

ECOLOGY AND ENVIRONMENTAL MONITORING OF MANDOVI, ZUARI AND CUMBURZUA CANAL COMPLEX DURING MONSOON MONTHS

By

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INTRODUCTION

India has a large number of estuaries which have their own ecosystems. Important estuaries in Goa are the Mandovi and the Zuari. They are used for navigation; there is a heavy barge traffic which carry iron and manganese ores to Marmugao Port. In addition, these estuaries are also a source of large quantity of fish and prawn juveniles for aquaculture. This is a complex and dynamic ecosystem which has different ecological niches. Therefore a project entitled "Ecology of Mandovi, Zuari and Cumburzua canal complex with reference to living resources and monitoring of environment" was started in June 1971. The present paper is the first part and covers the monsoon months from June to September 1971.

Earlier studies on estuaries and backwaters along the west coast of India were mostly confined to Cochin backwaters and very little is known about Goa estuaries. Studies on the environmental changes at one point in each of the two estuaries with reference to tides (Dehadrai, 1970 a & b), and organic production (Dehadrai & Bhargava, 1972) were undertaken earlier. The other studies by Murty & Das (1972), Das *et. al.*, (1972), Anand (1973), Parulekar & Dwivedi (1973), Parulekar *et. al.*, (1973), Bhargava (1973), and Bhargava and Dwivedi (1974) deal with different physico-chemical and biological aspects of the system. This study provides a comprehensive picture of the ecosystem including production at different trophic levels.

DESCRIPTION OF AREA

The Mandovi and Zuari rivers flow on northern and southern sides of Panjim Island. They form bays near Caranzalem and Marmugao respectively

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MATERIAL AND METHODS

In this estuarine net work of about 50km in length, 14 observation stations were fixed. Considering the substratum characteristics and navigation channel in lower reaches of Mandovi, four station 1A, 1B and, 2A 2B were operated along both the banks, at other places only one station was operated in the middle of the course (Fig. 2). Stations 5 and 9 are located at the opening of the Cumburza canal on the Mandovi and Zuari estuaries respectively and they represent the areas of mixed zones. Station 12 in Zuari could not be sampled due to rough weather except on a few occasions.

Fortnightly observations were made at all these stations and a difference of 11-15 days was maintained between the two consecutive observations. The water samples from surface, and one meter above the bottom were collected and studied for temperature, salinity, dissolved oxygen, phosphate, nitrates and silicates. Samples for chlorophyll and zooplankton were collected from surface only.

Standard methods were followed for analysis of all the hydrographic parameters. However, the values of $\text{PO}_4\text{-P}$ and $\text{NO}_3\text{-N}$ were not corrected for salt error.

For the estimation of chlorophyll and carotenoids, 500ml of water sample was filtered through a membrane filter of $0.45\mu\text{m}$ pore size. The extraction and analysis on spectrophotometer (VSU-2) was done by Richards with Thompson's method and calculated by the equation proposed by Strickland & Parsons (1965).

The zooplankton samples were taken by horizontal hauls by $1/4\text{m}^2$ HT net of $300\mu\text{m}$ mesh size and water filtered through the net was measured with a TSK flowmeter. The samples were preserved in 5% formalin neutralized with hexamine and then volume measured by displacement method and the biomass values computed to per m^3 .

The samples of benthos were collected by a Van Veen Grab having an area of 0.04m^2 . The samples were sieved through 0.5mm. Endecot Sieve to retain the macrofauna.

The tide and timing predicted for Marmugao Harbour supplemented by actual pole observations were used for determining the tidal phase of the observations. The period between two mid tides with high tide peak was taken as high tide phase and with low tide as minimum was classified into low tide phase.

OBSERVATIONS AND RESULTS

1. *Light penetration*

The penetration of light during monsoon season depends upon the degree

of mixing and the overcasting of the sky. The sacchi disc reading ranged between 0.32 to 1.1m in Mandovi sector, 0.29 to 0.77 in Cumburzua and 0.17 to 1.34 in Zuari sector. The observations in low tide showed still lower Sacchi disc readings. Lesser light penetration during low tide might be due to the silt coming with rain water from upper reaches. In late July and early August the Sacchi disc reading was low but thereafter it increased. The euphotic zone approximately varies between 0.96 to 0.13m in whole area. However, Cumburzua canal showed minimum values.

2. Temperature

The surface temperature varied between 26.1 to 30.6°C during high and low tide, while at bottom it varied between 23.5 and 30.4°C. Both at the surface and the bottom, the temperature was low in August particularly in Mandovi estuary and then again increased in September. The bottom temperature was always less than surface temperature. It ranged between 23.5 and 28.5°C in Mandovi 25.9 to 30.4°C in Cumburzua canal and 25.1 to 29.0°C in Zuari estuary. This may be particularly due to the entry of cold neretic water into the two estuaries. The surface temperature, wind, sunlight and freshwater discharge, also influence the water condition in these two complexes.

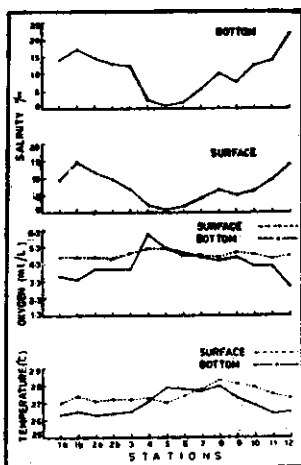


FIG. 3

Fig. 3 : The annual mean of temperature

Salinity (Fig. 3)

The salinity is the most significant parameter in an estuary and influences various processes. Very low salinity, a characteristic of monsoon, was observed and strong variations occurred with tides. The surface salinity varied from 0.12 to

30.25‰ in Mandovi sector, 0.12 to 15.66‰ in Cumburzua canal and 0.21 to 32.9‰ in Zuari estuary (Fig.3). The minimum salinity was observed at stations 5,6,7 throughout the period. The station 5 is in mid reaches of Mandovi and influenced more by fresh water and stations 6 and 7 are located in Cumburzua canal. The lowest salinity occurred in late July and August and thereafter it suddenly increased in September. This trend was noticed at all the stations. Significant difference was also noticed between the two banks of the river Mandovi at Station 1A, 1B and 2A and 2B. At station 1B the salinity was always higher indicating the existence of flow of neritic waters in a channel on western side of the estuary. The surface salinity during low tide was correspondingly low.

The salinity at the bottom was higher than at the surface. The range in this system was 0.12 to 33.58‰. Station 5 showed the minimum salinity throughout the period and the stations 6 & 7 in Cumburzua canal followed next. During the second fortnight of July the salinity was minimum but it increased to maximum in late September. The salinity in Zuari was invariably higher as compared to Mandovi. Similar to surface salinity, the bottom salinity values at stations 1A, 1B, 2A and 2B also showed variations. The values were higher at 1B and 2B, the surface and bottom, salinity therefore clearly indicate, the course of the channel for incoming waters. The data also indicates that Cumburzua canal becomes almost a freshwater channel for a short period.

Dissolved oxygen

The range of dissolved oxygen at surface is 1.93 to 7.30ml/l in Mandovi sector, 3.85 to 5.81ml/l in Cumburzua canal and 3.80 to 5.45ml/l in Zuari (Fig.3). In comparison to Mandovi estuary the variation in dissolved oxygen content are less in Cumburzua canal and Zuari estuary, particularly in surface waters. Few values obtained at low tide were comparable to high tide values and did not show differences.

At the bottom, oxygen varied between 0.91–8.55ml/l in Mandovi, 3.64–5.93ml/l in Cumburzua canal and 2.19–5.24ml/l in Zuari estuary. Significant variations occur at all stations at the surface and bottom. In monsoon these variations may be due to the rapid changes in the environment. However except on few occasions, the concentration of dissolved oxygen and its availability in the entire estuarine complex does not show oxygen depletion. In Mandovi estuary during late September a sudden decrease in oxygen was noticed in surface and bottom waters particularly during high tide, this may perhaps be due to some intrusion of oxygen deficient upwelled waters from nearshore areas (Sankaranarayanan and Jayaraman 1973).

Phosphates

The mean values of phosphate-P at all the stations are shown in Fig. 4. The variation in phosphate concentration in surface waters were from 0.04 to $1.75 \mu\text{g-at/l}$ in Mandovi, 0.13–1.26 in Cumburzua canal and from 0.26 to $1.17 \mu\text{g-at/l}$ in Zuari estuary, during high tide periods. The low tide values are also of a comparable order. The mean values were slightly higher in Zuari estuary at high tide while lowest value was recorded at station 7 in Cumburzua canal in early September.

In bottom waters the phosphate values in three sectors ranged between 0.24 to 1.99 in Mandovi, 0.33 to 1.70 in Cumburzua canal and 0.42 to $2.61 \mu\text{at/l}$ in Zuari. These values are higher as compared to surface values. Like surface, the phosphates at the bottom were lowest in Cumburzua and highest in Zuari. In the coastal water, organic phosphate is known to constitute upto 30% of the total phosphorus and this estuarine complex is also quite rich in phosphates.

Nitrates

Nitrate controls the availability of nitrogen for marine life. The nitrate values were higher than phosphate. Generally higher values were seen in July and minimum in second fortnight of September (Fig. 4). The values for surface

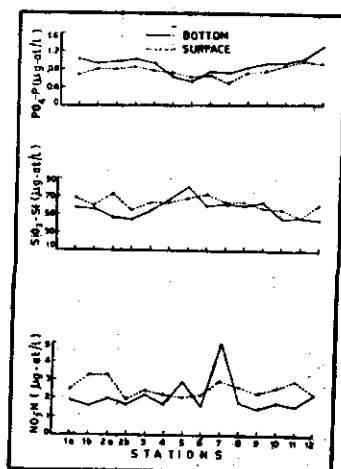


FIG. 4

Fig. 4 : The annual mean of Nitrate, Silicate and Phosphate in surface in surface and bottom waters.

water ranged between 0.25 to $4.11 \mu\text{g-at/l}$ in Mandovi 0.42 to 3.87 in Cumburzua canal and 0.36 to $4.56 \mu\text{g-at/l}$ in Zuari. In bottom waters, these ranges were 0.42 to 6.70 in Mandovi, 0.33 to 4.1 in Cumburzua canal and 4.08 to $4.57 \mu\text{g-at}$

Table 1 : Concentration of Chlorophyll-a (mg/m^3) in surface waters

Month	Date	Stations													
		1A	1B	2A	2B	3	4	5	6	7	8	9	10	11	12
June 71	5-6-71	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	26-6-71	0.91	2.38	2.32	1.92	1.79	2.33	3.11	4.66	4.44	6.00	6.58	5.00	3.83	3.06
July 71	13-7-71	2.51	2.88	3.13	4.45	3.72	4.27	4.72	7.33	—	—	4.12	3.11	3.32	3.65
	27-7-71	2.61	1.86	2.93	3.82	3.31	7.44	1.70	14.20	—	—	—	—	0.58	0
Aug. 71	10-8-71	—	—	2.56	4.66	—	—	—	3.71	0	0	5.08	1.44	0.55	0.17
	26-8-71	2.43	3.46	1.08	3.17	0.54	0	0.10	0.76	0.67	0	0	0	0.95	0.81
Sept. 71	10-9-71	1.13	1.83	0.39	0.84	1.39	0.41	0.65	6.79	5.03	2.57	3.65	6.05	—	—
	21-9-71	0	10.28	5.86	1.59	1.85	1.03	11.10	1.43	0.54	0.10	—	—	0	—

Table 2 : Concentration of Chlorophyll b (mg/m^3) in surface waters

Month	Date	1A	1B	2A	2B	3	4	5	6	7	8	9	10	11	12
June 71	5-6-71	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	26-6-71	0.35	0.03	0	0.12	0.47	0.13	1.21	0.71	0.75	0.01	2.28	0.27	0.25	1.66
July 71	13-7-71	0	0.35	0.09	0	0.01	0.06	1.47	0.17	—	—	0	0.40	0.02	0.26
	27-7-71	0	0.30	0	0.97	0.44	0.15	0.44	0	—	—	—	—	0.48	0
Aug. 71	10-8-71	—	—	0.01	0.17	—	—	—	0.21	—	—	0.19	0.08	0.21	0
	26-8-71	0.43	0.62	0	0	0.04	0	0	0	0.89	0	0	0	0	1.48
Sept. 71	10-9-71	0.08	0.72	0	0.19	0.24	0	0.05	1.28	2.13	0	0	0.58	—	—
	21-9-91	0	10.25	1.83	0.29	2.03	1.21	4.65	0.42	0.23	0	—	—	—	—

Table 3 : Concentration of Chlorophyll *c* (mg/m³) in surface waters.

Month	Date	Stations													
		1A	1B	2A	2B	3	4	5	6	7	8	9	10	11	12
June 71	5-6-71	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	26-6-71	1.31	0.74	2.80	1.81	2.84	0.70	3.77	2.20	1.96	0	3.53	3.18	2.80	0
July 71	13-7-71	1.50	2.57	1.80	4.30	5.12	0.63	7.50	5.71	—	—	—	1.60	1.72	3.54
	27-7-71	1.75	0.88	0.96	3.23	2.54	3.77	2.56	0	—	—	—	—	0.47	0.28
Aug. 71	10-8-71	—	—	1.04	3.16	—	—	—	1.07	—	—	0.13	2.24	0.47	0.21
	26-8-71	2.70	2.82	0	1.50	2.57	0	0	0	3.05	0	0	0	1.32	2.90
Sep. 71	10-9-71	0	0	0.31	0	0	4.64	0.37	0	0.44	0	1.72	0.44	—	—
	21-9-71	0	9.76	1.97	0	0	1.75	3.17	5.03	0.28	0	—	—	—	—

Table 4 : Concentration of Carotenoids (m-SPU/m³) in surface waters.

Month	Date	1A	1B	2A	2B	3	4	5	6	7	8	9	10	11	12
June 71	5-6-71	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	26-6-71	0.72	1.46	1.50	1.78	1.14	0.70	1.17	1.82	1.89	1.20	2.50	1.87	1.38	0.64
July 71	13-7-72	—	—	—	—	1.11	—	1.67	0	—	—	—	—	—	—
	27-7-71	1.25	0.93	1.38	1.54	0.86	1.71	1.60	2.22	—	—	0	0	0.62	0.54
Aug. 71	10-8-71	—	—	1.01	2.16	—	—	—	2.08	—	—	2.45	0.36	0.46	0.58
	26-8-71	1.92	1.52	0.53	2.29	1.60	0	0.77	1.30	6.96	0	0.60	6.8	4.13	5.17
Sept. 71	10-9-71	1.86	1.20	0.67	1.43	3.73	2.10	1.30	0.87	0	0.10	—	0.47	—	—
	21-9-71	0.73	3.0	1.83	0	2.35	2.43	1.06	2.00	1.80	0.97	—	—	—	—

/l in Zuari. In overall picture, the bottom values were less as compared to the surface values. Low values of nitrate were seen in surface and bottom water during low tide. In general, the waters were rich in nitrates.

Silicate (Fig. 4)

The availability of silicate is important for the siliceous phytoplankton. In surface Waters, at high tide the silicate values ranged between 17.48 to 134.30 $\mu\text{g-at/l}$ in Mandovi, 20.15 to 114.15 $\mu\text{g-at/l}$ in Cumburzua canal and 12.43 to 89.98 $\mu\text{g-at/l}$ in Zuari. The mean values were generally low in Zuari. The low tide values were still less than high tide values. The silicate values in bottom waters are also less than the surface values, the ranges at the three sectors are 20.14–120.07 $\mu\text{g/l}$ in Mandovi, 26.86–98.04 $\mu\text{g/l}$ in Cumburzua canal and 13.43–84.60 $\mu\text{g/l}$ in Zuari estuary.

Biological features.

Pigments : Among pigments, chlorophyll *a*, *b*, *c* and carotenoid were studied. Chlorophyll is an important constituents of phytoplankton and provides a quantitative index of phytoplankton production.

The mean values and monthly distribution of concentration of these pigments are given in Tables 1–4. The maximum and minimum of chlorophylls *a*, *b*, and *c* and carotencids are given below.

	Mandovi		Zuari		C. Canal	
	Max.	Min.	Max.	Min.	Max.	Min.
Chlorophyll <i>a</i> (mg/m ³)	11.10	0	6.58	0	14.20	0
Chlorophyll <i>b</i> (mg/m ³)	4.65	0	2.28	0	2.13	0
Chlorophyll <i>c</i> (mg/m ³)	7.50	0	3.53	0	5.71	0
Carotenoids m-S.P.U/m ³	3.73	0	6.80	0	6.96	0

The above data indicates large variations in the three sectors of the complex in all the pigments i. e. chlorophyll *a*, *b* and *c* and carotenoids. Amongst all the pigments, chlorophyll *a* is dominant and is followed by *c* and *b* respectively.

Amongst the three sectors, chlorophyll *a* was more in Cumburzua canal. In Mandovi higher concentration was found at low salinity. In Zuari the situation was different. Chlorophyll *b* at all the stations throughout the period was very low except at station 1B, where it was unusually high in September. Chlorophyll *c* had moderate concentration and was always less than Chlorophyll *a*. The ratio of chlorophyll *a* to carotenoid is more than one which also indi-

cates a healthy crop. The diurnal studies (Bhargava & Dwivedi, 1974) also support the general conclusion drawn in the present investigations.

The chlorophyll studies, therefore indicate that during monsoon the phytoplankton crop is variable, probably due to the tidal effect but is active and healthy. The concentration is more in Cumburzua canal and Mandovi than in Zuari estuary. This indicates that the fresh water influx is conducive for the growth of phytoplankton.

Zooplankton

Zooplankton constitutes the second trophic level of the food chain and forms the food for most of the fishes. The displacement volume of zooplankton has been expressed here as total biomass represented in ml/100m³ (table 5). The zooplankton biomass range was variable and irregularly distributed. The maximum value was noticed in the Cumburzua canal at st. 6 during the second fortnight of September. The biomass range was between 4-872ml/1000m³ in Mandovi sector, 14-1036ml/1000m³ in Cumburzua canal and 10-816ml/100m³ in Zuari. During the entire monsoon season, Zuari had greater tidal influence and higher zooplankton biomass. The faunal composition was also very diverse. From June to August the zooplankton was erratic but in September the biomass had higher values except at stations 4,5 and 6 during the first fortnight. The biomass values during high tide were high at stations 1A, 1B in Mandovi and 12 in Zuari, indicating that the high biomass was associated with the inflow of neritic water brought in during high tide. The biomass is generally good during the first fortnight of June, which is followed by a decline in the biomass and in the number of organisms. By September there is a wide spectrum of organisms, Copepodes was the major component in almost all the samples. During the first fortnight of June there is a mixed population comprising of neritic and estuarine species. Later they are found only at the mouth of the estuary, particularly at station 12 in Zuari where the fresh water influence is less than station 1A and 1B in Mandovi. The following copepod species, *Paracalanus parvus*, *Arrocalanus gracilis* and *Oithona rigida* at the mouth region (lower reaches) *Pseudodiaptomus binghami*, *Acartia centrura*, *A. spinicauda*, *A. plumosa* and *Oithona brevicornis* at the middle region and *Acartia southwelli*, *Acartiella graveli*, *A. sewelli*, *Heliodiaptomus cinctus*, *Diaptomus* sp. and *Cyclops* sp. at the upper reaches were some of the dominant species found in this estuarine system. It is evident that salinity plays an important role in the distribution of planktonic species in the estuaries.

Lucifer, hansani, is the only sergestid species found in this estuarine system almost throughout the period in varying degree, and are particularly more at highly saline areas. Chaetognaths show their presence in the beginning and at the

end of monsoon when the salinity is higher. *Sagitta bedoti* was common while other two species viz. *S. enflata* and *S. pulchra* are also recorded. Decapod larvae represented by zoea and megalopa of crabs and post larvae and mysis stages of penacids were present in the middle reaches of the estuaries. Cladocerans viz. *Evadne tergestina* and *Penilia avirostris* appear by the second fortnight of August and increase in numbers subsequently. *Lingula* larvae were present only during the second fortnight of September at station 10 and 11. Gastropod and Bivalve were present in good numbers at the mid reaches. Fish eggs and larvae were present almost throughout in varying degrees, although fish eggs were recorded in more numbers from the Mandovi sector by the second fortnight of September. Many neritic organisms appear in small numbers by late September indicating the reappearance of marine conditions.

Benthic production

The standing crop of macrobenthos including epifauna and infauna have been studied. These animals feed on the decayed organic matter and smaller animals and plants, but are important in food chain because they form the food of higher animals while a few, such as oysters, clams and mussels are directly edible. (Tables 6 & 7).

Their distribution is influenced by the substratum type and the environment. In this estuarine complex, 5 different types of substrata were observed; (i) Hard rocky, (ii) Sandy mud, (iii) Sand, (iv) Muddy sand and (v) Silty. Depending upon the kind of substratum different types of benthic animals in varying percentage were found at different stations as tabulated below. The other important factor affecting the distribution is salinity.

Distribution of benthic animals at different stations according to the substratum.

Type of Substratum	Stations	Benthic Infauna and Epifauna	Over all biomass gm/m ²
Hard-rocky	1A & 7	Cirripeds byozoans, oysters mussels, hydroids, isopods & amphipods.	2.4
Sandy mud (70-80%) (20-30%)	1B	Polychaeta-sedentaria and Mysids	9.7
Sandy	3,4,5&12	Pelecypoda and Polychaete errantia	46.2
Muddy sand (70-80%) (20-30)	6 & 8	Decapods and Polychaete errantia	25.5
Silty	2A,2B,9, 10 & 11	Polychaeta-sedantaria, amphipods, alphids, gobid fishes and planktonic forms	23.0

Table 5 : Distribution of Zooplankton biomass (ml/1000 m³) in surface waters.

Month	Date	Stations													
		1A	1B	2A	2B	3	4	5	6	7	8	9	10	11	12
June 71	5-6-71	160	191	45	31	20	62	135	146	—	38	21	13	21	11
	26-6-71	6	22	12	39	7	4	31	28	19	30	72	50	49	52
July 71	13-7-71	288	364	88	106	201	30	19	100	40	34	245	242	346	115
	27-7-71	11	34	24	28	27	18	25	14	70	30	25	10	51	44
Aug. 71	10-8-71	134	251	196	92	101	14	15	44	16	19	79	25	197	54
	26-8-71	149	167	217	110	88	19	27	33	26	248	513	424	229	266
Sept. 71	10-9-71	247	421	206	118	204	35	12	41	245	611	816	538	614	165
	21-9-71	96	75	186	200	288	178	872	1036	699	697	462	483	415	274

Table 6 : Distribution of benthic biomass (gm/m²)

Month	Date	Stations													
		1A	1B	2A	2B	3	4	5	6	7	8	9	10	11	12
June 71	5-6-71	0.56	0.01	7.49	40.13	0.93	0.10	0.05	4.2	0.82	12.25	78.78	4.14	0.09	—
	26-6-71	0.12	0.01	19.84	60.51	0.34	0.01	0.29	2.08	0.79	0.73	0.55	0.04	0.7	0.01
July 71	13-7-71	0.09	—	0.07	0.36	198.15	0.02	0.97	2.41	0.38	0.19	65.29	2.39	0.60	0.03
	27-7-71	2.24	5.22	0.06	0.73	73.04	—	1.02	1.45	—	20.15	0.01	1.27	—	—
Aug. 71	10-8-71	—	—	0.60	0.65	0.77	11.38	0.17	2.05	1.55	0.31	1.10	—	0.07	—
	26-8-71	0.05	17.37	0.80	0.37	0.80	0.81	0.07	8.31	4.17	2.75	0.11	44.85	0.12	2.81
Sept. 71	10-9-71	—	0.17	0.13	0.12	1.18	2.04	0.10	227.00	0.64	1.17	0.04	0.01	0.03	—
	21-9-71	0.69	—	1.74	0.06	2.81	0.50	0.44	8.74	0.11	1.32	0.02	0.06	0.05	—

Table 7 : Distribution of benthic population (Nos)

Month	Date	Stations													
		5	1	15	9	5	1	2	30	3	4	40	7	1	---
June 71	5-6-71	5	1	15	9	5	1	2	30	3	4	40	7	1	---
	26-6-71	4	4	35	31	7	1	11	40	1	4	15	2	4	3
July 71	13-7-71	8	-	7	5	14	2	4	76	2	4	63	4	200	25
	27-7-71	2	23	7	2	8	-	6	58	-	5	4	6	-	-
Aug. 71	10-8-71	-	-	26	14	103	215	13	13	1	5	9	-	3	-
	26-8-71	3	10	27	9	202	5	14	236	7	6	6	47	5	2
Sept. 71	10-9-71	-	4	16	36	64	7	3	129	4	5	17	1	3	-
	21-9-71	7	-	31	8	10	6	33	96	8	7	5	2	11	-

The biomass varies from 0.12 to 795.35g/m² in Mandovi; 0.27–62.7 in Cumburzia canal and 0.15–196.75 g/m² in Zuari estuary. It is thus seen that Mandovi and Zuari have a comparatively high benthic production except at mouths where probably due to unstable environment the benthic production is low (Parulekar & Dwivedi, 1973). The sandy substratum, low salinity and euryhaline animals accounts for higher biomass. The production of standing crop is steady in Cumburzia canal where the variations in environmental parameters are of lesser magnitude.

Diurnal changes in Estuarine Complex

The fortnightly observations at these 14 stations were supplemented by observations covering one complete tidal cycle of 24 hours at three stations. These stations were at Verem (1A) in Mandovi, Station 8 in Cumburzia Canal at Mercaim and station 11 in Zuari off St. Jacinto Island. Three hourly observations were made covering two low and two high tides to study hydrography at surface and bottom and chlorophyll and zooplankton at surface. The range of different parameters studied at surface waters are given below :

Parameters	Mandovi		C. Canal		Zuari	
	Max.	Min.	Max.	Min.	Max.	Min.
Temperature°C	29.00	27.80	29.00	28.00	28.80	27.75
Salinity ‰	19.69	2.45	11.49	1.70	13.69	4.31
D.O ₂ ml/l	5.34	4.52	5.37	4.45	5.50	4.45
pH	9.20	7.70	10.60	8.80	10.40	8.90
Total chlorophyll (a+b+c) (mg/m ³)	7.53	0.82	1.94	0.06	3.09	0.13
Carotenoid (m-S.P.U/m ³)	1.84	0.16	19.82	0.00	7.82	0.80
Zooplankton biomass (ml/1000m ³)	416.00	27.00	1222.00	143.00	1425.00	37.00

It is seen that the variations in temperature, O₂ and pH are nominal. The salinity showed large variations with tide. Though variations in dissolved oxygen were small, the oxygen content in general was high and was never below 4.45ml/l. This may be due to high wave action and mixing of fresh and neretic waters. The pH ranged between 7.7 to 10.6 indicating the waters were highly alkaline and productive.

Wide variation influenced by tides occur in chlorophyll content. The maximum concentration was in Mandovi and minimum in Cumburzia canal. However, in Mandovi, chlorophyll was found more during low tide, whereas in Cumburzia canal and Zuari the concentration was more in high tide, period. Carotenoid contents were low in Mandovi and Cumburzia canal but comparatively higher in Zuari estuary. The ratio of chlorophyll a to c and chlorophyll a

to carotenoid were more than one in Mandovi and Cumburzua canal but decreased sometimes in Zuari estuary.

The mean values for zooplankton biomass were also maximum in Zuari followed by Cumburzua canal and were minimum in Mandovi estuary. This is the direct indication that during monsoon, Zuari seems to be more productive than Mandovi. This condition exists, inspite of the fact that Chlorophyll concentration is more in Mandovi, which perhaps remains unutilised.

The study indicates that there are atleast three different ecosystems in this complex, which are comprised of Zuari, Cumburzua Canal and Mandovi. Both the estuaries have rich primary and secondary crop at their mouth region. However, in the Cumburzua canal the environment is more stable. It differs from both the estuaries in the kind of bottom, salinity, nutrients and in the productivity of phytoplankton, zooplankton and benthos. For the first time the present study provides comprehensive basic environmental data for this estuarine complex. This also provides baseline data for environmental monitoring which can be useful for studying further changes due to waste disposal and any other factor which may bring about changes in the estuarine ecology of this system.

Summary and conclusion

1. The ecological studies were conducted in the Mandovi, Zuari and connecting Cumburzua Canal complex during monsoon season from June to Sept. 1971.
2. The two estuaries have funnel shaped mouth and are separated by only a ridge, Tides in this complex are of semidiurnal types and the maximum tidal amplitude is about 2.3m.
3. Light penetration was low particularly in July and August. The euphotic depth varies between 0.51 to 4.13m. Minimum occurs in Cumburzua Canal.
4. Temperature ranged between 26.1 to 30.6°C at surface and 23.5 and 30.4°C at bottom. Low temperature was noticed in August. Bottom temperature seems to be influenced by cold neritic waters entering in the estuaries.
5. The salinity was affected by rain and tides and was characteristic of the monsoon. Low values were observed in July and August. Surface salinity was minimum in Cumburzua canal while Zuari showed higher salinity and range was very wide from 0.12 to 32.90‰ Bottom salinity as compared to surface was higher.
6. Dissolved oxygen variations in surface waters were large in Mandovi than in Cumburzua Canal and Zuari. The values did not show much difference

during high and low tide. Low oxygen was noticed in Mandovi during September which may be due to intrusion of oxygen deficient neritic waters.

7. Low values of $\text{PO}_4\text{-P}$ was noticed in September. Phosphate concentration was more in bottom waters than in the surface waters. Higher concentrations was noticed in Zuari. It ranged between 0.04 and 2.6 $\mu\text{g-at/l}$ in the entire system.
8. Chlorophyll *a*, *b* and *c* and carotenoids were studied. Chlorophyll *a* was highest in Cumburzua canal followed by Mandovi and Zuari. The chlorophyll concentration is highly variable and influenced by tides. Low tide crop dominate in Mandovi while chlorophyll is more during high tide in Zuari. The pigment ratios indicate a healthy phytoplankton crop.
9. The zooplankton biomass showed large variations. Highest mean biomass was seen in Zuari and was found to be associated with high salinity waters from nearshore areas coming during high tide. The biomass value increases in September which coincides with the start of fishing season.
10. The macrobenthos distribution was affected by substratum and salinity. The sand substratum, low salinity and euryhaline animals accounts for high biomass. The benthic biomass was low and most variable at mouths of the estuary. The standing crop was steady in Cumburzua canal

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