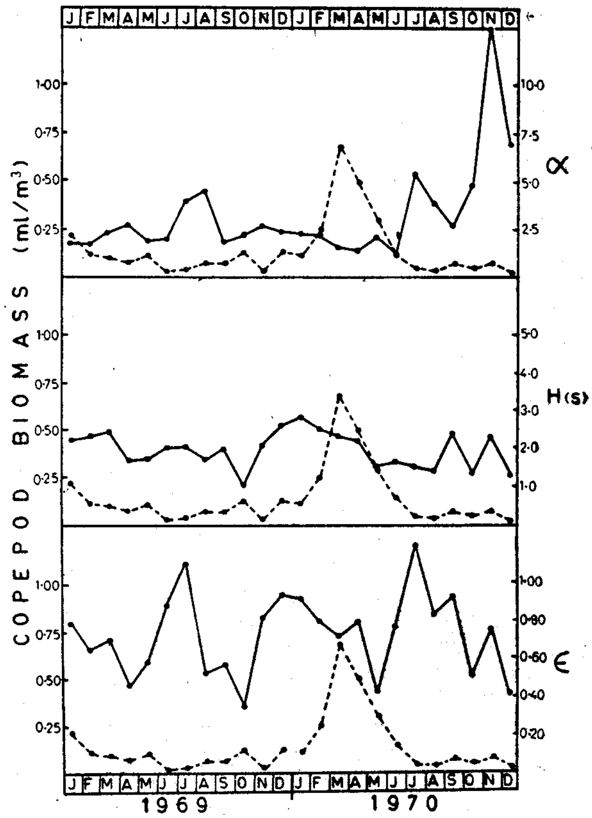

Fig. 4 — Seasonal changes in the diversity indices [α, H(s) and ϵ] in the copepod populations in relation to copepod biomass [●—●, diversity indices and ●- - - -●, copepod biomass]

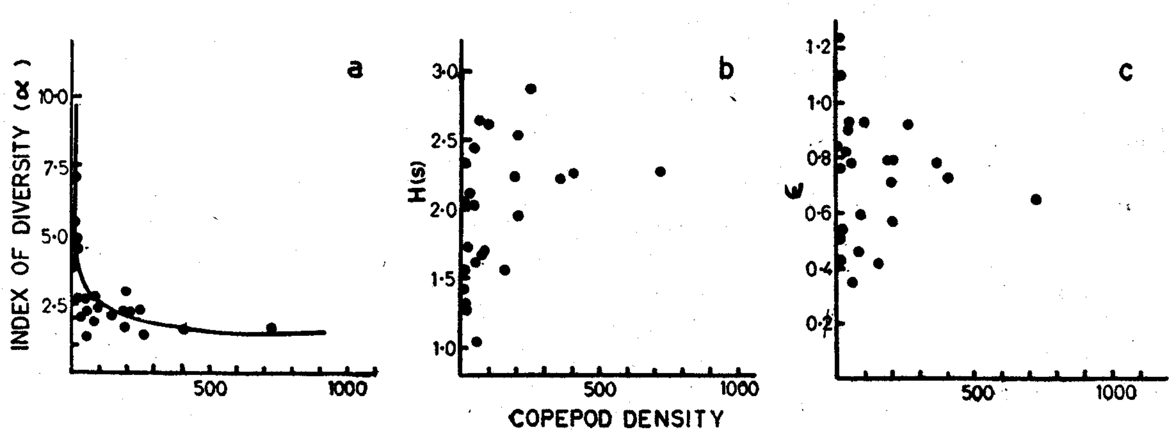

Fig. 5 — Relationship between diversity indices [a, α; b, H(s); and c, ϵ] and copepod density

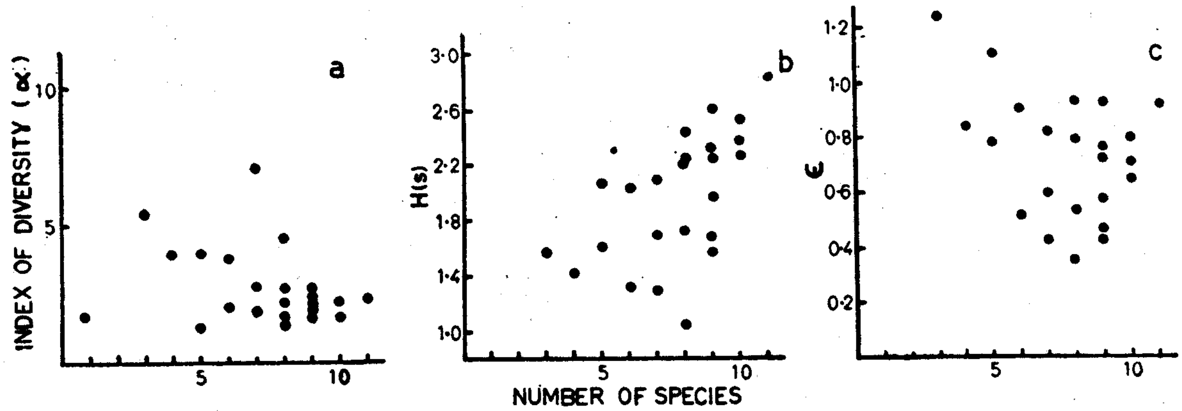

Fig. 6 — Relationship between diversity indices [a, α; b, H(s) and c, ε] and species number

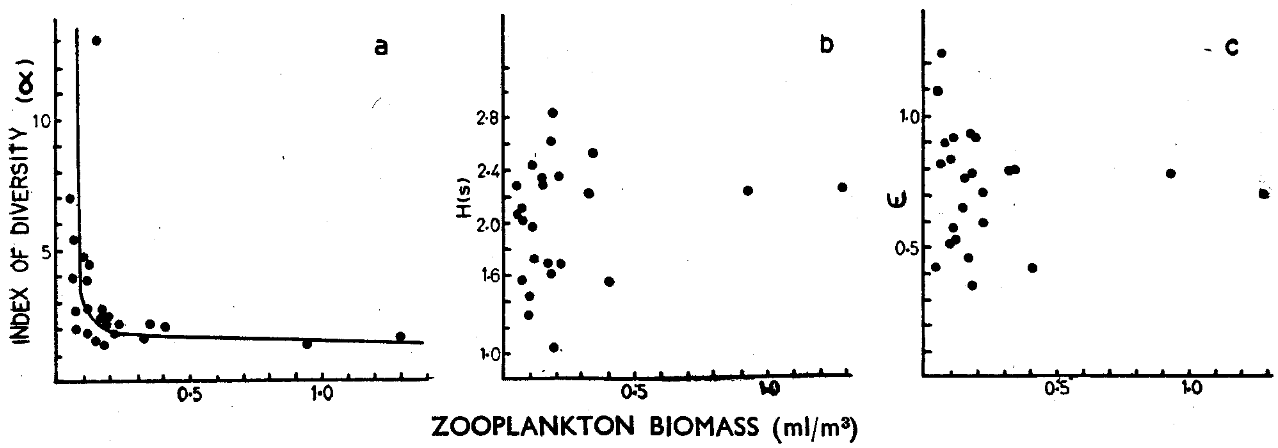

Fig. 7 — Relationship between diversity indices [a, α; b, H(s) and c, ε] and zooplankton biomass

have a high range, whereas at high values of biomass α values are generally less than 2 (Fig. 7a). The changes in the values of $H(s)$ and ε in relation to zooplankton biomass (Fig. 7b and c) do not indicate any definite trend. From such a relation the conclusion becomes logical that the size of the zooplankton biomass is not affected by the species composition as much as the population density is affected.

Discussion

To determine whether any relationship exists between the zooplankton biomass in the estuary and some of the environmental factors (temperature, salinity and food supply), correlation coefficients were at first calculated between biomass, temperature and salinity. The simple, partial and multiple correlation coefficients between these have been shown in Table 3. Significant correlations were found between biomass and temperature. The biomass-salinity values were not significant, which indicates that probably fresh water organisms also contribute to the total zooplankton biomass of the estuary. The highly significant relationship between temperature and salinity clearly indicates that the changes in one are associated with the other and that these two factors together explain a great deal of variation that occurs in the zooplankton composition of the estuary.

Similarly, a highly significant correlation was found between the species number of copepods and salinity, indicating that several species are of marine origin (Table 4). A negative correlation between temperature and species number seems to reflect that many species prefer low temperature. However, a positive and highly significant correlation between temperature and salinity suggests that high temperature and low salinity cannot exist simultaneously in the estuary and hence more species occur in such seasons when the salinity is still high and temperature begins to fall. Temperature and salinity give a significant multiple correlation coefficient with the species number (Table 4), suggesting that a great deal of variation in species is caused by these two parameters.

Table 3 — Simple, Partial and Multiple Correlation Coefficients Obtained Between Zooplankton Biomass (X), Salinity (Y) and Temperature (Z)

r_{XY}	r_{XZ}	r_{YZ}	$r_{XY.Z}$	$r_{XZ.Y}$	$R_{XY.Z}$
0·385	0·418*	0·608†	0·297	0·412	0·540*

Significant at * 5% level and † 1% level.

Table 4 — Simple, Partial and Multiple Correlation Coefficients Obtained Between Species Number of Copepod (S), Salinity (Y) and Temperature (Z)

r_{SY}	r_{SZ}	r_{YZ}	$r_{SY.Z}$	$r_{SZ.Y}$	$R_{SYZ.}$
0·778*	0·232	0·608*	0·767*	−0·116	0·781*

*Significant at 1% level.

TABLE 5 — SIMPLE, PARTIAL AND MULTIPLE CORRELATION COEFFICIENTS BETWEEN THE NUMBER OF INDIVIDUALS BELONGING TO 6 FAMILIES OF COPEPODS (D), SALINITY (Y) AND TEMPERATURE (Z)

Family	r_{DY}	r_{DZ}	$r_{DY.Z}$	$r_{DZ.Y}$	$R_{D.YZ}$
Acartiidae	0·433*	0·253	0·364	−0·052	0·436*
Centropagidae	0·413*	0·088(9)	0·454*	−0·225	0·767†
Pseudodiaptomidae	0·391	0·175	0·363	−0·085	0·398
Diaptomidae	−0·624†	−0·327	−0·566†	0·084(3)	0·627†
Pontellidae	0·339	0·337	0·180	0·175	0·377
Temoridae	0·238	0·155	0·184	0·013(0)	0·239

*Significant at *5% level and †1% level.

TABLE 6 — SIMPLE AND PARTIAL CORRELATION COEFFICIENTS BETWEEN COPEPOD DENSITY (D), SALINITY (Y), TEMPERATURE (Z) AND PHYTOPLANKTON PRODUCTION RATES (P)

r_{DY}	r_{DZ}	r_{DP}	r_{YZ}	r_{YP}	r_{ZP}	$r_{DP.Y}$	$r_{DP.Z}$
0·359	−0·014(2)	−0·400	0·657*	−0·497	−0·251	−0·274	−0·417

*Significant at 5% level.

TABLE 7 — CORRELATION MATRIX FOR THE COPEPODS BELONGING TO 6 MAJOR FAMILIES OF THE ESTUARY

	Acartiidae	Centropagidae	Pseudodiaptomidae	Diaptomidae	Pontellidae	Temoridae
Acartiidae						
Centropagidae	0·548*					
Pseudodiaptomidae	0·697*	0·365				
Diaptomidae	−0·204	−0·237	−0·210			
Pontellidae	0·470†	0·201	0·440†	−0·140		
Temoridae	−0·101	0·163	−0·122	−0·131	−0·18(9)	—

Significant at *1% level and †5% level.

Table 5 shows the correlation coefficients between the number of individuals belonging to six families of copepods and salinity and temperature. Significant correlations were found between the species of the two families (Acartiidae and Centropagidae) and salinity. However, Centropagidae, seems to have affinity with low temperature and hence its otherwise high correlation with the salinity gets masked. While almost all the families seem to show varying degrees of preferences to high salinity, Diaptomidae evidently prefers low salinity areas; the members of this family were actually recorded only during the monsoon months (Table 1). Of the six families, three (Centropagidae, Pseudodiaptomidae and Acartiidae) seem to prefer low temperature.

Table 6 gives the correlation coefficients between the total population of copepods, salinity, temperature and food supply. The quantitative data on food supply for the Cochin Backwater were taken from Qasim *et al.*[3]. These authors also give the estimates of 24 hr net production, which is the basic food material available for the next trophic level. The copepod numbers gave a positive correlation with the salinity, but these values being not significant show that the community as a whole consists of organisms which also prefer low salinity (Table 5). When the effect of salinity is eliminated, the copepod population shows a negative correlation with the food supply. As the copepod population in general prefers high salinity, the inverse correlation is obtained probably because the primary production remains high during the monsoon months when salinity becomes low and the copepod number is also low. These findings are in complete agreement with what had been reported earlier that the food supply is not a limiting factor in the estuary[27] (Table 6).

Tranter and Abraham[16] have identified 4 factors which they consider to be important for the coexistence of *Acartia* in the estuary, viz. tolerance to salinity, food supply, generation length and flow. In an estuary like the Cochin Backwater, which is so greatly influenced by the monsoon cycle, salinity is undoubtedly the most important factor and Tranter and Abraham[16] provide adequate data to support their exclusion hypothesis with reference to *Acartia* populations. However, with regard to the other 3 factors discussed by them, practically no supporting data have been given. They indicate that the quantity of food present in the estuary may be insufficient. This assumption has been drawn on the ground that the copepod population in the estuary is large. However, the validity of such an assumption is scarcely apparent in the light of reported figures of primary production from the estuary (daily gross = 0·5-1·5 gC/m^2; daily net = 0·35-0·88 gC/m^2 and 24 hr net = 0·12-0·58 gC/m^2) by Qasim *et al.*[3], which make the Cochin Backwater, from any standard, a highly productive ecosystem. Tranter and Abraham[16] give the range in the copepod density as 86-6171 counts/m^3 and call it the highest densities recorded anywhere in the world. As has been reported earlier, copepods constitute 50-90% of the total zooplankton biomass, and hence the values given by them make the zooplankton population as a whole by no means exceptional. Deevey[28] noted the total zooplankton counts of 8000/m^3 at station 'E' in the Sargasso Sea which is a well-known oligotrophic area. Moreover, if the food supply is a major factor in the estuary, one would expect peak abundance of the copepods to coincide with the phytoplankton maxima. The two cycles, on the other hand, are quite out of phase, and throughout the year the phytoplankton production far exceeds the rate of consumption by the zooplankton[27].

The correlation matrix in between the 6 major families has been shown in Table 7. A positive correlation coefficient between any one pair of families indicates that the number of specimens belonging to these families can increase or decrease in conjuction with each other. From this it can be concluded that these two can coexist. The positive correlation coefficient between any two pairs among the families Acartiidae, Centropagidae, Pseudodiaptomidae and Pontellidae provides evidence that these families combine to form a group by themselves. A negative correlation coefficient between any one pair indicates that when the number of specimens in one family increases, the number in the other decreases. From this it follows that the two families do not coexist. The family Diaptomidae seems well-adjusted to fresh water conditions and forms a group by itself. It occurs in abundance when the other families are absent largely because of its preference to very low salinity. As the correlation coefficients between Temoridae and the other families are mostly negative, it seems that this family forms another group by itself and becomes predominant when the other families are not so abundant.

From such an analysis it is evident that the six major families of copepods from the Cochin Backwater are so well-adjusted to the conditions prevailing in the estuary that at any one time of the year their presence or absence can easily be predicted.

References

1. Qasim, S. Z. & Reddy, C. V. G., *Bull. mar. Sci.*, **17** (1967), 95.
2. Qasim, S. Z., Bhattathiri, P. M. A. & Abidi, S. A. H., *J. exp. mar. Biol. Ecol.*, **2** (1968), 87.
3. Qasim, S. Z., Wellershaus, S., Bhattathiri, P. M. A. & Abidi, S. A. H., *Proc. Indian Acad. Sci.*, **59** (1969), 51.
4. Sankaranarayanan, V. N. & Qasim, S. Z., *Mar. Biol.*, **2** (1969), 236.
5. Qasim, S. Z. & Sankaranarayanan, V. N., *Mar. Biol.*, **15** (1972), 193.
6. Qasim, S. Z., Bhattathiri, P. M. A. & Devassy, V. P., *Mar. Biol.*, **12** (1972), 200.
7. Qasim, S. Z., Bhattathiri, P. M. A. & Devassy, V. P., *Mar. Biol.*, **16** (1972), 22.
8. Qasim, S. Z., Bhattathiri, P. M. A. & Devassy, V. P., *Mar. Biol.* (1973), (in press).
9. George, M. J., *Indian J. Fish.*, **5** (1958), 375.
10. Nair, K. K., Chandrasekharan & Tranter, D. J., *J. mar. biol. Ass. India*, **13** (1972), 203.
11. Menon, N. Ravindranatha, Venugopal, P. & Goswami, S. C., *J. mar. biol. Ass. India*, **13** (1972), 220.
12. Pillai, P. Parameswaran, *J. mar. biol. Ass. India*, **13** (1972), 162.
13. Srinivasan, M., *J. mar. biol. Ass. India*, **13** (1972), 173.
14. Nair, R. Vijayalakshmi, *J. mar. biol. Ass. India*, **13** (1972), 226.
15. Santhakumari, V. & Vannucci, M., *J. mar. biol. Ass. India*, **13** (1972), 211.
16. Tranter, D. J. & Abraham, S., *Mar. Biol.*, **11** (1971), 222.
17. Kasthurirangan, L. R. K., *Indian National Committee on Oceanic Research*, **2** (1963), 1.
18. Anraku, M. & Omori, M., *Limnol. Oceanogr.*, **8** (1963), 116.
19. Gauld, D. T., in *Some contemporary studies in marine sciences*, edited by H. Barnes (George & Unwin, London), 1966, 313.
20. Wyatt, T. & Qasim, S. Z., *Limnol. Oceanogr.*, **18** (1973), 301.
21. Fisher, R. A., Corbet, A. S. & Williams, C. B., *J. Anim. Ecol.*, **12** (1943), 42.
22. Margalef, R., in *Perspectives in marine biology*, edited by A. A. Buzzati-Traverso (University of California Press, California), 1960, 323.
23. Sutcliffe, W. H., *Ecology*, **41** (1960), 585.
24. Bowman, T. E., *Smithsonian Contrib. Zool.*, **96** (1971), 1.
25. Lloyd, M. & Ghelardi, R. J., *J. Anim. Ecol.*, **33** (1964), 217.
26. Sanders, H. L., *Am. Nat.*, **102** (1968), 243.
27. Qasim, S. Z., in *Marine food chain*, edited by J. H. Steele (Oliver & Boyd, Edinburgh), 1970, 46.
28. Deevey, G. B., *Limnol. Oceanogr.*, **16** (1971), 219.