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SEASONAL CHANGES IN MACROPHYTE ABUNDANCE AND COMPOSITION IN THE PEEL -HARVEY ESTUARINE SYSTEM

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Seasonal Changes in Macrophyte Abundance and Composition in the Peel-Harvey Estuarine System

Report to the Waterways Commission

Perth, Western Australia

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Contents

Preface

This report to the Waterways Commission discusses changes in macrophyte abundance and composition in the Peel-Harvey Estuarine system. It covers the period August 1984 to November 1987 inclusive. An earlier report (Lukatelich and McComb, 1985) contains the results of the macrophyte sampling programme between 1978 and August 1984. As in previous reports (Lukatelich and McComb 1983, 1984, 1985) the data are presented, where appropriate, with all previous information for the sampled sites so that long term trends may be established.

We are indebted to a number of persons, including G. Bastyan, K. Blyth, P. Lavery, T. McAuliffe, K. Pritchard, F. Salleo for help in the field and laboratory.

1.0 Introduction

The macroalgae problem in Peel Inlet dates from the late 1960's when complaints were first received about the accumulation and decomposition of algae in the shallows at Coodanup (Hodgkin *et al.*, 1980). Large quantities of macroalgae were accumulating and decomposing into a black, offensive smelling ooze, on what were previously clean, sandy beaches. Until the 1960's the dominant macrophytes in Peel Inlet were seagrasses (*Ruppia* and *Halophila*), these species are now confined to the shallows. The macroalgal problem has been continuous since 1969, although the size and species composition of the accumulations have changed with time.

Macroalgal accumulations are a major management problem on the northern (Coodanup) and western (Falcon) shores of Peel Inlet due to the close proximity of residential subdivisions and the fact that these shores lie in the direction of the prevailing south-westerly winds. Accumulations also occur on other less populated foreshores, particularly in Austin Bay and Robert Bay. Harvey Estuary is largely free of macroalgae, due to greater light attenuation although there are some macroalgal accumulations on the shores north of Dawesville.

The macroalgae cause considerable inconvenience to professional fisherman. In deep water, large offshore banks of macroalgae foul nets and tangle in the propellers of outboard motors. On the other hand, the increase in macroalgal growth has been accompanied by an increase in commercial fish catch (Lenanton *et al.*, 1984).

Another, though less obvious, problem caused by the macroalgal accumulations is the smothering of marginal rushes, resulting in their destruction, and consequent bank erosion.

The two techniques currently used for macroalgal removal are beach cleaning by tractors and offshore harvesting. These measures to free beaches of decomposing algae are costly and only partially effective. Major accumulations often form in the shallows some distance offshore, where they are inaccessible to both floating weed harvesters (minimum operating depth 50 cm) and tractors (maximum operating depth 20 cm). The destruction of rushes and other marginal vegetation by the tractors has resulted in severe erosion of the shoreline in some locations necessitating foreshore works (eg log-walling) to prevent further erosion. Sand is also removed from foreshores during harvesting, and is replaced by sand carted from other areas.

An indication of the relative magnitude of the macroalgal problem and the amounts removed by harvesting is seen by the fact that, in the 1983/84 harvesting season, about 8000 tonnes of material was removed from the beaches, while the estimated wet-weight of macroalgae in the system was about 300,000 tonnes. The total cost of harvesting operations in 1986-87 was $260,000, with 18,660 tonnes of material (which includes sand, water and macroalgae) removed. The onshore operations are significantly more cost-effective in removing macroalgae from the Inlet than offshore operations.

The macroalgal problem in Peel Inlet has resulted from increased phosphorus input, particularly from the coastal plain portion of the catchment, as a consequence of increased phosphatic fertilizer use in agriculture since the mid-1950's (Hodgkin *et al.*, 1985). Excessive growths of macroalgae, principally *Chaetomorpha* spp., *Cladophora* spp., *Enteromorpha* spp. and *Ulva* spp., have been reported for a number of enclosed estuarine and marine systems as a result of nutrient enrichment (e.g. Wilkinson, 1963; Edwards, 1972; Knox and Kilner, 1973; Buttermore, 1977; Bach and Josselyn 1978, 1979). All of these macroalgae have bloomed in Peel Inlet at some time over the last ten years.

This report examines changes in the biomass of macrophytes in the Peel-Harvey system in relation to environmental factors to determine the reasons for biomass fluctuations. Changes in algal dominance are also examined.

2.0 Materials and Methods

Macrophyte sampling was carried out at irregular intervals from 1978 to 1984 (no data are available for 1980 and 1983), and regularly, at quarterly intervals, since August 1984. In 1978 and 1979 the entire system was sampled at 36 sites, from July 1981 to August 1985 at 30 sites in Peel Inlet and the northern end of Harvey Estuary, and since November 1985 at 42 sites throughout the system (Fig. 1). The area referred to as 'Peel' in this report includes all of Peel Inlet and the northern section of Harvey Estuary (see Fig. 1); the remainder is referred to as 'Harvey'. The sites were selected to represent the main sectors of the system.

Plant biomass was estimated from 5 replicate cores (64 cm^2) at each site. Samples were sorted, oven dried at 70°C, and dry weights converted to grams per square metre. The amounts collected from the different sites ranged, in typical studies, from 0 -1500 g dry weight m^{-2}. Standard errors were generally 20-50% of the mean at a particular site.

The total biomass of macroalgae in the system was estimated by using a computer mapping technique (SYMAP; Dougenik and Seehan, 1977), which provided contours of different classes of biomass. The areas were planimetered and mean biomass for each class interval used to compute biomass. Such an estimate of biomass is of course very crude, considering the few sites sampled, for logistical reasons, in such a large water body. Nevertheless, as the same sites were sampled and the same method used, it is reasoned that while the absolute estimates are subject to inaccuracy, the time course is a reasonable representation of trends in total biomass.

2.1 Nutrient Analysis

Samples of tissue for nitrogen and phosphorus analysis were milled, replicates bulked, and 200 mg subsamples assayed for total tissue phosphorus (Strickland and Parsons, 1972) following digestion in concentrated nitric and perchloric acids. Tissue nitrogen was measured using the autoanalyser (Technicon Corp, Tarrytown, N.Y., method 334-74 W/B) after digestion in concentrated sulphuric acid in the presence of a mercury catalyst.

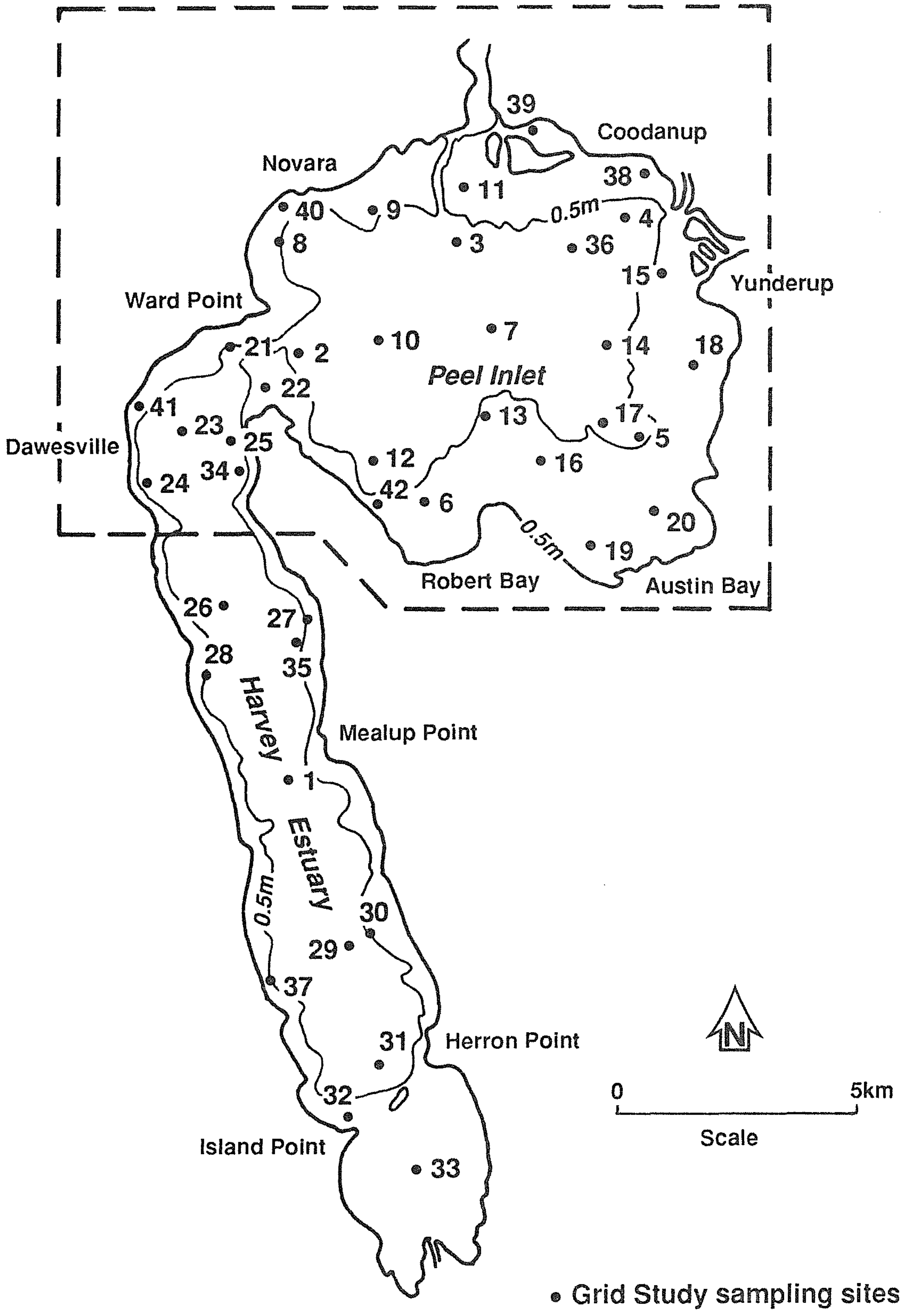


Figure 1. The Peel-Harvey system showing the location of the macrophyte sampling sites. The area enclosed by the dashed line is referred to as Peel in this report.

2.2 Water Parameters

Water column and sediment nutrients, salinity, oxygen, light attenuation and temperature were measured at some of the sites, at more frequent intervals than the sampling for biomass. Details of methods and results are given in Lukatelich and McComb (1985).

3.0 Results and Discussion

3.1 Biomass

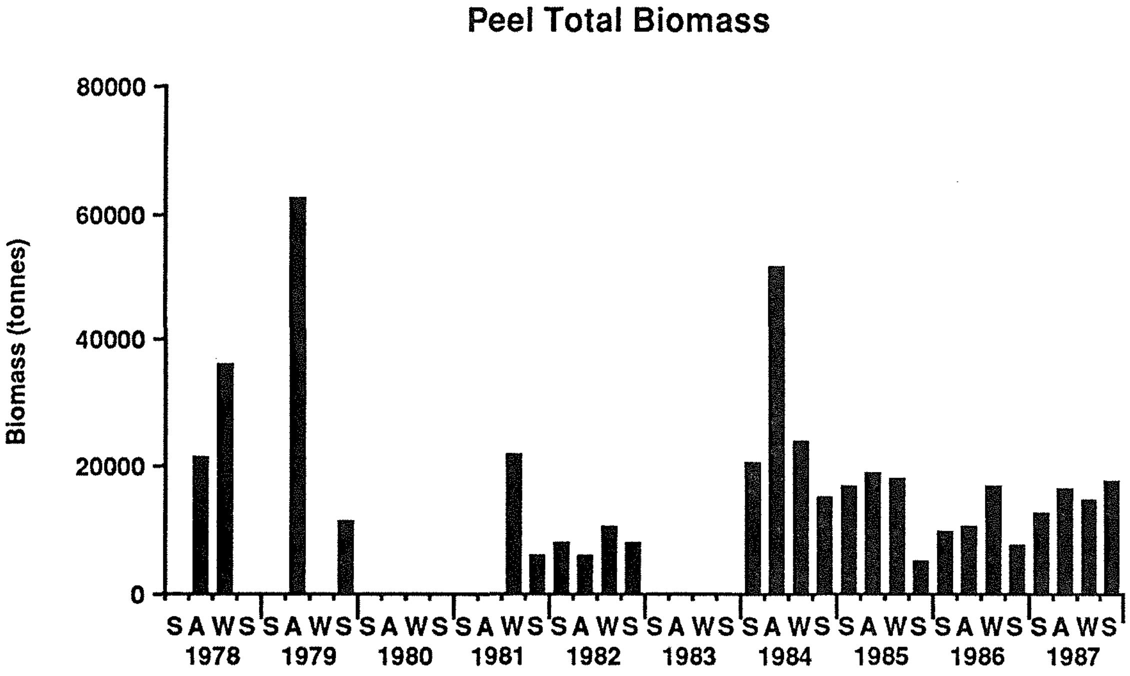
3.1.1 Peel

High macrophyte biomass occurred in Peel in 1978-79 and 1984, low biomass in 1981-82, and generally intermediate biomass levels between 1985-87 (Fig. 2). No macrophyte surveys were conducted in 1980 and 1983, and Peel total biomass has been conservatively estimated to have averaged 30,000 tonnes dry weight in 1980 and about 15,000 tonnes in 1983 (Lukatelich and McComb, 1985).

During a particular year, lowest biomass generally occurred in spring. In winter high light attenuation from humic stained river water, coupled with low water temperatures, severely reduces the growth rate of macroalgae. Light penetration is further reduced if there are *Nodularia* blooms in spring. No *Nodularia* bloom was recorded in the Peel-Harvey system in 1987/88 following well below average riverflow in winter 1987, and the highest biomass was recorded in spring.

3.1.2 Harvey

Harvey macrophyte biomass (Fig. 2) was generally much lower (5-7x) than that estimated for the Peel, even accounting for the much smaller surface area of the Harvey (Fig. 1). The highest recorded biomass in the Harvey was 154 g dry weight m^{-2} (winter 1987) compared with 740 g m^{-2} for the Peel (autumn 1979). Light attenuation is generally much greater in the Harvey compared to the Peel (Lukatelich and McComb, 1985), and severely limits macroalgal growth. No macrophyte surveys were carried out in the Harvey between 1980



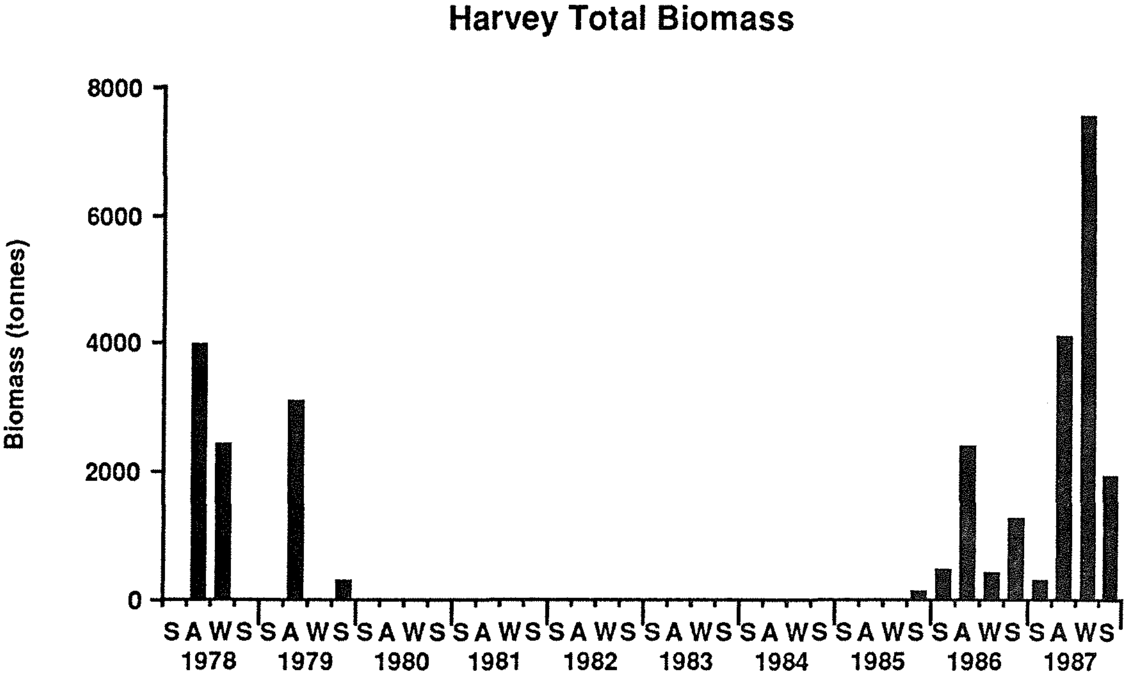


Figure 2. Seasonal changes in total plant biomass in Peel (above) and Harvey (below).

and spring 1985, but visual estimates of biomass suggest that total biomass probably never exceeded 1000 tonnes during this period. The peak biomass recorded in winter 1987 was consistent with improved light penetration; phytoplankton biomass was low the previous autumn (Table 1), and in winter the riverflow was well below average.

Table 1. Mean (surface and bottom) chlorophyll 'a' concentrations for the period March - May.

Year	Chlorophyll 'a' ($\mu g\ l^{-1}$) Peel	Chlorophyll 'a' ($\mu g\ l^{-1}$) Harvey
1978	2.4	6.5
1979	1.7	3.5
1980	4.6	3.6
1981	3.8	9.0
1982	3.8	17.8
1983	3.7	24.7
1984	3.0	10.1
1985	4.3	11.7
1986	1.4	10.9
1987	1.2	2.9

3.1.3 Individual Site Data

The biomass data for eastern Peel populations (sites 4, 5, 14) generally followed the changes in Peel total biomass (Fig. 3). High standing crops of macroalgae were present in 1978-79 and 1984-85, low biomass in 1981-82, except at site 5, and a somewhat higher biomass in 1986-87 (than 1981-82). The average standing crop at sites 4 and 14 in 1981-82 was 31 g m^{-2} compared with 60 g m^{-2} in 1986-87.

The western Peel populations (Sites 8, 23; Fig. 4) did not follow the same trends. Following the decline in biomass in late 1981, on only one occasion (spring 1984) was there a significant biomass recorded at site 23. This site is located in deep water (2.0 m) near Dawesville (Fig. 1) and high light attenuation due to *Nodularia* blooms has severely restricted macroalgal growth since 1981. The biomass at site 8 (Fig. 4) followed the changes in Peel total biomass, except that the standing crop in 1987 was similar to 1978-79 levels.

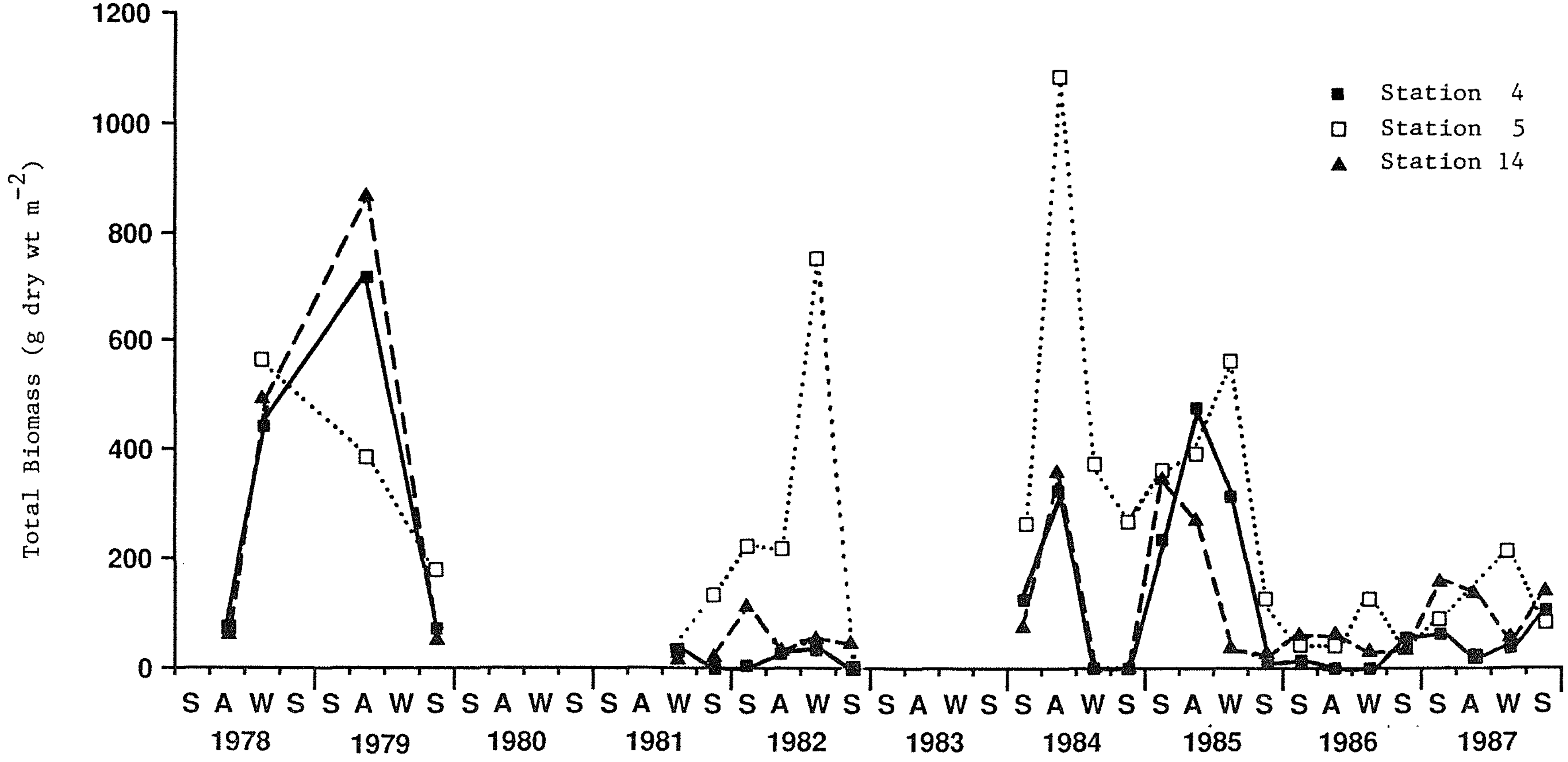


Figure 3. Seasonal changes in total plant biomass in the eastern Peel populations.

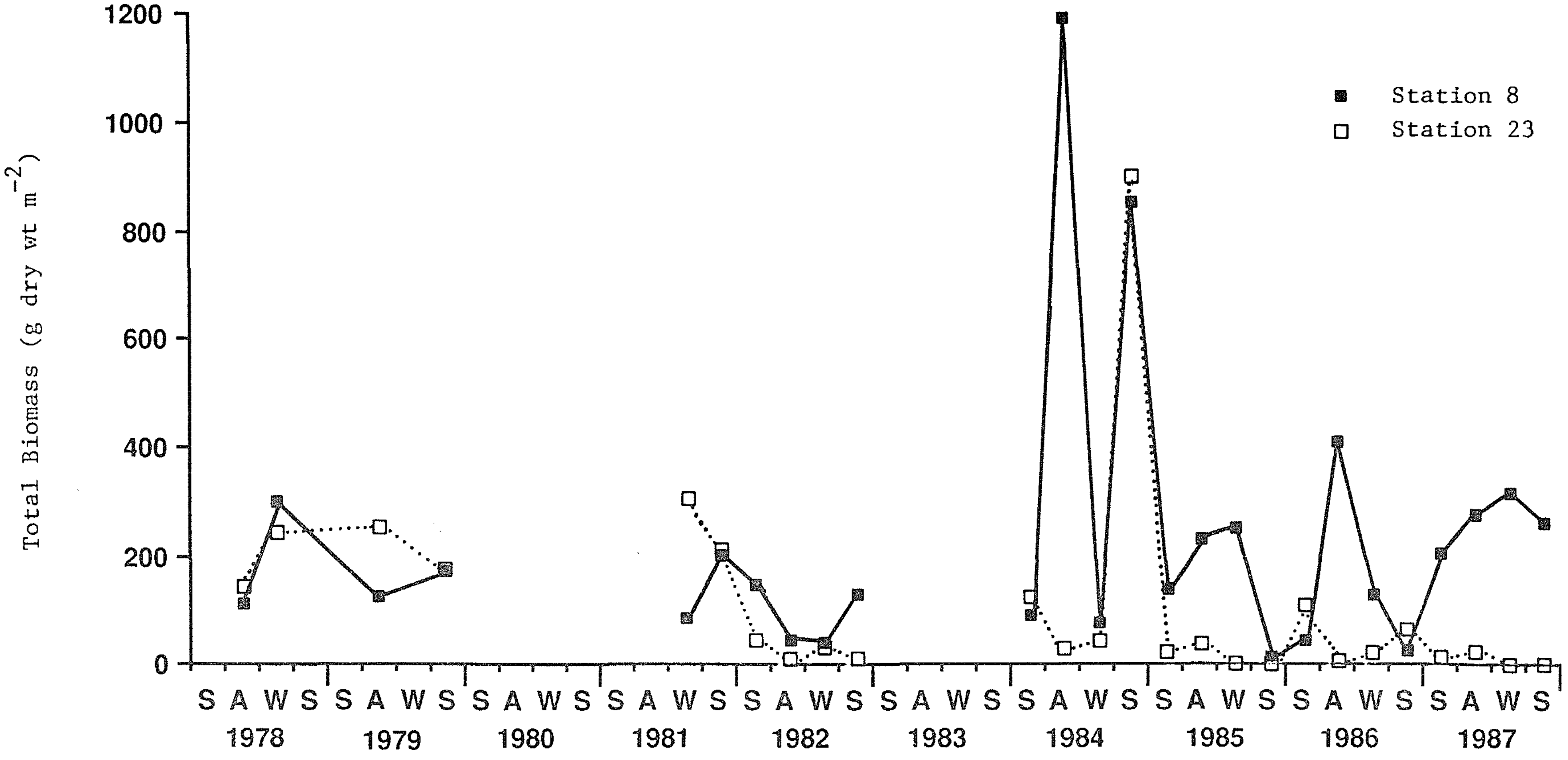


Figure 4. Seasonal changes in total plant biomass in the western Peel populations.

The biomass at the shallow Peel sites (18, 19, 20; Fig. 5) was generally much higher than that recorded in the deeper central basin sites. At the shallow sites biomass depends not only on growth at the site, but on export from deeper sites as well. Biomasses exceeding 4 kg m^{-2} were recorded at sites 19 and 20 in 1978-79. Since then the biomass has generally declined. This is thought to be largely due to the reduction in export of biomass from the deeper growth sites, rather than a significant reduction in growth at these sites. The area of the Peel covered with high biomass (> 100 g m^{-2}) has reduced significantly since the decline of *Cladophora* biomass in late 1979 (see below), and this has presumably led to a reduction in the export of biomass to the shallows, where the average biomass in 1986-87 was 193 g m^{-2}, not much higher than the average in 1981-82 (175 g m^{-2}).

3.1.4 Factors Controlling Inter-annual Variability

When the biomass for Peel was plotted against the mean light attenuation coefficient in the inlet for December to March each year (Fig. 6a), the two were found to be significantly, negatively correlated ($r = -0.82$, $p < 0.05$). This supports the suggestion of Lukatelich and McComb (1985), based on data to 1984, that macroalgal biomass in Peel has been largely determined by light availability.

Further, the attenuation coefficient was significantly, positively correlated ($r = 0.79$, $p < 0.05$) with the mean chlorophyll 'a' concentration in Peel Inlet for the same period (Fig. 6b). This suggests that the light available for macroalgal growth is largely determined by the amount of phytoplankton in the water column. The low biomass in 1982 was probably due to a prolonged *Nodularia* bloom in 1981/82, which was sustained by an unseasonal summer riverflow -the mean attenuation coefficient at that time was the highest recorded (Table 2). Tissue nitrogen and phosphorus concentrations (see below) do not suggest decreased nutrient availability in 1982.

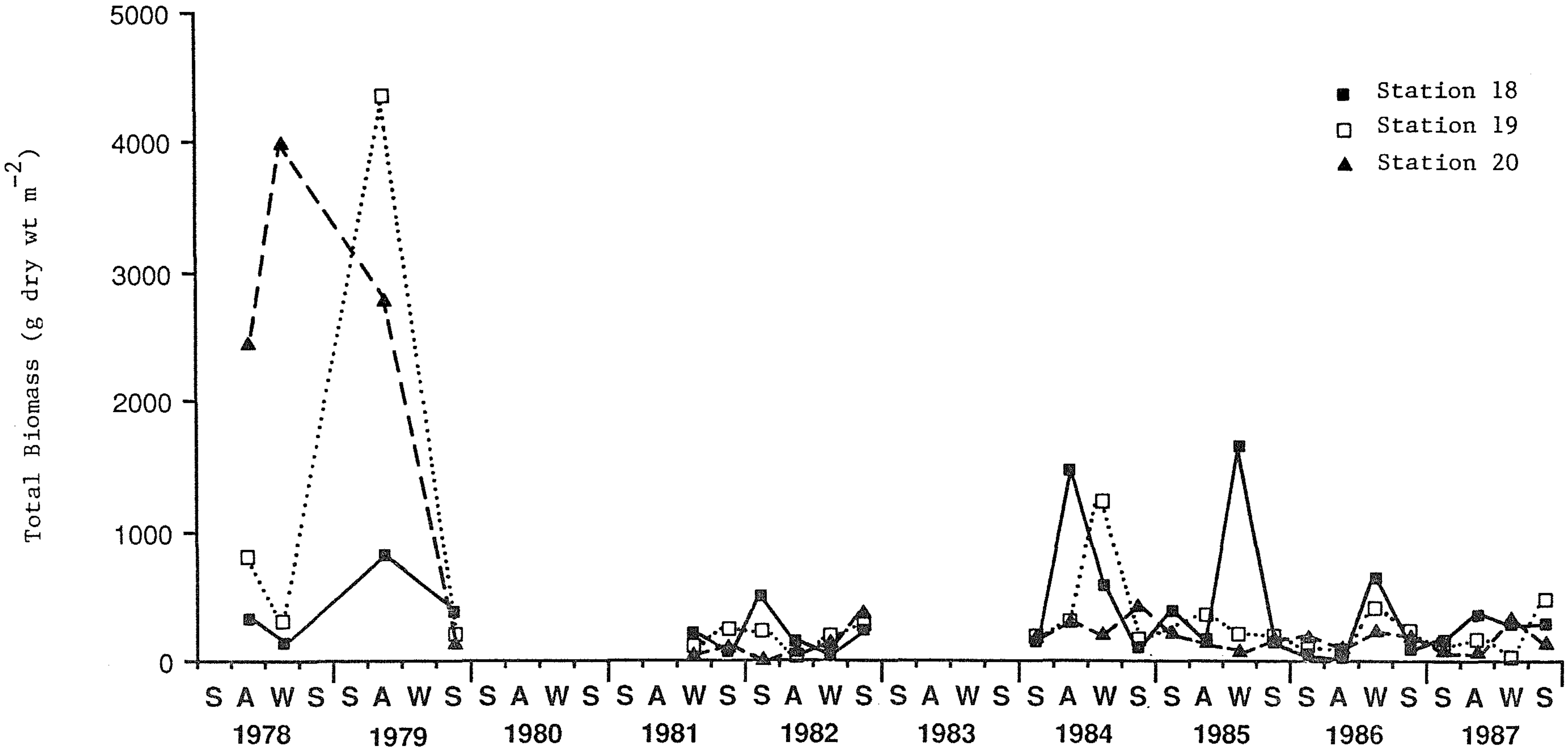


Figure 5. Seasonal changes in total plant biomass in the Peel shallows.

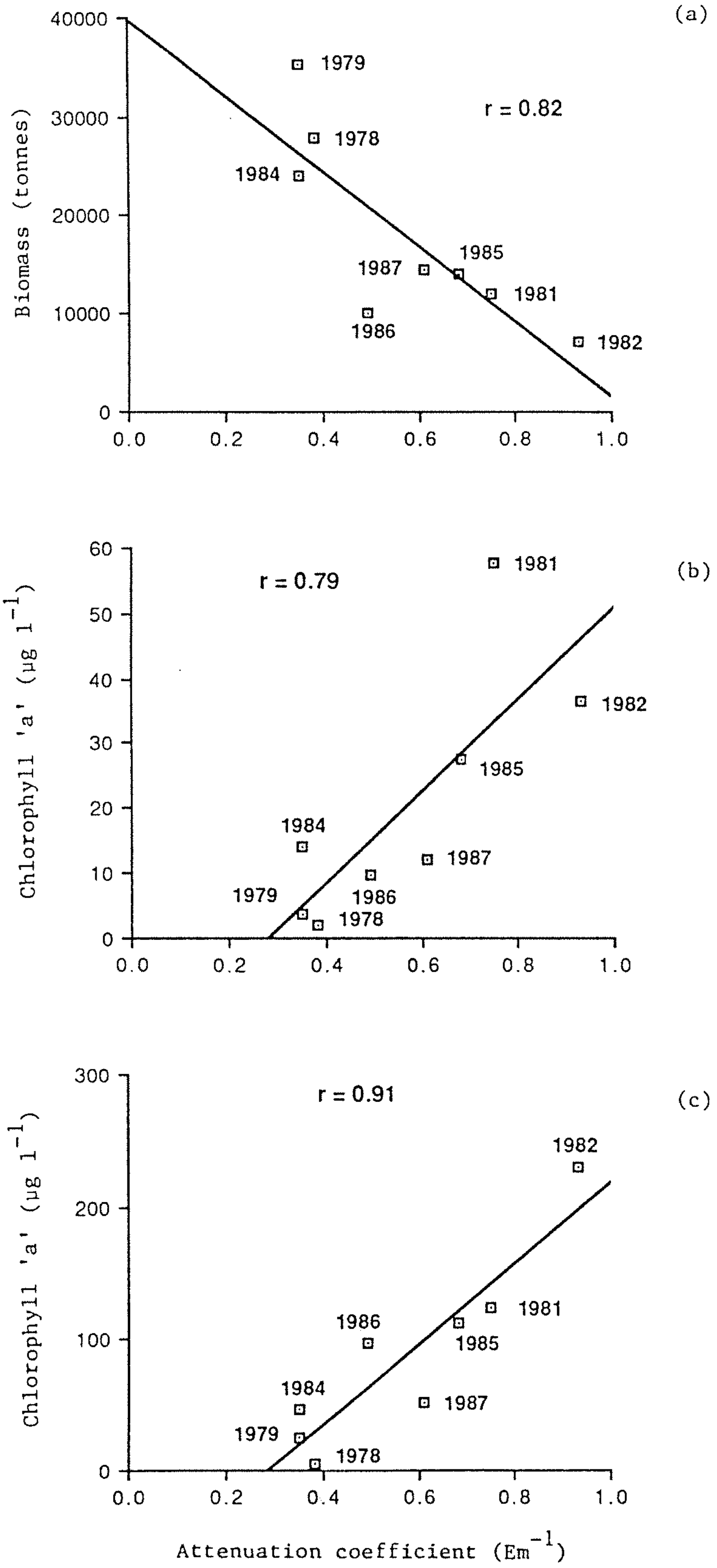


Figure 6. Relationship between mean attenuation coefficient for the period December to March and (a) mean macroalgal biomass; (b) mean Peel Inlet chlorophyll 'a' concentration for the same period; and (c) mean Harvey Estuary chlorophyll 'a' concentration for the same period.

Table 2. Mean attenuation coefficient for the period December to March.

Year	Attenuation coefficient (E m^{-1})	
	Peel	Harvey
1977/78	0.38	0.47
1978/79	0.35	1.22
1979/80	0.42	0.44
1980/81	0.75	1.71
1981/82	0.93	1.98
1982/83	0.41	1.12
1983/84	0.35	1.06
1984/85	0.68	1.64
1985/86	0.49	1.23
1986/87	0.61	1.19

Chlorophyll 'a' concentrations in Peel Inlet during December-March (Table 3) are largely determined by the size of the *Nodularia* bloom in Harvey Estuary. By early December salinities are generally too high in Peel Inlet for the growth of *Nodularia*, and most of the *Nodularia* in Peel Inlet at that time has been flushed from the Harvey. This suggestion is supported by the correlation between mean Peel Inlet attenuation coefficient and mean Harvey Estuary chlorophyll 'a' concentration ($r = 0.91$, $p < 0.01$; Fig. 6c). This correlation is stronger than that between the mean attenuation coefficient and chlorophyll 'a' concentration of Peel Inlet itself ($r = 0.79$); this is probably because of the presence at time of senescent *Nodularia* filaments in Peel Inlet. As mentioned above, salinities in Peel Inlet by December are unfavourable for *Nodularia* growth and cells flushed into Peel Inlet rapidly senesce and become bleached, but they still affect light attenuation. These relationships suggest that macroalgal biomass in Peel is to a certain extent controlled by the size of the *Nodularia* blooms in Harvey Estuary.

The mean chlorophyll 'a' concentration in Peel Inlet following the collapse of *Nodularia* blooms (March-May) has not varied significantly since the commencement of sampling (Table 1); fluctuations in Peel macroalgal biomass are therefore not due to changes in post-*Nodularia* bloom phytoplankton levels. The most important period for macroalgal growth in Peel Inlet appears to be December - March. This is not the case in the Harvey however, where in some years the collapse of the *Nodularia* bloom has been followed by large blooms of other phytoplankton. The mean Harvey Estuary chlorophyll 'a' concentration for the March - May period in 1987 (Table 1) was the lowest recorded to date, and there was a large increase in *Chaetomorpha* biomass in Harvey in autumn 1987 (see below).

Table 3. Mean (surface and bottom) chlorophyll 'a' concentrations for the period December to March.

Year	Chlorophyll 'a' ($\mu g\ l^{-1}$) Peel	 Harvey
1977/78	1.9	5.4
1978/79	3.8	25.5
1979/80	2.6	3.5
1980/81	57.7	123.7
1981/82	36.4	229.4
1982/83	8.2	73.1
1983/84	14.1	46.8
1984/85	27.6	112.8
1985/86	9.6	97.3
1986/87	12.2	51.4

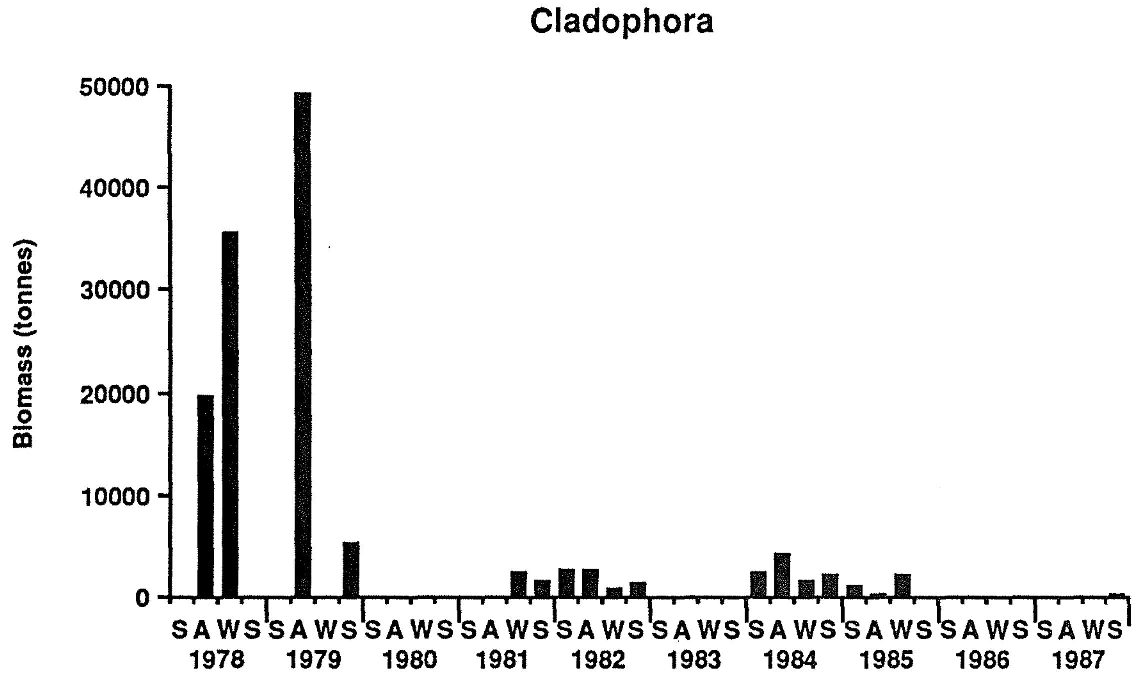
There are no statistically significant correlations between river nutrient loading and macroalgal biomass. It is suggested that, although nutrient loading allowed the accumulation of a large macroalgal biomass in earlier years, the light climate has restricted macroalgal growth in recent years. Nevertheless there does appear to be some association between Murray River flow and Peel macroalgal biomass. Significant Murray River flow occurred in 1978, 1981 and 1983, and large increases in macroalgal biomass were recorded in 1979 and 1984 following large Murray River flows. The *Nodularia* blooms in 1978/79 and 1983/84 were the smallest recorded and light attenuation was reduced in Peel Inlet in those years (Table 2). The large Murray River flow in 1981 was followed by a large *Nodularia* bloom in Harvey Estuary which, due to unseasonal riverflow in January 1982, did not collapse until late March. The high winter nutrient load in those years when there was significant Murray River flow had the potential to stimulate macroalgal growth in the following spring - summer, provided there was sufficient light available for growth.

3.2 Species Composition

The species of alga which dominates the biomass has changed several times since macroalgal surveys began in 1978. *Cladophora* was dominant in 1978 and 1979, but fell from an estimated 50,000 tonnes dry weight in March 1979 to 5000 tonnes in September 1979; *Cladophora* has not exceeded 5000 tonnes since then (Fig. 7). In fact *Cladophora* biomass in 1986-87 only exceeded 100 tonnes dry weight on one occasion (November 1987, 240 tonnes). *Cladophora* appears to have been the first alga responsible for the macroalgal problem in Peel Inlet. An algal survey in 1966 by Allender failed to find any *Cladophora* in Peel Inlet, and until the late 1960's local residents claim that seagrasses were the dominant macrophytes in Peel Inlet. Complaints from local residents about beach accumulations of *Cladophora* in the shallows of Coodanup were first received in 1969 (Hodgkin *et al.*, 1980), and *Cladophora* accumulations on the beaches increased dramatically between 1969 and 1974; beach clearing by tractors commenced in 1974.

Cladophora dominated algal biomass between 1969 and 1979. Examination of river flow data for the Murray River (Hodgkin *et al.*, 1980) show that between 1963 and 1968 average or well above average riverflow was recorded. These high flow events may have supplied Peel Inlet with the nutrients necessary to support the massive growths of *Cladophora* from 1969 onwards. The reason why *Cladophora* alone proliferated is not yet clear.

The principle growth sites of *Cladophora* were in the deeper central basin of Peel Inlet, where it formed a smooth carpet of balls (1-3 cm diameter) overlying a black ooze which consisted of decomposing *Cladophora* and sediment. *Cladophora* is the only macroalga to have successfully colonised the deeper central basin of Peel Inlet. Figure 8 shows the distribution of *Cladophora* biomass > 100 g m^{-2} in March 1979 and *Chaetomorpha* biomass >100g m^{-2} in September 1986. *Chaetomorpha* was largely confined to the shallows whereas *Cladophora* was able to maintain a significant biomass in the northern and eastern portions of the central basin. Due to its unique morphology, which reduced bottom roughness, *Cladophora* was not readily transported from the deeper central basin by



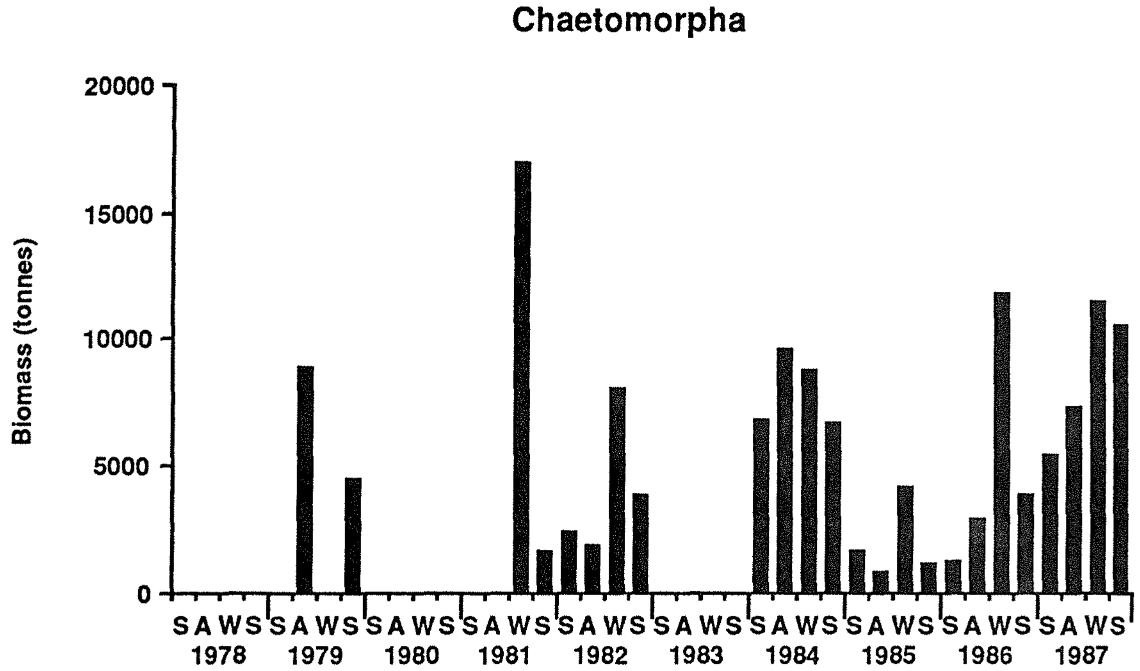
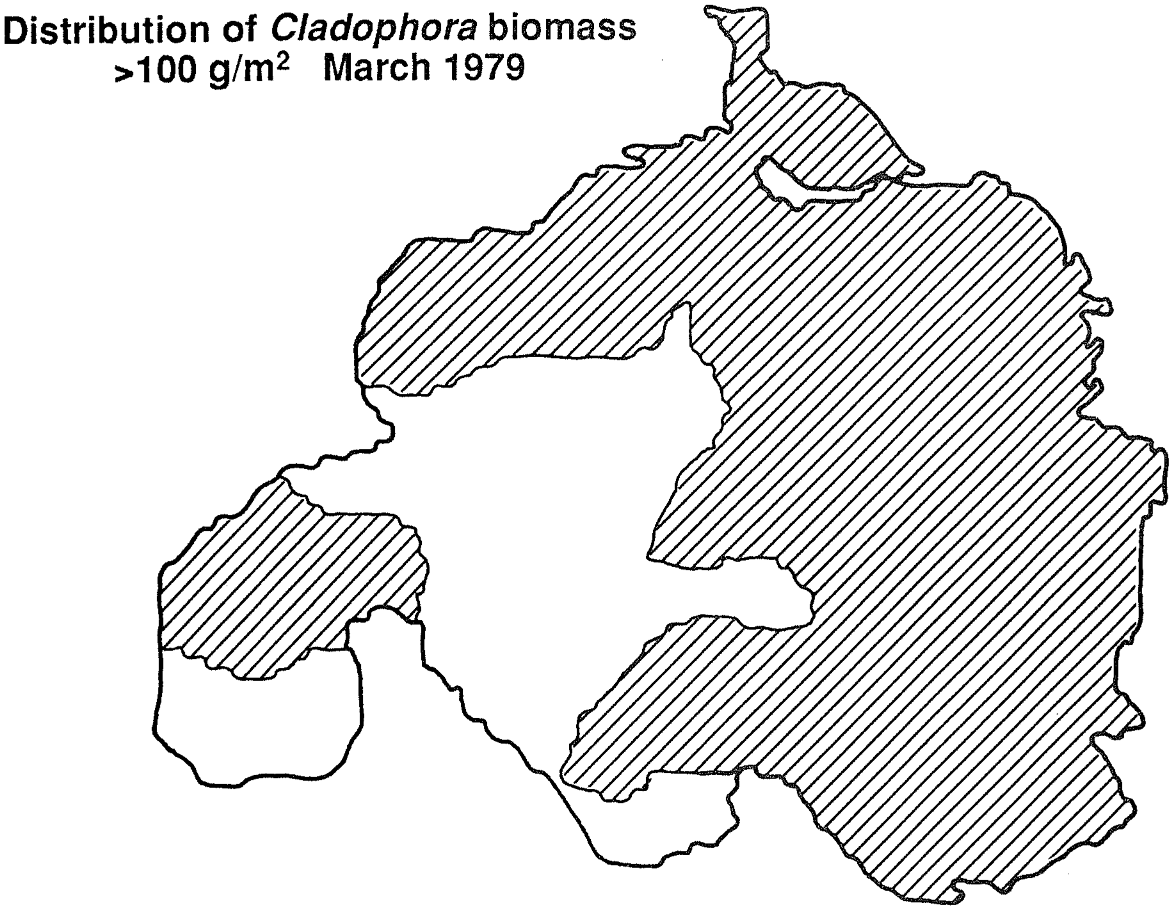
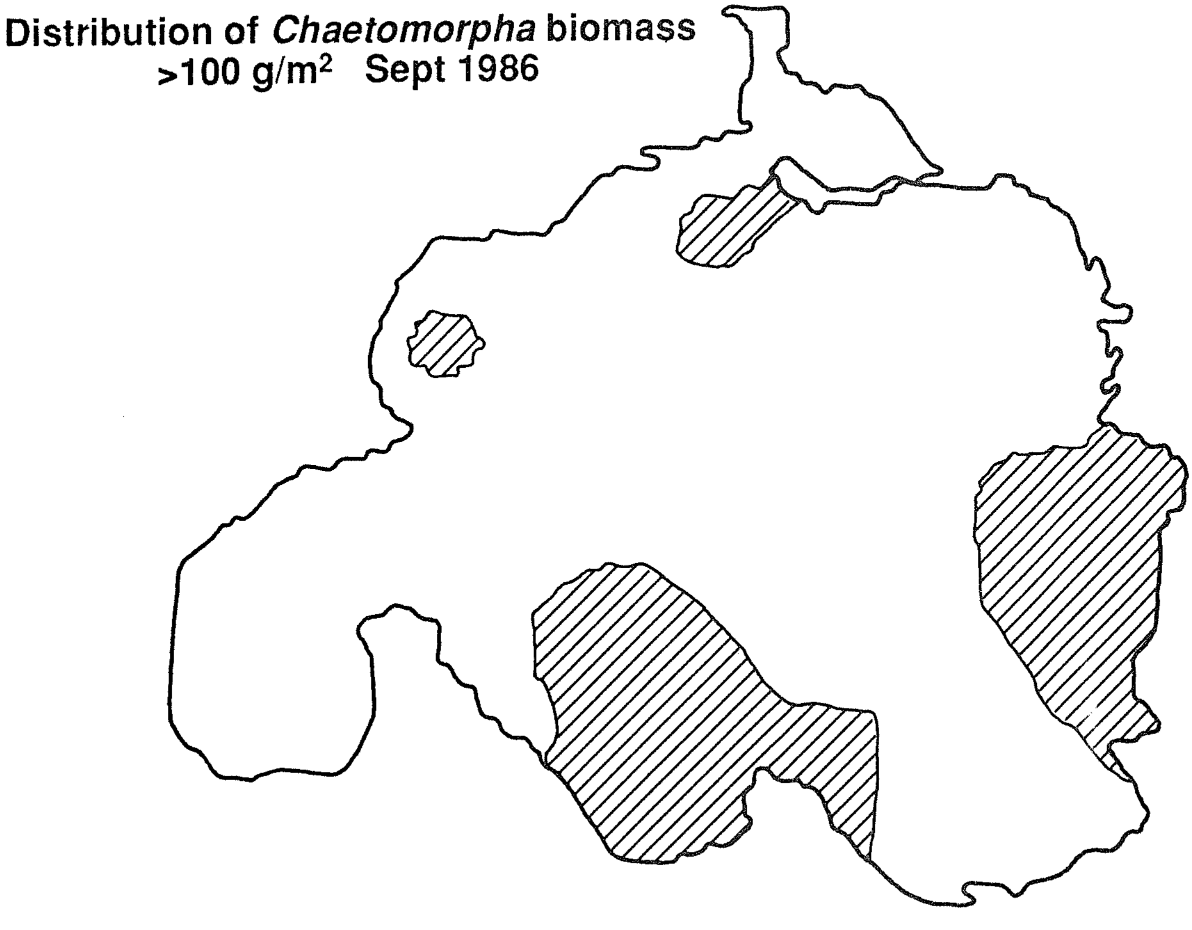


Figure 7. Seasonal changes in Cladophora (above) and Chaetomorpha (below) biomass.



Distribution of *Cladophora* biomass >100 g/m^2 March 1979



Distribution of *Chaetomorpha* biomass >100 g/m^2 Sept 1986

Figure 8. Distribution of biomass >100 gm^{-2} in March 1979 (above) and September 1986 (below).

wind-driven bottom currents. Export to the shallows, and ultimately the beaches, was mainly by surface wind-driven currents. Photosynthetically produced oxygen bubbles would become trapped between the filaments of a ball, giving rise to positive buoyancy. Windrows of floating *Cladophora* balls could be seen running across the surface of the inlet under gentle afternoon seabreezes. The other macroalgae that have dominated in later years (see below) have a much higher bottom roughness due to their morphology; large clumps in the case of *Chaetomorpha* and large sheets in the case of *Ulva*, which are easily transported to the shallows by wind-driven bottom currents. Permanent banks of *Chaetomorpha* and *Ulva* are only found in the shallows. When *Cladophora* was established in the deeper central basin the constant export of biomass to the shallows probably effectively prevented the growth of these other species due to smothering.

In the six months between March and September 1979 the total biomass of *Cladophora* fell dramatically (Fig. 7) and data from individual sites collected by Gordon *et al.* (1981) reveal that this decline occurred in two stages, the first of which began in winter 1978 at the deeper central basin sites.

There was a sudden and dramatic decline in *Cladophora* biomass at the deep water growth sites in July/August 1978, the most severe being a 1000 g m^{-2} decline over a one month period at a site near Yunderup (Gordon *et al.*, 1981). The most likely event that caused this decline was a severe storm from 18-22 July 1978. Mean hourly wind speeds averaged 12-14 m sec^{-1} over this entire period; such a severe storm is about a one in ten year event. The predominant wind direction was westerly. It is proposed that this storm broke up the *Cladophora* beds in the deeper central basin and transported the biomass to the shallows. Once exposed, the underlying black ooze from which the *Cladophora* bed derived most of the nutrients required for growth (Gordon *et al.*, 1981), would have been susceptible to resuspension and oxidation, which would have limited release of nutrients, particularly P. After this decline, conditions were not favourable for the growth of *Cladophora* in the deeper central basin, as a *Nodularia* bloom in Harvey Estuary the following spring caused prolonged turbidity, and nutrient loading from the rivers in 1979 was well below average (Hodgkin *et al.*, 1980).

The large *Cladophora* biomass recorded in March 1979 was largely confined to the shallows, and due to the export of biomass from the deeper central basin growth sites the previous winter, followed by some growth in the shallows. Between March and September 1979 *Cladophora* biomass at these shallow sites declined dramatically (Gordon *et al.*, 1981). This was apparently due to export of biomass to the beaches without subsequent replenishment from growth sites in the deeper central basin.

Between August 1978 and March 1979, the period of declining *Cladophora* biomass, *Chaetomorpha* biomass increased from 1 tonne to about 9000 tonnes dry weight (Fig. 7), and was restricted primarily to the shallows. It has been estimated that in 1980 *Chaetomorpha* biomass reached 30 000 tonnes (Lukatelich and McComb, 1985) and it apparently was an effective competitor for light and nutrients against *Cladophora* in the shallows, where *Cladophora* could not sustain a permanent population without export from deeper sites in the central basin.

Physiological experiments indicate that *Chaetomorpha* has a greater rate of phosphorus and nitrogen uptake than *Cladophora* (Lavery, 1988). In the field, *Chaetomorpha* also has a relatively fast growth rate, seldom approaching zero, unlike *Cladophora* which had distinct seasonality, with growth rates generally negative during the winter months (Lavery, 1988).

In 1981 and 1982 very high light attenuation occurred during the December to March macroalgal growth period (Table 2) due to dense *Nodularia* blooms, and the biomass of *Chaetomorpha* and other macrophytes declined (Figs. 2 and 7).

In contrast, in summer 1984, following above average riverflow and nutrient loading the previous winter and a significant improvement in light penetration due to a relatively small *Nodularia* bloom, macroalgal biomass increased. *Ulva* and *Enteromorpha* increased dramatically from negligible levels to 8 000 tonnes *Ulva* and 14 000 tonnes *Enteromorpha* (Fig. 9). *Chaetomorpha* (10 000 tonnes) was co-dominant with *Enteromorpha* and *Ulva* at this time. This sudden increase is interpreted as a typical response of these opportunistic species to increased nutrient availability and good growth conditions. Lukatelich and McComb (1985) presented evidence for an increase in phosphorus availability between 1981-83, and there was a marked decrease in light attenuation during the main growth period in 1983/84 (Table 2). Similar responses by these genera to localized nutrient enrichment have been reported by a number of other studies (eg. Lowthion *et al.*, 1985).

By 1985 *Ulva* had assumed dominance with a biomass approaching 14000 tonnes (77% of total macroalgal biomass) and remained dominant until winter 1986 (Fig. 10). In 1986 and 1987 there was a decline in the nutrient status of the system (Lukatelich and McComb, 1988) and *Chaetomorpha* resumed as the dominant macroalga (Fig. 10).

Red algae (Fig. 11), principally *Gracillaria*, rarely contributed a significant proportion of the total macroalgal biomass. Maximum biomass of red algae was recorded in autumn 1984, 9000 tonnes dry weight (about 20% of total macroalgal biomass), but generally red algal biomass is less than 1500 tonnes.

Maximum biomass of brown algae recorded to date is 350 tonnes dry weight (Fig. 11). The brown algal contribution to total macroalgal biomass is generally negligible, the maximum contribution being 2.5% in spring 1982.

In Harvey Estuary, macroalgal biomass in 1986-87 was dominated by *Chaetomorpha* (Fig. 12). In earlier years red algae, principally *Gracillaria*, have dominated on occasions. The growth rate of *Gracillaria foliifera* has been found to exceed that of *Ulva* sp. under low light

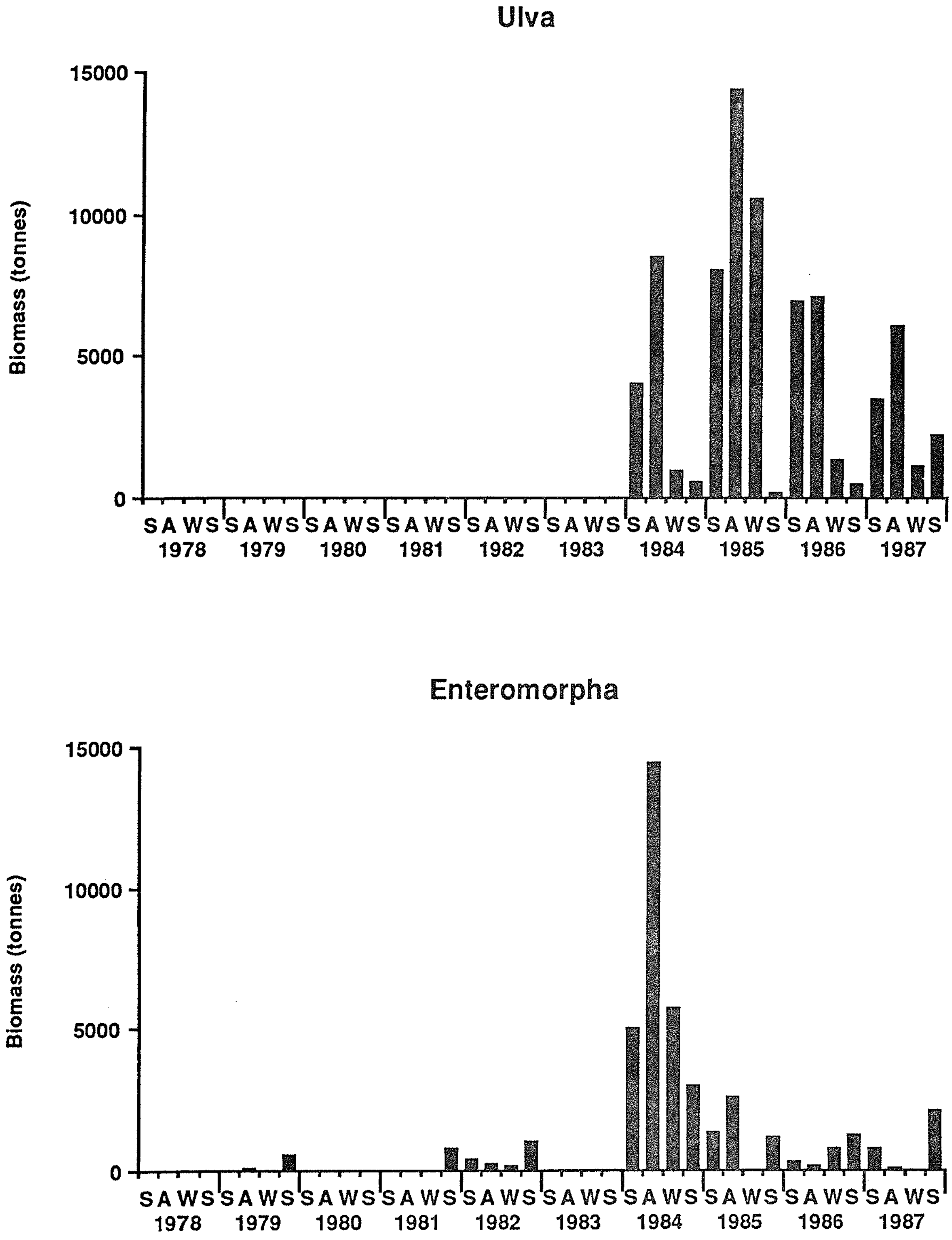


Figure 9. Seasonal changes in Ulva (above) and Enteromorpha (below) biomass.

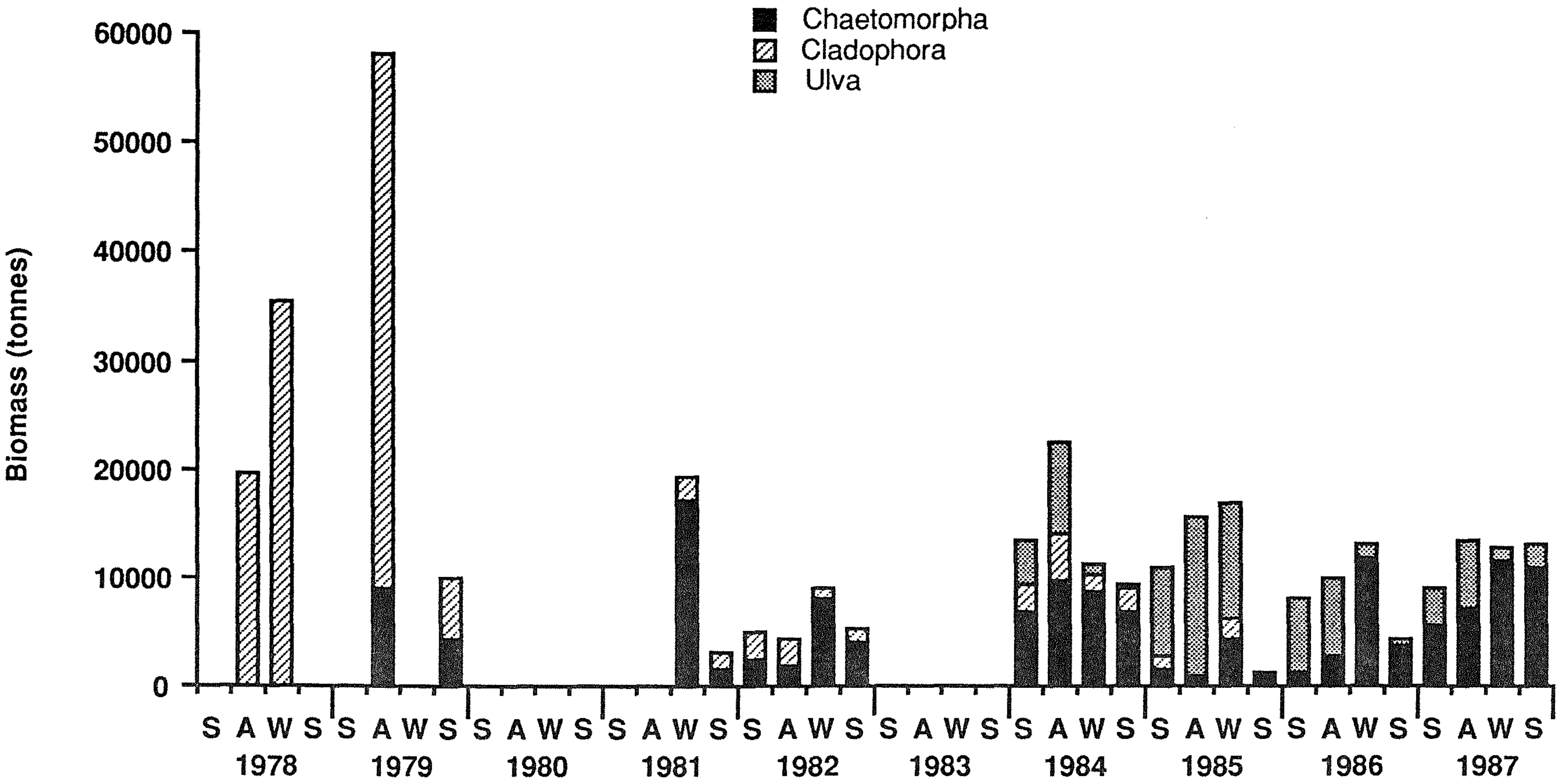
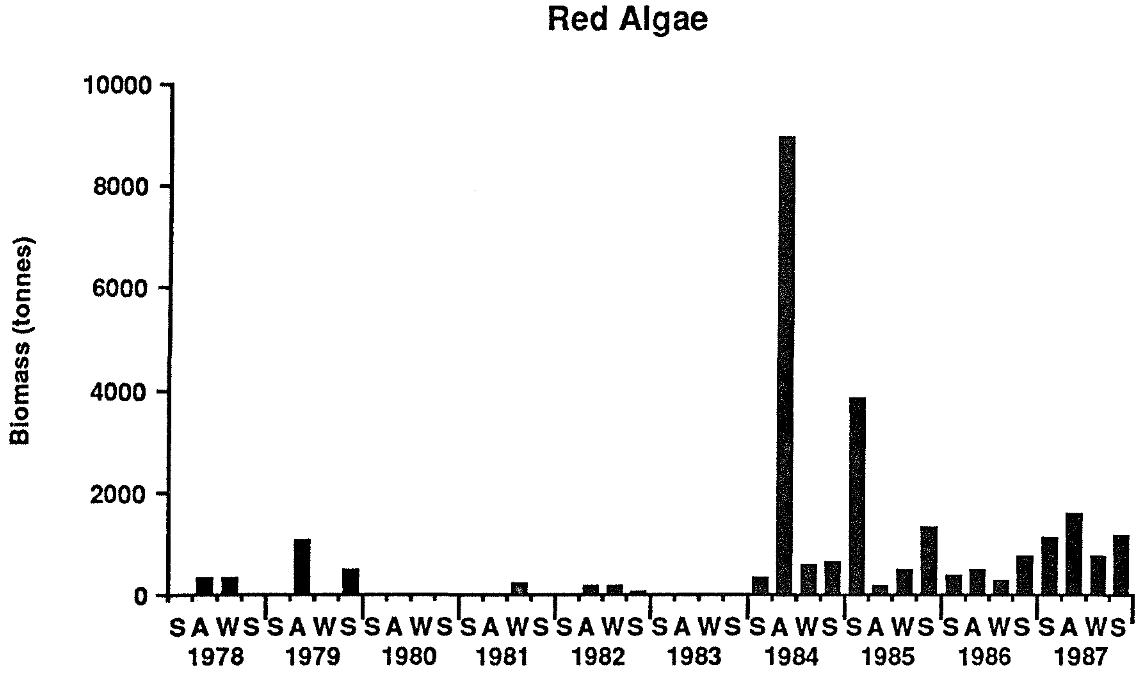


Figure 10. Changes in the biomass and species composition of macroalgae in Peel 1978-1987.



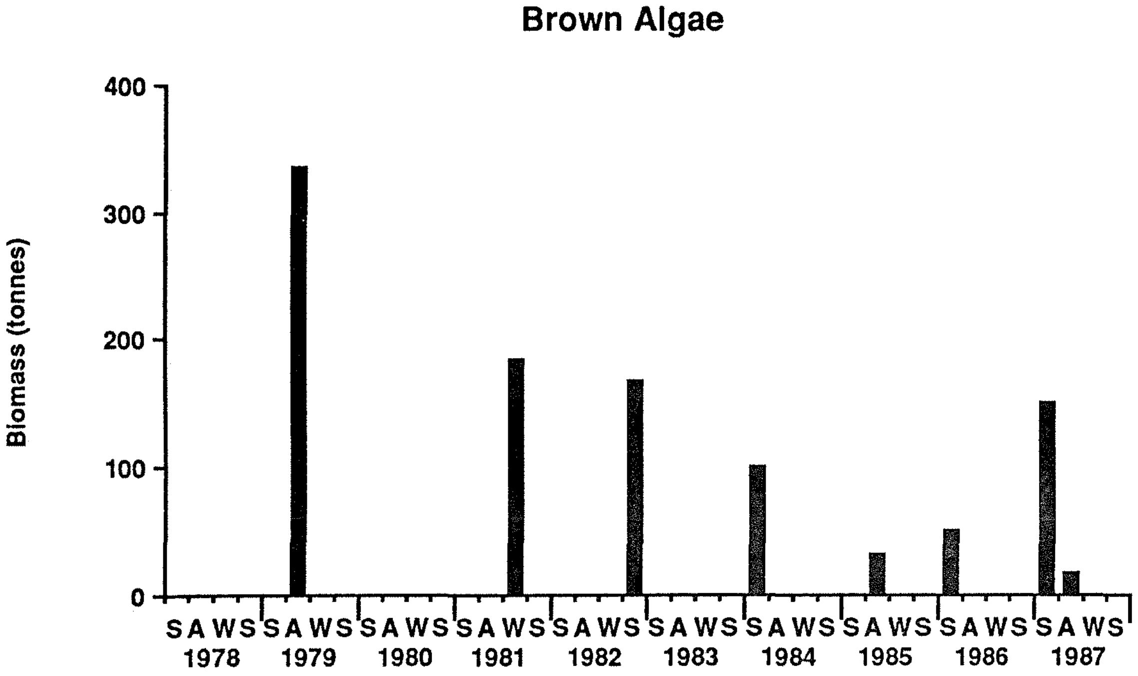


Figure 11. Seasonal changes in Red (above) and Brown (below) algal biomass.

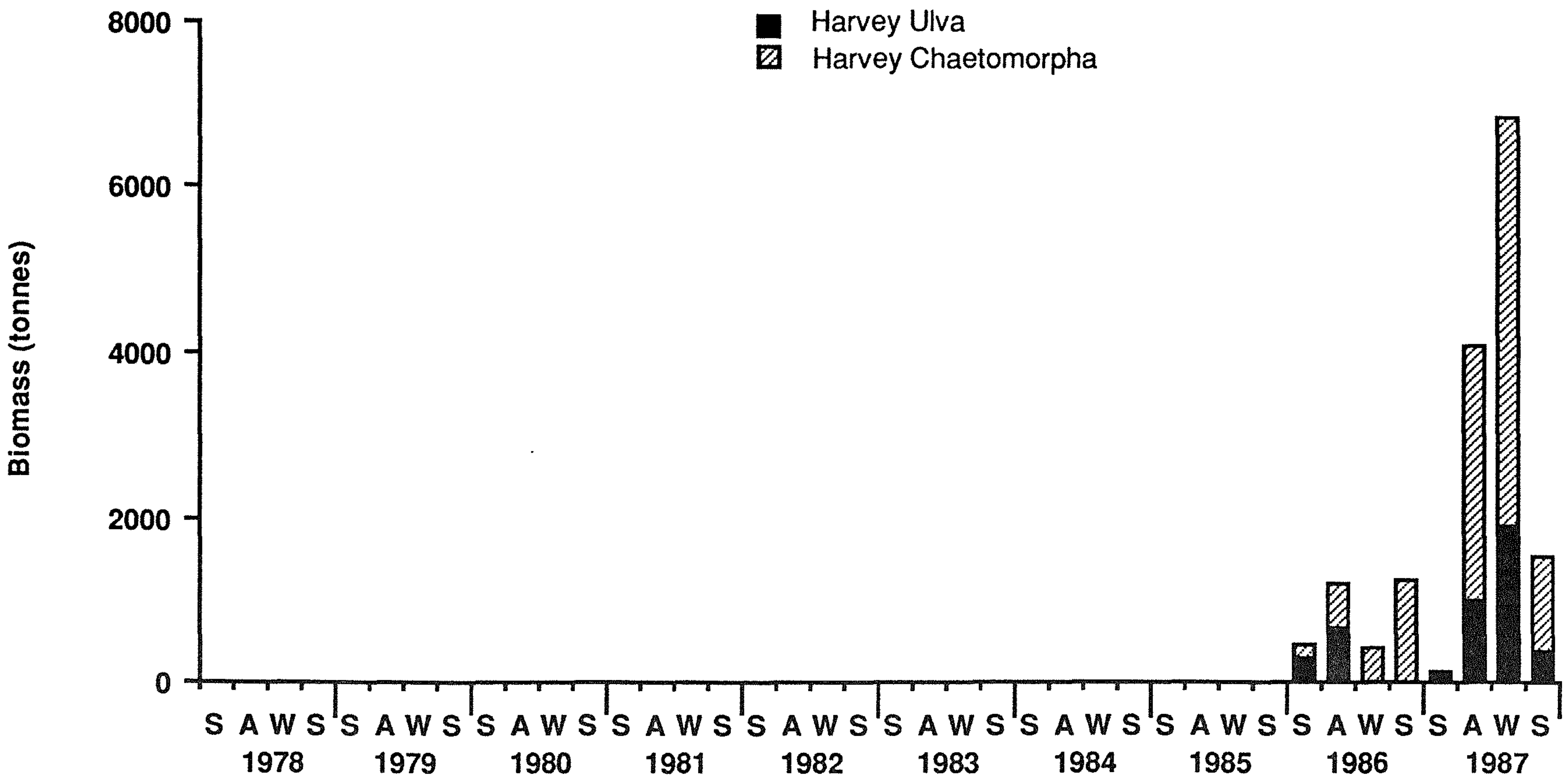


Figure 12. Changes in the biomass and composition of macroalgae in Harvey 1986-1987.

conditions (Rosenberg and Ramus, 1981). *Gracilaria* may be capable of out-competing green algae under the turbid conditions generally found in Harvey Estuary.

Seagrasses generally account for < 15% of total plant biomass in the system (Fig. 13) with a maximum of 26.9% (August 1984). The dominant seagrasses are *Ruppia megacarpa* and *Halophila ovalis*, but small beds of *Zostera* can be found near the entrance channel and *Lepilaena cylindrocarpa* grows amongst the *Ruppia* in Austin Bay.

Halophila ovalis is reported to have grown in the deeper central basin of Peel Inlet before *Cladophora* became dominant in the late 1960's. The deeper central basin *Cladophora* growth sites had remained bare, except for transient clumps of *Chaetomorpha*, since the demise of *Cladophora* in 1979, until 1986 when *Halophila* reappeared at these sites, and increased dramatically in 1987 (Fig. 14).

This reappearance appears to be related to available light. Figure 15 shows the mean light attenuation coefficient at station 4, a deep central basin site, each year between 1978 and 1987. The mean attenuation coefficient in 1986 was equal to the 'critical light level' for *Halophila* (Hillman, 1985) and in 1987 was well below this; that is, light was not so attenuated that *Halophila* could not grow. In contrast, between 1980 and 1985 the mean attenuation coefficient was well above the critical light level for *Halophila* and *Halophila* was therefore unable to grow. In 1978-79 the mean attenuation coefficient was below the critical level, but *Halophila* would have been excluded by the presence of *Cladophora*, which also benefitted from the relatively high light intensity on the estuary floor.

3.3 Tissue Nitrogen and Phosphorus Concentrations

3.3.1 *Cladophora*

Tissue nitrogen and phosphorus concentrations are consistent with earlier work (Gordon *et al.*, 1981a) in that *Cladophora* appears to be more phosphorus-limited than nitrogen-limited (Figs 16 and 17). The tissue nitrogen concentration rarely fell below the critical

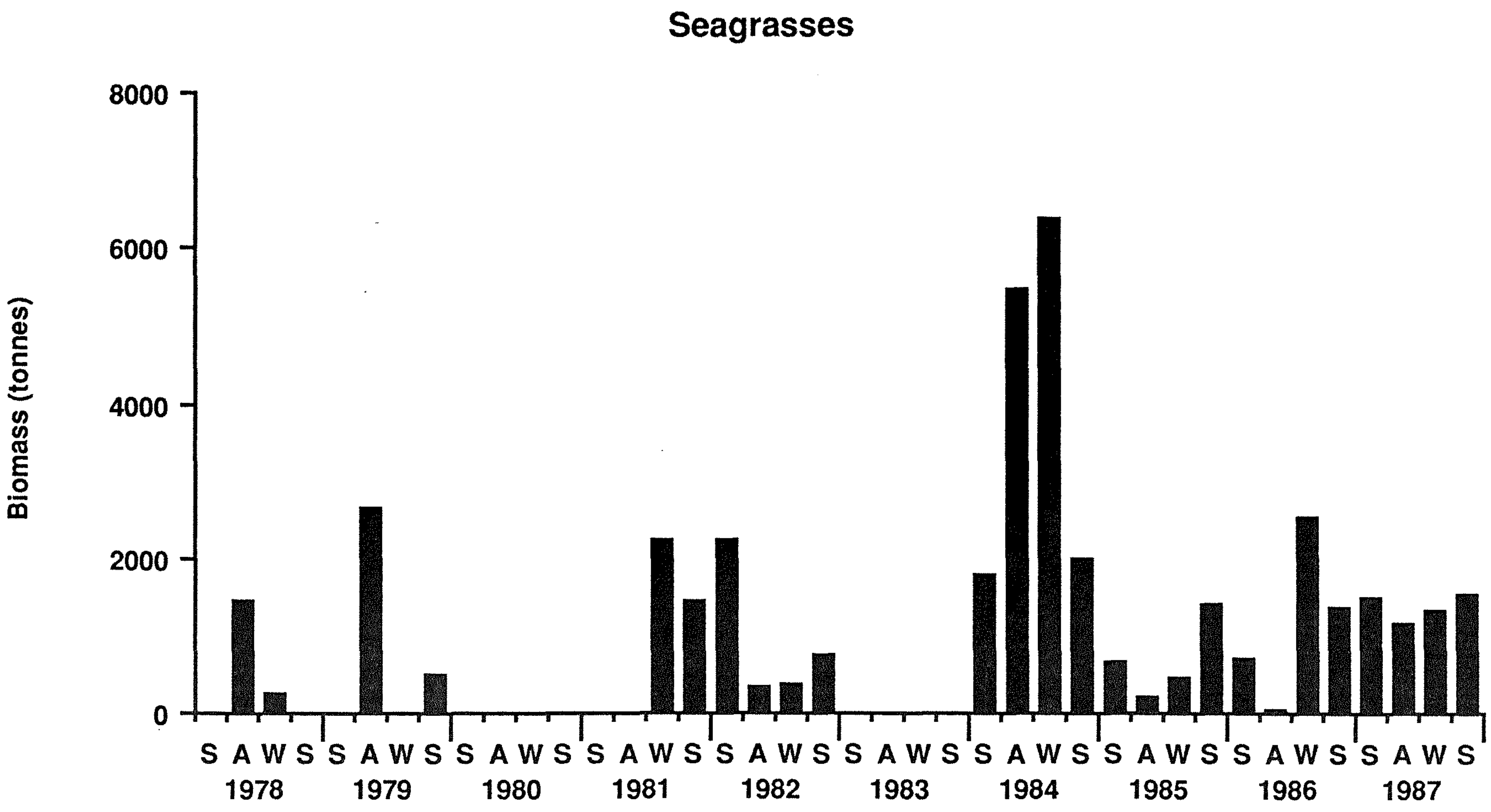


Figure 13. Seasonal changes in seagrass biomass.

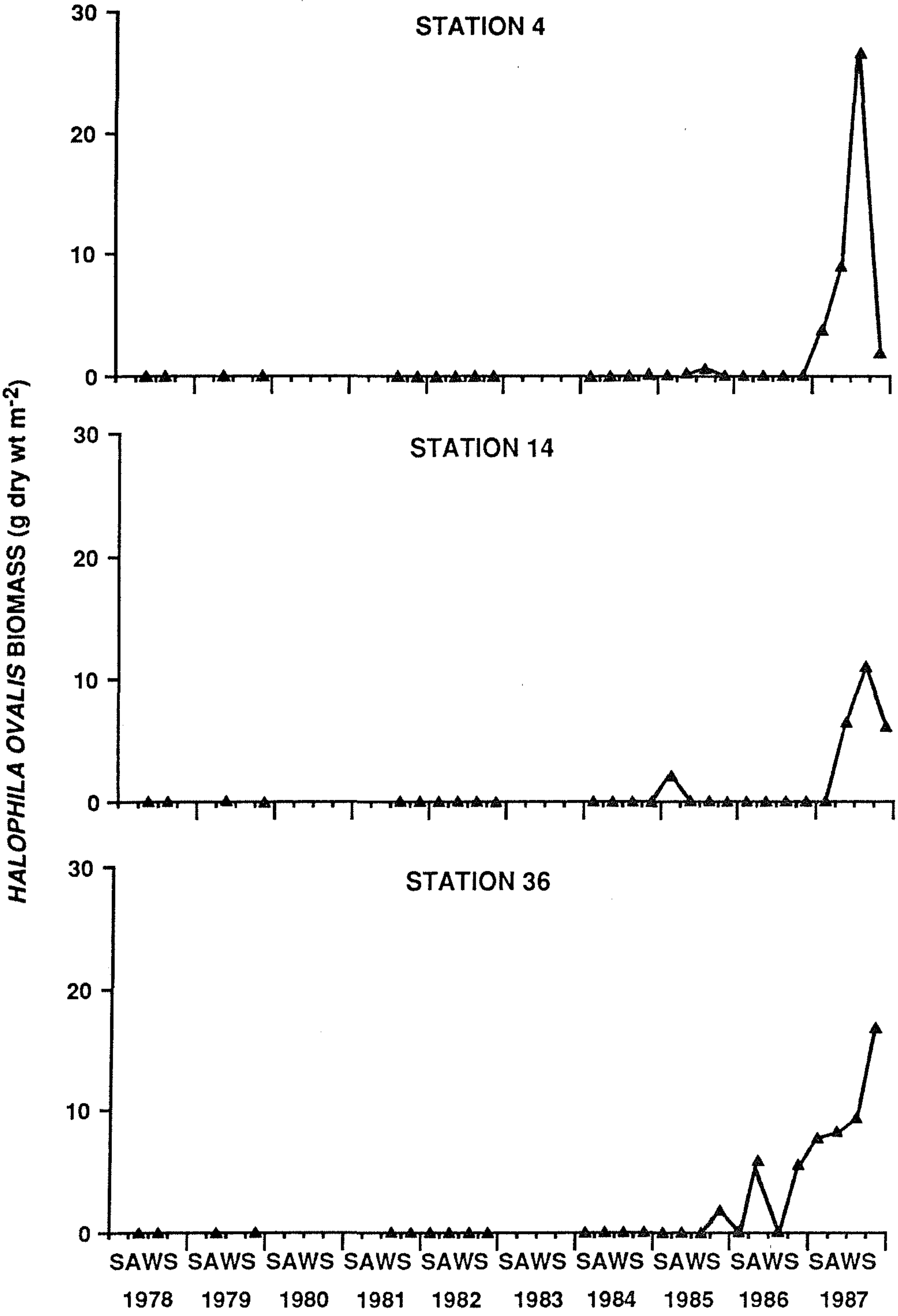


Figure 14. Halophila ovalis biomass at some eastern Peel deep water sites.

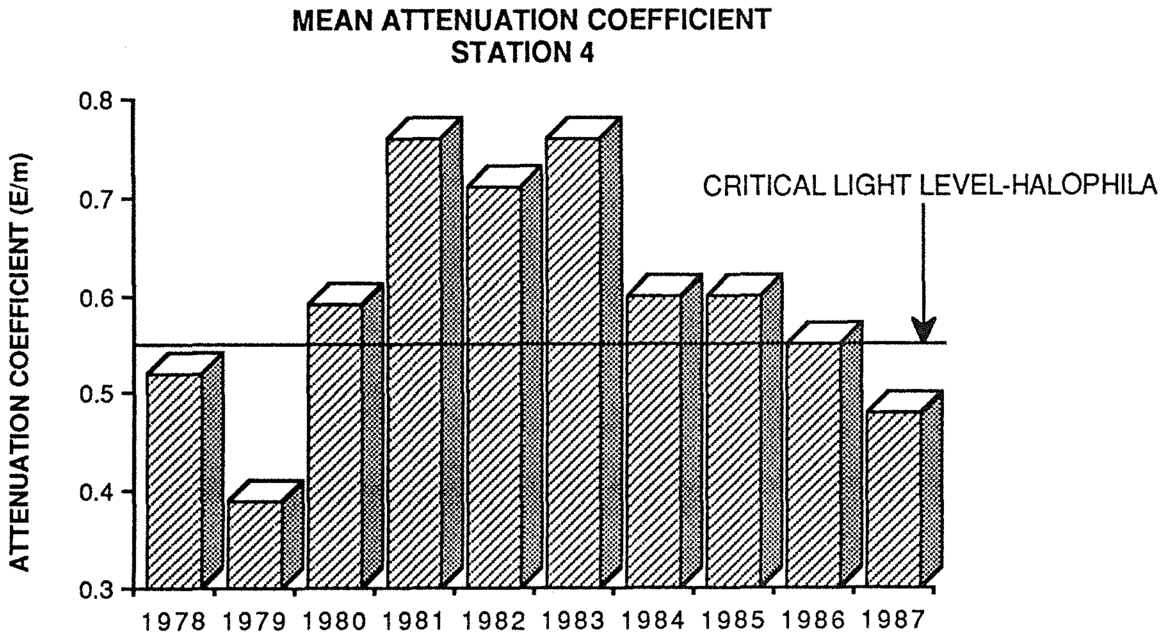


Figure 15. Mean attenuation coefficient at station 4.

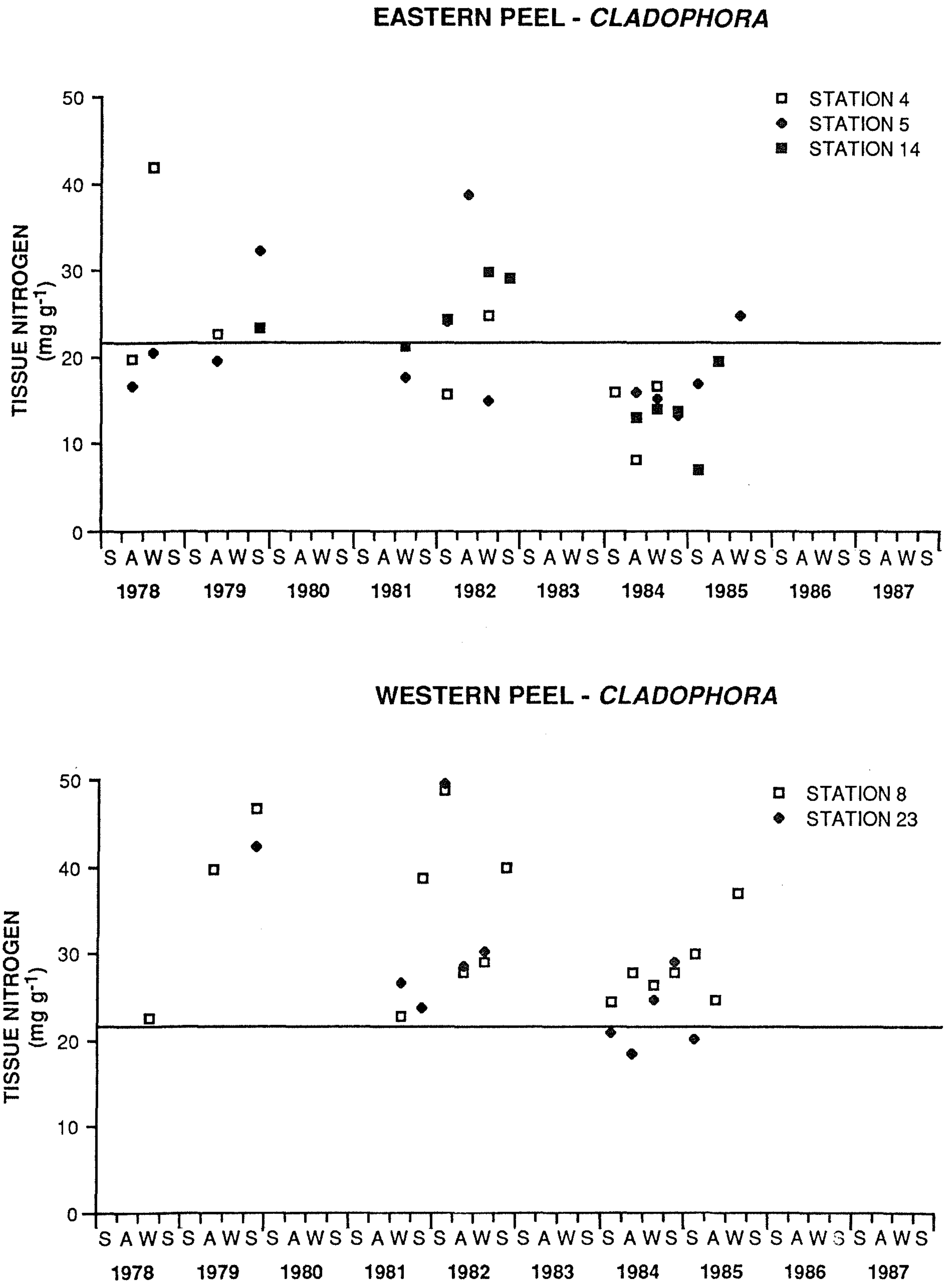
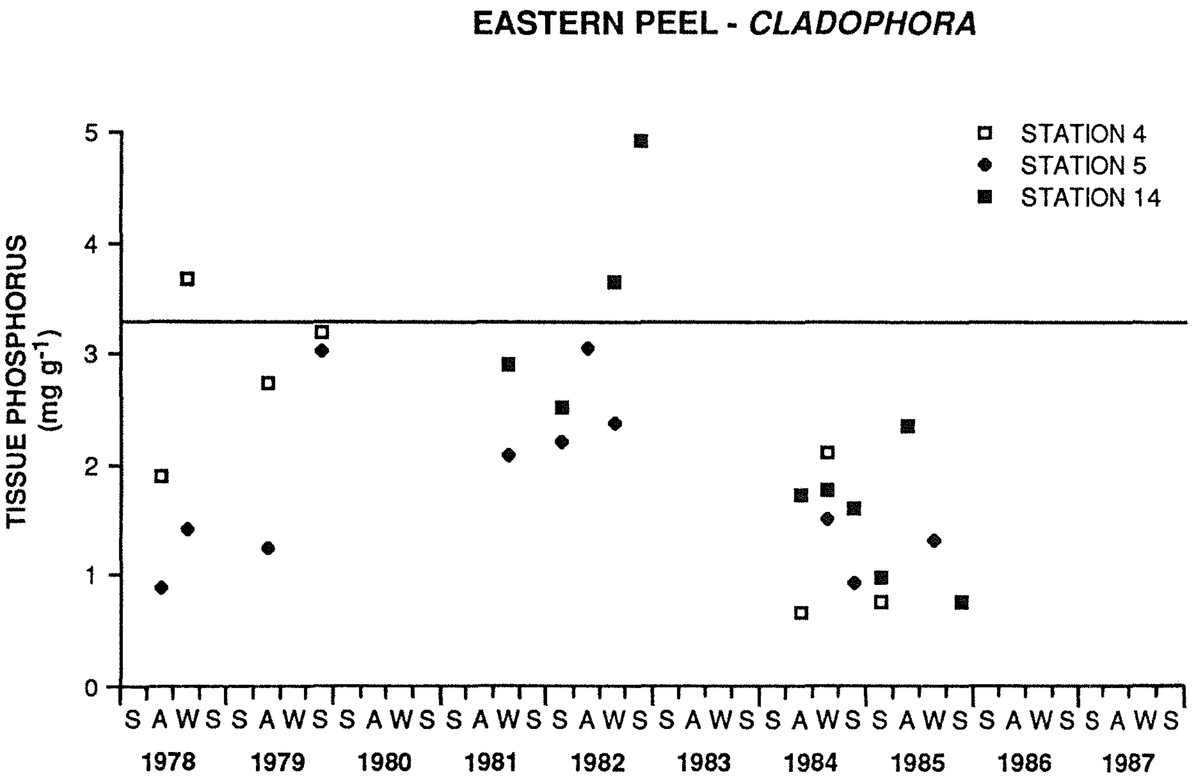


Figure 16. Seasonal variation in the concentration of nitrogen in the tissues of Cladophora from eastern Peel populations (above) and western Peel populations (below). The line shown is the critical concentration for Cladophora (Gordon et al. 1981b). Also shown on Figs 17-21.



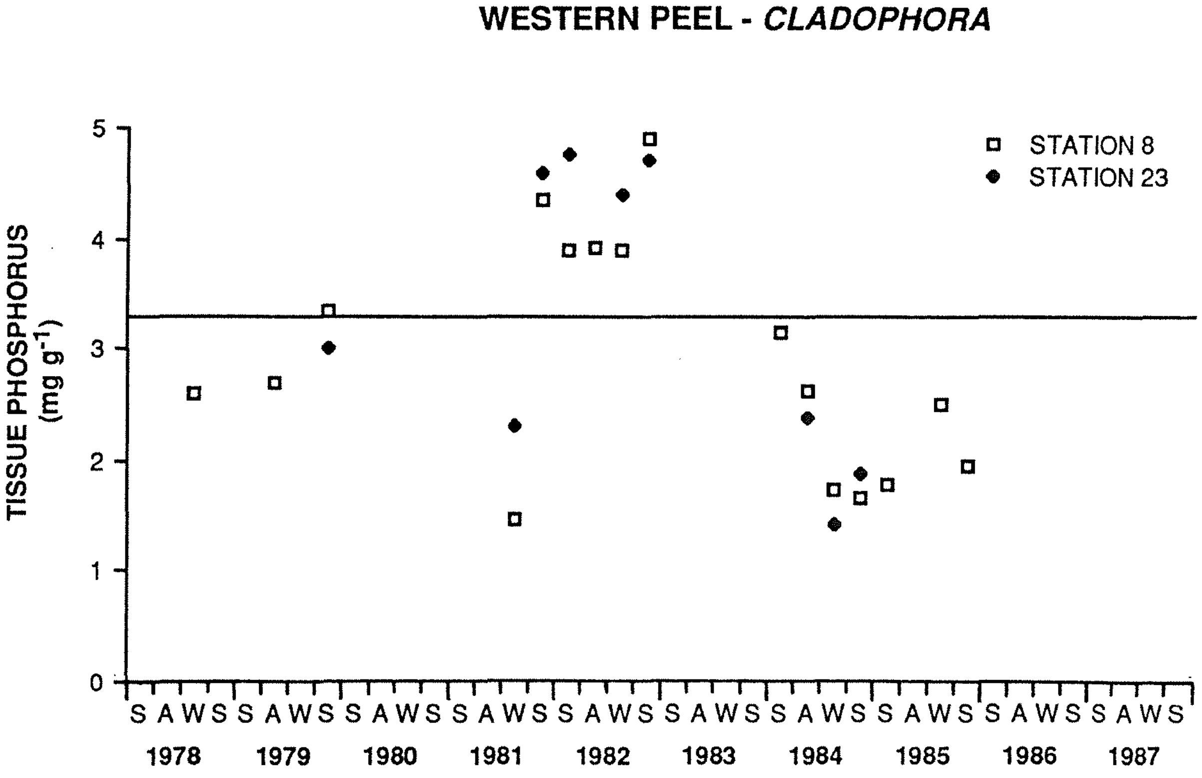


Figure 17. Seasonal variation in the concentration of phosphorus in the tissues of Cladophora from eastern Peel populations (above) and western Peel populations (below).

concentration at the Cox Bay and Dawesville sites (Fig. 16) whereas at the eastern Peel sites the tissue nitrogen concentration was often below the critical concentration. There is no obvious trend in the tissue nitrogen data, except for a fall in 1984-85, which was more marked in the eastern populations, where all but one *Cladophora* sample in 1984-85 had a tissue concentration lower than critical.

Tissue phosphorus concentrations showed a downward trend, most obvious for the western Peel (Fig. 17). Concentrations were generally below critical until October 1981; they remained high throughout 1982. No data are available for 1983, but concentrations fell again in 1984-85 to below those in 1978-79. The eastern Peel populations showed a similar (though less obvious) trend (Fig. 17). As with nitrogen, the western Peel sites had higher tissue phosphorus concentrations. No tissue nitrogen and phosphorus analyses could be carried out in 1986-87 due to the paucity of *Cladophora* biomass (see above).

3.3.2 *Chaetomorpha*

Tissue nitrogen concentrations (Fig. 18) show similar trends to *Cladophora*, in that the eastern populations generally had lower concentrations than the western, and tissue nitrogen concentrations have fallen since 1984. Of the western Peel sites, the Dawesville site generally had the highest tissue nitrogen concentrations.

The critical nitrogen and phosphorus concentrations for *Chaetomorpha linum* have not been determined, and the critical concentration for *Cladophora* is shown for comparison. Eastern Peel tissue phosphorus concentrations have declined since 1984.

Assuming the relationships are similar in the two genera, it appears that phosphorus may limit growth more often than nitrogen. The tissue phosphorus concentration was rarely above the *Cladophora* critical concentration for both the eastern and western populations (Fig. 19).

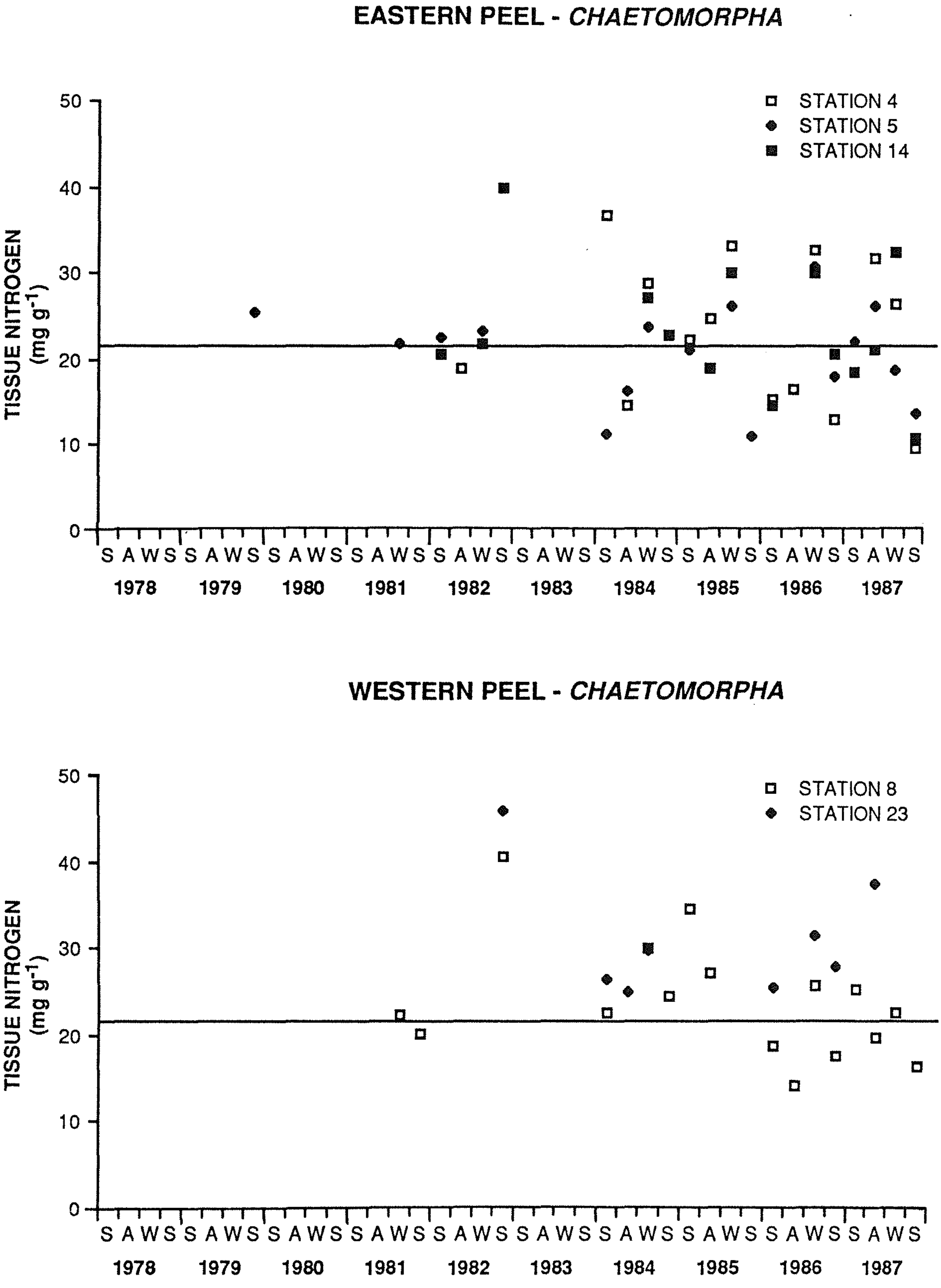


Figure 18. Seasonal variation in the concentration of nitrogen in the tissues of Chaetomorpha from eastern Peel populations (above) and western Peel populations (below).

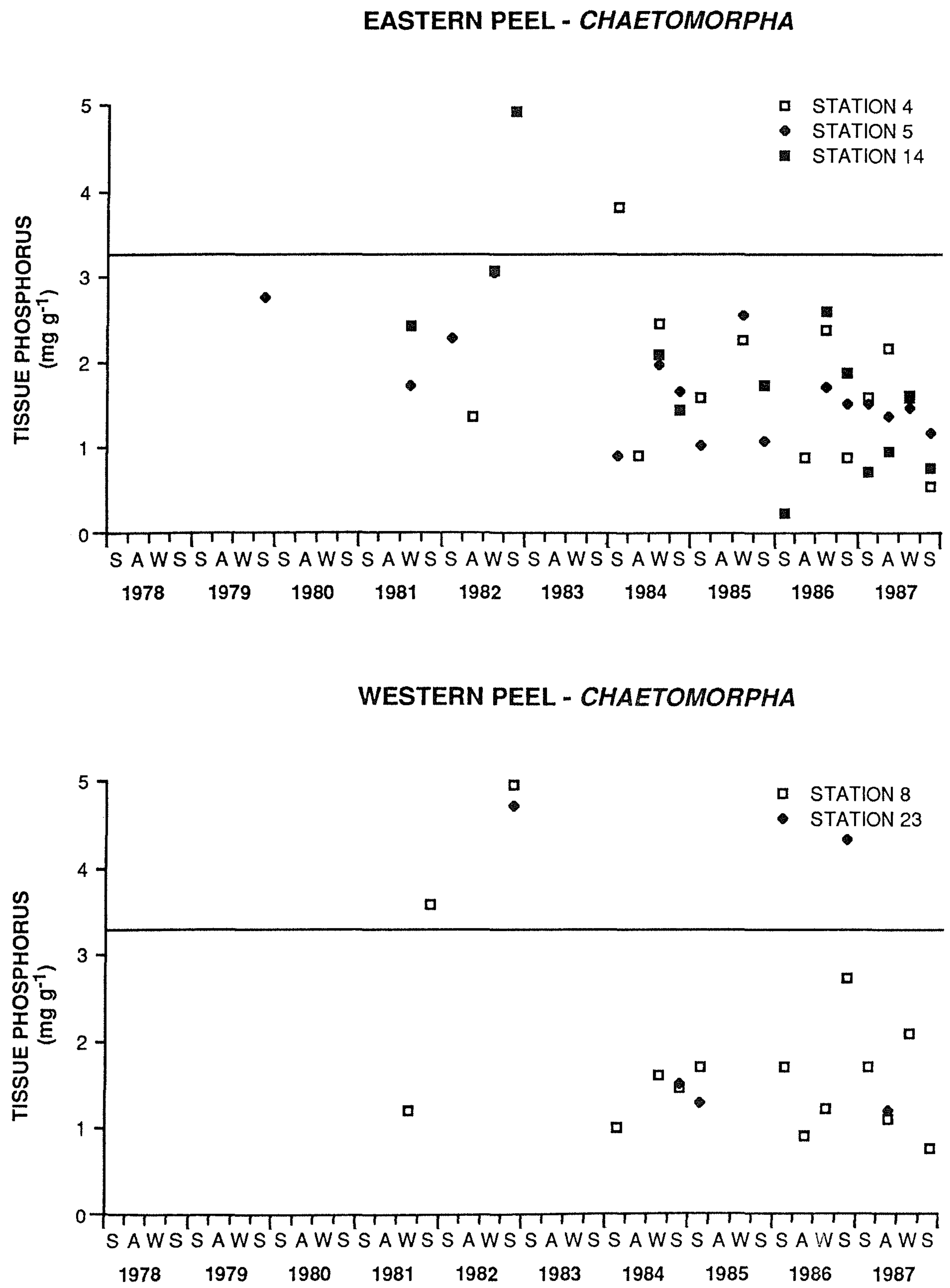


Figure 19. Seasonal variation in the concentration of phosphorus in the tissues of Chaetomorpha from eastern Peel populations (above) and western Peel populations (below).

3.3.3 *Ulva*

Tissue nitrogen concentrations (Fig. 20) were similar to *Chaetomorpha* and *Cladophora* but tissue phosphorus concentrations (Fig. 21) were generally much lower than in *Chaetomorpha* and *Cladophora*. Either *Ulva* has a lower critical phosphorus concentration (the critical nitrogen and phosphorus concentration for *Ulva rigida* is also unknown) or it is severely phosphorus limited in the system. The western *Ulva* populations generally had higher tissue nitrogen and phosphorus concentrations.

3.3.4 Discussion

There appears to have been a significant increase in *Cladophora* tissue phosphorus concentrations in late 1981 and 1982, following a large phosphorus input in the winter of 1981 and the summer floods of January 1982. There is also some evidence of increased phosphorus recycling from the sediments in the Harvey following the winter of 1981 until December 1983 (Lukatelich and McComb, 1985). In Harvey, the mean chlorophyll a concentration for the period March to May inclusive was much higher in 1982 and 1983 compared with other years (Table 1). In those years there were also large benthic *Oscillatoria* blooms after the collapse of *Nodularia*, and the *Oscillatoria* bloom was much larger in 1983 than 1982. Water column organic phosphorus concentrations increased during 1982 and 1983 in both estuaries (Lukatelich and McComb, 1985).

Tissue phosphorus concentrations in *Cladophora* and eastern *Chaetomorpha* showed a marked fall from early 1984 to 1987 compared to 1981-82 and this correlates with:

- A decrease in Harvey mean chlorophyll a concentration for the March-May period between 1983 and 1987 (Table 1) and the absence of an *Oscillatoria* bloom since 1983;

- A decrease in water column organic phosphorus concentrations since the 1983/84 *Nodularia* bloom (Lukatelich and McComb, 1988).

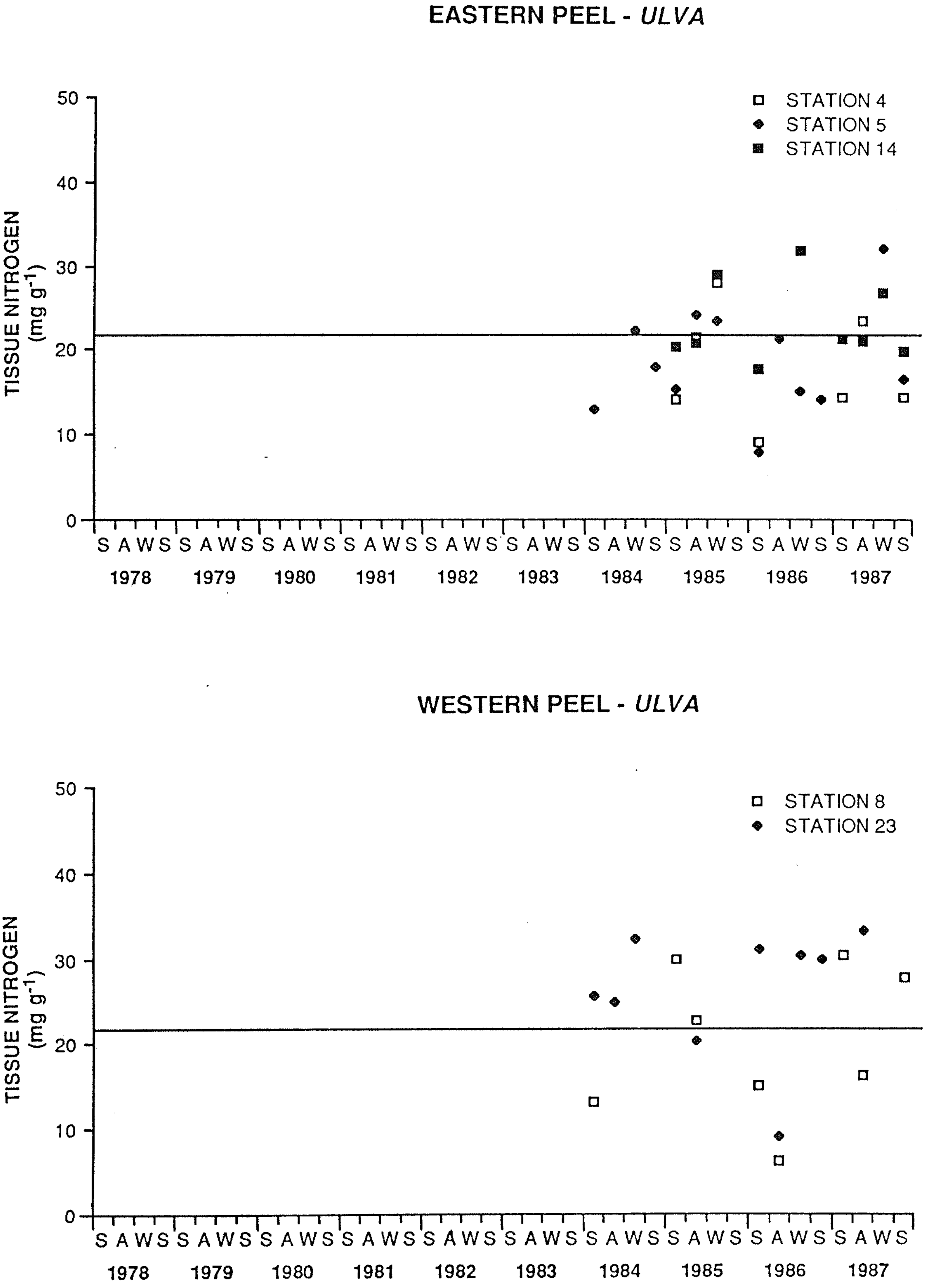


Figure 20. Seasonal variation in the concentration of nitrogen in the tissues of Ulva from eastern Peel populations (above) and western Peel populations (below).

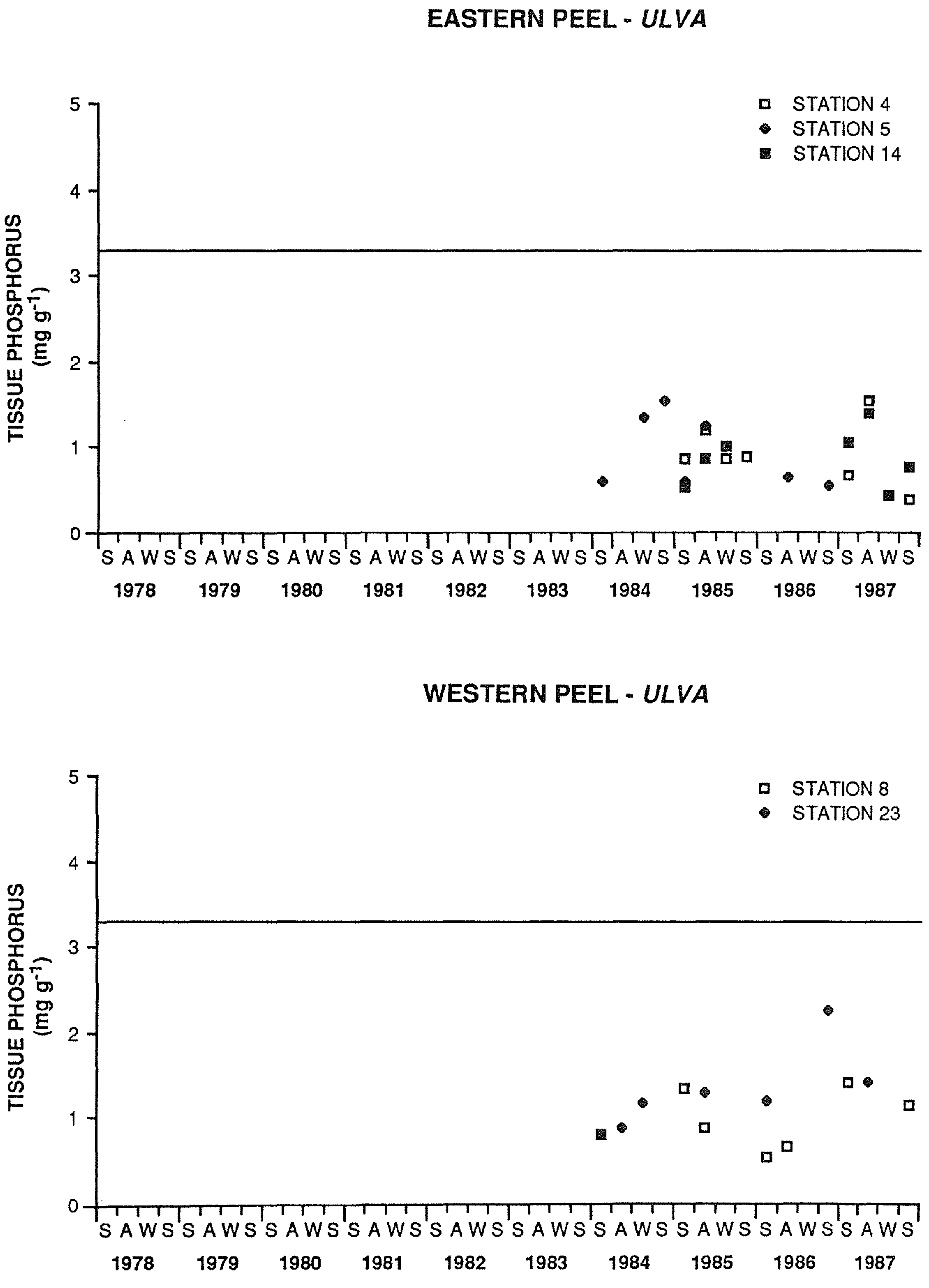


Figure 21. Seasonal variation in the concentration of phosphorus in the tissues of Ulva from eastern Peel populations (above) and western Peel populations (below).

The above points, and a fall in tissue phosphorus concentrations in 1984, suggest that there may have been a reduction in phosphorus recycling and availability in 1984 compared with the period from winter 1981 to December 1983. As noted earlier, increased light attenuation was presumably responsible for reducing macroalgal growth in 1981 and 1982. Under abundant nutrient supply but poor growth conditions the tissue concentrations of phosphorus would be expected to increase. With the improvement of light penetration in 1984 macroalgal growth rates increased, and tissue concentrations fell. The amount of available phosphorus was probably responsible for the changes in light attenuation during this period, because of its effect on phytoplankton biomass.

Cladophora and *Chaetomorpha* tissue nitrogen concentrations were either above or just below the *Cladophora* critical nitrogen concentration between 1978-1982. Presumably nitrogen was readily available during this period. However, from 1984 to 1987 tissue nitrogen concentrations declined in both the eastern and western populations, and this is correlated with:

- A decrease in water column organic nitrogen concentrations from 1984 (Lukatelich and McComb, 1988);

- Below average flow and hence nitrogen load from the Murray River from 1984;

- A reduction in the size of *Nodularia* blooms in Peel Inlet from 1983/84 and a much smaller *Nodularia* bloom in Harvey Estuary in 1986/87.

Tissue nitrogen and phosphorus concentrations for all species were higher in the western Peel populations compared to the eastern Peel populations. Lukatelich and McComb (1985) suggested that the eastern Peel macroalgal populations were largely supported by nutrient loading from the Murray and Serpentine Rivers, and Harvey River and the Harvey Estuary *Nodularia* blooms were the main source of nutrients for the western populations. The much higher nutrient status of Harvey Estuary compared to Peel Inlet (Lukatelich and McComb, 1985) is reflected in the higher tissue nutrient concentrations of the western Peel macroalgal populations.

4.0 Conclusions

Light appears to be the primary limiting factor at present for macroalgal growth in the Peel-Harvey system, and light attenuation during the critical growth period is largely controlled by the size of the *Nodularia* blooms in Harvey Estuary. If light attenuation should decrease, macroalgal blooms would be expected to increase, perhaps to levels similar to those experienced in 1978 and 1979, providing sufficient nutrients are available.

The decline of *Cladophora* biomass is viewed as a two stage event, firstly a sudden, dramatic decline in biomass at the deep water growth sites followed by a subsequent decline of biomass in the shallows. This is seen as the result of a single catastrophic event that was compounded by other changes in the physiochemical characteristics of Peel Inlet.

Subsequent changes in species composition can be explained in terms of responses to the prevailing physicochemical characteristics of the water column. Periods of high phosphorus availability and favourable light conditions will tend to be dominated by *Ulva* while *Chaetomorpha* will tend to dominate periods of lower (though still eutrophic) phosphorus availability.

Halophila ovalis biomass in the deeper central basin of Peel Inlet increased dramatically in 1987. The reappearance of *Halophila* in the central basin appears to be related to improved light penetration in 1986-87 and the lack of competition from macroalgae.

Tissue nitrogen and phosphorus concentrations in the dominant macroalgal species have declined in recent years. This is probably a response to the below average riverflow, and hence, nutrient load experienced since 1984. If tissue nutrient concentrations continue to decline they may become the primary factor limiting macroalgal growth in the Peel-Harvey system.

Tissue nitrogen and phosphorus concentrations, for all species tested, were higher in the western Peel populations compared to the eastern Peel populations reflecting the higher nutrient loading of the Harvey compared to Peel.

The growth characteristics of *Chaetomorpha* and *Ulva*, in comparison to *Cladophora* are the subject of a current PhD programme designed to document reasons for species succession in quantitative terms.

5.0 Recommendations

In order to more thoroughly document the spread of *Halophila* into the central basin of Peel Inlet, and the effects of changes in the physicochemical environment on *Halophila* biomass, it is suggested that two permanent transects be set up between the 0.5 m AHD contour and the 2.0 m AHD contour at stations 4 and 14. Qualitative (cover) and quantitative (biomass) sampling should be carried out twice a year along the transects.

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