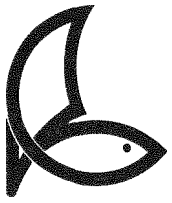
WATER QUALITY MONITORING PROGRAMME in the MURRAY RIVER

DECEMBER 1981 TO AUGUST 1982

R.J. LUKATELICH
A.J. McCOMB



Waterways Commission
Peel Inlet Management Authority
REPORT NO 3
1983

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WATER QUALITY MONITORING PROGRAMME IN THE MURRAY RIVER

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Report to the Waterways Commission

by

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1. Introduction

This report is concerned with aspects of the water quality of the lower reaches of the Murray River, from Ravenswood Bridge downstream to the opening of the river into Peel Inlet (Fig. 1). This 8 km stretch of river (and another 15 km upstream to Pinjarra) is under tidal influence, and like Peel Inlet may in part become hypersaline in late summer. Following the first substantial winter rains in the catchment, the saline water is driven from the Murray, which is then essentially fresh until river flow ebbs and and salt water penetrates once again from the estuarine basin.

As part of the Peel-Harvey estuarine study (Hodgkin et al. 1980), water samples were collected from a site near Ravenswood Bridge, and used to estimate nutrient input to the estuary; for that purpose most sampling had been carried out during the winter months, when the rivers were flowing. However, from this and other work it was clear that the water of the Murray was generally poor, and occasional fish kills have been reported in late summer or early autumn, indicating a deterioration in quality during the summer months, when there is little river flow.

The present study was designed to provide more detailed information about water quality and physical structure, which would aid in management decisions concerning the river, provide information for designing more intensive work on fish kills, and allow comparisons to be made with the earlier data collected during the Peel-Harvey study.

In addition to studying the main channel of the river, attention was also given to a small canal estate which opens on to the river (Fig. 1), so as to compare the water in the canal with that in the main river channel.

Water quality in this estuarine section of the Murray River is dominated by five processes: river flow; density-driven exchange of water between the river channel and estuarine basin (Peel Inlet); tidal exchange; exchange of nutrients with the sediments; and vertical mixing.

Significant flow along the lower river only occurs when the flow at the gauging station upstream (Baden Powell Water Spout) exceeds 10,000 m3 day-1 (Black and Rosher 1980), but during this study there was a significant flood event in late January which for our purposes provided an interesting perturbation of conditions in the river.

The flow data for this period are not yet available from the Public Works Department, but flow events are indicated by changes in salinity in the data prescribed here.

Exchange with Peel Inlet (which in turn communicates with the ocean through the narrow inlet channel at Mandurah) is, at periods of no river flow, dominated by differences in water density between the river channel and the estuarine basin. Evaporation from the estuarine basin raises the salinity there, and would lead to the transfer of saline water upriver, where the surface is relatively protected from wind by the banks, partly shaded, and has a much lower surface to volume ratio than the basin. Localised wind-mixing of surface and bottom (more saline) water (for example at an exposed river bend, or in the estuarine basin), would also lead to differences in water density profiles at different places, resulting in the re-distribution of water upstream or downstream.

Water level fluctuations in the estuary, dominated by barometric effects but with a small astronomic tidal component (e.g. Black et al. 1982), will lead to the penetration or recession of saline waters in the lower levels of the river.

When the river is not flowing, vertical mixing is controlled primarily by the interplay between salinity structure - more dense saline water tending to form a stable layer at the bottom of the water column - and wind-induced vertical mixing. Because light penetration into the river water is poor (see below), water at depth might be expected to become oxygen depleted in the absence of photosynthesis and vertical mixing, and show nutrient release from sediments. Such conditions might provide possible reasons for fish deaths - oxygen depletion or ammonia toxicity - and might lead to enhanced phytoplankton growth if subsequent mixing were to bring nutrient-rich water into the photic (light) zone.

2. Sampling Programme and Funding Arrangements

The sites (Fig. 1) were visited after regular monitoring trips in Harvey Estuary and Peel Inlet, and were generally collected between 1200 and 1500 hours. Methods of sampling and analytical techniques are as for the Peel-Harvey project (Hodgkin et al. 1981, and references given in that report).

Sampling proceeded from 29.12.81 to 3.8.82. It was carried out in a boat belonging to the Department of Conservation and Environment, manned by staff from the Waterways Commission and the Centre for Water Research, University of Western Australia (UWA). Analyses were carried out in the University laboratories. Partial funding was provided by Sunland Pty Ltd., an organization with interests in developing a canal estate in the region. This funding was provided through the Waterways Commission until 30.3.82, and subsequently from a grant which Sunland had provided to the Centre for Water Research (UWA). This latter grant was primarily to fund a detailed study into stratification and mixing in the river, carried out as part of a senior student project by N. Dadamo, under the supervision of Professor J Imberger, Department of Civil

Engineering. There is an ongoing programme of integration between the results reported here and those of Mr Dadamo.

3. Results

The data are presented in Appendix A, arranged as time series plots relating to each site. While the complete series is placed on record, much of the following discussion is relevant to all sites. For convenience, the reader is referred to site 4 (i.e. Figs. 4.1 to 4.10), which exemplify the trends in the data. Data for the other sites are discussed more briefly. A complete data listing has also been provided to the Waterways Commission, and is computer listed at the Centre for Water Research.

The mean depth of each site is given in Table 1.

3.1 Salinity

The river is generally stratified with respect to salinity (e.g. Fig. 4.1), destratification occurring at times of peak river flow, when all water previously contained by the river channel was flushed into the estuarine basin. This occurred in late January when, as a result of unseasonal summer rain, there was a significant flood event, and again in the more normal winter flow of early August. There were occasional mixing events at other times, and at specific sites. For example at station 1 (Fig. 1.1), which is a shallow site, there was complete mixing on 13.4.82. This is attributed to wind stirring, as it was not obvious at the other sites. Attention might also be given to the wind-induced mixing event on 5.1.82, which can be seen in the profiles at all sites. At some sites the mixing was not complete, but there was a significant change in salinities. This mixing event will be commented on in relation to the other parameters below. The river was most markedly stratified at site 4, which is the most removed from the estuarine basin.

Salinities at all sites ranged from a freshwater minimum (1 °/oo) to about that of marine water (35 °/oo), and slightly in excess of marine water at station 2.

3.2 Temperature

This ranged seasonally from 28 °C in summer down to 13 °C, minor perturbations being due to changes in air temperature, wind speed and radiaton. There was some temperature stratification, which was most marked at site 4, a deep site (Table 1) and the most upstream. This temperature stratification is seen because of the stabilization of the water column brought about by the marked differences in salinity with depth. Nevertheless, at a given salinity, temperature diferences will lead to water movement through changes in density.

3.3 Oxygen

Both absolute values (e.g. Fig. 4.3) and percent saturation (Fig. 4.4) are presented, and as both show essentially the same trends, attention is directed to percent saturation. At 100% saturation, oxygen content of the water is saturated with respect to air, at the particular temperature and salinity of the readings. At sites 1 and 3 (Figs. 1.4 and 3.4), the shallowest sites, percent saturation was rarely below 30%, but at sites 2 and 4, which are deeper, they were much lower. For example at station 4, from March until the period of river flow oxygen saturation in the bottom waters was from 10% down to 0%. This is consistent with the marked salinity stratification at these sites. Oxygen saturation at station 2 was only occasionally below 30%, and being more exposed and less stratified was probably more wind-mixed over the period April-July than was station 4.

As with salinity, destratification is due to river flow and wind-mixing. For example in Fig. 2.4, destratification due to wind-mixing raised the bottom oxygen level to 80% saturation on 5.1.82. The late January river flow also brought oxygen-rich water to the site. There was another presumed wind-mixing event in March, and in July there was an increase in bottom oxygen levels due to winter river flow. Similar mixing events can be seen at the other sites, the shallower sites appearing more erratic because they are more frequently wind-mixed.

3.4 Nutrients

Nutrient levels were clearly related to river flow and deoxygenation. All sites had a similar mean phosphate level at the surface for the whole period of the study, the main differences being in the bottom waters and due to water depth and its relation to stratification and sediment exchange. Phosphate levels were highest in the bottom waters at sites 2 and 4 (Figs. 2.5 and 4.5), as these sites were the most stratified. The phosphate level was much higher in the bottom waters of station 4 than in any other site. There was a marked reduction in phosphate in early May, which coincided with a slight increase in bottom dissolved oxygen levels and a change in salinity. The mixing event which occurred early in the data series (see above) also led to an equalization of phosphate concentrations in top and bottom waters.

Organic levels were approximately the same at all sites (65 $\mu g\ \ell^{-1}$ at site 4; Fig. 4.6). There was some stratification, but this was not as marked as for phosphate. Phosphate levels generally exceeded those of organic phosphorus at times of river flow, and at some of the sites was then much less than organic levels for a considerable period of time. However at the deeper sites, where phosphate was released from the sediments (see above) phosphate levels exceeded organic phosphorus for most of the non-flow period.

Nitrate levels were similar at all sites (e.g. Fig. 4.7), reaching a maximum of 2500 $\mu g\ \ell^{-1}$ during the unseasonal summer flow in late January. Another peak occurred during the more normal winter flow.

During non-flow periods nitrate was almost undetectable. Nitrate is transported into the area by river flow and is then lost, essentially through biological transformations.

In contrast to nitrate, ammonium levels were not dominated by river flow, and were on the whole relatively low in the surface water. At all sites levels were higher in the bottom water than near the surface. At the commencement of sampling there was a high concentration in the bottom water at site 2 (Fig. 2.8) and this was mixed by the wind-stirring event mentioned earlier. Sediment release during the stagnant period produced high levels of ammonium at site 4, the deepest site (Fig. 4.8). There was a fall in bottom ammonium concentration at the same time as the fall in phosphate mentioned earlier. Sites 1 and 3 generally had the lowest levels of ammonium, again because they are the shallowest sites and most subject to wind-mixing (Figs. 1.8 and 3.8). The high ammonium levels were correlated with low nitrate levels. Lack of oxygen at depth would have inhibited microbiological conversion of ammonium to nitrate. For example, at station 4, although there was a fall in ammonium levels in early May it was not converted to nitrate.

Organic nitrogen levels were essentially similar at all sites, and as with organic phosphorus, there was no strong stratification (e.g. Fig. 4.9). Peak concentrations were generally measured at times of river flow.

3.5 Chlorophyll

All sites had low levels of chlorophyll at times of peak river flow, because of the flushing effect of the river (e.g. Fig. 4.10). During periods of little or no flow, levels were generally around 15 $\mu g\ \ell^{-1}$, but occasional blooms up to 100 $\mu g\ \ell^{-1}$ were recorded. Each site showed a surface bloom in June and July, before peak river flow, but when there had been sufficient flow to bring nitrogen and phosphorus into the surface water. Although present at all sites, the magnitude of the bloom differed at different sites, ranging from 30 to 100 $\mu g\ \ell^{-1}$. It is difficult to be sure whether this surface bloom moved down the river, or was generated at the sampling stations, but as the most upstream site had a level of only 30 $\mu g\ \ell^{-1}$, while the downstream site had 100 $\mu g\ \ell^{-1}$, there must have been substantial growth in the lower reaches of the river.

The mixing event early in the time series (5.1.82), which mixed phosphate and ammonium into the surface waters, led to an increase in chlorophyll levels, which can be seen at sites 2 and 3 in particular (Figs. 2.10 and 3.10). Bottom chlorophyll levels at site 2 rose from 11 to 35 $\mu g\ \ell^{-1}$ in a week as a result of this mixing event.

The river flow in late summer, which brought increased nutrients to the system, appeared to lead to some localised blooms. For example, in Fig. 4.10 there can be seen an increase in chlorophyll 'a' from 3.6 to 22.6 $\mu g\ \ell^{-1}$ over the period 26.1.82 to 16.2.82. However, none of these blooms were sustained for long periods of

time. During periods without river flow, chlorophyll levels rose and fell rather erratically with a time between successive maxima of about 4 weeks.

At some sites there was little significant difference between the chlorophyll in surface and bottom waters. At the shallow site 1 there was a marked increase in phytoplankton in the bottom water in June (Fig. 1.10); there was a change in salinity at that time, suggesting mixing with the surface water. This peak was not observed at other sites. At the deepest sites (e.g. Fig. 4.10), the chlorophyll levels were much lower at depth than at the surface, and this is consistent with the poor light penetration through the water column. Growth rates would be much higher in the surface water than at depth, where there is little light.

3.6 Windslee Canal Sites

There were two sites in the Windslee Canal, one in each arm of the estate (Fig. 1). Rather than work through each variable, attention will be drawn to differences between the variables measured in the canal, as compared to those at site 2, in the river near the entrance to the canal. The data for salinity (Figs. 5.1 and 6.1 cf 2.1) show similar trends, except that destratification of the river in February and August was not accompanied by complete destratification in the canal. The surface salinities were essentially the same, and the surface waters were presumably readily exchanged with the river, while salinities at depth remained considerably higher than at the surface. This may be due to irregularities in the bottom, preventing exchange of bottom water with the river. There was less exchange at site 6 (most removed from the river) than at site 5, which was nearer the entrance to the canal estate. With cessation of river flow, salinities quickly adjusted to be essentially the same as in the river. At other times there were small differences between the canal site and the river. It should also be remembered that the depth of the sites in the canal is approximately 1.5 m, while bottom data for the river were taken at 3 m; more detailed analysis would be required to clarify the exchange behaviour of the canal estate.

Broadly speaking, dissolved oxygen levels moved in sympathy with those in the river, but there are exceptions, and these are related to stratification events (Figs. 5.4, 6.4 and 2.4). For example, in August the river was completely destratified and bottom oxygen levels rose to some 90% saturation. In the canal estate, as noted above, complete destratification did not occur at that time, and oxygen levels remained low at depth.

Phosphate levels during no-flow periods were lower in the canal estate than at depth in the river; thus there was less phosphate release from the sediments in the canal. Organic phosphorus levels were approximately the same as in the river, and similarily rather erratic.

Ammonium levels in the canal estate were generally similar to those in the river, though differences were occasionally noted. There was little ammonium release during the long no-flow period, consistent with the relatively high levels of oxygen in the bottom waters at that time. In February there was a marked decrease of oxygen in the bottom water, and at that time a marked increase in ammonium. Similar trends can be seen in June. Again the data emphasise the role of stratification in controlling oxygen and sediment nutrient release levels. Nitrate levels were essentially the same as in the river, apart from the minor differences due to different rates of destratification, as discussed above. Organic nitrogen levels were again similar to the river, both in mean levels and general trends.

Chlorophyll levels are generally comparable with those in the river (Figs. 2.10 cf 5.10 and 6.10; differences in vertical scales should be noted).

4. Discussion

4.1 A comparison of the river and the estuarine basin.

Table 2 compares the water quality in two stretches of the river with that at a site in Peel Inlet, near the mouth of the Murray (Fig. 1). Results at this site in the Inlet are comparable with those at two other sites in the estuarine basin, which are also regularly sampled (Lukatelich and McComb 1982). The data are for the period 2nd March to 9th June 1982, when the river was not flowing.

The estuarine site is shallow compared with the mean of the river sites, and light penetration, as indicated by the Secchi depth, is better in the estuarine basin than the river. The whole water column, and the sediment surface, are in the photic zone in the basin and therefore capable of supporting plant growth; while in the river the Secchi disc disappears at a metre or so below the surface, water at depth in the river thus not allowing significant photosynthesis.

In salinity, the basin was close to the marine salinity of 35 $^{o}/_{oo}$ and was typically well mixed vertically. In the narrow river, sheltered from wind, stratification was marked. Temperatures were slightly higher in the river than the basin.

Dissolved oxygen levels were high in all the surface waters, and throughout the water column in the basin. However, because of poor light penetration in the river, which precludes photosynthesis at depth, oxygen levels were generally reduced.

Chlorophyll was on average considerably higher in the river than the estuary. (The estuary site did not carry a bloom of Nodularia during the sampling period. Elsewhere in the system, and especially in the Harvey, this organism reaches very high concentrations, which have not, as far as we are aware, extended

into the Murray River or Windslee Canal.)

Phosphate increases markedly in the river, especially at depth, where reduced oxygen levels promote sediment release. Ammonium in surface waters decreases, but in bottom water increases markedly, as one moves upstream. Nitrate falls somewhat. The ratio of nitrogen to phosphorus (calculated by atom, for these inorganic nutrient sources) was 35.9 in the basin, and 5.00 and 5.18 in two stretches of the river. This suggests that nitrogen is in relatively short supply compared to phosphorus in the river - the reverse is true for the basin - and such conditions might at first appear to favour the growth of blue-greens. Nevertheless, it should be mentioned that there is abundant nitrogen in the form of ammonium at depth in the river. The organic forms of nitrogen and phosphorus show similar levels in all samples.

In overview, the water quality of the river, as exemplified by increased phosphate and ammonium levels, oxygen reduction, reduced light penetration, and increased chlorophyll levels, is considerably worse than that of the estuarine basin.

4.2 A comparison of the canal estate and the river

Table 3 compares data for the Windslee Canal with site 2 , which is in the middle of the river near the entrance to the canal. It should be noted that the river is deeper than the canal, and so the bottom water in the river is not exchanging horizontally with the bottom water in the canal. In general, the mean data for river and canal are very comparable, with some differences in the range shown by the measured parameters; these reflect small differences in the time course of events in river and canal, referred to in detail in the Results section. The canal is stratified, as seen for salinity, oxygen, and nutrients; destratification would reduce mean phosphate and nitrate concentration, and increase ammonium. Chlorophyll is very variable with no significant differences in the means.

4.3 Long-term trends

Appendix B shows the available water quality data for site 4 (Ravenswood Bridge) over the entire period of Peel-Harvey monitoring. This shows the generally poor water quality during periods of little or no river flow, when the water in the river is stratified; and periods of high nitrate when the river is flowing. Because of the variability in the data set it is not possible to reach any firm conclusions about whether or not water quality in the river channel has deteriorated significantly during the period of the study.

4.4 Fish kills

As noted in the Introduction, occasional fish kills have been observed in the Murray River in late summer or early autumn, and there was a fish kill reported during the period of the present study. There was a sampling trip four days before, and another ten

days after a reported death of sea mullet (Mugil cephalus) on 3rd April 1982. There was a small phytoplankton bloom preceding the report; mean surface chlorophyll levels were 5 $\mu g\ \ell^{-1}$ on 16.3.82, but had risen to 22 $\mu g\ \ell^{-1}$ on 30.3.82, four days before the event. The species of phytoplankton concerned is not known.

The river showed marked salinity stratification at the time, but this stratification was present for some weeks both before and after the death of the fish. Oxygen levels were very low at depth at Houghman's Bend (site 7) and Ravenswood Bridge (site 4), but had been low for three weeks before the reported fish mortality. Adjoining stations did not have such low levels of oxygen at the time, and surface waters were oxygen-rich at all sites.

Ammonium levels were high (955 $\mu g\ \ell^{-1}$ NH4-N at Ravenswood Bridge) immediately before the fish kill, and there had been marked increases at other sites. For example, at site 7 ammonium had increased from 36 $\mu g\ \ell^{-1}$ on 30.3.82 to 389 $\mu g\ \ell^{-1}$ on 13.4.82. Increases in chlorophyll and ammonium were also observed in the Windslee Canal.

It is not possible to resolve the reasons for the death of fish from the data available, but it does not appear to have been directly related to a marked change in stratification or mixing, nor to the sudden depletion in oxygen levels. A rise in ammonium levels, perhaps accompanied by a shift in pH which would generate ammonia, known to be toxic to fish, remains a possibility, though it should be noted that the surface water had low ammonium concentrations, and a number of the sites did not have particularly high concentrations of ammonium at depth. Another possibility is the occurrence of a bloom of toxin-producing phytoplankton, but although there were increases in the concentrations of chlorphyll in the water before the fish kill, the concentrations reached were not very high. More intensive sampling at an appropriate time, accompanied by experimental work with fish in tanks, would help in analysing more directly the causes of fish mortality.

5. Summary

1. Data for water quality parameters are presented as time series data for 7 sites in the Murray River and 2 in an adjoining artificial canal, for the period 29.12.81 to 3.8.82.

2. The river showed marked salinity stratification except during periods of substantial flow.

3. Light penetration was poor, with a Secchi depth of about 1.0-1.5 metres in a water body 2-6 m deep.

4. During periods of low flow, unmixed water below the halocline shows reduced oxygen levels and high levels of phosphate and ammonium ions.

5. Phytoplankton blooms occurred in the surface waters, up to 100 $\mu g\ \ell^{-1}$ chlorophyll 'a'. Enhanced levels occurred after mixing and river flow, and at intervals of some four weeks at other times.

6. Average nutrient, chlorophyll and salinity levels were similar in the artificial canal as compared with the river channel, with small differences in detail in the time series plots.

7. Water quality was worse in the river than Peel Inlet during the period when the river was not flowing, as shown by decreased light penetration, increased surface chlorophyll, decreased oxygen at depth, and increased phosphate and ammonia.

8. Plots are also presented for the period 30.9.77 to 3.8.82, for the site near Ravenswood Bridge. The data do not allow conclusions to be drawn about long-term trends in water quality in the river.

9. Death of fish was reported in the river on one occasion, during a prolonged period of stratification, characterised by low oxygen levels in bottom waters; there was no marked change in oxygen or salinity structure at the time of the reported fish deaths. Ammonium and chlorophyll levels had risen before the event.

6. References

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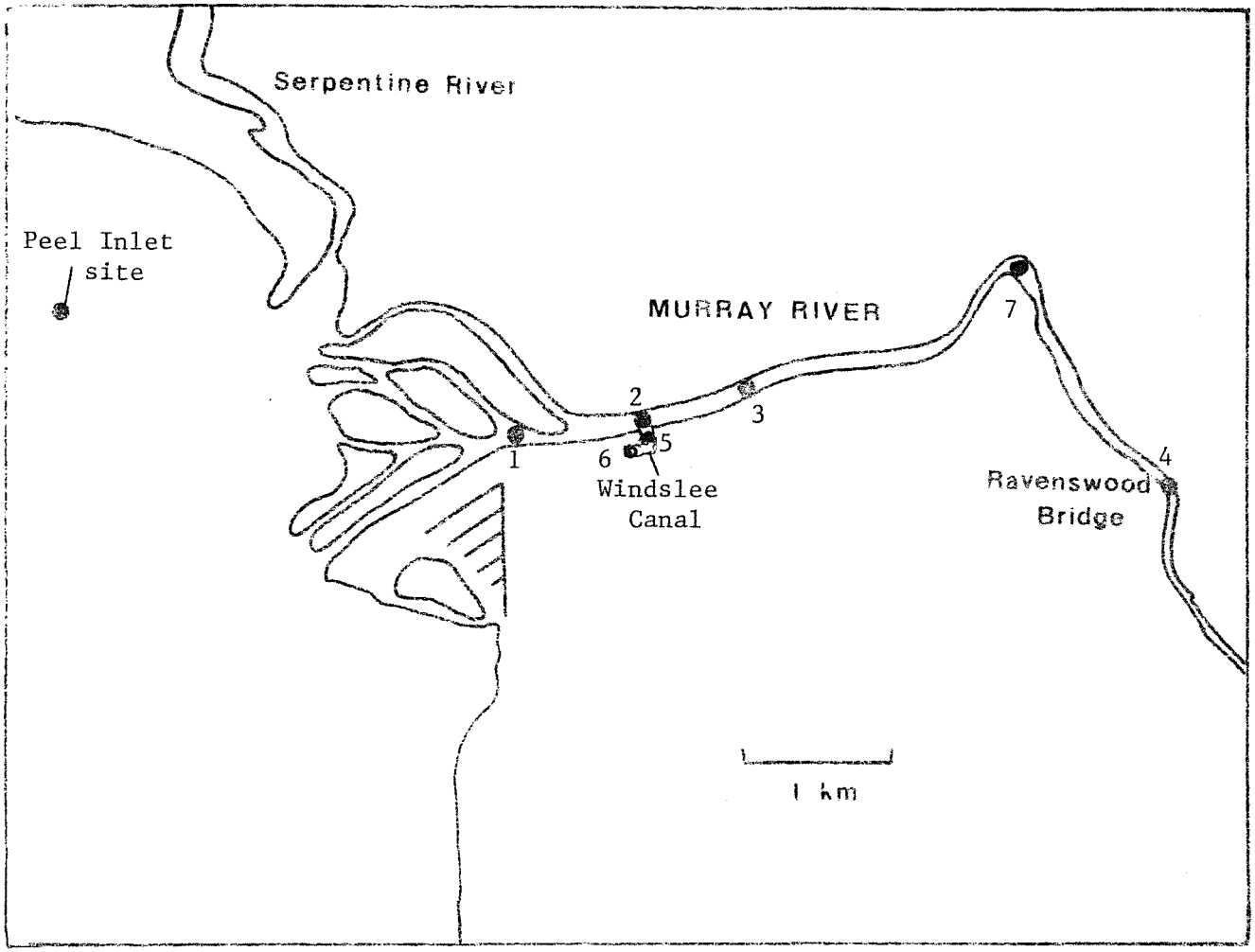

Fig. 1. Sampling sites.

Table 1. Water depths at the sites as measured during the sampling programme.

Site	Mean depth (m)
1	2.2
2	3.3
3	2.1
4	4.5
5	1.9
6	2.1
7	6.4

Table 2. A comparison of the Murray River with Peel Inlet.

Data are for the period 2.3.82 to 8.6.82, when the river was not flowing, and are means, with ranges in brackets. The sites are shown in Fig. 1. The river data are averaged for the three sites closest to the estuary, and the remaining two further upstream.

		Peel Inlet (Station 4)	Murray River Sites 1, 2 and 3	Murray River Sites 4 and 7
Depth (m)		2.0 (1.8 - 2.2)	2.5 (2.0 - 3.0)	5.1 (4.5 - 5.8)
Secchi disc depth (m)		>2.0	1.4 (1.0 - 1.5)	1.2 (0.9 - 1.4)
Salinity °/oo	S	34.1 (30.5 - 35.9)	18.6 (13.3 - 24.0)	11.1 (6.3 - 16.3)
	B	35.1 (32.0 - 36.1)	31.1 (26.1 - 34.1)	29.9 (24.8 - 32.9)
Temperature (°C)	S	18.9 (15.0 - 23.0)	20.4 (15.7 - 24.4)	21.0 (15.5 - 25.3)
	B	18.9 (15.0 - 22.7)	19.8 (14.9 - 25.8)	23.8 (17.9 - 27.6)
Chlorophyll ($\mu g\ \ell^{-1}$)	S	1.8 (0.5 - 4.3)	9.2 (4.7 - 17.9)	14.6 (4.3 - 48.9)
	B	2.3 (0.4 - 7.5)	9.6 (2.4 - 20.0)	4.9 (2.4 - 8.6)
Dissolved Oxygen (%)	S	111.4 (72.7 - 131.6)	116.7 (75.4 - 149.8)	116.4 (65.7 - 144.3)
	B	108.5 (66.9 - 162.1)	71.3 (41.3 - 85.0)	19.6 (5.9 - 46.2)
PO_4-P ($\mu g\ \ell^{-1}$)	S	3.2 (1.0 - 7.0)	12.4 (5.7 - 32.7)	8.8 (5.0 - 16.0)
	B	3.5 (1.0 - 9.0)	10.9 (6.7 - 20.0)	52.9 (9.0 - 117.0)
Organic-P ($\mu g\ \ell^{-1}$)	S	56.0 (32.0 - 72.0)	58.2 (25.0 - 89.3)	56.5 (34.5 - 72.5)
	B	53.0 (33.0 - 65.0)	68.5 (43.0 - 90.3)	62.6 (49.5 - 85.5)
NH_4-N ($\mu g\ \ell^{-1}$)	S	40.0 (7.0 - 72.0)	22.7 (8.3 - 86.7)	15.1 (9.0 - 19.5)
	B	42.2 (12.0 - 85.0)	66.4 (14.0 - 129.7)	280.0 (100.0 - 554.0)
NO_3+NO_2-N ($\mu g\ \ell^{-1}$)	S	10.2 (5.0 - 8.0)	5.3 (3.0 - 11.0)	5.2 (3.5 - 8.5)
	B	14.5 (5.0 - 38.0)	10.3 (2.7 - 17.7)	5.3 (2.5 - 9.0)
Organic-N ($\mu g\ \ell^{-1}$)	S	755 (353 - 1036)	865 (610 - 1032)	777 (560 - 966)
	B	739 (335 - 1116)	850 (568 - 1057)	800 (656 - 968)

Table 3. A comparison of water quality in the canal with a site in the river.

Data are for the entire sampling period (29.12.81-3.8.82), and are means with ranges in brackets. Sites are shown in Fig. 1.

		Murray River Site 2	Windslee Canal Sites 5 and 6
Depth (m)		3.3 (2.8 - 5.0)	2.0 (1.6 - 2.8)
Secchi disc depth (m)		1.20 (0.25 - 1.65)	1.00 (0.35 - 1.55)
Salinity (^{o}/oo)	S B	12.5 (1.2 - 24.4) 25.9 (1.2 - 37.4)	12.6 (1.4 - 26.5) 25.9 (14.2 - 33.5)
Temperature ^{o}C	S B	20.8 (11.8 - 28.1) 20.9 (12.1 - 26.9)	20.8 (11.8 - 28.4) 22.3 (14.9 - 28.3)
Chlorophyll ($\mu g\ \ell^{-1}$)	S B	11.5 (0.4 - 98.6) 6.9 (0.1 - 34.7)	8.5 (0.1 - 24.2) 9.7 (0.1 - 25.1)
Dissolved Oxygen (%)	S B	105.3 (64.0 - 158.0) 61.5 (8.7 - 86.8)	101.2 (61.3 - 144.9) 55.3 (8.1 - 104.7)
PO_4-P ($\mu g\ \ell^{-1}$)	S B	29.1 (6.0 - 121.0) 45.8 (4.0 - 231.0)	22.9 (5.0 - 103.0) 14.1 (5.0 - 63.0)
Organic-P ($\mu g\ \ell^{-1}$)	S B	63.1 (22.0 - 205.0) 78.2 (33.0 - 143.0)	58.5 (20.5 - 97.5) 74.6 (35.0 - 136.0)
NH_4-N ($\mu g\ \ell^{-1}$)	S B	74.4 (6.0 - 368.0) 187.0 (8.0 - 1227.0)	73.5 (9.5 - 337.0) 180.8 (9.0 - 745.0)
NO_3+NO_2-N ($\mu g\ \ell^{-1}$)	S B	251.1 (2.0 - 2425.0) 225.9 (2.0 - 2375.0)	270.0 (1.0 - 2300.0) 174.9 (2.5 - 1550.0)
Organic-N ($\mu g\ \ell^{-1}$)	S B	1151 (419 - 2429) 1289 (538 - 2624)	1206 (711 - 2558) 1297 (687 - 2679)

Appendix A. Time series plots of data for the period 29.12.81 to 3.8.82, for 7 sites in the Murray River. The figures are arranged with the first digit indicating the site number as shown in Fig. 1, and the second indicating the parameters, in the order given in the text. Thus for site 1 the figures are:

1.1 salinity

1.2 temperature

1.3 oxygen (absolute values)

1.4 oxygen (percentage saturation)

1.5 phosphate

1.6 organic phosphorus

1.7 nitrate

1.8 ammonium

1.9 organic nitrogen

1.10 chlorophyll.

For site 2, the corresponding figures are 2.1 to 2.10, and so on. In each case the broken line is for surface water (0.1 m), the solid line about 0.1 m above the bottom.

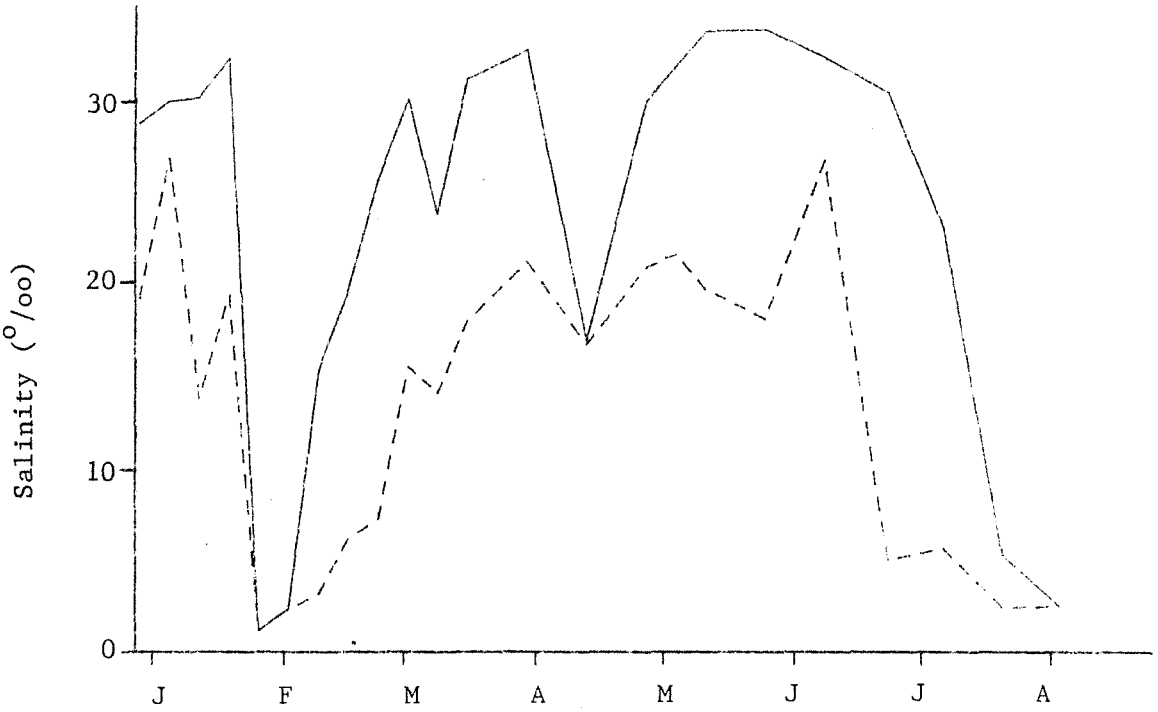

Fig. 1.1 Salinity

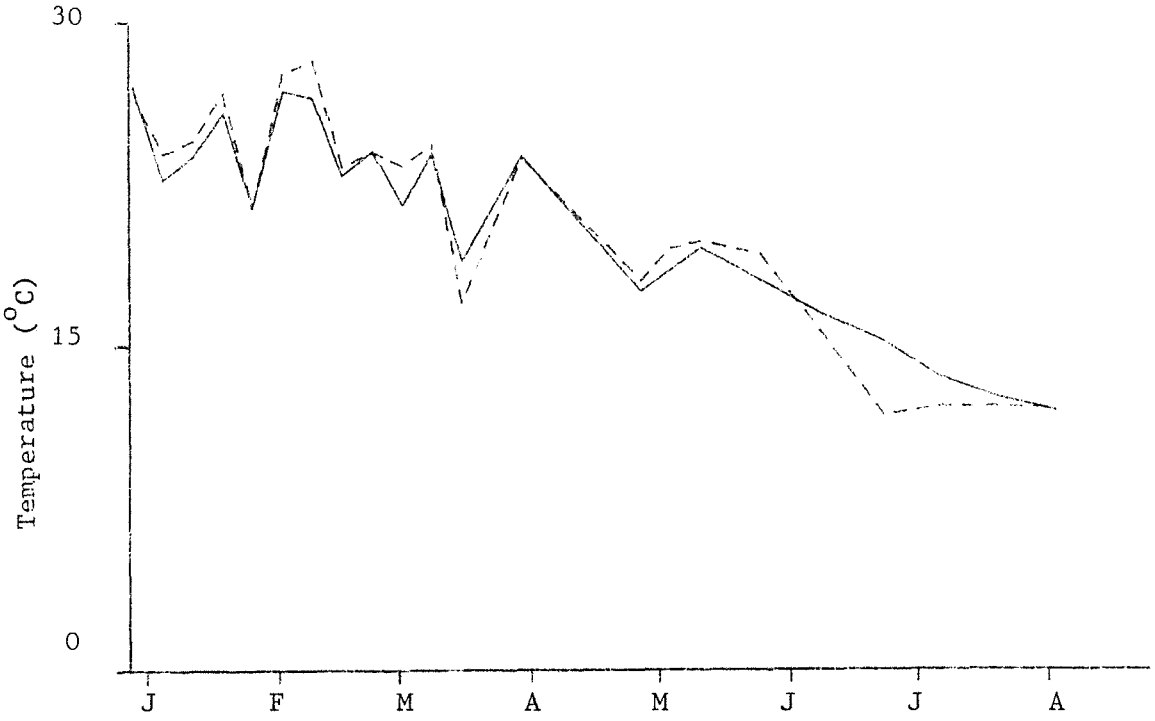

Fig. 1.2 Temperature

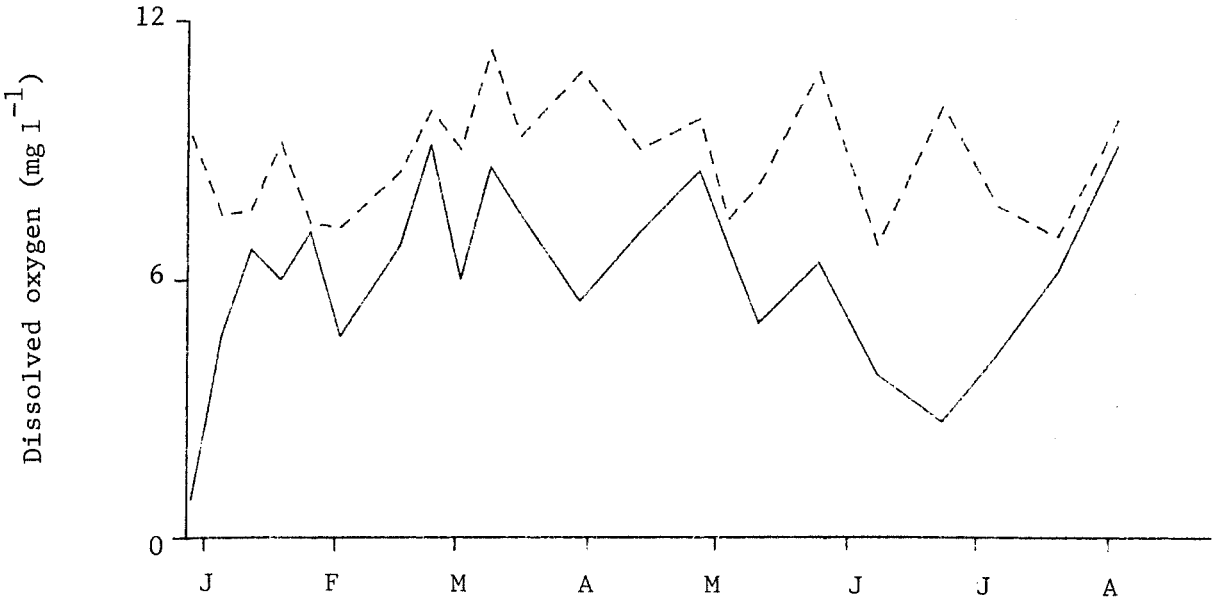

Fig. 1.3 Dissolved oxygen

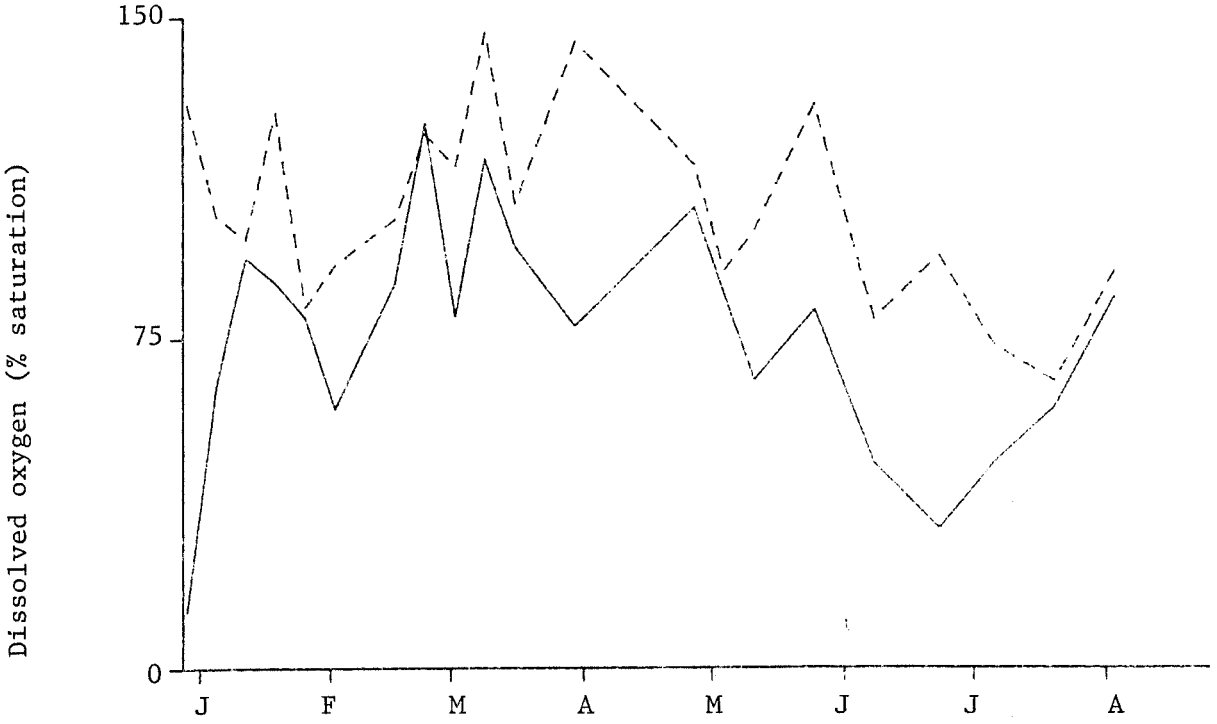

Fig. 1.4 Dissolved oxygen

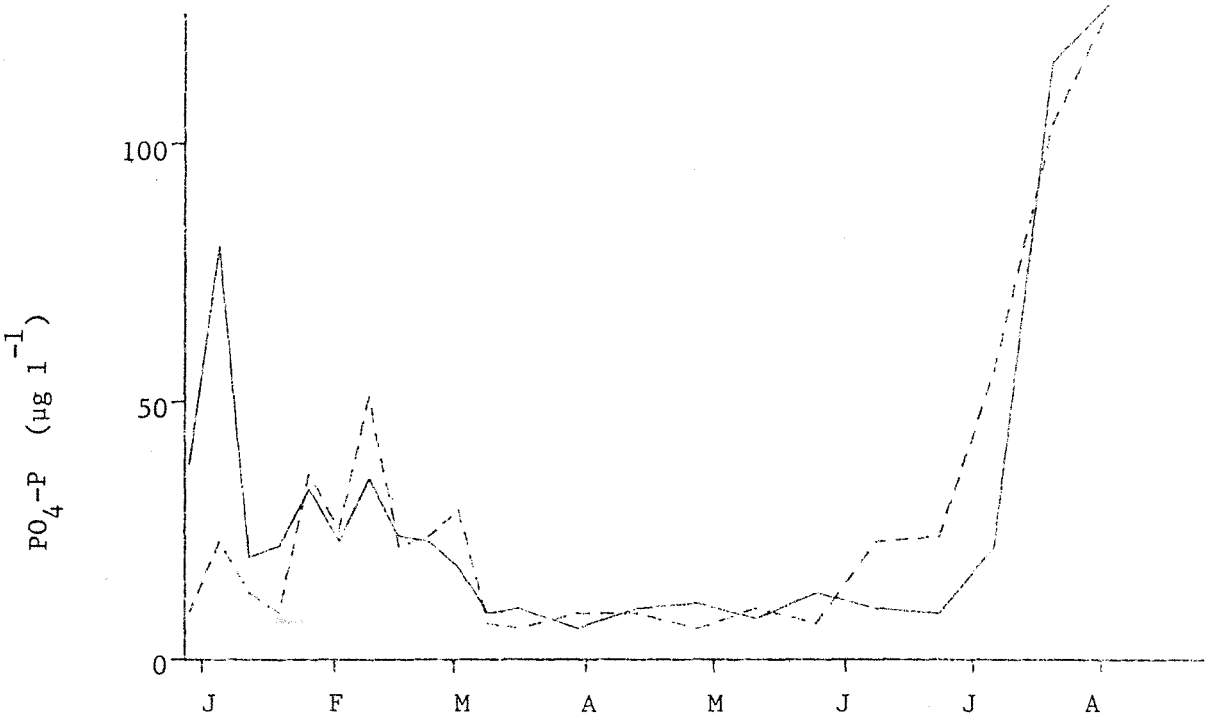

Fig. 1,5 Phosphate phosphorus

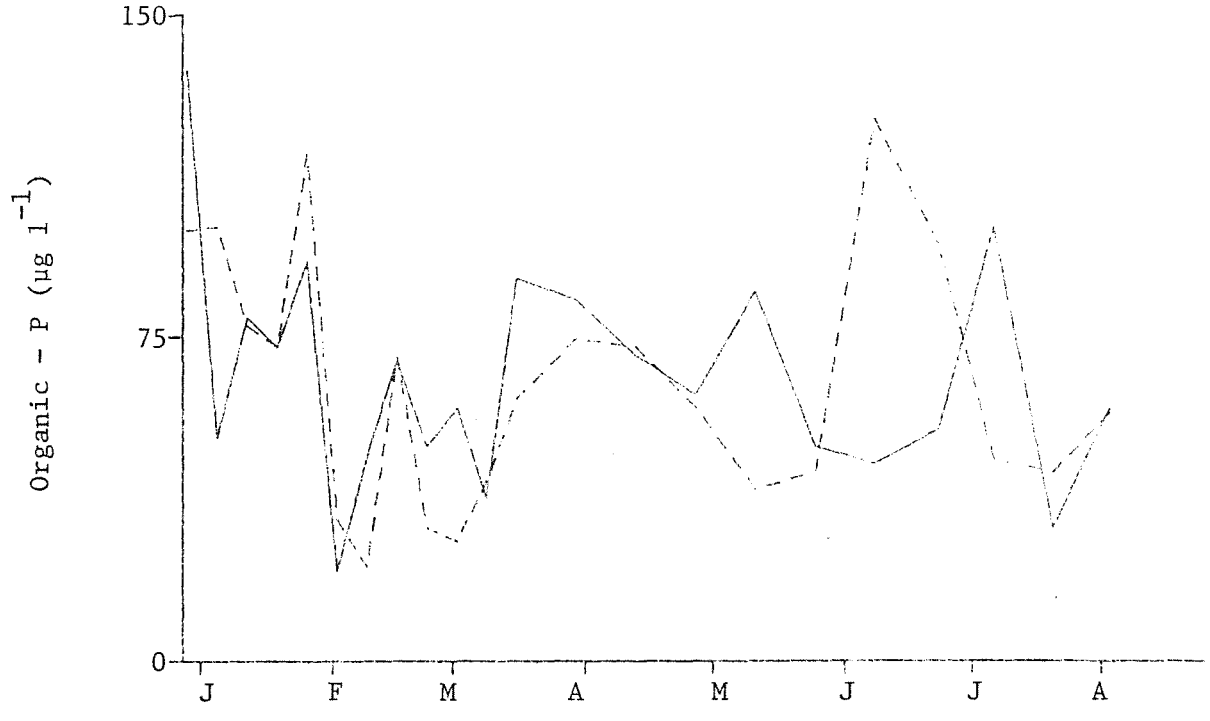

Fig. 1.6 Organic phosphorus

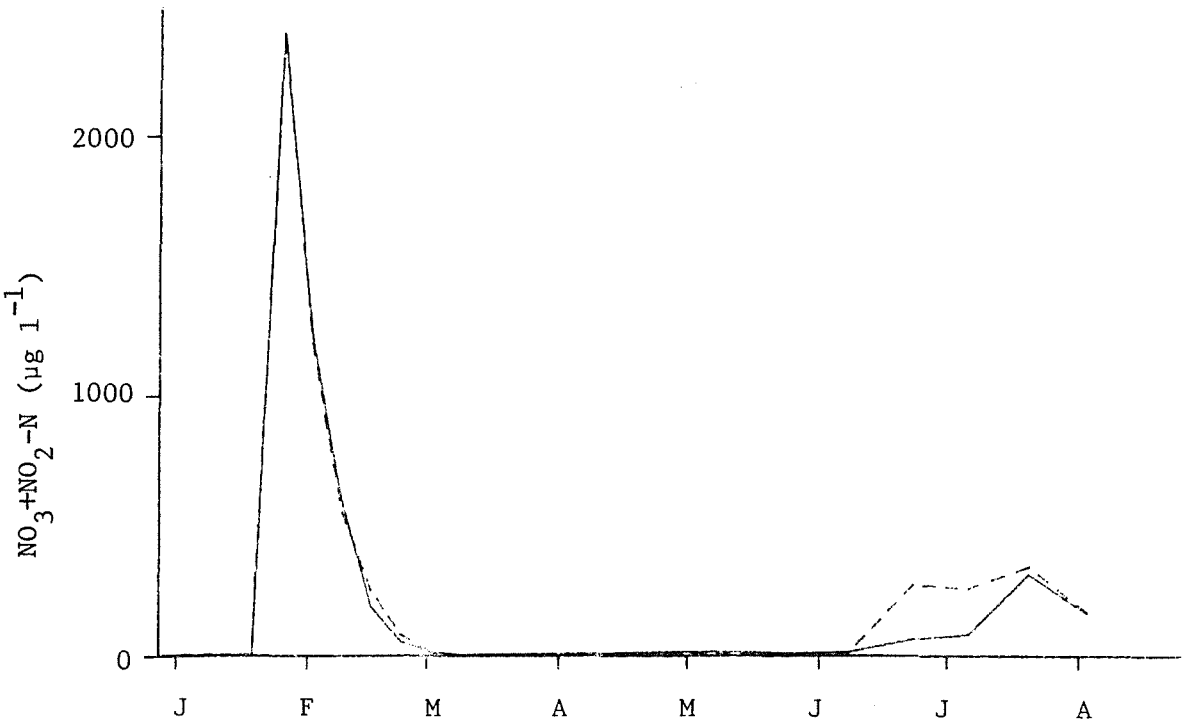

Fig. 1.7 Nitrate-nitrite nitrogen

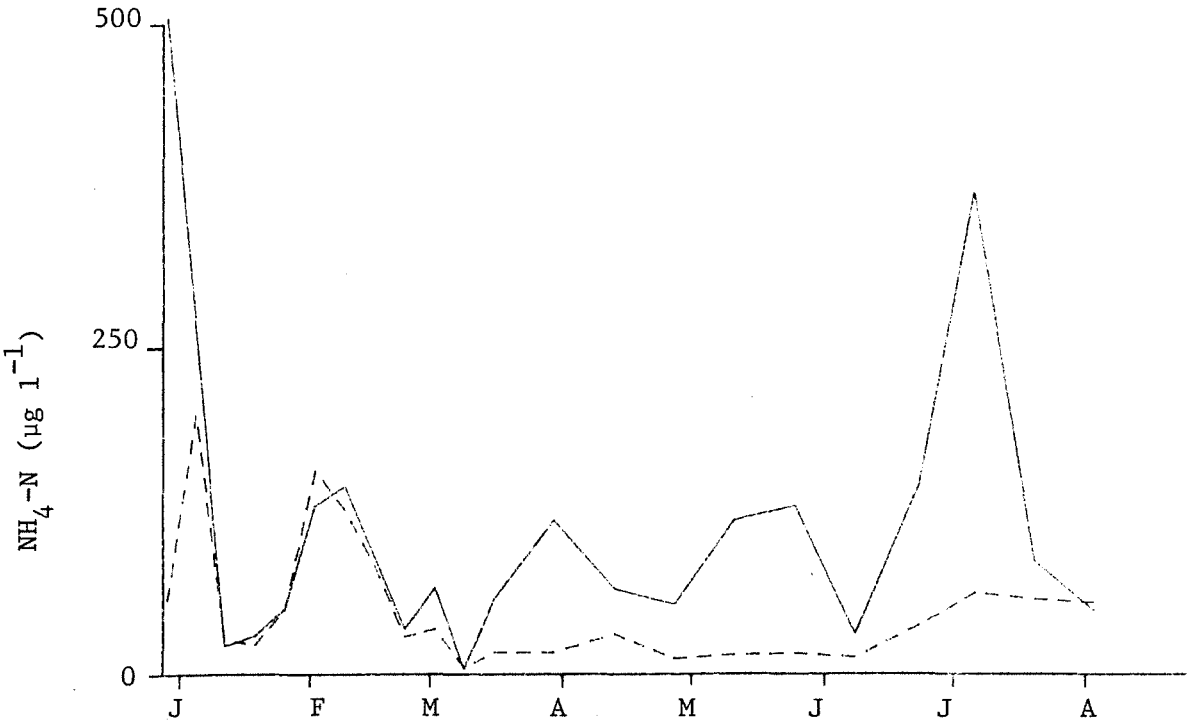

Fig. 1.8 Ammonium nitrogen

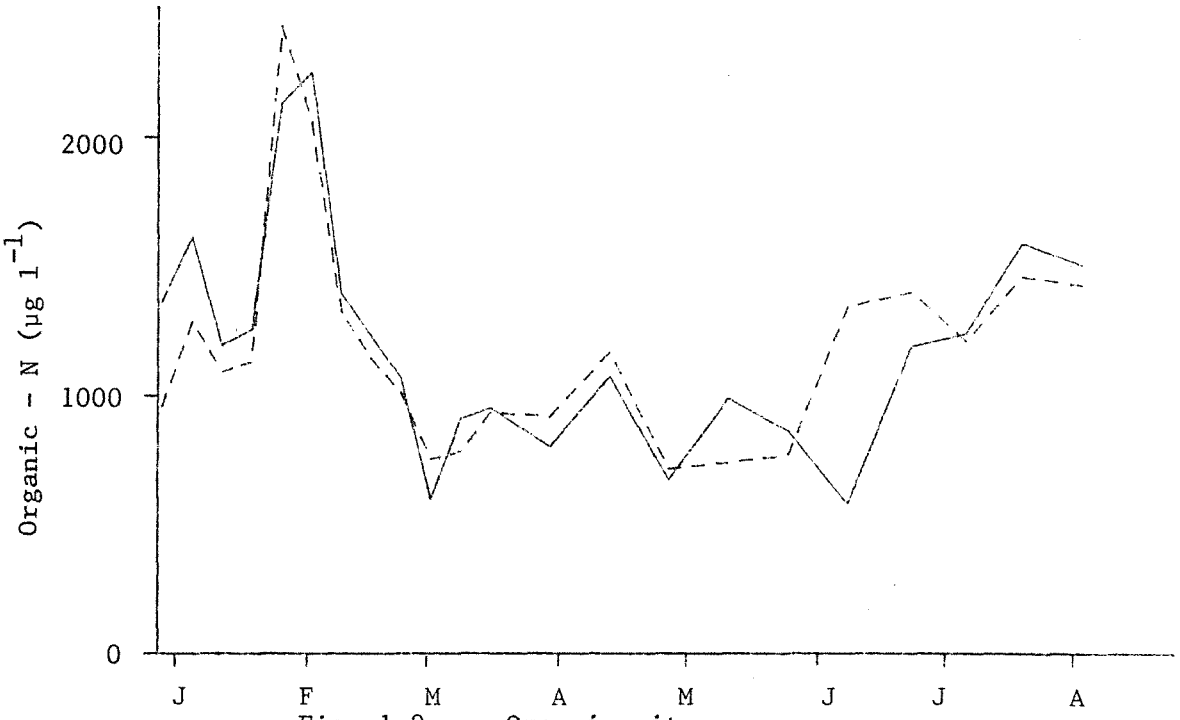

Fig. 1.9 Organic nitrogen

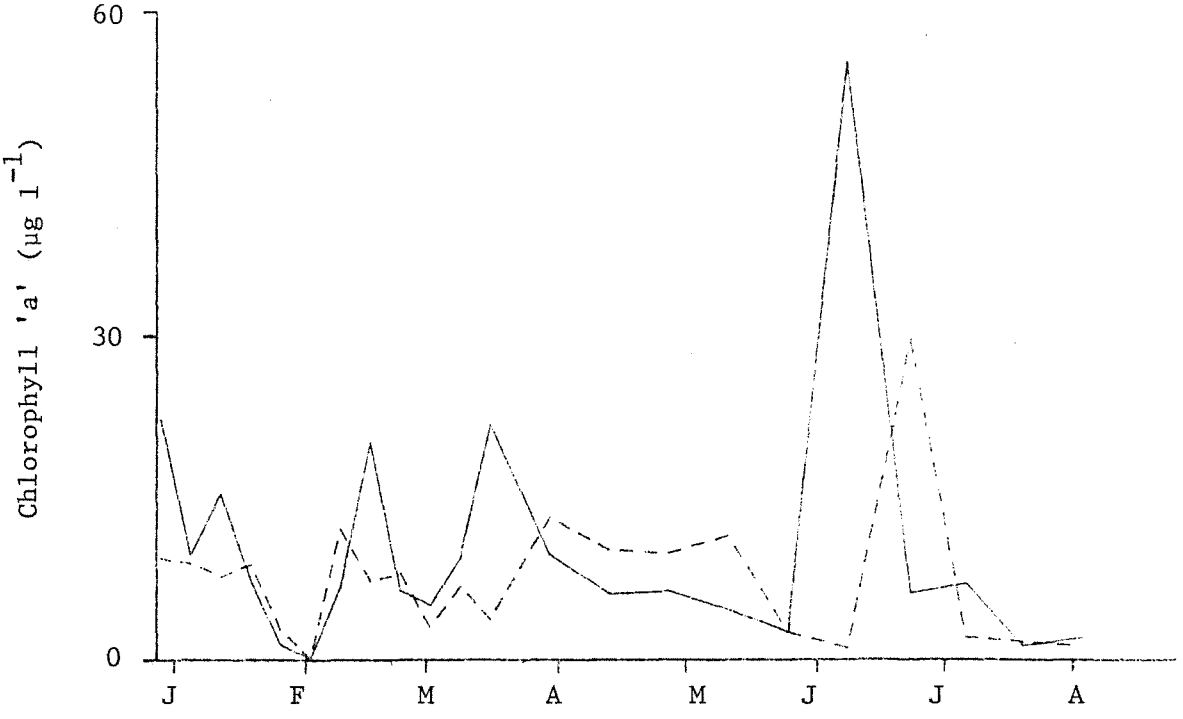

Fig 1.10 Chlorophyll 'a'

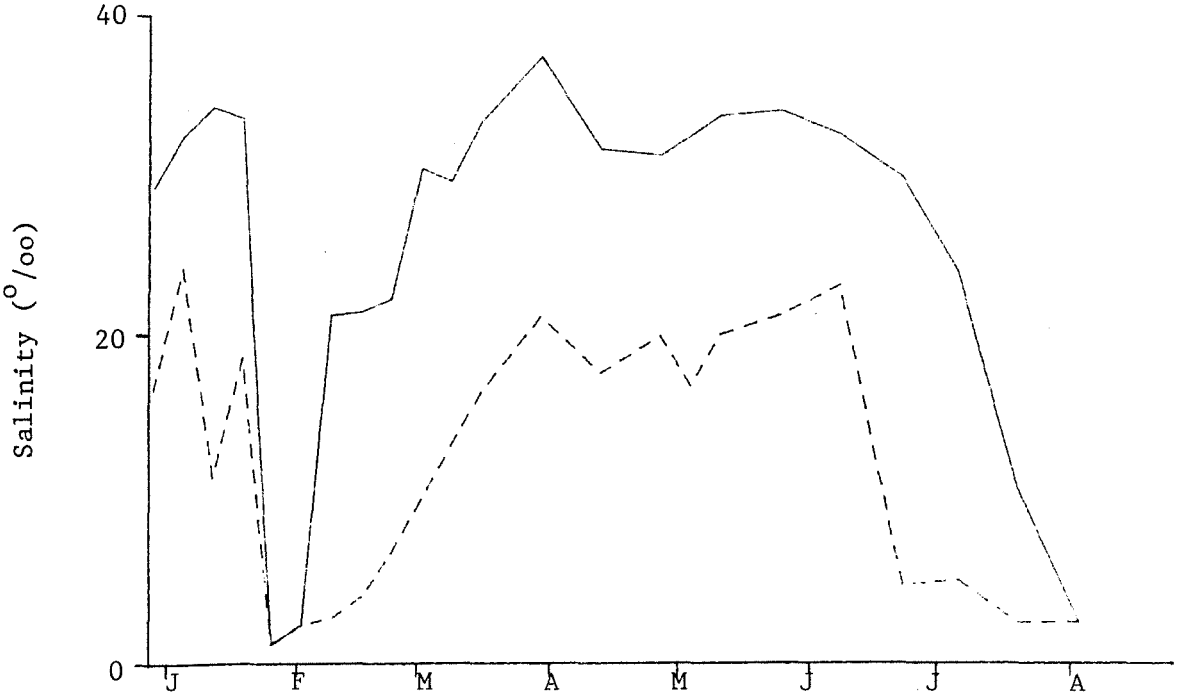

Fig. 2.1 Salinity

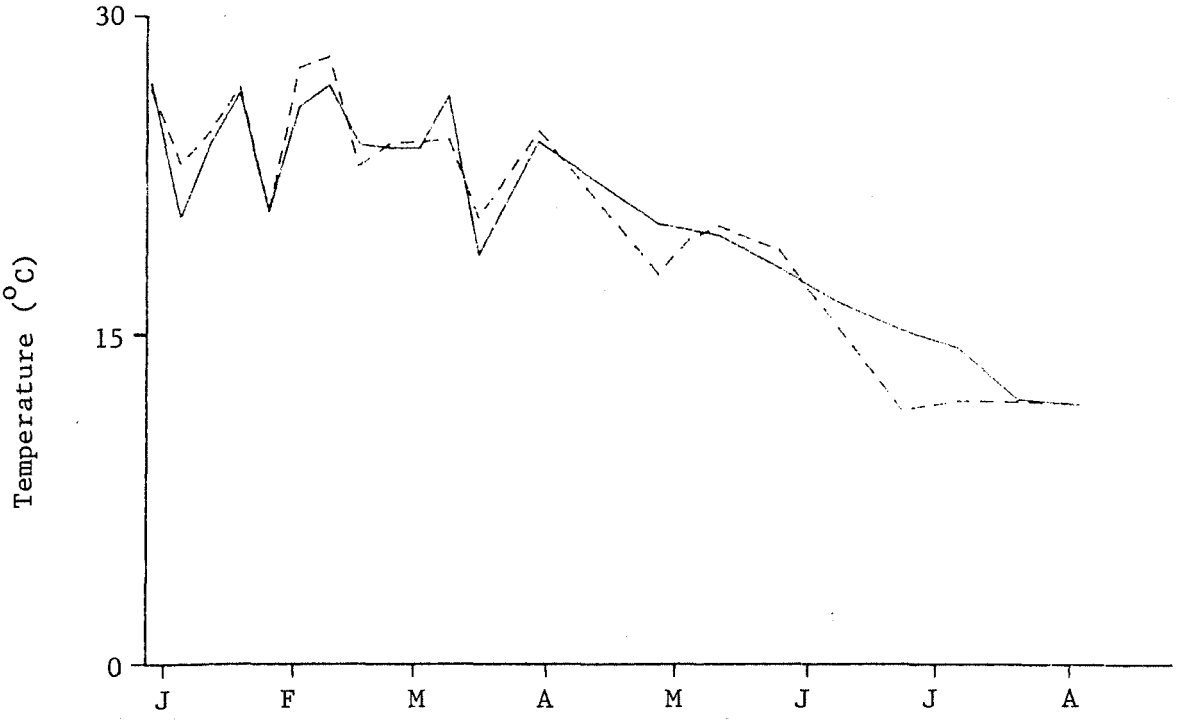

Fig. 2.2 Temperature

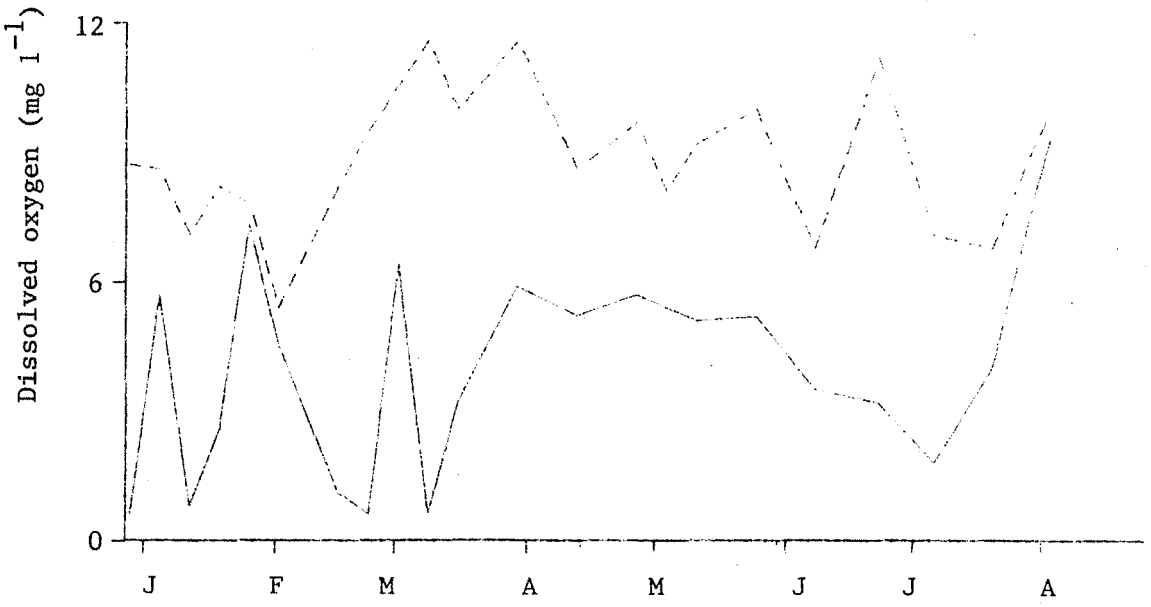

Fig. 2.3 Dissolved oxygen

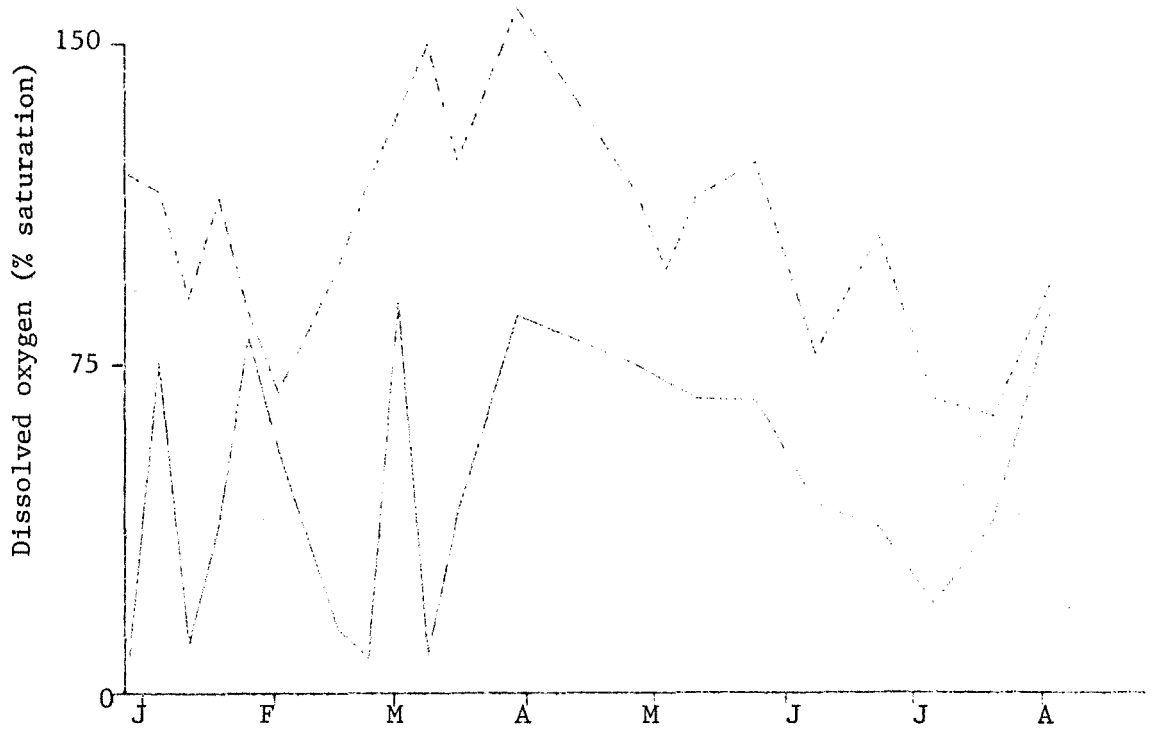

Fig. 2.4 Dissolved oxygen

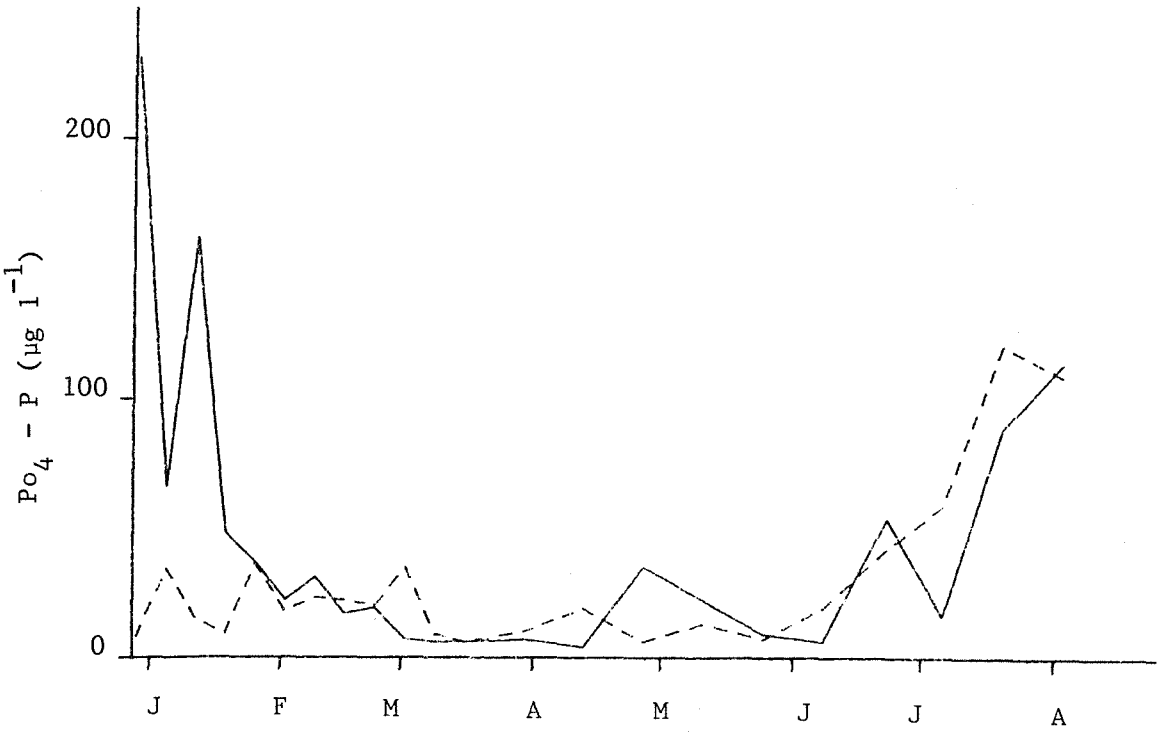

Fig. 2.5 Phosphate phosphorus

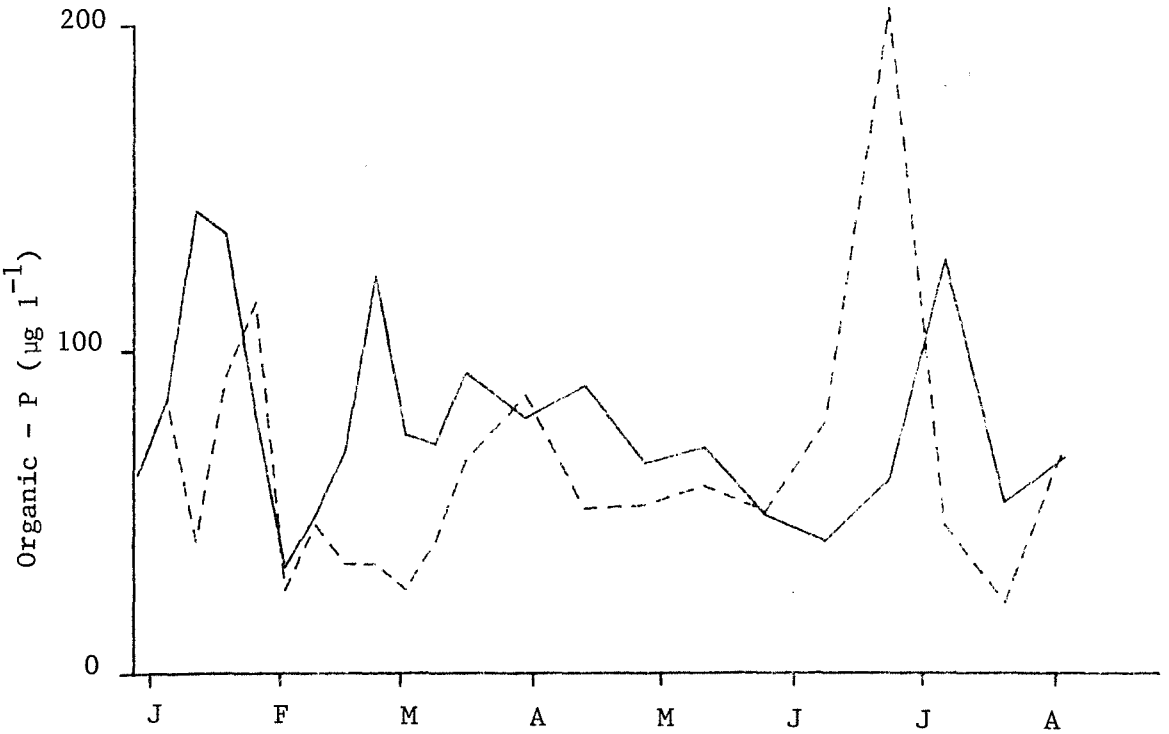

Fig. 2.6 Organic phosphorus

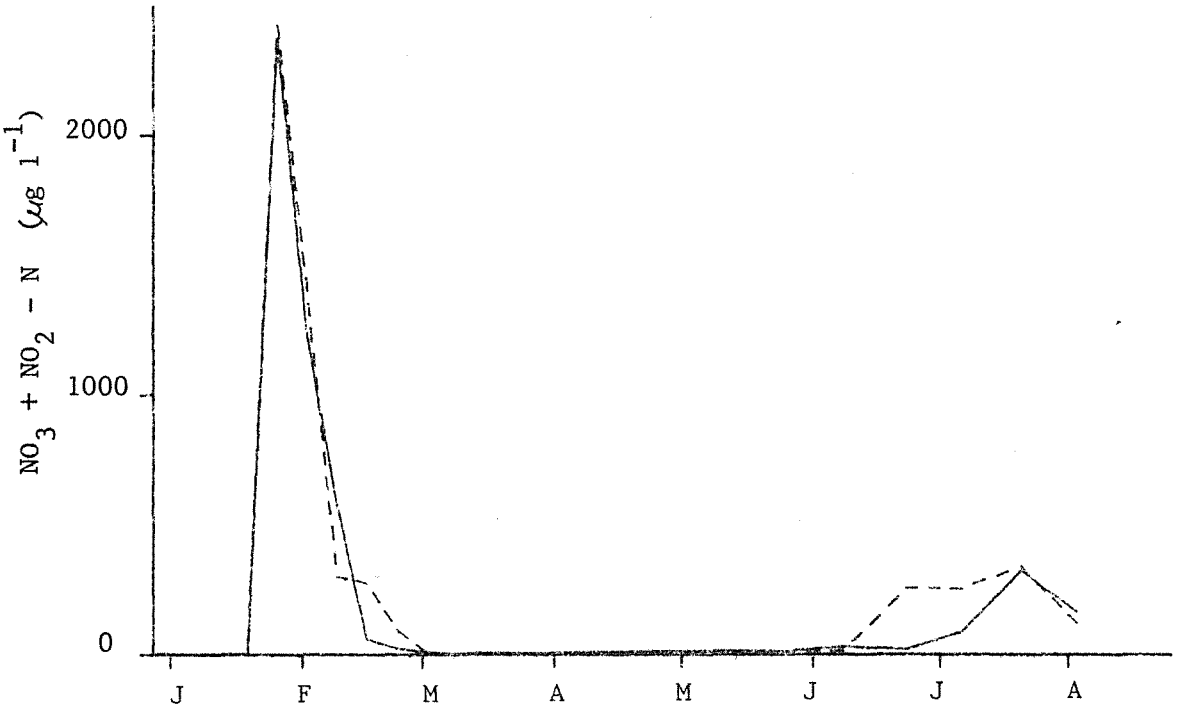

Fig. 2.7 Nitrate-nitrite nitrogen

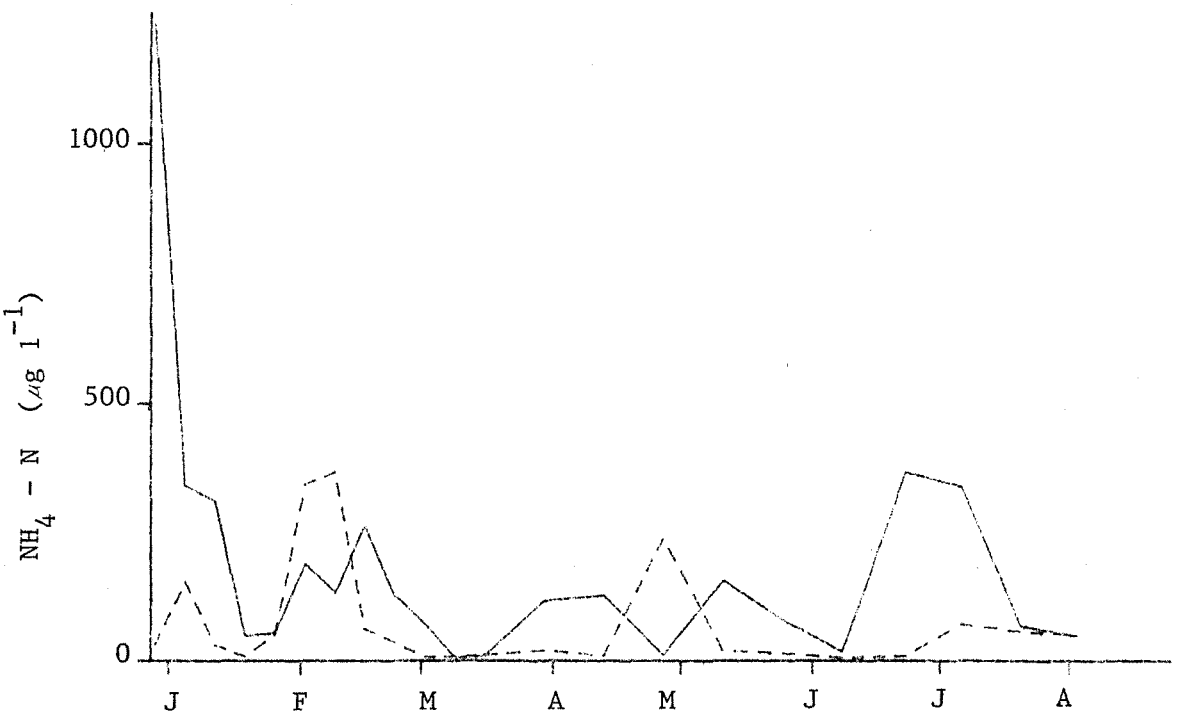

Fig. 2.8 Ammonium nitrogen

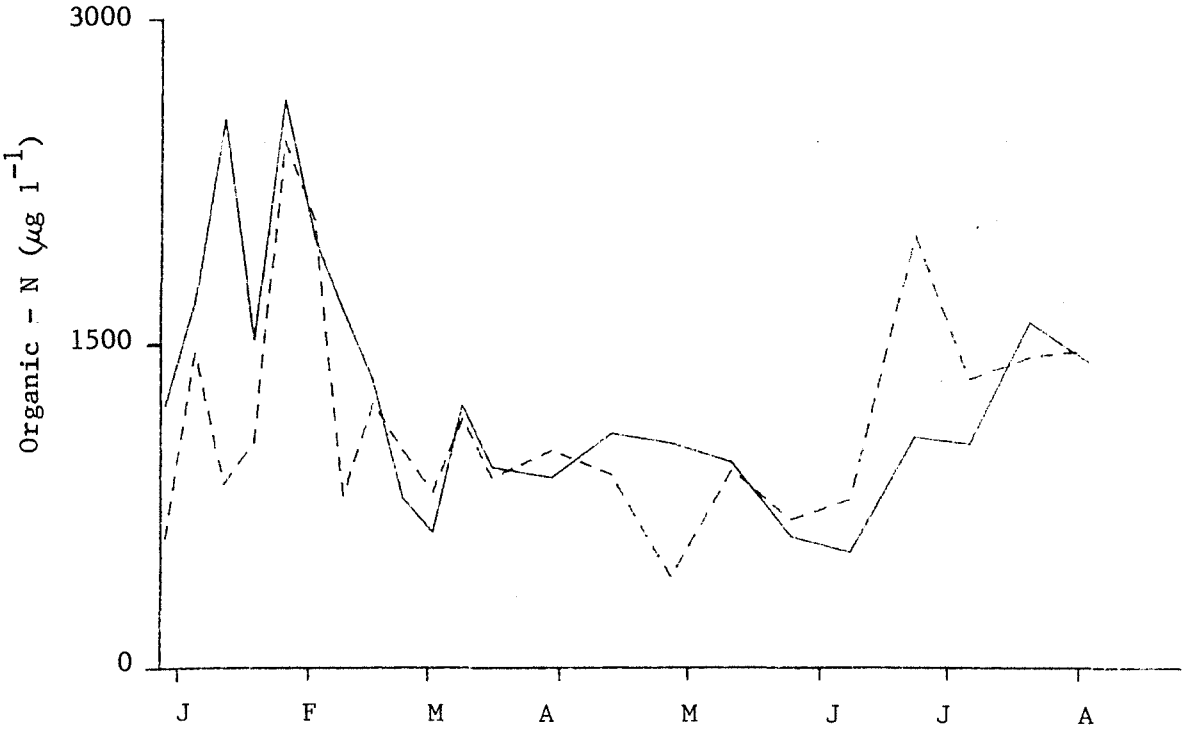

Fig. 2.9 Organic nitrogen

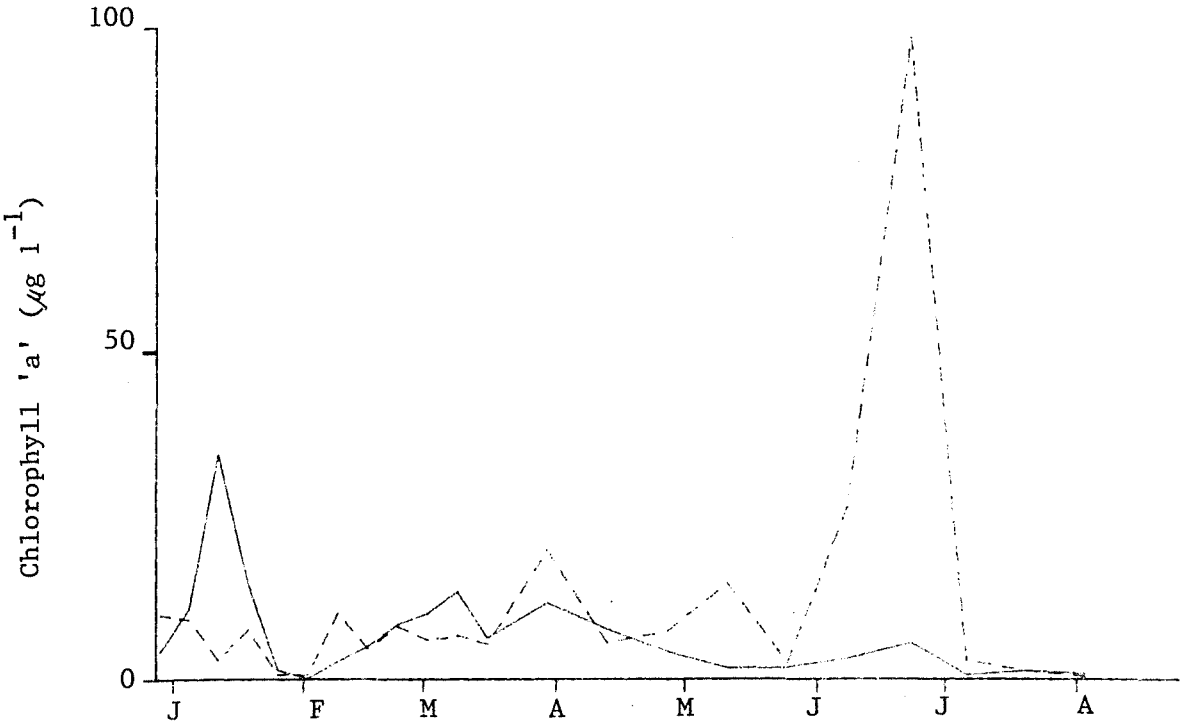

Fig. 2.10 Chlorophyll 'a'

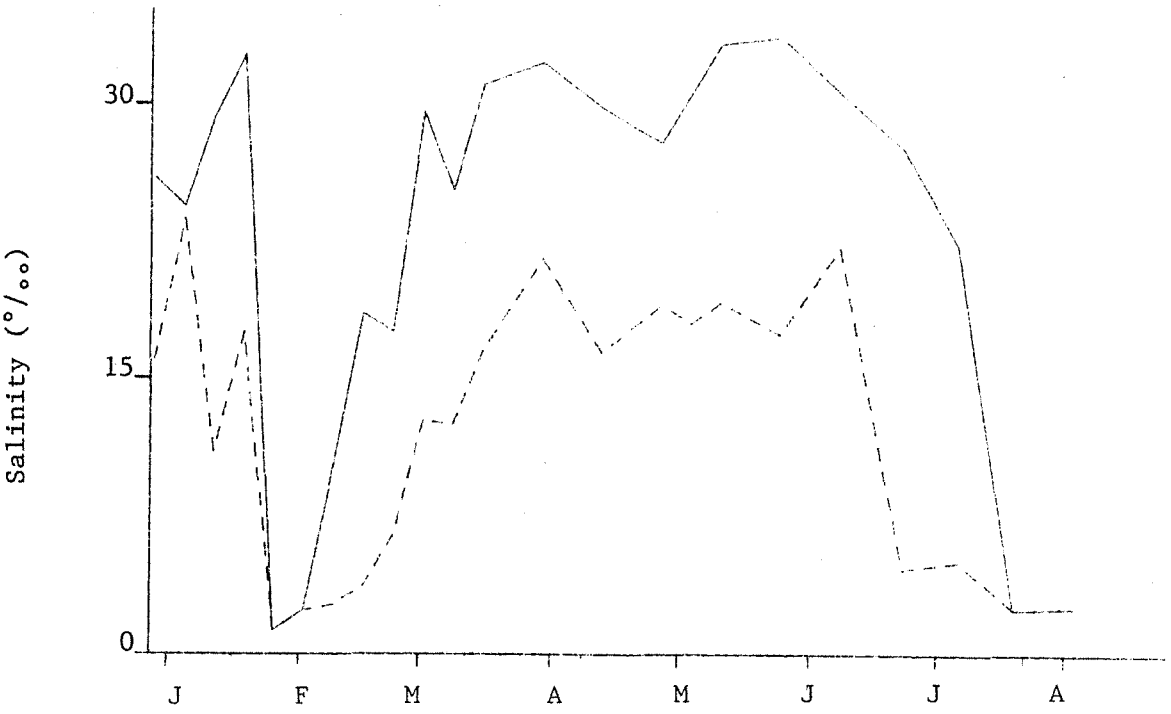

Fig. 3.1 Salinity

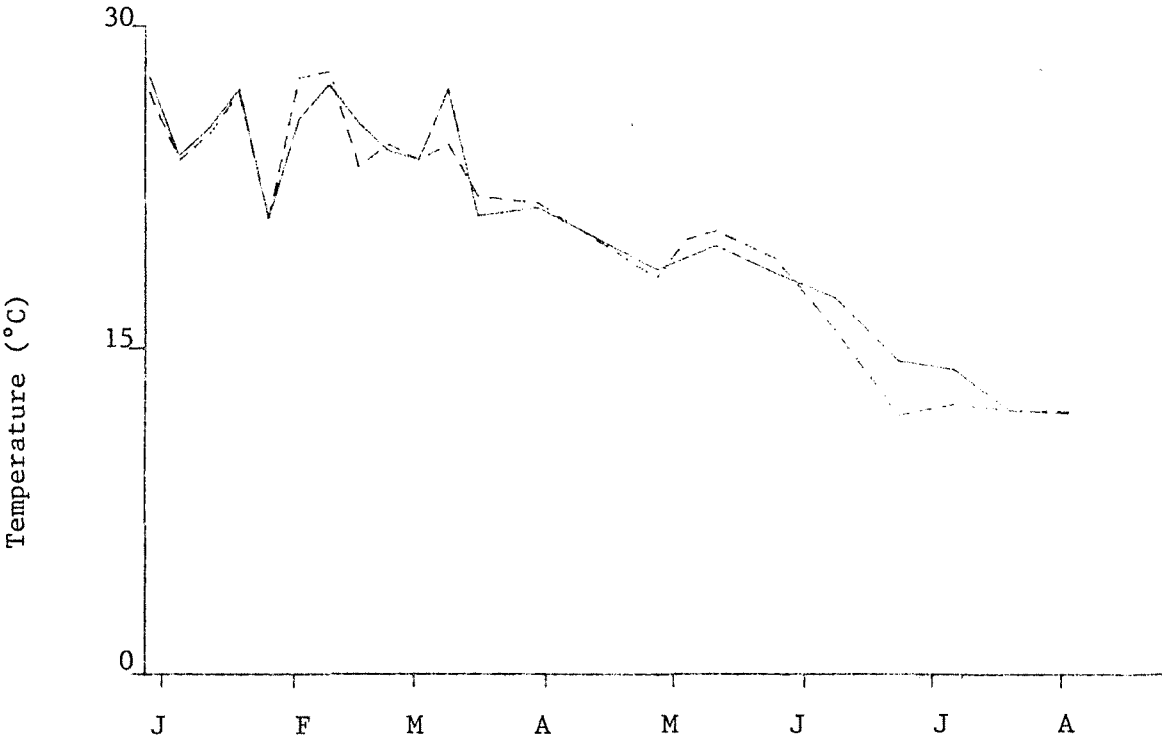

Fig. 3.2 Temperature

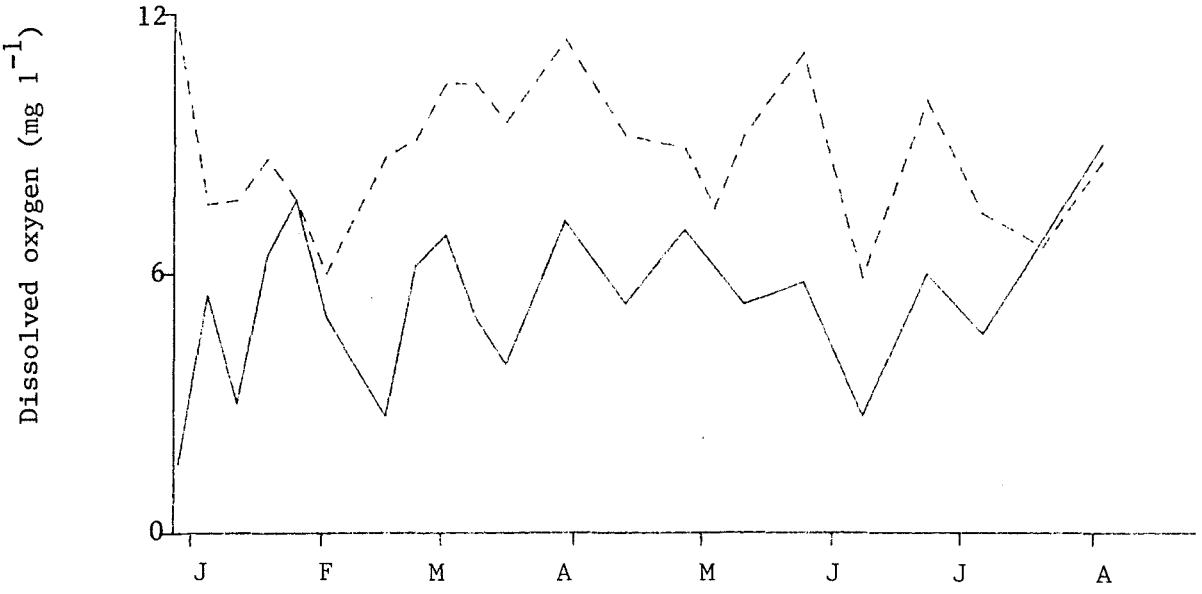

Fig. 3.3 Dissolved oxygen

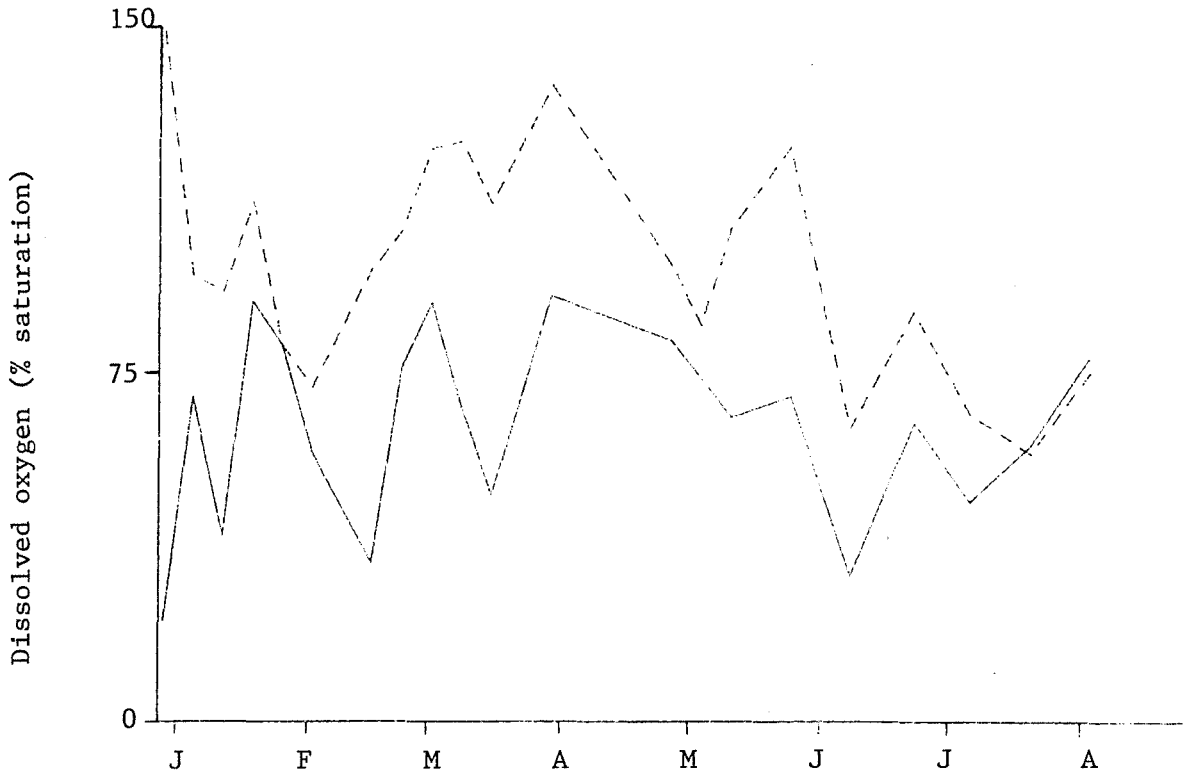

Fig. 3.4 Dissolved oxygen

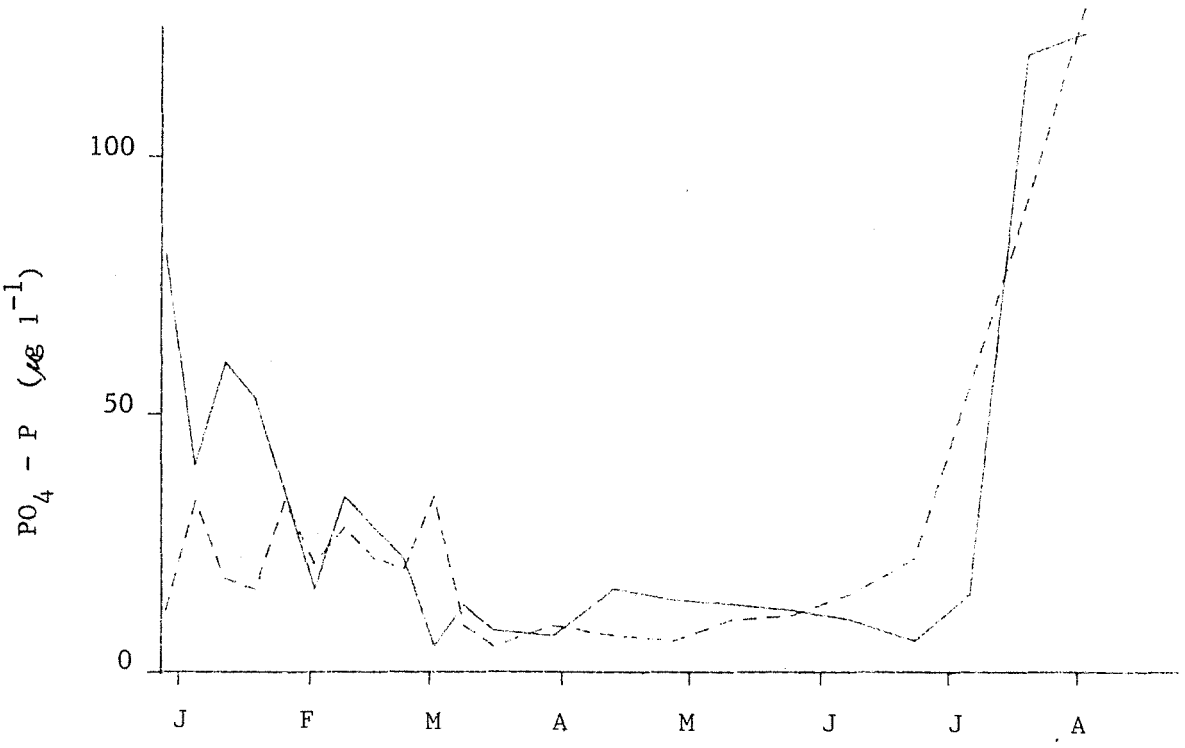

Fig. 3.5 Phosphate phosphorus

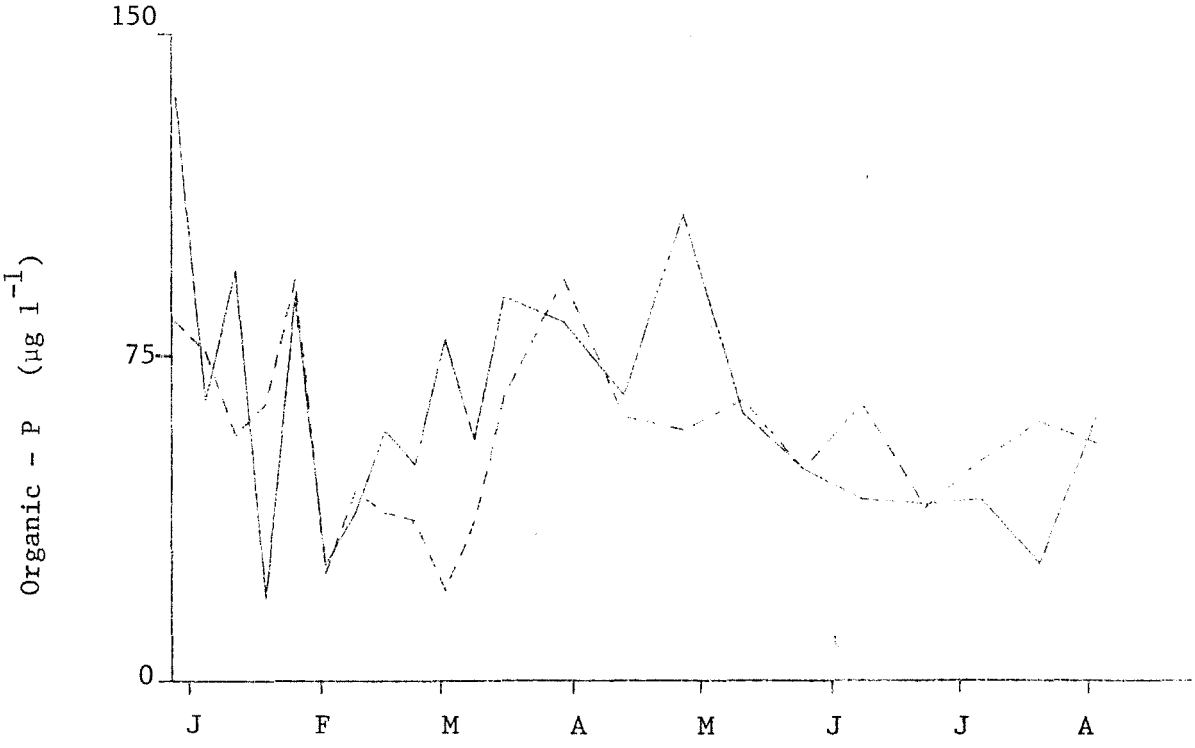

Fig. 3.6 Organic phosphorus

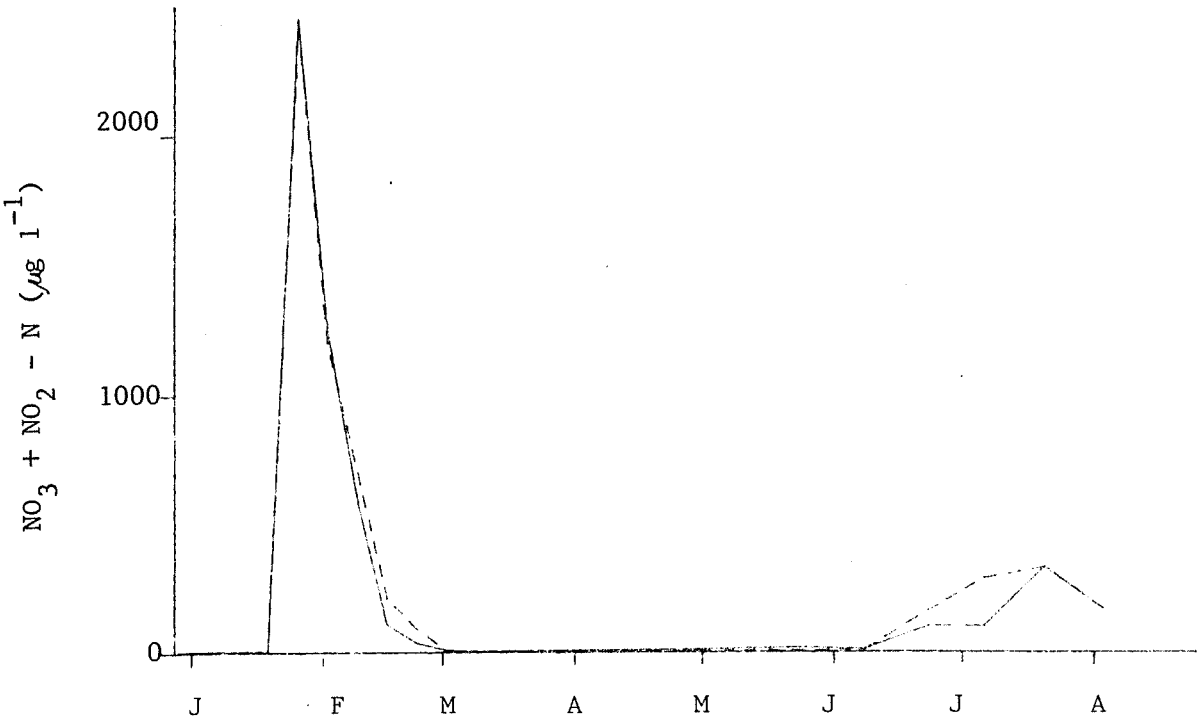

Fig. 3.7 Nitrate-nitrite nitrogen

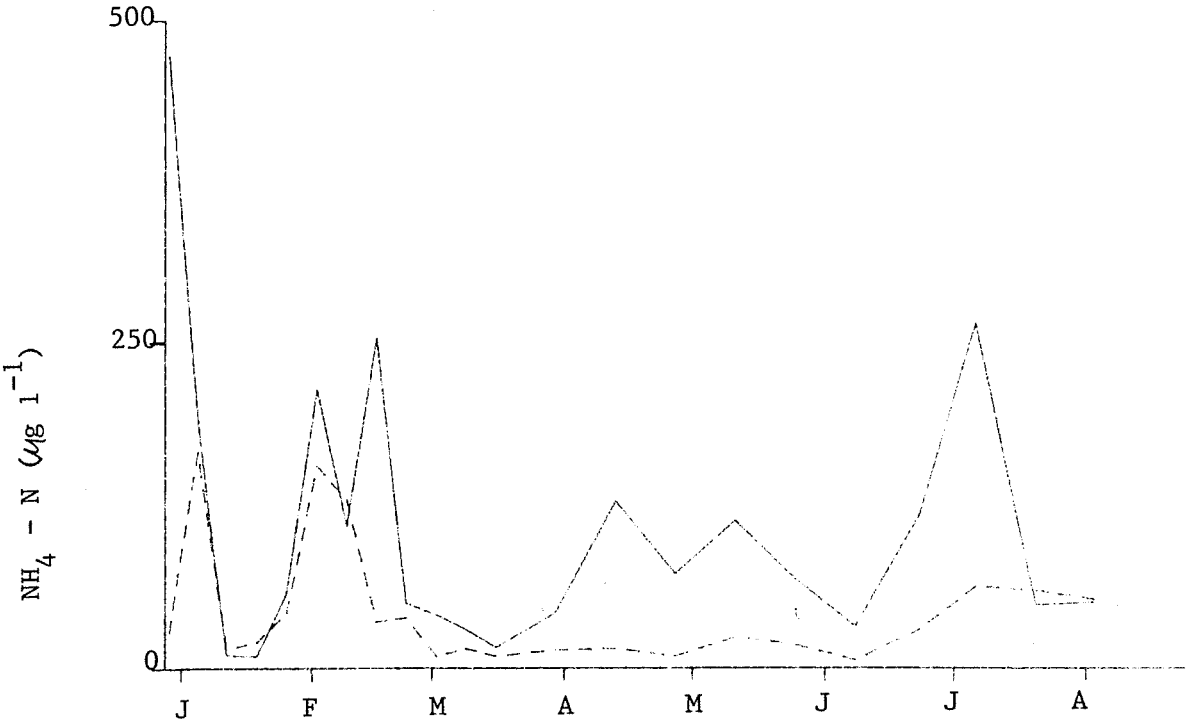

Fig. 3.8 Ammonium nitrogen

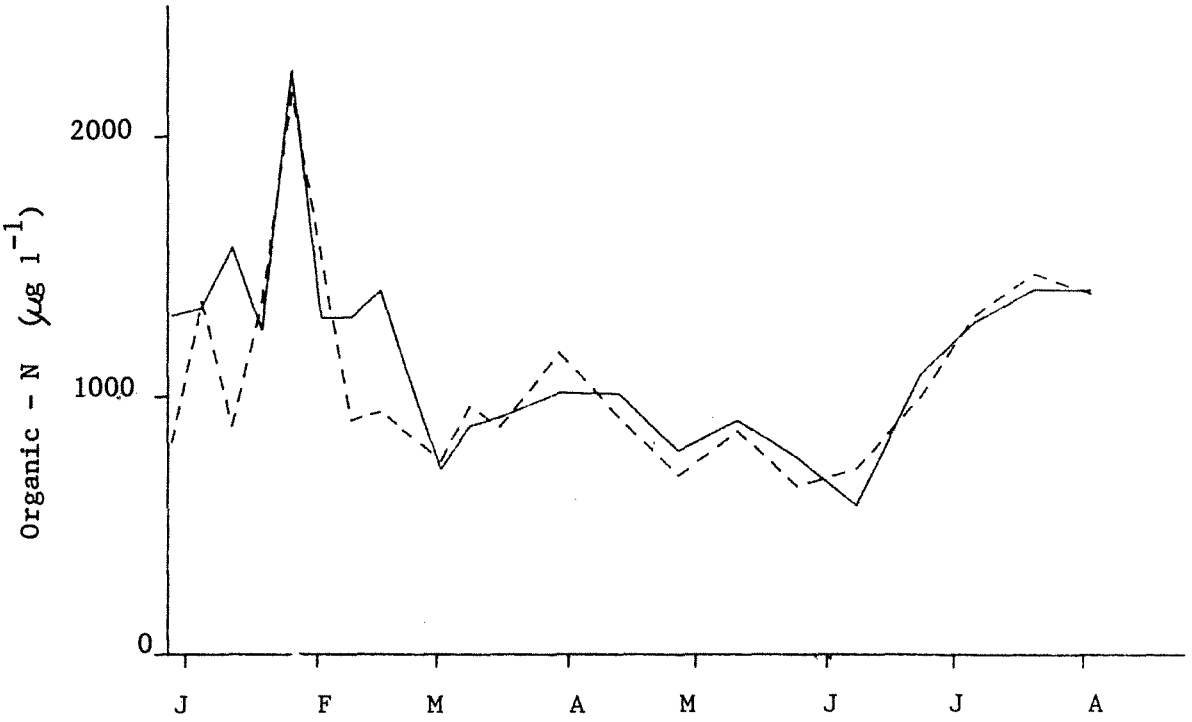

Fig. 3.9 Organic nitrogen

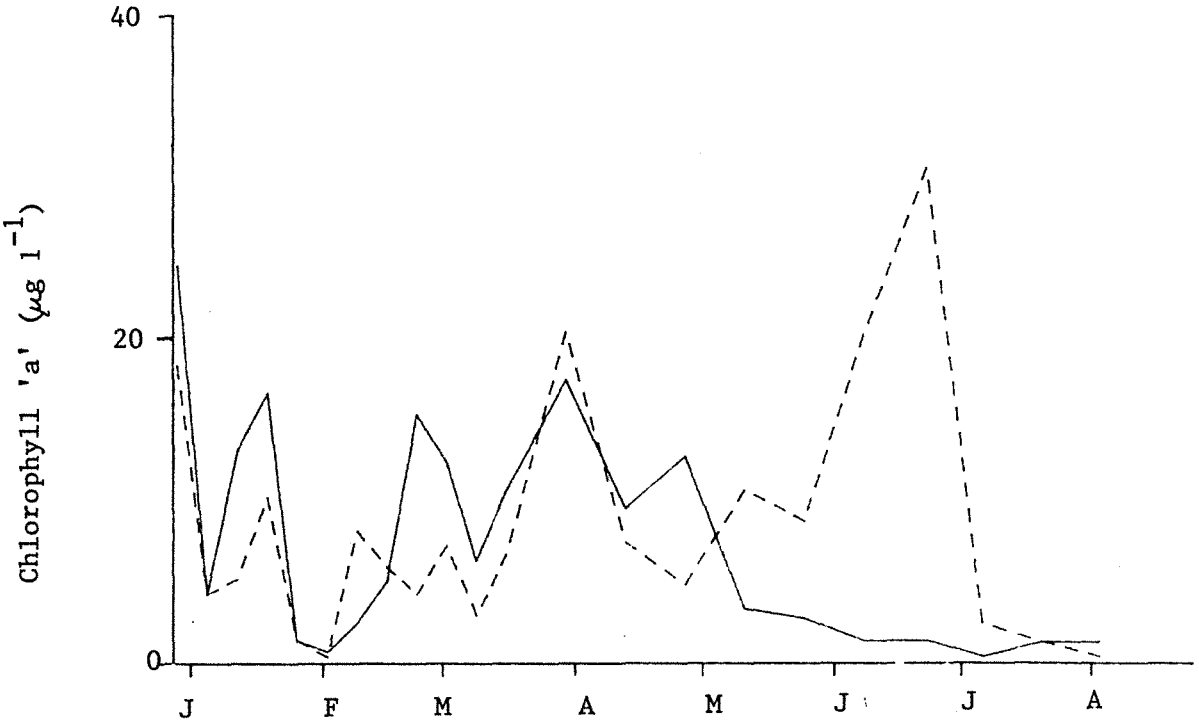

Fig. 3.10 Chlorophyll 'a'

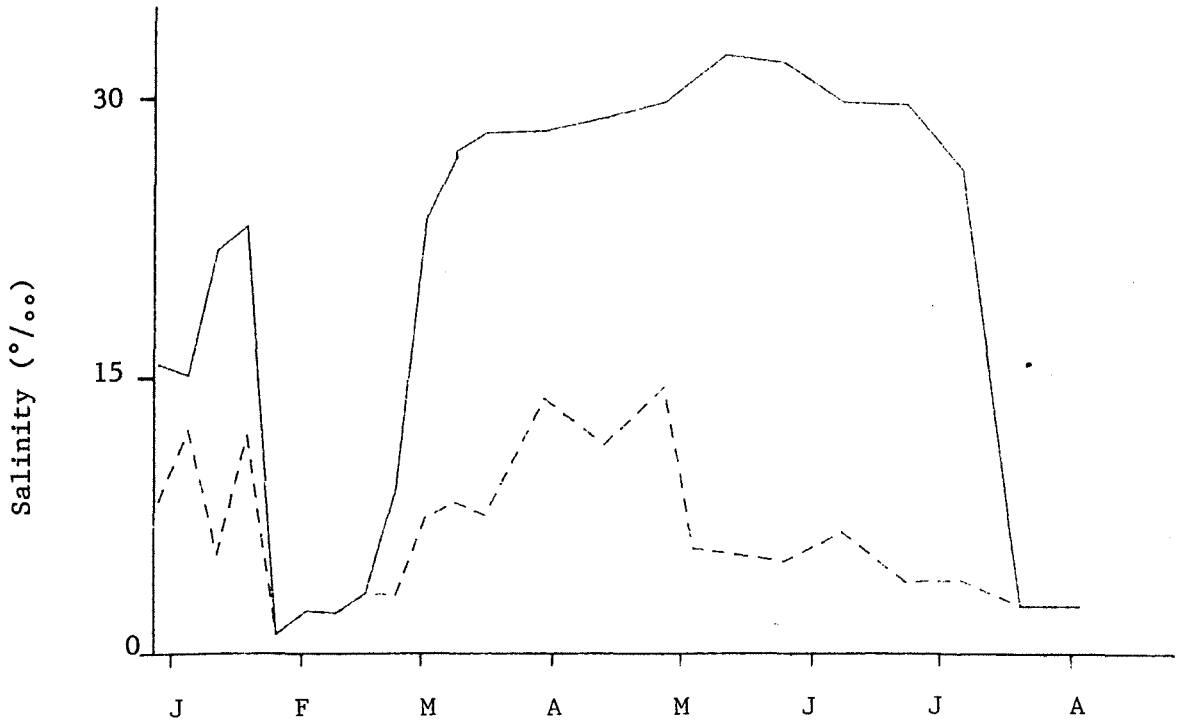

Fig. 4.1 Salinity

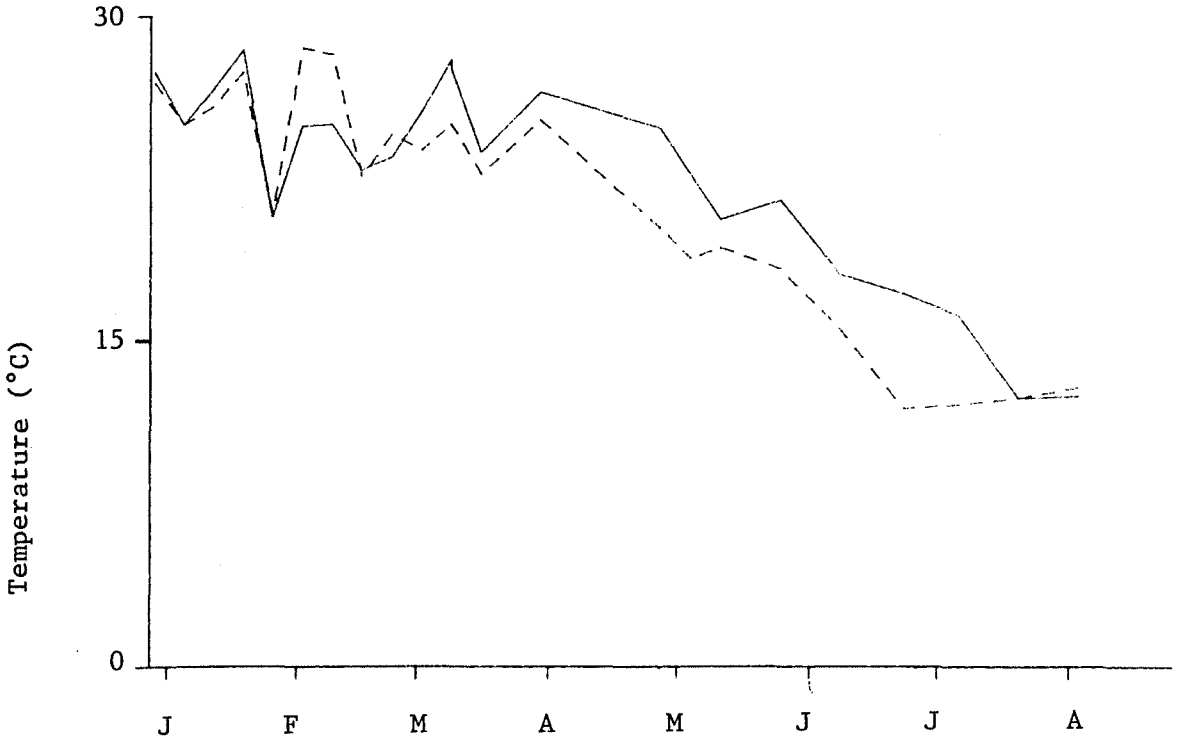

Fig. 4.2 Temperature

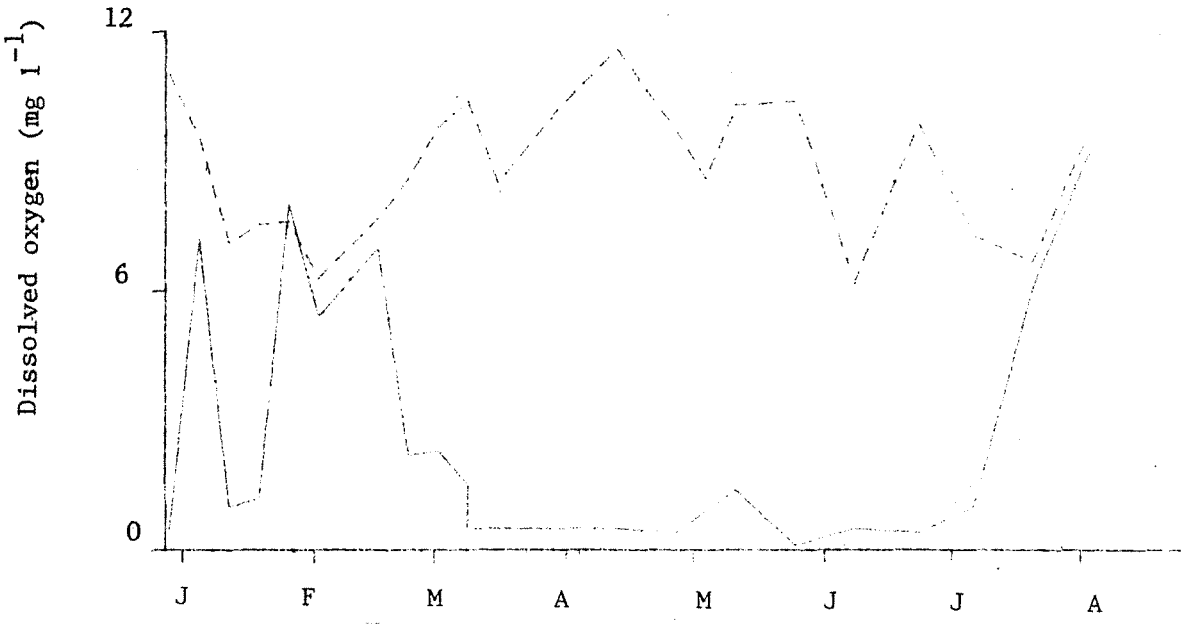

Fig. 4.3 Dissolved oxygen

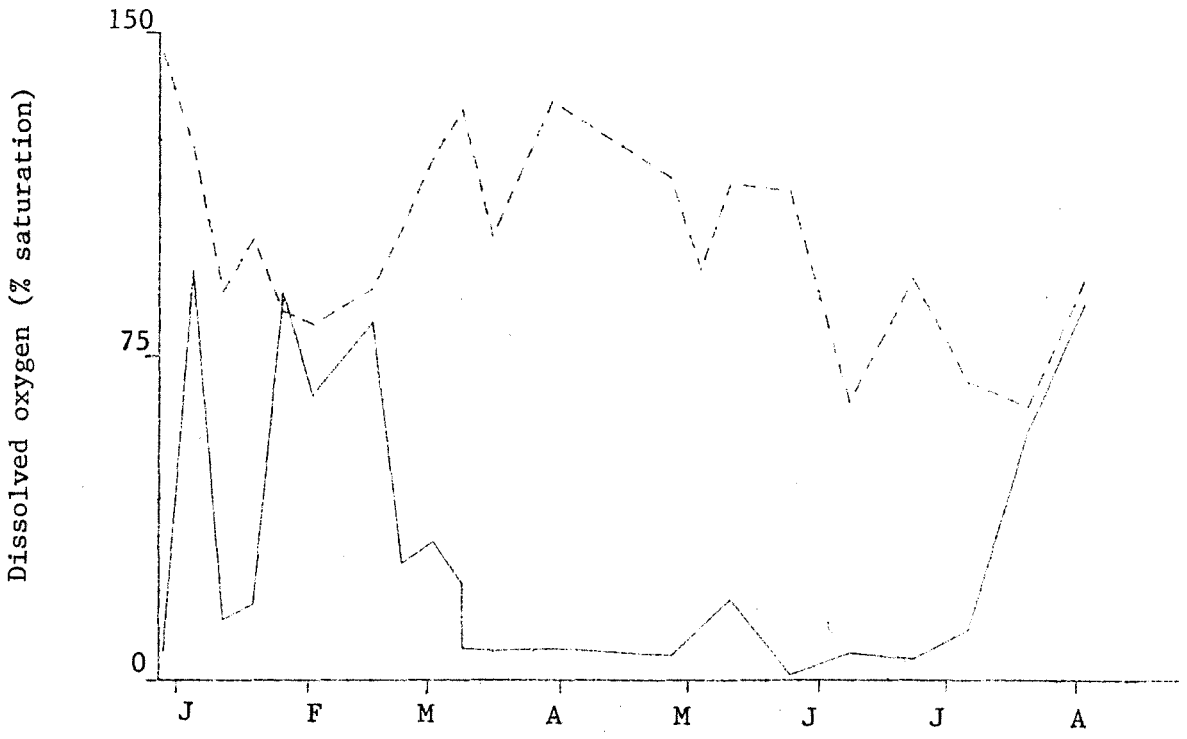

Fig. 4.4 Dissolved oxygen

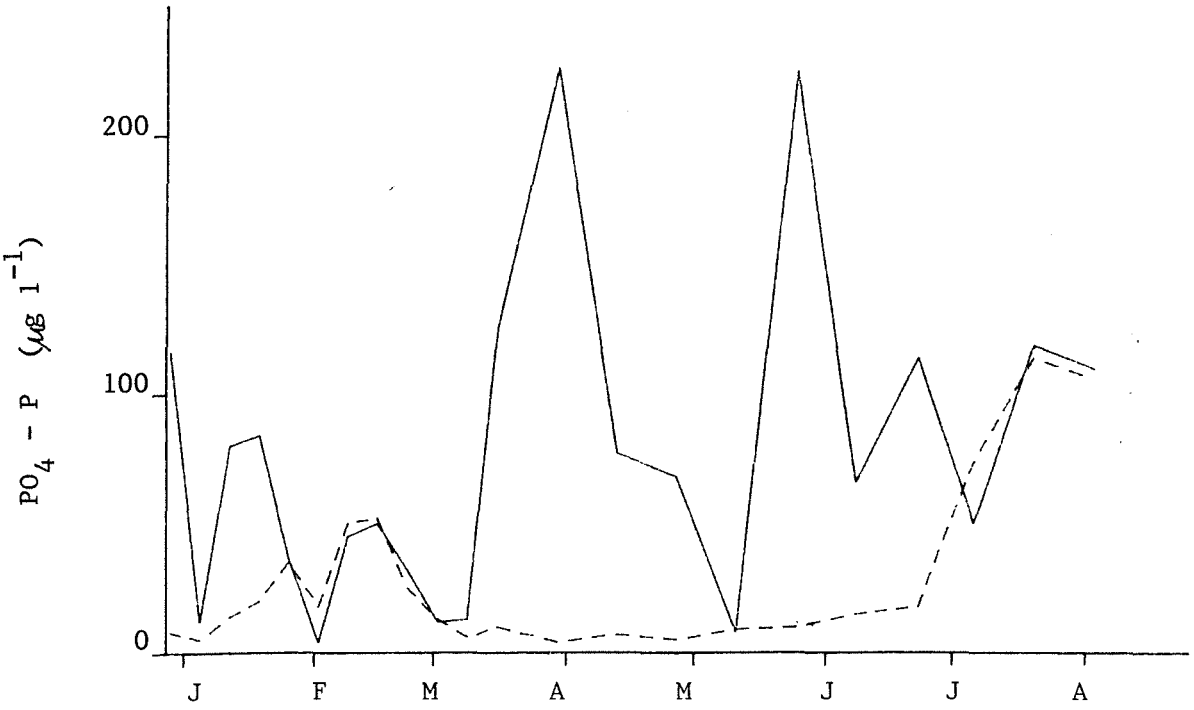

Fig. 4.5 Phosphate phosphorus

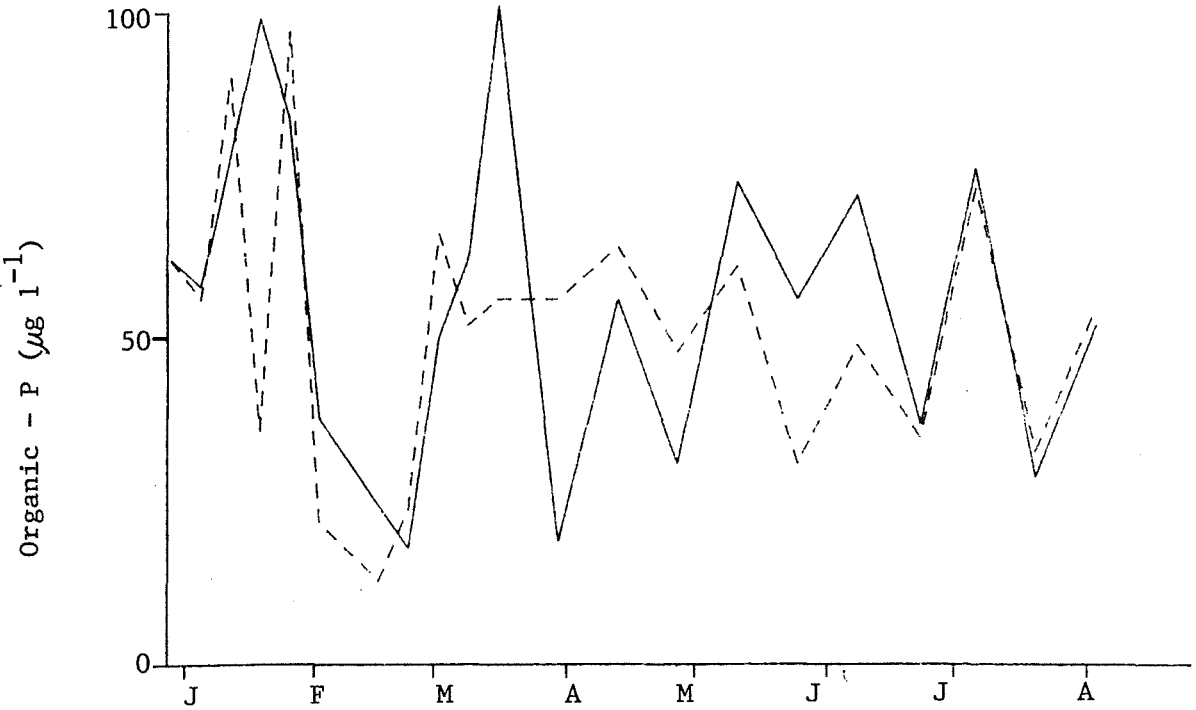

Fig. 4.6 Organic phosphorus

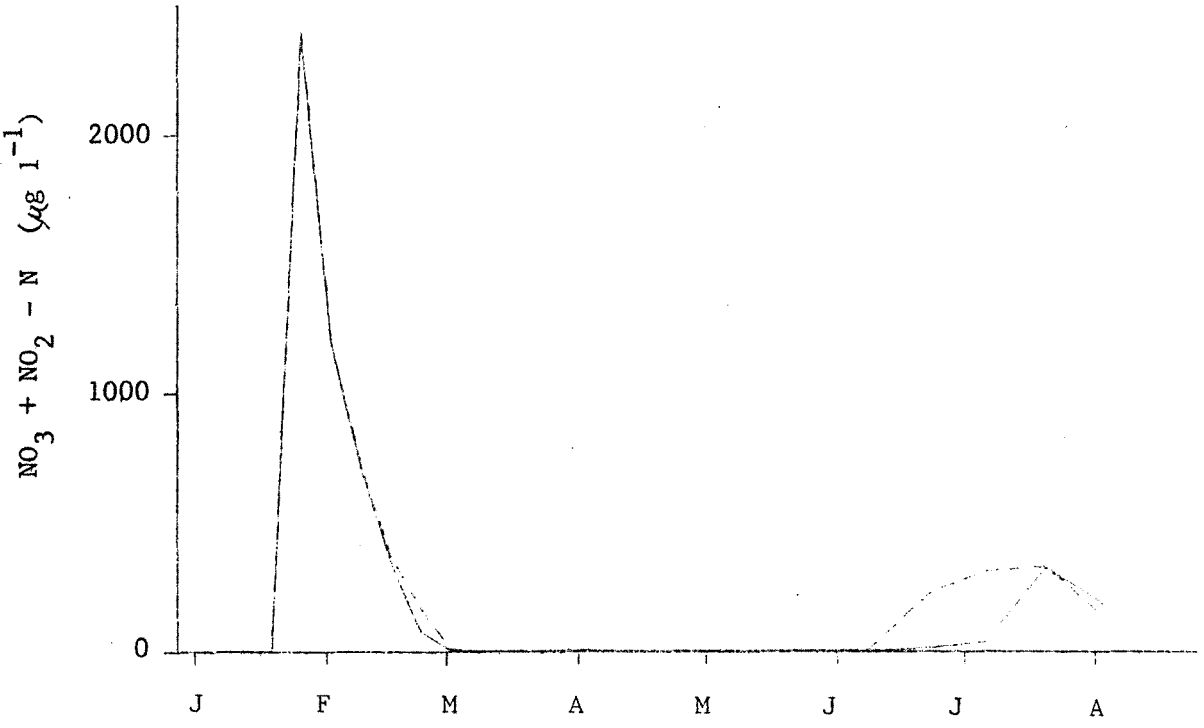

Fig. 4.7 Nitrate-nitrite nitrogen

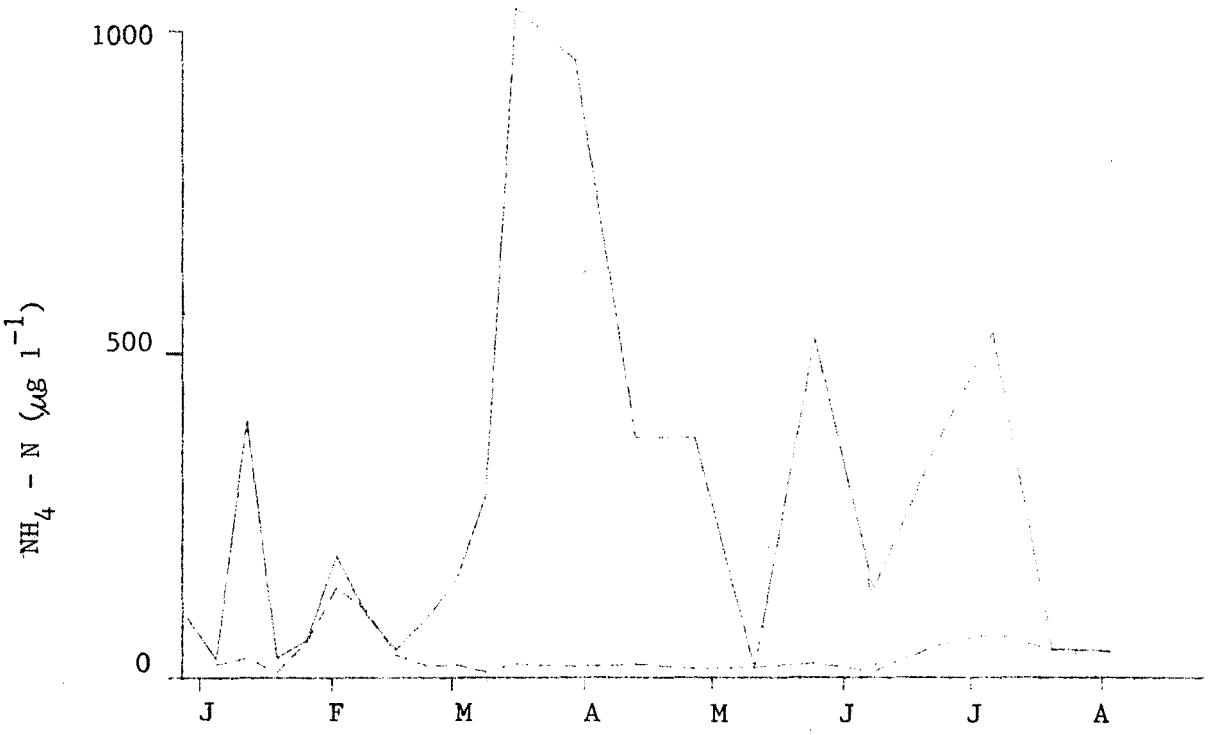

Fig. 4.8 Ammonium nitrogen

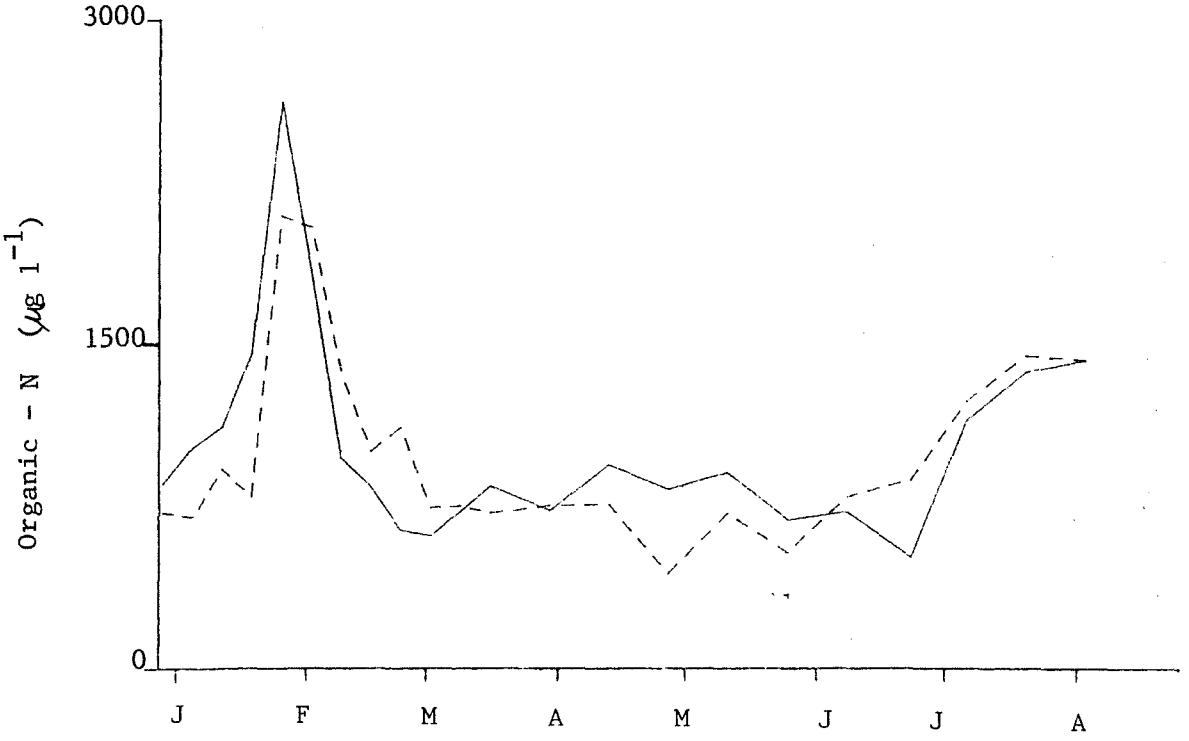

Fig. 4.9 Organic nitrogen

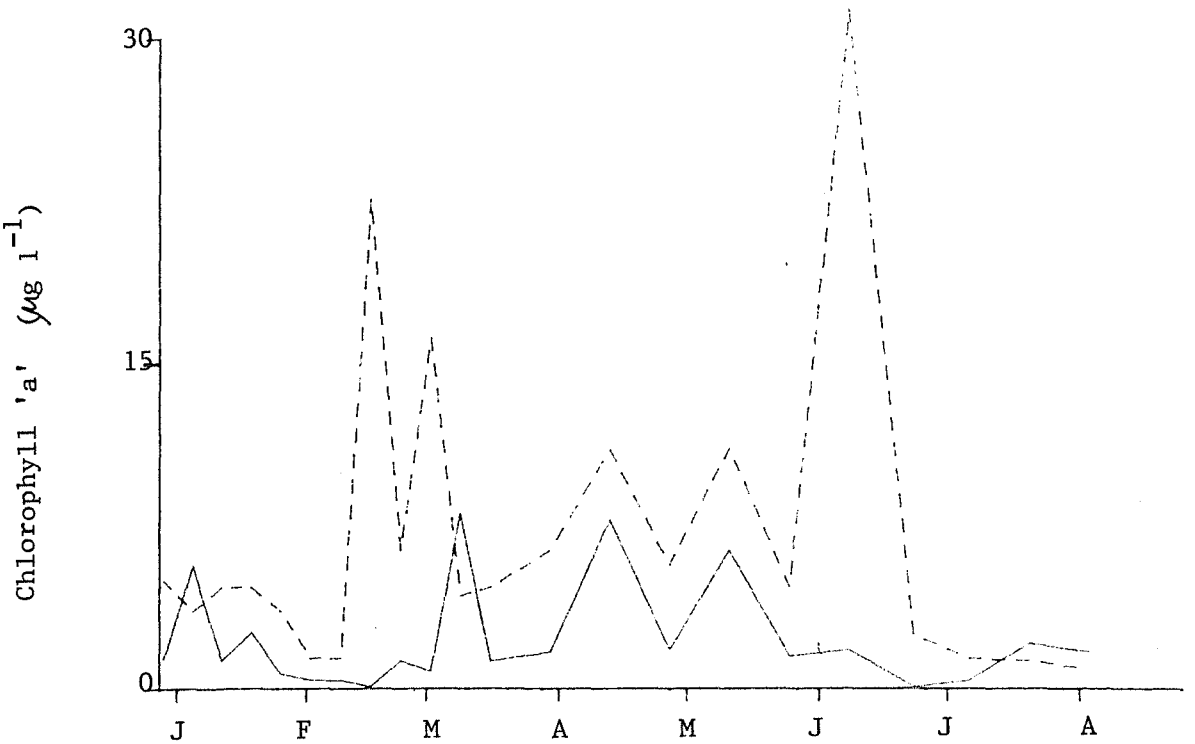

Fig. 4.10 Chlorophyll 'a'

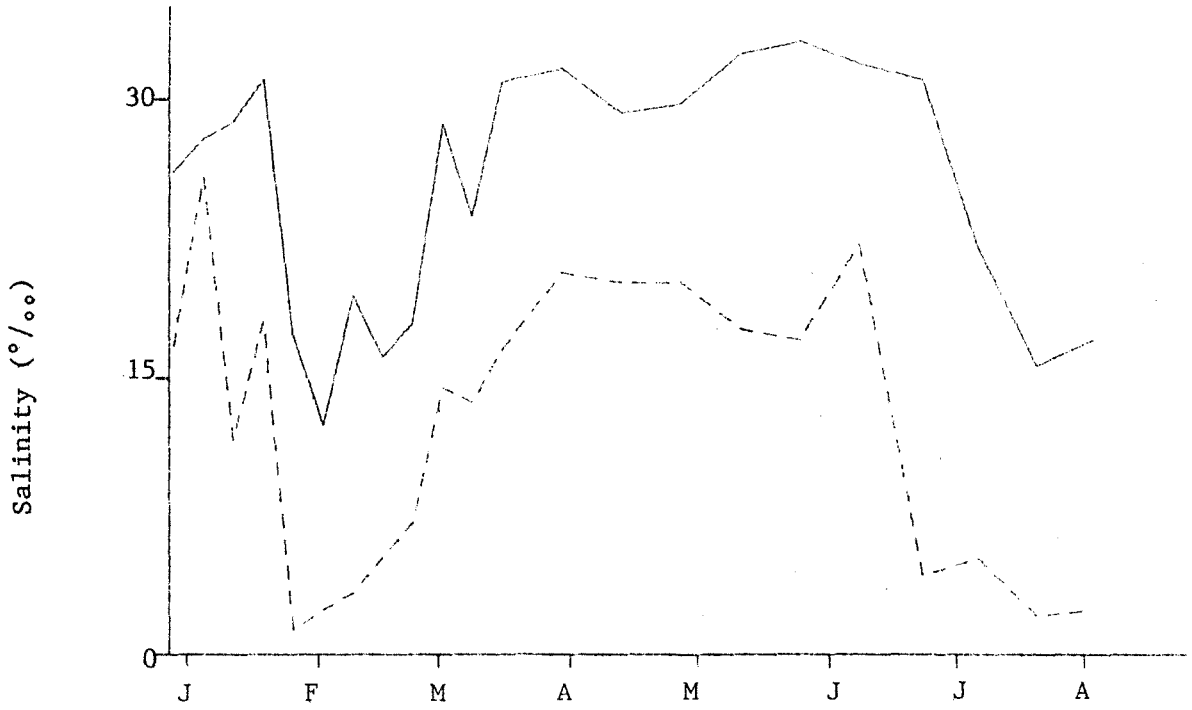

Fig. 5.1 Salinity

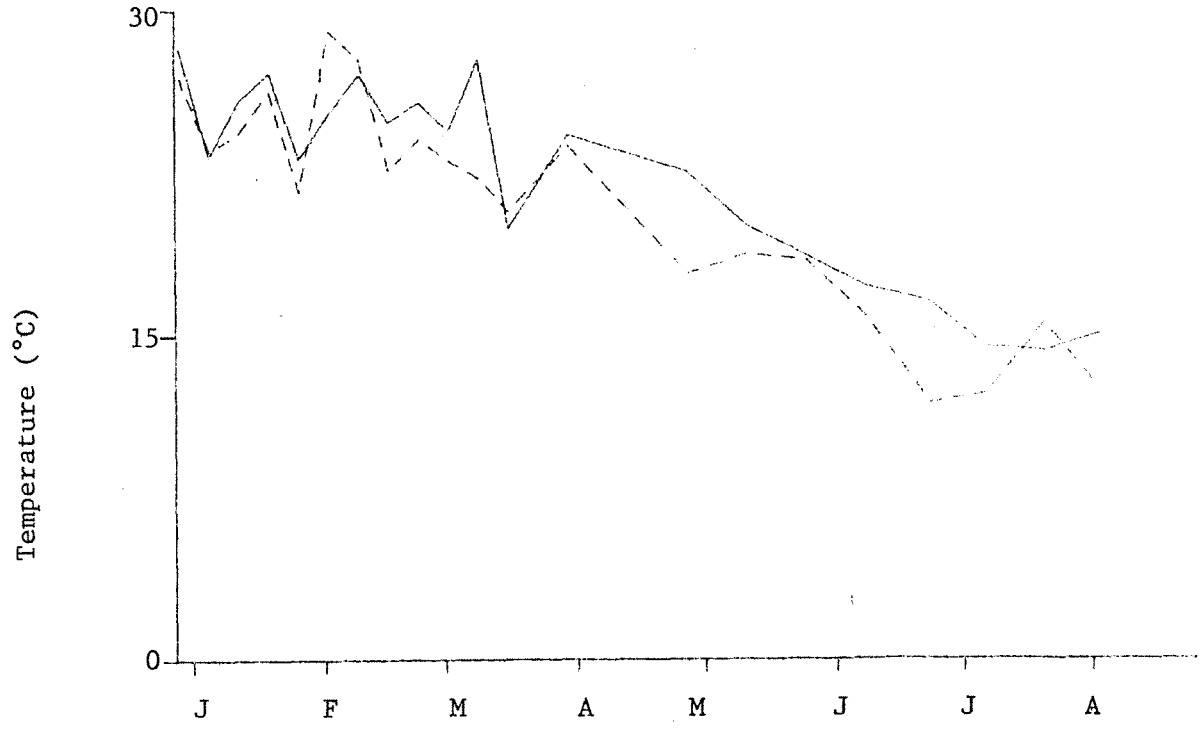

Fig. 5.2 Temperature

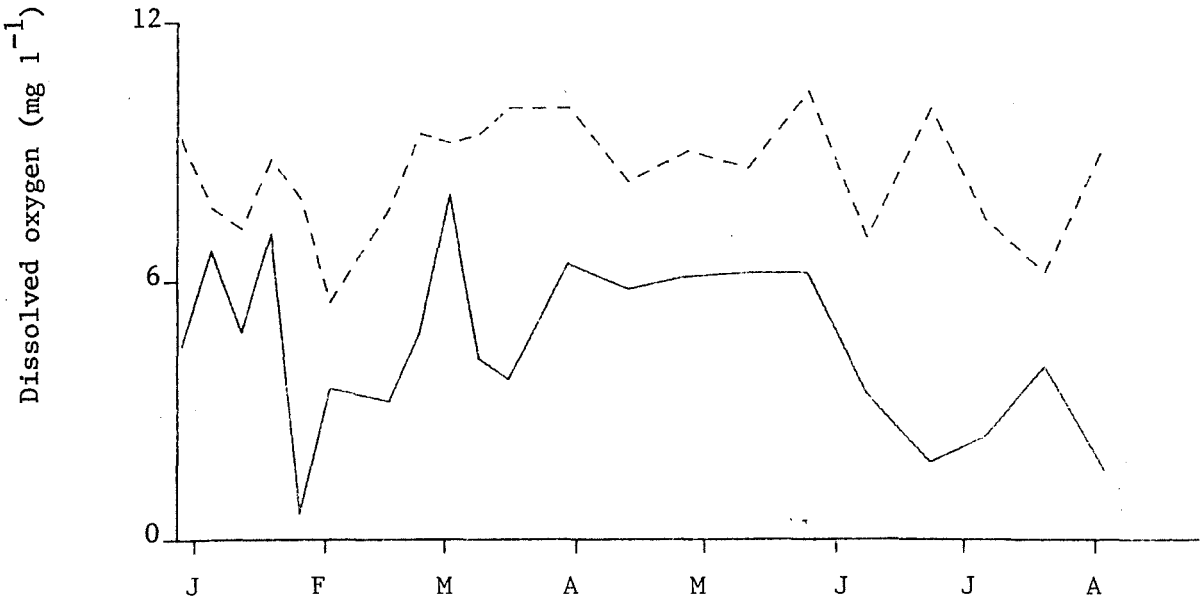

Fig. 5.3 Dissolved oxygen

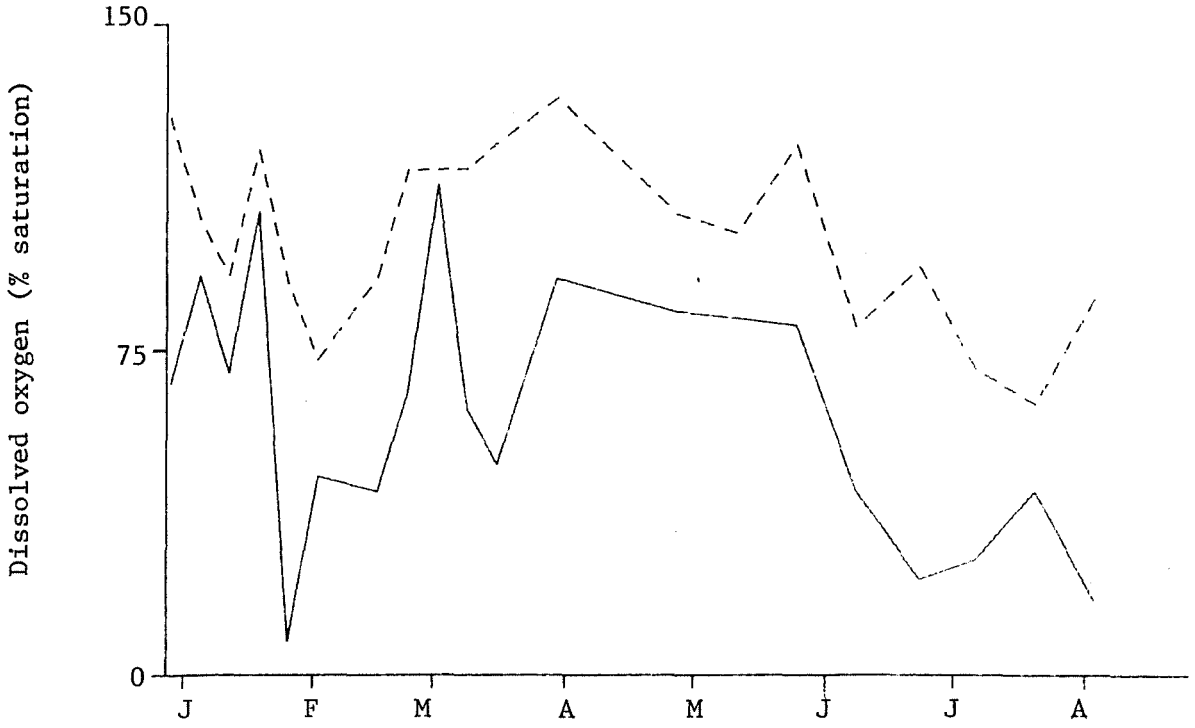

Fig. 5.4 Dissolved oxygen

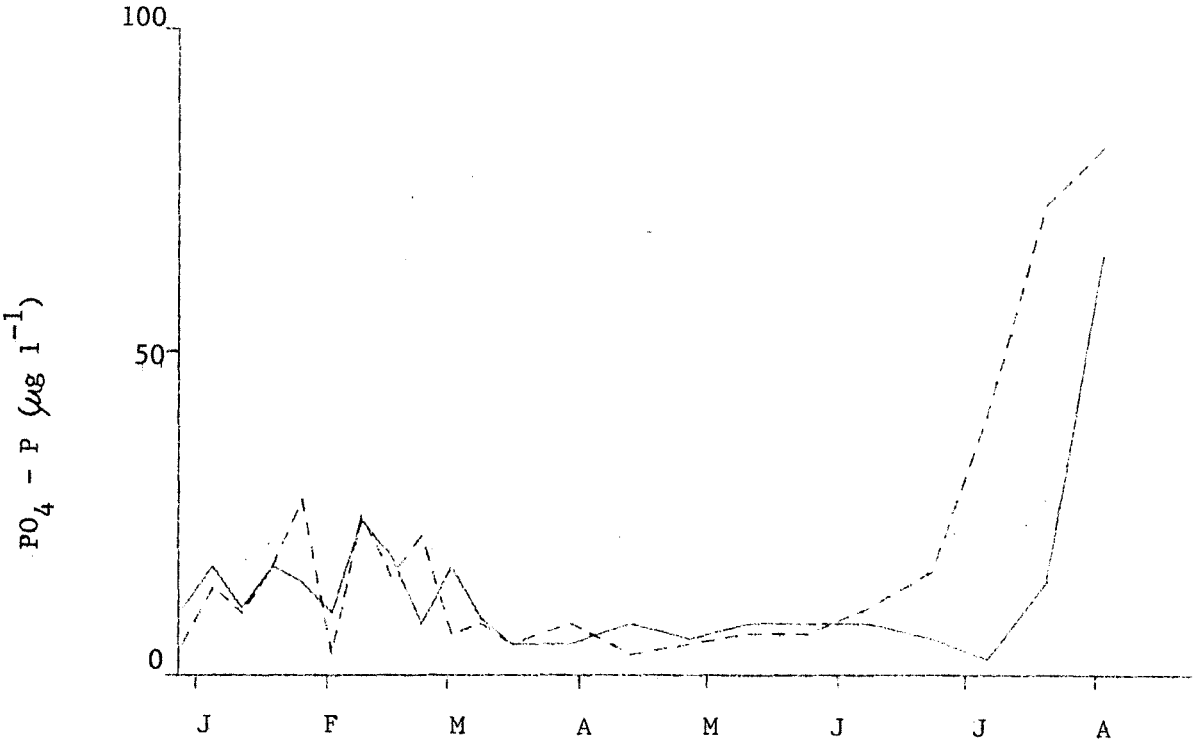

Fig. 5.5 Phosphate phosphorus

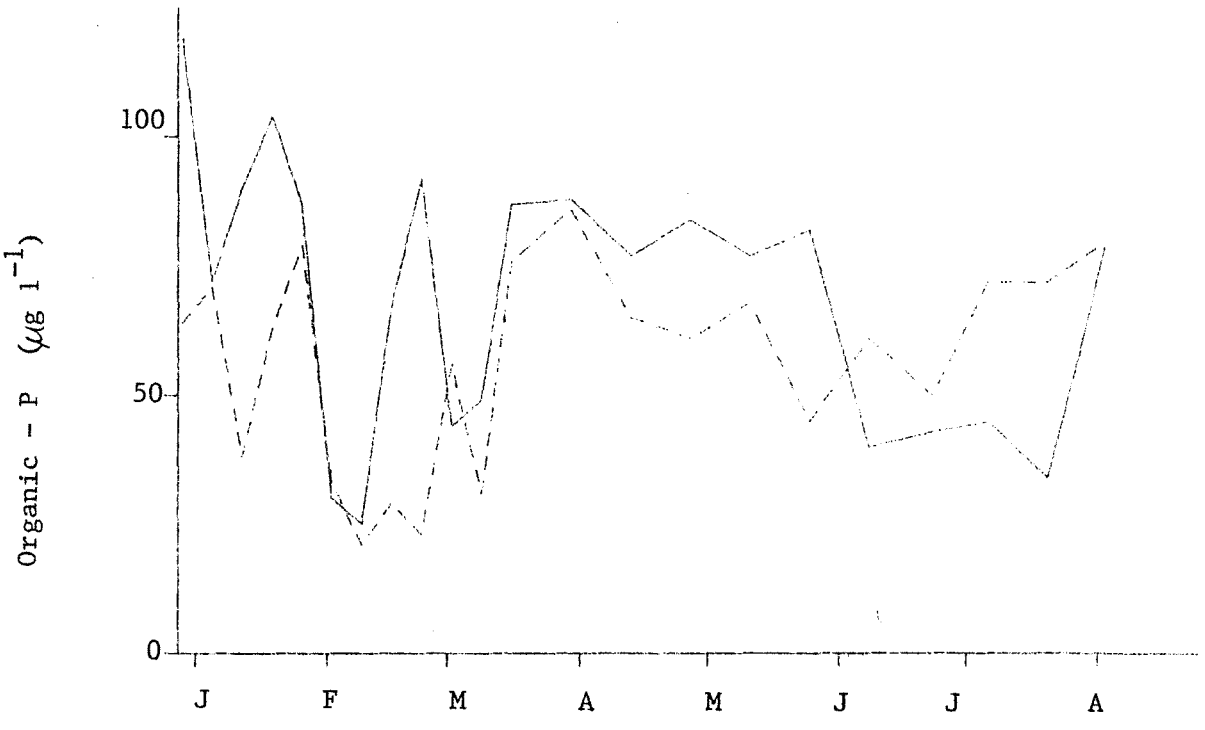

Fig. 5.6 Organic phosphorus

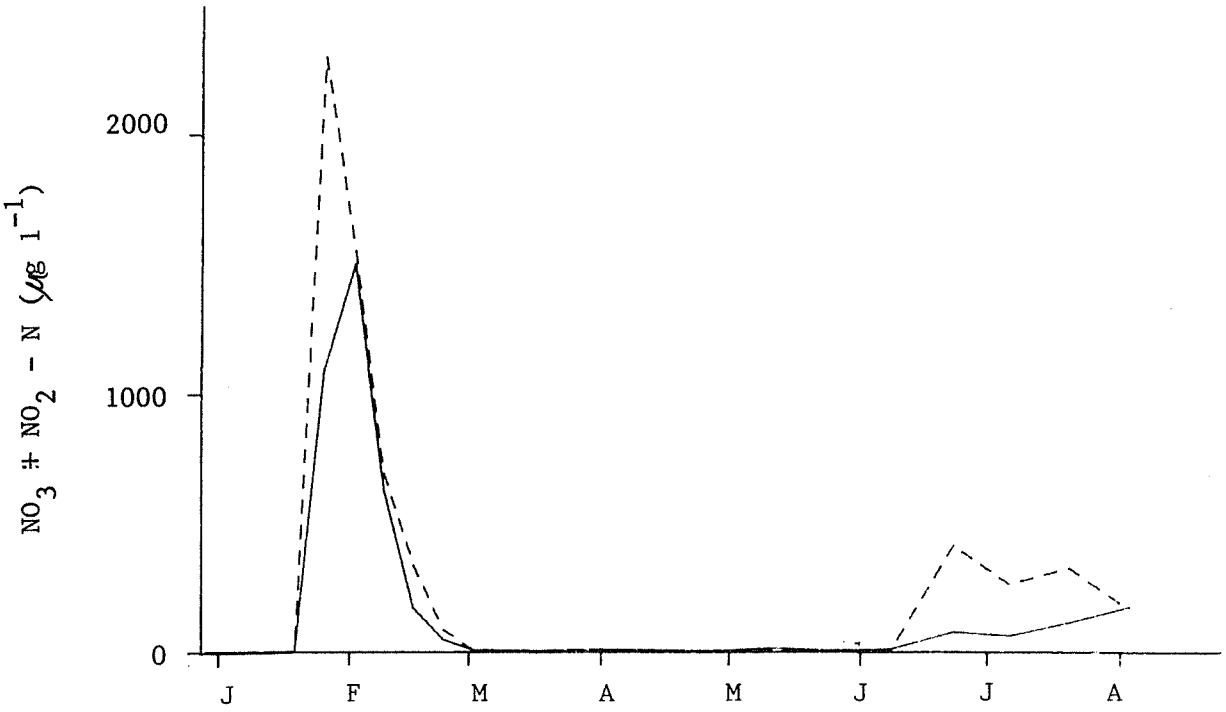

Fig. 5.7 Nitrate-nitrite nitrogen

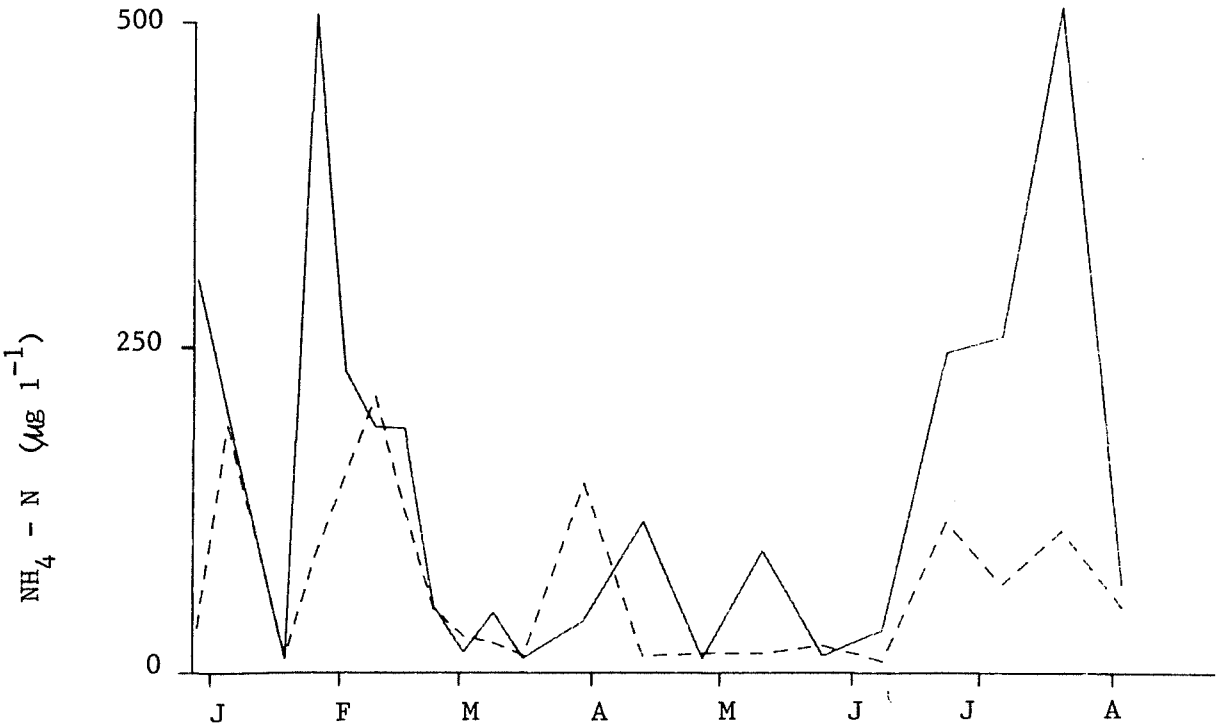

Fig. 5.8 Ammonium nitrogen

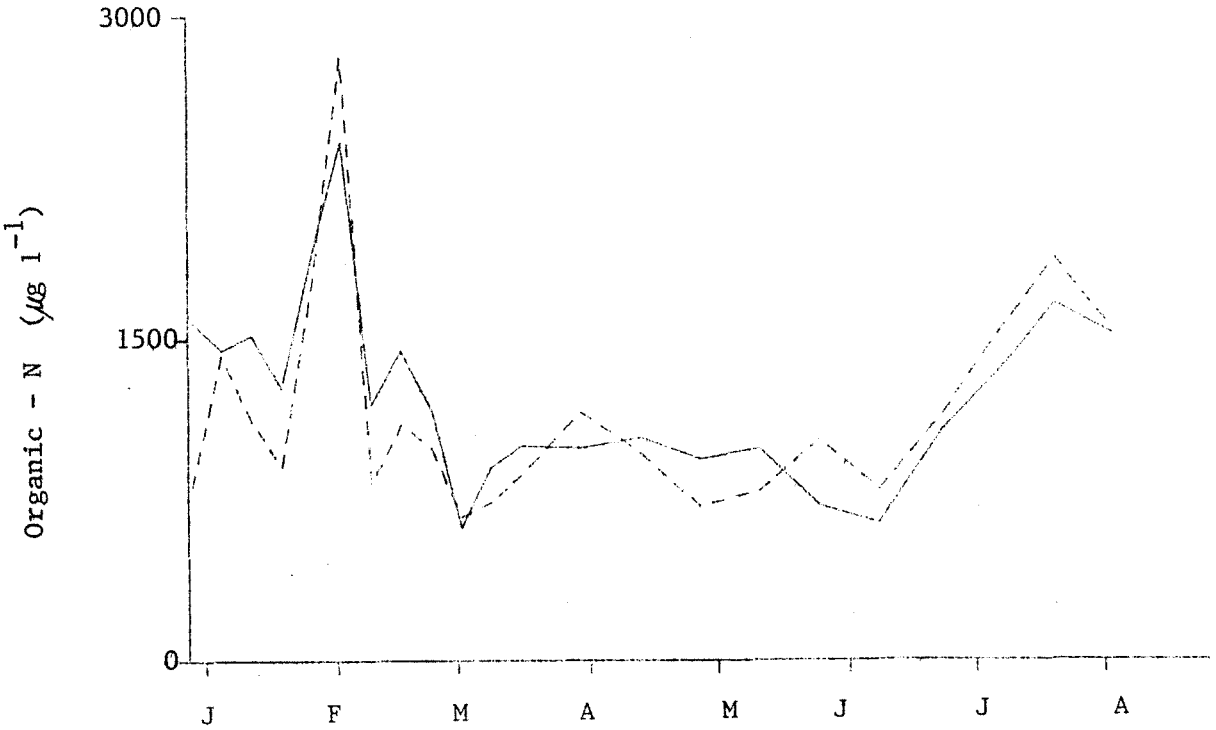

Fig. 5.9 Organic nitrogen

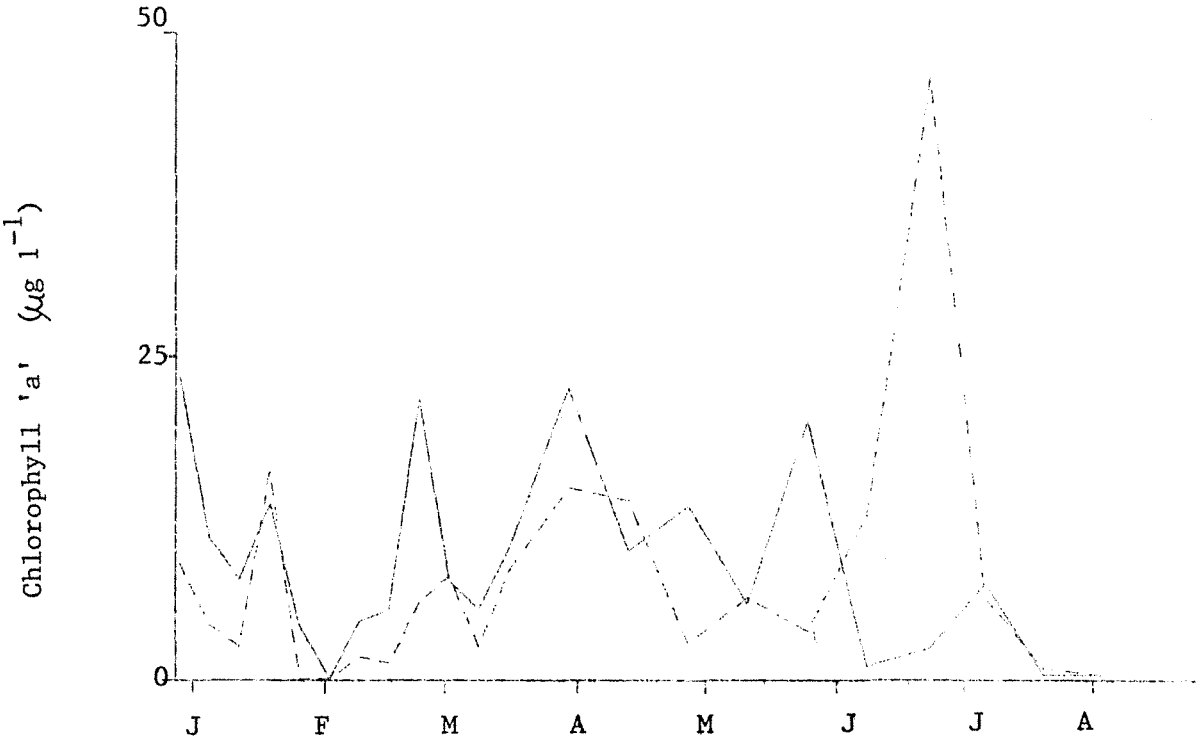

Fig. 5.10 Chlorophyll 'a'

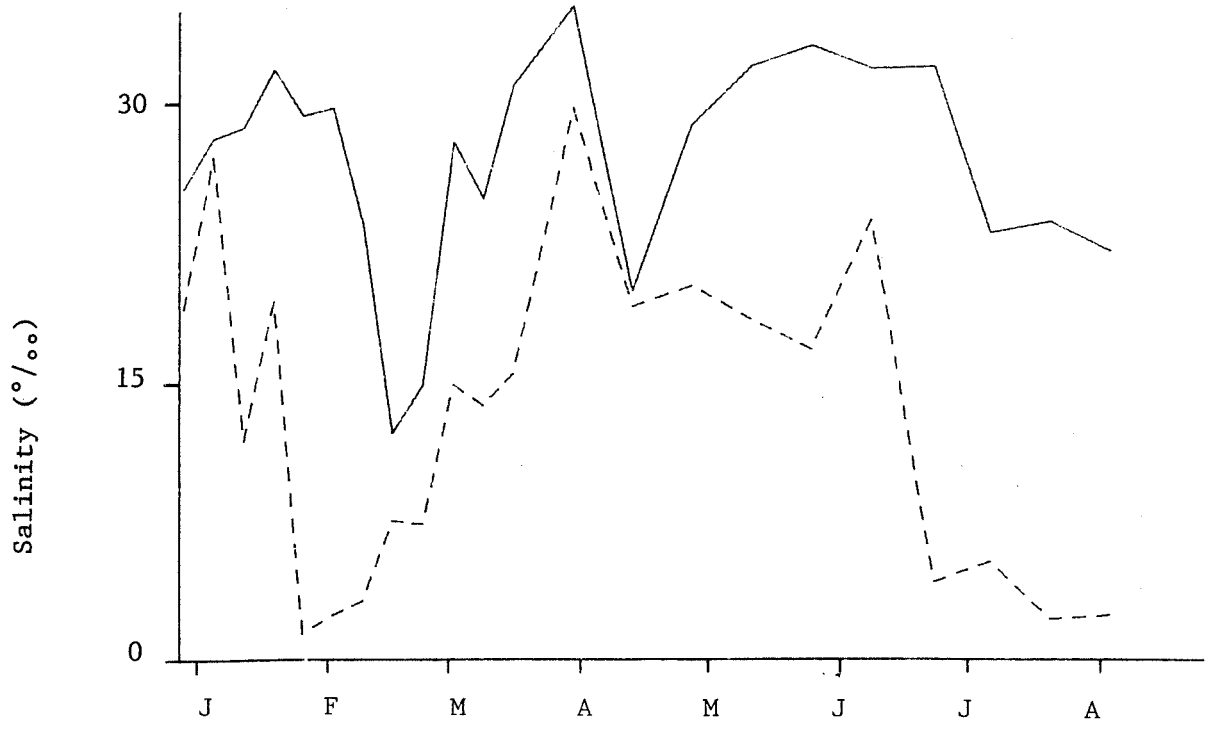

Fig. 6.1 Salinity

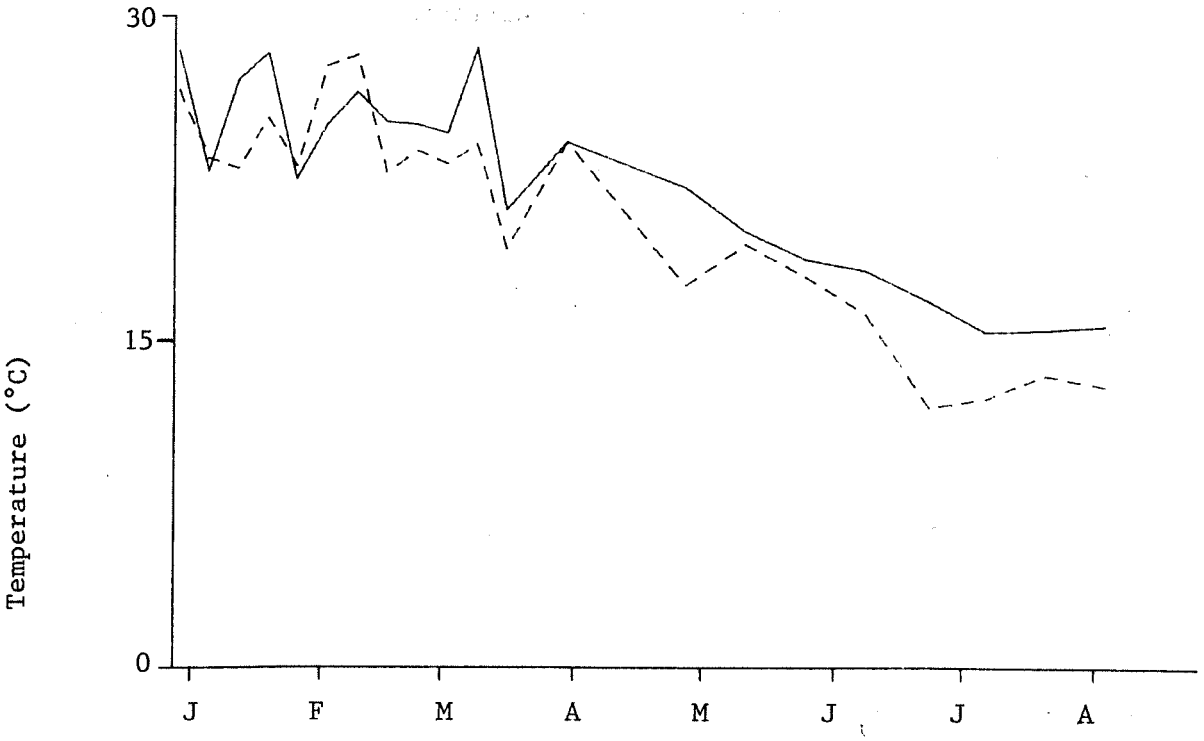

Fig. 6.2 Temperature

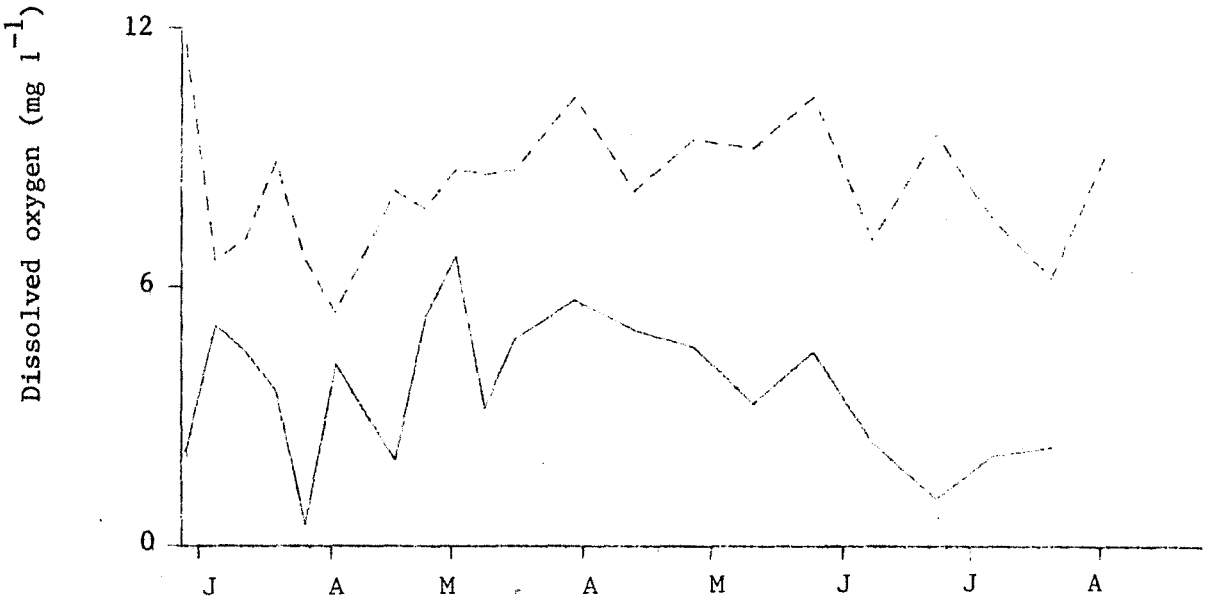

Fig. 6.3 Dissolved oxygen

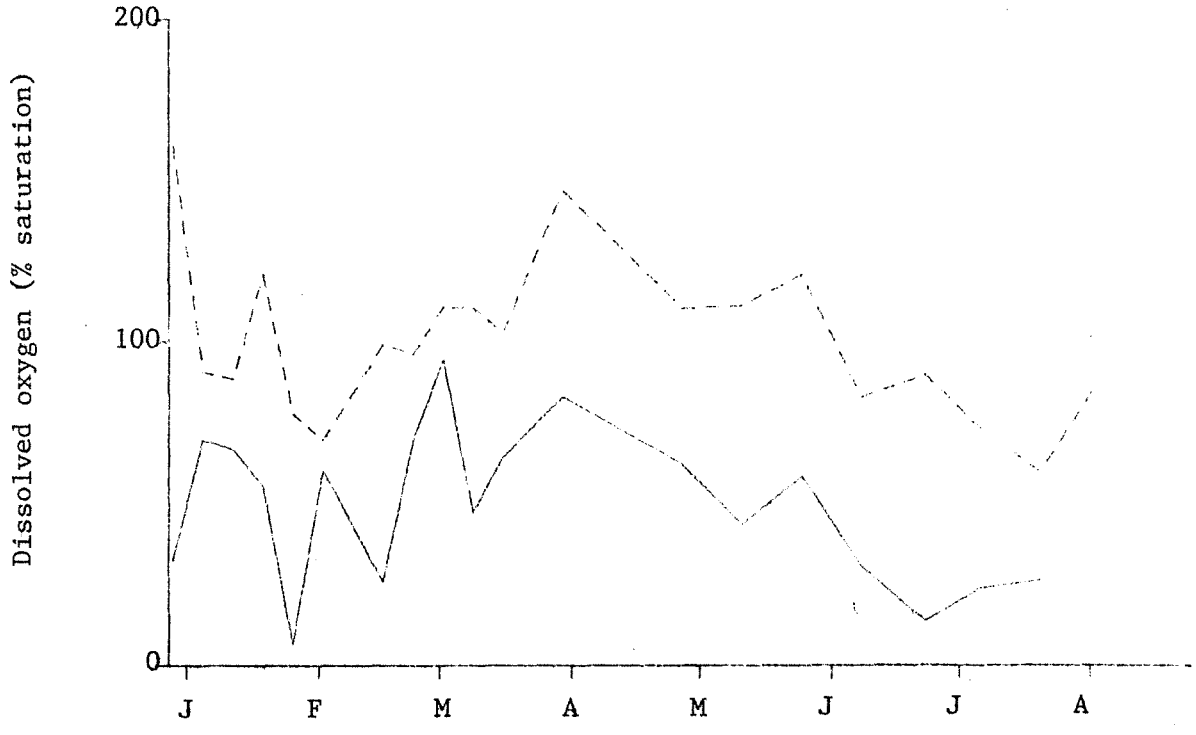

Fig. 6.4 Dissolved oxygen

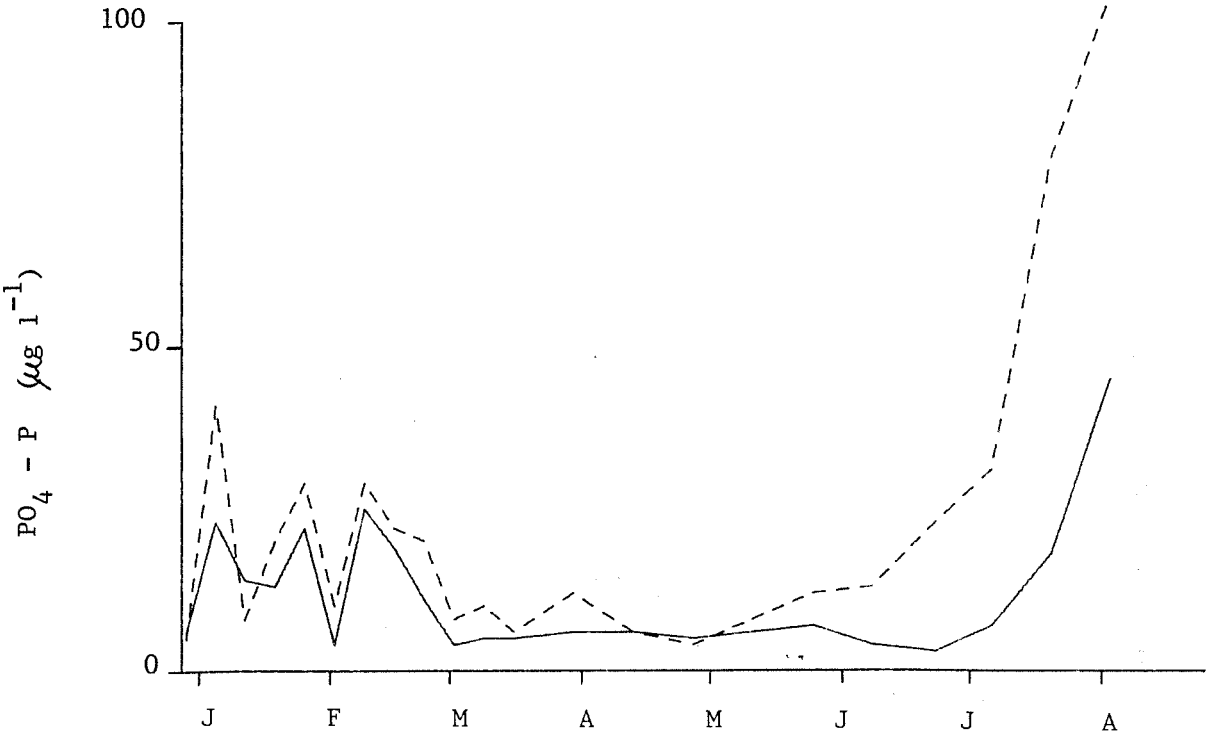

Fig. 6.5 Phosphate phosphorus

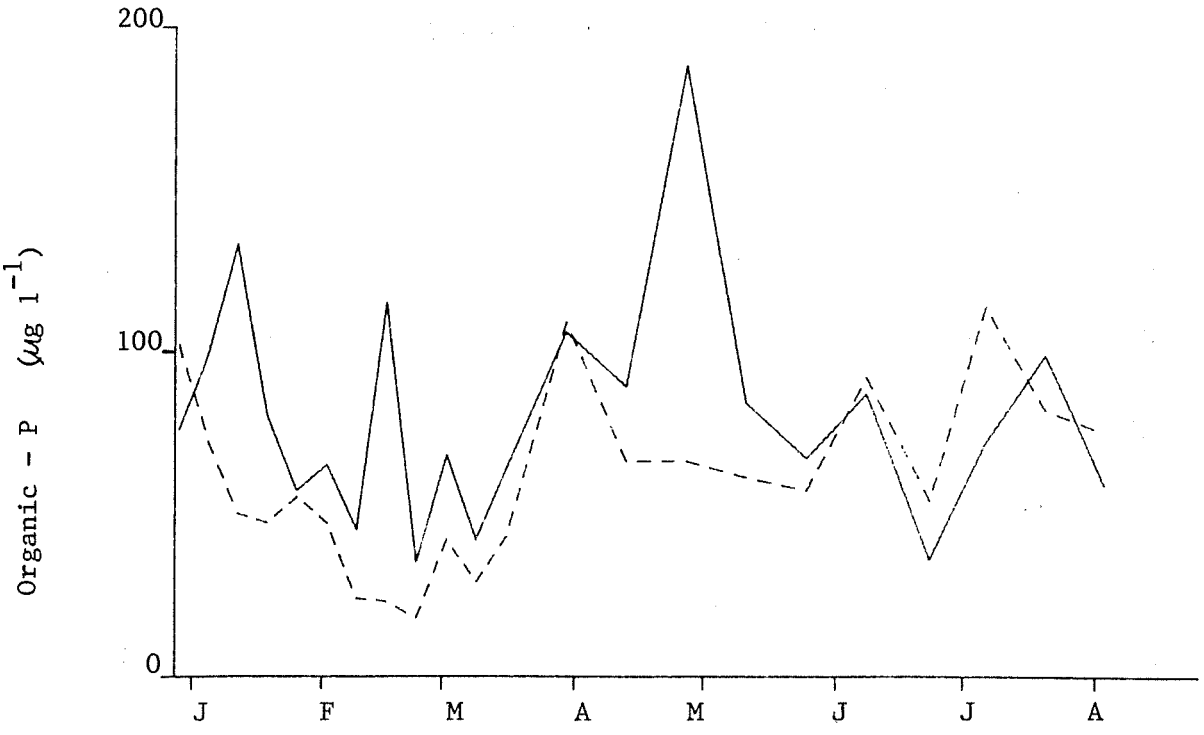

Fig. 6.6 Organic phosphorus

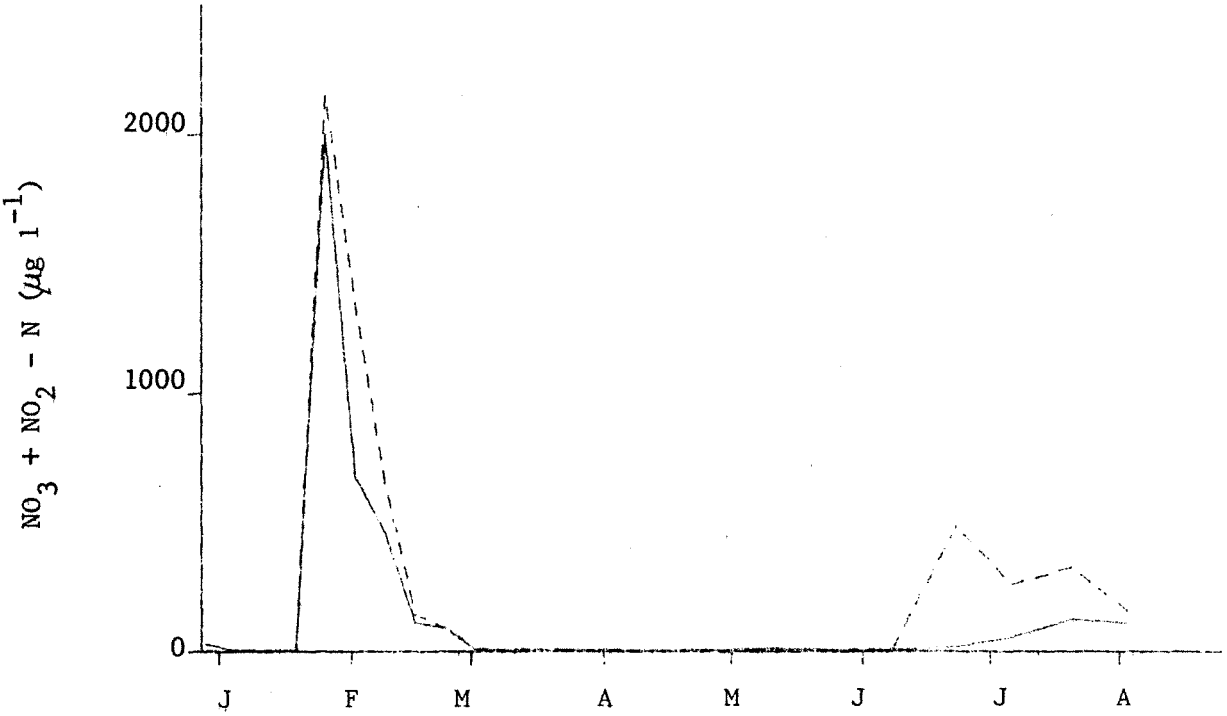

Fig. 6.7 Nitrate-nitrite nitrogen

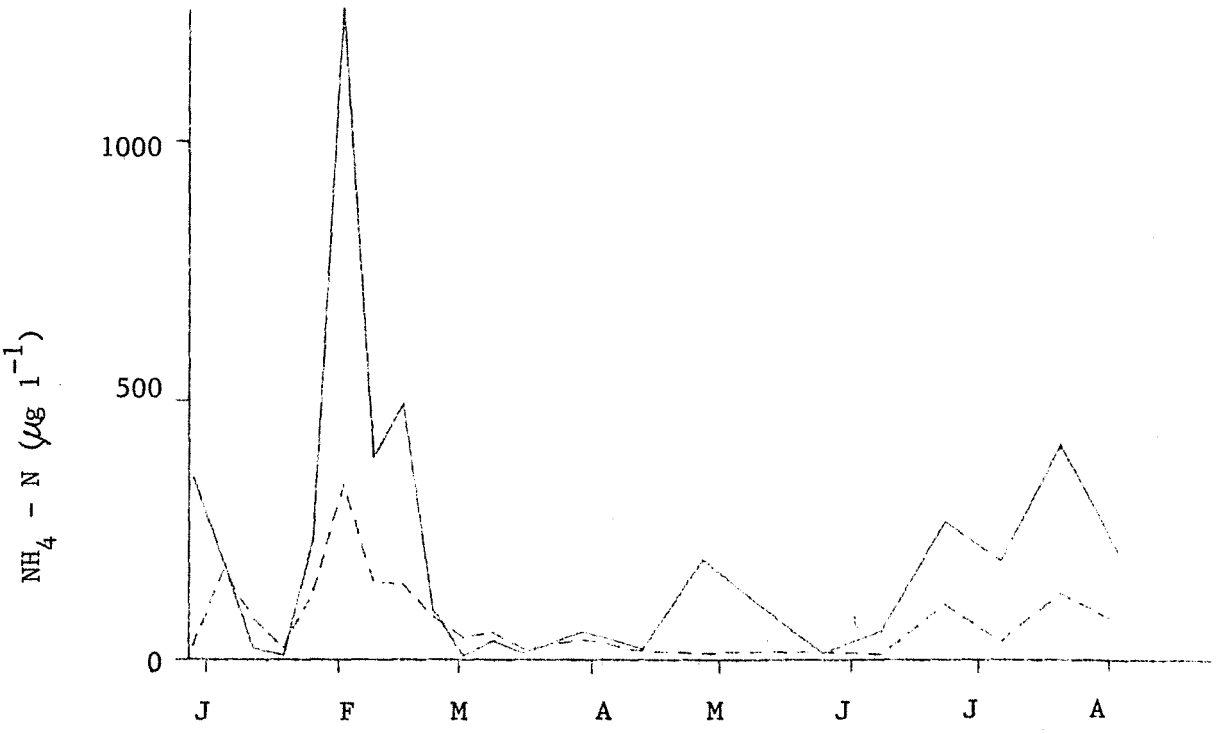

Fig. 6.8 Ammonium nitrogen

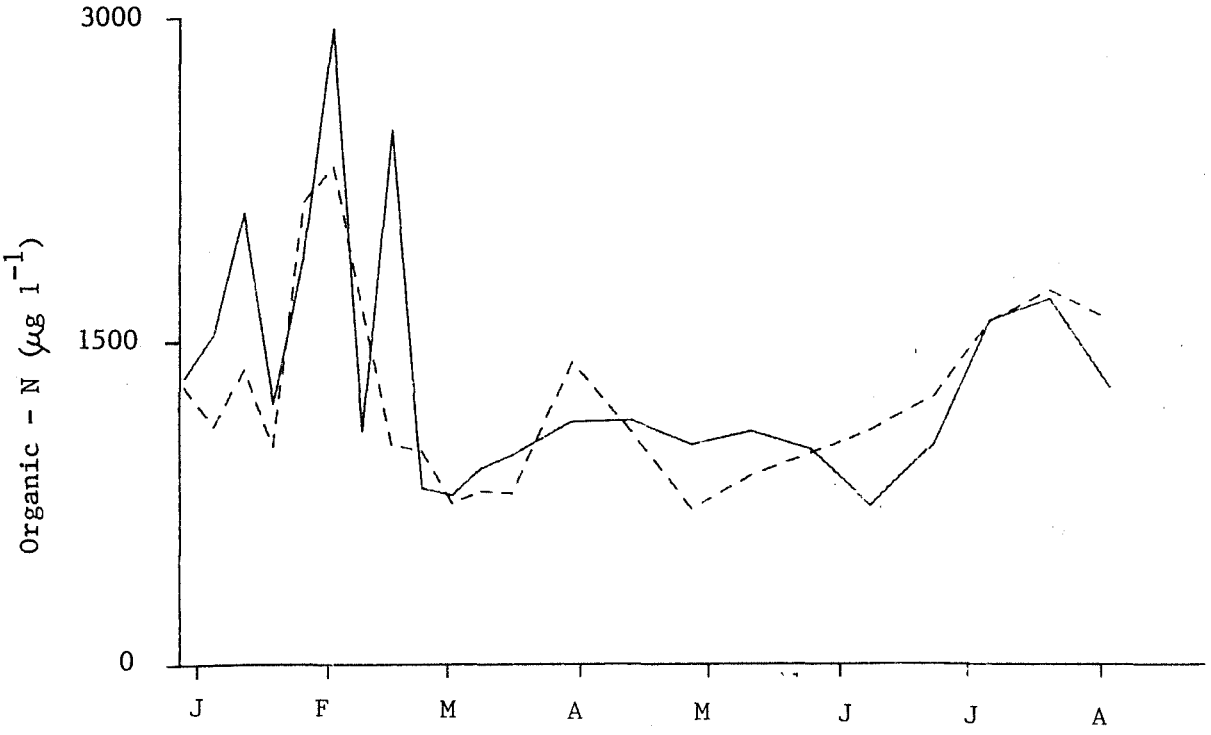

Fig. 6.9 Organic nitrogen

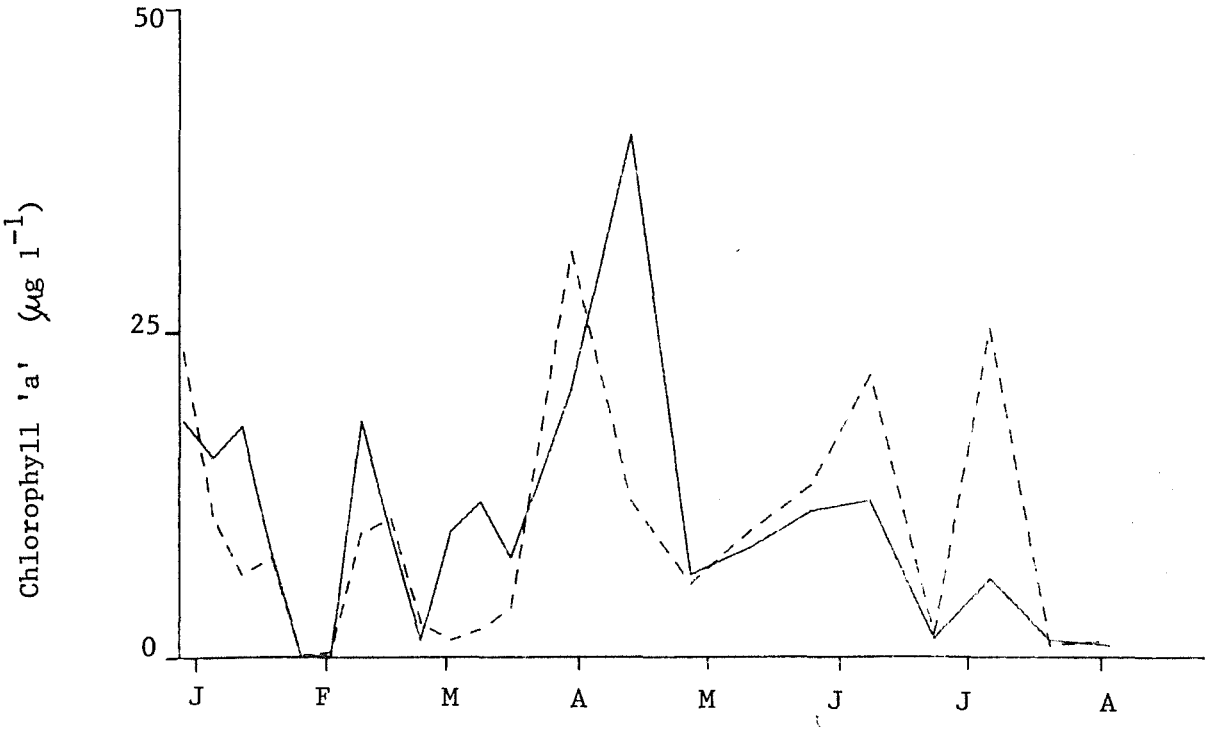

Fig. 6.10 Chlorophyll 'a'

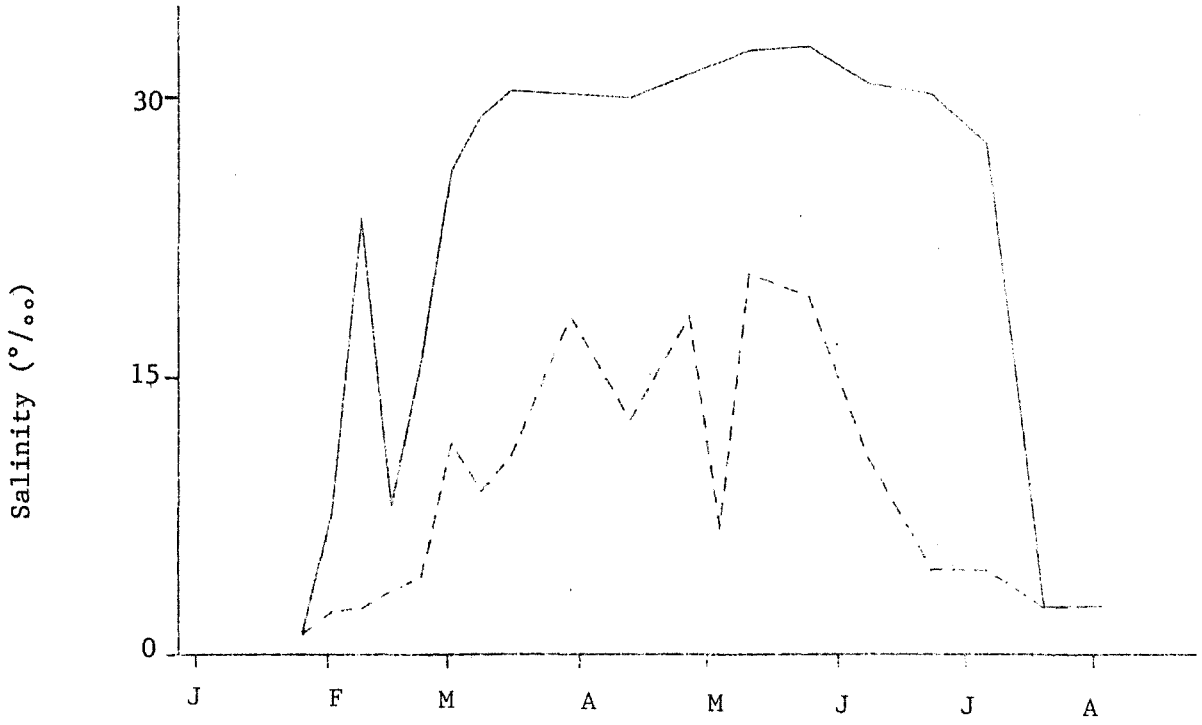

Fig. 7.1 Salinity

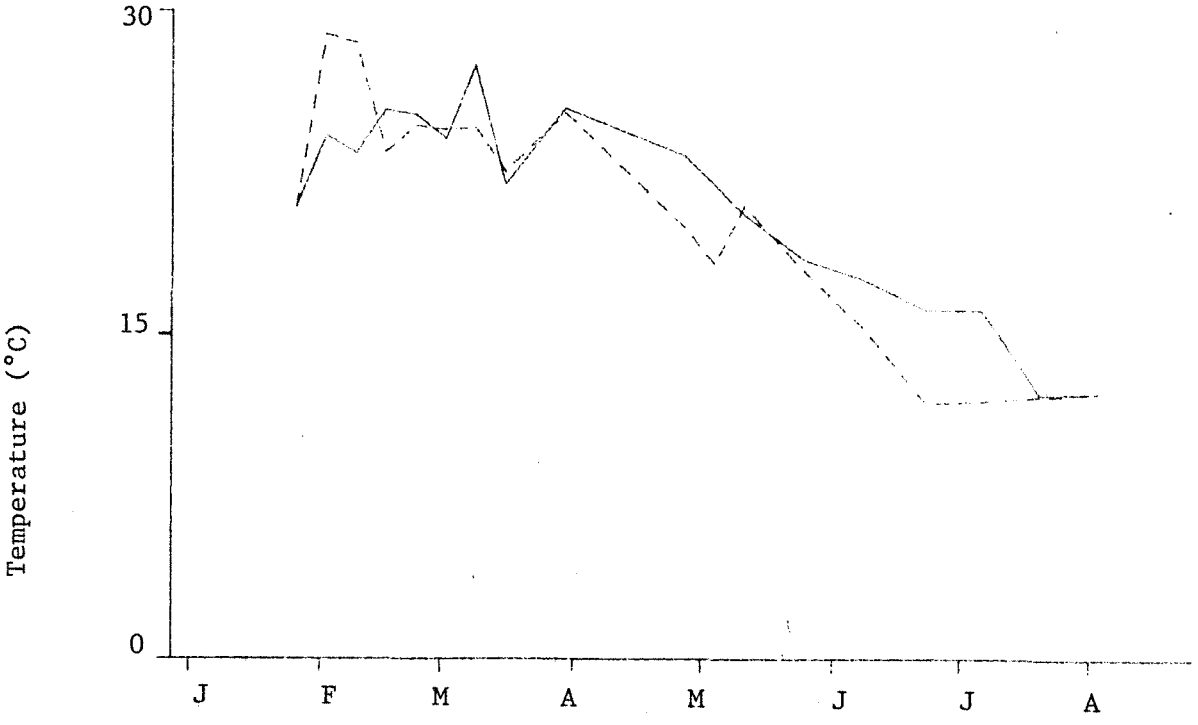

Fig. 7.2 Temperature

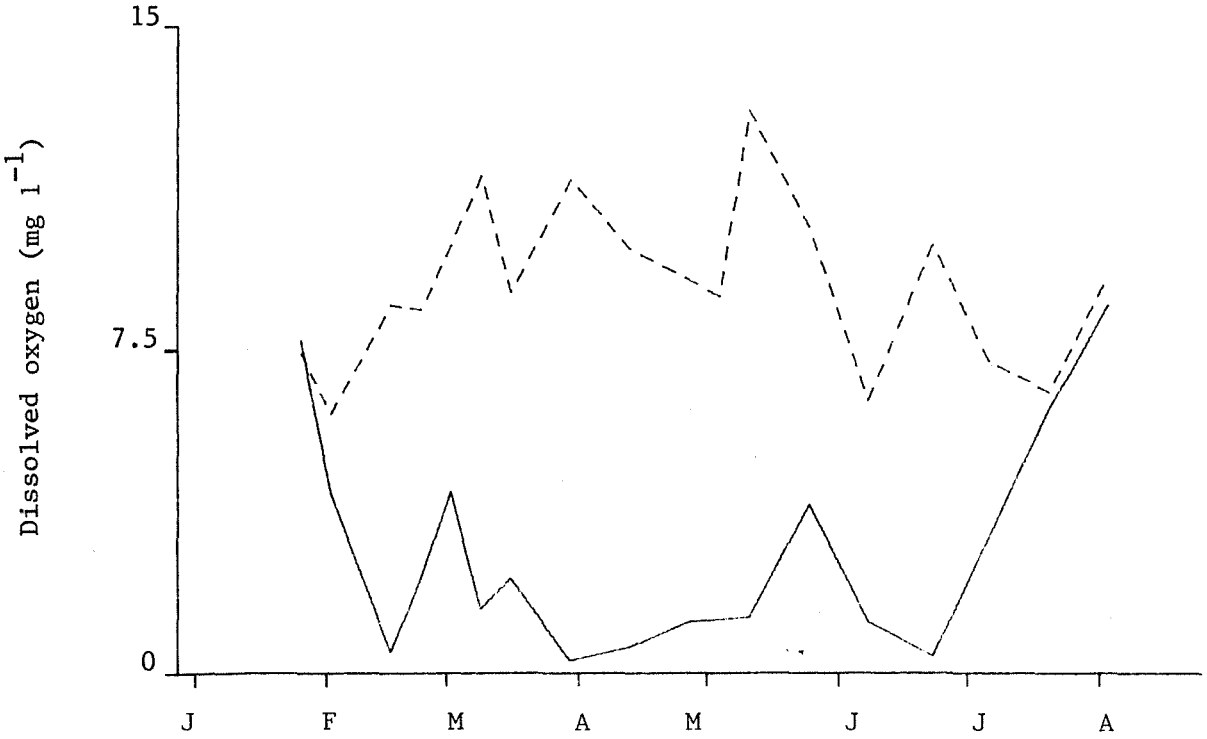

Fig. 7.3 Dissolved oxygen

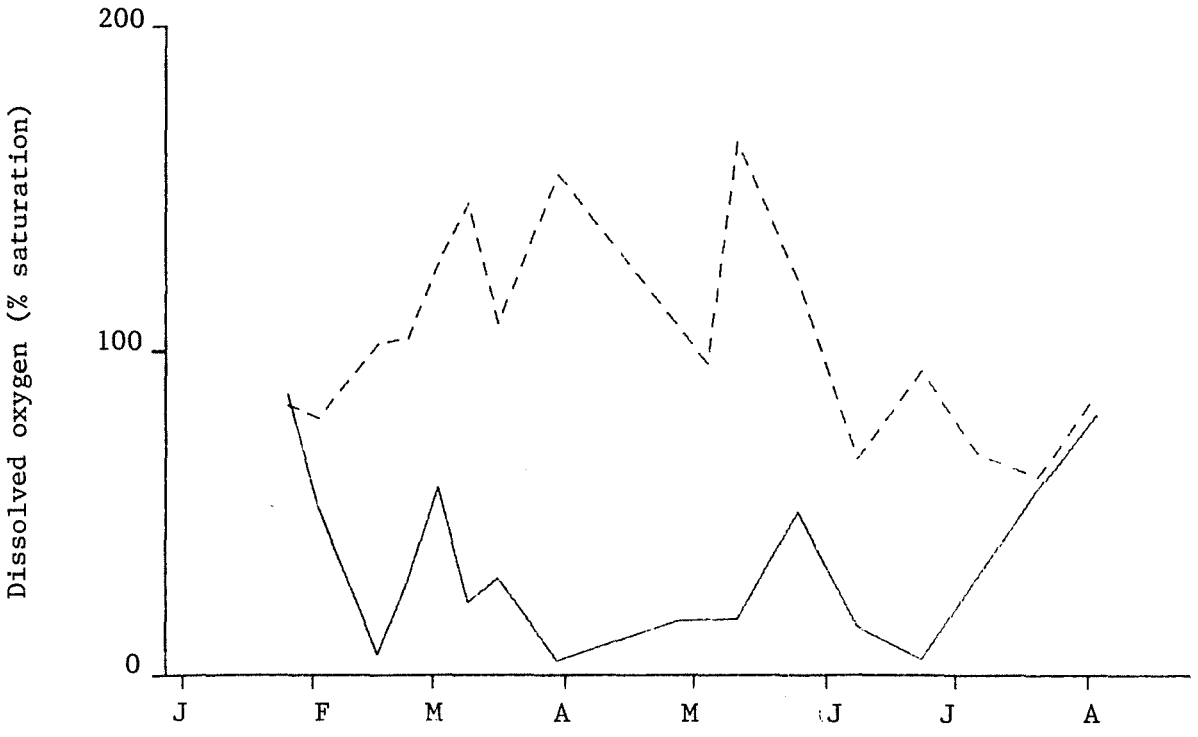

Fig. 7.4 Dissolved oxygen

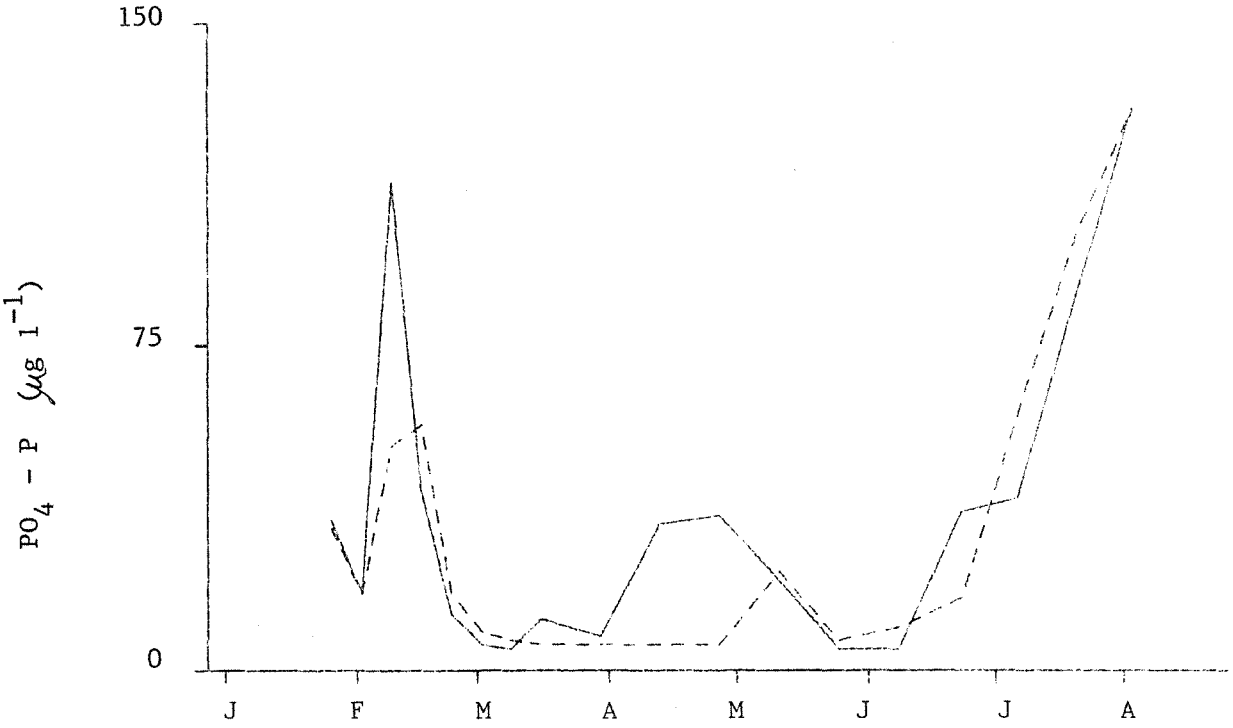

Fig. 7.5 Phosphate phosphorus

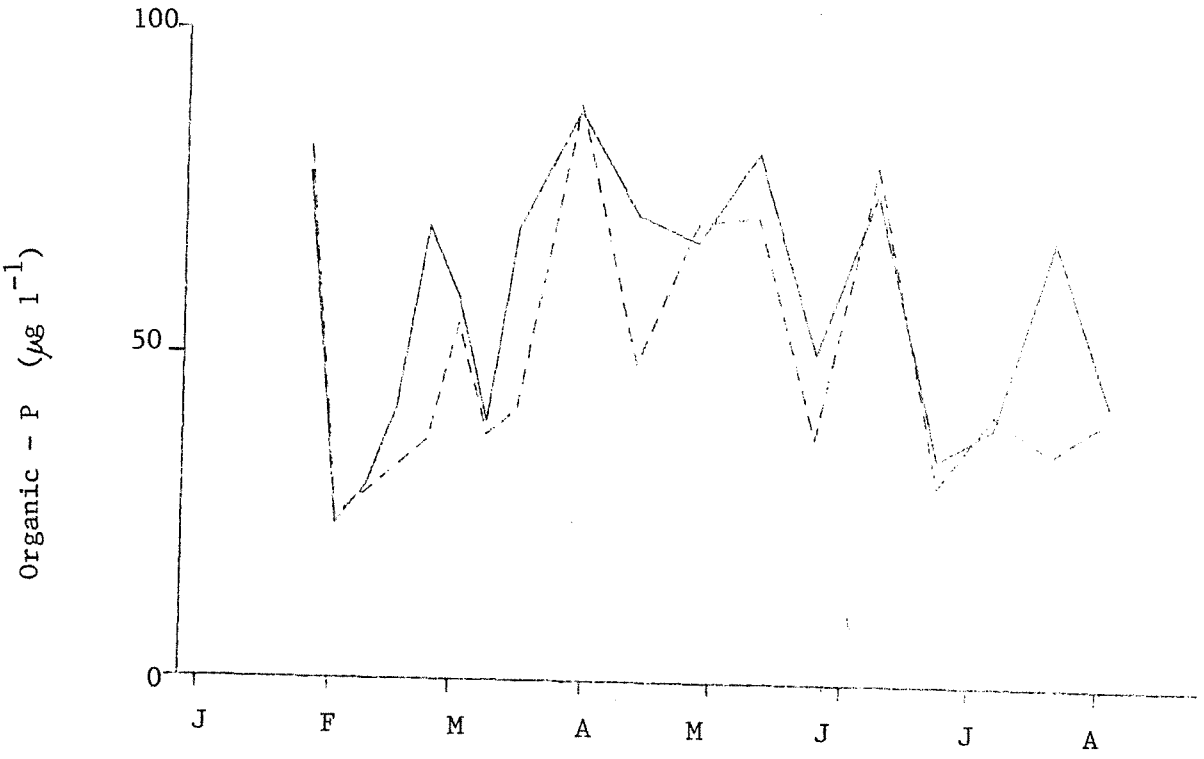

Fig. 7.6 Organic phosphorus

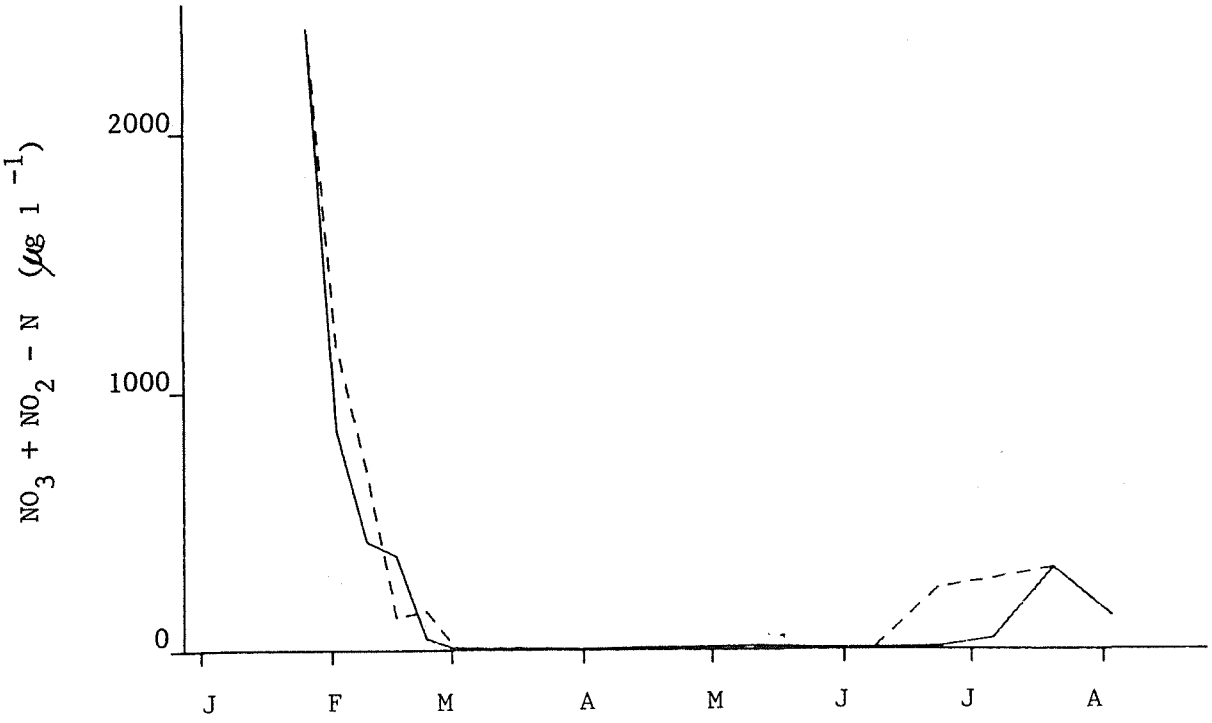

Fig. 7.7 Nitrate-nitrite nitrogen

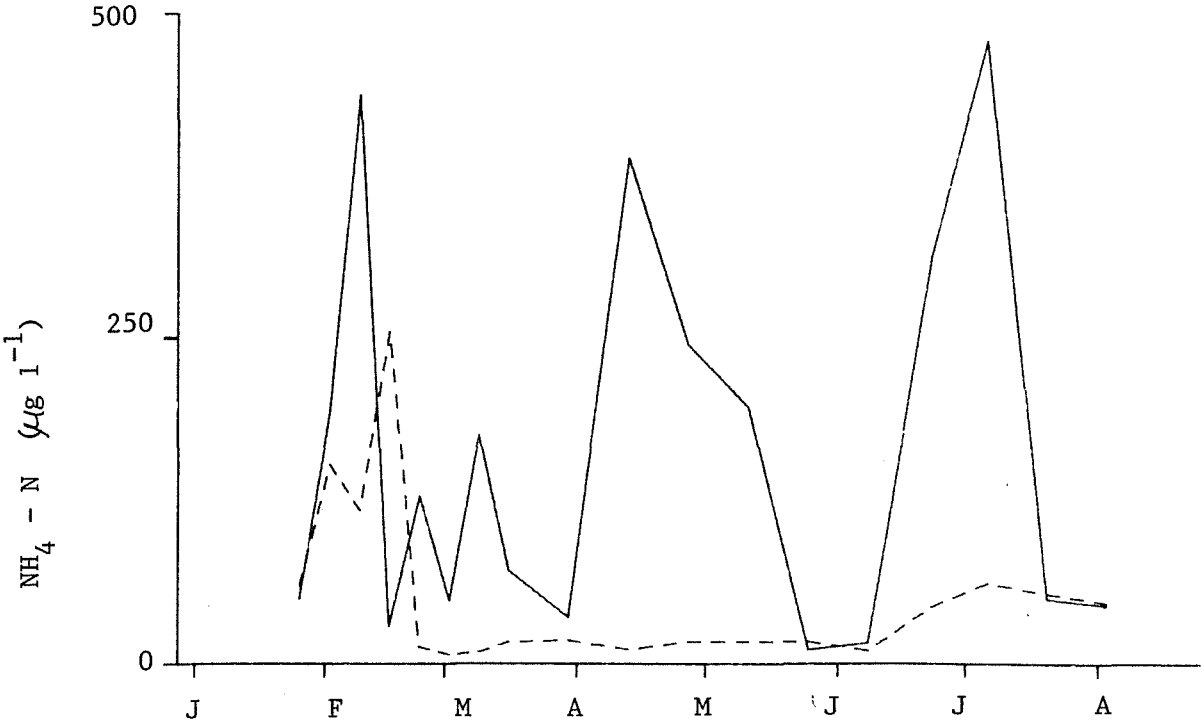

Fig. 7.8 Ammonimu nitrogen

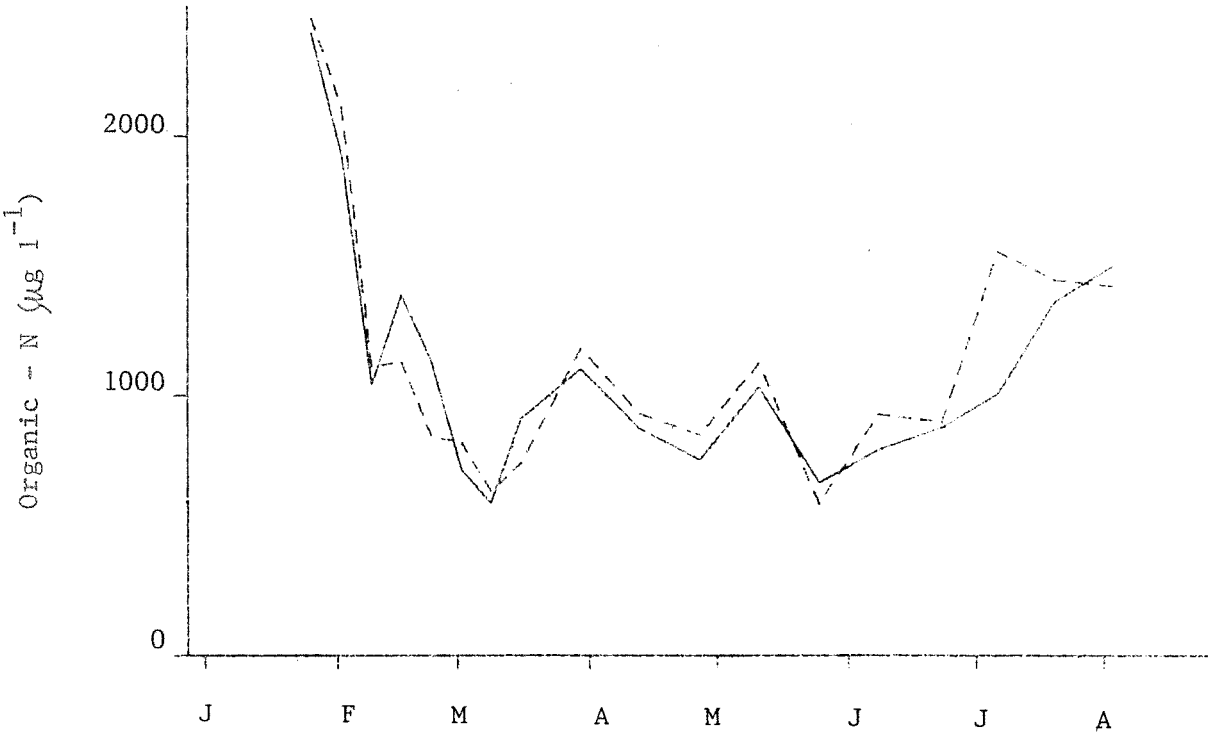

Fig. 7.9 Organic nitrogen

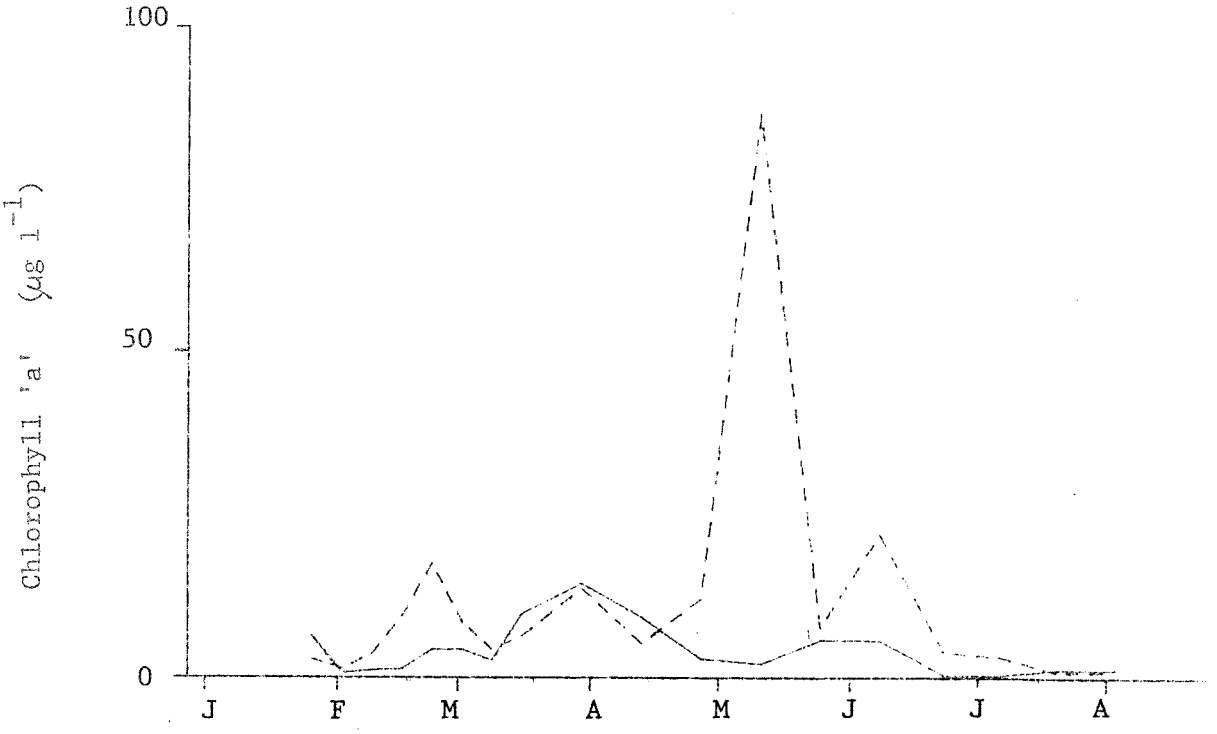

Fig. 7.10 Chlorophyll 'a'

Appendix B. Long-term plots of nutrient levels at the Ravenswood Bridge site (Site 4, Fig. 1) over the period 30.9.77 to 3.8.82. Figures are labelled B1 to B5.

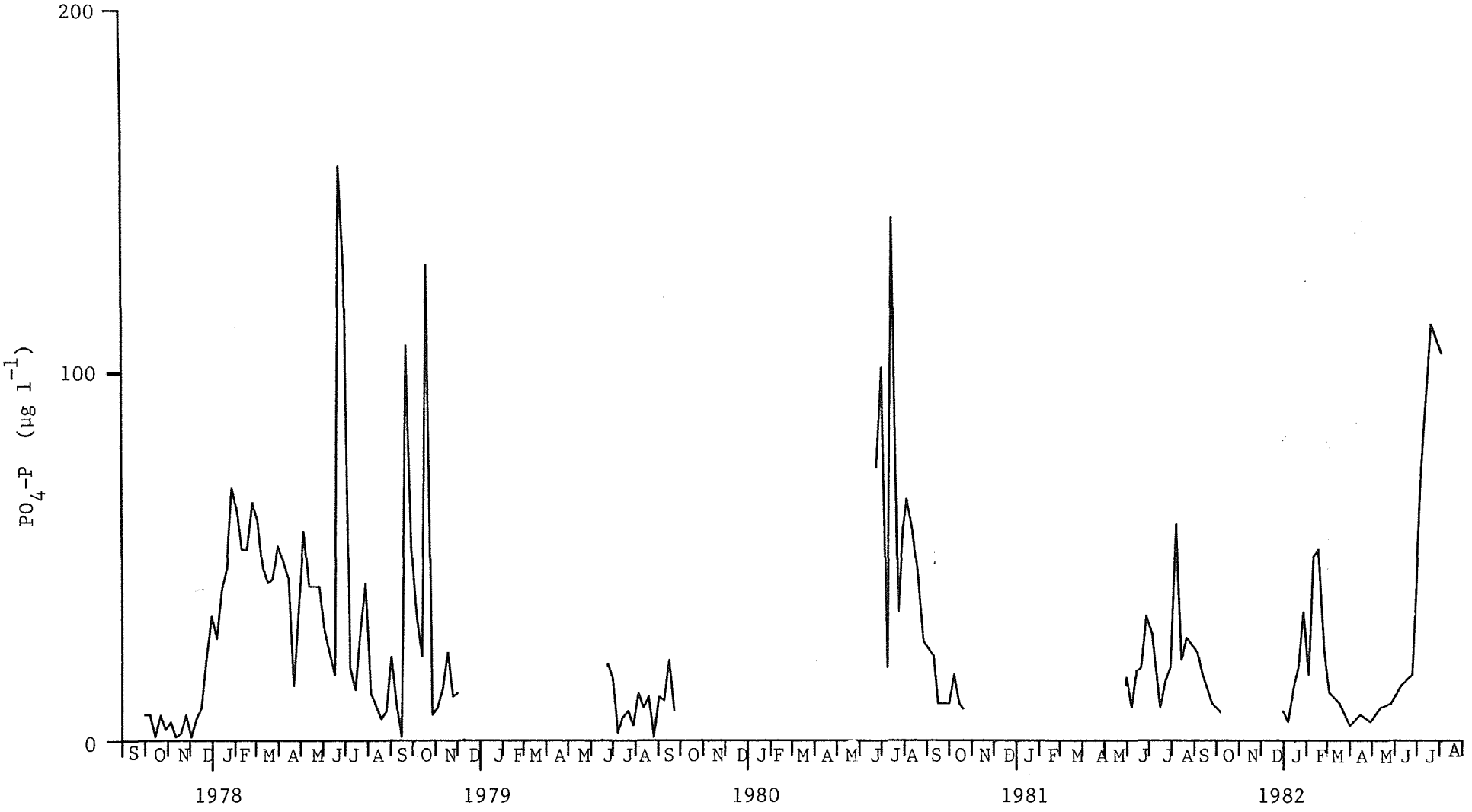

Fig. B1 Surface phosphate phosphorus, Revenswood Bridge, Murray River.

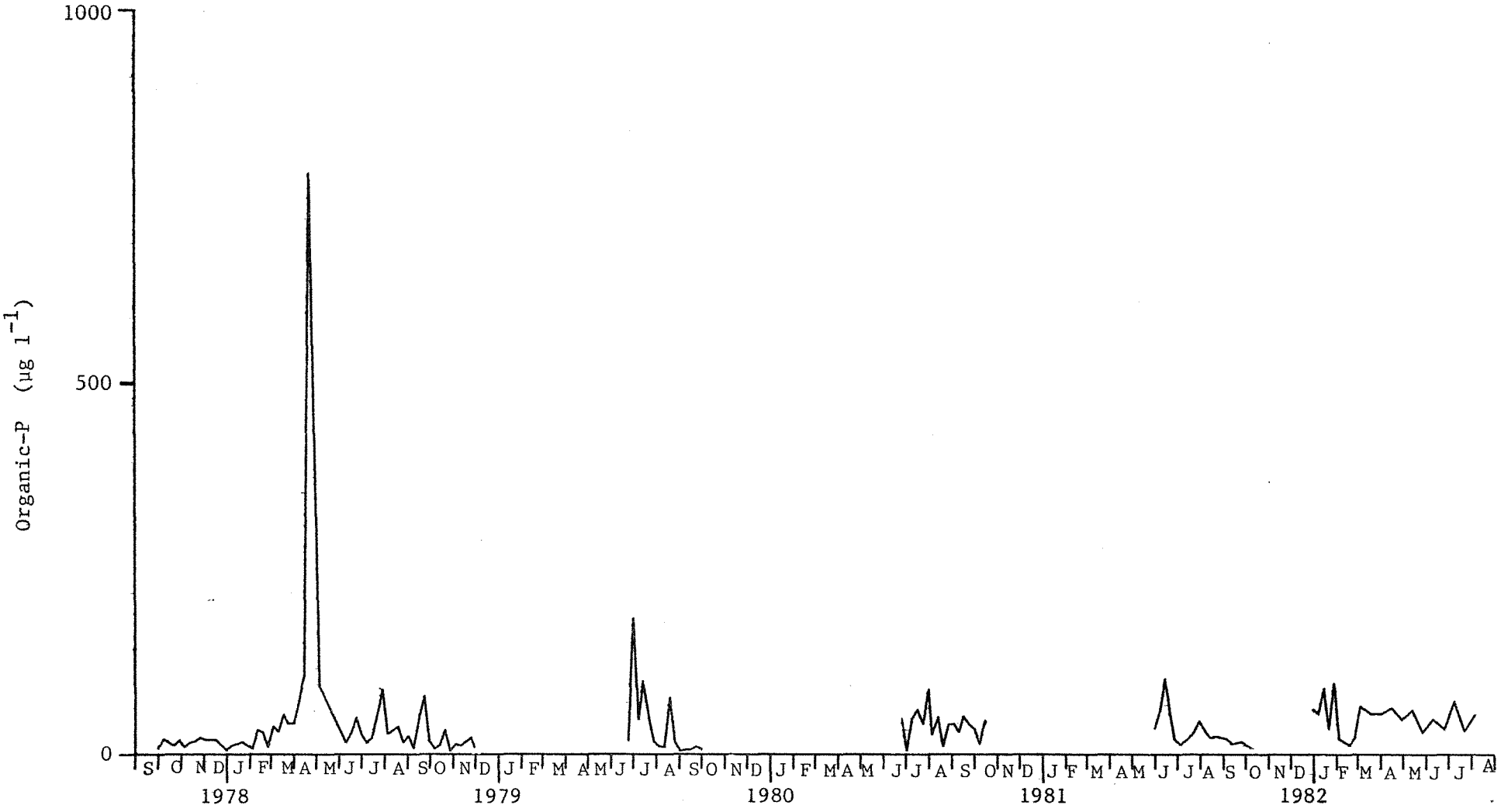

Fig. B2 Surface organic phosphorus, Ravenswood Bridge, Murray River.

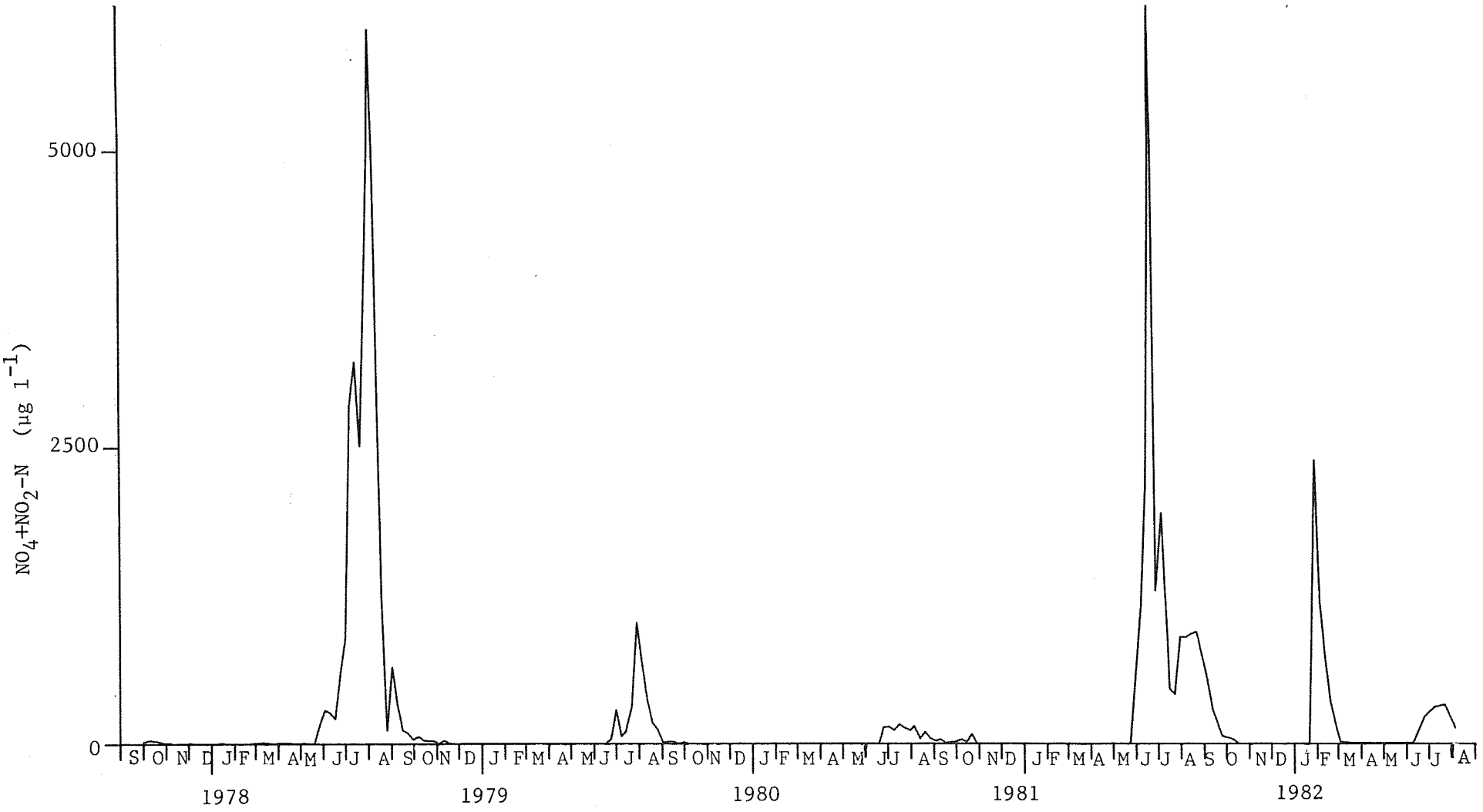

Fig. B3 Surface nitrate-nitrite nitrogen, Ravenswood Bridge, Murray River.

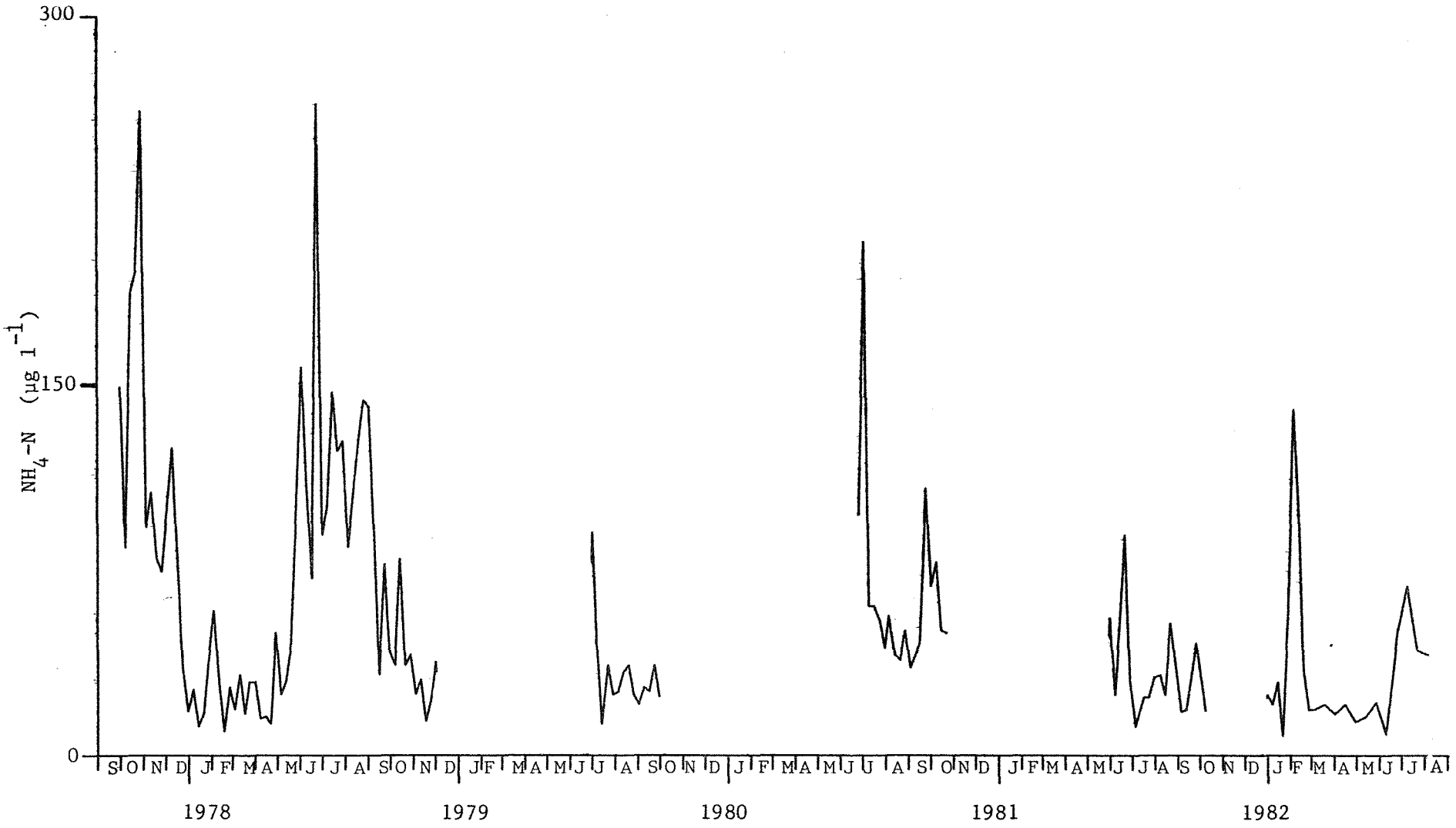

Fig. B4 Surface ammonium nitrogen, Ravenswood Bridge, Murray River.

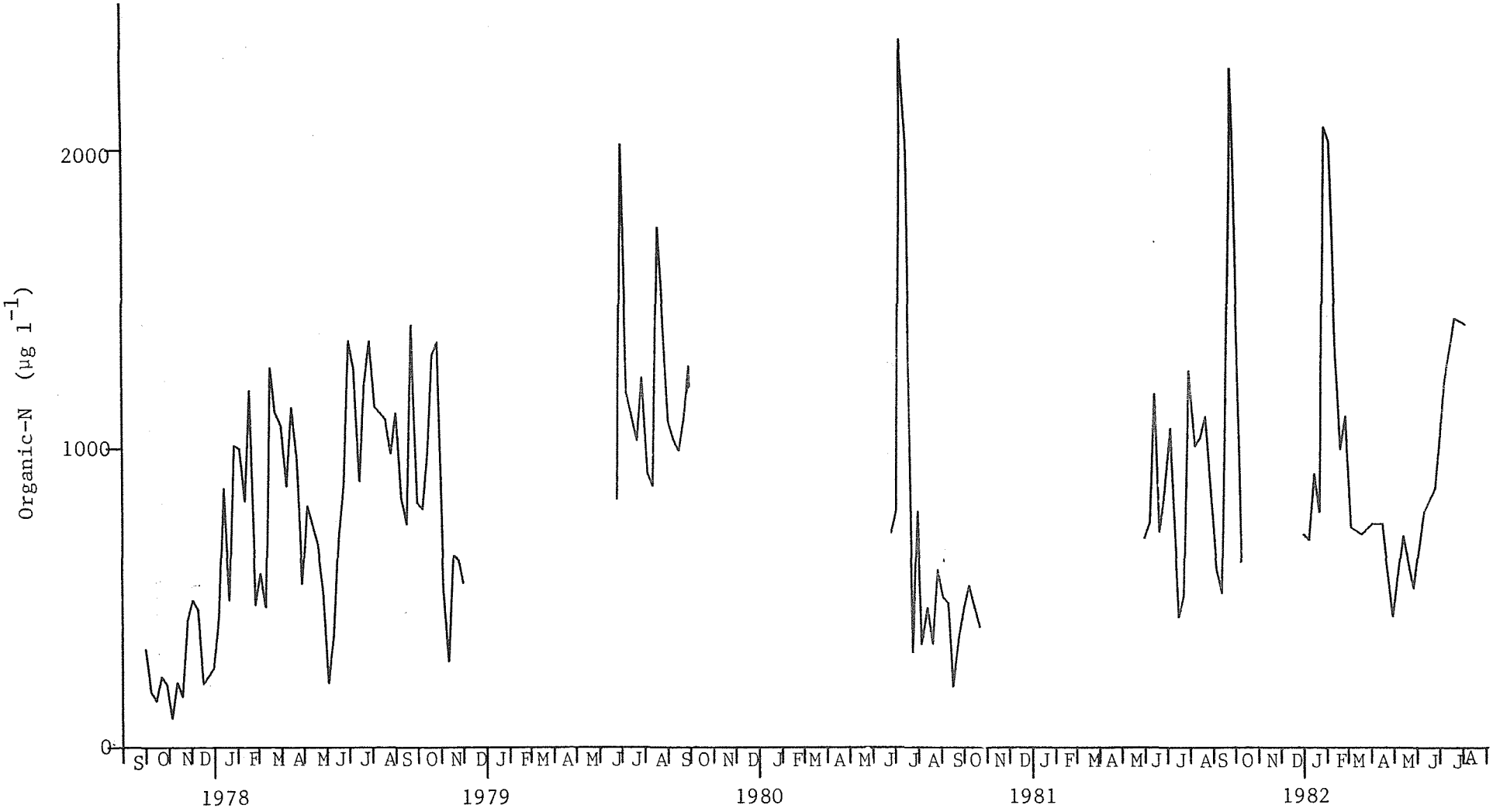

Fig. B5 Surface organic nitrogen, Ravenswood Bridge, Murray River.