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HYDROGRAPHIC CONDITIONS, COMPOSITION AND DISTRIBUTION OF PLANKTON IN RELATION TO POTENTIAL RESOURCES OF PARAÍBA RIVER ESTUARY.

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ABSTRACT

The hydrological conditions, composition, seasonal fluctuations of plankton in relation to the potential resources of Paraíba river estuary are discussed. A total of 87 planktonic species are recorded and the mean total of phyto- and zooplankton are compared, together with salinity, temperature, visibility and pH variations. While the salinity, transparency and pH increase seaward, the temperature generally decreases. The abundant diatom production in estuarine waters is enhanced by rich nutrients but no direct correlation between diatom density and zooplankton population exists in the estuary. An inverse relation betweenphyto- and zooplankton is evident in the coastal waters. The enormous diatom production might be partly consumed by the herbivorous fishes and filter-feeders. The present findings are of considerable importance to further studies.

INTRODUCTION

Estuaries are usually embayments where the sea invades a river system. Consequently, estuaries become complex but an important ecological habitat. The estuaries normally support a rich variety of living organisms which are constantly subject to tidal effects due to rhythmic rise and fall of the sea level and thus making the hydrological conditions more dynamic and often turbulent. Because of the variable abiotic and biotic factors, the organisms living there are well adapted for life in such most rigorous conditions. Paraíba river estuary provides one such environment. Despite its economic and commercial importance very little or no attention has been paid to evaluate the potential resources in relation to the hydrological conditions of this multiple estuary. The species composition and abundance of primary producers such as plankton are also presently unknown.

The only available previous works on Paraíba river estuary include a narrow aspect of geomorphology of the littoral region (FREYBERG, 1930; OTTMANN et al, 1962; MABESOONE et al, 1970). It is the purpose of this series, thefore, to study the potential values, seasonal and regional distribution patterns of plankton, together with the physico-

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chemical variables which have a direct bearing on the living organisms of the estuary and the coastal water which is proximal to the mouth of the estuary.

PHYSIOGRAPHY AND ECOLOGY OF THE PARAÍBA RIVER ESTUARY

The Paraiba river estuary is an extensive inshore bay-like inlet located along the northeastern coast of the Atlantic Ocean approximately between the latitudes 6° 57' 30" and 7° 8' 30" and between longitudes 34° 56' 20" and 34° 50' 0" (Fig. 1). The river es-

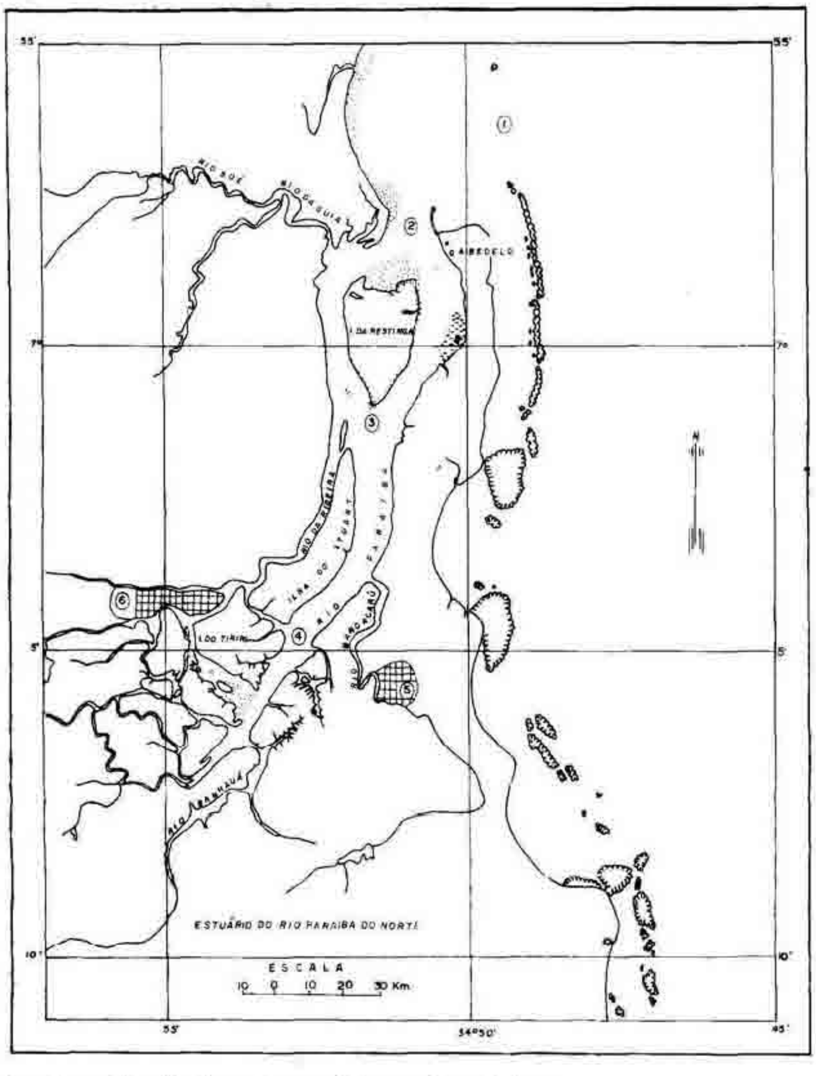

Fig. 1 - Location of Paraiba river estuary and the sampling stations.

tuary is separated from the sea by a narrow strip of land which extends to just over twenty four kilometres to join the main land. The depth of the estuary is not uniform but the maximum mean being 9.89m in the harbour area but usually a canal, with depth between 4 to 8 m, extends along the south easterly bank of the estuary. The harbour installations and the small town are built mainly along the river side. All along the sea side, about a kilometre away from and parallel to the beach, is a slightly discontinuous coral reef with the sandstone base (MABESOONE, 1964) which supports a fairly rich ichthyofauna, crustaceans, especially lobsters, echinoderms, corals and many other invertebrate animals and a variety of benthic algae.

The trunk of the estuary, together with its main multiple tributaries, covers an area of about 36.9 km^2. The large river mouth forms the principal part of the Cabedelo Port which is situated on the north easternbank of the estuary proximal to the sea and provides landing facilities for small commercial vessels and for productive source of both commercial and sport fisheries. On the northwestern bank of the harbour exists one of the largest whale factories where commercial catches are landed periodically. The port also provides sheltered harbour for small transport boats across the estuary and some amenities to the local population.

A couple of small sandy islands lie in the middle of the throat of the estuary and divide the bulk of the landward water for a short while only to merge again behind the islands. The southern tips of these islands are usually muddy perhaps, under the tidal influence and a fairly high concentration of fauna, dominated by molluscs, thrive well there (see Table 1). Consequently, the estuary and the nearby coral reef and the other crustacean fisheries represent a sizable economy with commercial potential.

TABLE 1. GENERAL CHARACTERISTICS OF THE SAMPLING STATIONS

STATION	LOCATION		MEAN DEPTH m	ENVIRONMENTAL FEATURE
	LATITUDE	LONGITUDE		
1.	6°56' 23'' S	34°50' 36'' W	11.00	Marine, neritic with high salinity.
2.	6°58' 03'' S	34°51' 01'' W	09.89	Slightly estuarine with admixture of oceanic and fresh water origins. sandy bottom.
3.	7°01' 04'' S	34°52' 36'' W	02.76	Estuarine, admixture of water continued: soft muddy bottom formed by tidal influence, normally very rich in benthic fauna, especially *Mytilus*.
4.	7°04' 36'' S	34°53' 03'' W	03.28	Highly estuarine with a mixture of sandy and muddy bottom.
5.	7°05' 39'' S	34°51' 01'' W	02.65	Extremely estuarine with very low salinity, with much fresh water run off; firm soft muddy bottom. Special site for oyster culture.
6.	7°04' 01'' S	35°52' 36'' W	02.34	Extremelly estuarine with greater freshwater runoff and salinity fluctuates: soft muddy bottom. Special area of fish culture and oyster culture.

On either side, the estuary is bordered by submerged mudbanks and fringed with mangrove swamps, particularly *Avicenia tomentosa*, *Rhizophora mangle* and *Laguncularia racemosa*. The intertidal zone of mud flats varies in extent between tides. The bottom of the river system is usually sandy and silting contributes to the bottom turbidity, sedimentation and to the general lack of transparency of the bottom water. Except in the part of the estuary where there are many fishing and domestic boats which may add some raw sewage, there is no evidence of pollution. In fact, it has not been subject to many changes which could influence the ecology of the estuary drastically. Tides around the area are relatively lower than the sea and the tidal amplitude varies between 1.5 to 2.4m.

MATERIALS AND METHODS

Sampling stations were selected covering wider areas of the estuary and a coastal station proximal to the river mouth, but intensive samplings were carried out in the areas where the oceanic water mixes with the fresh water runoff and those areas which are now productive for oyster and fish culture.

Physico-chemical factors were determined as a part of the ecological survey. Six main sampling stations were selected (Fig. 1 & table 1) and samplings were made monthly. The depth, surface temperature, pH, salinity, transparency and other hydrological parameters, together with plankton sampling, were measured routinely. Plankton samples were all collected using standard nets at a uniform speed and the nets were usually towed just below the surface. The plankton samples were preserved in 4% neutral formaldehyde. They were later concentrated to 100 ml volume and analysed by placing 1 ml of sub-sample. The mean of three separate counts was taken as the representative number for each sub-sample. Where necessary, permanent slides were made from a part of the sample for confirmation.

The salinity was determined by the standard silver nitrate method and found to be more satisfactory than the use of a refractometer. A small mechanised seaworthy boat was used for sampling throughout the survey periods. Tidal predictions were made from the naval tide table for the Cabedèlo Port. Since previous information was not available, the area of the estuary has been determined with the help of a "planimeter".

All field and analysis data were transferred to an IBM computer for processing. The data include taxonomic group of each species and the concentration of plankton and hydrographic parameters, (Tables 2-4).

TABLE 2 – HYDROGRAPHICAL DATA FOR THE SAMPLING STATIONS

YEAR	MONTH	DAY	TIME	DEPTH m	TEMP.°C	SALINITY ‰	pH	TRANSPARENCY m
				STATION 1				
1977	JUN	15	9,35	10,00	28,00	35,00	6,2	4,20
1977	JUL	27	13,35	12,00	26,00	34,60	7,0	2,00
1977	AUG	24	13,55	11,00	25,00	34,60	7,0	1,40
1977	SEP	14	–	–	–	–	–	–
1977	OCT	26	11,43	12,70	28,20	36,20	6,0	1,50
1977	NOV	16	9,30	9,00	28,00	36,84	7,0	0,90
1977	DEC	14	9,00	11,00	28,80	36,80	7,0	1,00
1978	JAN	15	8,30	11,00	28,00	36,60	7,0	1,00
				STATION 2				
1977	JUN	15	9,15	8,00	28,00	33,00	6,8	1,00
1977	JUL	27	12,45	10,00	26,00	31,20	6,8	0,80
1977	AUG	24	13,15	12,00	26,50	31,70	6,5	0,60
1977	SEP	14	13,54	10,00	27,10	33,75	6,0	0,45
1977	OCT	26	10,45	9,10	28,00	33,20	5,5	0,20
1977	NOV	16	10,05	9,50	27,80	35,40	6,5	0,70
1977	DEC	14	10,15	10,50	28,60	35,40	5,5	0,90
1978	JAN	15	9,20	10,00	28,50	35,20	6,0	0,60

TABLE 3 – HYDROGRAPHICAL DATA FOR THE SAMPLING STATIONS

YEAR	MONTH	DAY	TIME	DEPTH m	TEMP.°C	SALINITY ‰	pH	TRANSPARENCY m
				STATION 3				
1977	JUN	15	13,50	3,00	28,00	29,00	7,2	1,70
1977	JUL	17	11,45	3,00	27,00	13,30	6,4	0,70
1977	AUG	24	11,45	4,10	26,00	27,70	6,2	2,00
1977	SEP	14	12,55	4,20	27,00	25,00	6,4	1,00
1977	OCT	26	12,52	2,30	28,80	29,00	6,5	0,50
1977	NOV	16	11,15	2,00	28,25	31,20	5,5	0,40
1977	DEC	14	12,15	1,50	28,20	29,00	5,0	0,30
1978	JAN	11	10,30	2,00	28,60	31,80	5,5	0,15
				STATION 4				
1977	JUN	15	–	–	–	–	–	–
1977	JUL	17	10,45	5,50	26,00	4,50	7,0	0,20
1977	AUG	24	10,50	2,60	26,50	21,10	6,0	1,00
1977	SEP	14	11,55	2,00	27,30	19,70	6,5	0,60
1977	OCT	26	13,45	2,10	28,60	24,20	6,5	0,80
1977	NOV	16	12,30	3,50	29,00	25,40	5,0	0,80
1977	DEC	14	–	–	–	–	–	–
1978	JAN	11	11,55	4,00	29,50	24,20	5,00	0,12

TABLE 4 – HYDROGRAPHICAL DATA FOR THE SAMPLING STATIONS

STATION 5

YEAR	MONTH	DAY	TIME	DEPTH m	TEMP.°C	SALINITY ‰	pH	TRANSPARENCY m
1976	SEP	7	15,30	2,50	29,00	17,80	6,4	0,32
1976	OCT	5	14,15	2,00	26,00	20,10	6,5	0,38
1976	NOV	23	8,00	2,80	29,80	20,60	6,8	0,40
1976	DEC	7	16,30	2,10	29,10	21,60	7,0	0,36
1977	JAN	11	8,45	2,90	25,00	22,20	6,5	0,40
1977	FEB	10	9,20	3,50	26,20	22,00	7,4	0,38
1977	MAR	25	8,10	3,40	27,40	22,60	6,8	0,32
1977	APR	10	9,50	2,30	28,00	22,40	6,5	0,40
1977	MAY	18	11,00	3,00	29,20	20,80	6,9	0,36
1977	JUN	25	11,15	2,70	28,40	5,80	7,0	0,38
1977	JUL	1	17,00	1,70	27,00	6,20	7,8	0,39
1977	AUG	4	8,30	2,90	29,80	16,40	7,2	0,34

STATION 6

YEAR	MONTH	DAY	TIME	DEPTH m	TEMP.°C	SALINITY ‰	pH	TRANSPARENCY m
1976	SEP	7	17,20	2,90	29,80	16,80	6,4	0,40
1976	OCT	5	16,30	2,70	26,00	18,00	6,7	0,34
1976	NOV	23	10,00	2,00	30,00	19,40	6,5	0,40
1976	DEC	7	18,00	2,60	29,00	21,40	6,6	0,39
1977	JAN	11	11,00	2,50	25,20	21,80	6,8	0,30
1977	FEB	10	10,45	2,40	26,00	20,00	6,2	0,35
1977	MAR	25	11,00	2,50	27,00	22,00	6,4	0,32
1977	APR	10	12,00	1,90	28,40	22,00	6,8	0,39
1977	MAY	18	13,30	2,00	29,00	18,40	7,0	0,37
1977	JUN	25	13,00	2,20	28,00	2,50	7,0	0,31
1977	JUL	1	19,15	1,80	28,00	4,80	6,8	0,35
1977	AUG	4	10,40	2,60	30,00	15,80	7,0	0,40

RESULTS

Hydrographic consideration

TEMPERATURE

Owing to the fact that this work was confined largely to the estuary and only to the smaller area of the coastal region proximal to the river mouth, the depth was limited to a maximum of 12 m. The temperature was, therefore, obtained usually from the surface except the locations where mixing was suspected or potential culture was proposed.

The surface waters are subject to diurnal variations which are largely due to intense heating during day time and cooling by night. The minimum temperature was noticed usually early in the mornings. The mean temperature (Fig. 2) was somewhat low in the coastal waters, slightly high in the principal mixing area of river mouth and, as one proceeds further landward along the estuary, the temperature gradually increased, thus showing a horizontal gradient, although this pattern was slightly altered during summer.

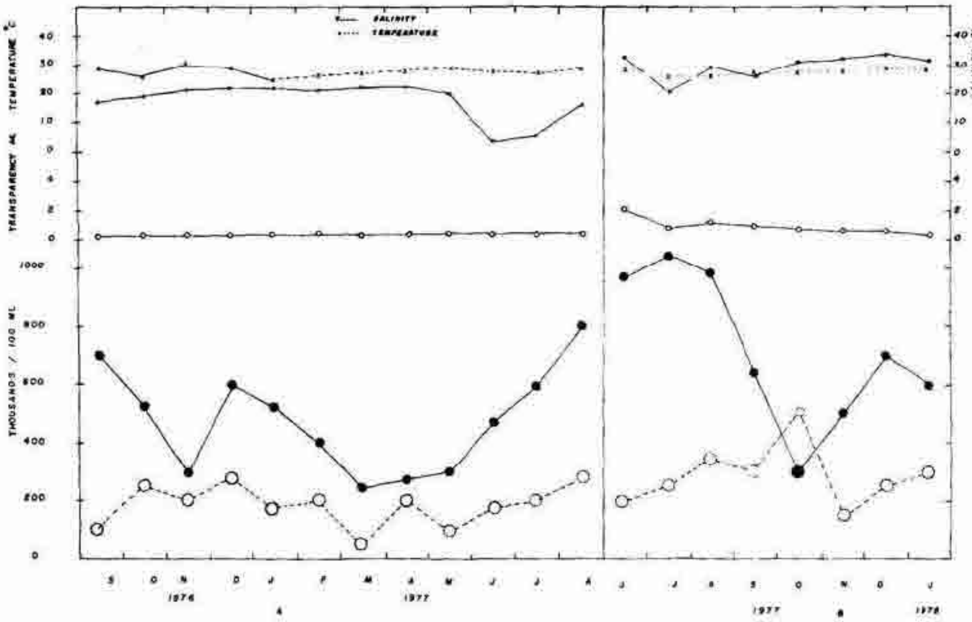

Fig. 2 - Seasonal fluctuations of total phytoplankton numbers (solid line) compared with zooplankton (broken line). The points represent the mean values of: B, stations one to four combined; and A, stations five to six combined in relation to the mean temperature, salinity and secchi disc reading

It is an interesting feature that the temperature not only varied from region to region but also from year to year, depending much on the weather conditions. The maximum temperature recorded during the year 1976-8 in the coastal waters was 28.80°C and for estuary 30°C respectively, however, generally higher temperature in the estuary than in the sea was noticed.

SALINITY

The salinity distribution shows distinctly both vertical and horizontal gradients produced by the penetration of sea water, with greater salinity, landward beneath the surface layer of a much diluted or fresh water moving seaward, the latter was particularly true during the tropical torrential rainfall. The tidal flow to and fro of the estuary occurs both during the rainy season and the drier summer. The marked variation in salinity values of a horizontal gradient (Fig. 2) appears to depend principally upon the origin of the water mass, evaporation from the surface, prevailing wind and also to some extent the restricted large but a single opening of the Paraíba river estuary into the sea.

The salinity variations are also a consequence of diurnal mixing process of sea water and that of the considerably diluted or almost fresh water under the tidal currents. The coastal water usually has a high salinity, the average being 35.81 °/oo, which is typical of Atlantic Ocean, while the mouth region where the mixing was evident showed a sightly less surface salinity than the bottom sample thus clearly indicating vertical stratification. Wider salinity range between 29 to as low as 5 °/oo is generally confined to the fairly large area of the estuary under culture investigation. The lowest salinities were noticed near the terminations of the tributaries where often fresh water runoff is maximum and this is particularly so during the winter.

pH

pH was determined on surface water in all samples, both at high and low tides.

The pH range for the estuarine waters was less compared with the coastal water (Fig. 3). The pH range for coastal waters was 6.0 to 7.2; for the mouth region of the estuary, where mixing takes place, the pH was 5.5 to 6.8 and the distal segments of the estuary showed usually low and more variable pH within the range of 5.0 to 7.2 (Tables 3 & 4).

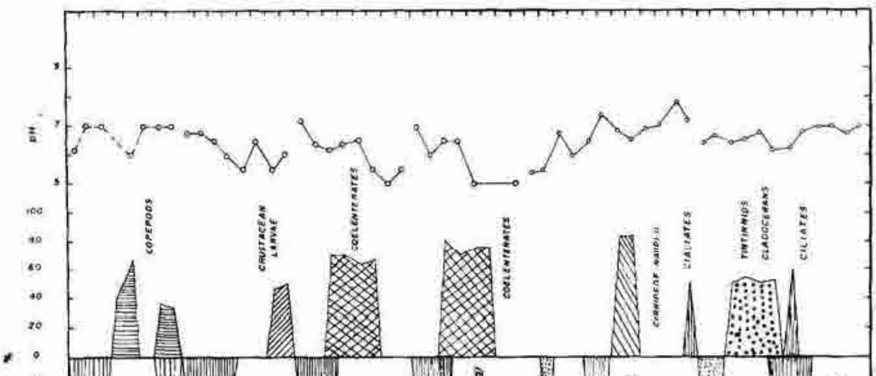

Fig. 3 - Relative dominance of planktonic organisms characteristic to each of the eight stations studied. The values expressed as percentage of the total phyto- and zooplankton and compared with pH

The high pH in the coastal water and the deeper part of the estuary proximal to the sea might be due to high rate of photosynthesis where free carbondioxide is removed by the algal contents (ATKINS, 1925). The very low pH which is characteristic of the distal tributaries of the estuary, might be associated with turbidity and the ocurrance of the detrital materials and other effluents of terrestrial and fresh water origin. The low pH might also be due to grazing by zooplankton. It is of interest that the medusae and ctenophores, especially of the *Beroe* type, were commonly found in such abundance in the distal segments of the estuary where pH was usually low which indicates that these animals have preference to low pH.

CURRENTS

Currents are mainly of tidal nature associated with the incoming and the outgoing tides. The landward current under the influence of the incoming tide and partly induced by the wind carries fairly warmer and high salinity water of the oceanic origin and that of the seaward current, with the returning tide, carries fresh water and much detrital materials.

During the turn of the tide the sea water enters the harbour and flows up the estuary and fans out to a short distance and then converges just behind the small "resting" island to diverge again into the distal canals. The effective flow of the oceanic water penetrates beyond the "resting" island and lifts the river water, particularly during the winter, under the heavy torrential rainfall, to form a tongue of surface layer which extends seaward beyond the river mouth. This observation is contrary to the one reported by MABESOONE et al. (1970) who stated that "the river water runs off as a strong under current" and perhaps their work was confined to only the surface layer near the river tributaries.

On the other hand, the seaward currents are often accelerated to more than 0.8 knot as the tide begins to recede. The effective flow carries the water mass beyond the river mouth far into the sea. The mixing process can be casily noticed under the turbulent conditions when the tide rises and falls.

TRANSPARENCY

Visibility measurements, using Secchi disc, clearly reflect the large difference between coastal water and the estuarine water which carries far too suspended particles. The mean values for visibility measurement at different stations from one to six were: 1.7, 0.66, 0.84, 0.59, 0.36 and 0,36 m respectively.

Suspended matters consisted mainly of silt, micro - and macrodetrital materials. Sedimentation rate was carried out only at stations 5 and 6 and they showed that the sedimentation rate did not exceed. 1mg/1/h(SINGARAJAH, 1977, b). But these areas are presently under culture and the waters entering and leavingunder the tidal flow are somewhat regulated and the sedimentation rate in the main segments of the estuary is expected to be a little higher because of the free influx of the detritus and organic debris from many canals.

Plankton

COMPOSITION AND DOMINANCE:

A total of 46 species of phytoplankton belonging to 4 taxonomic groups and 41 zooplankton organisms, excluding the multitude of crustacean larval forms, were recorded. (Tables 5 & 6). Since no previous information on plankton of Paraiba coast is available, the planktonic organisms are arranged according to their taxonomic groups, reducing them as far as possible, to species because such a list would be useful. The nomenclature of the algae, in particular, follows the check lists of HENDEY (1974) and PARKE, et al (1976). Fig. 2 shows the seasonal fluctuations of total phytoplankton numbers compared with total zooplankton numbers for the entire sampling period, in relation to mean variation of temperature and salinity.

TABLE 5

PHYTOPLANKTON SPECIES RECORDED FROM STATIONS IN COASTAL WATER AND THE PARAIBA RIVER ESTUARY AND THEIR SEASONAL DISTRIBUTION.

	1976				1977												78
BACILLARIPHYCEAE	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J
Actynoptychus undulatus (Bailey) Ralfs	-	-	-	-	-	-	-	-	-	R	R	C	C	C	C	R	R
Asterionella japonica Cleve	-	-	-	-	-	-	-	-	-	C	C	C	C	R	R	R	R
Bellerochea malleus (Brightwellii)	-	-	-	-	-	-	-	-	-	R	R	R	R	C	C	C	C
Biddulphia aurita (Lyngbye) de Brebisson	-	-	-	-	-	-	-	-	-	R	R	R	C	C	C	A	A
B. mobiliensis (Bailey) Grunow	-	-	-	-	-	-	-	-	-	R	R	R	C	C	A	A	A
B. regia (Schultze) Ostenfeld	-	-	-	-	-	-	-	-	-	R	R	R	R	R	C	C	C
B. sinensis Greville	-	-	-	-	-	-	-	-	-	R	C	C	C	C	R	R	R
Campylodiscus sp Ehrenberg	-	-	-	-	-	-	-	-	-	C	C	A	A	C	R	R	R
Chaetoceros affinis Lauder	-	-	-	-	-	-	-	-	-	C	C	C	C	R	R	C	C
C. debilis Cleve	-	-	-	-	-	-	-	-	-	A	A	C	C	C	C	A	R
Cocconeis britanica Naegeli	-	-	-	-	-	-	-	-	-	-	-	-	-	R	R	C	C
Coscinodiscus centralis Ehrenberg	-	-	-	-	-	-	-	-	-	A	A	A	C	C	C	R	R
C. gigas Ehrenberg	-	-	-	-	-	-	-	-	-	C	C	C	C	C	R	R	R
C. sp Ehrenberg	-	-	-	-	-	-	-	-	-	A	A	C	R	R	R	R	R
Ditylum brightwellii (West) Grunow	-	-	-	-	-	-	-	-	-	C	C	A	A	C	C	C	C
Eucampa zodiacus Ehrenberg	-	-	-	-	-	-	-	-	-	R	R	R	C	C	R	R	R
Fragilaria oceanica Cleve	-	-	-	-	-	-	-	-	-	R	R	R	R	R	C	C	R
Grammatophora oceanica (Ehrenberg) Grunow	-	-	-	-	-	-	-	-	-	C	C	C	C	R	R	R	R
Gyrosigma sp Hassall	C	C	C	C	C	A	A	A	C	C	C	C	C	C	C	C	C
Hemiaulus sinensis Greville	-	-	-	-	-	-	-	-	-	R	R	R	R	R	C	C	R
Hemidiscus hardmannianus (Greville) W. Smith	-	-	-	-	-	-	-	-	-	R	R	R	R	R	R	-	-
Lauderia annulata Cleve	-	-	-	-	-	-	-	-	-	C	C	C	C	R	R	R	R
Melosira sulcata (Ehrenberg) Kutzing	-	-	-	-	-	-	-	-	-	C	C	C	C	C	C	R	R
Navicula sp Bory	-	-	-	-	-	-	-	-	-	R	R	R	R	R	R	R	R
Nitzschia closterium (Ehrenberg) W. Smith	-	-	-	-	-	-	-	-	-	C	C	R	R	-	-	-	-
N. longissima (de Brebisson) Ralfs	-	-	-	-	-	-	-	-	-	-	-	-	C	C	-	-	-
Planktoniella sol (Wallich) Schutt	-	-	-	-	-	-	-	-	-	R	R	R	R	-	-	-	-
Pleurosigma naviculum de Brebisson	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	R	R
Rhizosolenia alata Brightwellii	-	-	-	-	-	-	-	-	-	-	-	-	R	R	R	-	-
R. setigera Brightwellii	-	-	-	-	-	-	-	-	-	R	R	R	R	R	R	R	R
R. styliformis Brightwellii	-	-	-	-	-	-	-	-	-	R	R	-	-	-	-	-	R
Skeletonema costatum (Greville) Cleve	-	R	R	R	-	-	-	R	R	C	C	C	C	R	R	R	R
Stictodiscus japonicus	-	-	-	-	-	-	-	-	-	-	-	-	-	R	C	C	C
Streptotheca tamesis Shrubsole	R	R	-	-	-	R	R	C	C	C	A	A	C	R	R	R	R
Surirella rorata Frenguelli	-	-	-	-	-	-	-	-	-	-	-	-	-	R	C	C	C
Thalassionema nitzschioides Grunow	-	-	-	-	-	-	-	-	-	C	C	R	R	R	R	R	R
Thalassiosira subtilis Ostenfled	-	-	-	-	-	-	-	-	-	C	A	C	C	R	R	R	R
DINOPHYCEAE																	
Ceratium furca (Ehrenberg) Dujardin	-	-	-	-	-	-	-	-	-	A	A	C	C	C	C	A	A
C. fusus (Ehrenberg) Dujardin	-	-	-	-	-	-	-	-	-	A	A	C	R	R	R	R	R
C. massiliense (Gourret) Jorgensen	-	-	-	-	-	-	-	-	-	C	C	C	C	R	R	R	R
C. tripos atlantica Ostenfled	-	-	-	-	-	-	-	-	-	A	C	C	R	R	R	R	C
C. vultur Cleve	-	-	-	-	-	-	-	-	-	C	C	C	R	R	R	R	R
Peridinium depressum Bailey	-	-	-	-	-	-	-	-	-	A	A	A	A	C	C	R	R
Prorocentrum micans Ehrenberg	-	-	-	-	-	-	-	-	-	C	C	R	-	-	-	-	-
SILICOFLAGELLATES																	
Dictyocha speculum Ehrenberg	-	-	-	-	-	-	-	-	-	-	-	-	-	R	C	R	R
CYANOPHYCEAE																	
Oscillatoria erythraea (Ehrenberg) Kutzing	-	-	-	-	-	-	-	-	-	R	R	R	R	R	C	C	C

Criteria of the symbols

A = ABUNDANT > 500 organisms / 1 ml subsample
C = COMMON > 100 < 500 organisms
R = RARE < 100 organisms

PHYTOPLANKTON

Among the phytoplankton, the diatoms comprised 36 species, Dinophyceae.7 species, silicoflagellates 1 species and Cyanophyceae 1 species.

BACILLAROPHYCEAE:

Diatoms constituted the most commonest and dominant components of the phytoplankton and generally occured all throughout the year, with clear seasonal fluctuations (Table 5 & Fig. 2). The *Cosinodiscus centralis* was the most abundant, closely followed by *Cosinodiscus sp, Streptotheca tamesis, Skeletonema costatum, Ditylum brightwellii, Biddulphia sinensis, Bellerochea malleus, Gyrosigma sp, Melosira sulcada* and *Chaetoceros* in numerical order. Other species were frequently encountered but showed no distinct fluctuations or peak of blooming. *Planktonella sol* apperard only on a couple of occasions in the coastal waters and never in the estuary. The concentration of *Cosinodiscus centralis* and distribution of *Gyrosigma sp* generally increased quite significantly in the estuarine waters with the decreasing salinity. The maximum number of *Cosinodiscus centralis*, however, occured at stations 3 & 4. The total number of phytoplankton also far exceeded during June to August reaching a peak bloom. The peak was largely due to this species which constituted more than 81.1% of the total phytoplankton population (Fig. 3).

It is of particular interest that the diatom bloom reached its peak during June to August when the salinity was low and the temperature was only slightly reduced which usually coincided with the heavy rainfall.

The Dinophyceae ranked second in order of numerical abundance and their concentration increased seaward but the maximum number was noticed during August to October closely following the diatom bloom.

Although the Dinophyceae generally diminished during February to April, the *Ceratium furca* was the most abundant number of this group and was found during most part of the year.

The silicoflagellates and Cyanophyceae were represented only in small numbers and usually during December to January.

The *Gyrosigma sp* was also dominant and found consistently at all segments of estuarine waters and appears to prefer euryhaline conditions though *Cosinodiscus* appeared to be a stenohaline species.

ZOOPLANKTON

The seasonality of zooplankton is relatively uniform than the phytoplankton (Fig. 2). There were, however, two peaks of zooplankton, dominated predominantly by copepods. The copepod peak usually appeared just after the diatom bloom of June to August, and attained a maximum density in October, followed by a succession of a second peak of a rather smaller size. This was noticed during November to January after which the numbers reduced considerably, perhaps, this second peak might be due to hatching of many of the eggs since nearly 28% of the copepod population during this period composed of juveniles.

Of the copepods, the calanoid forms, especially, *Eucalanus elongatus* and *Labidocera fluviatilis* were most abundant and they occured generally throughout the year. The distribution of these species, however, increased seaward with increasing salinity, and they entered up the estuary only to the part proximal to the sea. However, *Labidocera fluviatilis* has been reported to be a brackish water species (BJORNBERG, 1963). Second, in terms of numerical abundance, was again a calanoid copepod, *Acartia longiremis* which occured as a sudden burst and largely contributed to second peak mentioned above. The others in apparent order of numerical abundance were the calanoid *Centropages violaceus*, *Temora stylifera*, the harpacticoid, *Euterpina acutifrons*, and the cyclopoid *Oithona* and *Copilia* were relatively less abundant. The *Euterpina acutifrons* was occasionally found in large numbers with decreasing salinity.

MEROPLANKTON

Many forms of crustaceans, chiefly larvae, the zoeal and megalopa stages, were noticed. The adult forms were principally *Lucifer* and *Mysis* and the juvenile ones included *Paenids* and shrimps. The larvae however, dominated the crustacean population and were numerically significant at the station two than any other stations, particularly during October to December. Fish eggs and larvae were also found fairly commonly at stations 1 & 2. The cladocera, especially *Evade*, together with rotifers, were mostly confined to stations five and six. These were represented in fairly large numbers during winter while the *Penilla* appeared to prefer the drier summer with slightly increased salinity.

Although the cirripede nauplii were common throughout the estuary, all the year round, they were most abundant at station five than in any other stations and they comprised about 80% of the total zooplankton population. Bivalve larvae were the second in abundance but they appeared to show a single peak during August - September. The polychaete larvae also generally dominated during July to September but with much fluctuations.

Among Chaetognatha, *Sagitta enflata* was the most commonest and dominant form and found generally throughout the year, but confined to mostly neritic water and the river mouth where the waters of different origin mix. The other species occasionally found in fairly large numbers were *Sagitta serratodenta atlantica*, *Krohnitta subtilis* but they entered up the estuary as far as station four. The other rather incidental species were *Sagitta bipunctata* and *Sagitta macrocephala*.

The coelenterates: the abundance of medusae and ctenophores was a remarkably constant feature as they were found at stations three and four in very large numbers all throughout the year. The reduced pH particularly seems to induce their abundance in these stations, despite the diminished zooplankton density observed.

In summary it can be said that characteristics for waters of different stations in numerical abundance of total plankton combined were: at station one: diatoms and copepods, station two: diatoms, dinoflagelates and crustacean larvae, station three and four: showed striking similariteis with maximum production of *Cosinodiscus* and with abundance of coelenterates, especially hydromedusae and ctenophores; station five: was generally dominated by cirripede nauplii and station six: predominated by ciliates, including tintinnids. Rotifers and cladocerans appered to be endemic to stations 5 & 6.

The relative dominance of planktonic groups, expressed as percentage, are compared with mean pH (Fig. 3 and also see Table 6 for list of zooplankton).

Potential Resources of economic importance in relation to hydrological conditions and plankton densities

Table 7 shows the commercially important species of fishes, crustaceans and shellfish which are always found in appreciable numbers in the Paraiba river estuary. Besides nutrients, the salinity condition perhaps, is the single most important factor which favours the distribution and densities of these species and the temperature fluctuations appear to be only of secondary importance to salinity.

TABLE 7. SOME OF THE HIGHLY ESTEEMED AND CULTURABLE FISH RESOURCES OF PARAIBA RIVER ESTUARY

GROUP	GENUS	SPECIES	BRAZILIAN NAME
TELEOSTS	*Mugil*	*M. cephalus*	(curimã)
		M. brasiliensis	(tainha)
		M. dobula	(tainha)
		M. sp.	(tainha)
	Diapterus	*D. rhombeus*	(carapeba)
	Sphyraena	*S. sp*	(bicuda)
	Anguilla	*A. bostoniensis*	(amureia)
	Cynoscion	*C. striatus*	(pescada)
CRUSTACEANS	*Penaeus*	*P. aztecus*	(camarão)
		P. brasiliensis	(camarão)
		P. duorarum	(camarão)
	Crangon	*C. sp*	(camarão)
	Carcinus	*C. paguras*	(caranguejo)
		C. maenas	(camarão)
	Callinectes	*C. sapidus*	(siri)
SHELLFISH	*Crassostrea*	*C. paraibanensis* S.	(ostra)
		C. (brasiliana) L. *rhizophorae*	(ostra)

The most esteemed and commonest herbivorous fishes are those of the Mugilidae family. The crustaceans such as prawns and shrimps, possibily detrital feeders, and crabs, omnivorous, are also widely distributed and their abundance seems associated with the heavy rainfall. The sedentary benthic filter-feeders which are so selective of the estuarine habitat are found in considerable numbers, usually in the shallower parts of the estuaries (SINGARAJAH, 1977 a). It is of some interest that the benthic samples collected, using Peterson grab, at the stations 3 and 4, revealed that the soft muddy bottom is rich in *Mytilus*. These live in large colonies partially burried in the muddy layer which ranged between 0.80 to 1.10 m in thick. The abundance of other economic source such as oysters having great commercial potential had already been reported recently, elsewhere (SINGARAJAH, 1977 b).

DISCUSSION

From the foregoing observations and the data collected, so far, it can be concluded that the Paraiba river estuary is essentially a tidal one but with direct connection with the sea. However, there is a clearly defined and consistent vertical stratification of salinity producet by the penetration of salt water mass from the Atlantic Ocean beneath the surface layer of fresh water, intermingling under the tidal influence. This feature is initially restricted to and more clearly seen near the river mouth and the harbour areas where the water is deeper. The slightly increased salinity of the bottom water seems to be constant and continues to a considerable extent into the deeper parts of the estuary. Mid-water sample analyses confirm this. In the relatively shallower estuarine segments distal to the sea, which receive the river tributaries and canals, the salinity is so dilute and varies with tidal oscillation. The resulting horizontal gradients of the salinity variation depends largely on the fresh water runoff and weather conditions.

The hydrological conditions of the estuary, therefore, are greately influenced by the exchange between the coastal Atlantic waters and the estuary and between the estuary and the fresh water runoff from the river system, tidal flow, turbulence, sedimentation, winds, lowering of salinity and slight increase in temperature and by considerable enrichment of the nutrients. These appear to be responsible for the enormous production of diatoms, especially *Cosinodiscus* during June to August, which coincides with winter.

A complete appraisal of the factors controlling the plankton production in Paraíba river estuary needs further investigation. The following discussion is somewhat limited by lack of full data. Nevertheless, the present findings are of considerable importance to further studies.

The major contributory factors known to control the phytoplankton level are: light, nutrients, including trace elements and vitamins, and tidal flow. ODUM et al., (1974) associated the tidal flow with that of mechanical energy and VERBERG et al. (1976) suggested that the tidal energy is the principal factor in determining the high degree of productivity of salt mashes.

Despite the relative shallowness, the unusually high concentration of diatoms at stations 3 and 4, indicates that these are most productive within the estuarine realm. The present findings show no direct correlation between the abundance of plankton productivity and estuarine fishes. However, the period of crustacean larval abundance coincided with the second peak of diatom bloom and such concentration of larvae usually was found at the station 2 where the sea water mixes with the fresh water. Consequently, there was a slight drop in salinity than the costal water but this was relatively more than the salinity in other parts of the estuary. The reverse situation was particularly true with temperature. The relative abundance of crustacean larvae in the region of mixing of waters of different origin suggests that conditions of salinity and temperature there probably tend to favour the spawning and development processes of many crustaceans and, perhaps, the larvae may be dependent upon these conditions for survival. ORTON (1920) first emphasized the importance of temperature to breeding in marine invertebrates.

The relationship between zooplankton and diatom production is not so clearly defined in the estuarine system though this is frequently observed in coastal waters. The zooplankton increases in such numbers and reaches a peak closely following the diatom bloom. A second peak also was noticed which was concomittant with second bloom of the diatom. The pattern suggests that when the rise in numbers of total zooplankton occured, a fall in the phytoplankton was evident, thus indicating an inverse relationship (Fig. 2) betweem phyto- and zooplankton. The hypothesis relating to inverse relationship of plankton is discussed by SVERDRUP et al. (1961).

It is of interest that among all the copepods observed, the *Euterpina acutifrons* was found widely distributed up the estuarine waters and the numbers decreased toward station 4 preferring apparently an optimum salinity range. *Euterpina acutifrons* has been reported to be world wide in distribution in tropical as well as subtropical waters (GONZALEZ et al., 1965). TUNDISI et al. (1968), working with planktonic crustaceans, also reported that *Euterpina acutifrons* was able to tolerate salinity above 8.8 ‰ and he placed this species second in order of salinity tolerance, particularly at temperature 28ºC, amog the copepods.

On the other hand, the relative less population of diatoms at stations 5 and 6 compared with all others might be due to limited light penetration as indicated by the values of Secchi disc reading. Nevertheless, these areas are by no means less productive since microflagellates far outnumbered all other phytoplankton groups (Fig. 3). Stations 1 and 2 also showed slightly low density of diatoms than stations three and four, although the dominance of diatom at the latter stations was largely due to a single species such as *Cosinodiscus centralis* where as the coastal and the river mouth stations showed a rich variety of species. The apparent reduction of density of phytoplankton in these stations might also be due to grazing down by zooplankton. The decrease in number of marine species generally in the estuarine stations might have beem imposed by the reduced salinity and increased temperature.

Despite the rich production of diatoms inthe estuarine waters, with the exception of coelenterates, it was noticed that there was a general lack of zooplankton to consume such abundance of phytoplankton production. This was in marked contrast with stations 1 and 2 where the main components of zooplankton population were copepods and crustacean larvae respectively. At station 1, the copepods alone contributed to 66% of the total population of the zooplankton. The numbers reduced significantly towards estuary with decreasing salinity. The situation forces the question as to what then is the real purpose of the primary producers to such a wasteful magnitude in these productive parts of the estuary? Perhaps, while a part of the diatoms may be lost in the estuarine circulation, the bulk may be consumed by the herbivorous pelagic fishes, prawns and shrimps, and the benthic filter-feeders which contribute significantly to the economic resources of the economic resources of the estuary (Table 7). These are valuable indigenous fishes and always found in the estuary in great abundance.

SUMMARY

The present work briefly reports the findings on hydrological conditions, composition and abundance of plankton in relation to the potential resources of the Paraiba river estuary.

A vertical salinity stratification was observed at the river mouth and the harbour areas and a horizontal salinity gradient extends up the estuarine waters landward which is very much influenced by weather conditions. The surface temperature distribution also shows a horizontal gradient but this tends to decrease seaward. The visibility and pH values generally increase seaward. The estuarine segments, particularly stations 2 and 3, are extremely rich in organic detris and nutrients which have profound effect upon the productivity of the plankton, especially the diatoms.

The Atlantic water penetrates into the estuary and lifts the river water to the surface which extends seaward beyond the river mouth. A total of 87 planktonic organisms belonging to the two major groups of phyto- and zooplankton are recorded and their seasonal fluctuations and total numbers are compared, in relation to variations of salinity and temperature. The average total phytoplankton ranged between 270,000 to 1,050,000/100 ml. Among the phytoplankton, the diatoms constituted the most commonest and dominant component. *Cosinodiscus centralis*, *Cosinodiscus sp*, *Streptotheca tamesis* and *Skeletonema costatum* were the most abundant and they occured frequently. The others in numerical abundance were *Ditylum brightwellii*, *Biddulphia sinensis*, *Gyrosigma sp*, *Melosira sulcata*, and *Chaetoceros*.

The *Cosinodiscus centralis* and *Gyrosigma sp* generally showed increasing concentration up the estuarine waters with decreasing salinity and this tendency was more so with *Gyrosigma sp*.

The second abundant group of phytoplankton was Dinophyceae with *Ceratium furca* being the common and dominant species. The other groups encountered were Silicoflagellates and Cyanophycea but these were found only in smaller numbers.

The seasonality of the zooplankton was relatively uniform than the phytoplankton. However, two distinct peaks of zooplankton were noticed, the major peak in October and the second during December - January. The mean total zooplankton generally ranged between 100,000 to 510,000/100 ml.

But these were dominated by copepods (40 to 66%). The calanoid copepods were more numerous and represented by *Labidocera fluviatilis*, *Eucalanus elongatus*, *Acartia longiremis*, *Temora stylifera* and *Centropages furcata*, others were the harpacticoid *Euterpina acutifrons* and the cyclopoid *Oithona* and *Copilia* in apparent order of their numerical abundance.

The calonoid copepods generally increased in numbers seaward, while the harpacticoid *Euterpina acutifrons* was widely distributed in most segments of estuary proximal to the sea and appeared to prefer an optimally decreased salinity.

The crustacean larvae dominated, particularly at station 2, where the waters of different origins mix and these conditions appear to favour the spawning and developmental processes of the crustaceans. The other commonest zooplankton found in abundance were coelenterates, including ctenophores, but these always dominated the stations 3 and 4 perhaps, they prefer the reduced pH associated with the water. The cirripede nauplii were, though common, but found in such abundance and they exceeded 80% of the zooplankton population especially at station 5. Station 6 was always dominated by ciliates (60%) tintinnids, and cladocerans in numerical abundance.

The findings, so far, show no direct correlation between diatom production and zooplankton abundance in the estuarine system, but in the coastal and river mouth waters an inverse relationship does occur. The enormous quantity of diatom production in the estuary, influenced by rich nutrients, might be consumed by herbivorous pelagic fishes of Mugilidae family, crustaceans such as prawns and shrimps and the rich benthic filter-feeders, particularly, shellfish. These form some of the important economic resources of the estuary with great commercial potential. The Chaetognatha was represented by *Sagitta enflata*.

These findings are of considerable importance for further investigations.

RESUMO

O presente trabalho relata, de maneira resumida, as pesquisas realizadas sobre as condições hidrológicas, composição e abundância de plânctos em relação aos recursos em potencial do estuário do Rio Paraíba.

A salinidade vertical estratificada foi observada na boca do rio e nas áreas portuárias, enquanto que o gradiente de salinidade horizontal diminui na superfície das águas do estuário em direção à terra, e por sua vez, é muito influenciado pelas condições meteorológicas. A distribuição da temperatura da superfície também mostra um gradiente horizontal, mas esta tendência diminui em direção ao mar. A visibilidade e os valores de pH geralmente aumentam na direção do mar.

Os sedimentos do estuário, particularmente os das estações 2 e 3 são extremamente ricos em fragmentos orgânicos e nutrientes que atuam diretamente na produtividade dos plânctos, especialmente nas algas microscópicas.

As águas do oceano Atlântico penetram no estuário, elevando consequentemente, as águas do rio para uma superfície que se extende em direção ao mar, além da boca do rio.

Foi observado um total de 87 organismos planctônicos pertencentes aos dois grupos principais de fito- e zooplânctos. Foram registradas as suas flutuações sazonais e os totais comparados em relação às variações de temperatura e salinidade. A média do total observado variou entre 270.000 e 1.080.000 por 100 ml.

Entre os fitoplânctos, as algas microscópicas se constituem no componente mais comum e dominante. *Coscinodiscus centralis*, *Coscinodiscus sp.*, *Streptotheca tamesis* e *Skeletonema costatum* foram as algas mais abundantes e frequentes. Outras algas de certa abundância numérica foram *Ditylum brightwellii*, *Biddulphia sinensis*, *Gyrosigma sp.*, *Melosira sulcata* e *Chaetoceros*.

As *Coscinodiscus centralis* e as *Gyrosigma sp.* geralmente mostraram uma concentração crescente à medida que aumentava a distância para o mar, ou seja, com uma salinidade decrescente. Esta tendência foi mais notada com a *Gyrosigma sp.* O segundo grupo abundante de fitoplânctos foi o das *Dinophyceae* com *Ceratium furca* sendo a espécie mais comum e dominante. Outros grupos encontrados em menores números foram Silicoflagellates e Cyanophycea.

A sazonalidade dos zooplânctos foi relativamente mais uniforme que a dos fitoplânctos. Entretanto, duas tendências altistas foram observadas, a primeira em outubro e a segunda em dezembro e janeiro. A média do total de plânctos variou entre 100.000 e 510.000 por 100 ml. Mas estes foram dominados por copépodes, (De 40 a 66%). Os copépodes calanóide foram mais numerosos, e representados principalmente pelos *Labidocera fluviatilis*, *Eucalanus elongatus*, *Acartia longiremis*, *Temora stylifera* e *Centropages furcata*. Outros copépodes observados foram harpacticóide, *Euterpina acutifrons*, os ciclopóides *Oithona* e *Copilia*, em ordem aparente da sua abundância numérica.

Os Copepoda Calanoida geralmente aumentaram em número em direção ao mar, enquanto que os harpacticóides *Euterpina acutifrons* foram distribuídos em mais segmentos do estuário, próximo ao mar, e parecem preferir uma salinidade decrescente.

A larva Crustacea dominou, particularmente a estação 2, onde águas de origens diversas se misturam e nestas condições aparentam favorecer a desova bem como o processo de desenvolvimento dos crustáceos. Outros zooplanctos mais comumente encontrados em abundância foram os celenterados incluindo os Ctenophora, porém estes últimos sempre dominantes nas estações 3 e 4, talvez por uma preferência ao reduzido pH da água. Os náuplios de cirripédios foram encontrados em tal abundância que excederam a 80% da população dos zooplanctos, especialmente na estação 5. A estação 6 foi sempre dominada por ciliados (60%), tintinídeos e cladóceros, em abundância numérica.

Os resultados encontrados até agora não evidenciam uma correlação direta entre a produção de algas microscópicas e a abundância de zooplanctos no sistema do estuário. O que ocorre, entretanto, é uma relação inversa nas águas costeiras e nas águas das bocas dos rios. A enorme quantidade de algas microscópicas produzidas no estuário, influenciada por ricos nutrientes, é provavelmente consumida por peixes herbívoros do oceano, família Mugilidae, crustáceos, como pitús e camarões, e os ricos moluscos bênticos particularmente os mariscos. Alguns destes últimos, formam os recursos econômicos do estuário com grande potencial comercial. Os Chaetognatha foram enormemente representados pela *Sagitta enflata*. Estes resultados são de importância considerável para as futuras investigações nesta área.

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REFERENCES

ATKINS, W. R. G., 1925. The hydrogen ion concentration of the sea water in its relation to photosynthetic changes. *J. mar. Biol.* Ass. (U. K.), *13*:93-118.

BJORNBERG, T. K. S., 1963. On the marine free living copepods off Brazil. *Bol. Inst. Oceanogr.* S. Paulo, *13*:1-142.

FREYBERG, B. von., 1930. Zerstoerung und sedimentation an mangroveskuste Brasiliens. *Leopoldina*, *6*:69-117.

GONZALEZ, J. G. &BOWMAN, T. E., 1965. Planktonic copepods from Bahia Fosforescente, Puerto Rico and adjacent waters. *Proc. U. S. Nat. Mus.* *117*:241-304.

HENDEY, N. I., 1974. A revised check-list of British Marine Diatoms. *J. mar. Ass.* U. K., *54*:277/- 300.

MABESOONE, J. M., 1964. Origin and age of sandstone reefs of Pernambuco (Northeastern Brazil). *J. Sedim. Petrology*, *34*:715-726.

MABESOONE, J. M. & COUTINHO, P. N., 1970. Littoral and shallow marine geology of Northern and Northeastern Brazil. *Trab. Oceanogr. Univ. Federal Pe.* Recife, *12*: 1-214.

ODUM, H. T., COPELAND, B. J. & McMAHAN, E. A., 1974. *Coastal ecological systems of the United States.* The Conservation Foundation Washington, D. C.

ORTON, J. H., 1920. Sea temperature, breeding and distribution in marine animals. *J. mar. Ass. U. K.*, *12*:339-366.

OTTMANN, F. & COUTINHO, P. N., 1962. Estudo dos sedimentos de Cabedelo, recolhidos pela D. H. N. *Inst. Oceanogr. Univ. Recife,* Internal Report, p.p. 3.

PARKE, M. & DIXON, P. S., 1976. Check-List of British Marine Algae Third revision *J. mar. biol. Ass. U. K.*, *56*:527-594
SINGARAJAH, K. V., 1977a. Investigation into Growth, Density, Reproductive cycle, Motality and Ecology of the oyster *Crassostrea brasiliana. Ciência e Cultura, 29*(7):808.
SINGARAJAH, K. V., 1977b. Investigation into taxonomy growth, density, ecology, reproductive cycle, mortality and culture of the giant oyster, a new species *Crassostrea paraibanensis* S. Univ. Fed. Paraiba pp. 1 - 30. (To be published).
SVERDRUP, H. U., JOHNSON, M. W. & FLEMING, R. H., 1961. The Oceans, their physics, chemistry and general Biology. Asian Students Edition. 1087 pp.
TUNDISI, J. & TUNDISI, T. M., 1968. Plankton studies in a mangrove environment. V. Salinity tolerances of some planktonic crustaceans. *Bol. Inst. Oceanogr. S. Paulo, 17*(1): 57-65.
VERNBERG, F. J., DAME, Jr. R. F. & BONNELL, R. D., 1976. Estuarine ecosystem studies with special emphasis on the North inlet estuary, South Carolina. *An. Acad. brasil. Cienc., 47* (Suplemento) 75-87.
Standard taxonomic references are not included here.

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