

Ecology of Indian estuaries—V: Primary productivity of the Ashtamudi estuary, south-west coast of India

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Abstract. Primary productivity at four representative stations in the Ashtamudi estuary has been presented. The average gross and net productivities in the surface water was maximum at Neendakara, the bar mouth zone and minimum at Kadapuzha, the riverine zone consistently exposed to pollution from paper mill effluents. Ashtamudi, the station directly on the gradient line and Kanjirakode, the station equidistant from Kadapuzha and Ashtamudi presented a transition phase with regard to the primary productivity. In the bottom water also productivity was minimum at the polluted zone. Generally productivity at sub-surface levels was higher than that at the surface. A seasonal pattern, independent of various environmental parameters, was discernible both in the gross and net productivity changes at surface and sub-surface levels. High concentrations of dissolved oxygen, silicate and nitrite helped to maintain higher productivities at Neendakara, Ashtamudi and Kanjirakode on several occasions during the year. The fact that productivity at the polluted Kadapuzha station was the lowest, indicates that the paper mill effluent has considerably disturbed the productivity mechanism of this otherwise healthy ecosystem.

Keywords. Gross productivity; net productivity; ecological factors; surface and bottom waters.

1. Introduction

Since all organic matter available in our estuary is primarily synthesised by the primary producers and the products are transferred to consumers through different trophic levels, the amount of primary production is the most significant factor which determines whether or not a particular body of water is important from the fisheries angle. Despite its growing importance, studies on the primary productivity of the estuarine waters of India are few and far between. Dehadrai (1970), Dehadrai and Bhargava (1972a), Bhargava (1973), Bhargava *et al* (1977) and Bhattathiri *et al* (1976) have reported results of investigations carried out in the Mandovi-Zuari estuaries in Goa. Another well-documented estuary along the west coast of India is the Cochin estuarine system (Qasim 1970, 1979; Qasim and Reddy 1967; Qasim *et al* 1968, 1969, 1972, 1974; Nair *et al* 1975; Pillai *et al* 1975). These papers have dealt in detail the various aspects of primary productivity. On the east coast of India data are available from the Vellar estuary (Bhatnagar 1971, Purushothaman and Bhatnagar 1976; Subramonian and Venugopalan 1978). Qasim (1979) attempted to review the productivity studies in the Indian seas and estuaries. Dunbar (1979) reviewed the productivity mechanisms in diverse climatic zones in the world.

Kerala is endowed with an extensive tract of perennial and temporary estuaries lying almost parallel to the Arabian Sea. Of the 30 such water bodies, report on the primary productivity is available only from the Cochin backwater. The present investigation was undertaken in the light of the lacuna that exists in our scientific understanding of the nature of productivity of the large number of these estuaries in Kerala with a view to preparing detailed field plans to establish aquaculture farms along the backwater tracts of Kerala. The study is particularly relevant in the context of the ever-increasing threat to the estuarine ecosystem of Kerala from various sources of pollution such as factory effluents, oil spills, retting etc. It is intended as a base line study which would be helpful to plan out programmes of fish culture in the state.

2. Environment

The present investigations have been conducted in the Ashtamudi estuary (latitude: $8^{\circ}53' \text{ N}$ – $9^{\circ}02' \text{ N}$; longitude: $76^{\circ}31' \text{ E}$ – $76^{\circ}41' \text{ E}$) (figure 1). The Kallada river with a catchment basin of about 960 km^2 after traversing for about 120 km, across the state drains into the estuary. A paper mill, situated on the banks of the river is a major source of pollution. Four stations *viz* Neendakara (I), Ashtamudi (II), Kanjirakode (III), and Kadapuzha (IV) have been selected for regular observations. Station I is the marine-dominated estuary mouth, station IV is a riverine zone while stations II and III are intermediate zones.

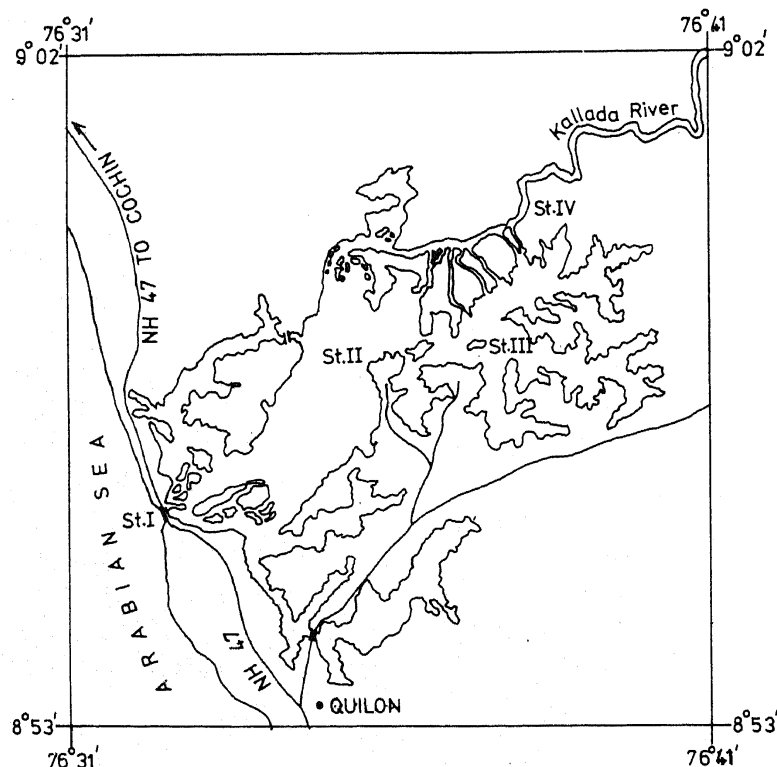


Figure 1. Map of the Ashtamudi estuary showing the study sites.

3. Material and methods

The present study was undertaken during July 1980–June 1981 in the surface and bottom waters at four stations in the Ashtamudi estuary. The rate of primary production was measured following the light and dark bottle method as given by Strickland and Parsons (1972) and modified by Qasim *et al* (1969). All precautions suggested by Vollenweider (1969) have been strictly followed in conducting the experiments. The bottom water samples were kept at about 2 m depth for all experiments. Analysis of variance technique as given by Snedecor and Cochran (1967) was used for various statistical tests.

4. Results

Fortnightly variations in the gross and net productivities in the Ashtamudi estuary during 1980–1981 are shown in figures 2 and 3. The mean seasonal variations and the annual mean are presented in table 1.

4.1 Gross productivity

The maximum gross productivity of the surface water at Neendakara was recorded in July (341.82 mg C/m³/hr), at Ashtamudi and Kadapuzha in August (280.40 and 227.90 mg C/m³/hr respectively) and at Kanjirakode in November (208.89 mg C/m³/hr) (figure 2). Gross productivity touched zero values at all these stations during September and October. When the average values were computed a seasonal pattern has emerged at Neendakara when July–October recorded the highest figure (196.56 mg C/m³/hr) and November–February, the lowest (91.03 mg C/m³/hr). March–June was found to be a period of recovery (table 1). The seasonal variation at Neendakara was significant ($p < 0.01$) (table 2). Such a distinct seasonal pattern was however absent at the other

Table 1. Mean seasonal and annual variations in the primary productivity (mg C/m³/hr) of the Ashtamudi estuary.

		Stations							
		Neendakara		Ashtamudi		Kanjirakode		Kadapuzha	
		NP	GP	NP	GP	NP	GP	NP	GP
Season I July–October 1980	SW	101.17	196.56	61.46	105.15	55.83	83.16	55.16	103.28
	BW	85.45	170.35	115.02	171.40	87.80	123.75	31.50	78.87
Season II November '80– February '81	SW	48.36	91.03	68.25	110.38	59.79	123.01	39.74	100.74
	BW	81.88	117.94	68.21	127.94	68.50	164.34	55.42	96.91
Season III March–June 1981	SW	73.59	156.67	68.84	112.20	47.48	121.70	50.86	106.82
	BW	57.92	184.51	86.69	130.81	61.10	135.93	69.91	113.09
Yearly mean	SW	74.37	148.09	66.18	109.24	54.37	109.28	48.59	103.62
	BW	75.08	157.60	89.97	143.38	72.46	141.34	48.94	96.29

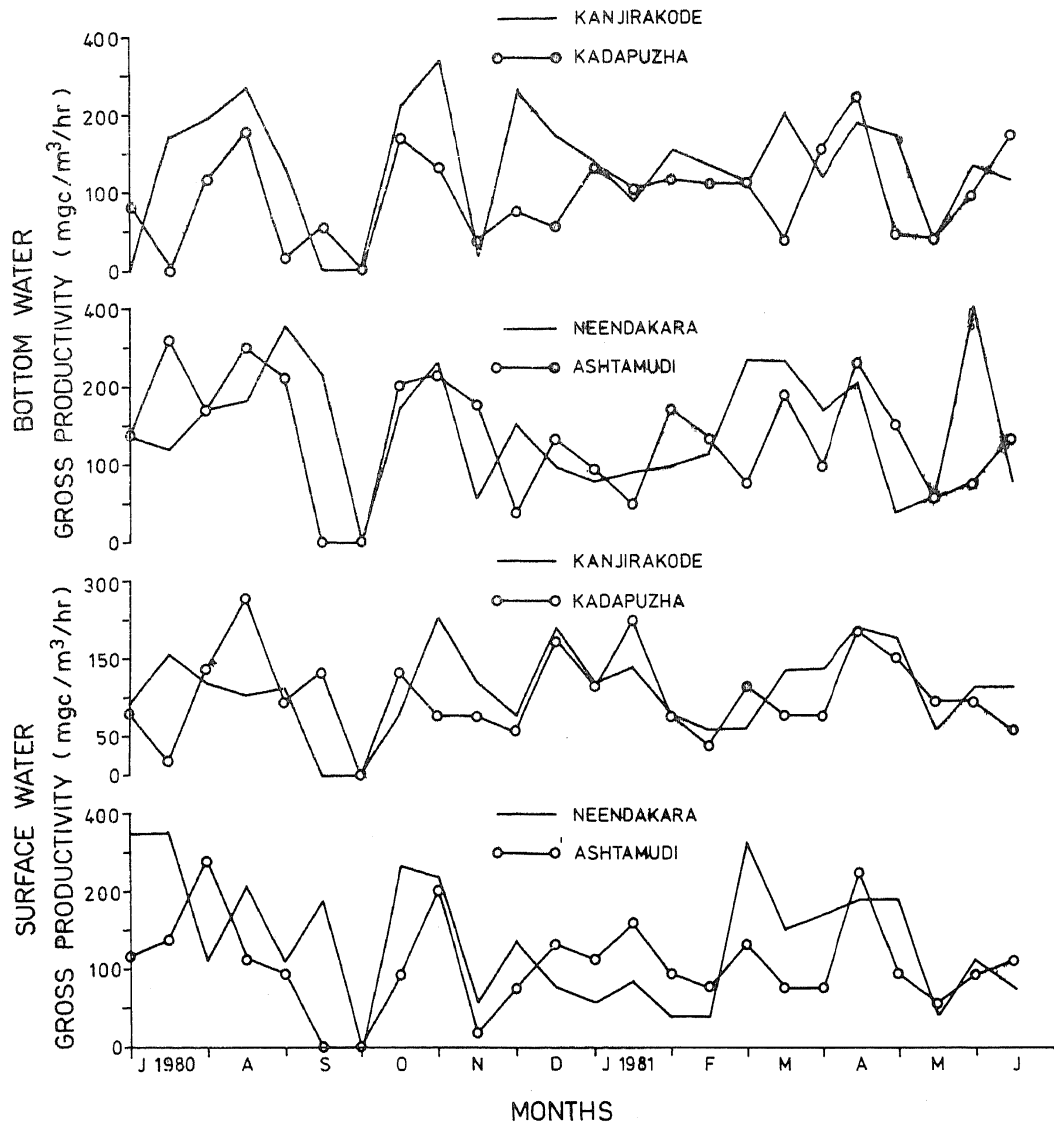


Figure 2. Fortnightly variations of the gross productivity in the surface and bottom waters of the Ashtamudi estuary during 1980-1981.

stations and the variations were not significant. As the range in the seasonal production was low it can be concluded that the gross productivity in the surface water at these stations was relatively uniform throughout the year. The average annual gross productivity in the surface water was maximum at Neendakara (148.09 mg C/m³/hr), the station nearest to the marine zone and minimum at Kadapuzha (103.62 mg C/m³/hr), situated farthest from the sea on the riverine zone. Ashtamudi is the station that lies directly on the gradient line from the marine-dominated Neendakara to the freshwater-dominated Kadapuzha station. At Ashtamudi the annual average was 109.24 mg C/m³/hr. So a downward trend in gross production was evident from Neendakara to Kadapuzha reflecting the consequences of pollution resulting from the paper mill effluents reaching the area. Kanjirakode is the station that lies equidistant from Kadapuzha and Ashtamudi in the innermost segment of the estuary. Here the

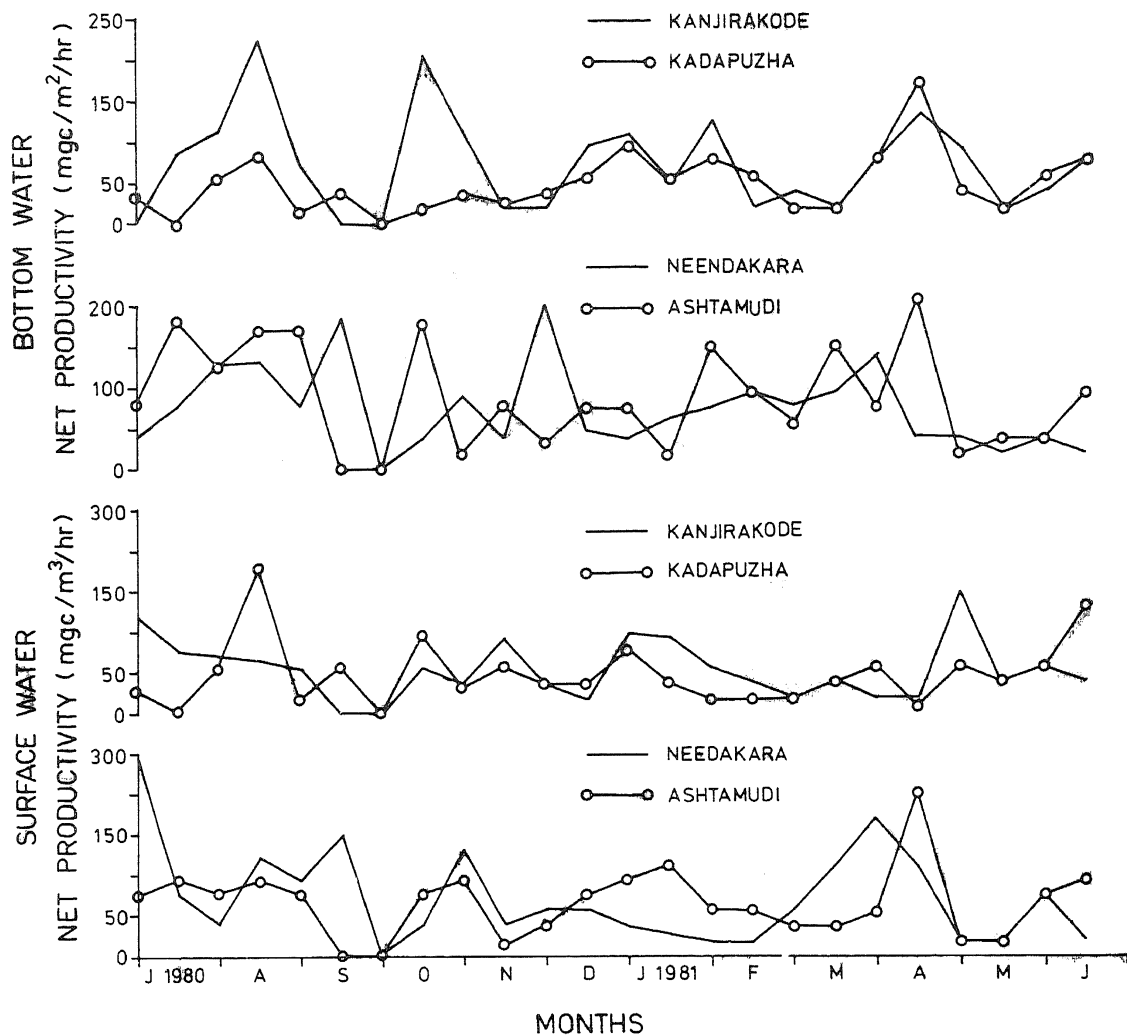


Figure 3. Fortnightly variations of the net productivity in the surface and bottom waters of the Ashtamudi estuary during 1980–1981.

gross productivity was slightly higher than that at Neendakara. However, the variations between the stations were not statistically significant (table 4).

The gross productivity in the bottom water at Neendakara was maximum in June (398.78 mg C/m³/hr), at Ashtamudi in July (322.83 mg C/m³/hr), at Kanjirakode in November (341.82 mg C/m³/hr) and at Kadapuzha in April (246.87 mg C/m³/hr). No productivity was observed just as in the surface water during September–October at all the stations (figure 2). Computation of seasonal values has shown that the gross productivity that was higher during July–October at Neendakara and Ashtamudi fell to lower values during November–February and gave higher figures during March–June (table 1). At Kanjirakode low values during July–October picked up in the succeeding period and declined afterwards. At Kadapuzha gross productivity maintained an ascending trend from season I to season III. Seasonal gross productivity in the bottom water was maximum at Neendakara (184.51 mg C/m³/hr) during March–June, at Ashtamudi during July–October (171.40 mg C/m³/hr), at Kanjirakode during

Table 2. *F*-values from analysis of variance test comparing the net and gross productivities in the surface and bottom waters of the Ashtamudi estuary.

Source	Stations											
	Neendakara		Ashtamudi		Kanjirakode		Kadapuzha					
	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW	SW	BW
Between net and gross productivities	20.7263(c)	17.0191(c)	22.8914(c)	11.4245(c)	24.4281(c)	24.8808(c)	25.1163(c)	33.7896(c)				
Between seasons	8.0263(b)	0.7125	0.2462	3.5804(a)	1.3568	0.5685	0.2850	5.1167(a)				
Between periods within seasons	3.1136(b)	1.7940	6.2486(b)	6.5303(b)	1.9899	4.4649(b)	2.5642(a)	5.6953(b)				

a: Significant at 5% level; *b*: Significant at 1% level; *c*: Highly significant.

Table 3. F-values from analysis of variance test comparing the productivities of the surface and bottom waters in the Ashtamudi estuary.

Source	Stations											
	Neendakara			Ashtamudi			Kanjiarakode			Kadapuzha		
	NP	GP	NP	NP	GP	GP	NP	NP	GP	NP	NP	GP
Between surface and bottom waters	0.0024	0.1685	6.5641(a)	4.1460	1.7027	4.3853(a)	0.0013	0.3352				
Between seasons	1.6487	4.4139(a)	0.9600	0.5161	0.5360	2.3533	0.5152	0.7472				
Between periods within seasons	1.8477	1.8716	4.2037(b)	2.8567(b)	1.3291	2.9090(b)	1.7445	2.8622(b)				

a: Significant at 5% level; b: Significant at 1% level

Table 4. *F*-ratio from analysis of variance test comparing the net and gross productivities between the different stations in the Ashtamudi estuary.

	<i>F</i> -ratio			
	NP-SW	NP-BW	GP-SW	GP-BW
Between different stations	1.4948	3.2660(a)	2.7064	3.2680(a)
Between seasons	0.7715	0.3200	0.8300	0.3272
Between periods within season	1.3804	2.2876(b)	2.6955(b)	2.9554(b)

a: Significant at 5% level; b: Significant at 1% level

November–February (164.34 mg C/m³/hr) and at Kadapuzha during March–June (113.09 mg C/m³/hr). The seasonal variations were significant only at Ashtamudi and Kadapuzha ($p < 0.05$) (table 2). The annual average gross productivity in the bottom water was higher than that of the surface water at all the stations except Kadapuzha where the situation was the reverse. The annual averages show that the gross productivity in the bottom water also exhibited a decreasing trend from Neendakara to Kadapuzha. The annual average at Neendakara was 157.6 mg C/m³/hr, at Ashtamudi it was 143.38 mg C/m³/hr. The value at Kanjirakode was lower than that at Ashtamudi but higher than that at Kadapuzha (table 1). The variation between the gross productivity in the bottom waters was significant between all the stations ($p < 0.05$) (table 4). But the variation of gross productivity between the surface and bottom waters was significant only at Kanjirakode (table 3).

4.2 Net productivity

The net productivity of the surface water at Neendakara was maximum in July (284.85 mg C/m³/hr), at Ashtamudi in April (208.89 mg C/m³/hr), at Kanjirakode in May (151.92 mg C/m³/hr) and at Kadapuzha in August (180.40 mg C/m³/hr). Net productivity at all these stations was nil for a brief period during September and October (figure 3). Neendakara and Kadapuzha stations resembled each other in their seasonal variations in that the net productivity during July–October was maximum at both the stations. The values declined during November–February and picked up in the subsequent period (table 1). At Ashtamudi net productivity maintained an ascending trend from season I to season III and at Kanjirakode low productivity during July–October reached peak values during November–February and declined thereafter. The annual averages have shown that the net productivity in the surface water was maximum at Neendakara (74.37 mg C/m³/hr), and minimum at Kadapuzha (48.59 mg C/m³/hr). The values decreased from the marine to the freshwater zone along the gradient as was seen in the gross productivity of the surface water. However, the variations between the stations were not significant (table 4).

The net productivity of the bottom water was maximum in December

(208.89 mg C/m³/hr) at Neendakara, in April (218.79 mg C/m³/hr) at Ashtamudi; in August (225.86 mg C/m³/hr) at Kanjirakode and in April (170.91 mg C/m³/hr) at Kadapuzha (figure 3). Nil values were observed at all the stations during September–October. In the case of the bottom water, the seasonal net productivity was maximum at Neendakara and Kanjirakode during July–October and it maintained a decreasing trend throughout the succeeding seasons. At Ashtamudi the peak value during July–October decreased during November–February and showed a trend of recovery during March–June. At Kadapuzha net productivity in the bottom maintained an upward trend from season I to III (table 1). The annual net production was only slightly higher than that in the surface water and did not show a decreasing trend from the marine to the freshwater zone as was seen in surface water net production. Annual production was maximum at Ashtamudi (89.97 mg C/m³/hr) and minimum at Kadapuzha (48.94 mg C/m³/hr). The variation between the stations has been significant ($p < 0.05$) (table 4). When the net and gross productivities in the various stations were computed it was significant both in the surface and bottom waters (table 2). The variation of the net productivity in the surface and bottom waters was significant only at Ashtamudi (table 3).

5. Discussion

5.1 Primary productivity and ecological factors

5.1a *Light*: One of the most obvious ecological factors influencing primary production is the amount of solar energy reaching the surface of the sea (Nair and Thampi 1980) and it depends on the altitude of the sun and the changing weather pattern. The light that penetrates the water varies from fortnight to fortnight. The mean seasonal depth of light penetration at the various stations are given below.

Season	Depth of light penetration (in cm) at the various stations			
	Neendakara	Ashtamudi	Kanjirakode	Kadapuzha
July–October	68.56	92.04	88.94	83.51
November–February	130.56	160.50	148.50	100.94
March–June	69.13	114.25	133.88	72.00

The mean light penetration was lowest at all the stations during July–October synchronising with high turbidity and heavy river discharge. Light penetration was maximum during November–February, the period of bright sunshine during the year. It declined during March–June. The fortnightly light penetration depth was maximum at Neendakara (187.5 cm) in the latter half of January, at Ashtamudi (219 cm) in early February, at Kanjirakode (228 cm) in late February and at Kadapuzha (138.5 cm) in late January. Light penetration depth was minimum in early July at Neendakara (39.5 cm), at Ashtamudi (44.8 cm) and at Kanjirakode (28.5 cm) whereas at Kadapuzha it was observed in late September (15.1 cm).

When the variation in light penetration depth at the various stations has been placed in conjunction with the fortnightly data on the rate of gross and net productivity it was

found that the peak in the production has been quite independent of high or low illuminations. The peaks of gross productivity occurred at Neendakara in July, at Ashtamudi in early August, at Kanjirakode in early November and at Kadapuzha in the latter half of August. The peaks of net productivity occurred at Neendakara in early July, at Ashtamudi in late April, at Kanjirakode in early May and at Kadapuzha in late August. None of these observations synchronised with the peak illumination recorded in the area. This shows that the fortnightly variations in light penetration have not acted as a limiting factor in the productivity mechanism of the Ashtamudi estuary as a whole. Similar situations have been observed by Steeman Nielsen (1963) and Qasim *et al* (1969) in certain tropical areas.

Roughly three times the sechi disc depth is taken as the euphotic zone (Nair, 1970). Accordingly the euphotic zone at Neendakara ranged from 1.18 to 5.62 m, at Ashtamudi from 1.34 to 6.57 m, at Kanjirakode from 0.85 to 6.84 m and at Kadapuzha from 0.45 to 4.15 m. The size of the euphotic zone in the Ashtamudi estuary is bigger than that observed in the Cochin estuary (Qasim *et al* 1968) and in the Mandovi-Zuari estuary (Qasim 1979) where the range was 2 to 6 m and 1 to 4 m respectively. In the Vellar estuary the euphotic zone reaches the bottom (Purushothaman and Bhatnagar 1976). Further, in the Ashtamudi estuary, it was also noticed that the mean depth of the euphotic zone was maximum during November–February and minimum during July–October periods. When we consider the productivity data in the context of the information on the size of the euphotic zone it can be seen that the productivity maxima were independent of the euphotic zone in the estuary.

Another interesting factor noticed was the slightly higher productivity rates in the bottom layer than that of the surface water. The situation was reverse only at Kadapuzha where the water was polluted. Nair and Thampi (1980) have explained the reason for the slightly higher productivity in the bottom waters of tropical areas. According to them even though light is a prime necessity for photosynthesis and the rate of photosynthesis varies in proportion to the light intensity, there is a limit at which plants become light-saturated and further increase in illumination produces no further increase of photosynthesis. In bright sunlight, the surface water seem to receive illumination above the saturation level for most of the phytoplankton. In such a situation maximum photosynthetic production occurs beneath the surface layer depending upon light intensity. Such a situation can be attributed to the higher productivity rates in the bottom waters of the Ashtamudi estuary. Venugopalan (1969) reported higher productivity in the bottom waters of the Vellar estuary during February–April 1966 whereas Purushothaman and Bhatnagar (1976) during the same period in 1969 reported lower productivity in the bottom water of the same estuary. In the Cochin estuary also bottom water productivity was less than that of the surface water. According to Qasim *et al* (1969), nearly 90% of the total production is confined to a narrow zone of 0–1.5 m. During February–May (pre-monsoon period) and during June–September (monsoon period) when the turbidity was very high maximum production occurred at the surface, but during October–January (post-monsoon period) when the light penetration was greater maximum production occurred below the surface.

5.1b Other ecological factors: The gross and net primary productivity in the Ashtamudi estuary has been considered in the context of the highly fluctuating physicochemical factors ruled by the monsoon rain and river discharge. Rainfall and

river discharge were the heaviest during July–October followed by November–February.

Correlation analysis was done to find out how the physicochemical factors are related to the gross and net productivity changes in the Ashtamudi estuary and the data are presented in table 5.

The correlation coefficient did not reveal any significant relationship between primary production and either temperature, or salinity or hydrogen-ion-concentration. Pillai *et al* (1975) observed a similar situation in the Vembanad lake where temperature and salinity did not show any significant impact on the productivity of the ecosystem whereas Purushothaman and Bhatnagar (1976) observed a positive correlation of productivity with temperature and salinity. Qasim (1972) stated that the temperature of water is of little direct importance to production in tropical seas whereas salinity has a marked influence on photosynthesis and growth of phytoplankton.

The correlation between dissolved oxygen and the gross productivity in the surface water was remarkable in that productivity increased and decreased along with the fluctuations in the oxygen concentration. The correlation was significant at 5% level at Ashtamudi and at 1% level at Kanjirakode. In the bottom water, although the correlation was remarkable, it was significant at 1% level only at Kanjirakode. The correlation of dissolved oxygen with the net productivity in the surface and bottom waters was also noticeable at the various stations in the estuary, but was not significant. Depletion of dissolved oxygen in the surface and bottom waters caused total failure of primary production at all the stations during September–October. High concentrations of dissolved oxygen always tended to result in higher gross and net productivities. Such was the relationship of oxygen with the gross and net productivities in the Ashtamudi estuary.

Availability of nutrients has been recognised as one of the major factors controlling primary production (Qasim 1972). Data on phosphate, nitrate, nitrite and silicate have been collected to determine the extent of influence of these factors on the gross and net production in the estuary. Phosphate showed a positive correlation with the gross productivity in the surface water at Neendakara whereas the relationship at the other stations was negatively correlated irrespective of the fact that phosphate was always available in the environment. Phosphate in the bottom water also exhibited a negative correlation with the gross productivity in most of the stations. With regard to the net productivity phosphate had a positive correlation only in the surface and bottom water at Neendakara and in the surface water at Kadapuzha.

High concentration of nitrate was observed at Kanjirakode and Kadapuzha, the latter showing the higher values. But the highest values at the four stations did not coincide with the highest production. The correlation with the gross productivity in the surface water was positive only at Kanjirakode and Kadapuzha and in the bottom water only at Ashtamudi and Kanjirakode. The correlation with the net productivity in the surface water was positive only at Kadapuzha and in the bottom water was positive only at Neendakara and Kanjirakode. At all other stations the correlation was negative. However none of the correlations was statistically significant (table 5).

Nitrite depletion was evident at Neendakara, Ashtamudi and Kanjirakode for a short while during March–April but does not seem to have inhibited primary production. The correlation of the gross production with the nitrite distribution was significant at 5% level only at Kadapuzha whereas at the other stations the relationship was negative. The net productivity at Neendakara and Kanjirakode had a positive

Table 5. Correlation coefficient between the environmental parameters and gross and net productivities in the Ashtamudi estuary.

Parameters	Stations												
	Neendakara				Ashtamudi				Kadapuzha				
	GP	NP	GP	NP	GP	NP	GP	NP	GP	NP	GP	NP	
Temperature	SW	0.1039	-0.0074	-0.1977	-0.2622	-0.1150	-0.4137	0.0146	-0.3294				
	BW	-0.0930	-0.1664	-0.2966	-0.1782	0.0352	0.0876	0.0713	0.1497				
pH	SW	-0.1436	-0.1415	0.2167	0.1720	0.1408	-0.0714	0.2492	-0.0901				
	BW	-0.1648	-0.0845	0.0337	0.2479	-0.1111	0.1065	0.2178	0.3685				
Salinity	SW	-0.2490	-0.2368	0.0506	0.1163	0.1554	-0.0695	0.0083	-0.2950				
	BW	-0.0028	-0.0626	-0.1925	-0.0471	0.1197	0.1538	0.2266	0.3224				
Oxygen	SW	0.3661	0.0972	0.4251 ^a	0.3111	0.6724 ^b	0.3455	0.3009	0.3115				
	BW	0.3588	0.2862	0.3389	0.2097	0.5903 ^b	0.4468 ^a	0.0380	-0.0759				
Phosphate	SW	0.0129	0.0262	-0.2981	-0.1449	-0.1998	-0.0254	-0.2515	0.0217				
	BW	-0.1187	0.1328	0.1728	-0.1189	-0.0175	0.1272	-0.1632	-0.2819				
Nitrate	SW	-0.0215	-0.0181	-0.0082	-0.0632	0.0229	-0.1414	0.2520	0.3699				
	BW	-0.0746	0.2682	0.0499	-0.1008	0.2599	0.2088	-0.1191	-0.2040				
Nitrite	SW	-0.2163	0.0417	-0.2936	-0.0734	-0.2510	0.0628	0.4196 ^a	0.1188				
	BW	0.1180	0.2231	0.0364	0.0429	-0.0518	0.2086	-0.1409	-0.1290				
Silicate	SW	-0.0253	-0.0174	0.1451	0.1002	0.0427	0.3043	0.0703	0.2813				
	BW	0.0175	-0.1626	0.3483	0.2339	-0.1399	0.1188	-0.1595	-0.1114				

^aSignificant at 5% level; ^bSignificant at 1% level

correlation with nitrite in the surface and bottom waters (table 5).

Silicate concentration was noticed in appreciable concentrations at Ashtamudi, Kanjirakode and Kadapuzha stations. Its correlation with the gross productivity in the surface water was positively correlated at all these stations, whereas in the bottom water the correlation was positive only at Neendakara and Ashtamudi. Similarly the correlation with the net productivity in the surface water was positively correlated at Ashtamudi, Kanjirakode and Kadapuzha whereas in the bottom water, the correlation was positive only at Ashtamudi and Kanjirakode.

Qasim *et al* (1969) stated that while there is a close correlation between the cycles of phosphorus and organic production in the Cochin backwaters, the nitrogen cycle is completely unconnected with the productivity rhythm. But according to Pillai *et al* (1975) nitrite did not show any relationship with primary production rates while phosphate distribution showed a negative relationship with the production rate in the same backwater tract. In the present study our data on the gross and net productivities, although exhibited certain positive trends with the environmental factors, generally remained independent with regard to peak productions both in the surface and bottom water. Sankaranarayanan and Qasim (1969) observed no firm basis for believing that the instantaneous concentrations of nutrients on inorganic salts in the estuary provide a significant source of phytoplankton bloom.

The gross and net productivity in the estuary during the present investigation showed interesting correlation in that the surface water at Neendakara showed a correlation coefficient 0.6113, whereas at Ashtamudi it was 0.7635, at Kanjirakode it was 0.6724 and at Kadapuzha it was 0.4263. The correlation was significant at 1% level in the first three stations and at 5% level in the last mentioned station. The correlation in the bottom water was 0.7252 at Ashtamudi, and 0.6512 at Kanjirakode both values significant at 1% level. The correlation pattern observed at Neendakara and Kadapuzha was the same as that observed in the surface water. Such correlations have been observed in the Cochin estuary (Qasim *et al* 1969; Qasim 1970), in the Mandovi-Zuari estuarine system (Dehadrai 1970; Dehadrai and Bhargava 1972b) in the Vellar-Coleron estuaries (Venugopalan 1969; Bhatnagar 1971; Purushothaman and Bhatnagar 1976) and in the mangrove ecosystem at Porto Novo (Krishnamoorthy and Sundararaj 1973).

5.2 Comparison with other estuaries

A scrutiny of the data on primary productivity rates available from the Indian estuaries has shown that the Ashtamudi estuary is one of the extremely productive estuaries in the country with tremendous resilience to face the threat of pollution and sustain a rich fishery composed of prawns, crabs, clams and fishes. The gross productivity in the Ashtamudi estuary ranged from 18.99 to 341.82 mg C/m³/hr in the surface water and from 18.99 to 398.78 mg C/m³/hr in the bottom water, whereas in the Vellar-Coleron estuarine system it varied from 11.77 to 36.99 mg C/m³/hr in the surface and from 21.88 to 58.83 mg C/m³/hr in the bottom water (Venugopalan 1969). The net productivity in the Ashtamudi estuary ranged from 4.80 to 284.85 mg C/m³/hr in the surface and from 31.30 to 225.86 mg C/m³/hr in the bottom water while the range in the Vellar-Coleron system was 6.72 to 25.22 and 18.48 to 47.07 mg C/m³/hr respectively. This shows that the gross and net productivities in the Ashtamudi estuary obtained now are much higher than the productivities in the Vellar-Coleron estuarine

system on the east coast of India. The data provided by Bhatnagar (1971) also justify this conclusion.

For comparison with the Cochin estuary and the Mandovi-Zuari estuaries, the present data have been computed into 14 hr day production following Qasim *et al* (1969). Thus, the gross productivity in the Ashtamudi estuary ranged from 88.68 to 1596.3 mg C/m³/day in the surface and from 88.68 to 1862.3 mg C/m³/day in the bottom waters. In the Mandovi estuary gross productivity range was from 135 to 550 mg C/m³/day and in the Zuari the range was from 150 to 580 mg C/m³/day in the surface waters (Qasim 1979). No value was available for the bottom waters of these estuaries. Similarly the net productivity in the Ashtamudi estuary ranged from 22.41 to 1330.25 mg C/m³/day in the surface water and from 73.10 to 1054.77 mg C/m³/day in the bottom water. The range in the surface water net productivity at Mandovi was from 95 to 274 mg C/m³/day and at Zuari from 60 to 245 mg C/m³/day. These values show that the Goan estuaries are less productive than the Ashtamudi estuary. The values of gross and net productivities in the Cochin estuary, computed for the entire water column, are expressed in mg C/m²/day. According to Qasim *et al* (1969) the gross productivity in the Cochin estuary varied from 311 to 1851 mg C/m²/day and the net productivity from 232 to 1211 mg C/m²/day. According to a more recent record the highest production recorded in the Cochin estuary was 245 mg C/m³/hr (Pillai *et al* 1975). Although the different methods followed in the estimation of productivity places a limitation in comparison it can be reasonably stated that the Cochin estuarine system is slightly less productive than the Ashtamudi estuary. However it must be noted that both these estuaries on the south-west coast of India are highly productive throughout the year and are much more productive than the estuaries on the coast of Goa and on the east coast of India. It is reported that the mangrove swamps on the east coast of India at Pichavaram are extremely productive ecosystems when compared with open estuarine tracts. The average gross and net productivities here stood at 756 and 629 mg C/m³/day respectively (Krishnamoorthy and Sundararaj 1973).

The surface and sub-surface productivity pattern differs widely in the different geographical regions. In the Ashtamudi estuary sub-surface productivity was more than that of the surface layer whereas in the Cochin estuary sub-surface production was less than that of the surface layer (Qasim *et al* 1969). In the Vellar-Coleron estuarine system both the patterns were observed at different times (Venugopalan 1969; Purushothaman and Bhatnagar 1976). Bhargava *et al* (1978) reported that in the Arabian sea also sub-surface productivity was found to be maximum at different regions and at different times. They have attributed this to the chlorophyll maxima and concomitant high rate of photosynthesis at sub-surface levels.

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