The Nutrient Status of Wilson Inlet (1984 — 1985)

Department of Conservation and Environment
Perth, Western Australia

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ABSTRACT

In response to the concern of local residents about the condition of Wilson Inlet, a study of the inlet and its catchment was undertaken during 1982-83. While the results for that study were clear, it occurred during an atypical year; the winter had a particularly low rainfall and the sand bar between the estuary and the ocean was breached for the shortest period of any winter. To obtain some understanding of the variability likely to be encountered in the estuary between years, another, smaller study was undertaken in 1984-85.

The main conclusions about nutrient concentrations in plant tissues, the importance of phosphorus, total plant biomass and general ecosystem behaviour were similar to those reached in the earlier study, despite very different winters. Catchment behaviour, in relation to nutrient losses to streamflow was also generally similar, with somewhat higher concentrations of nutrients associated with a winter of higher runoff. The main contrast was the large amount of nitrogen, especially in the form of nitrate, which came from the larger subcatchments during the present study.

Rainfall was much closer to the long-term mean in 1984 and there was a 2.8 times increase in streamflow for the whole Wilson Inlet catchment compared to 1982. The phosphorus load of 19 tonnes was lower than the 30 tonnes predicted for an average year on the basis of the 1982 results. The nitrogen load of 340 tonnes was slightly higher than predicted for an average year from the 1982 study.

Salinities were lower and nutrient concentrations and water column loads higher in winter in the present study due to the higher streamflows. Chlorophyll 'a' concentrations and water column load were also higher, presumably in response to the higher nutrient loads. Estimates of total plant biomass in winter were similar, and the results of both studies show that *Ruppia* biomass is one of the major nutrient banks in the Inlet. Sediment nutrient loads were similar in both studies.

A nutrient budget was calculated for one cycle of bar opening and closing. There was a net retention of phosphorus of 9 tonnes (49% of total input), and net retention of nitrogen of 217 tonnes (63%). The percentage of total riverine phosphorus load retained by the inlet was similar in both studies. In contrast, it was estimated that there was net export of nitrogen in the previous study.

CONTENTS

TABLES

FIGURES

1. INTRODUCTION

A study was undertaken in 1982/83 of nutrients and plant biomass in Wilson Inlet, concentrating on nutrient loading from catchments in the winter of 1982, and nutrient concentrations and plant material present in the estuary until the following June (Lukatelich, Schofield and McComb, 1984). As it eventuated, that winter had a particularly low rainfall and the sand bar between the estuary and the ocean was breached for the shortest period of any winter since 1959, when the bar did not open at all.

While the results for that study were clear, it occurred during an atypical year and hence provided a reason for collecting data in a second year. Another reason was to obtain some understanding of the variability likely to be encountered in the estuary between years. The following more modest programme was therefore undertaken from winter 1984 through to the following summer. As shown below, the choice of year was apppropriate for providing a contrast to the conditions of the previous study: rainfall in 1984/85 was particularly high and the sand bar remained open for the longest period on record.

The latest study concentrated on streamflow and nutrient concentrations for the river waters during winter, with a greatly reduced sampling programme for plant biomass and nutrient concentrations in the estuary. The main thrust of this report is to compare the results with those of the previous study. To this end a nutrient budget was estimated for the estuary, in order to assess the relative amounts of nitrogen and phosphorus retained by estuarine processes.

2. MATERIALS AND METHODS

2.1 ESTUARY SAMPLING

Two intensive sampling surveys (grid studies) were carried out at 16 sites (Figure 1) on 31 July 1984 and 25 April 1985. Water, plant and sediment samples were collected and analysed as outlined by Lukatelich et al, (1984). Total water column nutrient and chlorophyll 'a' load, plant biomass, plant tissue nutrient load, and sediment nutrient and chlorophyll 'a' load, were estimated from planimetry of computer drawn maps as described previously.

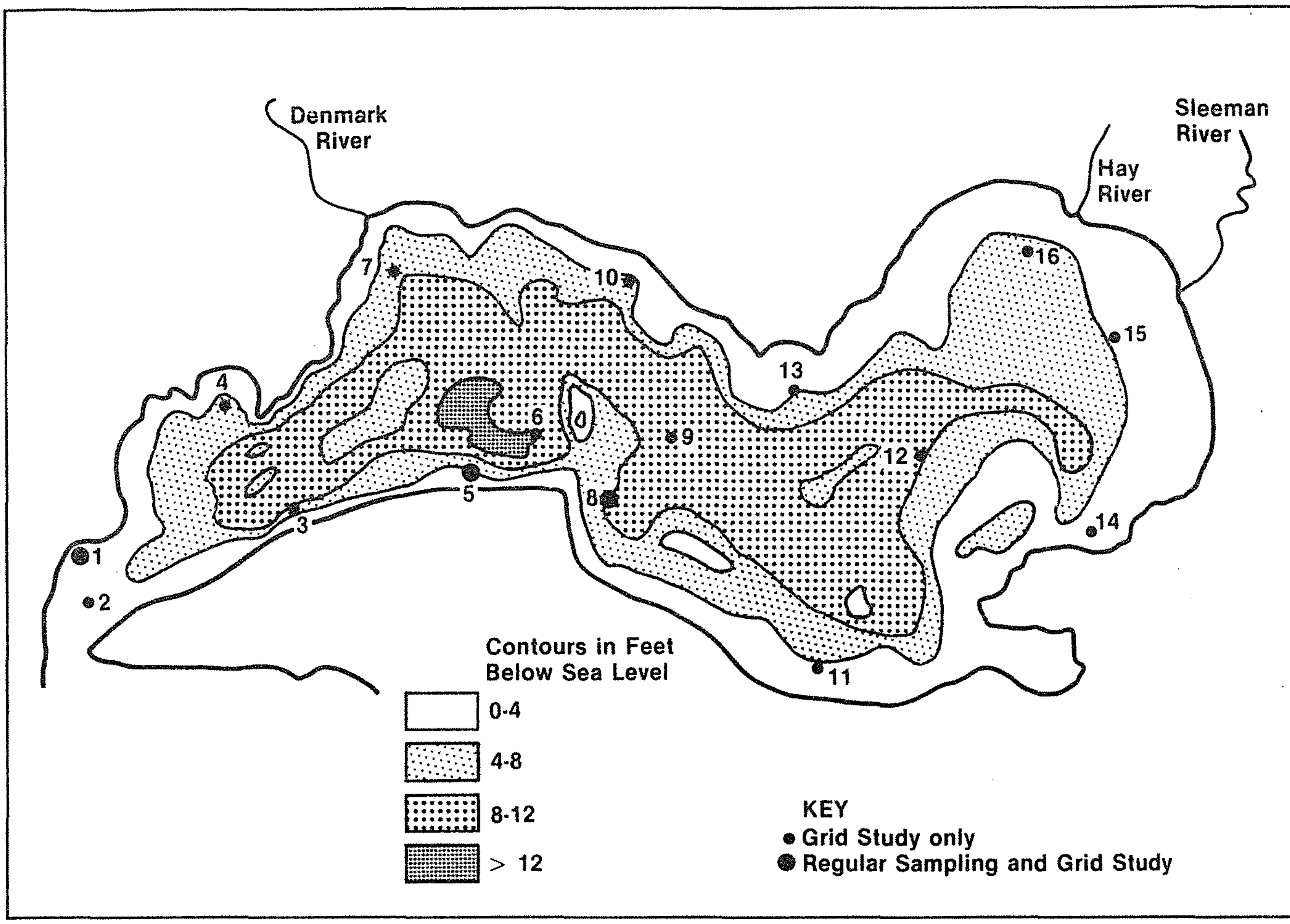

Figure 1. Bathymetry and location of sampling sites in Wilson Inlet.

2.2 ESTIMATES OF STREAMFLOW AND NUTRIENT INPUT

To estimate streamflow and nutrient input to the inlet, a network of sampling and gauging points was established in the catchment (Figure 2). The network was similar to that described by Lukatelich et al. (1984), except the Denmark Agricultural Research Station was excluded. Also one gauging point was moved to a better location. All the gauging points were located some distance upstream of the Inlet to avoid the problem of back- flooding as the Inlet water level rose prior to the sand bar opening. On the major catchments, the Denmark and the Hay, Water Authority of Western Australia gauging stations were in operation and provided a continuous streamflow record. (The gauging station reference numbers are Denmark:603136 and Hay:603004). Gauging at the other points of the network was reliant on volunteer daily staff gauge readings. Unfortunately, consistent daily records were not always obtained in this way. Water levels were converted to instantaneous streamflows using rating curves developed at each point. Improved rating curves were obtained by a wider range of manual current meterings.

Nutrient sampling at the gauging points was weekly. All the samples were collected on the same day, which involved a round trip of about 250 km. Samples were stored in sealable, plastic whirlpaks and processed as described previously (Lukatelich et al, 1984). Sampling was conducted over the period 6 July-19 October 1984, representing the major runoff period of the year.

Streamflow inputs to the Inlet were calculated from continuously gauged records (supplied by the Water Authority of WA), or from simple interpolation of instantaneous daily flows. Nutrient loads were calculated from the product of estimated weekly flows and instantaneous weekly nutrient concentrations.

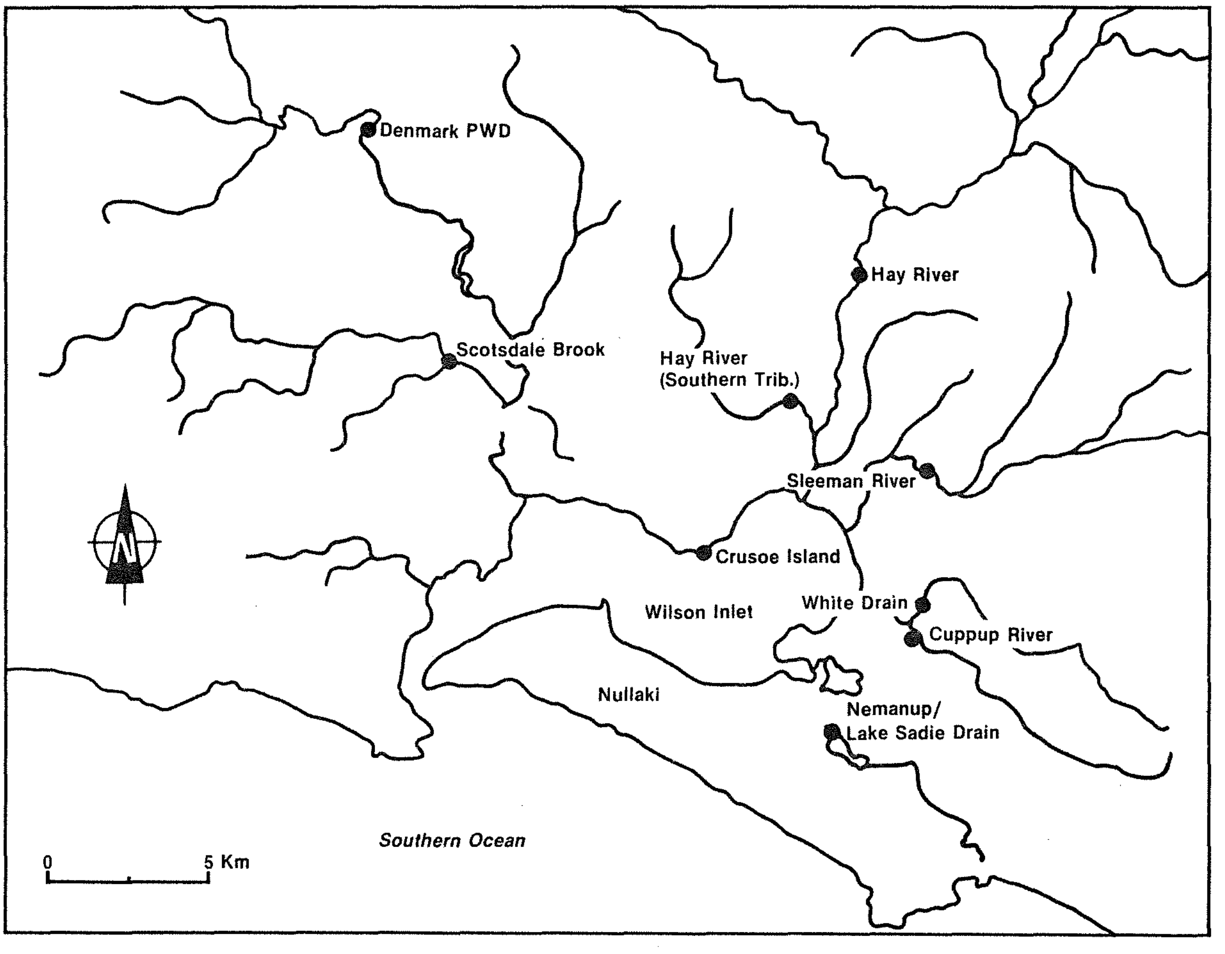

Figure 2. Gauging and sampling stations for the Wilson Inlet nutrient study.

Table 1 Channel through the Wilson Inlet sand bar: opening and closing dates, duration and position of opening [1]

Year	Opening Date	Closing Date	Period Open (Days)	Position of Opening
1954	NA[2]	NA	-	West Side
1955	15 June 55	NA	-	"
1956	10 June 56	NA	-	"
1957	8 August 57	NA	-	"
1958	7 August 58	28 December 58	147	"
1959	Bar Not Open	-	-	-
1960	12 July 60	5 January 61	177	"
1961	4 July 61	24 December 61	173	"
1962	17 August 62	24 January 63	160	Middle to East Side
1963	4 July 63	19 January 64	199	"
1964	22 July 64	NA	-	"
1965	24 August 65	NA	-	"
1966	27 July 66	NA	-	"
1967	18 July 67	April 68	277 15	"
1968	1 August 68	14 February 69	198	"
1969	1 September 69	22 December 69	113	"
1970	2 August 70	22 February 71	204	"
1971	16 July 71	4 March 72	231	West Side
1972	10 August 72	10 December 72	122	"
1973	13 August 73	14 February 74	185	"
1974	5 August 74	NA	-	"
1975	30 July 75	February 76	~ 199	"
1976	6 July 76	February 77	~ 223	"
1977	7 August 77	February 78	~ 191	"
1978	30 June 78	2 March 79	246	"
1979	16 July 79	February 80	~ 213	"
1980	1 August 80	24 January 81	176	"
1981	3 July 81	8 March 82	248	"
1982	21 July 82	10 September 82	51	"
1983	13 September 83	26 January 84	135	"
1984	5th August 84	10th May 85	279	"
1985	13th August 85	-	-	"

1 Sources of information: Water Authority of WA; Harbours and Rivers Section, Albany District Office; Department of Fisheries and Fauna File 142/51.

2 NA = Not Available

3. RESULTS

3.1 WATER LEVEL

The water level in the estuary is dominated by the time of opening of the bar (Lukatelich et al, 1984). The bar was breached on 5 August 1984 and was open until 10 May 1985 (Table 1). This was the longest period on record, in contrast to the earlier study when the bar was open for the shortest period on record.

3.2 TEMPERATURE, SALINITY AND DISSOLVED OXYGEN

Water temperatures (Figure 3) were similar to those recorded during the previous study (Lukatelich et al, 1984). Salinities in July 1984 were lower than at the same time in the earlier study (Figure 3). This was probably due to the higher streamflows recorded in 1984; estimated total flow prior to the bar opening in 1982 was 26.6 x $10^6 m^3$ (Lukatelich et al, 1984), whereas in 1984, 54.9 x $10^6 m^3$ flowed into the Inlet prior to bar opening. As a result of increased exchange with the ocean, due to the much longer period when the bar was open, salinities in April 1985, were higher than April 1983 (Figure 3). Salinity stratification was negligible in both studies. Dissolved oxygen concentrations (Figure 3) measured in April 1985 were similar to those in April 1983, and typical for that time of year.

3.3 NUTRIENT IN ESTUARY WATER

3.3.1 PHOSPHORUS

Phosphate phosphorus concentrations in July 1984 were lower than those recorded at the same time in 1982, even though riverine phosphorus loading in 1984 was about double the 1982 loading (Figure 4). The lower concentrations may have been due to assimilation by a higher phytoplankton biomass present in 1984. The mean chlorophyll 'a' concentration in July1984 was 8.1 μgL^{-1} compared with 2.7 μgL^{-1} in July 1982. Organic phosphorus concentrations in July 1984 were higher than those measured at the same time in the earlier study, possibly due to the larger phytoplankton biomass present at that time and the higher streamflows which had a higher phosphorus load (see below). Phosphate and organic phosphorus concentrations in April 1985 were comparable with those measured in April 1983.

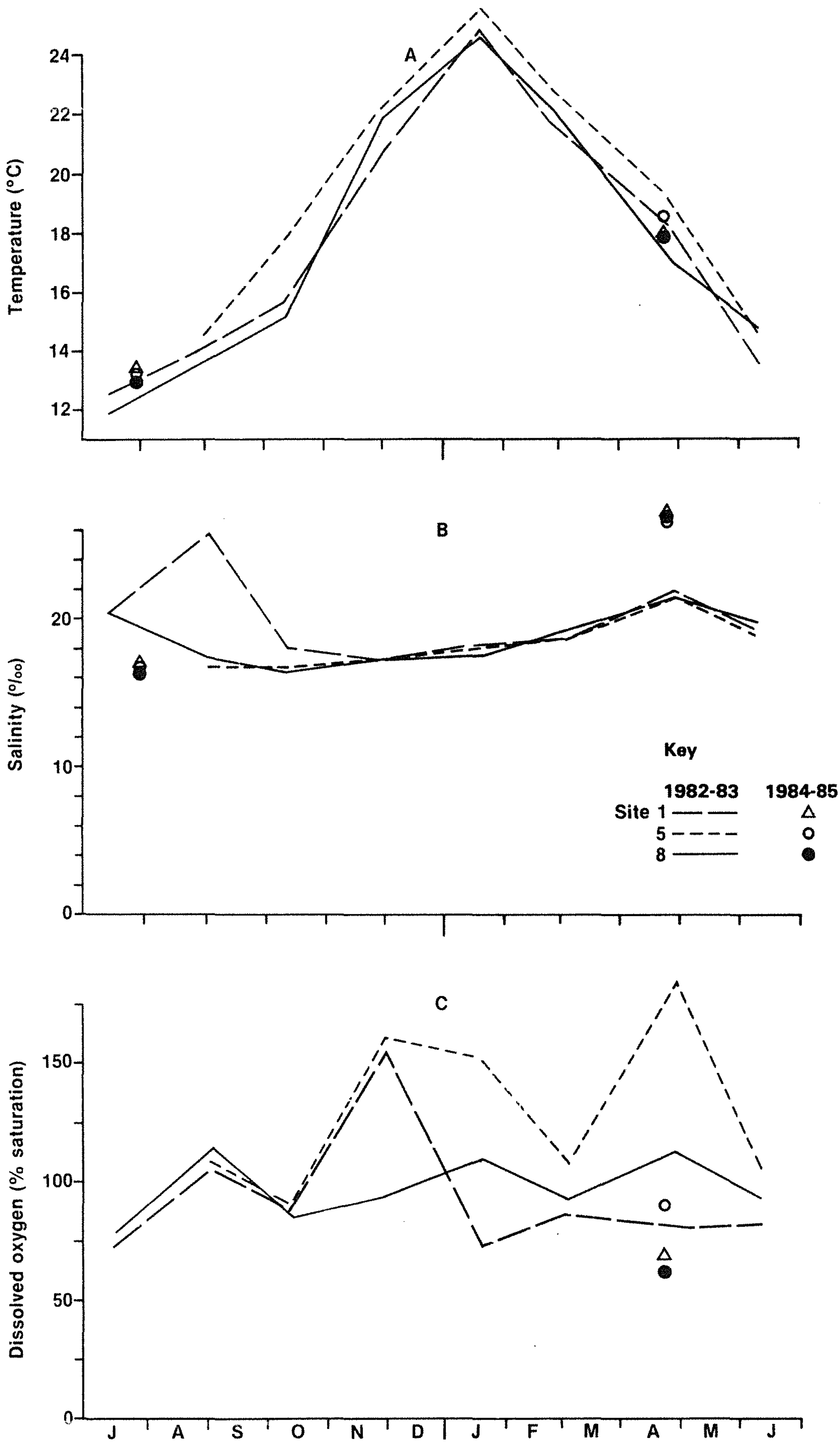

Figure 3. Seasonal variation in (A) temperature; (B) salinity; (C) dissolved oxygen in Wilson Inlet. Each point is the mean of surface and bottom readings.

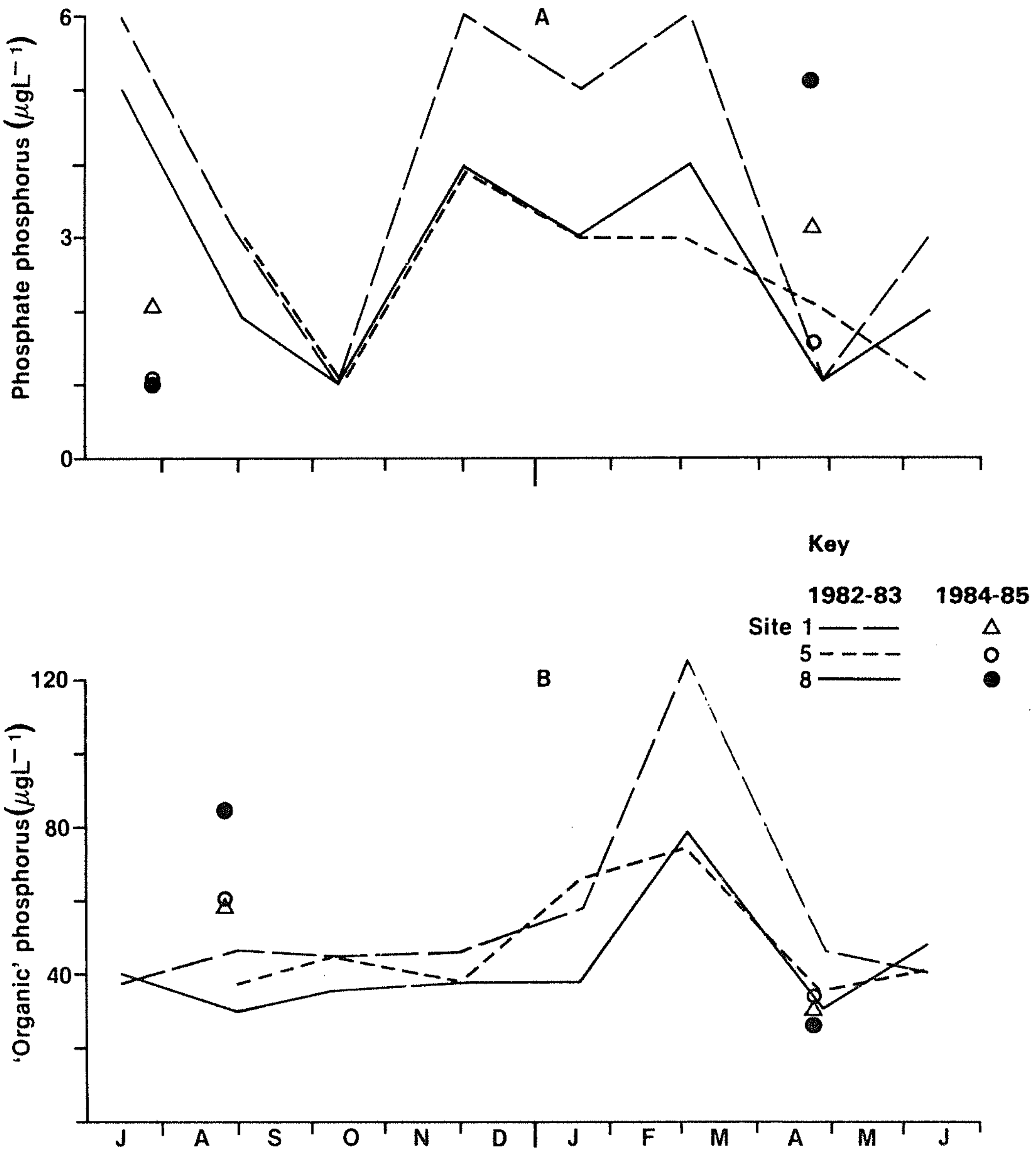

Figure 4. **Seasonal variation in phosphorus concentration of the water column in Wilson Inlet. (A) Phosphate phosphorus; (B) 'organic' phosphorus. Each point is the mean of a surface and bottom sample.**

3.3.2 NITROGEN

Nitrate-nitrogen concentrations (Figure 5) in July 1984 were much higher than those measured in July 1982 due to the much higher riverine nitrate loading in 1984 (see below). Nitrate concentrations in April 1985 were similar to those measured in the previous study.

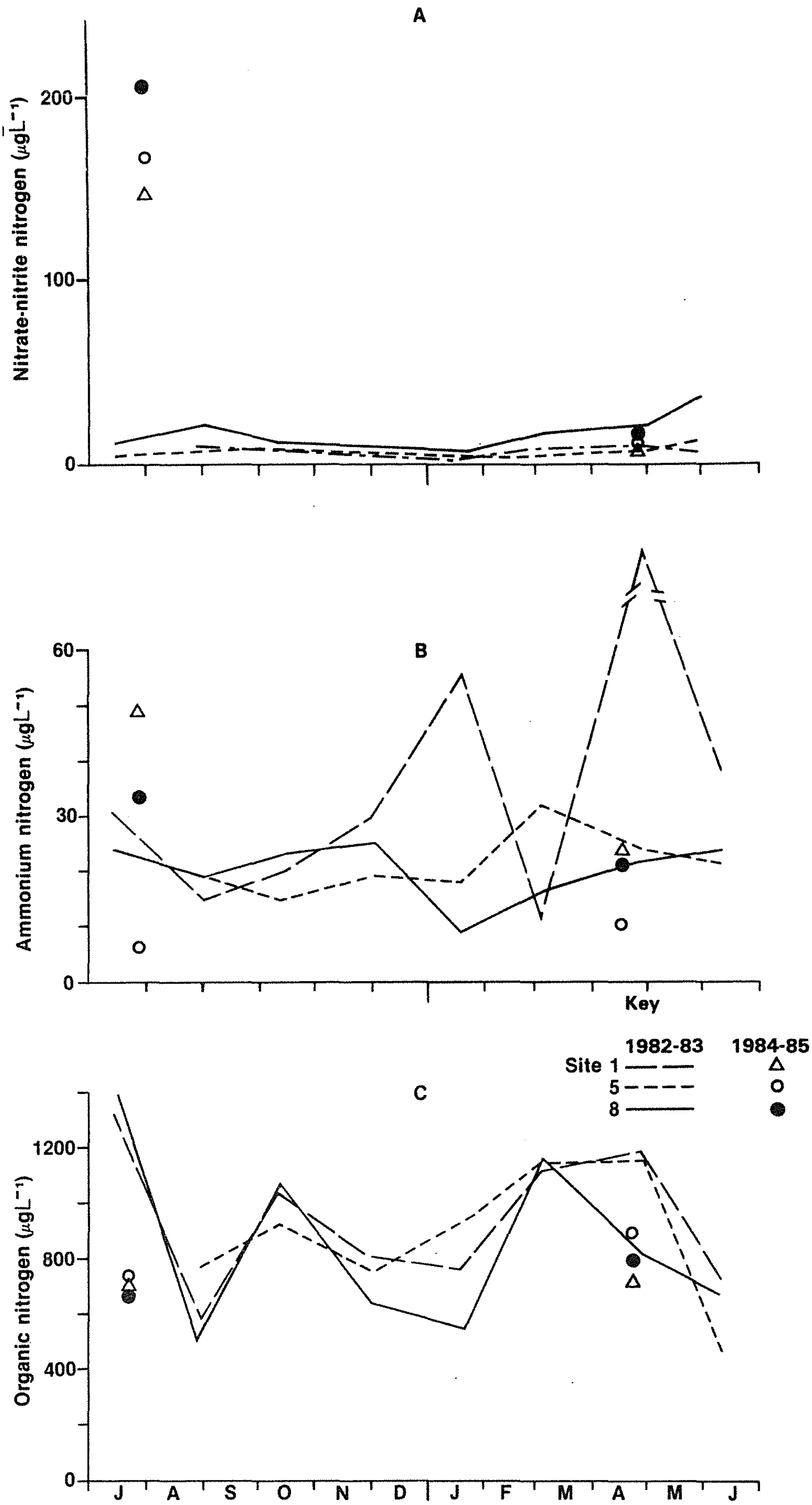

Figure 5. Seasonal variation in the nitrogen concentration of the water column in Wilson Inlet (A) Nitrate-nitrite nitrogen; (B) Ammonium nitrogen; (C) organic nitrogen. Each point is the mean of a surface and bottom sample.

Ammonium nitrogen concentrations measured in 1984/85 (Figure 5) were similar to those measured in 1982/83, though the concentration at site 1 in April was much lower than at the same time in the earlier study. *Ruppia* biomass at site 1 in 1984/85 was also much lower (see below), and the high ammonium concentrations in 1983 may be attributed to the decomposition of the large *Ruppia* biomass present at that time. Organic nitrogen concentrations (Figure 5) were within the range of concentrations recorded in 1982/83.

3.4 PHYTOPLANKTON

Surface chlorophyll concentrations measured in 1984/85 are shown in Figure 6. Concentrations in July 1984 were much higher than in July 1982. This is attributed to the higher riverine phosphorus and nitrogen loadings in 1984 (see below). The chlorophyll 'a' concentrations measured in April were similar in both studies, and if anything, somewhat lower in the second.

Mean chlorophyll 'a' concentrations (average of surface and bottom chlorophyll concentrations) are also shown in Figure 6. The differences in mean chlorophyll 'a' concentration were similar to those outlined above.

The dominant taxa of phytoplankton were similar in both studies.

3.5 MACROPHYTE BIOMASS

As in the previous study, *Ruppia megacarpa* dominated plant biomass. *Ruppia* above-ground biomass (Figure 7) in July 1984 was similar to that measured in 1982 at sites 5 and 8; however the above-ground biomass at site 1 was much lower in the present study. Site 1 is close to the local boat launching ramp, where, as build-up of *Ruppia* was impeding boat progress, the area was cleared of *Ruppia* with a back-hoe in late 1983. Above-ground biomass had not recovered to its former high level when sampling was carried out in July 1984.

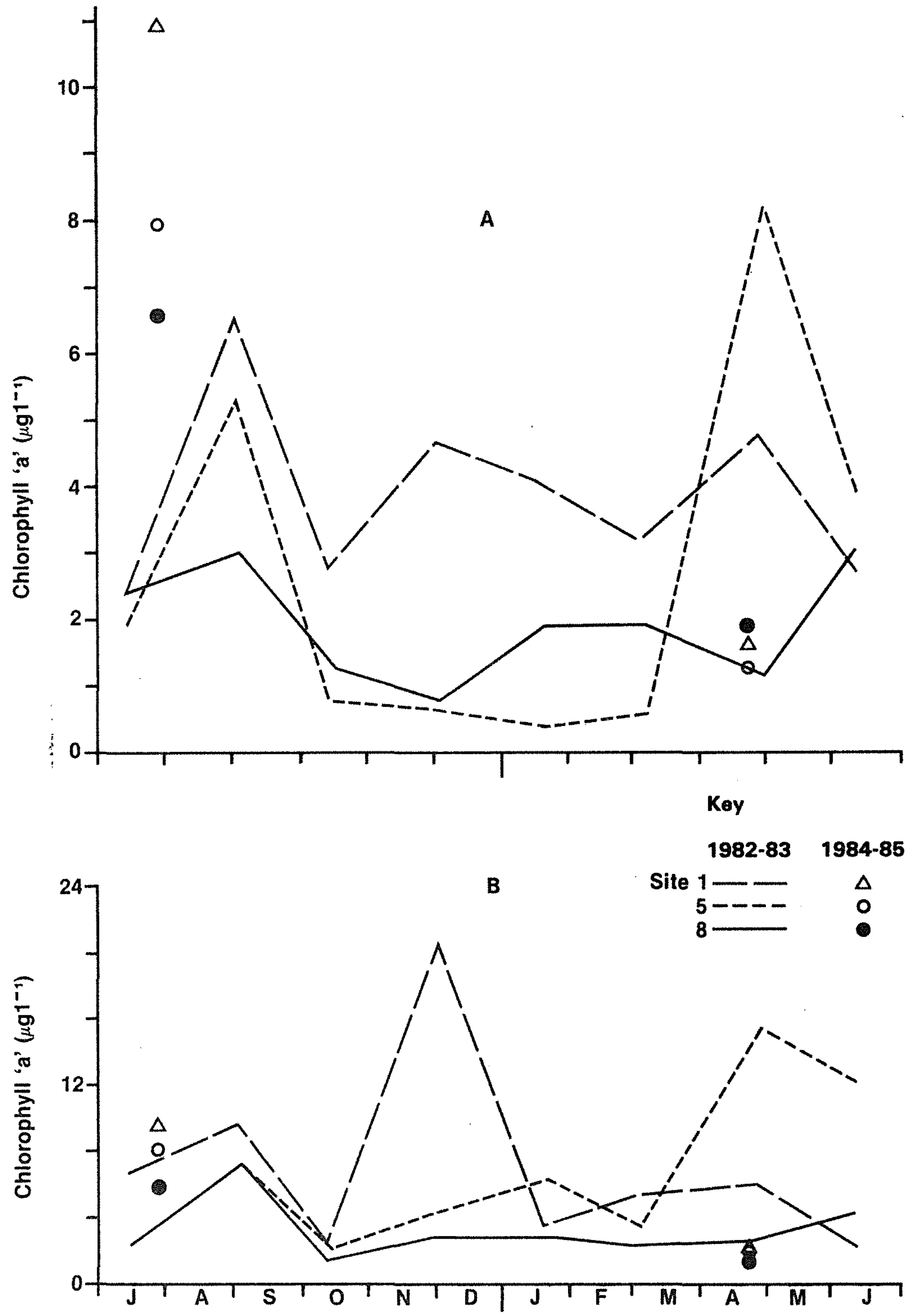

Figure 6. Seasonal variation in chlorophyll 'a' in Wilson Inlet. (A) surface; (B) mean concentration between a surface and bottom sample.

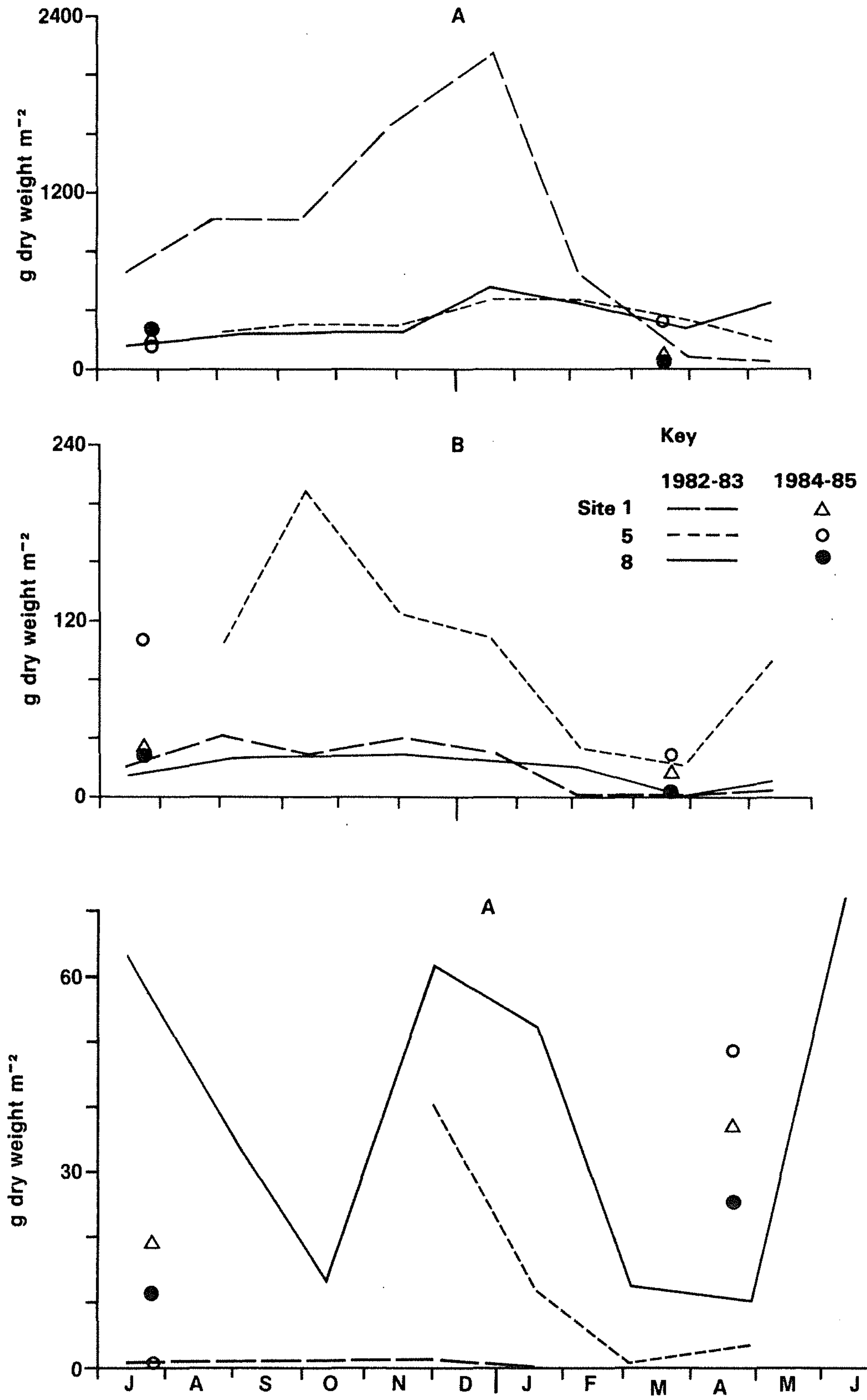

Figure 7. Seasonal changes in (A) *Ruppia* above-ground biomass; (B) *Ruppia* below-ground biomass; and (C) macrophyte biomass (excluding *Ruppia*).

In April, above-ground biomass was lower in 1985 than in 1983. Senescence of above-ground material appears to have begun earlier in 1985.

Below-ground biomass of *Ruppia* was similar in both studies (Figure 7). In July, the ratio of above-ground material to below-ground material was similar in both studies (Figure 8), with the exception of site 1, where, as mentioned above, weed clearing had been carried out. Due to the earlier senescence of above-ground material in 1985, the ratio of above-ground material to below-ground material in April was lower.

Figure 7c shows the biomass of macrophytes other than *Ruppia*. The biomass of other macrophytes was low in comparison to Ruppia biomass, as in the earlier study (Lukatelich et al, 1984).

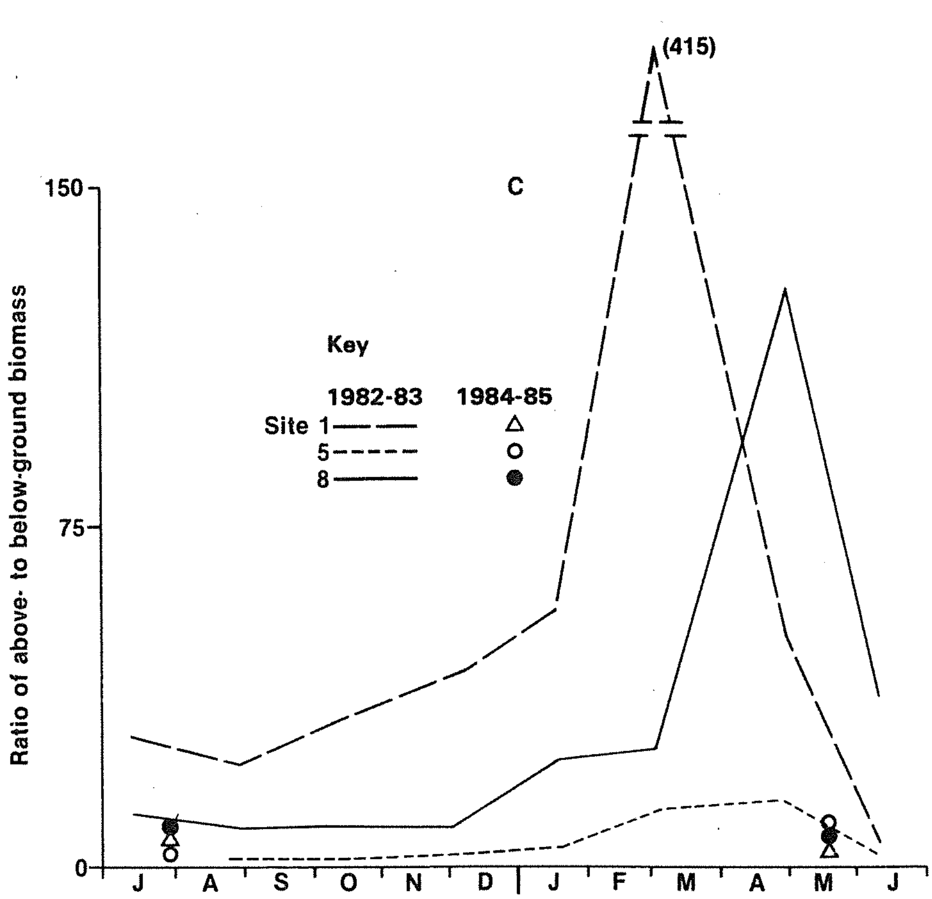

Figure 8. Seasonal changes in the ratio of above-ground to below-ground biomass in Wilson Inlet.

3.6 TISSUE NITROGEN AND PHOSPHORUS CONTENT

Nutrient concentrations in above and below-ground *Ruppia* tissue are shown in Figures 9 (total nitrogen) and 10 (total phosphorus). Nitrogen concentrations in above-ground, and to a lesser extent below-ground material, were higher in July 1984. These higher concentrations may have been due to the much higher water column nitrate concentrations in 1984. In April, the above-ground tissue nitrogen concentrations were similar to those measured in the earlier study. The tissue nitrogen concentration of below-ground material was lower in the present study in April, perhaps due to the redeployment of stored nitrogen reserves in the rhizome to above-ground material. As in the earlier study, above-ground material had higher tissue nitrogen concentrations than below-ground material. The above-ground tissue nitrogen concentrations were comparable with those given by Thursby (1984) of 25-30 mg g^{-1} for *Ruppia maritima* as critical for supporting maximum growth. Below-ground tissue nitrogen concentrations were lower, especially in April 1985, than those given by Thursby (1984) and may indicate possible nitrogen limitation.

Tissue phosphorus concentrations (Figure 10) in above- and below-ground material were lower in July and comparable in April with those measured in the earlier study. Concentrations of phosphorus in above-ground and below- ground material were similar. In both studies the tissue phosphorus concentrations were well below those given by Thursby (1984) of 2.5-3.5mg g^{-1} for *Ruppia maritima* as critical for supporting maximum growth.

The tissue nutrient data support the conclusions of the earlier study (Lukatelich et al, 1984) that phosphorus may be more critical to the growth of *Ruppia* than nitrogen. The ratio of nitrogen to phosphorus (Figure 11) in both above- and below-ground material was above 10:1, a typical ratio for plant material, in both studies.

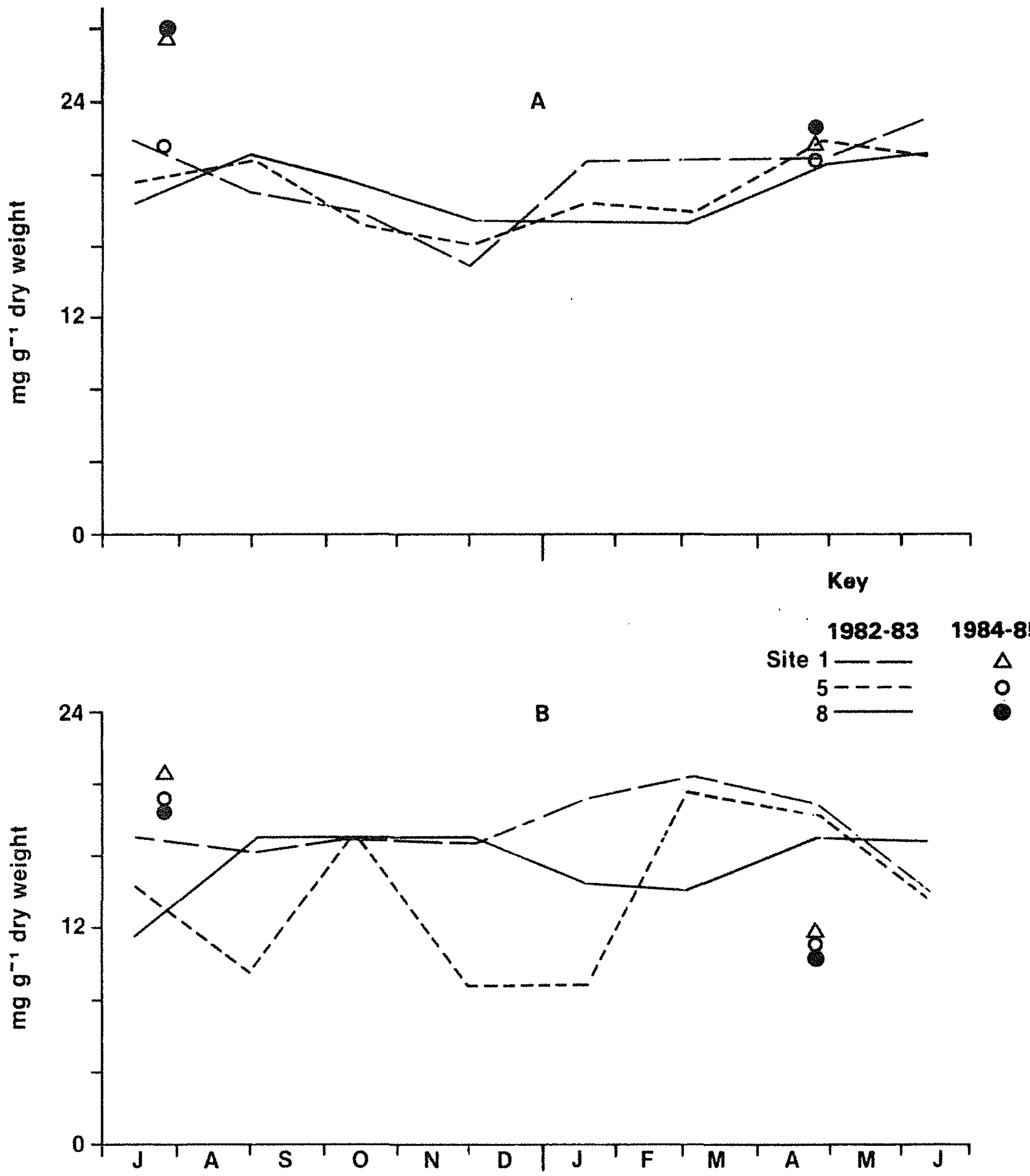

Figure 9. The nitrogen concentration in the tissues of *Ruppia* from Wilson Inlet: (A) above-ground material; and (B) below-ground material.

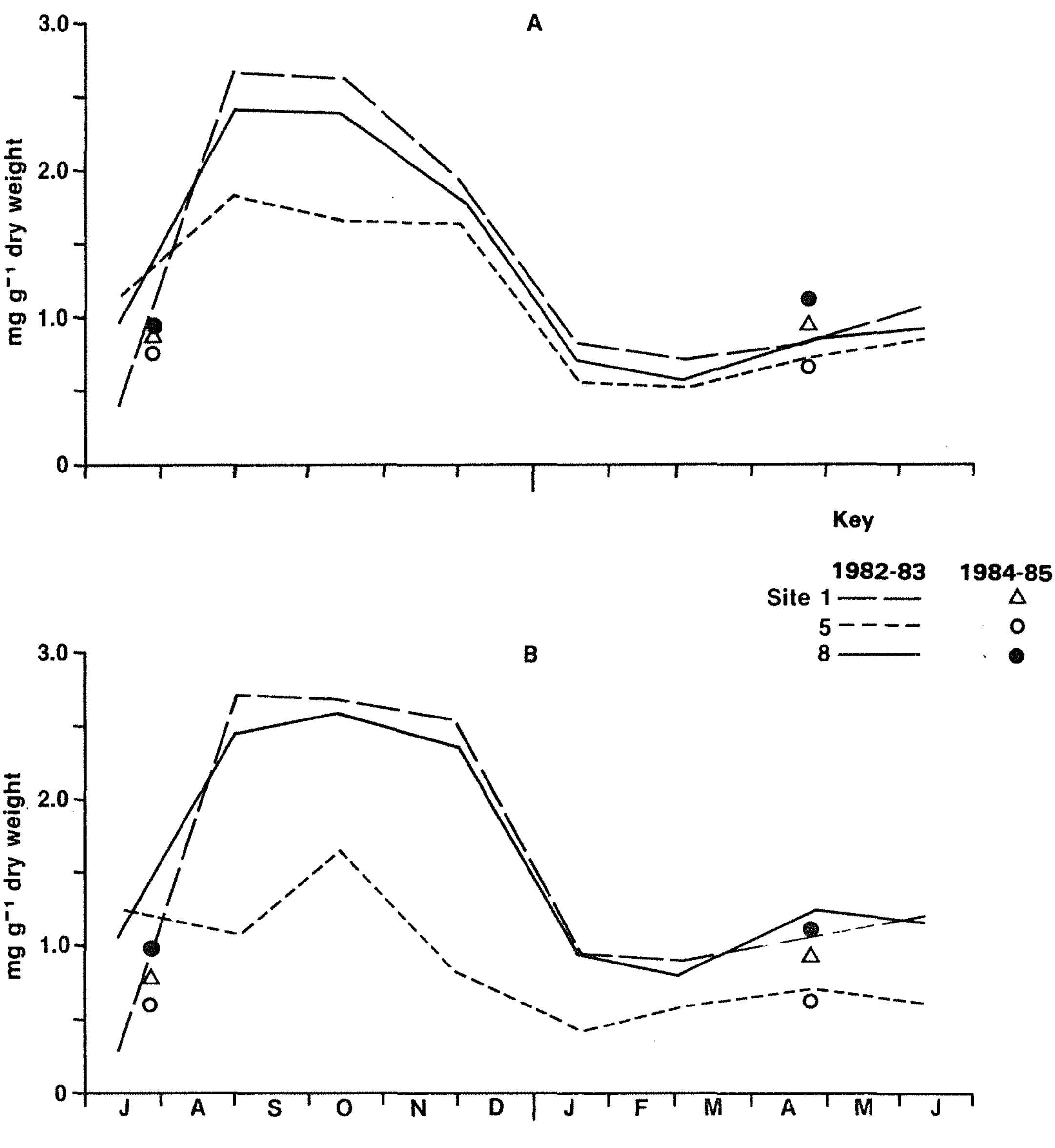

Figure 10. Concentrations of phosphorus in the tissues of *Ruppia* from Wilson Inlet: (A) above-ground material; (B) below-ground material.

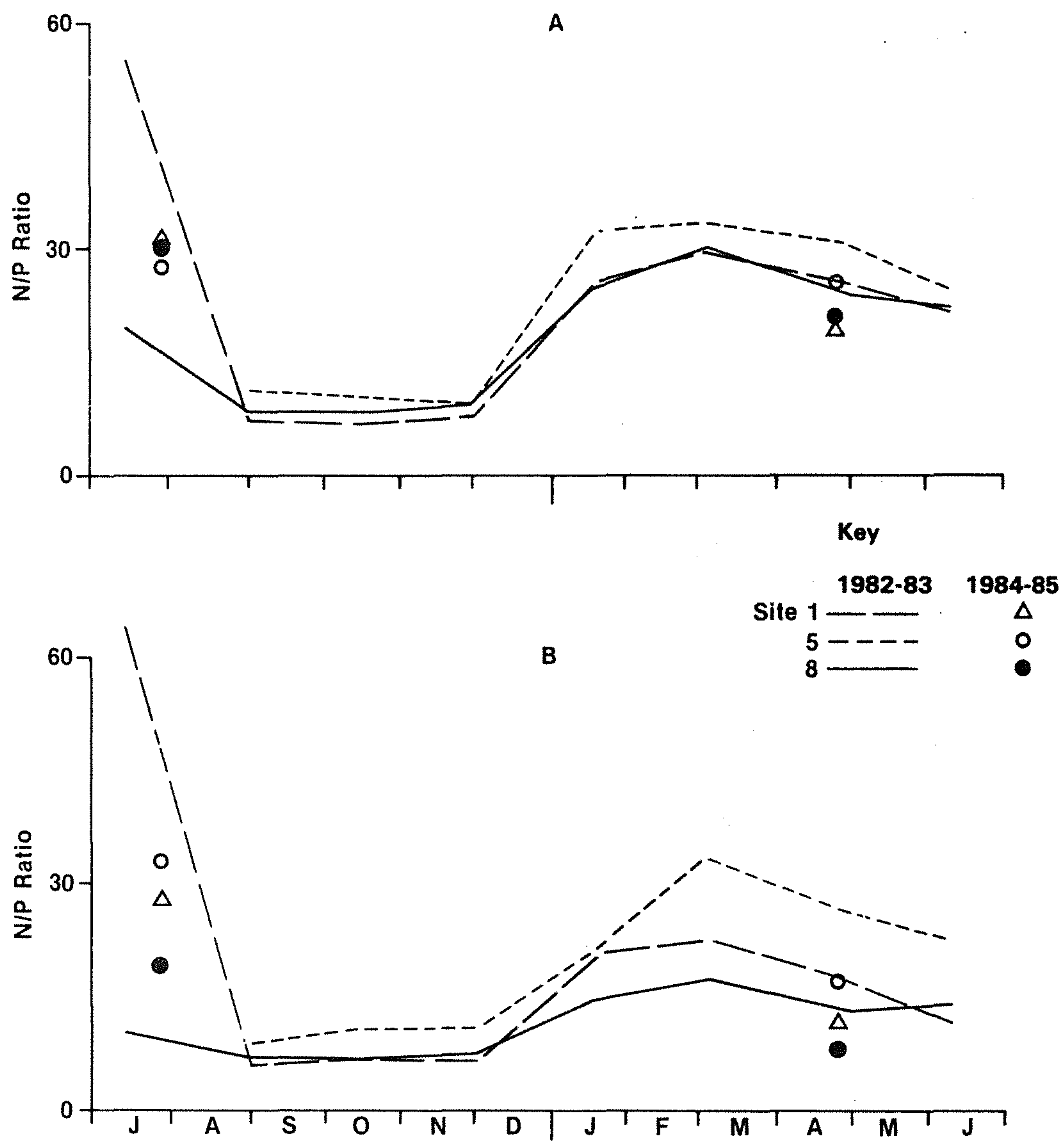

Figure 11. The ratio of nitrogen to phosphorus in the tissue of *Ruppia* from Wilson Inlet: (A) above-ground material; (B) below-ground material.

3.7 PLANT BIOMASS AND NUTRIENT LOADS

Planimetry of computer drawn maps enabled the total water column nutrient content to be computed, and this is compared with the data from the earlier study in Table 2. The phosphorus content of the water column was much higher in July 1984. This was due to the much higher riverine phosphorus loading in that year (see below). The phosphate content of the water column was lower in July 1984 despite the much higher riverine total phosphorus loading since, as noted above, most of the available phosphorus had been incorporated into organic material. The phosphorus content of the water column in April was similar to the previous estimate at that time of year.

The nitrogen content of the water column was lower in July 1984 than in 1982, but comparable in April to previous estimates. The nitrate content of the water column was much higher in July due to the much higher riverine nitrate loading in 1984 compared to 1982 (see below). The organic nitrogen load content in July 1984 was much lower. The organic nitrogen load of the water column in July 1982 was high as a result of sediment resuspension (Lukatelich et al, 1984).

Table 2. Total nutrient content of the water of Wilson Inlet (tonnes)

	July 1982	December 1982	April 1983	July 1984	April 1985
Phosphorus					
Phosphate	1.33	0.31	0.14	0.37	0.48
Organic phosphorus	4.09	5.11	3.48	12.21	3.54
Total phosphorus	5.42	5.42	3.62	12.58	4.02
Nitrogen					
Ammonium	5.13	2.07	2.81	4.06	1.21
Nitrate	1.30	0.57	1.52	29.32	0.45
Organic nitrogen	175.59	70.27	86.30	96.09	86.00
Total nitrogen	182.02	72.91	90.63	129.47	87.66

Sediment nutrient loads are shown in Table 3. Estimates of the nitrogen and phosphorus load in the top 2 cm of sediment were within the range of previous load estimates. The sediment nutrient load was much greater than the water column load in both studies on all occasions.

Table 3 Sediment nutrient content of Wilson Inlet (tonnes)

	July 1982	December 1982	April 1983	July 1984	April 1985
Phosphorus					
Extractable phosphate	3.50	1.43	0.57	0.56	0.75
Total phosphorus	84.65	167.00	196.82	104.56	132.73
Nitrogen					
Extractable nitrate	0.17	0.28	0.34	0.35	0.31
Extractable ammonium	20.27	3.68	2.68	4.36	4.88
Total nitrogen	713.82	1292.19	737.59	1077.91	-

[1] Data are for the top 2 cm of sediment.

The amount of nutrient contained in plant material was computed by first assessing the total plant biomass (Table 4) and converting this, using the known tissue nutrient concentrations of N and P, to total nutrient content (Table 5). Total plant biomass in July 1984 (Table 4) was very similar to that estimated in July 1982. However, in April 1985, the estimated plant biomass was much lower than any previous estimate. This was mainly due to the loss of above-ground *Ruppia* material.

The amount of nutrient contained in plant material (Table 5) in July 1984 was similar to the July 1982 estimate, but as a result of the lower *Ruppia* above-ground biomass, plant nutrient content in April was lower than previous estimates.

Table 4. Plant biomass in Wilson Inlet (tonnes)

	July 1982	December 1982	April 1983	July 1984	April 1985
Ruppia					
Above-ground	7,704	11,819	9,569	7,361	3,874
Below-ground	775	2,270	688	1,293	848
Total	8,479	14,089	10,257	8,654	4,722
Algae					
Reds	466	1,505	236	97	885
Greens	47	8	13	1	8
Browns	60	13	35	56	160
Total	9,052	15,615	10,541	8,808	5,775

Table 5 Plant tissue nutrient content of Wilson Inlet (tonnes)

	July 1982	December 1982	April 1983	July 1984	April 1985
Phosphorus					
Ruppia above-ground	6.86	22.42	6.28	6.61	2.48
Ruppia below-ground	0.66	2.74	0.44	0.93	0.56
Reds	0.23	0.91	1.04	0.06	0.34
Greens	0.05	0.01	0.004	0.0002	0.002
Browns	0.04	0.03	0.011	0.02	0.0
Total	7.84	26.11	7.775	7.6202	3.432
Nitrogen					
Ruppia above-ground	158.00	196.00	180.00	151.41	71.97
Ruppia below-ground	9.75	23.14	9.12	26.91	11.18
Reds	6.48	25.10	6.24	2.26	19.59
Greens	0.55	0.16	0.28	0.01	0.06
Browns	1.09	0.29	0.79	0.89	2.51
Total	175.87	244.69	196.43	181.48	105.31

The chlorophyll load of the water column in July 1984 was three times higher than any other estimate (Table 6), as a result of the relatively large riverine nutrient load in 1984. On all occasions the chlorophyll content of the top 1 cm of sediment greatly exceeded that in the overlying water column (Table 6).

Table 6. Water column and sediment chlorophyll 'a' content of Wilson Inlet (tonnes)

	July 1982	December 1982	April 1983	July 1984	April 1985
Water	0.33	0.22	0.23	1.09	0.29
Sediment	5.52	7.07	4.67	5.89	4.63
Total	5.85	7.29	4.90	6.98	4.92

3.8 STREAMFLOW

Where continuous gauging station records were not available, the accurate determination of streamflow volumes was difficult to calculate owing to short time-scale variations in discharge, and in some cases to unstable stream beds. Even daily stage records were not obtained for some periods at some sites. For the purpose of the study it was considered adequate to estimate streamflow volume by multiplying instantaneous discharge by the appropriate time period.

The 1984 streamflow at the Denmark River gauging station (603136) is shown in Figure 12 along with rainfall for the same period. Comparison of annual rainfall and streamflow to 1982 and the long-term means are made in Table 7. Annual rainfall in 1984 was 6% above the long-term mean and 25% above the 1982 value. Streamflow was 20% higher than the long-term mean, and 5.25 times the 1982 flows. The variability of annual streamflow with rainfall as represented by these figures is well recognised throughout the region.

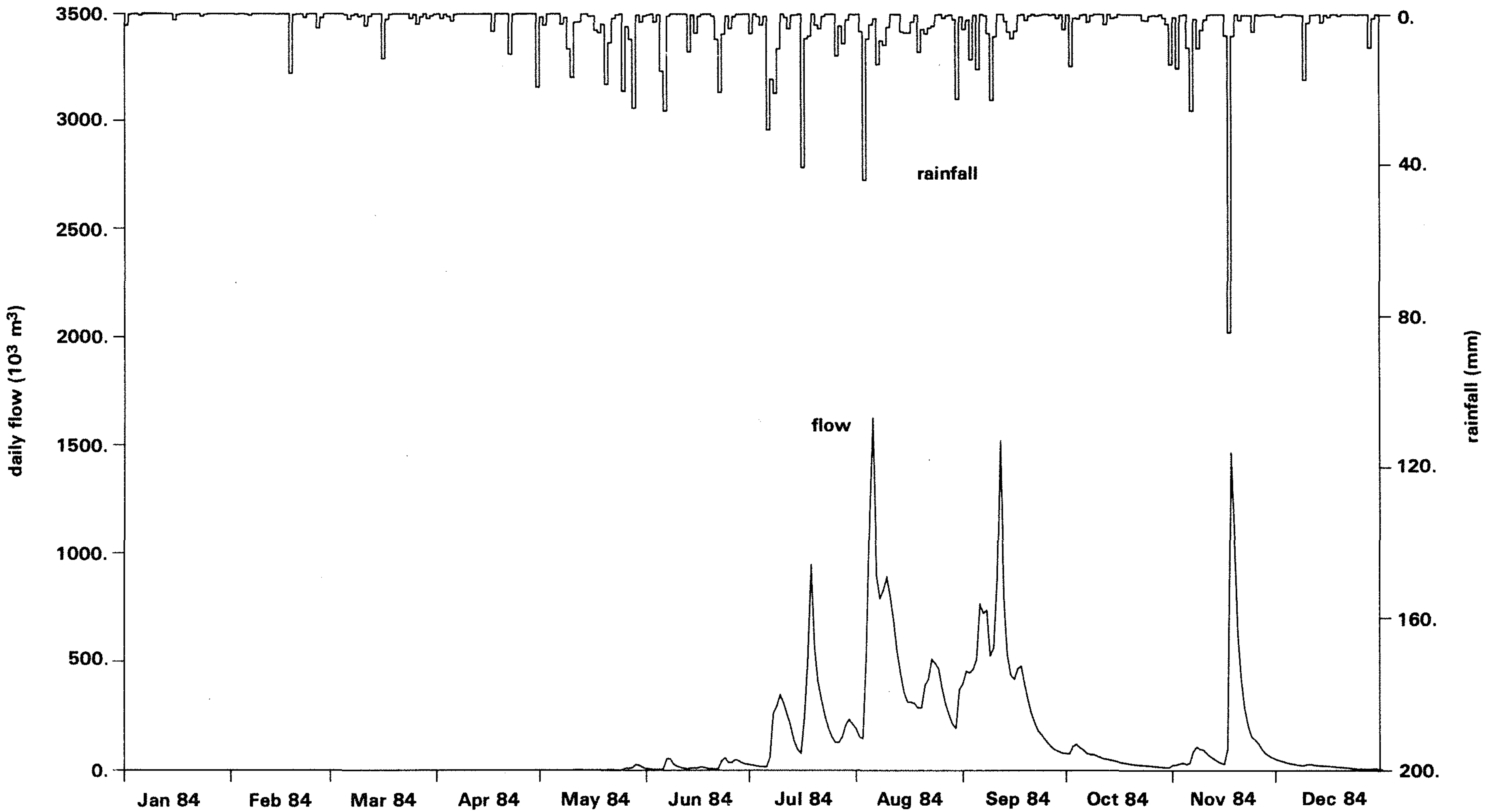

Figure 12. 1984 rainfall and streamflow at Denmark River gauging station (603 136).

Table 7. Comparison of annual rainfall and streamflow values for Denmark catchment (units mm)

	1982	1984	Long-Term Mean (LTM)	1984 / 1982	1984 / LTM
Rainfall	809	1017	960	1.26	1.06
Streamflow	16	84	70	5.25	1.20

3.9 NUTRIENT CONCENTRATIONS IN RIVER WATER

The samples collected weekly at the sampling points were analysed for nutrients as described previously. The arithmetic mean, flow-weighted mean, range and standard deviation for each nutrient for each stream are given in Table 8. Total phosphorus concentrations are typical of the range of values recorded elsewhere (eg Uttormark, Chapin and Green, 1974; Cullen, Rosich and Belz, 1978; Kesari and Vass, 1982 and Birch, Forbes and Bott, 1985), with the lower mean values being associated with heavily forested catchments (eg Denmark R and Hay R) and higher mean values associated with cleared agricultural land (eg Sleeman R, Cuppup R, White R and Sunny Glen Ck). Phosphate phosphorus concentrations are generally higher than organic phosphorus concentrations on the agricultural catchments and lower on the forested catchments.

Total nitrogen concentrations in the catchment were also typical of values cited elsewhere (Uttormark et al, 1974, Kesari and Vass, 1982 and Birch et al, 1985). The contribution of ammonium was small for all streams. Nitrate-nitrite nitrogen concentrations, however, were variable between catchments, having moderately high concentrations in the Hay and Cuppup Rivers. The time-series nutrient concentrations only show significant trends for nitrate-nitrite nitrogen concentrations, which are usually at their highest at the beginning of the winter, and decline fairly rapidly as winter progresses.

Table 8. Statistics of streamflow nutrient concentrations (units $\mu g\ L^{-1}$).

	Ortho-P				Organic P				Total P				Ammonia				Nitrate-nitrite				Organic N				Total N			
Stream	AM	FWC	R	SD	AM	FWC	R	SD	AM	FWC	R	SD	AM	FWC	R	SD	AM	FWC	R	SD	AM	FWC	R	SD	AM	FWC	R	SD
Lake Sadie Drain	35	45	9-79	21	68	74	37-120	26	102	119	50-183	41	26	27	15-47	9	80	88	1-285	88	1447	1510	674-2193	546	1553	1625	725-2283	496
White R	93	99	23-122	24	55	55	32-81	14	147	154	93-183	22	32	40	17-50	11	304	375	6-1700	485	1693	1673	954-2357	408	2029	2089	1440 3353	454
Cuppup R	74	94	17-106	30	71	71	37-100	16	145	165	79-196	37	32	40	13-51	13	614	642	5-2900	933	1515	1518	755-2339	388	2160	2200	1241 4000	864
Sleeman R	162	202	49-379	97	67	68	17-112	23	228	269	115-434	93	42	47	14-80	20	121	119	34-475	115	1631	1761	1095-2476	465	1793	1927	1173 2557	426
Hay R	19	22	6-34	7	46	45	38-55	6	65	68	56-77	8	25	26	8-34	8	1149	965	63-3000	1209	1072	1105	702-1427	211	2246	2095	1065 4050	1157
Sunny Glen Ck.	114	127	2-268	69	58	54	33-166	20	174	180	46-434	88	50	41	7-77	32	51	44	4-140	43	1501	1583	836-2340	493	1602	1666	495-2409	492
Denmark R	9	10	5-15	3	39	39	32-54	6	47	49	38-63	7	23	24	16 32	4	242	202	12-1250	367	820	807	497-1274	230	1085	1033	590-2010	353
Scotsdale Bk	21	23	10-39	7	77	81	35-448	103	98	104	55-462	102	22	23	12-30	5	107	128	18-325	95	647	665	271-1234	239	775	815	501-1438	238

AM = arithmetic mean
FWC = flow-weighted concentration
R = range
SD = standard deviation

3.10 NUTRIENT LOADS FROM STREAMS

Stream discharge and nutrient loads for each stream for 1984 are given in Table 9. Data from the sampling period (6 July - 19 October) were extrapolated to the whole year on the basis of Denmark gauged flows and the flow-weighted mean concentration for the sampling period. The data in Table 9 were also scaled-up to whole catchment areas on the basis of direct proportionality to area.

The nutrient loads shown in Table 9 are considered to be of the order of magnitude expected for an average rainfall year. The total phosphorus load of 19 tonnes is not considered as unduly high for a body of water such as Wilson Inlet. The value is less than the 30 tonnes predicted for an average year on the basis of the 1982 results. The total nitrogen load was slightly higher than the 280 tonnes predicted for an average year from the 1982 data.

Table 9. 1984 flows and nutrient loads

Catchment	flow	Ortho-P	Organic P	Total P	Ammonia	Nitrate-Nitrite	Organic N	Total N
	$10^6 m^3$	(tonne)	(tonne)	(tonne)	(tonne)	(tonne)	(tonne)	(tonne)
Denmark R	53.5	0.51	2.11	2.61	1.29	10.83	43.20	55.30
Scotsdale Br	17.0	0.38	1.38	1.76	0.39	2.17	11.32	13.87
Hay R	87.3	1.92	3.91	5.91	2.24	84.21	96.43	182.84
Sunny Glen Ck	6.2	0.78	0.33	1.11	0.25	0.27	9.80	10.31
Sleeman R	12.8	2.58	0.88	3.45	0.60	1.53	22.59	24.72
White R	5.4	0.53	0.30	0.83	0.21	2.02	8.99	11.22
Cuppup R	13.4	1.26	0.95	2.21	0.54	8.62	20.36	29.51
Lake Sadie Dr	7.1	0.32	0.52	0.84	0.19	0.62	10.67	11.48
Totals	202.7	8.3	10.4	18.7	5.7	110.3	223.4	339.3

4. DISCUSSION

4.1 COMPARISON OF 1982/83 AND 1984/85

There was a large difference between the two studies in the length of time the bar was open; the shortest period (51 days) on record in 1982/83, and the longest period (279 days) in 1984/85. Salinities were higher in April 1985 compared with April 1983 because of the increased opportunity for exchange with the ocean.

Salinities were lower in 1984 due to the higher streamflows. Phosphorus and nitrate concentrations and total water column loads were higher than those measured in July 1982. Chlorophyll 'a' concentrations and total water column load were also higher, presumably in response to the higher nutrient loads.

Estimates of total plant biomass in July were similar for both studies, but due to the earlier senescence of *Ruppia* above-ground material in April 1985, total plant biomass was much lower than in the earlier study. Plant nutrient load followed the changes in total plant biomass.

Sediment nutrient loads were similar in both studies.

1984 was a considerably better year than 1982 for estimating average nutrient inputs and balances for Wilson Inlet, because rainfall was much closer to the long-term mean. Comparison of the data for the two studies shows some interesting differences. Table 10 gives a comparison of 1982 and 1984 streamflows and nutrient loads. It is apparent that the major increase in streamflow, total phosphorus and total nitrogen export are attributed to the Denmark and Hay rivers, and to a lesser extent the Cuppup River. The significantly higher streamflows of the Denmark and Hay Rivers demonstrates the sensitivity of these large forested catchments to rainfall; a fact that has been observed throughout the jarrah forest. For the Wilson catchment as a whole, the 2.8 times increase in streamflows was accompanied by a slightly smaller increase in phosphorus load of 2.2 times, but a significantly higher increase in nitrogen load of 4.2 times.

Table 10. Comparison of 1984 and 1982 flows and nutrient loads

Catchment	Ratio 1984/1982 Flow	Total P	Total N
Denmark R	4.85	6.37	9.10
Scotsdale Bk	1.70	2.07	1.83
Hay R	3.74	5.79	12.71
Sunny Glen Ck	1.22	1.09	1.15
Sleeman R	1.13	1.05	0.97
White R	1.58	1.36	2.23
Cuppup R	3.03	2.28	4.48
Lake Sadie Dr	1.67	1.91	1.86
Catchment Total	2.78	2.17	4.23

The higher increase in nitrogen export from drainage can be largely attributed to higher nitrate-nitrite losses, as shown in Table 11. The Wilson Inlet catchment average increase in nitrate-nitrite concentration was 18.4 times. The Hay River had an increase of two orders of magnitude in nitrate-nitrite concentration, whilst the Cuppup, White and Denmark rivers showed a one order of magnitude increase. Concentration changes in all other nutrients were comparatively small.

The fertilizer usage in Wilson Inlet catchment for the period 1981-85 is shown in Table 12. It is clear that there has not been any dramatic changes in application rates over this period, although a slight decline in the application rate of superphosphate is evident. Since the use of nitrogenous fertilizers has not increased significantly, the much greater nitrogen loading to the estuary in 1984 is attributed to the hydrological differences between the two years.

Table 11. Comparison of 1984 and 1982 flow-weighted mean nutrient concentrations.

	Ratio 1984/1982						
Catchment	Ortho-P	Organic P	Total P	Ammonia	Nitrate -Nitrite	Organic N	Total N
Denmark R	1.1	1.3	1.4	1.1	8.0	1.6	1.9
Scotsdale Bk	1.2	1.3	1.2	1.1	2.9	1.0	1.1
Hay R	2.6	1.3	1.6	1.6	94.6	1.9	3.4
Sunny Glen Ck	1.1	0.7	0.9	1.2	2.6	0.9	0.9
Sleeman R	1.1	0.6	0.9	1.0	4.0	0.8	0.9
White R	1.1	0.6	0.9	0.9	11.8	1.2	1.4
Cuppup R	0.6	1.5	0.8	1.6	18.8	1.1	1.5
Lake Sadie Dr	1.2	1.5	1.4	0.8	4.8	1.3	1.3
Mean	1.3	1.1	1.1	1.2	18.4	1.2	1.6

Table 12. Fertilizer use in Wilson Inlet catchment for the period 1981-85

(data from Australian Bureau of Statistics, WA office)

Year	Area Fertilized	Superphosphate		Straight nitrogenous fertilizers	Other artificial fertilizers including potash and compounds and mixtures containing nitrogen
	(ha)	(tonnes)	(kg ha^{-1})	(tonnes)	(tonnes)
1981-82	112789*	16555	147	185	2921
1982-83	70822	9963 (508)+	141	318 (42)	1625 (364)
1983-84	77247	9956 (483)	129	131 (114)	1778 (438)
1984-85	79481	100088	127	163	2602

* Based on 1981 gescoding squares (see Figure 1, Humphries et al, 1982).

\+ Figures in brackets refer to tonnes applied to unspecified areas of non-pasture.

4.2 ESTIMATED NUTRIENT BUDGET FOR WILSON INLET

From knowledge of stream inputs and ocean outputs, it is possible to calculate a water and nutrient budget for one cycle of sand bar opening and closing. This allows an estimate to be made as to whether there has been net retention of riverine nutrients, or export of nutrients from Wilson Inlet. The budget calculations and assumptions were the same as those outlined in the previous study (Lukatelich et al, 1984).

The results of the water and nutrient budget are shown in Table 13. The nutrient balances are computed from stream flow-weighted mean concentrations and Inlet mean concentrations. On this basis, it was found that the net retention of phosphorus was 8.7 tonnes (49% of total input), while for nitrogen it was 216.7 tonnes (63%) (Table 13). The percentage of total riverine phosphorus load retained by the Inlet was similar in both studies, but the amount retained was much greater in 1984/85 due to the higher riverine phosphorus load in that year.

In contrast, it was estimated that there was net export of nitrogen in the previous study (Lukatelich et al, 1984), compared to 63% retention in 1984/85. There was a much larger riverine nitrogen load in 1984/85; 342 tonnes, compared to 58 tonnes in 1982/83. There was also a lower total nitrogen concentration at the time of bar opening. As mentioned previously (Lukatelich et al, 1984), the export of nitrogen in 1982/83 may have been overestimated because of the effects of sediment resuspension. However, even if nitrogen export at the time of bar opening in 1982/83 had been overestimated by 100%, the net retention of nitrogen would have been only about 25% of total riverine input.

When making comparisons between the nutrient budgets for 1982/83 and 1984/85, it must also be considered that the amount of nutrient lost due to exchange with the ocean, while the bar is open, is not included in the calculations. In 1982/83 the amount of nutrient lost in this way was thought to have been minimal, because the bar was open for such a short time. However, due to the much longer period when the bar was open in 1984/85, exchange with the ocean may have been more significant. In the previous study, estimates were made of the amount of nutrient that may be lost due to exchange with the ocean under different flushing regimes (Lukatelich et al, 1984), and it was suggested that perhaps a 50% exchange might occur in years when the bar remained open for long periods. However, even allowing for a four-fold increase in the amount of nutrient lost with 50% exchange, there would still have been significant net retention of both nitrogen and phosphorus in 1984/85.

One striking feature of the budget (Table 13) is the large amount of nitrogen estimated to have been accumulated by the estuary before bar opening - 131 tonnes, as compared with 28.5 tonnes in 1982/83. The N:P ratio in the estuary was about 90:1, and so it is unlikely that the nitrogen would have been totally removed by phytoplankton or *Ruppia* biomass - indeed the N:P ratio of *Ruppia* tissue was no higher than on the previous occasion. It may therefore be suggested that much of the nitrate apparently retained in the system was lost through microbial denitrification.

4.3 GENERAL

In overview, it can be seen that the main conclusions about nutrient concentrations in plant tissues, the importance of phosphorus, total plant biomass and general ecosystem behaviour were generally similar to those reached in the earlier study, despite the very different winters. Catchment behaviour, ie in relation to nutrient losses to streamflow was also generally similar, with somewhat higher concentrations of nutrients associated with the winter of higher runoff. The main contrast was the large amount of nitrogen, especially in the form of nitrate, which came from the larger subcatchments during the present study. In this behaviour these catchments appear to resemble that of the Murray River, which enters Peel Inlet. The upstream section of the Murray Catchment rarely flows strongly, but when it does so in years of high rainfall, eg 1978, the concentration of nitrate in its waters, and so in the waters of Peel Inlet, rises dramatically; in 1978 the concentration of nitrate nitrogen in Peel Inlet reached some 3000 $\mu g\ L^{-1}$, more than ten times that recorded in Wilson Inlet in the present study.

Table 13. Estimated nutrient budget for Wilson Inlet (1984-85)

	Water Budget				Nutrient Budget					
Sand-bar Function	Streamflow Input ($10^6 m^3$)	Rainfall - Evap on Inlet ($10^6 m^3$)	Ocean Loss ($10^6 m^3$)	Change in Inlet water storage ($10^6 m^3$)	P input Streamflow (tonne)	P output ocean (tonne)	P change in Inlet (tonne)	N input streamflow (tonne)	N output ocean (tonne)	N change in Inlet (tonne)
Closed 26.1.84-5.8.84	54.9	-4.7	0.0	50.2	6.6	0	+6.6	131.1	0	+131.1
Open 5.8.84-12.8.84	18.6	0.9	-47.8	-28.3	1.4	-3.8	-2.4	24.4	-44.5	-20.1
Open 13.8.84-10.5.85	119.9	-46.1	-95.7*	-21.9	9.9	-5.4	+4.5	186.7	-81.0	+105.7
Totals	193.4	-49.9	-143.5	0.0	17.9	-9.2	+8.7	342.2	-125.5	+216.7

* Value not measured but used to close water balance.

4.4 POINTS TO BE CONSIDERED FOR MANAGEMENT

Wilson Inlet is showing one major symptom of eutrophication, the large amount of macrophyte growth which is comprised mainly of *Ruppia*. There is some evidence that this has increased in recent years. On the other hand, water quality is generally good, as indicated by low summer nutrient levels, low levels of phytoplankton in the water, lack of oxygen depletion and comparison with other south-western estuaries (Lukatelich et al, 1984).

The results of both studies show that *Ruppia* biomass is one of the major nutrient banks in the system, and its removal would significantly reduce the nutrient content in the system. However, as discussed previously, (Lukatelich et al, 1984) it is not desirable to totally remove *Ruppia* because other more undesirable species may take its place. Care must be exercised in using harvesting as a mechanism for eutrophication control. Harvesting in localized areas, as was carried out in 1983 in Poddy Shot Bay, would be beneficial in removing part of the nutrient bank without eliminating *Ruppia* from the system.

Opening of the bar allows estuary water to escape to the ocean. The amount of nutrient lost at the time of opening is a simple reflection of the height difference between the estuary and sea level, and the nutrient concentration of the estuary water.

An important effect of having the bar open is to allow the loss of river water to the ocean, rather than its ponding and evaporation within the estuary itself. Even in years of weak river flow, significant losses to the ocean may occur. If it were feasible for the bar to be opened earlier eg June and for it to be kept open, significantly greater losses of nutrient may occur because this would greatly reduce the residence time of nutrient- rich river water in the Inlet. This would result in less time for nutrient uptake by plants, and so reduce nutrient retention. The results of this study show that by the time of bar opening, most of the available riverine phosphorus load had been assimilated into organic matter, and presumably a significant proportion trapped in the system. If the bar had been opened earlier, much of this phosphorus may have flowed straight to the ocean, significantly reducing nutrient retention.

The advantages of such opening would have to be weighed against the possible reduction in scouring of the bar, through reduced initial flow rates.

The major factors governing nutrient inputs to Wilson Inlet were addressed in the previous study (Lukatelich et al, 1984). Future land use changes which are likely to increase nutrient input to the estuary are:

- Clearing of native vegetation for agricultural use and the conventional application of fertilizers. This applies particularly to areas of sandy soils under high rainfall.
- Increasing the drainage network.

The most susceptible areas in the above respects are the catchments of the Sleeman, White and Cuppup Rivers, Nemanup-Lake Sadie Drain and the southern extremity of the Hay River catchment. These catchments are all under relatively high rainfall, have 20 - 40% uncleared private land and 40 - 100% sandy soils.

Two land use practices which may decrease nutrient input to the Inlet have arisen from the Peel-Harvey study, namely the use of less superphosphate (while still maintaining full agricultural production) and the use of slow release fertilizers and sulphur only fertilizers. These practices are still under investigation but, if proven successful, will be applicable to the sandy soils of the Albany-Denmark region.

4.5 FURTHER WORK

Although the overall water quality of the Wilson Inlet system is satisfactory, the large *Ruppia* biomass is indicative of gradual nutrient enrichment. The results of the two studies described show that significant nutrient retention is occurring at the present time. Increased nutrient enrichment will favour the growth of epiphytes on the *Ruppia*; already this is noticeable in some areas, and could lead to its eventual demise. *Ruppia* could possibly be replaced by either phytoplankton and/or macroalgae, which may lead to a far greater nuisance than the *Ruppia* is at present. Continued low frequency monitoring could be carried out to assess any gradual deterioration.

An assessment should be made of the possible application in the Wilson Inlet catchment of any modifications to agricultural practice to reduce nutrient inflow into the Peel-Harvey system.

If practicable, experimental harvesting of *Ruppia* could be undertaken in some parts of the estuary as a control measure, and the effects of harvesting known amounts of biomass assessed by subsequent monitoring.

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