THE EFFECTS OF EPIPHYTES ON SEAGRASSES IN COCKBURN SOUND

DEPARTMENT OF CONSERVATION AND ENVIRONMENT
PERTH WESTERN AUSTRALIA

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Summary

The continuing degeneration of seagrass meadows in Cockburn Sound was established by mapping the distribution on Parmelia Bank during 1980.

Seagrass leaf production at Carnac Island was approximately twice the leaf production at Woodman Point where epiphyte loads were high.

Monitoring of environmental parameters indicated that light was the most limiting factor in the Sound; high epiphyte loads were most likely to be the result of increasing nutrient levels in the Sound. It was demonstrated that epiphytes caused a reduction in light levels reaching the seagrass blades, which lead to a decrease in seagrass photosynthesis, at Woodman Point, of up to 80%.

It was concluded that the increased epiphyte growth, owing to high nutrient levels, was the probable cause of the diminishing area and density of seagrass meadows in Cockburn Sound.

INTRODUCTION

In her report to the Department of Conservation and Environment, Cambridge (1979) explained that the standing crop of seagrasses in Cockburn Sound had been reduced from 4 195 ha to 880 ha between 1954 and 1978 (a reduction of 80%). It was concluded that the major decline in seagrass was associated with the industrial complexes established since 1954 (Figure 1).

Cambridge attributed the deterioration of the seagrass meadows to a combinaation of increased phytoplankton blooms and high epiphyte loads. (Epiphytes are organisms which live attached to other plants). High epiphyte loads had often been seen in Cockburn Sound, and on occasion "accumulations of filamentous algae blanketed the substrate like billowing clouds" (Cambridge 1979).

An increase in phytoplankton, epiphytes, and periphyton (organisms attached to non-living substrates) often occurs after an increase in water nutrients (e.g. Kindig & Littler, 1980; Rastetter & Cooke, 1979; Fitzgerald, 1969; Carpenter, 1980; Phillips *et al*., 1978; Mathieson & Mathieson, 1976). *Posidonia* plants transplanted into Cockburn Sound from Warnbro Sound (Figure 1) gave reduced growth rates and rapid development of macroepiphytes when compared with seedlings replanted at Warnbro Sound. Nutrient levels in Cockburn Sound are well above those found in neighbouring oceanic waters, and the high load is largely derived from a fertiliser plant (CSBP/KNC) and a sewage outfall (Figure 1).

Cambridge (1979) suggested that the following sequence of events accounts for the loss of seagrass in Cockburn Sound.

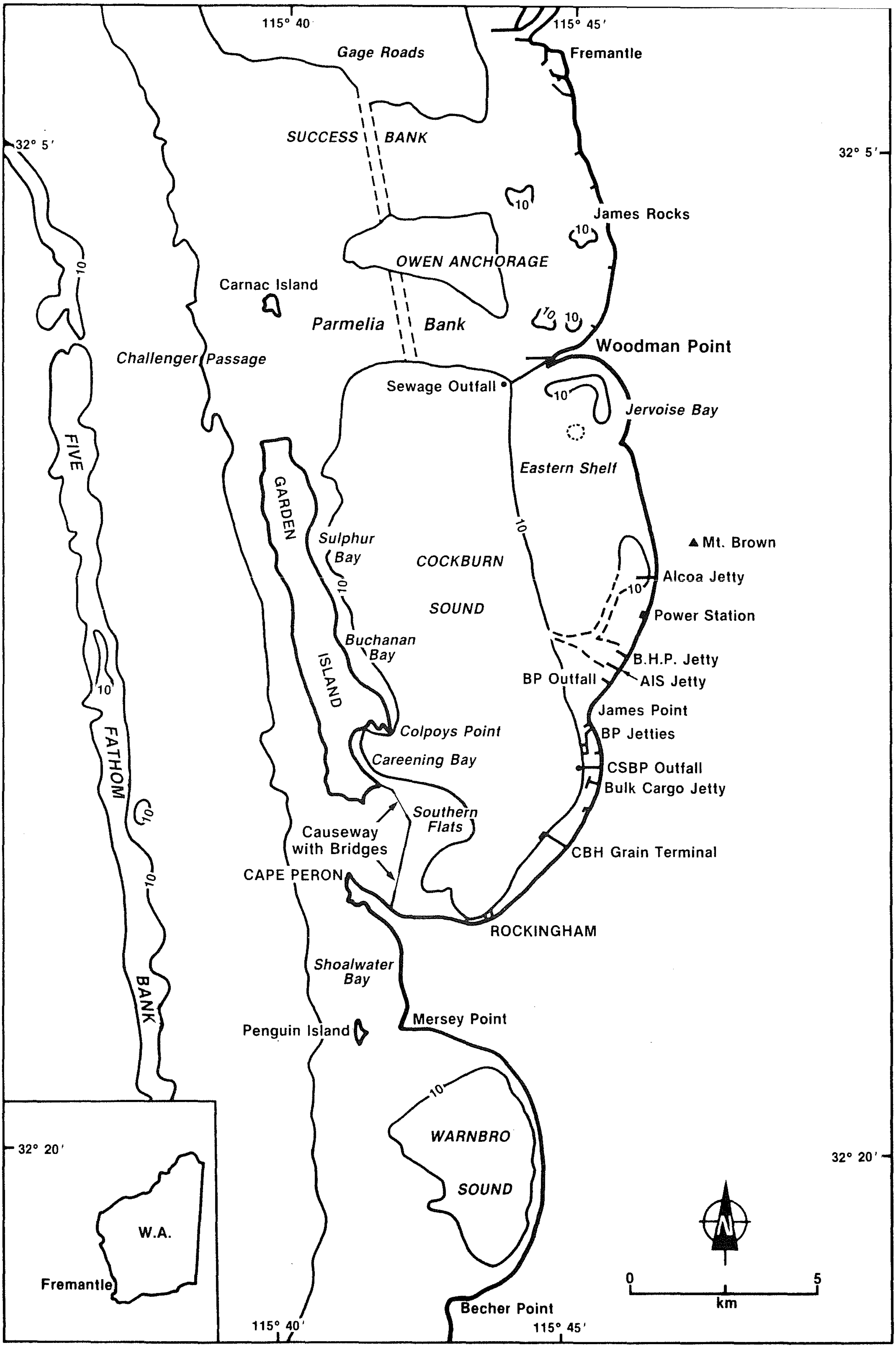

Figure 1 Study Area

- Increased nutrient concentrations stimulated the growth of epiphytes and filamentous algae.

- The increased epiphyte load reduced the light available to the seagrass leaves, so reducing the proportion of fixed energy available for growth and reproduction of the seagrass.

- Phytoplankton levels increased, increasing turbidity and further reducing light availability.

- As stored reserves in the seagrass rhizomes were used, the number of shoots declined and the leaf canopy thinned.

- With the thinning of the leaf canopy the seagrass meadows became more vulnerable to other factors such as storm damage and grazing by sea urchins, ultimately leading to widespread death of the seagrass.

The hypothesis that epiphyte loads rise to levels which, by reducing light, reduce photosynthesis to levels which are critical for survival, rested largely on circumstantial evidence. The present work was designed to obtain more direct information about epiphyte loads and their possible relation to seagrass growth in the Sound. The work proceeded through 1980 in three directions:

- The question of whether or not seagrasses are still declining in the Sound was investigated by mapping the seagrass distribution on Parmelia Bank (Figure 1), for comparison with the distribution in 1977.

- Two sites were selected in the Parmelia Bank area, one which appeared to be deteriorating, the other apparently vigorous. Seagrass growth rates and epiphyte loads were investigated in these areas, along with growth of periphyton on artificial substrates.
- Light reductions by known epiphyte and periphyton loads were computed, and the effect of the degree of shading on seagrass photosynthesis was investigated in the laboratory.

THE MAPPING OF SEAGRASS ON PARMELIA BANK

Introduction

As part of her survey of seagrass dieback between 1954 and 1977, Cambridge (1983) prepared a map of Parmelia Bank area (1:25 000) from 1977 aerial photographs. The present work was designed to produce an up-to-date map for comparison. It was reasoned that if the seagrass is still deteriorating, and the explanation lies ultimately in high nutrient load, then depletion will be relatively marked in the eastern area of Parmelia Bank. This area is subject to the passage of nutrient rich water from Cockburn Sound into Owen Anchorage (Chiffings, 1979).

The detailed map would also provide a basis for the remainder of the project, and important reference material for future monitoring.

Materials and Methods

A base map of scale 1:10 000 was chosen, corresponding with the size of the mosaic of aerial photographs assembled in 1977. It was prepared by enlarging the navigation chart of Cockburn Sound (Aus 117), which is at a scale of 1: 25 000.

Vertical photographs were taken from a height of about 2 300 m using an Hasselblad camera containing aerochrome 2443 infra-red film. They were taken on 29 April 1980 between 0830 and 0930 hours so that the sun angle was less than 40^{0}, to keep glare and reflections to a minimum. A three inch lens was used, giving transparencies with a scale of 1: 30 000. The photography was undertaken by Mr P. Hicks of Land Resources Management, CSIRO, Floreat Park. This aerial photography is now held by the Department of Conservation and Environment Library, as is the original of the final map.

The film was processed as for colour positive transparencies which were projected onto the base map. Community boundaries could, in most cases, be distinguished.

For further identification it was necessary to carry out a ground survey. This involved 'spot' dives and underwater transects. At each of the spot dive locations, a record was made of species of seagrass (if present) and approximate density in relation to the categories used by Cambridge in her 1977 map.

The transects (0.5-1.3 km) were carried out using underwater sleds and scuba apparatus. During the long transects, notes were made of changing species, distribution and condition, and approximate distance.

Position fixes were taken using compass bearings at each of the spot dives and transect end points, in points, in order to locate the sites on the chart.

Results and Discussion

Using the general categories of the 1977 map (1: 25 000), the 1977 photographs, 1980 aerial photographs, and field verification, a detailed map (1:10 000) was prepared.

A reduction of the map to the scale of 1:25 000, the scale of the 1977 map, is given as Figure 2. The obliquely hatched sections (continuing die-back) indicate areas of seagrass meadows which have become clearly reduced in standing crop between 1977 and 1980. The area of the continuing die-back sections is approximately 80 ha which represents more than 25% of the seagrass beds on Parmelia Bank. In 1977 Cambridge had classified the seagrass in some of these areas as being continuous healthy meadows, whereas in the field work of the present study, seagrass meadows had low shoot density and apparently diminished shoot size. Other areas show the absence of seagrass, where in 1977 they were present.

This reduction has taken place mainly on the north-eastern section of the bank where water, enriched by the nutrients from the fertiliser plant and the sewage outlet, passes over the bank (Chiffings, 1979).

It is concluded that a reduction in the seagrass meadows occurred between 1977 and 1980, and is likely to be continuing at the present time.

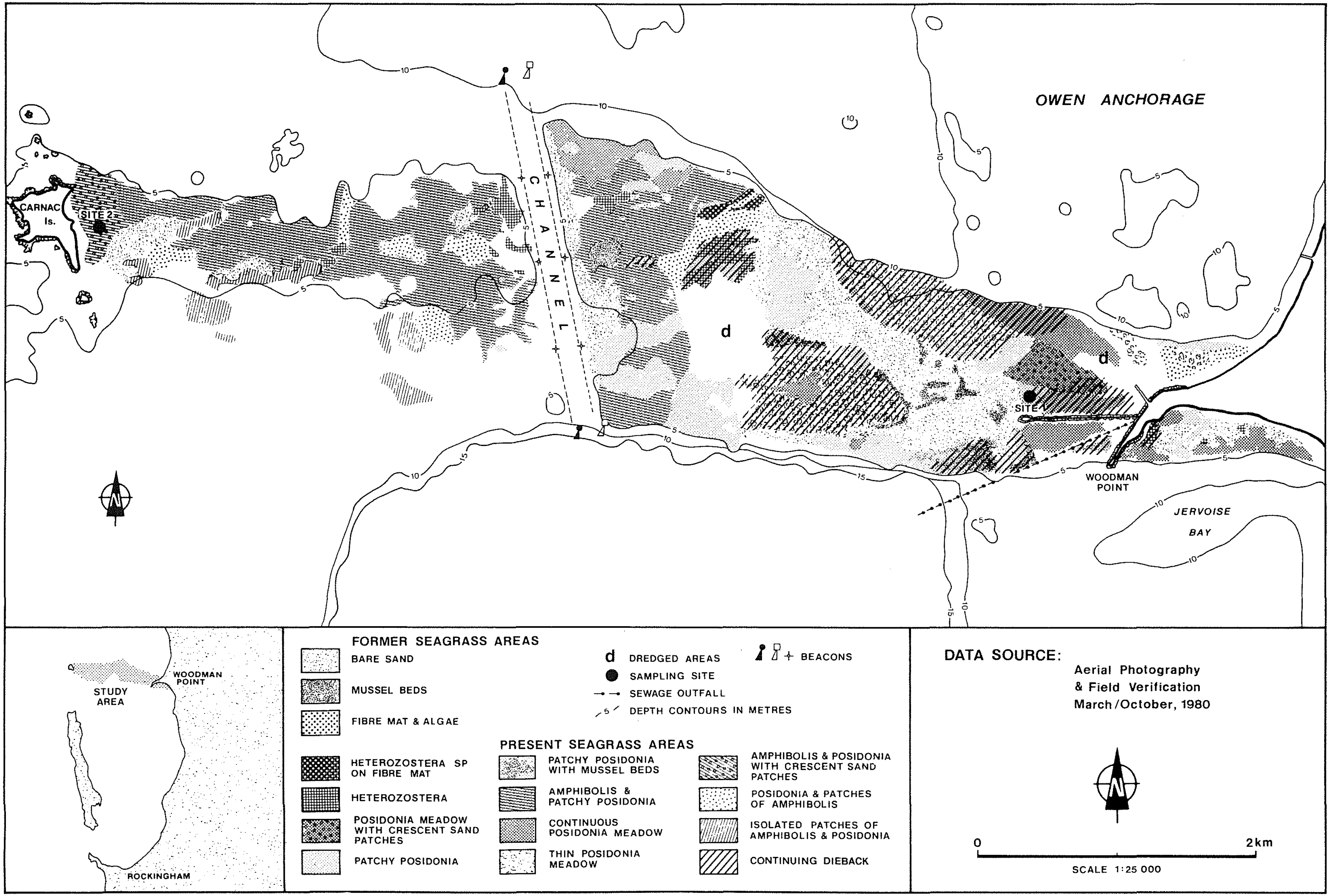

Figure 2 Seagrass distribution on Parmelia Bank, Cockburn Sound.

SEAGRASS PRODUCTION ON PARMELIA BANK

Introduction

As noted in Chapter 1, one aim was to compare the above-ground production of a degenerating seagrass meadow, with that of an apparently healthy meadow. Along with leaf production, measurements were to be made of epiphyte loads at the two regions.

An apparently unaffected meadow was selected 200 metres offshore from Carnac Island where water is predominantly oceanic (Chiffings, 1979). A site with degenerating seagrass meadow was selected north-east of Woodman Point. The meadow was relatively sparse, and had clearly become more sparse between 1977 and 1980. The depth at both sites was approximately three metres (Figure 2).

Posidonia australis was chosen for investigation, as it was present at both sites in homogeneous meadows, whereas other seagrasses usually occurred in mixed stands.

Leaf production of *P. australis* was measured by the method originally developed by Zieman (1974); this is currently accepted as the least ambiguous method of estimating seagrass productivity (Zieman & Wetzel, 1980).

Underground (roots and rhizomes) production is not taken into account using this method, but it is thought to be an order of magnitude lower than leaf production (McComb *et al*., 1980).

To aid interpretation of production results, environmental parameters (light, temperature, wind and water nutrient levels) were also monitored during the study period.

Materials and Methods

Seagrass Growth

A leaf was marked by punching a hole (1-2 mm diameter) through the leaf sheath and enclosed leaf, using surgical tongue forceps (Kirkman & Reid, 1979). The holes were punched close to the top of the sheath so as not to alter the osmotic potentials within the sheath (Tyerman, 1980). As the sheath does not grow, the sheath hole acts as a reference point against which the displacement of the hole in the enclosed blade can be measured.

Seven plastic-coated steel quadrats, each of an area 0.1 m^2, were placed in the seagrass bed, and all shoots within each quadrat marked. After approximately 14 days, the shoots inside each quadrat were harvested, placed in separate plastic bags, and returned to the laboratory. The numbers of shoots and flowers were recorded. Two shoots from each quadrat were rinsed in seawater and frozen for epiphyte load analysis (see method page 23).

Measurements of growth were made using the section of each shoot above the reference hole in the sheath, and any new, unpunched leaves.

Epiphyte Removal and Shoot Processing

Shoots were immersed in 10% hydrochloric acid to remove the carbonate of encrusting calcareous algae, and epiphytes scraped off with a one-sided razor blade. The shoots were washed in fresh seawater and divided into two sections: A, the fresh growth, consisting of the part of each punched leaf below the reference hole and any new leaves, and B, the rest of the leaf, from the hole to the leaf-tip. Each component was measured and dried to a constant weight at $70^{o}C$ (usually 48 hours).

Standing crops were calculated by summing the weights of old and new leaves (A and B) and expressed on a m^2 basis. Leaf production was calculated by the weight of new leaves (A) divided by the number of days between marking and collecting, and expressed per m^2 (Zieman, 1974). Turnover rates or community replacement rates can be calculated by dividing the standing crop by the production value, which gives the number of days required to replace a single crop. West & Larkum (1979), however obtained what they term 'turnover rates' of leaves by dividing leaf blade production by the leaf standing crop, which gives the dry weight of new growth produced per gram dry weight of plant per unit time; for comparison, the same calculation was carried out on the data collected here.

Environmental Data

Water samples were collected and analysed for nitrate, ammonium, phosphate and phytoplankton (as chlorophyll a). Temperature and light data were interpolated from monthly Cockburn Sound cruise data (Chiffings, in prep.) using the results from the stations nearest those used in the seagrass study. Light attenuation coefficients in conjunction with the incident radiation data (DCE 1980) were used to estimate the quantity of light reaching the seagrass beds.

Each of the measured parameters was plotted against time, and a value read off for the midpoint of the seagrass sampling period (i.e. between the day of hole punching and the day of harvest).

An estimate was made of wind speed, as follows: The total number of hours of wind within each speed range (<10-20, 20-30, 30-40, >40 knots) was calculated from daily wind data (Fremantle Port Authority), and multiplied in each case by the mean of the wind speed range (i.e. 5, 15, 25, 35, 45 knots respectively).

For each seagrass growth period (i.e. from day of punching to day of harvest) an estimate was made of the mean daily wind speed, in knot hours per day).

Correlations were determined using the Scattergram program of Nie et al. (1975).

Results

Seagrass Growth

The leaf standing crops, leaf production, turnover rates, growth per shoot and inflorescence results for both sites are given in Table 1.

Standing Crop

The standing crop at Woodman Point was consistently less (42% on average) than at Carnac Island (Table 1). The graph of the seasonal standing crops at both sites (Figure 3) showed no consistent trends, although winter

TABLE 1: **GROWTH OF <u>POSIDONIA AUSTRALIS</u> AND STANDING CROP AT WOODMAN POINT AND CARNAC ISLAND**
MEAN (N = 7) AND STANDARD DEVIATIONS ARE SHOWN

CARNAC ISLAND (Site 2)								WOODMAN POINT (Site 1)							
Month	Leaf standing crop gdwt/m^2	Leaf production gdwt$^+$/m^2/ day	Turnover** rate mgdwt/gdwt/ day	Growth per shoot mgdwt/ day	Shoot density no. shoots/ m^2	Inflorescence No. of flowers/ m^2	Inflorescence dry wt flowers/ gdwt/m^2	Month	Leaf standing crop gdwt/m^2	Leaf production gdwt/m^2/ day	Turnover** rate mgdwt/gdwt/ day	Growth per shoot mgdwt/ day	Shoot density no. of shoots/ m^2	Inflorescence no. of flowers/ m^2	Inflorescence dry wt of flowers gdwt/m^2
JAN*	356 ±55	3.2 ±0.5	9.0					JAN*	221	2.3 ±0.2	10.4				
FEB	202 ±30	3.2 ±0.1	15.8	7.0	460			FEB	123 ±8	2.7 ±0.2	22.0	6.9	390		
MAR	187 ±12	3.1 ±0.4	16.6	7.0	460			APR	59 ±3	0.9 ±0.1	15.3	2.6	340		
MAY	246 ±15	2.8 ±0.2	11.4	4.4	630			MAY	75 ±8	1.1 ±0.1	14.7	2.7	410		
JUL	152 ±9	1.8 ±0.2	11.8	3.3	550	220	279	JUL	62 ±7	1.0 ±0.1	16.1	2.9	350		
AUG	149 ±19	1.9 ±0.2	12.8	3.7	510	230	292	AUG	57 ±3	0.8 ±0.1	14.0	2.2	370	10	13
SEP								SEP	71 ±5	1.1 ±0.1	15.5	3.1	350	14	18
DEC	191 ±10	3.8 ±0.2	19.9	6.0 ±0.2	608 ±23			DEC	138 ±5	2.5 ±0.2	18.1	6.8 ±0.6	379 ±32		
JAN 1981	280 ±27	5.5 ±0.6	19.6	7.8 ±0.6	700 ±31			JAN	160 ±11	3.0 ±0.2	18.8	7.7 ±0.6	428 ±44		
Mean Values	201 ±18	3.2 ±0.4	14.6 ±1.4	5.6 ±0.7	520 ±60			Mean Values	93 ±15	1.7 ±0.3	16.1 ±1.1	4.3 ±0.6	380 ±12		
Bonna Point Botany Bay NSW	228 ±9.5	1.9 ±0.2	8.4	8.8	215	Rare		Quibray Bay Botany Bay NSW	121 ±3	1.3 ±0.2	10.6	16.3	80	Infrequent	

* Epiphytes not scraped off

** Turnover rate as calculated per West & Larkum (1979)

$^+$dwt dry weight

crops were low when inflorescences were not taken into account. The results of West and Larkum (1979) showed that standing crops in Botany Bay were similar to those recorded here.

The mean shoot density at Woodman Point (380 shoots/m^2 was 27% less than at Carnac Island (520 shoots m/^{2}). Inflorescences were rare at Woodman Point with an average of 30 shoots per flower compared with two shoots per flower at Carnac Island.

Leaf Production

In contrast to standing crop, the leaf production curve (Figure 4) shows a seasonal pattern at both sites. Production is high in the summer months, and falls to a minimum in early spring when inflorescences are initiated.

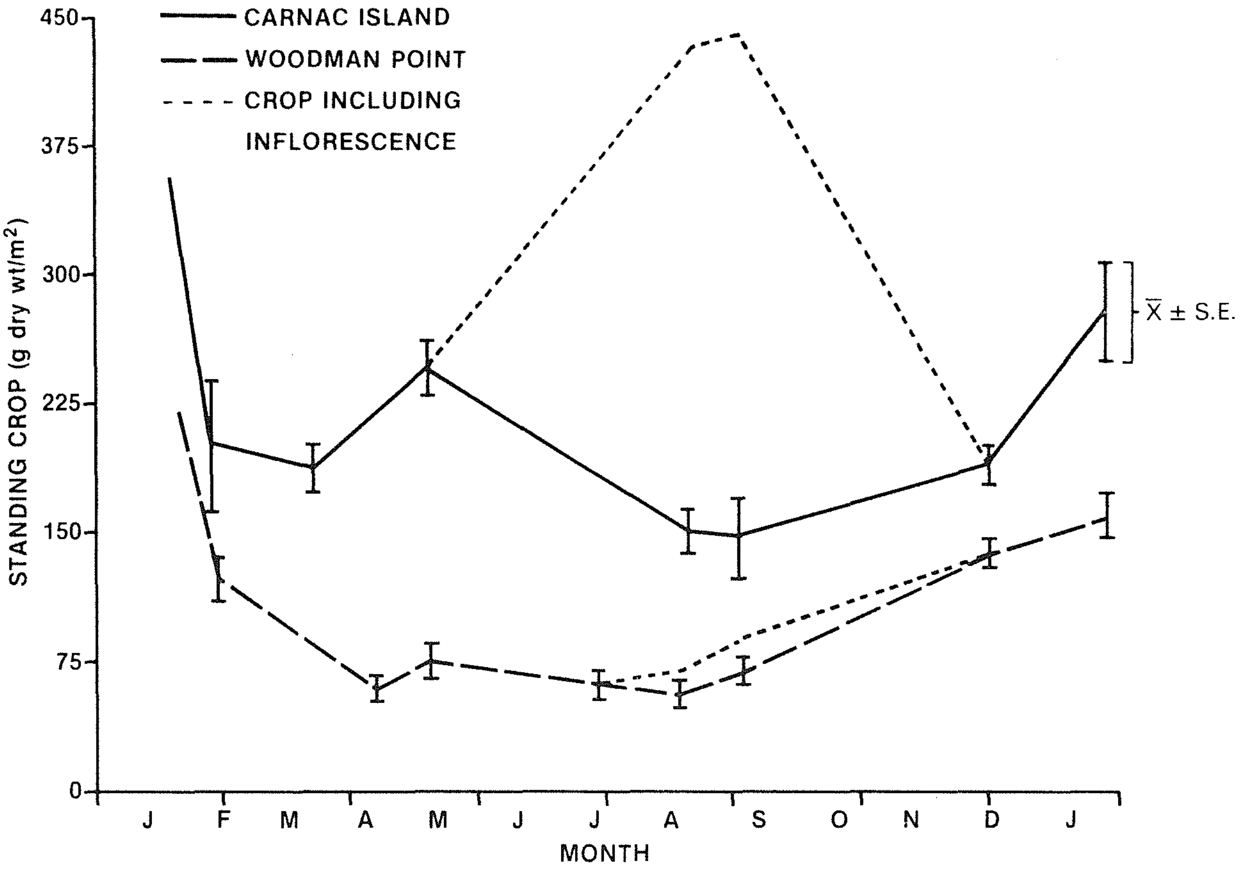

Figure 3 Seasonal standing crop 1980/81

At Woodman Point the mean leaf production and growth per shoot were significantly lower (47% and 25%, respectively) than the means at Carnac Island (Table 1). The decrease in production during autumn was marked at Woodman Point (Figure 4).

Growth curves of similar shape were recorded by West and Larkum (1979) for Posidonia near Sydney. Cambridge (1979) measured the yearly mean growth of P. australia in Warnbro Sound, W.A. (at 2.5 m depth), as 3.2 g dry weight/ shoot m/^{2}. This is similar to that found here at Carnac Island.

The shoots at Carnac Island generally consisted of three or four blades (0.37 g dry weight/shoot) whereas at Woodman Point the older blades tended to break off prematurely under the heavy epiphyte loads and there were rarely more than two blades per shoot (0.20 g dry weight/shoot). Growth rates

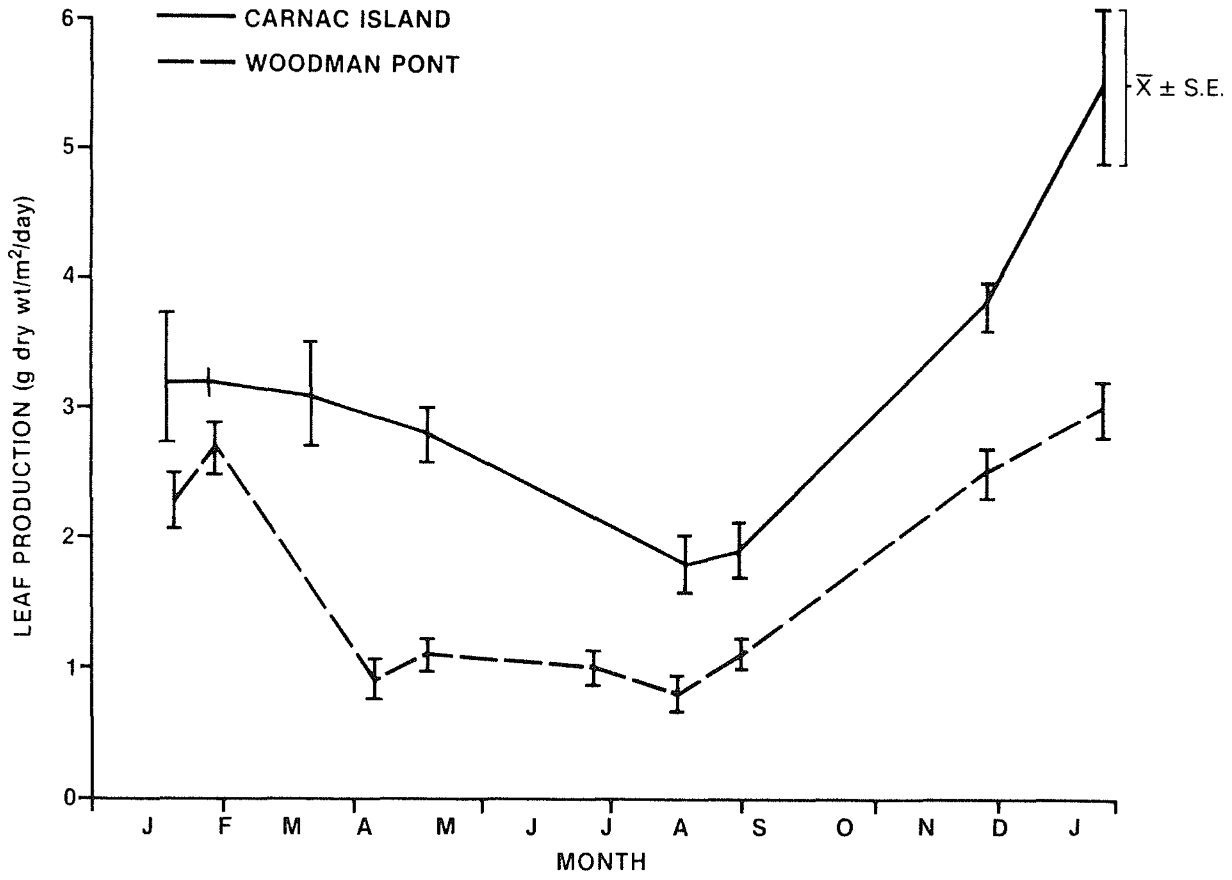

Figure 4 Seasonal leaf production 1980/81

(turnover rates in West & Larkum, 1979) were not significantly different at the two sites (Table 1). The difference in standing crops resulted from lower shoot density, fewer leaves per shoot and the increased loss of older leaves at Woodman Point. Presumably, the growth rates at Woodman Point were maintained by rhizome depletion, although the verification of this would require monitoring the rhizomes.

The inflorescences are not included in the above calculations since their growth rate is unknown and they are composed largely of photosynthetic tissue.

At Carnac Island, the mean turnover time, as calculated by the method of Zieman (1974), was 69.2 days, and at Woodman Point it was 57.3 days. These figures are not significantly different ($p > 0.1$) but it must be remembered that the standing crop is very much higher at Carnac Island.

Environmental Data

Levels of phosphate and chlorophyll a were significantly higher ($p < 0.01$ t-test) at Woodman Point than at Carnac Island (Figures 5 and 6). This confirms the expectation that nutrients released by the fertiliser plant and the sewage outlet to the south of the site pass across the bank in the prevailing water currents. Ammonium and nitrate levels (Figures 7 and 8) were low and not significantly different. This can be explained because phytoplankton use nitrogen and phosphorus in ratios between 10:1 and 20:1 (Goldman, 1976), and in Cockburn Sound the ratio is less than this (Chiffings, 1979). Much of the available inorganic nitrogen would have been taken up by the phytoplankton.

Light and temperature showed a marked seasonal trend, the maximum level in summer decreasing to a minimum in winter, then increasing again in spring (Figures 9 and 10).

The wind estimate data are given in Figure 11. The high wind runs (hour per day) in February and March arose mainly from the persistent, daily land/sea-breezes, typical of the summer weather pattern. The daily weather synoptic charts (Department of Home Affairs and Environment, Bureau of Meteorology, monthly weather review) show only one significant front passing in February. The high wind values in July and August, however, resulted from a series of fronts which are usually accompanied by rough seas and a heavy oceanic swell. The light summer winds could cause water turbulence but the water movement would be much less severe than the rough seas and heavy swell in winter. This could partly explain why a high wind estimate coincides with a high standing crop in February and a low standing crop in July and August. Under storm conditions, leaf blades tend to break off and in very severe storms, shoots can be pulled from the sediment, causing a decrease in leaf biomass.

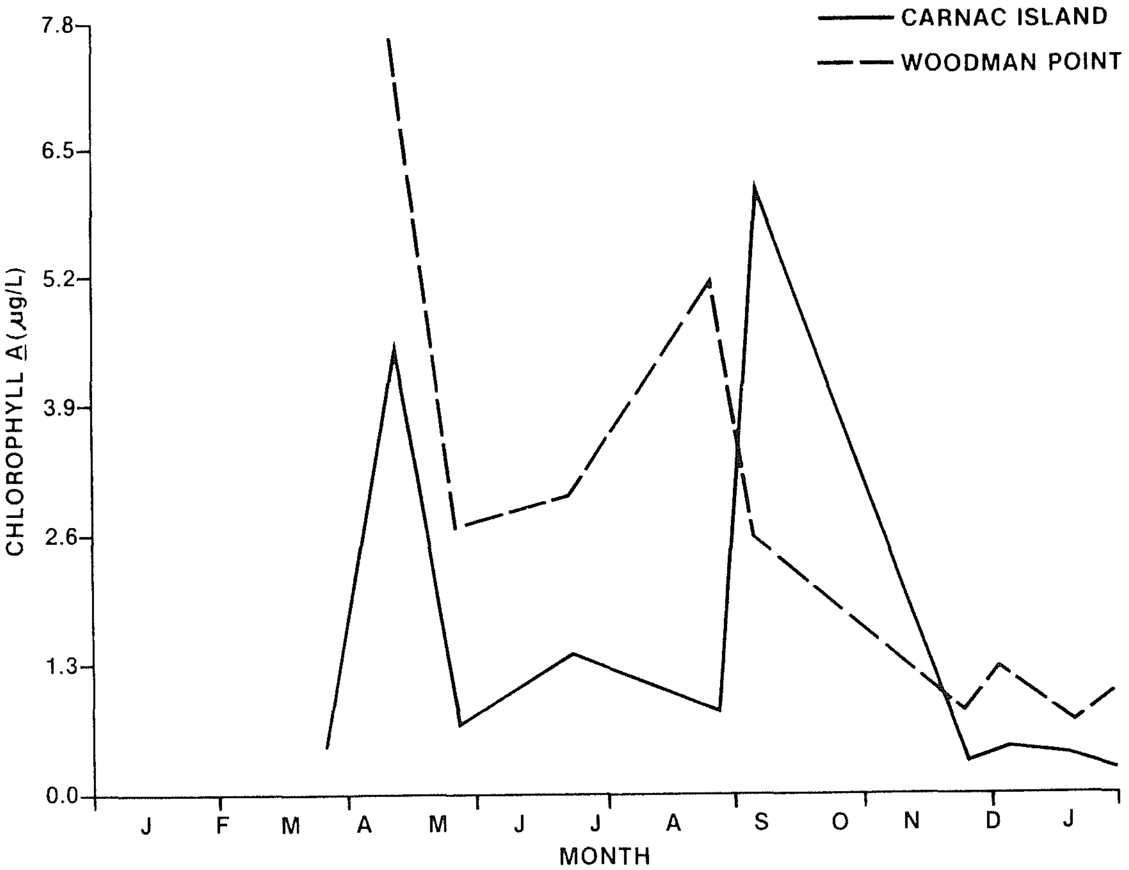

Figure 5 Chlorophyll a concentration in the water column 1980/81

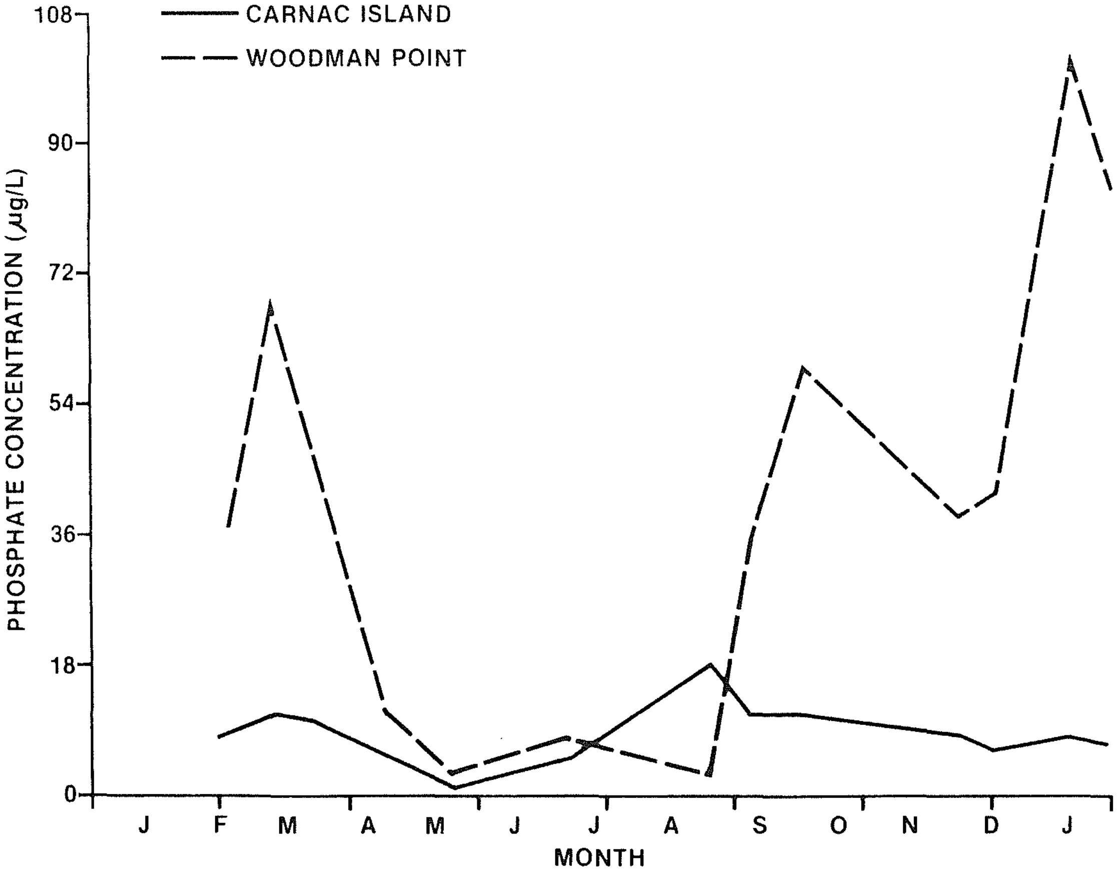

Figure 6 Phosphate concentration in the water column 1980/81

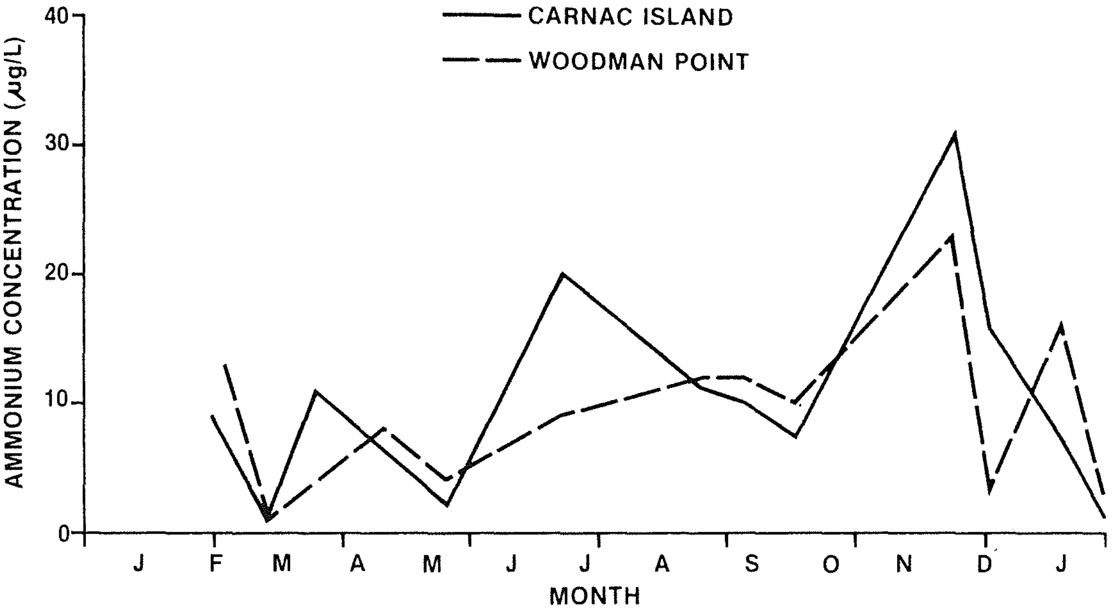

Figure 7 Ammonium concentration in the water column 1980/81

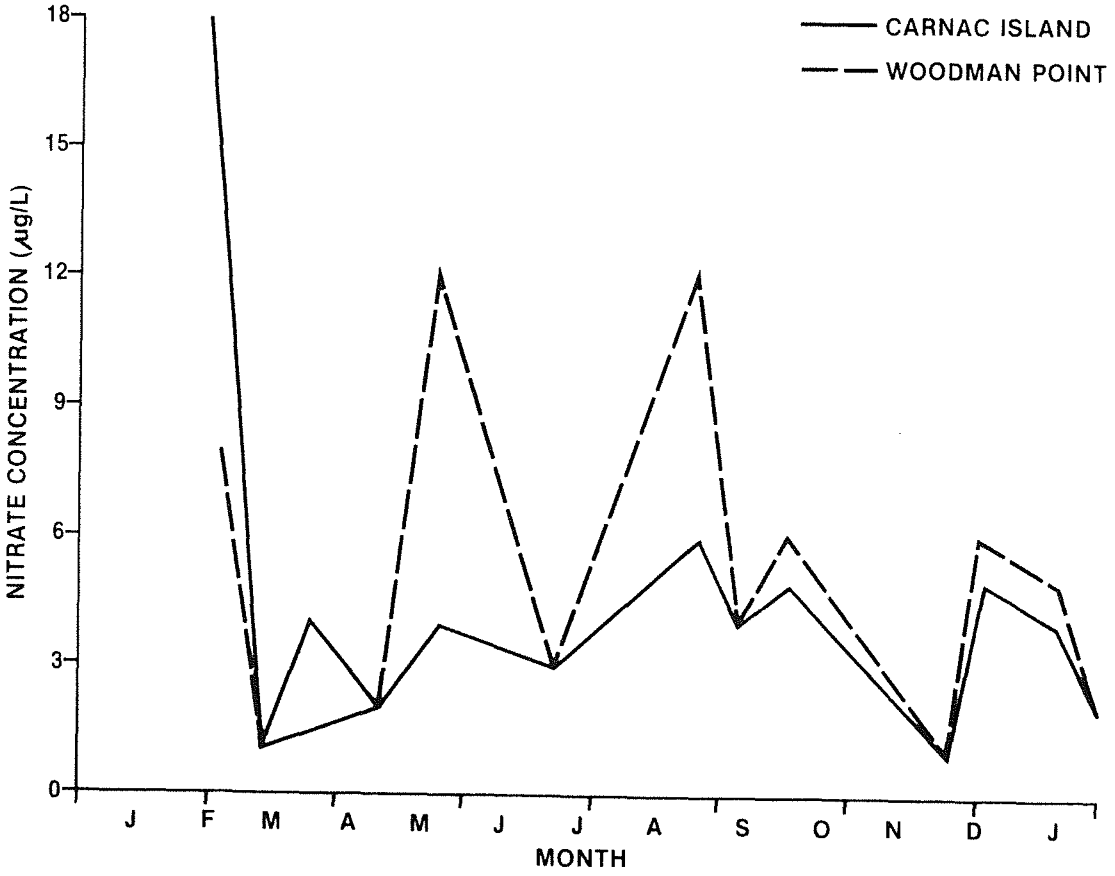

Figure 8 Nitrate concentration in the water column 1980/81

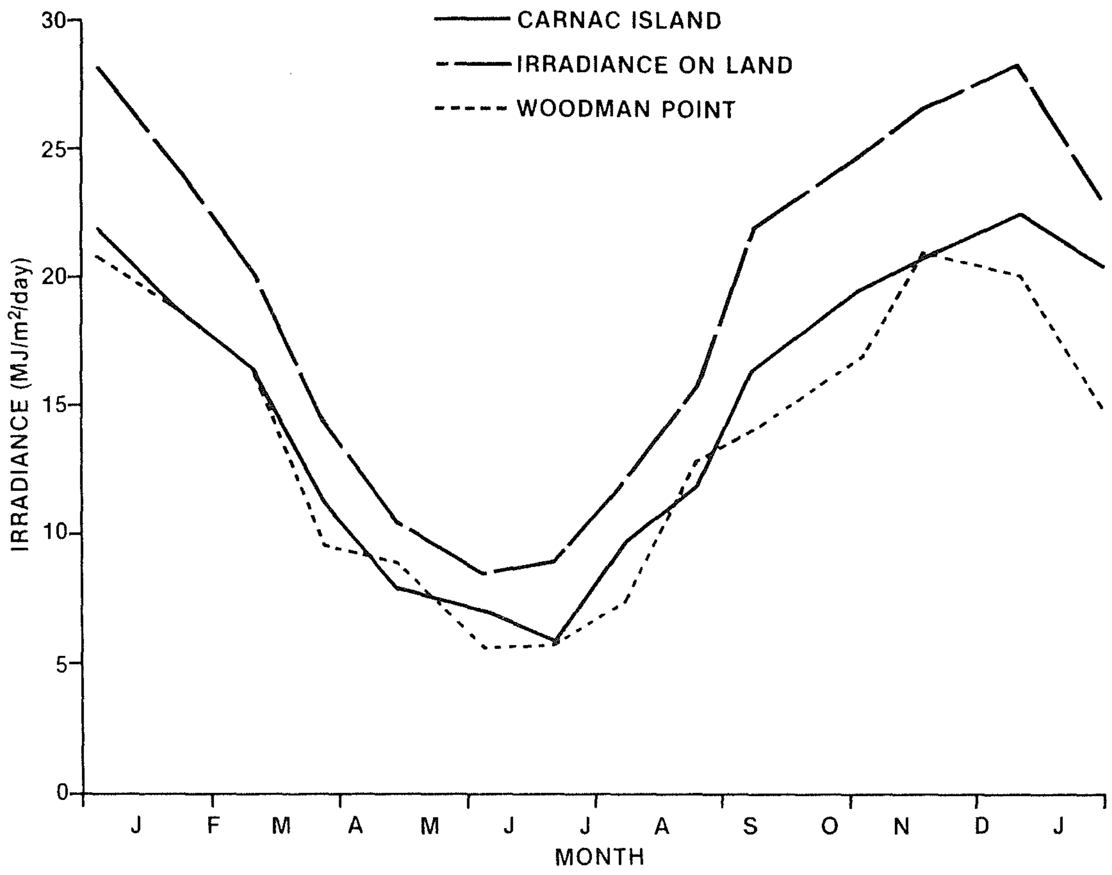

Figure 9 Light reaching the seagrass beds at Carnac Island Woodman Point and the recording station at Kwinana

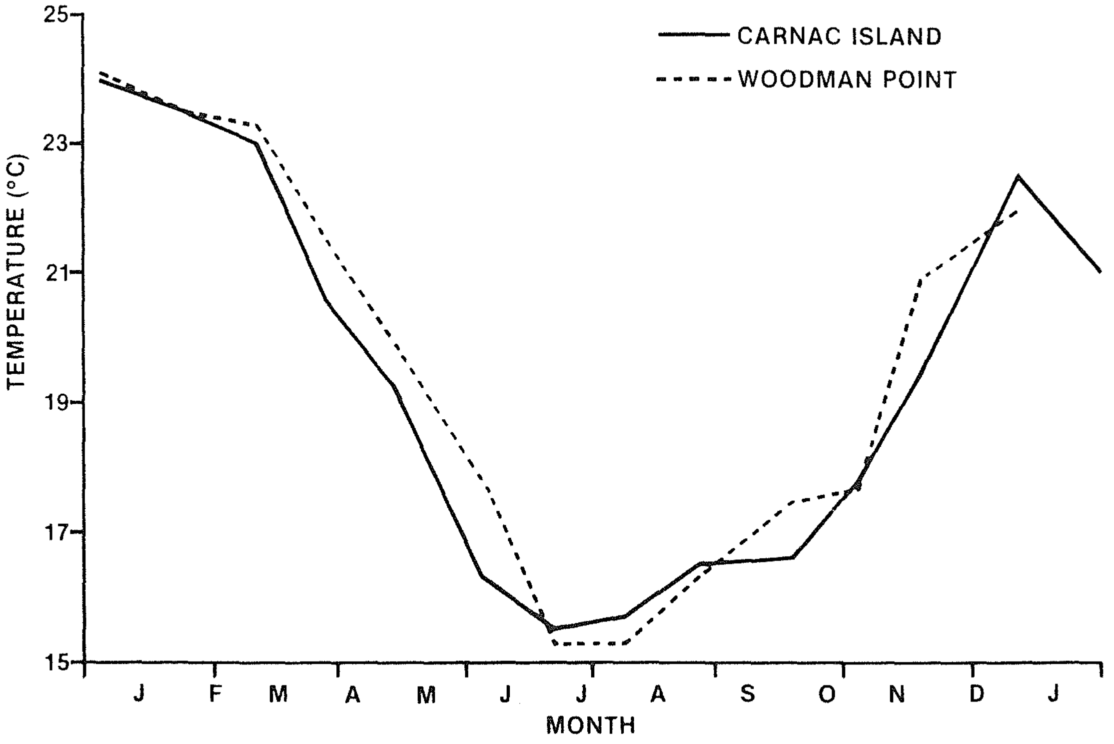

Figure 10 Water Temperature

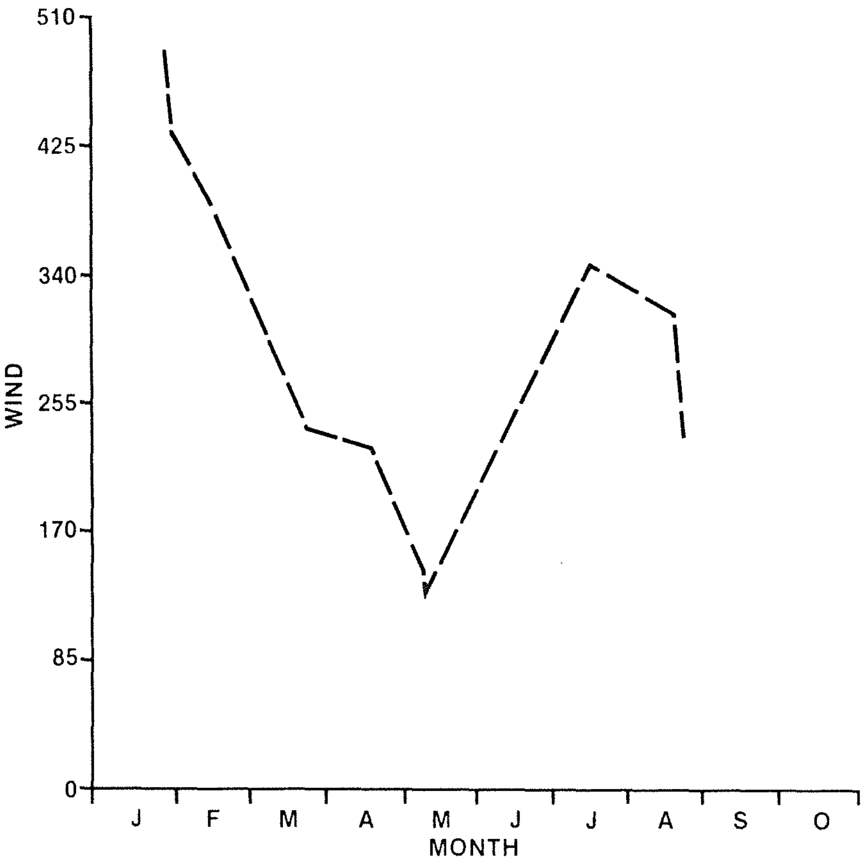

Figure 11 Wind estimates (knot hours/day) 1980

Correlations

Data from both sites and all times were pooled to look for correlations between growth and environmental variables. The regressions of leaf production against light and temperature (Figures 12 and 13) gave significant correlation coefficients as did standing crops against these variables. However, no other significant, linear correlations were found. Table 2 shows all correlation coefficients ranked in order of significance.

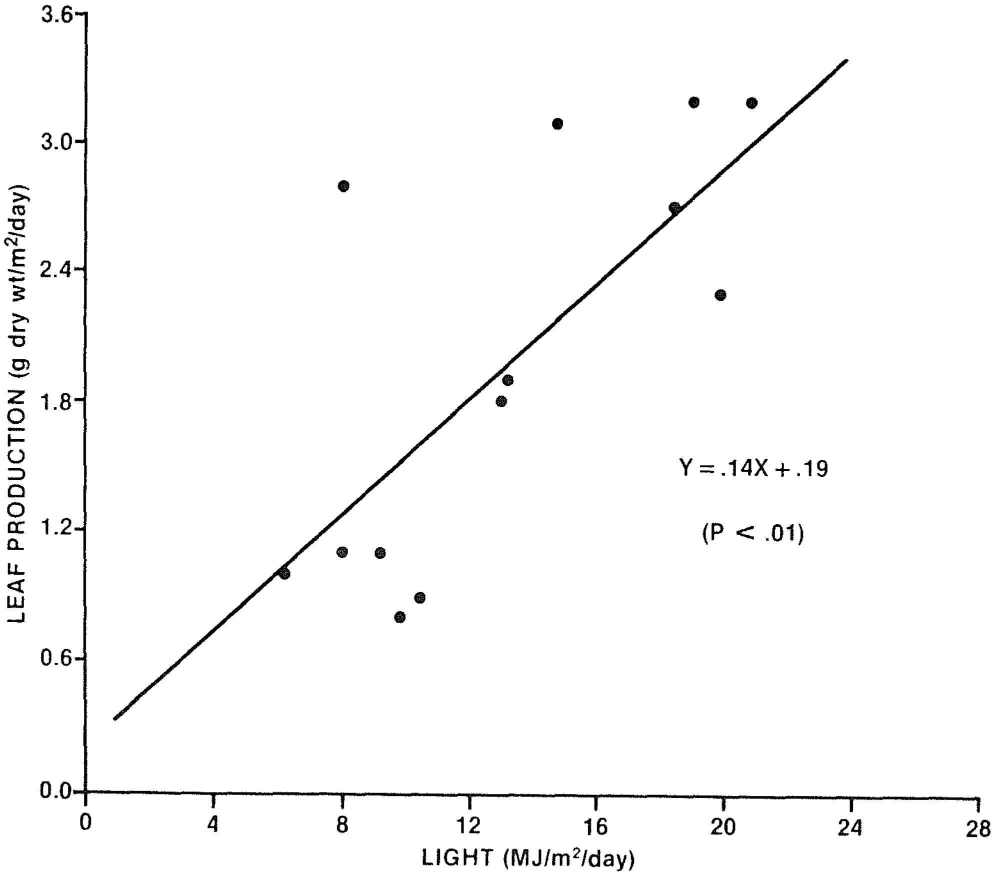

Figure 12 Correlation between leaf production and light

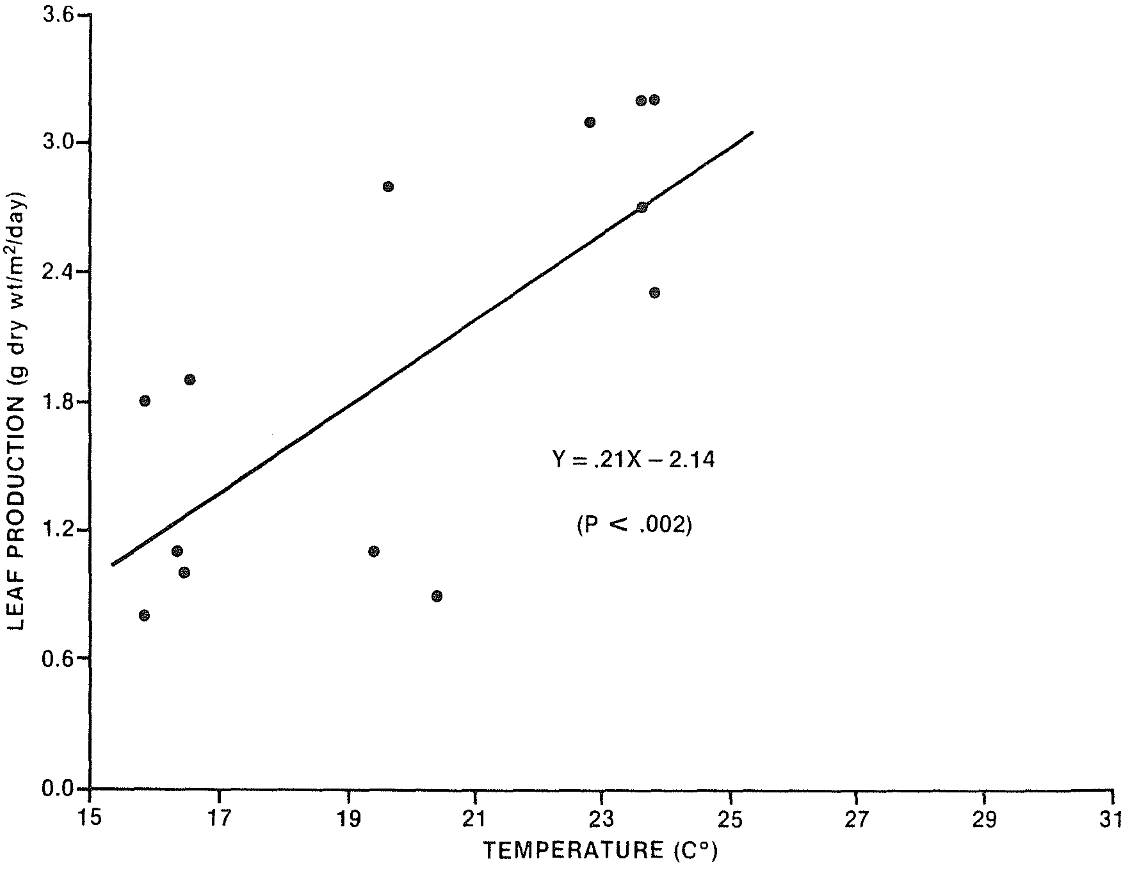

Figure 13 Correlation between leaf production and temperature

TABLE 2: **CORRELATION COEFFICIENTS, IN ORDER OF SIGNIFICANCE, OF PRODUCTION RESULTS WITH ENVIRONMENTAL PARAMETERS**

LEAF PRODUCTION			LEAF STANDING CROP			LEAF GROWTH RATE		
factor	r	significance of r	factor	r	significance of r	factor	r	significance of r
Temperature	0.747	0.0017	Temperature	0.668	0.006	NH_4	0.351	0.120
Light	0.736	0.0020	Light	0.604	0.014	Chl a of water	0.439	0.138
NO_3	-0.394	0.0916	Wind	0.421	0.098	PO_4	0.197	0.260
Chl a of water	-0.453	0.1295	Chl a of water	-0.449	0.132	Wind	-0.142	0.339
Wind	0.341	0.1523	NO_3	-0.310	0.151	Temperature	0.103	0.369
PO_4	0.134	0.3317	NH_4	-0.055	0.430	Light	-0.085	0.391
NH_4	0.110	0.360	PO_4	0.036	0.454	NO_3	-0.005	0.494

r = correlation coefficent
factor = environmental variable

Discussion

The recurring trend in these results is that the seagrasses at Carnac Island are much more vigorous than those at Woodman Point, which confirms visual observations and the interpetation of aerial photographs. A combination of a lower growth per shoot (25% lower) and a less dense meadow (7%) result in a 47% lower production at Woodman Point as compared with Carnac Island.

Another important outcome is the dependence of production on irradiance and temperature. The water temperature is in effect governed by irradiance in that the water body is heated by the solar radiation, and in this study the correlation coefficient of the regression between light and temperature was 0.76 ($p < 0.01$). It may be suggested that of the environmental variables investigated here, light is the most important in regulating seagrass growth. Despite this likely importance of incident light in controlling seagrass growth, it seems unlikely that the difference in growth between the two sites could be explained by a difference in light reaching the beds. Chiffings

(1979) demonstrated a strong correlation between light attenuation and chlorophyll a. Although chlorophyll a levels were higher at Woodman Point than at Carnac Island, the meadows at both sites were in shallow water (3 m), the light reaching the meadows (as calculated in this study) was not significantly different. It appears unlikely that the lower production at Woodman Point is caused by light reduction by phytoplankton alone.

A similar conclusion was reached by Cambridge (1979) who emphasised the possible importance of epiphytes in reducing light.

EPIPHYTES

Introduction

Although there is a considerable amount of information on the epiphyte loads of seagrasses, much of the work has been descriptive and very little quantification has been done. An exception is the work of Penhale (1977), who measured the productivity and biomass of epiphytes on eelgrass (*Zostera marina*) using labelled carbon techniques. Her results showed epiphytes accounting for 24% of the biomass and 18% of the productivity of *Z. marina* beds in Florida.

Since the epiphyte population is believed to be predominantly algal in Cockburn Sound (Cambridge, pers. comm.), the amount of chlorophyll a in the epiphytes per unit area of seagrass leaf was used as a routine measure of epiphyte load. The dry weights of the epiphytes were also measured.

The growth of 'epiphytes' on artificial substrates was also investigated, to compare sites and times, and to investigate reductions in incident light.

The growth of 'epiphytes' on artificial substrates appears to be comparable with growth on aquatic plants. In this study, two types of artificial substrate were employed. Glass slides were chosen, as a standard method of monitoring periphyton growth in estuaries and lakes. However, it has also been suggested that seagrass blades are especially favourable to epiphytes because they are distributed through the water column, and hence exposed to light and nutrients (Harlin, 1980). The epiphyte population may also be influenced by the flexing of the seagrass blade. For this reason plastic seagrass similar to that described by Barber _et_ _al_., (1979) was also employed.

In order to relate epiphyte load to the shading they cause, the light passing through glass slides and plastic grass was measured, with and without periphyton and related to the amount of chlorophyll present.

Materials and Methods

Epiphytes on _Posidonia_ _australis_

Seagrass shoots from each of the harvests (previous chapter) were washed, measured and frozen at -10^{o}C. Epiphytes could then be removed with minimal damage to the seagrass blades. While the shoot was still frozen, most of the epiphytes flaked off easily and the remainder could be gently scraped off using a one-sided razor blade. The shoot was dried to constant weight at 70^{o}C. The epiphytes were filtered onto a glass fibre filter (Whatman, GF/C) for subsequent drying or chlorophyll _a_ extraction. For dry weight determination, filters were dried to constant weight at 105^{o}C. Chlorophyll extractions were carried out as described in Standard Methods (1971) for periphyton analysis. The filters plus epiphytes were ground and extracted in acetone (90% v/v), and the optical density of the extracts determined by spectrophotometry Chlorophyll a and phaeophyton levels were calculated (Standard Methods 1971) and expressed as mg chlorophyll a per m^2 of leaf.

Complications arose when macroepiphytes were present. Only the proportion of the epiphyte that was directly above a leaf was included. The leaf concerned was placed under a sheet of plastic, and the outlines of both shoot and macroepiphytes drawn. The macroepiphytes were removed with forceps, and their chlorophyll a contents determined. The drawings were photocopied, and using a digitizer, the areas of A, B and C were measured (Figure 14).

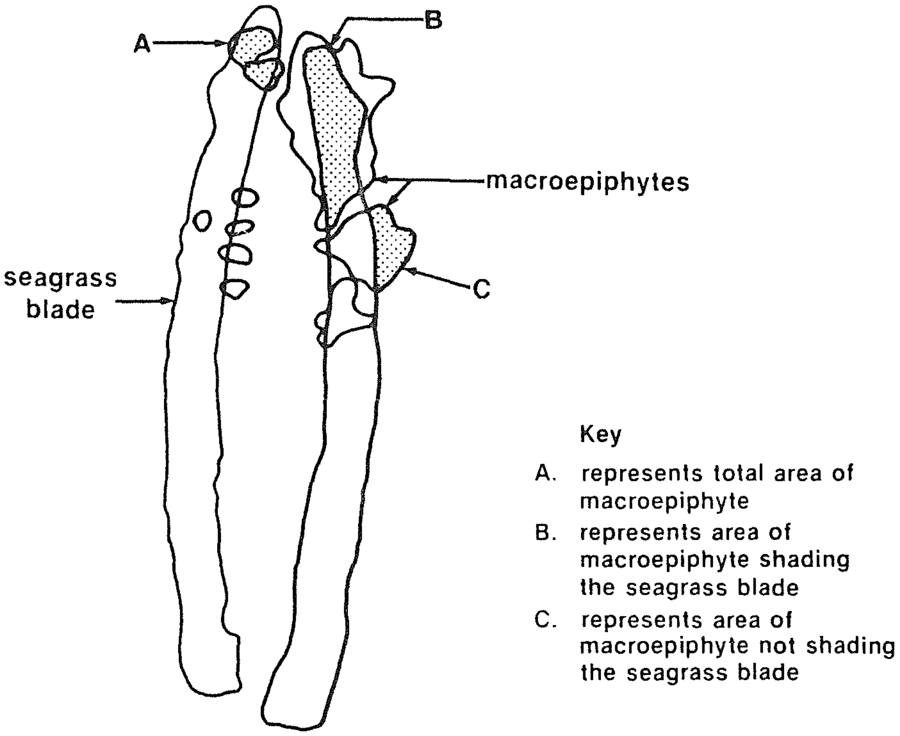

Figure 14 Example tracing of macroepiphytes.

Portion C was calculated as a percentage of A, and subtracted from the gross chlorophyll a of the macroepiphytes. The net result, expressed per m^2 of leaf, was added to the microepiphyte load.

On one occasion, leaves in a quadrat at each site were punched as for growth determinations (previous chapter). After 35 days the plants were harvested, and the epiphyte loads on the new growth of each leaf determined. Ten shoots from each quadrat were rinsed in seawater, measured, and divided into sections. These were frozen separately and the epiphytes removed for dry weight and chlorophyll determination.

Epiphytes on Artificial Substrates (Periphyton)

Glass Slides:

Samplers were constructed of PVC to hold six glass slides each (Figure 15). Two samplers were attached by rope to a sub-surface buoy, with the slides in one sampler held vertically, those in the other horizontal. During heavy weather in June the sub-surface buoys and samplers were lost, and it was necessary to attach the samplers to the chain of the site marker buoys.

Samplers were collected and fresh ones put down every two or three weeks. On collection, the slides were removed from the holders and placed into vials with filtered seawater, before returning to the laboratory.

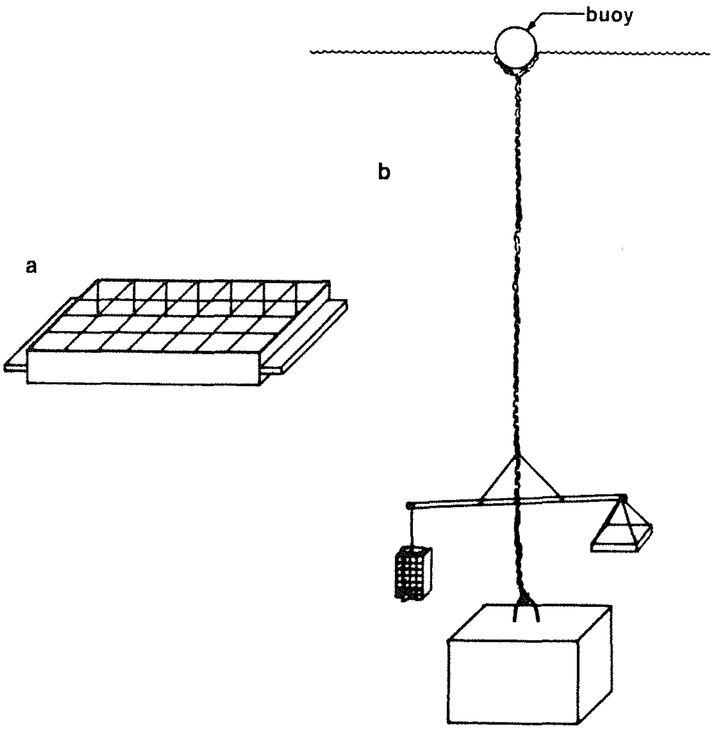

Figure 15 Racks used for collection of periphyton on glass slides (a) and the method of deployment at the study sites (b)

Light Reduction by Epiphytes:

Before periphyton removal, the light transmitted through each slide was measured to work out the relation between light reduction and epiphyte load. This was done by placing the slides on a stand made of PVC tubing, which had a light meter (Licor) clamped inside such that the sensor was in the centre of the stand (Figure 16). In order to reduce reflection effects and keep periphyton hydrated, the stand was submerged in an aquarium filled with seawater. The light source was a single beam from a fibre optics instrument (Scott-Mainz KL 150 B, 150 watt globe). Light readings at three different intensities (400, 700 and 1 500 $\mu E^2/s$) were taken through a blank slide as a reference. Experimental data were expressed as a percentage of light reduction by the periphyton. In some cases red light was used for the determinations. An optical filter with a transmission wavelength of 647 nm (which is close to the absorption wavelength of chlorophyll a), was placed between the light source and the slide. Light readings were made with and without the filter. If the light reduction by the epiphytes was approximately the same with and without the filter, it could be assumed that the

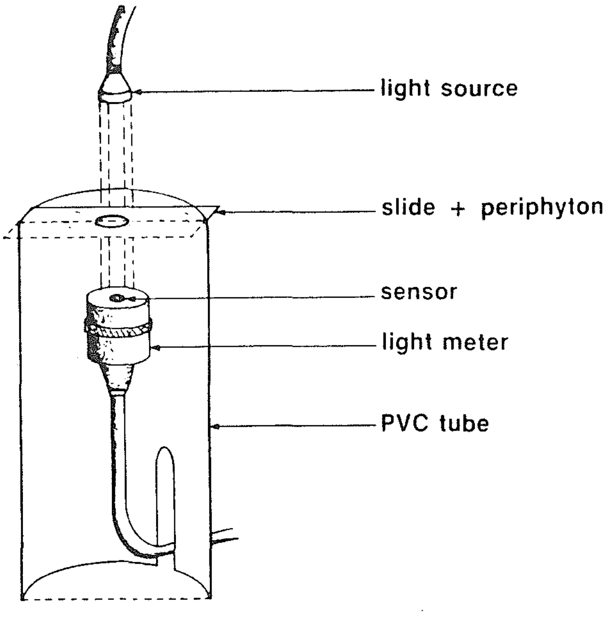

Figure 16 Experimental apparatus for measuring light reduction by periphyton on glass slides

shading was mainly caused by chlorophyll-containing (green) epiphytes.

Periphyton was removed from the slides using a one-sided razor blade and washed onto GF/C glass fibre filters for dry weight and chlorophyll determination as described for seagrass epiphytes.

Plastic Seagrass:

Quadrats of plastic seagrass (0.1 m^2) were assembled using a base of plastic-coated, woven steel mesh (25 mm). Strips of plastic approximating a mean seagrass shoot size, with blade lengths of 60 mm, 300 mm and 385 mm and widths of 11 mm were attached to the grid, using staples and plastic-coated copper wire. The quadrats of plastic grass were planted at each site and the growth of epiphytes observed over a two month period.
After 35 days, ten strips were harvested, kept in plastic bags filled with seawater and returned to the laboratory. The strips were cut into sections approximately 7.5 mm long so that two could be placed lengthwise on a microscope slide. The segments were held to the slide with plastic-coated copper wire at each end, and light readings made in the same way as with the glass slides using a piece of plastic without epiphytes as a reference. The periphyton was then scraped off for dry weight and chlorophyll analysis.

Results

A list of epiphytes from all three substrates (glass slides, plastic seagrass and P. australis) is given in Table 3. The list is not comprehensive but does show similar communities on all three substrates, although Ulva and Myrionema were not found on the glass slides. Very few hydroids and no Ulva or _Enteromorpha_ were found at Carnac Island. All epiphytes listed here are included in those found by Cambridge (1979).

TABLE 3: **EPIPHYTES FOUND ON SEAGRASS BLADES, GLASS SLIDES AND PLASTIC GRASS IN THIS STUDY**

Substrate: _Posidonia australis_ EPIPHYTES	Substrate: Glass Slides PERIPHYTON	Substrate: Plastic Grass EPIPHYTES
ALGAE	ALGAE	ALGAE
Green Algae (**Chlorophyta**)	**Chlorophyta**	**Chlorophyta**
Enteromorpha	_Enteromorpha_ sp	_Ulva lactuca_*
_Ulva lactuca_*		
Red Algae (**Rhodophyta**)	**Rhodophyta**	**Rhodophyta**
Laurencia sp	_Laurencia_ sp	_Laurencia_ sp
Melobesia sp	_Melobesia_ sp	_Melobesia_ sp
Ceramium sp	_Ceramium_ sp	_Ceramium_ sp
Polysiphonia sp	_Polysiphonia_ sp	_Polysiphonia_ sp
Brown Algae (**Phaeophyta**)	**Phaeophyta**	**Phaeophyta**
Myrionema sp	_Ectocarpales_ sp	_Myrionema_ sp
	Cyanochloronta	
	_Calothrix_* sp	
INVERTEBRATES	INVERTEBRATES	INVERTEBRATES
Foraminifera	Foraminifera	Foraminifera
Hydroids*	Hydroids*	Hydroids*

*Only at Site 1 (Woodman Point)

Epiphytes on _P. australis_

Epiphyte loads are shown in Figures 17 and 18 expressed as both dry weight and chlorophyll per unit area for the time period from February 1980 to January 1981. The chlorophyll _a_ curves appear seasonal with low loads at the end of summer, and an increase in mid autumn. This was followed by a fall again in winter and an increase in load during the spring months, a drop in load before increasing again in summer. Because of harsh weather conditions, load data were not obtained during the winter months at Carnac Island, but one can assume (using periphyton results below) that there would have been a decrease in load in about July (dotted line on Figure 17). The loads were

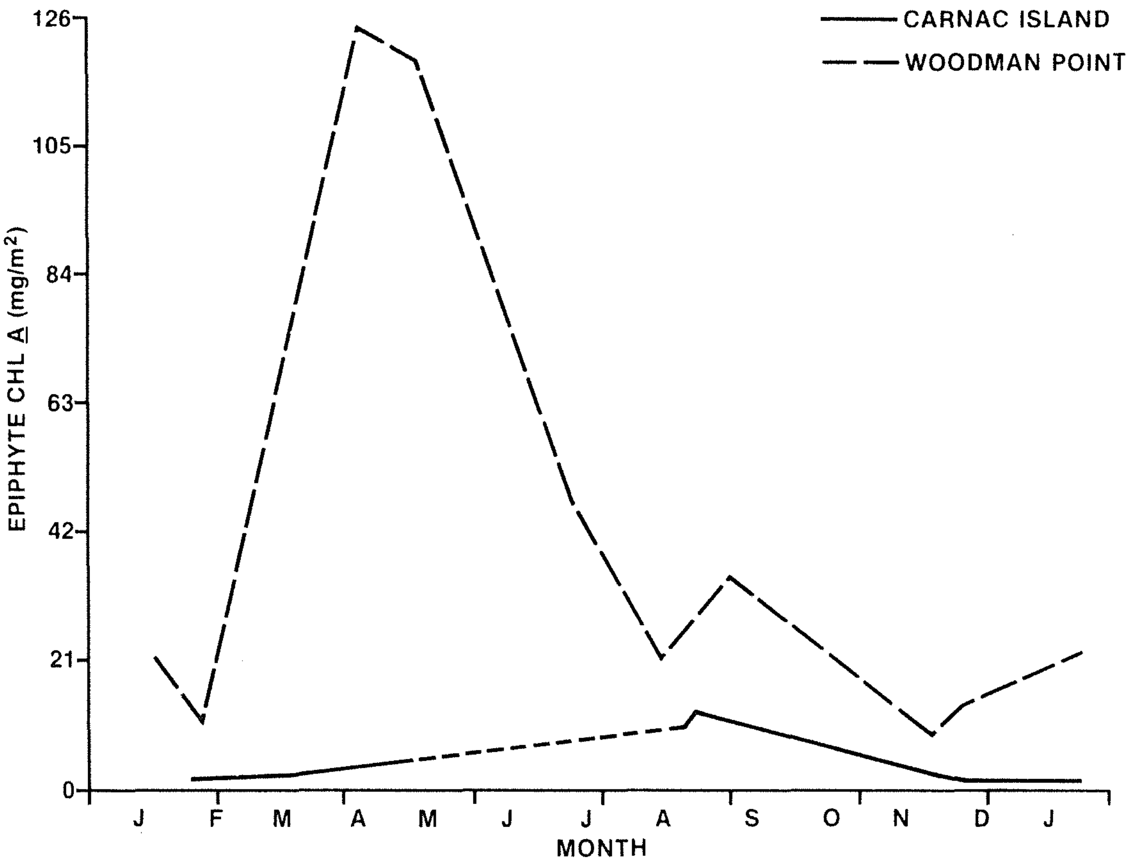

Figure 17 Seasonal epiphyte loads chlorophyll a 1980/81

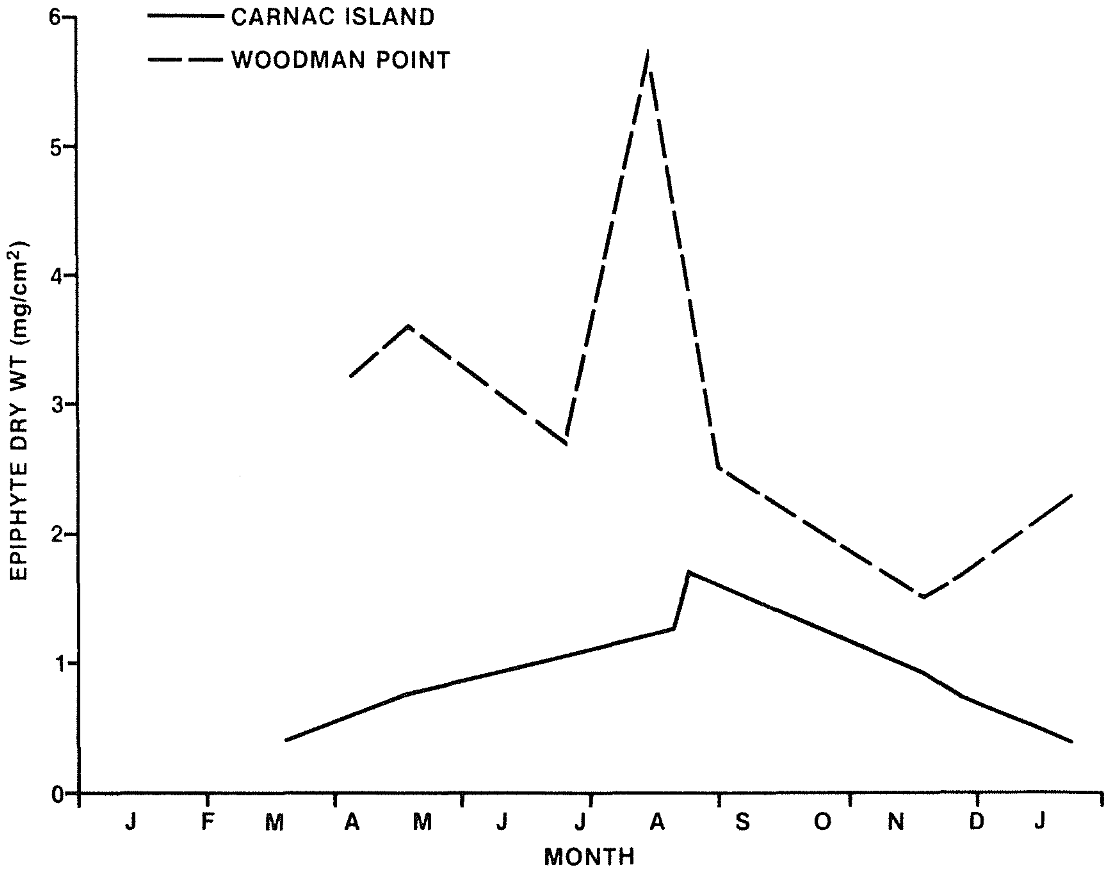

Figure 18 Seasonal epiphyte loads as dry weight 1980/81

much higher at Woodman Point, as was the amplitude of the growth curve. At Woodman Point, the high dry weight load in August/September can be mainly attributed to sand particles trapped by the macroepiphytes and hydroids, which were not reflected in the chlorophyll a measures of epiphyte load. At Carnac Island however, the dry weight and chlorophyll a curves show similar seasonal trends.

The epiphyte loads on the fresh growth were less than those on the rest of the leaf, confirming general observations (Table 4).

TABLE 4: **EPIPHYTE LOADS ON FRESH GROWTH AND ON THE REMAINDER OF THE PLANT**

SECTION OF LEAF BLADES	EPIPHYTE LOADS AT EACH SITE mg/cm^2	
	Carnac Island	Woodman Point
Fresh Growth (35 days)	0.12 ± 0.03	0.28 ± 0.02
Remainder of Leaves	1.65 ± 0.50	6.6 ± 1.7
TOTAL LEAF	0.96 ± 0.30	3.8 ± 0.9

Periphyton

Glass Slides:

The periphyton levels show similar seasonal trends (Figures 19 and 20) to those of the epiphytes. The loads, as with the epiphytes (Figures 17 and 18) were higher at Woodman Point.

Unfortunately, the data at Woodman point are incomplete owing to loss and breakage of the slides, but there is a seasonal trend, and after the decline in winter, the periphyton levels increased again in spring.

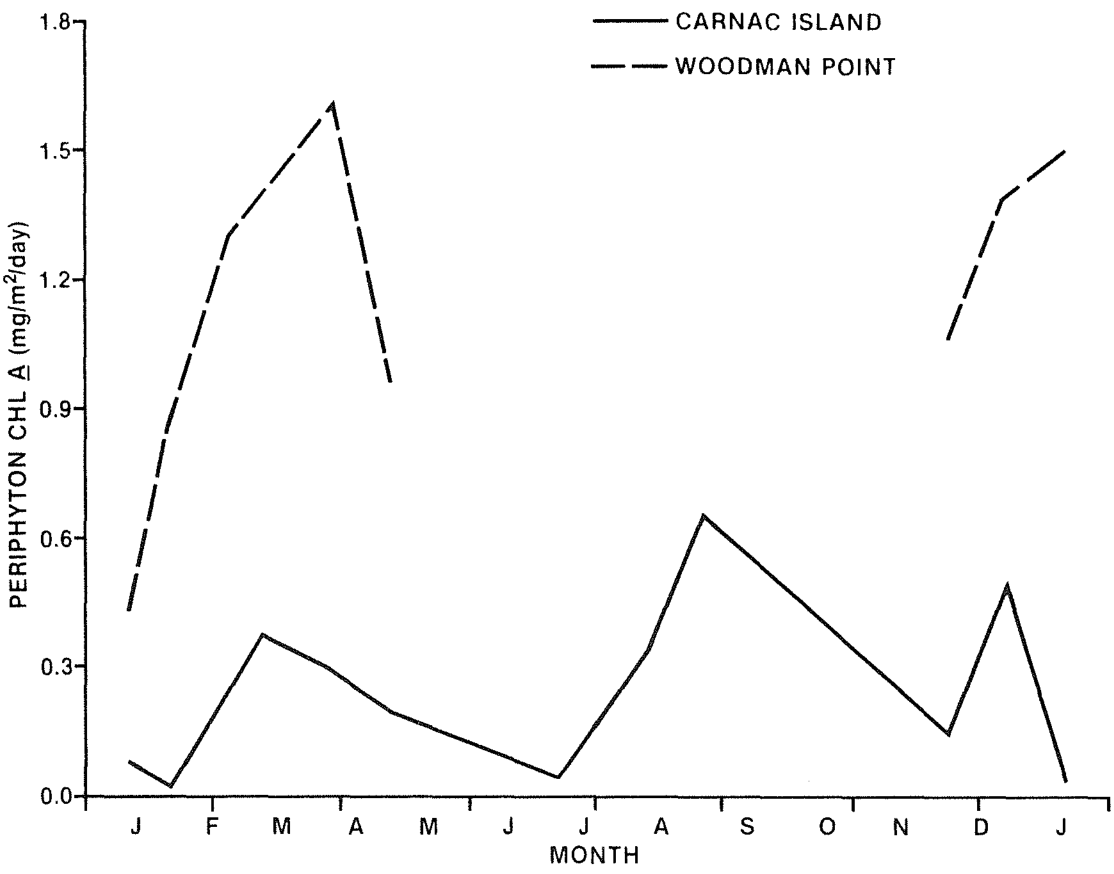

Figure 19 Seasonal growth of periphyton chlorophyll a 1980/81

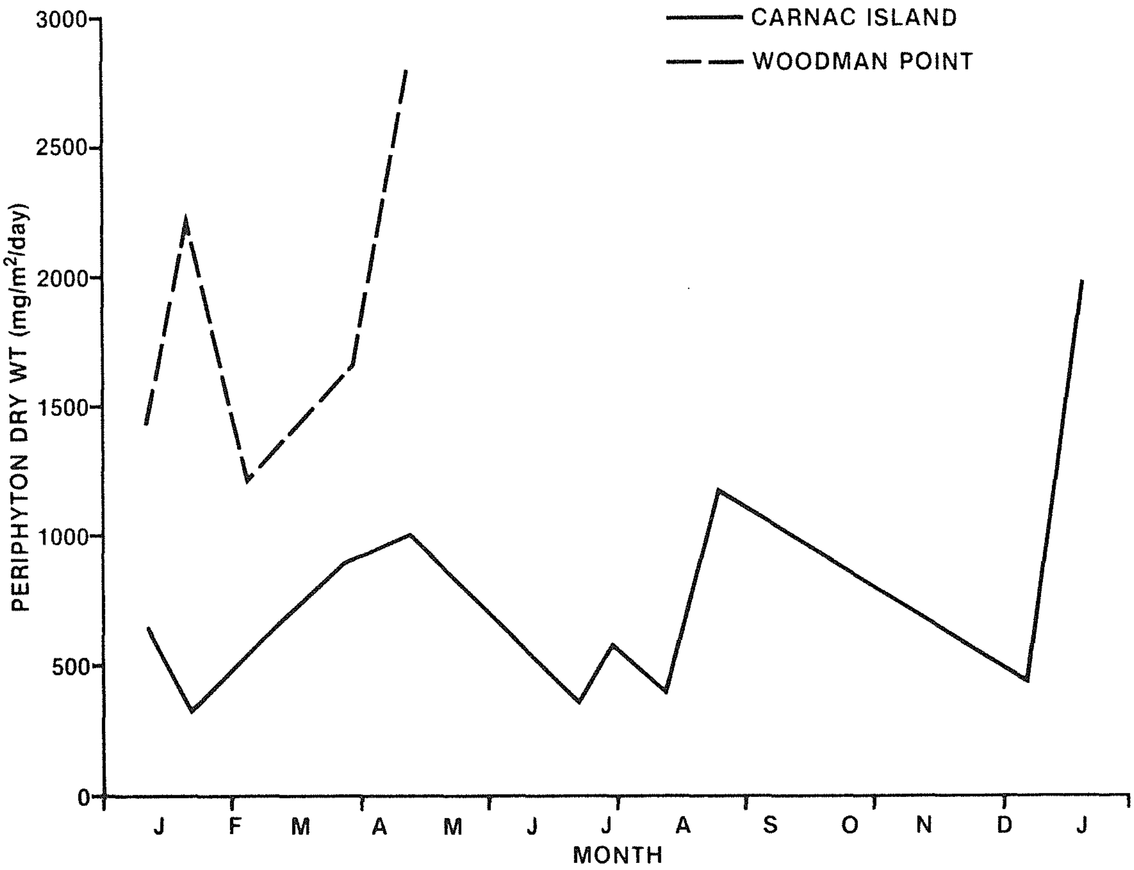

Figure 20 Seasonal growth of periphyton chlorophyll a 1980/81

The dry weight curve is rather more erratic, due mainly to sand grain accumulation as observed on seagrass blades.

Plastic Seagrass:

After three weeks at both sites periphyton had begun colonising the plastic seagrass (Table 3), in much the same manner as epiphytes colonise seagrasses. The principal epiphytes at Carnac Island were the calcareous algae, which also colonised the plastic seagrasses at Woodman Point though not as evenly. Macroepiphytes colonised the Woodman Point "plants" once the crust had been formed.

Light Reduction by Epiphytes

The light reduction, when plotted against dry weight and chlorophyll a levels (Figures 21 and 22), shows an approximation to a natural growth type curve:

$f(x) = 100(1 - y^{-0.2x})$ and $f(x) = 100(1 - y^{-0.5x}) \pm 4xy^{-0.5x}$

The light reduction by epiphytes on plastic grass showed similar curves.

In general, using the filter gave slightly lower though not significantly different light reductions, suggesting that the light reduction is caused predominantly by chlorophyll a containing periphyton. It was concluded that chlorophyll a levels gave a reasonable indication of periphyton (and epiphyte) loads.

Of course, discrepancies occurred when sand grains were present, causing underestimation of light reduction when only using chlorophyll a levels.

Using the chlorophyll a curve (Figure 22) one can deduce the light reduction by epiphytes on seagrass leaves. The mean epiphyte load at Woodman Point was 3.4 μg Chla/cm^2 which represents a light reduction of approximately 82%. At Carnac Island, the mean load was 0.37 μg Chla/cm^2 which represents a light

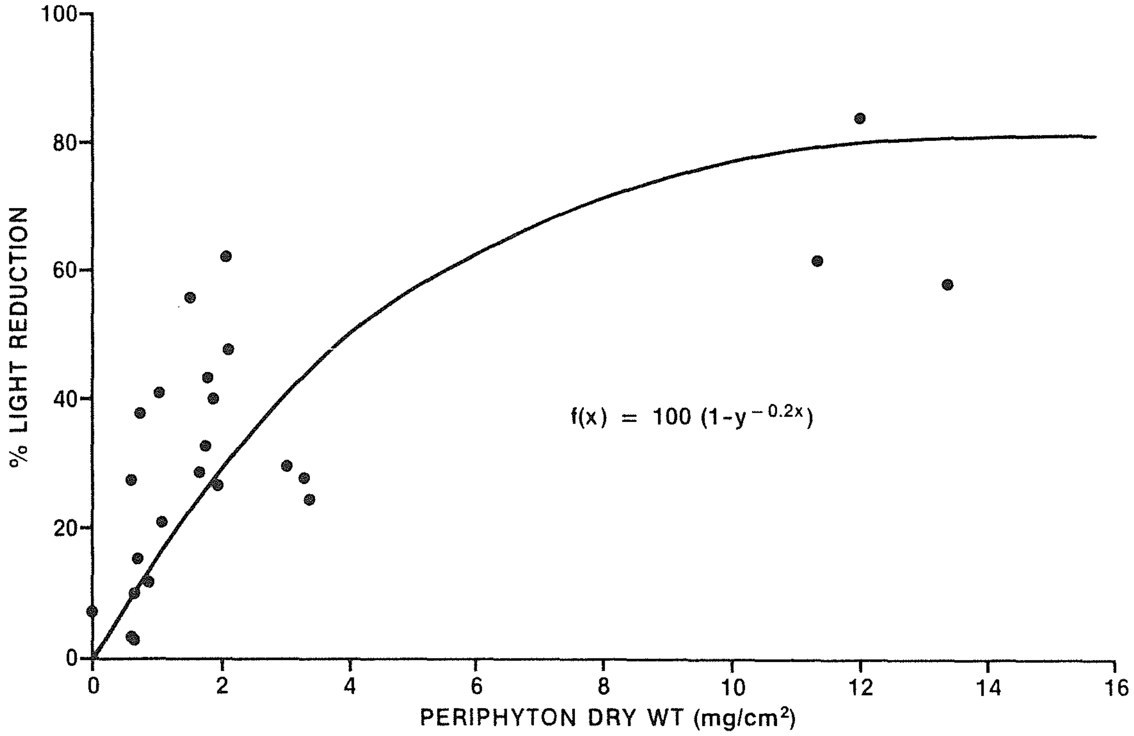

Figure 21 Light reduction (%) versus periphyton dry wt

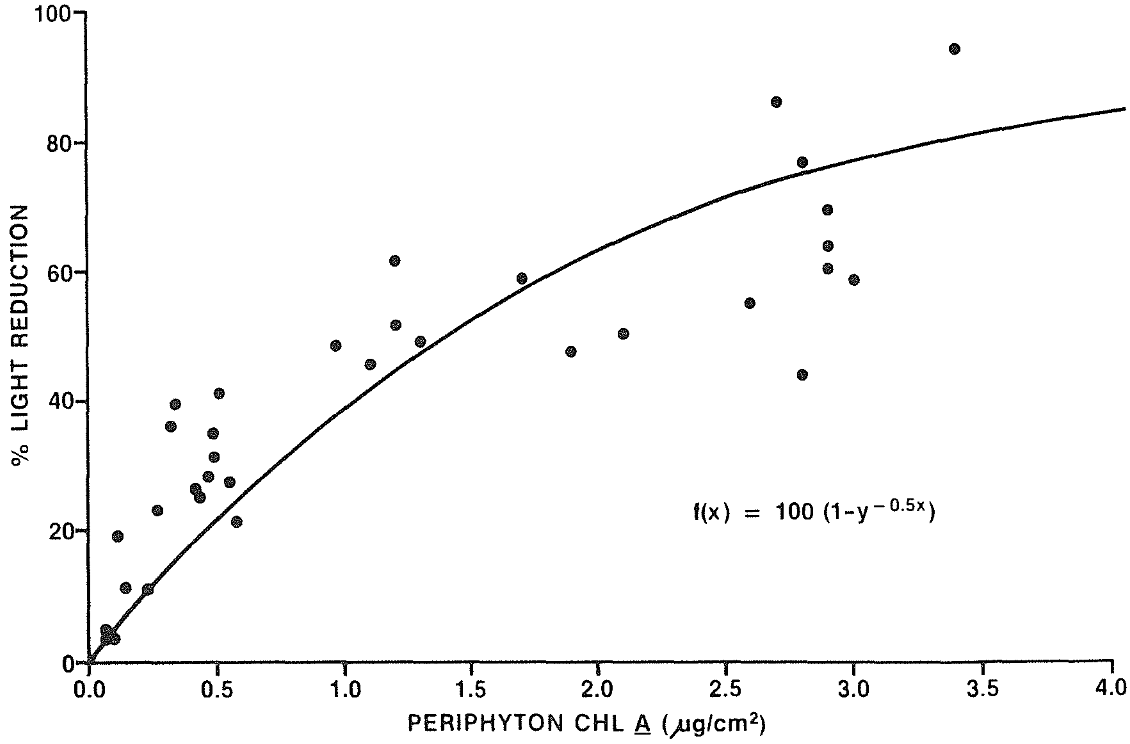

Figure 22 Light reduction versus periphyton chlorophyll a content

reduction of 17%. It must be remembered, however, that the epiphytes are not evenly distributed and that at the base of the shoots, the epiphyte loads are very low. Using values recorded above 0.28 and 0.12 μg Chl<u>a</u>/cm^2 for the fresh growth at Woodman Point and Carnac Island, the light reduction for this section of the blade would be 13% and 6% respectively. This section (35 days growth) represented approximately 45% of the leaf. Simply, one could suggest that on the initial 35 days growth (45%), the epiphytes would be reducing the light by 13% and 6%. On the rest of the leaf, light reduction would be 96% and 56% for the shoots on this particular harvest. This constitutes a total light reduction of 58% and 34% at Woodman Point and Carnac Island respectively. A more accurate measure could be obtained by determining the colonisation rate of the epiphytes on the seagrass leaf to obtain a growth curve, and using the rate of growth of seagrass, the epiphyte loads along the blade could be calculated.

Epiphytes and the Environment

Correlation coefficients of epiphytes and periphyton with environmental parameters are given in Table 5.

Chiffings (1979) indicates that phytoplankton populations in Cockburn Sound are controlled by the availability of nitrogen. Since the epiphytes and periphyton are predominantly algal, it is likely that they will respond to nutrients in the same manner as do the phytoplankton. The correlations between chlorophyll a concentration in the water column and epiphyte and periphyton loads, support this idea.

TABLE 5: **CORRELATION COEFFICIENTS OF EPIPHYTE AND PERIPHYTON LOADS WITH ENVIRONMENTAL PARAMETERS, LISTED IN ORDER OF SIGNIFICANCE**

EPIPHYTE Chlorophyll *a*			EPIPHYTE dry weight			PERIPHYTON Chlorophyll *a*			PERIPHYTON dry weight		
factor	r	significance of r	factor	r	significance of r	factor	r	significance of r	factor	r	significance of r
Chl *a*	0.811	0.007	NO_3	0.636	0.033	Chl *a*	0.900	0.019	Chl *a*	0.803	0.050
Light	-0.462	0.065	Chl *a*	0.534	0.086	Light	-0.409	0.120	PO_4	0.428	0.109
Wind	-0.4909	0.075	PO_4	-0.431	0.123	Wind	-0.391	0.149	Wind	-0.402	0.142
NH_4	-0.363	0.123	Temp	-0.417	0.132	PO_4	0.338	0.170	Light	-0.346	0.164
PO_4	-0.107	0.371	Light	-0.408	0.138	NO_3	-0.187	0.303	NO_3	0.321	0.183
Temp	-0.098	0.382	NH_4	0.201	0.302	Temp	-0.128	0.362	NH_4	0.195	0.295
NO_3	-0.0425	0.448	Wind	0.205	0.330	NH_4	0.074	0.419	Temp	0.021	0.478

r = correlation coefficient
factor = environmental parameters

The correlation between periphyton loads and epiphyte loads (Table 6), indicating that epiphytes grow just as readily on artificial substrates as they do on seagrass leaves, suggests that the epiphytes are not receiving nutrients from the seagrasses. This also validates the use of artificial substrates as a means of sampling epiphytes.

TABLE 6: **CORRELATION BETWEEN PERIPHYTON AND EPIPHYTE LOADS**

	PERIPHYTON Chlorophyll *a*		PERIPHYTON dry weight	
	r	significance of r	r	significance of r
EPIPHYTE Chl *a*	0.835	0.003	0.683	0.020
EPIPHYTE dry weight	0.883	0.010	0.830	0.020

r = correlation coefficient

Discussion

The ability of the epiphytes to colonise artificial substrates, and to do so at levels which are comparable with those on seagrass leaves, emphasises that the main requirement by the epiphytes of the seagrass blade is a surface on which to grow, rather than, for example, the leaching of nutrients from the blades. A similar conclusion has been reached by several authors working in other regions (Phillips et al., 1978; Mathieson & Mathieson, 1976). In comparing glass with plastic, general observations, and the fact that macroperiphyton grew on the plastic grass but not the slides, suggest that the plastic grass is the more effective substrate for sampling epiphyte populations.

The growth of both epiphytes and periphyton is greater at Woodman Point than at Carnac Island. Presumably this results from the higher nutrient content of the water at Woodman Point.

Light reductions by epiphytes, deduced from periphyton light experiments, were 96% on 55% of the plant and 13% on the other 45% (new growth) at Woodman Point. At Carnac Island, the light reduction values were 56% on 55% of the plant and 6% on 45%. Thus the light reduction was significantly greater at Woodman Point than at Carnac Island.

THE REDUCTION IN LIGHT BY EPIPHYTES AND ITS EFFECT ON SEAGRASS PHOTOSYNTHESIS

Introduction

The epiphyte loads at Woodman Point were substantially higher than at Carnac Island. However, it was necessary to discover if the consequent light reduction might have a critical effect on the growth of the plant; sufficient to decrease its production to the extent that is evident in Cockburn Sound. In the following experiments, an attempt was made to determine the effect of light reduction on seagrass photosynthesis and hence production.

Materials and Methods

Shoots of *P. australis* were collected from a seagrass meadow in Cockburn Sound and transported at 10°C to the laboratory where they were transferred to an aerated cylindrical tank and kept at 20°C in seawater. Shoots of plastic grass were also collected and kept under the same conditions.

Oxygen Production

The Clark-type electrode (Rank Brothers, Bottisham, England) was used for monitoring oxygen production, and hence photosynthetic rates, of *P. australis*. The electrode works on a polarographic principle where a polarizing DC voltage releases electrons at a silver anode bathed in chloride (KCl), allowing the reduction of oxygen concentration at the cathode, at a polarizing voltage of 0.6v, thus giving the oxygen concentration in the cell From this the rate of oxygen production can be measured using a chart recorder. The electrodes were covered with saturated KCl solution, and a piece of lens tissue (1 cm^2) placed over them, with a hole in the centre for the cathode. The tissue was covered by a piece of tephlon membrane (1 cm^2) and an incubation vessel was screwed down tightly with a rubber ring holding the membrane in position. The incubation vessel (volume 8 ml) was a cylinder of Perspex in a water jacket (20°C) bounded by another Perspex cylinder. The medium inside the cell was stirred with a magnetic stirrer driving a small, glass-covered 'flea'. The apparatus was calibrated with air-saturated seawater at 20°C, and a zero was set after the addition of sodium dithionite.

Before each run, the cell was filled with filtered seawater and deoxygenated by bubbling through carbon-dioxide-enriched nitrogen for two minutes. Leaf segments were kept upright by means of a small plastic covered wire stand. The light source was a quartz halogen lamp (Phillips 150 w) which was shone at right angles to the leaf face, so that one side was totally illuminated. Light intensities were varied at the source. Photosynthetically-active radiation reaching the leaf was measured for each setting of the source by using a light sensor (Licor Lambda Instrument Company, Nebraska, USA) held in a half-vessel constructed of perspex so that refraction due to the water and perspex could be taken into account.

Segments of *P. australis* (about 25 mm) were cut and placed into the cell, and dissolved oxygen concentration recorded for 20 minutes (after a lag phase, see results section). The epiphytes were then removed for chlorophyll extraction, and the process repeated with the leaf segments without epiphytes. This process was carried out using segments of *P. australis* with no epiphytes and plastic seagrass with varying epiphyte loads. Each leaf segment was measured, ground, and the chlorophyll *a* content measured after extraction in 90% acetone.

Results

Aquatic vascular plants can store and recycle oxygen within the airfilled lacunae of the leaf (Sculthorpe, 1967), and this might lead to inherent errors in the method described here, with an under-estimation of the photosynthetic rates. When a leaf segment was placed in the apparatus, a lag phase was observed, usually lasting about ten minutes, after which the oxygen production rate proceeded at a constant level: presumably the lag phase was the time taken for the lacunae within the leaf segment to be filled, before oxygen was released to the surrounding water. The rate of oxygen production after the lag was used in calculations. There was no lag phase when measuring the oxygen production from epiphytes on plastic seagrass.

The oxygen production rates (hence photosynthetic rates) were calculated per cm^2 and per mg chlorophyll a. Figure 23 shows the photosynthesis of seagrass blades with no epiphytes at varying PAR levels. The line plotted through the points is similar to the P-I curves obtained for P. oceanica by Drew (1979). Figure 24 shows photosynthesis before and after epiphyte removal. Both curves show similar classic photosynthesis versus irradiance (P-I) curves (Steeman Nielson, 1975; Drew, 1979). Other P-I curves of leaves with varying epiphyte loads are presented in Figures 25 and 26.

The similarity of the oxygen production of leaves with no epiphytes (Figure 23) to that of the scraped leaves (Figure 24 lower curve) suggests that the removal of epiphytes did not damage the photosynthetic ability of the leaf.

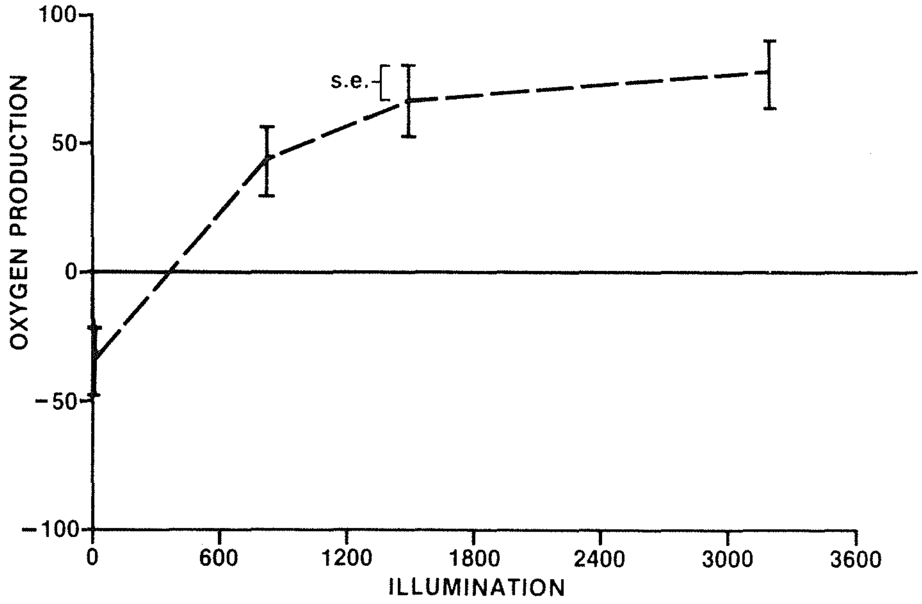

Figure 23 Mean oxygen production (μg/cm^2/min) versus illumination (μE/cm^2/s) of *P. australis* leaves with no epiphytes (n = 3)

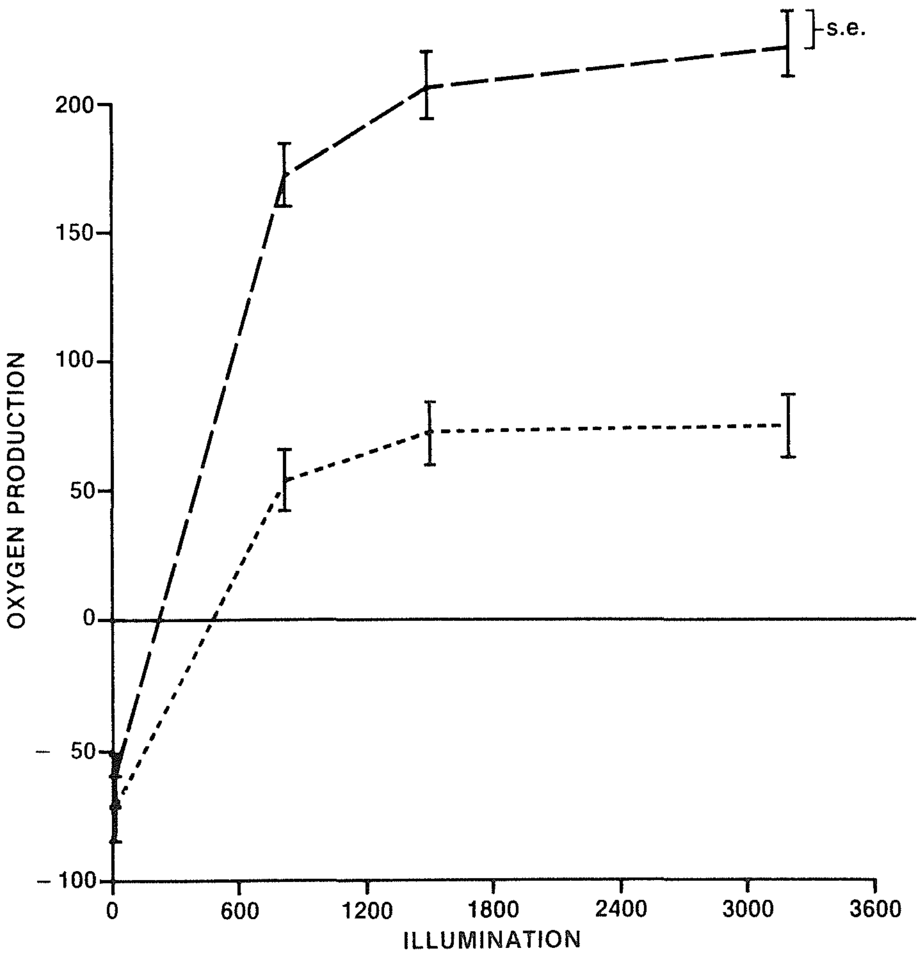

Figure 24 Mean oxygen production (µg/cm^2/min) versus illumination (µE/cm^2/s) of *P. australis* leaves before (———) and after (----) epiphyte removal (n = 3)

This was further tested as follows: the oxygen production of 'epiphytes' alone, on plastic seagrass, at saturation was plotted against chlorophyll a content (Figure 27); this gave a linear correlation (regression through the origin) of 0.88 ($p < 0.05$). Knowing the amount of chlorophyll present in epiphytes, the oxygen production of the epiphytes on a seagrass blade could then be extrapolated from the graph; this should be the same as the difference between oxygen production at saturation before and after epiphyte removal.

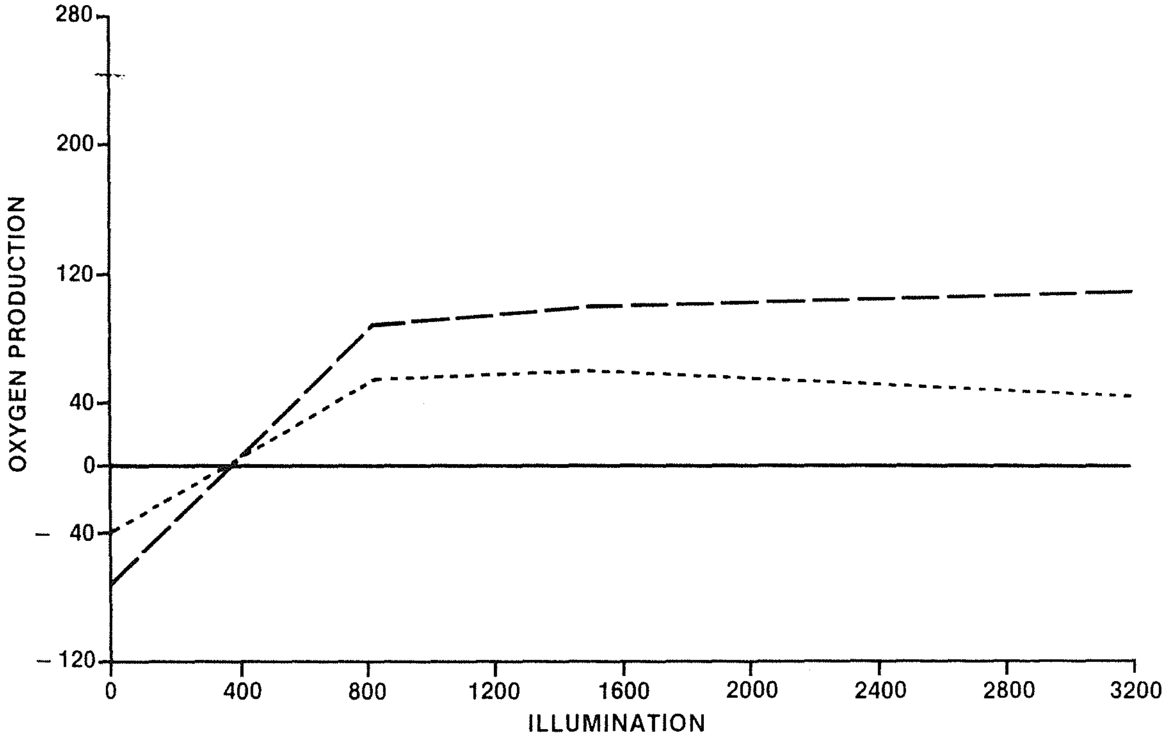

Figure 25 Oxygen production (μg/cm^2/min) versus illumination (μE/cm^2/s) of a leaf before (— — —) and after (----) epiphyte removal (Epiphyte load was 3.74 μg Chl a/cm^2)

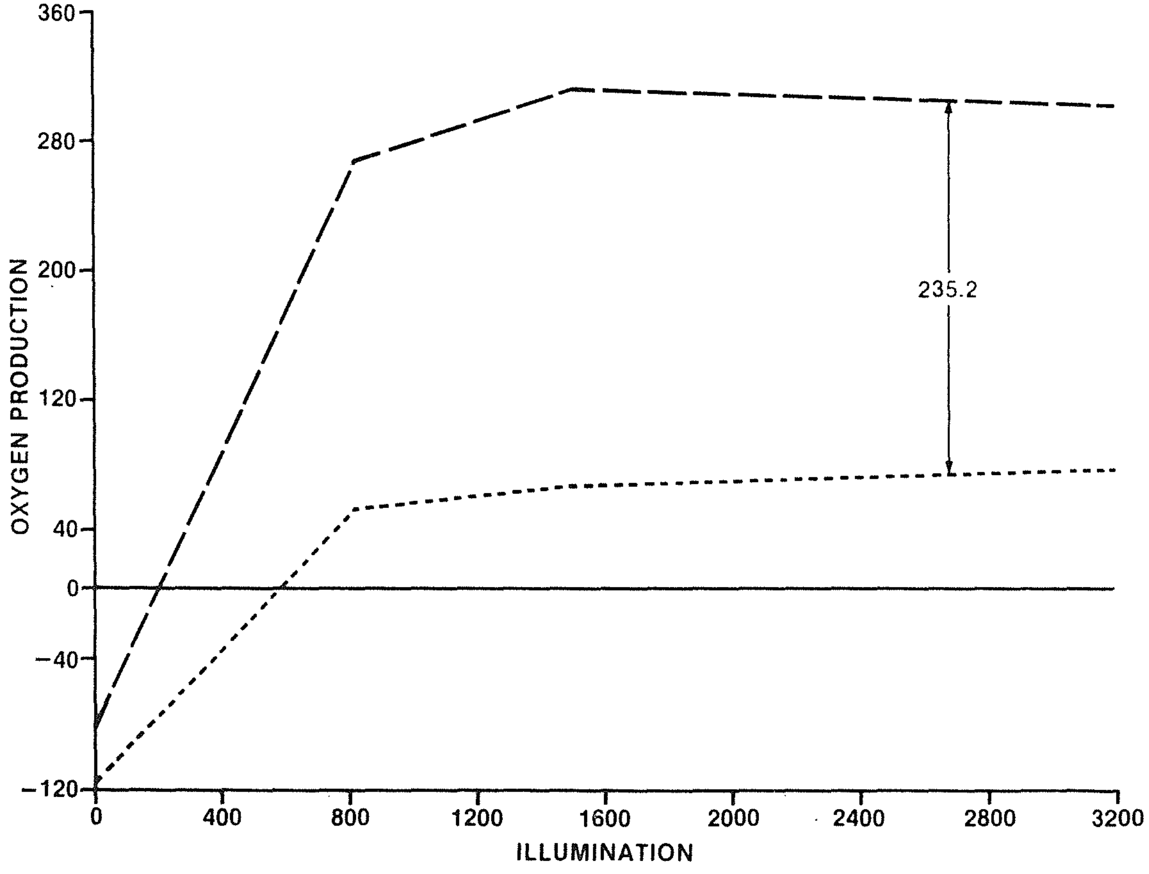

Figure 26 Oxygen production (μg/cm^2/min) versus illumination (μE/cm^2/s) of a leaf before (— — —) and after (----) epiphyte removal (Epiphyte load was 3.74 μg Chl a/cm^2)

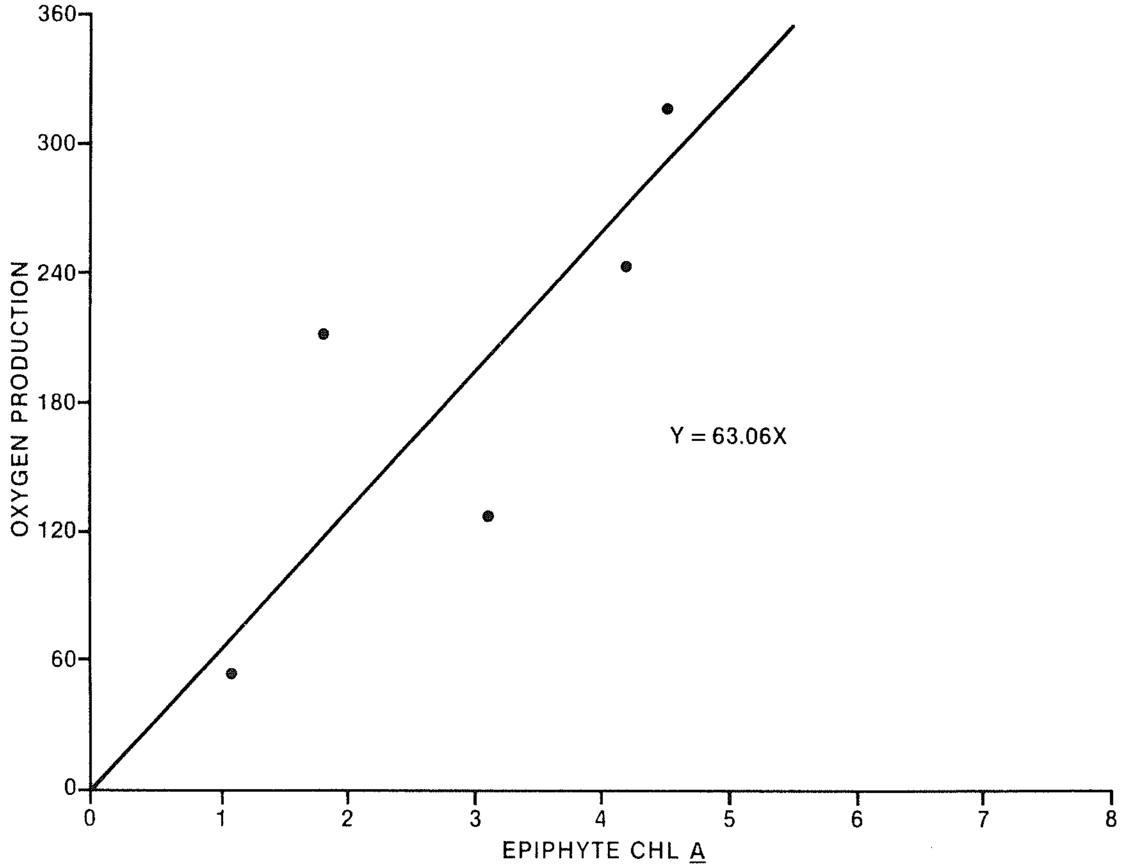

Figure 27 Oxygen production (μg/cm²/min) of periphyton (μg chl a/cm²) at light saturation

The epiphyte load on the seagrass leaf (Figure 26) was 3.74 μg/cm² which represented an oxygen production of 235.8 ± 26 $\mu gO_2/cm^2/min$ (Figure 27). The difference between saturation levels of oxygen production before and after epiphyte removal (Figure 27) was 235.2 $\mu gO_2/cm^2/min$. This is further verification that there was very little damage to the leaf caused by scraping to remove epiphytes, and that a large proportion of the oxygen production of a leaf with epiphytes is due to the epiphytes.

Discussion

The levels of PAR reaching the seagrass meadows at a depth of three metres in Cockburn Sound are about 300 to 700 $\mu E/cm^2/s$. It can be seen from the P-I curves in this investigation that these levels would be barely enough to light saturate photosynthesis in the seagrass. It can be seen that the shading by epiphytes, as calculated in the previous chapter would bring about a marked reduction in photosynthesis and hence production. At Woodman Point, the light reduction by epiphytes was calculated to be 96% for 55% of the shoot and 13% for the rest. From the P-I curve in Figure 23 light reduction would cause a decrease in photosynthesis of approximately 57% at a PAR of 500 $\mu E/cm^2/s$. By comparison at Carnac Island, the light reduction by epiphytes was 56% and 6%. From Figure 23, this would cause a 15% decrease in photosynthesis.

These results are of the same order of magnitude as those of Sand-Jensen (1977) who estimated the reduction of photosynthesis by epiphytes on eelgrass (*Zostera marina*) to be 31%. He measured the photosynthesis of eelgrass at varying PAR using radioactive carbon techniques.

The growth curve at Woodman Point (Figure 4) showed a sudden fall in mid-April which coincided with a marked increase in epiphyte load (Figure 17). The relationship between leaf production and epiphyte loads for the whole data set showed a log-linear relationship ($r = 0.87$, $p < 0.001$, Figure 28). A similar relationship was obtained when leaf standing crop was plotted against epiphyte load. The relationship is likely to result from that between epiphyte loads and light reduction (Figure 22). Indeed the correlation between leaf production with the light reduction due to epiphytes (Figure 29) was highly significant ($r = -0.79$, $p < 0.01$). These relationships are all consistent with the view that epiphyte loads restrict the growth of the seagrass.

The calculations above are approximate, but the magnitude of the reduction in photosynthesis is illustrated. Thus it is likely that the shading by epiphytes has a marked effect on the production of seagrass at Woodman Point.

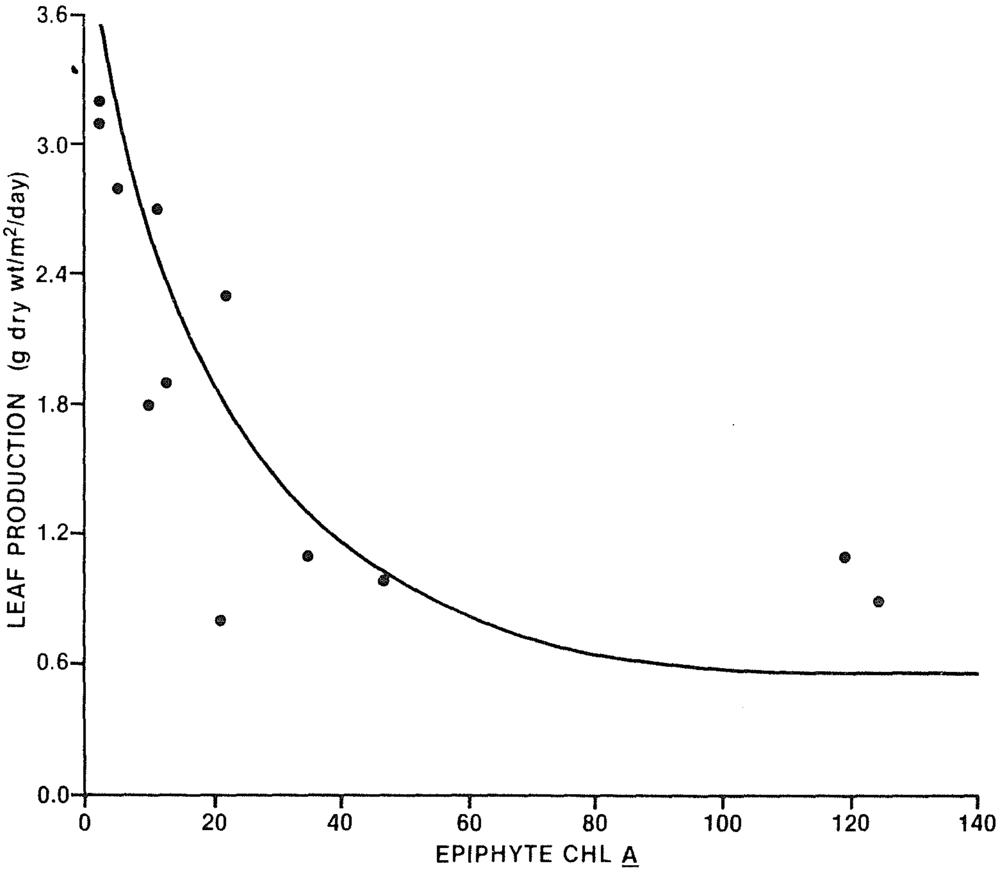

Figure 28 Leaf production (g dwt/m^2/day) versus epiphyte load (mg/m^2)

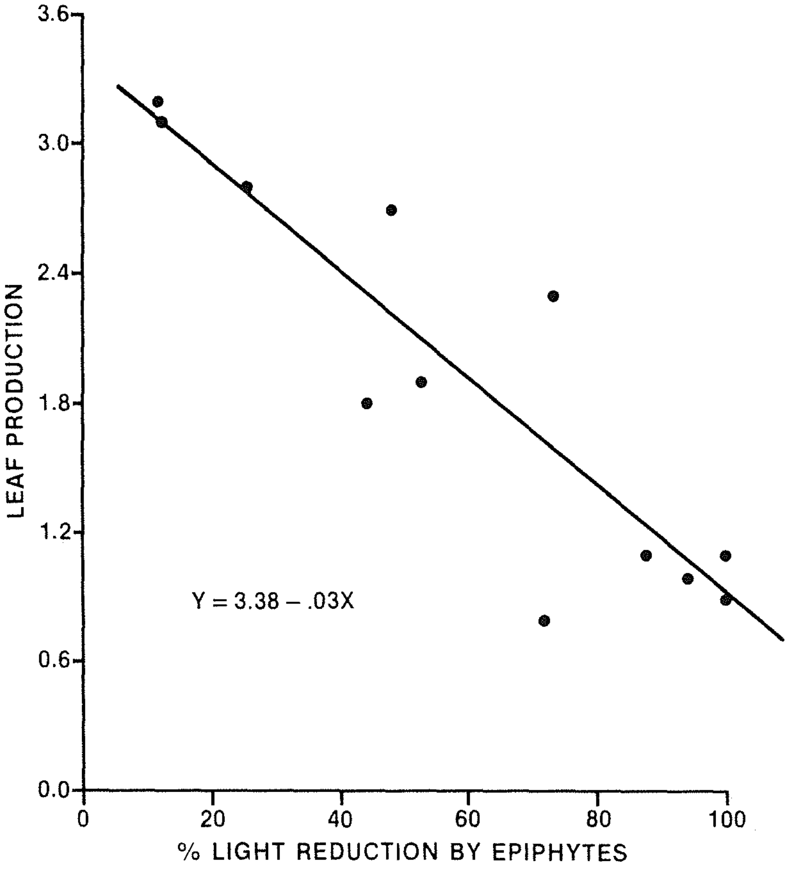

Figure 29 Leaf production (g dry wt/m^2/day) versus light reduction (%) by epiphytes

On reviewing the results of this study there seems little doubt that the hypothesis put forward by Cambridge (1979), suggesting that the enhanced growth of epiphytes has been responsible for the decline of seagrasses in Cockburn Sound, is tenable.

SUMMARY OF RESULTS AND CONCLUSIONS

Present Seagrass Degeneration

The depletion of seagrass on Parmelia Bank is continuing at the present time (1980). It appears significant that the most evident areas of decline are in an area which receives nutrient-enriched waters.

Leaf Production

The leaf production at Woodman Point was 47% less than leaf production at Carnac Island, and the mean growth per shoot was 25% less.

Epiphyte Loads

It has been shown that nutrient enrichment of the water column can lead to an increase in epiphyte growth. With respect to the two study sites, the mean epiphyte loads at Woodman Point were almost an order of magnitude higher than at Carnac Island. In the water column, phosphate and chlorophyll a concentrations were significantly higher at Woodman Point.

Light Reduction by Epiphytes

An estimation of the reduction (due to epiphytes) of the light reaching the seagrass blades, gave a value at Woodman Point (58%) almost twice that at Carnac Island (34%). This light reduction by epiphytes could cause decreases in production of approximately 60% and 15% respectively.

The light reduction by phytoplankton blooms alone (about 10%) may not be significant. If, however, the seagrass is already under stress due to epiphytes, the extra 10% shading could be important.

It is concluded that the growth of seagrass at Woodman Point has been markedly reduced by the shading effect of epiphytes.

Leaf Production and Epiphyte Loads

The growth curve at Woodman Point showed a sudden fall in mid-April which coincided with a marked increase in epiphyte load. The relationship between leaf production and epiphyte loads for all the data showed a log-linear relationship ($r = 0.87$, $p < 0.001$). A similar relationship was obtained when leaf standing crop was plotted against epiphyte loads and light reduction. Indeed the correlation between leaf production with the light reduction caused by epiphytes was highly significant ($r = - 0.79$, $p < 0.01$). These relationships are all consistent with the view that epiphyte loads restrict the growth of the seagrass.

Conclusion

On reviewing the results of this study there seems little doubt that the hypothesis put forward by Cambridge (1979), suggesting that the enhanced growth of epiphytes has been responsible for the decline of seagrass in Cockburn Sound, is tenable.

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REFERENCES

Barber, W.E., Greenwood, J.C. & Crocos, P. 1979. Artificial seagrass - a new technique for sampling the community. Hydrobiologia, 65 : 135-140.

Cambridge, M.L. 1979. Cockburn Sound Environmental Study Technical Report on Seagrass. Report No. 7. (Department of Conservation and Environment, Western Australia.)

Carpenter, S. 1980. The decline of *Myriophyllum spicatum* in a eutrophic lake. Can. J. Bot., 58 : 527-535.

Chiffings, A.W. 1979. Cockburn Sound Environmental Study Technical Report on Nutrient Enrichment and Phytoplankton. Report No. 3. (Department of Conservation and Environment, Western Australia.)

Chiffings, A.W. (in preparation). Nutrient enrichment and phytoplankton growth in Cockburn Sound, Western Australia. Ph.D. thesis, University of Western Australia.

DCE 1980 Kwinana Air Modelling Study, unpublished data. (Department of Conservation and Environment, Western Australia.)

Drew, E.A. 1979. Physiological aspects of primary production in seagrass. Aquat. Bot., 7 : 139-150.

Fitzgerald, G.P. 1969. Some factors in the competition or antagonism among bacteria, algae and aquatic weeds. J. Phycol. 5 : 351-359.

Goldman, J.C. 1976. Identification of nitrogen as a growth limiting nutrient in west waters and coastal marine waters through continuous culture algal assays. Water Res. 10 : 97-104.

Harlin, M. 1980. Seagrass epiphytes. Pp. 117-152 *in* Phillips, R.C, & McRay, P.C. (Eds.) "Handbook of Seagrass Biology," (Garland, STPM Press, New York).

Kindig, A.C. & Littler, M.M. 1980. Growth and primary productivity of marine macrophytes exposed to domestic sewage effluents. Mar. Env. Res., 3 : 81-100.

Kirkman, H. & Reid, D. 1979. The study of the role of the seagrass *P. australis* in the carbon budget of an estuary. Aquat. Bot., 7 : 173-183.

Mathieson & Mathieson, 1976. Fastvoksende vegetation i Randers Fjord of Grund Fjord. *In*: Gudenaaunderogelsen Randers Fjord, Kap. 2. Environplan A/S. Kobenhaven, cited by Penhale, P.A. 1977.

McComb, A.J., Cambridge, M.C., Kirkman, H., & Kuo, J. 1980. Biology of Australian seagrasses. Pp 259-293 *in* J.S. Pate & A.J. McComb (eds) "Biology of Australian Plants". (University of Western Australia Press).

Nie, H.H., Haldai Hull, C., Jenkins, J.G. Steinbrennerk, & Brant, D.H. 1975. "SPSS: Statistical Package for the Social Sciences". (McGraw-Hill, New York).

Penhale, P.A. 1977. Macrophyte - epiphyte biomass and productivity in an eelgrass (Z. marina) community. J. Esp. Mar. Biol. Ecol., 26 : 211-224.

Phillips, G.L. Eminson, D., & Moss, B. 1978. A mechanism to account for macrophyte decline in progressively eutrophic freshwaters. Aquat. Bot., 4 : 103-126.

Rastetter, E.B. & Cooke, W.J. 1979. Responses of marine fouling communities to sewage abatement in Kaneohe Bay, Oahu, Hawaii. Mar. Biol. 53 : 271-280

Sand-Jensen, K. 1977. The effects of epiphytes on eelgrass photosynthesis. Aquat. Bot., 3 : 55-63.

Sculthorpe, C.D. 1967. "The Biology of Aquatic Vascular Plants." (Edward Arnold, London.)

Standard Methods 1971: For the examination of water and waste water, Edition, American Public Health Assoc., American Water Works Assoc., Water Pollution Control Federation.

Steeman Nielsen, E. 1975. "Marine Photosynthesis: With Special Emphasis on the Ecological Aspects." Elsevier Oceanography Series, No. 13, (Elsevier Scientific Publishing Co., Amsterdam.)

Tyerman, S. 1980. Water Relations of Seagrasses. Unpublished manuscript, given as paper at National Seagrass Workshop, Sydney University, February 1980, convened by A.W.D. Larkum.

West, R.J. & Larkum, A.W.D. 1979. Leaf productivity of the seagrass P. australis in eastern Australian waters. Aquat. Bot. 7 : 57-65.

Zieman, J. 1974. Methods for the study of the growth and production of Turtle grass (Thalassia testudinum). Aqua culture, 4 : 139-143.

Zieman & Wetzel, 1980. Productivity in seagrasses: methods and rates. Pp. 87-116 in R.C. Phillips & P.C. McRay (Eds.) "Handbook of Seagrass Biology" (Garland STPM Press, New York).

APPENDIX 1

ASSESSMENT OF THE DECLINE OF SEAGRASS ON THE NORTHERN SIDE OF WOODMAN POINT

Prepared for the Department of
Conservation and Environment
by K. Silberstein
May 1981

INTRODUCTION

The following study is an investigation of seagrass meadows surrounding sand washing operations on the north eastern section of Parmelia Bank.

Seagrass meadows provide food and shelter for fauna and are important for trapping and binding the sediment. They are also important in nutrient cycling and their leaves provide a substrate for the settlement of microbes, animals and algae (epiphytes).

In 1972 sand washing operations were established for the recovery of sand from dredging in Cockburn Sound. After dredging, the material is transferred into a barge and deposited as an underwater stockpile reclaimed by a suction dredge and pumped to the plant. It is washed in fresh water before being screened to remove plant matter and shells. Some of the very fine particulate sediment, which is caught in suspension, does not go through the screens and is consequently discharged as part of the waste. The screened sand is dewatered and transferred via a water injected pipeline to the cement works. The waste, therefore, consists of very fine silt-like sediment, shells and organic matter (mostly seagrass blades and rhizomes). Since August 1979, the waste has been deposited into a dredged hole immediately north of the jetty. Prior to this it was discharged directly on to the beach next to the jetty. The fine silt and particulate organic matter causes an increase in turbidity surrounding the jetty (visibility as low as 0.2 m has been noted). From observations of the plant operation, it is apparent that the turbidity of adjacent waters occurs from several sources, these have been identified as:

1. Dumping sand at the end of the jetty
2. Propeller wash from the dump barges
3. Waste material from the plant.

It is believed that the turbidity caused by the waste disposal technique is by far the major component of total load, although no quantitative assessment was possible. In addition it was noted that fine material released since 1972 has resulted in a considerable sediment 'blanket' in adjacent waters. The sediment rapidly goes into suspension when the waters are agitated by wave action.

Cambridge (1979) and Silberstein (1980) concluded that light is the principal limiting factor for seagrass growth in the Cockburn Sound area. It is possible therefore, that the increase in turbidity has an impact on the seagrass meadows.

The aims of the present study were:

1. (a) To determine the current status of the seagrass meadows and whether or not their conservation can be justified.
    (b) To provide useful baseline data for future monitoring.
2. To investigate the extent of the decline of the seagrass surrounding the sand washing jetty and identify possible causes.

METHODS

An aerial photograph of the area, taken in 1980 of the scale of 1:25 000 was enlarged to the scale of 1: 5 000 to enable a detailed plan of the seagrass distribution to be drawn. Categories based on seagrass species and density were designated. Field verification along transects (T1, T2, T3) was carried out using an underwater sled (manta board) which was towed behind a boat. The sled was manned by a diver using SCUBA. A sheet of waterproof paper was taped to the board to enable notes to be taken regarding seagrass species and densities. This information could then be combined with the information taken from aerial photographs and a map prepared showing seagrass distribution.

The following sequence of aerial photographs of the area was obtained.

1965 - scale 1:15 840
- Before sand mining operations had started and prior to the existence of Wapet Groyne.

1972 - scale 1:25 000
- During plant construction, the jetty had been built and dredging had started.

1975 - scale 1:5 000
- After three years of operation with waste disposal directly onto the beach in front of the plant.

1978 - scale 1:25 000
- The year of changeover to the current method of disposal (after hole had been dredged).

1980 - scale 1:25 000 and 1: 5 000
- The most recent photograph available, showing the results of two years of the existing waste disposal method.

The seagrass distribution was traced from each of the photographs. The area of seagrass meadows from each photograph was estimated using a computerised digitiser. It was then possible to follow the seagrass deterioration in connection with the development on the plant and the two disposal systems.

RESULTS AND DISCUSSION

Seagrass meadows on the north eastern section of Parmelia Bank were categorised as follows:

Category 1 represented continuous meadows of *P. australis* and *P. sinuosa*. These meadows, although relatively healthy and with a shoot density comparable with healthy seagrass meadows elsewhere, showed a marked reduction in leaf canopy.

Category 1a - as above with traces of *Amphibolis* sp.

Category 2 - represented *Posidonia* meadows (as described in category 1) with crescent shaped sand patches; a natural phenomenon resulting from water movement and sand accretion.

Category 3 represented meadows of *Posidonia* which appeared to be under stress not only was the leaf canopy diminished but the shoot density appeared to have been reduced by at least 30%.

Category 4 represented areas where fibre mats and algae were all that remained of the seagrass bed.

The 1965 photograph showed that the seagrass meadows covered the whole of the study area, which represented approximately 65 ha of seagrass meadow. Table 1 shows the area covered by seagrasses calculated from the photographs.

TABLE 1

AREA COVERED BY SEAGRASS FROM 1965 TO 1980 ON THE NORTH EASTERN SECTION OF PARMELIA BANK

Year	Seagrass area (ha)	Area dredged (ha) for navigation channels (progressive total)	Comments
1965	65.2 ± 0.6	nil	
1972	59.3 ± 0.5	3.7 ± 0.1	The remaining 2.2 ha appeared to have been stripped during dredging operations
1975	55.5 ± 0.5	4.4 ± 0.1	0.5 ha of 4.4 ha was caused by excavation of the James Matthews wreck by Museum
1978	50.2 ± 0.4	6.4 ± 0.1	
1980	46.3 ± 0.4	6.4 ± 0.1	A total of 5.1 ha (includes 2.2 ha of 1972) of seagrass appears to have been stripped during dredging

The table shows that in 1980 there were about 19 ha less seagrass than in 1965. Of this about 6.4 ha had been dredged for navigation channels of the sand washing operations. A further 5.1 ha appeared to have been stripped during the dredging operations. No other reason for its rapid disappearance was apparent. A decline in the health of seagrass was also observed.

Figure 1 shows the distribution of seagrass in 1980. It indicates relatively healthy seagrass meadows (Categories 1 and 2) and those showing signs of deterioration (shoot density and leaf canopy declining, Category 3). Figure 1 also shows the distribution of seagrass meadows in 1972, while the sand washing plant was under construction.

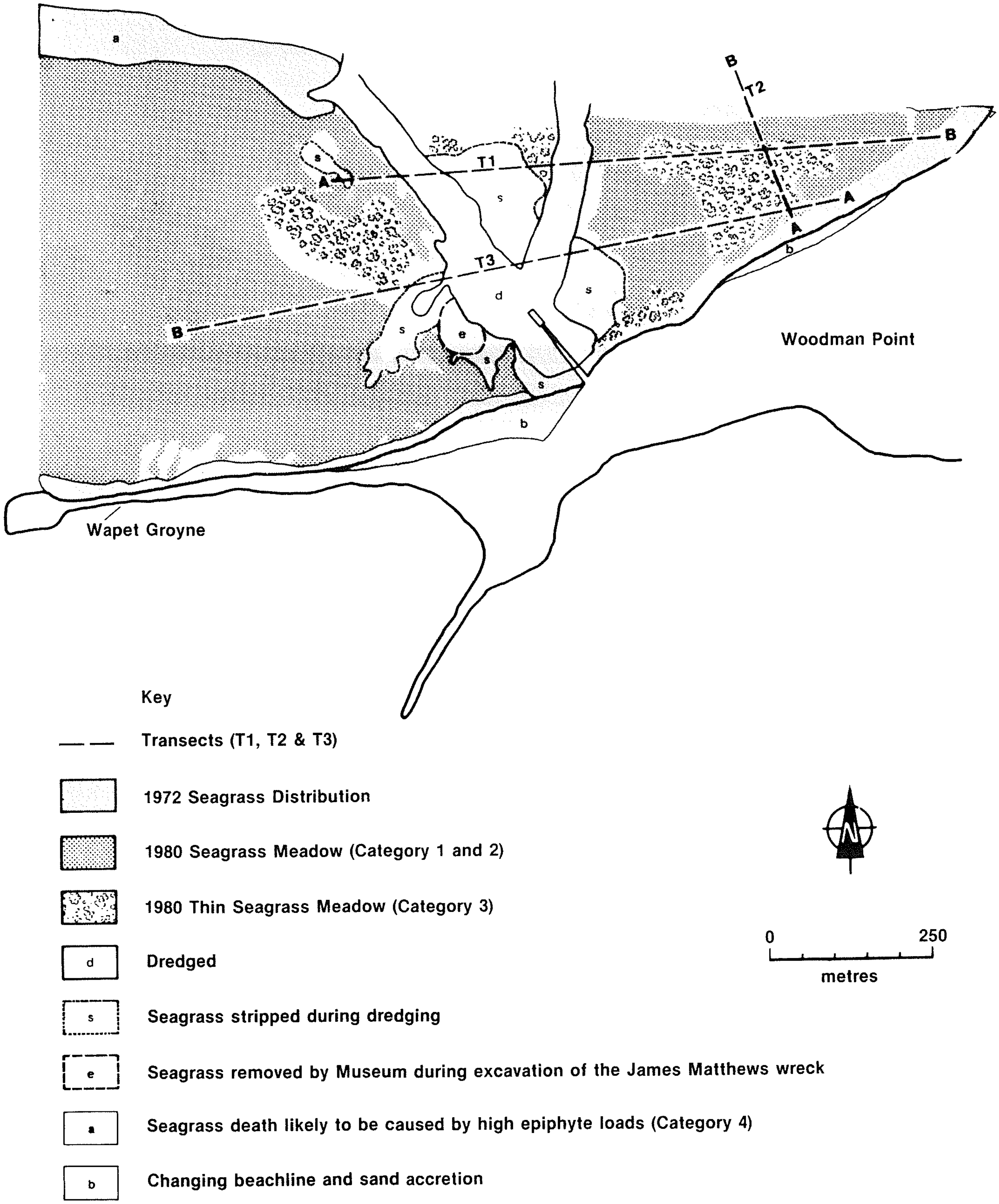

Figure. 1 Seagrass distribution on the north eastern section of Parmelia Bank.

Both Figure 1 and Table 1 show that a proportion, 11.5 ha (approximately 60%) of the seagrass loss was caused by the dredging operations. The death of the remaining 40% and the deterioration of seagrass quality (Figure 1) suggests the presence of some form of stress on the plants.

A marked change in beachline resulting from sand accretion occurred between 1965 and 1980. This could explain part of the disappearance of seagrass (section b in Figure 1) amounting to approximately 2.5 ha of seagrass meadows.

In Cambridge (1979) and Silberstein (1980) large scale seagrass deterioration has been attributed to light stress from heavy epiphyte growth. The epiphyte growth is stimulated by high nutrient levels in the water. This could explain the death of seagrass in section a in Figure 1, which represents a further 2.5 ha. The section of the bank adjacent to the eastern side of the sand washing jetty, is sheltered from the high nutrient waters of Cockburn Sound by the Wapet Groyne. Therefore epiphytes were unlikely to be the cause of the decline on that section of the bank. This was substantiated by field surveys which showed that epiphytic growth was not excessive. Light was, however, the most likely limiting growth factor (Cambridge, 1979) and it is logical to suggest that the high turbidity of the water was responsible for causing light stress on the seagrass meadows. Monitoring of light attenuation coefficients would be necessary to quantify this factor.

It is relevant here to list the series of events resulting from light stress on seagrass in other areas of Cockburn Sound.

- reduction of light available to the seagrass leaves;

- a greater proportion of fixed energy was then required for maintenance and less for growth and reproduction of seagrass;

- as stored reserves in the Posidonia rhizomes were used, the number of shoots declined and the leaf canopy thinned;

- with the thinning of the leaf canopy the seagrass meadows became more vulnerable to other factors such as storm damage and grazing by sea urchins, ultimately leading to the widespread death of seagrass (Cambridge, 1979).

Although widespread death has not occurred in the present study area, the early stages of leaf canopy thinning and shoot density decline, have been observed. Under the present conditions of high turbidity, the deterioration is likely to continue. If these seagrass beds are to be saved it will be necessary to reduce the turbidity.

The meadows west of the sand washing jetty are a popular site for fishing and if the seagrass is allowed to deteriorate completely, the fish population will decline rapidly. The death of the seagrass would also add to the already high turbidity of the water and the sediment would become less stable.

CONCLUSION

The seagrass meadows of the study area are showing signs of decay - the leaf canopy appears to be diminishing and in some areas the shoot density is declining. Since the sand washing plant started operating in 1972, approximately 19 ha of the original seagrass meadows have disappeared.

Approximately 60% (11.5 ha) of this 19 ha was caused by the dredging and stripping of seagrass associated with the approach channels to the sand washing plant. Of the remaining 40%, about 2 ha are in the vicinity of the jetty as are the sections of the meadows which are showing signs of deterioration (Figure 1). The most likely cause for the seagrass decline is the reduction in light reaching the seagrass beds, owing to high turbidity of the water.

The seagrass meadows are not beyond saving and if the turbidity of the water in this area was reduced then it is likely that the seagrass meadows will re-establish themselves in the non-dredged areas. If the seagrass meadows are allowed to deteriorate further, not only will the area be less useful or desirable for recreational purposes, but the instability of the sediment may contribute to erosion problems resulting in changes to the present beachline. The conclusions reached in this study were based on detailed examination of aerial photography and limited field verification. A more accurate assessment of seagrass decline in this area would require more detailed field work. Notwithstanding the above comment, it is considered that the findings are valid.

REFERENCES

Cambridge, M. 1979. Cockburn Sound Environmental Study Technical Report on Seagrass. Report No. 7. (Department of Conservation and Environment, Western Australia)

Silberstein, K. 1980. The Effects of Epiphytes on Seagrasses. M.Sc. Preliminary Thesis submitted to Botany Department, University of Western Australia.