Marine Biology 14, 25—31 (1972)

Ecological aspects of plankton production*

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Abstract

The study was carried out in the neritic and estuarine waters of Porto Novo, Coromandel Coast, Bay of Bengal, India during the period January, 1960 to December, 1967. The average displacement volume of plankton usually varied between 2 and 4 c^3/m^3. During summer, with a season of high plankton productivity, the average plankton displacement volume rose to 8 c^3/m^3. Generally speaking, the average zooplankton density (standing crop) was usually between 80,000 and 100,000 organisms/m^3, of which copepods alone comprised usually between 70,000 and 90,000 organisms/m^3. The average copepod density per sample varied from 30,000 to 50,000 organisms/m^3. However, in the summer months, the copepod density was usually not less than 100,000 organisms/m^3; in some years this was even higher (from 125,000 to 170,000 organisms/m^3). Copepods comprised between 80 and 95% of the zooplankton population. The maximum non-copepod population in the zooplankton seldom reached 30%, was often below 25%, and usually less than 20%. During the period March to October (in some years as early as February, and in some years up to November), either an increasing or a steady trend of plankton production was evident. It would appear that salinity and rainfall determine the occurrence and distribution of plankton in Porto Novo.

Introduction

The importance of plankton in the economy of the sea is very well known. A very characteristic and important aspect of plankton production is its variation in space and time. The present account deals with aspects of plankton production and its ecology at Porto Novo and compares it with those elsewhere.

Material and methods

Plankton was collected systematically from both nearshore and estuarine waters of Porto Novo, India. The present account covers mainly the period from January, 1960 to December, 1967. The plankton samples were collected mostly from the 10 fathom line (Station *A*), the 5 fathom line (Station *B*) and the mouth of the Vellar Estuary (Station *I*). For specific purposes, collections were also made from the 20 fathom line and from estuarine stations located upstream. Oblique, horizontal, and vertical hauls were made, particularly at Station I. A calibrated flow-meter was attached to the net during later studies (however, all values are computed in terms of cubic metres of water filtered). Generally, 3 to 5 m^3 of water were sampled. The minimum was 2 m^3, and the maximum about 40 m^3. The plankton net was made of bolting silk Nos. 10 and 20, depending upon availability of the cloth. A considerable percentage of copepod-nauplii loss occurred using No. 10 net. In the case of *Acartia* nauplii this loss was about 50%; in other words, the retention using No. 10 net was 50.50% (based on a series of six observations). Plankton collections were made as frequently as possible, ranging from almost daily collections to collections on alternate days or once every 3 to 5 days during inclement weather. During the same cruise, marine and estuarine plankton collections were made, but at times, marine collections had to be abandoned during very rough sea conditions or the monsoon season. Every effort was made to perform as many collections as possible, although this was, to a large extent, dictated by weather vagaries. During the summer, daily collections were attempted, but in winter and rough weather, these were biweekly, weekly, fortnightly or even monthly at Station *A* and the other marine stations. In some years, with a very bad monsoon, the intermission was even more prolonged. Pump collections of plankton samples were also made. Details of method, description of stations etc., are given in earlier communications (KRISHNAMURTHY, 1962, 1967a, b).

The plankton volumes were recorded by the displacement method to the nearest 0.10 c^3, and expressed in c^3/m^3. Larger organisms such as *Pleurobrachia*, *Phyllosoma* larvae and juvenile fish, etc., were not included when estimating the total plankton volume. The smaller zooplankton organisms were counted in known amount of aliquots; the errors in counting amount to less than 10%, and the accuracy of the numbers given in the present study is subject to this range of error.

Results

In earlier communications (KRISHNAMURTHY, 1962, 1967a, b) seasonal variation in plankton has been dis-

* Contribution No. 189 from the Centre of Advanced Study in Marine Biology, Marine Biological Station of Annamalai University, Porto Novo, Tamilnadu, India.

cussed. Only the salient features, with a few ecological highlights, are given here for the extended period of observations.

Maximum plankton productivity was attained during the period February/March to October/November. During the summer months, diatoms and copepods were the dominant components of the plankton. Quantitative increases in dinoflagellates, although restricted to periods, could also be noticed in summer. *Noctiluca* was dominant during certain months (e.g. August), and showed two or three maxima per year. The main peak varied over the years, although it usually occurred during August. The bulk of the zooplankton consisted mainly of copepods (between 80 to 95% during the years of investigation). The other important zooplankton components were coelenterate larvae, siphonophores, Medusae, ctenophores, *Pilidium* larvae, Müller's larvae, crustacean larvae, Cladocera, annelid larvae, chaetognaths, cyphonautes larvae, *Lingula* and *Actinotrocha* larvae, veligers, pteropods, heteropods, echinoderm larvae, larvae and adults of prochordates, etc. The differences in the composition of estuarine and neritic plankton were not great. They are discussed separately below:

Marine (neritic) plankton

The mean monthly displacement volume over the years varied normally between 1.30 to 4.60 c^3/m^3, attaining 8.00 c^3/m^3 in peak seasons. Marked seasonal occurrence was noteworthy in the following: *Noctiluca*, *Oscillatoria* (*Trichodesmium*), veligers, pteropods, heteropods, trochophores, larvae of Stomatopoda, Brachiopoda, (*Lingula*), Phoronida (*Actinotrocha*), Polychaeta, Echinodermata, *Amphioxus*, *Balanoglossus* (*Tornaria*); and Cladocera, salps and doliolids.

The Copepoda distribution can be grouped as follows:

(1) Species which occurred consistently at Station *A*: *Eucalanus elongatus*, *Euchaeta marina*, *Pontella princeps*, *Pontellopsis herdmanni*, *Acartia danae.*

(2) Species which occurried consistently at Stations *A* and *B*: *Nannocalanus minor*, *Canthocalanus pauper*, *Rhincalanus cornutus*, *R. nasutus*, *Undinula vulgaris*, *Oithona plumifera*, *Sapphrina nigromaculata.*

The changes in plankton volume generally showed two peak periods. The first peak lasted for three months, from March (or February in some years) to June (or July), and from August to October (or November). Usually the first peak was more pronounced (in 1965 it was the second peak). In general, December and January registered low volumes of plankton.

Copepods varied markedly in species composition from season to season, with one or more copepod species being predominant for a short time only. Like phytoplankton, the dominant copepod species varied to some extent over the years.

Estuarine plankton

As already stated, owing to easy accessibility, collections were more regular, intensive and numerous in this group. The plankton-displacement volume varied over the years, usually from 0.90 to 4.00 c^3/m^3, and with blooms of up to 7.00 c^3/m^3 and, rarely, even higher. As at marine Stations *A* and *B*, the bulk of the zooplankton consisted mainly of copepods, constituted by six genera: *Acrocalanus*, *Paracalanus*, *Euterpina*, *Acartia*, *Pseudodiaptomus* and *Oithona*. The most common species were: *Acrocalanus gracilis*, *Paracalanus parvus*, *Euterpina acutifrons*, *Acartia erythraea*, *A. spinicauda*, *Pseudodiaptomus aurivilli*, *P. serricaudatus* and *Oithona rigida*. Although these species occurred throughout the year, they had specific periods of dominance. During May to July, copepod abundance closely succeeded or coincided with diatom bloom. The following species of copepods seem to be restricted to this station: *Acartia chilkaensis*, *A. kempi*, *A. southwelli*, *A. seshaiyai* and *A. sewelli*. Of these, *A. kempii* and *A. sewelli* have been recorded as brackish-water forms by SEWELL (1948). The new species of *Acartia* recorded here, *Acartia seshaiyai* (SUBBARAJU, 1968), would also appear to be confined to this station.

The average copepod density was 85,457 organisms/m^3; the average zooplankton density was 92,082 organisms/m^3. The average zooplankton volume was 2.00 c^3/m^3 (these figures relate to 1967).

Seasonal succession

The timing of the primary peaks in diatoms and copepods varied slightly between neritic and estuarine stations. The period May to July saw increased phytoplankton activity, particularly of diatoms; the secondary peak was from September to November. After November, a declining trend in copepod numbers was noted which continued to February. The summer season was also a high zooplankton-production season. As in the phytoplankton, the timing and duration of the zooplankton peak varied from year to year. Between 1960 to 1963, a sharp decline was evident during August/September. However, in 1964 and 1965, the peak copepod activity occurred in September, dominated by *Oithona rigida*; while the overall average per sample was between 31,000 to 50,000 organisms/m^3, in September in these years the values rose to 263,800 and 125,000 organisms/m^3, respectively. Increase or decrease in copepod numbers often occurred abruptly (Table 1 shows the peak periods of occurrence of common copepods in Indian waters). In summer months, copepod density was not less than 100,000 organisms/m^3, and was often even much higher. The minimum and maximum figures were about 7,000 (November) and 286,000 (June) organisms/m^3, respectively.

Table 1. *Peak periods of abundance of some common copepods in Indian waters*

Species	East Coast				West Coast	
	Porto Novo	Madras	Visakhapatnam	Mandapam	Trivandrum	Calicut
Acartia erythraea	May/August	May, February/March	April/June, August	April/September, April/May, October/January	December	December
Paracalanus spp.	April/May	November/December, September/May	January/April	January/February, November	October/December	December
Euterpina acutifrons	May	December/January, September/May	March, July, September		May/August	December
Oithona spp.	August/September	August/September	February/June	August/September April	January/March, July/August	December
Pseudodiaptomus aurivillii	April/July	August/December	April	December/January	—	—
P. serricaudatus	January/April, August/October	July/December	March, June and July	September (Krusadai) August/April	—	—
P. annandalei	October/December	April	—	November/February	December/February, August	—
Metacalanus aurivillii	—	All seasons	March, May, July, September, October	March (not dominant)	—	—

Discussion

Fig. 1 shows the generalized trend (as given by Bogorov, 1958) of the plankton production at different latitudes; the figure also includes the generalised trend at Porto Novo. In Porto Novo waters, the seasonal changes differ from that generalised for tropical waters in having one or more maxima from April to September instead of showing low densities during

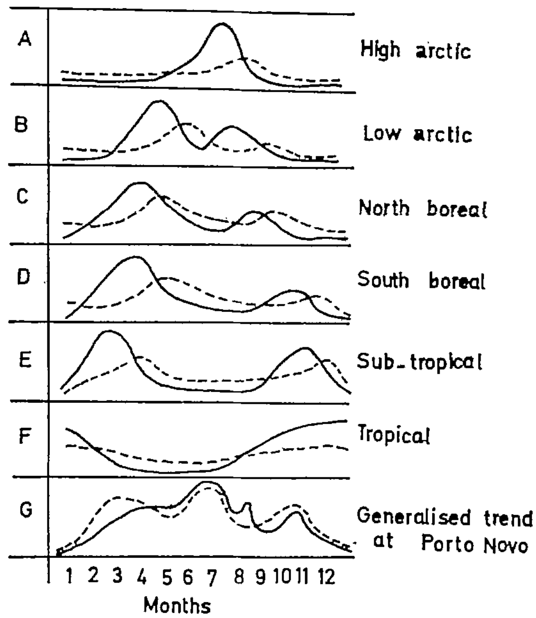

Fig. 1. Generalised trend of seasonal changes in plankton at different latitudes; solid line: phytoplankton abundance; broken line: zooplankton abundance (*A* to *F* after Bogorov, 1958)

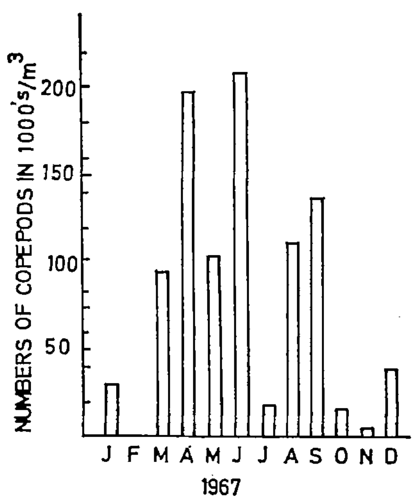

Fig. 2. Monthly mean copepod numbers per m³ in pump samples filtered through No. 20 bolting silk net at Station I during 1967

this period. It is interesting, in this connection, to observe that there is a close correlation between latitudinal distribution and duration of life history. This has been demonstrated with *Acartia erythraea* in local waters (SUBBARAJU, 1967); and regression analysis reveals this close correlation as summarised in Table 2 (see also Table 4).

Table 2. *Duration of developmental time in relation to latitude in different species of the genus Acartia*

Acartia species	Latitude	Developmental time (weeks)	
		Observed	Calculated
A. clausii	62°00′ N	8.00	8.30
A. clausii	50°15′ N	6.00	5.40
A. clausii	41°10′ N	3.00	3.16
A. tonsa	41°30′ N	3.50	3.20
A. tonsa	25°37′ N	2.00	1.80
A. erythraea	11°29′ N	1.00	0.95

Table 3. *Approximate percentage of copepods in zooplankton at various localities*

Region	Copepods (%)	Authority
Southampton (England)	42	RAYMONT and CARRIE (1964)
York River, USA	64	JEFFRIES (1962a, b, 1964)
Indo-Pacific Region	68	WICKSTEAD (1961)
Great Barrier Reef	71	RUSSELL and COLMAN (1931)
Porto Novo, India	91 (1967 data)	Present study

A number of workers have reported on the density of zooplankton and copepods in different regions of the world: DEEVEY (1948, 1956) and JEFFRIES (1964) in American waters; LOHMANN (1908), HARVEY et al. (1935), MARE (1940), DIGBY (1953), WIBORG (1954), HANSEN (1960) and RAYMONT and CARRIE (1964) in European waters, GANAPATI and SUBBA RAO (1958), SUBRAHMANYAN (1959) and WICKSTEAD (1961) in eastern seas. RUSSELL (1931) has compared the zooplankton of the Great Barrier Reef with that of Plymouth, England, but there is difficulty in making accurate comparisions, since the methods of collection and sampling have not been uniform. Nevertheless, comparison is worthwhile attempting for a relative assessment of plankton potential of different localities. The density of copepods is shown in Table 3 as percentage in zooplankton population.

It will be seen from the above table that the proportion of copepods in the zooplankton varies within wide limits from place to place. At Southampton, England, the predominant organisms were cirripede nauplii. In York river (USA) plankton also, cirripede nauplii were the major components, at times amounting to 50% of the total zooplankton population. In Raritan Bay (USA) and Narragansett Bay (USA), the polychaete larvae were dominant. In Porto Novo (India) waters, the maximum non-copepod population in the zooplankton was about 30%. It is interesting to note that the cyclopoid copepod *Oithona* was not predominant at Southampton, but was dominant in Long Island Sound (USA), Kiel Bay (Germany), and in the present area under discussion. During September, in 1964 and 1965, the local copepod population, as stated already, was comprised of predominantly *Oithona rigida*. In these 2 years, the major peak of copepods shifted to September. The population pro-

Table 4. *Number of generations and developmental period recorded in Acartia tonsa and A. clausi at various localities*

Authority	Locality	*Acartia tonsa*		*A. clausi*	
		No. of generations	Developmental time (weeks)	No. of generations	Developmental time (weeks)
WIBORG (1954)	Norway	—	—	2	8—10
DEEVEY (1948)	Tisbury Great Pond (USA)	2	6—7	2	8—10
DEEVEY (1960)	Delaware Bay (USA)	5—6	4	—	—
FROLANDER (1955)	Narragansett Bay (USA)	3—4	6—8	3	9—10
JEFFRIES (1955)	Charlestown (USA)	3	6—8	2	10
RAYMONT and MILLER (1962)	Woods Hole (USA)	—	3—4	—	—
CONOVER (1956)	Long Island Sound (USA)	4	3—4	4	8
MARSHALL (1949)	Loch Striven (UK)	—	—	4	5—6
DIGBY (1950)	Plymouth (UK)	—	—	4	5—6
JEFFRIES (1962a, b)	Raritan Bay (USA)	6	5—6	3	7—9
WOODMANSEE (1958)	Biscayne Bay (Florida)	11	3—7	—	—
ZILLIOUX and WILSON (1966)	Laboratory culture	—	25 days	—	—
HEINLE (1966)	Patuxent river estuary (USA)	—	1—2 weeks	—	—
Present study	Porto Novo (India)	12 (*A. erythraea*)	1—2 weeks	—	—

portion of copepods in local waters varied usually between 80 and 95%.

Density of plankton (standing crop)

It would be worthwhile to compare the present findings with similar observations reported elsewhere. In some places like Tisbury Great Pond, Long Island Sound, and Block Island Sound (USA) and Southampton, samples have been collected with No. 10 nets. The maximum number of total zooplankton organisms reported was about 100,000 organisms/m^3 in Tisbury Great Pond (Deevey, 1948) and over 200,000 organisms/m^3 in Long Island Sound (Deevey, 1956). The average zooplankton densities were 48,000 and 61,000 organisms/m^3 for Block Island Sound and Long Island Sound, respectively. The average number of zooplankton at Southampton was in the order of 18,000 to 32,000 organisms/m^3. At Porto Novo, the average copepod numbers alone were about 42,000 organisms/m^3, and thus formed more than the average zooplankton densities at Southampton.

In Plymouth waters, Harvey et al. (1935), Mare (1940) and Digby (1950) recorded zooplankton abundance using No. 25 silk nets. The maximum zooplankton density record at Plymouth was 55,000 organisms/m^3, with an average density of 30,000 organisms/m^3; at Porto Novo, the average zooplankton density for 1967 was 92,082 organisms/m^3 (copepods alone amount to 85,457 organisms/m^3), which was about three fold that of Plymouth plankton (Fig. 3 shows a relative assessment of the standing crop of zooplankton). In Kiel Bay, the average density of zooplankton was 142,846 organisms/m^3; this figure includes copepod eggs also. The zooplankton numbers of Porto Novo are exclusive of copepod eggs. In Indian waters, Ganapati and Subba Rao (1958) reported average zooplankton densities of 138,333 organisms/m^3 with finer nets (No. 30 net). The present (Porto Novo) figures were slightly less, but this could be due to differences in the nets used. On the west coast of India (Calicut), Subrahmanyan (1959) recorded average zooplankton density about thirty times higher than that recorded in Kiel Bay by Lohmann (1908).

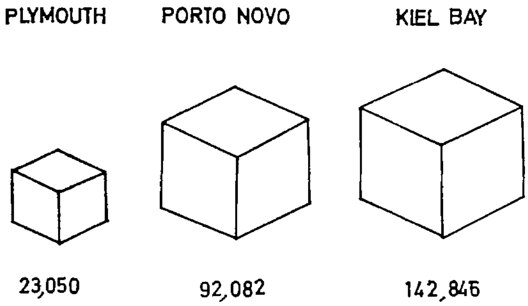

Fig. 3. Zooplankton standing-crop. Numbers at various locations per m^3

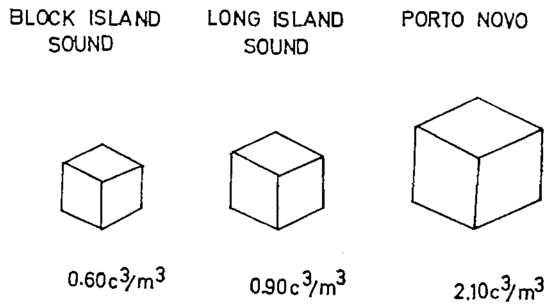

Fig. 4. Plankton displacement volume (c^3/m^3) at various locations

Comparison of plankton volumes

Fig. 4 shows the relative plankton-displacement volume at various locations. As already stated, comparison between different areas is rather difficult, since the collection methods employed vary. However, the present findings are generally comparable with observations of Bigelow (1926), Bigelow and Sears (1939), Riley (1939, 1947) and his group (Riley and Bumpus, 1946; Riley et al., 1949), and with similar studies carried out in Long Island Sound, Block Island Sound and Tisbury Great Pond. Over the Continental Shelf and from Cape Cod to Chesapeake Bay, Bigelow and Sears (1939) recorded zooplankton volumes between 0.40 to 0.80 c^3/m^3; the zooplankton of Georges Bank yielded a minimum of 0.72 c^3/m^3; the mean zooplankton volume of Block Island Sound was 0.68 c^3/m^3 and the mean plankton volume for Long Island Sound was slightly higher at 0.95 c^3/m^3. A maximum of 2.50 c^3/m^3 has been recorded by Barlow (1955) in Tisbury Great Pond. The average zooplankton volume of Porto Novo compares favourably with Block Island Sound, Long Island Sound and Tisbury Great Pond.

The zooplankton at Porto Novo showed marked seasonal fluctuations, the magnitude of peak periods being similar to those in temperate climes. Wickstead (1961) observed that the plankton of tropical waters (Indo-Pacific region) simulated the spring bloom, and explained the similarity on the basis of monsoon seasons. As Porto Novo lies in the monsoon belt, this explanation holds good for local waters also. The zooplankton densities and plankton volumes, in general, were low in the first and last quarters of the year. The low zooplankton and copepod numbers coincided with low salinity from October/November to February/March. Generally speaking, numerical abundance corresponded to high-salinity values between April and September. The occurrence and duration of the high and low zooplankton and copepod seasons varied slightly from the norm prescribed above from year to year.

For the local waters, salinity records are available for several years. Salinity values at Station *I* usually varied between 20 and 30‰ from October to March. The monsoon is in full swing during October to December. During this period, the estuary is flooded and salinity approaches even that of fresh water for some days, depending upon the continuity and intensity of the rains both here and further inland in the area of the Vellar river. The salinity of the coastal waters also falls considerably during this period. On the other hand, from April to September, the salinity range was rather limited between 28 and 35‰ (this range varied to some extent from year to year, the range of variation was even much less for some years) and remained rather steady. It would appear that local rainfall and salinity govern the plankton cycle. At Calicut (India), Jacob and Menon (1947) observed swarms of copepods from October to March; copepod occurrence was low from April to September, with minimum numbers during May and June. The maximum rainfall and minimum salinity coincided with minimum copepod numbers during May and June at Calicut also. At Porto Novo, apart from the primary peaks of phytoplankton and copepoda, several short-term peaks of phytoplankton and copepoda also occurred from February/March to November every year. The fishing activity in local waters, especially of clupeids and pelagic fishes, in general, was more intensive during this period, and the total yield of fish catches was greatest when copepods were most abundant.

Summary

1. Ecological aspects of plankton production have been studied in nearshore and estuarine waters of Porto Novo, India from 1960 to 1967. The results obtained are compared in the light of similar observations recorded elsewhere.

2. The mean monthly plankton displacement volume was between 2 and 3 c^3/m^3; it rose to as much as 8 c^3/m^3 during summer in some years.

3. During the years of investigation, the period of maximum plankton productivity was from February/March to October/November.

4. Apart from the primary peaks of phytoplankton and copepod productivity, several secondary short-term peaks of phytoplankton and of copepods also occurred during the period of major productivity.

5. Average zooplankton density was about 92,000 organisms/m^3; numbers of copepods alone amounted to about 85,000 organisms/m^3 (1967 data). Average percentage of copepods varied within wide limits of 80 to 95%. The maximum non-copepod population in the zooplankton seldom reached 30%, was often below 25%, and usually less than 20%.

6. In the summer months, copepod density was not less than 100,000 organisms/m^3, being often much higher (between 120,000 to 180,000 organisms/m^3); the maximum amounted to about 286,000 organisms/m^3. On the other hand, average copepod numbers per sample, for the rest of the year, varied from 30,000 to 50,000 organisms/m^3.

7. The occurrence, distribution and components of the copepod population varied over the years, with one or more species being predominant for any one period. In some years, the primary copepod peak, composed mainly of the cyclopoid copepod *Oithona rigida*, occurred during September. The primary peak of copepods usually occurred about June/July.

8. Increases or decreases in copepod numbers often occurred very abruptly.

9. It would appear that salinity and rainfall control, to a large extent, the occurrence and distribution of Porto Novo plankton.

Acknowledgements. We have great pleasure in thanking the Director, Professor R. Natarajan, Centre of Advanced Study in Marine Biology, Porto Novo, India, for facilities, and the former Director, Professor R. V. Seshaiya for his advice and help. We are grateful to the Ministry of Education, Government of India, the University Grants Commission, and the Council of Scientific and Industrial Research, for financial support.

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Date of final manuscript acceptance: January 3, 1972. Communicated by N. K. PANIKKAR, Panaji