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COCKBURN SOUND ENVIRONMENTAL STUDY

TECHNICAL REPORT ON SEAGRASS

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FOREWORD

Cockburn Sound began its development as the outer harbour for the Perth-Fremantle area in the 1950's. Since then a major industrial complex has been built up on the eastern shores. Wastewater from several industries and from a major sewage treatment plant is discharged directly into the Sound's waters. A naval facility has been established on Garden Island, which is now linked with the mainland by a causeway, whose construction was completed in 1973.

The industrial area has continued to expand and the Sound's waters are used increasingly for recreation and fishing by both commercial and amateur fishermen.

Concern for deterioration of the marine environment and the building of the causeway led to a series of baseline studies carried out between 1970 and 1975 on the ecology, hydrology and beach morphology of Cockburn Sound. Early in 1975 the Environmental Protection Authority let a contract to a consultant to make a comprehensive review of these studies to identify problems, to propose approaches to solutions and to point out aspects requiring further research. After the review had been considered by the Environmental Protection Authority and the Conservation and Environment Council, the Western Australian Government allocated $500,000 for a three year (1976-1979) environmental study.

As approved by Cabinet, the objective of the environmental study of Cockburn Sound was to obtain the information necessary to manage the Sound for multipurpose use, accommodating recreational and fishing activities as well as use for port and industry.

The Cockburn Sound Study Group, a core group of professional and technical personnel, was established in November, 1976. The major aspects requiring investigation were identified and designated as segments of the overall study. Work on the segments was carried out by members of the Study Group and by consultants, government departments and universities.

This report covers the work of one of these segments. The conclusions and recommendations presented here relate specifically to the work of this segment. They do not necessarily reflect the conclusions or management proposals detailed in the overview Cockburn Sound Study Report, which has drawn from all segment reports.

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SUMMARY OF RESULTS AND CONCLUSIONS

Scale of Seagrass Depletion

Before industrial development began on the eastern shore of Cockburn Sound in 1954, seagrass meadows occupied about 4 000 hectares of the sand banks rimming the deep basin of the Sound extending down the sand slopes to a depth of some 10-12 metres. At present (1979) only about 900 hectares remain, mostly along the Garden Island shore and across the northern boundary, Parmelia Bank, although in this area seagrasses are no longer present at depths greater than 5-6 metres. Thus only 22 per cent of the original meadows persist. The original 4 000 hectares of seagrass meadows are estimated to have produced about 23 000 tonnes of leaf material each year, projected from an average rate of production of 5-6 tonnes per hectare per year. The average production rate over the 900 hectares present today is about 3-5 tonnes per hectare per year giving a total of some 4 000 tonnes of leaf material per year. This is a sixfold reduction in seagrass production in 25 years.

Pattern of Deterioration

The first stage in establishing the hypothesis to account for decline of the seagrasses was to examine the pattern and time of deterioration from aerial photographs. Although incomplete these provide a valuable record of the progressive deterioration.

Initial loss occurred over an area of four hectares between 1961 and 1963 on James Point. There were no major losses close inshore on the eastern fringing banks before the end of 1967. It is known that the start of the major dieback south of James Point was between 1967 and 1969. Dieback on the Eastern Shelf occurred sometime between 1960 and 1976. More specific dates cannot be given because of the inadequate photographic records.

Early in 1971, construction began of a 3 000 meter long, rockfill causeway across Southern Flats, the shallow southern opening to Cockburn Sound, and this was completed by early 1973. The causeway is breached by bridges at two points and the relatively high velocity of flow through these resulted in localised scouring within a year of completion. By 1976, of the 550 hectares of seagrass that were present on Southern Flats in 1970, about half were dead or showing reduced vigour. Much of the remaining meadow was patchy, invaded by mussels or carrying heavy epiphytic algal growths. This widespread deterioration could not be attributed to scouring action.

During the period 1972-1976, all but a few small patches of seagrass disappeared from the wide fringing meadow extending from Rockingham to the present site of the CBH grain terminal, and from the narrow meadow on the steep sand slopes of Careening Bay. Much of the seagrass south of Woodman Point and on Parmelia Bank, north of the sewage outfall, also died or was depleted.

The model to explain the decline in seagrass must take into account this pattern of deterioration: first localised around the BP oil refinery outfall, then extending north from the CSBP/KNC outfall, then south from this point, and with major southern deterioration occurring along the Rockingham foreshore, Southern Flats and in Careening Bay following construction of the Causeway.

SUMMARY OF RESULTS AND CONCLUSIONS (Cont'd)

Factors Producing Localised Loss of Seagrass

A number of activities including construction of groynes and breakwaters, dredging and the dumping of dredge spoil have been observed to lead to localised depletion of seagrass; for example, at Careening and Sulphur Bay, Parmelia Bank and Woodman Point, adjacent to the oil rig construction site at Jervoise Bay, at James Point owing to the dredging of Stirling Channel and scouring on Southern Flats associated with the Causeway bridges.

Grazing by dense populations of a sea urchin was found to be associated with localised destruction of seagrass meadows north of Rockingham. However, there is no evidence that this outbreak was widespread or played any part in the general decline of seagrasses.

The release of industrial discharge may also be implicated in the death of seagrass by the introduction of toxins. Aquarium trials showed that the BP oil refinery effluent was toxic to seagrasses, but in the time span of the trials only at concentrations considerably in excess of those likely to be found even a short distance from the outfall. However, during rare calms when dilution and mixing of the effluent would be minimal, relatively undiluted effluent could drift some distance. Although long term exposure to low concentrations may well inhibit seagrass growth, especially by pollutants accumulated in sediment, toxicity alone is unlikely to have caused elimination of seagrass from the entire eastern shore; other factors must be invoked. On the other hand, it is reasonable to attribute death localised around the BP oil refinery outfall to toxic effects.

Thermal pollution can be discounted as a possible cause of seagrass depletion. Warm water discharged from cooling systems tends to float on top of the colder seawater and is dispersed rapidly, so that even during calms the influence of warm water immediately above the substrate is measurable only within a short distance of the outfalls.

This is true also of freshwater discharge to the Sound. Freshwater, in addition to that which falls as rain or is added as groundwater, enters the Sound only from stormwater runoff and through drains discharging into the nearshore. If not mixed by wind and wave action freshwater floats above salt water and is unlikely to have more than very limited local influence on the plants.

Shading by Phytoplankton

Enrichment of the water of Cockburn Sound by plant nutrients, phosphorus and nitrogen, and the consequent increase in phytoplankton has been documented by Chiffings, 1979 (16). The waters now always have a higher density of phytoplankton than both the open ocean and the semi-enclosed bay of Warnbro Sound. Reduction of water transparency and shading to a point where benthic plants are unable to persist has been recorded frequently in the literature on eutrophication of lakes and estuaries. The reduction of light by the water column (light attenuation) averaged over Cockburn Sound was consistently higher than the open ocean, and higher than Warnbro Sound during summer, the season of maximum growth in *Posidonia*. Shading by phytoplankton is only sufficient to account for recession of the seagrass meadows from deeper water; from a depth of 10 metres to less than 5 metres. It is not sufficient to explain loss of the meadows once present in depths less than 5 metres.

SUMMARY OF RESULTS AND CONCLUSIONS (Cont'd)

Excessive Epiphyte Growth

There is, however, another method by which shading may reduce photosynthesis of plants in shallow water, and that is the presence of epiphytes (i.e. attached algae).

Heavy growths of epiphytic algae were consistently observed in seagrass meadows in Cockburn Sound during the investigation. Sporodic accumulations of filamentous algae blanketing the substrate like billowing clouds have also been observed. This was in contrast with the absence of blanketing algae and relatively sparse cover of epiphytes on leaves of seagrasses in Warnbro Sound. Thick mats of filamentous algae or epiphytes also developed rapidly on transplanted seagrass and underwater equipment placed along the eastern shore. During transplant trials, plants in Cockburn Sound rapidly acquired a thick cover of epiphytes and growth was greatly depressed as compared with control transplants in Warnbro Sound. This excessive growth of epiphytes is attributed to nutrient enrichment of the water and is considered to be the major factor causing depletion of seagrass meadows in shallow water.

Other factors may have contributed indirectly to the deterioration of the meadows once a thinning or patchiness occurred in them. The most notable of these was the reduction in the capacity of meadows to act as sediment traps, so that sand was winnowed out by wave action from around the bases of the seagrass plants thus further reducing vigour, and providing a fibrous substrate for mussel settlement.

Geological History of Cockburn Sound

In examining causes of widespread death, the stage of geomorphic evolution must be considered, particularly in view of comments in the report on sedimentology of Cockburn Sound (France, 1978 (21)).

The major building phase of Cockburn Sound is thought to have neared completion some 1-2 000 years ago, following the Holocene rise and then a slight fall in sea level combined with transport of sediment north into the Sound before closure of the southern end by sediment ridges linking Point Peron to the mainland. Once this sediment supply to the fringing banks ceased, bank-building was restricted to extension of Southern Flats into the southern basin of the Sound, where most of the sediment from external sources was trapped. More limited bank growth continued on Parmelia Bank.

Sediment Accretion and Seagrass Growth

Continued accretion of sediment is the key to vigorous growth of *Posidonia* species which dominate the submarine meadows of Cockburn Sound; a consequence of the nature of growth of the vigorous underground stems (rhizomes). But while *P. australis* and *P. ostenfeldii* only flourish in areas where the accretion rate is high, *P. sinuosa* tolerates far less sediment accretion and even develops a growth pattern of elevated rows separated by sediment depressions in response to the limited sediment supply. With low sediment supply growth is slower but a dense meadow produces seeds and spreads rapidly to fill any small space created artifically providing the bare substrate is not eroded.

Sediment Accretion and Seagrass Growth (Cont'd)

However, changes caused by the reduced sediment input may occur over a longer time scale and there would have been time for *Posidonia* to be replaced by other seagrasses, such as *Amphibolis* or a *Halophila-Heterozostera* community, on the relatively sheltered fringing bank. These plants do not require continuous sediment accretion, but they do not seem to compete well with any established and vigorous *Posidonia* meadow. On the other hand, even changes that result from a major construction, such as a groyne, lead eventually to a new equilibrium and colonisation of the new sediment substrate.

Thus, although some species of seagrass would be less favoured by Cockburn Sound reaching its geomorphic end point, this static condition is not adequate to account for the rapid degradation of the seagrass meadows which occurred progressively, first on the eastern shore and then on Southern Flats and Parmelia Bank.

Conclusion

The start of major dieback between 1967 and 1969 south of James Point corresponds with the initial release of effluent rich in nutrients from Kwinana Nitrogen Company (KNC). Enrichment of the waters by nutrients resulted in excessive growth of epiphytic algae which lead to the deterioration of *Posidonia*. Effluent from KNC added large quantities of nitrogen compounds into the nearshore zone, an area of restricted circulation over the shallow banks. The dieback spread first north from the KNC outfall and was plainly visible in 1969 photographs about one year after the outfall began discharging, then south in subsequent years. It is considered that dieback on the Eastern Shelf could have occurred in a similar way, although the timing is less clear.

Excessive dieback on Southern Flats is attributed to a combination of the nutrient enrichment from industrial sources and reduced water exchange across the Southern Flats meadows with construction of the Causeway.

On Parmelia Bank a similar dieback is apparent in the zone of influence of the sewage outfall, from which effluent rich in nutrients has been discharged since 1966 by the Woodman Point Treatment Plant.

When sites of decline are related to prevailing patterns of water circulation, sites, such as the eastern shore of Garden Island and western sections of Parmelia Bank, which receive regular intrusions of oceanic water still have healthy meadows of seagrass, whereas areas in which nutrients accumulate as a result of development of gyres or poor circulation on shallow banks correspond to areas of seagrass depletion. It is concluded while disturbances including dredging, scouring, release of heated or toxic effluents, may have resulted in localised loss of seagrass it has been the release of nutrient rich effluents which has promoted the growth of algal epiphytes which shade the leaves and primarily lead to the widespread death of the seagrass.

The conclusion that nitrogen is the effluent component which has been particularly important in the seagrass decline rests on circumstantial evidence: the temporal pattern of decline, the work of Chiffings, 1979 (16) on phytoplankton and data from the literature shows that larger algae are nitrogen limited. From this it is inferred that the growth of epiphytes is nitrogen limited. If nutrients, particularly nitrogen, continue to build up in the water column, the dieback can be expected to continue.

SUMMARY OF RESULTS AND CONCLUSIONS (Cont'd)

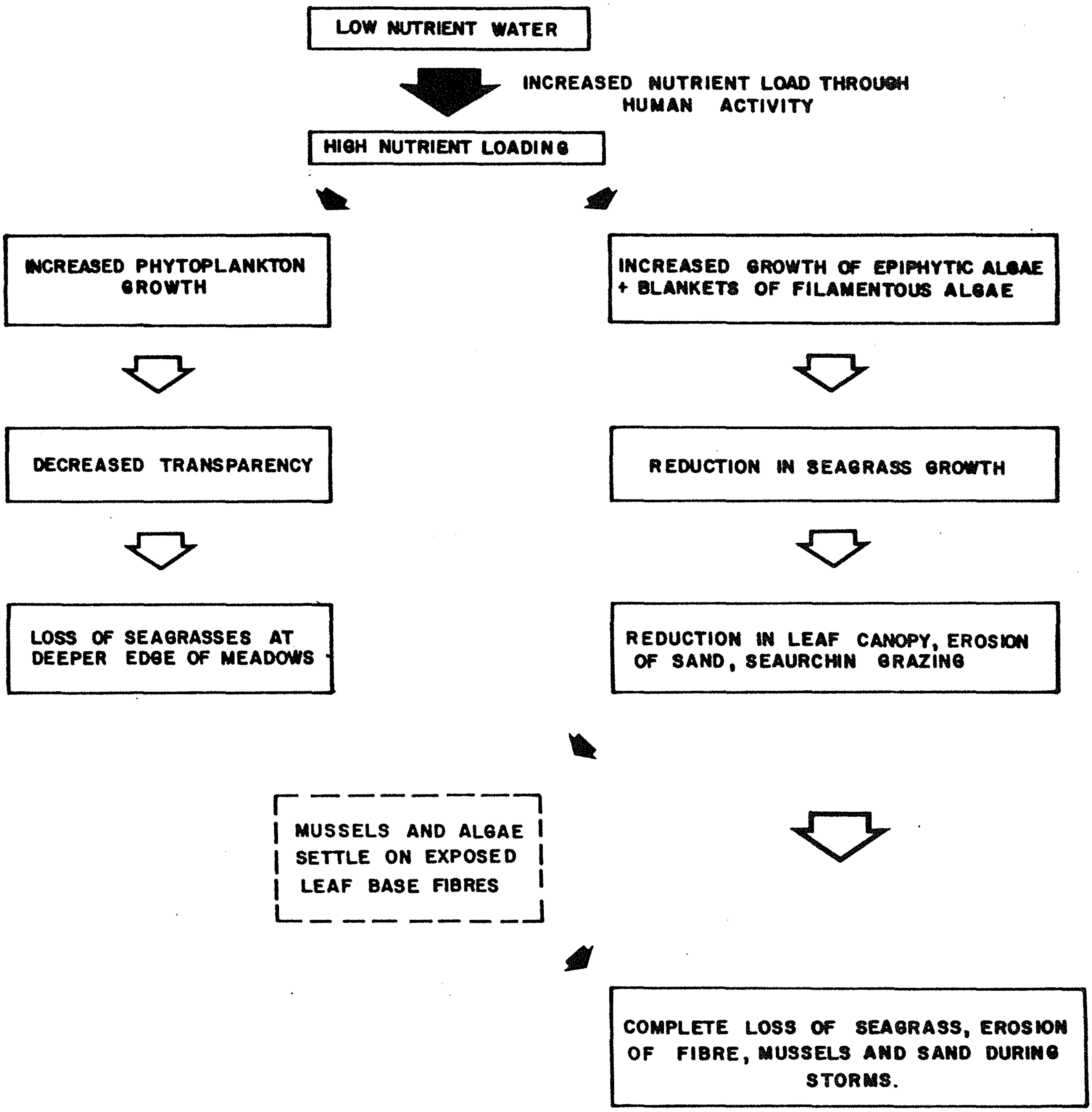
Conclusions (Cont'd)

The biological importance of seagrasses lies in their production of plant matter using inorganic substances and energy from the sun, their provision of substrate for the settlement of algae, animals and microbes on the leaves, their provision of cover for fauna and in slowing water movement resulting in trapping of detritus and the formation of a more stable sand substrate. Their geomorphic importance lies in trapping and binding sediments and diminishing wave energy impinging upon bank and beach sediments. Every effort should therefore be made to ensure the survival of the remaining 22 per cent of the meadows in Cockburn Sound.

The re-establishment of seagrass, either naturally or artificially is unlikely to succeed until water quality improves by reduction of available nitrogen. Conditions of sedimentation are probably unsuitable for the natural recolonisation of the *Posidonia* meadows although other seagrass species could be expected to vegetate the banks. Further investigation on colonisation by southern Australian seagrasses would be needed to detail the species likely to colonise the denuded banks.

The model to account for the major death of seagrass arises from field observations on deteriorating seagrass and transplant studies, the pattern of deterioration and timing of effluent release and from accounts of deterioration of water plants from eutrophied areas given in the scientific literature.
It is recommended that further work be carried out to quantify the relationship between available nutrients, excessive growth of epiphytes and the response of the seagrass to shading by epiphytes. This would be necessary if steps are not taken to considerably reduce nutrient input to the Sound.

MODEL: LOSS OF SEAGRASS IN COCKBURN SOUND



1. INTRODUCTION

1.1 The Problem

Seagrass meadows regresss naturally when subjected to adverse conditions, such as local shoaling, high rates of sediment accretion, turbidity, and physical disturbances but during the past 20 years the seagrass meadows of Cockburn Sound have receded rapidly. This recession first became evident on the eastern shore between 1961 and 1963 and has subsequently extended many kilometres along the eastern sublittoral platforms. More recently, meadows on the Southern Flats area have also regressed. The present enquiry documents this death of the seagrass meadows and seeks to understand its cause and some of the effects. The objectives of the study were as follows:

- Measurement of the present distribution of seagrasses within the Sound, in order to compare with that prior to industrial development.
- Determination of whether the seagrasses continue to recede.
- Research under controlled conditions designed to identify specific causes of the decline of the seagrass.
- Studies (jointly with other workers) upon the effects of loss of seagrass (a) biologically and (b) mechanically.
- Assessment of the environmental conditions necessary if seagrasses were to be re-established in the now denuded areas.

1.2 Seagrasses

One of the world's richest seagrass floras is to be found on the temperate Western Australian coast where 15 species of seagrass, marine flowering plants of the families Potamogetonaceae and Hydrocharitaceae, occur between 25°S and 35°S; their distribution limited to the north by tropical coral reefs and to the south-east by the cliffs on the Great Australian Bight. Here seagrasses have been found to depths of 40 m in clear waters but the extensive marine meadows growing in the lee of the reefs and semi-sheltered marine embayments dominated by species of *Posidonia* and *Amphibolis* are usually found only to depths of 10-15 m and occasionally 20 m.

All seagrasses are rhizomatous plants, depending upon extension and branching of the rhizome for their expansion in area and generation of new actively growing tissue (Tomlinson, 1974 (76)). In *Posidonia* spp., the dominant seagrasses in Cockburn Sound, the plant is organised into several discrete entities; the rhizome, a fibrous, starchy, branching underground stem bearing semicircular scars from old leaves which divide the rhizome into a series of internodes of varying lengths; the roots, fibrous and much branched, which serve to anchor the plant and absorb nutrients; the growing tip or meristem borne at the apex of the rhizome where new rhizome and leaf tissues are continuously produced; the leaf bases, colourless fibrous sheaths wrapping around the growing tip protecting the young tissue; the leaves, long and straplike containing the green pigments for photosynthesis and a vascular system for transporting nutrients manufactured or absorbed by the leaves to the underground parts (Kuo and Cambridge, 1978 (40)).

Although *Posidonia* spp. produce seeds regularly and seedlings are common, the meadows persist as dense stands of underwater vegetation only as a result of continued rhizome growth and branching to maintain or initiate

1.2 (Cont'd)
the growth points at the rhizome apices; in this way the leaf density relates directly to the number of rhizome apices per unit area.

Posidonia and *Amphibolis* are noteworthy for their ability to colonise sandy substrates and to develop a dense leaf canopy over what was previously bare sand. In the protection thus provided from waves and shifting sand there develops a rich community which includes an epiphytic community, sheltered benthos and abundant juvenile and small fish.

The elements, dynamics and distribution of seagrass communities of the temperate Western Australian coast were poorly known at the commencement of this study. Investigations concurrent with the Cockburn Sound seagrass studies are continuing upon the taxonomy of the genus *Posidonia*, as well as the nature and processes acting upon seagrass communities of south western Australia, thus enabling the Cockburn Sound seagrass to be viewed within their regional context.

Two species of *Posidonia* co-exist in the sublittoral of Cockburn Sound. Although similar in appearance they can be distinguished by vegetative morphology (Cambridge and Kuo, 1979 (13)), the most obvious difference being a discontinuity in the width of the strap-like leaves.

Posidonia australis has wide leaves (10-15 mm) and favours areas where sediment is accreting. *Posidonia sinuosa* has narrow leaves (7-9 mm) and shows maximum development in areas where sediment accretion is much less.

The two species display clear-cut preferences in habitat, particularly with respect to the sediment supply, which are important in the succession of the seagrass meadow and bank development.

Under conditions of limited sediment supply and a prevailing wave direction, *P. sinuosa* has a linear growth pattern with rows of tightly packed shoot apices interspersed by shallow sand gutters. When viewed from above the seagrass has the appearance of a grain field sown in regular furrows. The width of the vegetated rows and gutters varies according to the sand supply usually 30-40 cm wide but the orientation is always in the direction of the prevailing wave trains. The sandy gutters do not seem to be static; the fibrous remains of *P. sinuosa* can usually be found a few centimetres below the sand. The larger scale pattern of the rows is similar to that developed in longitudinal sand ribbons with the rows anastomosing or dividing after a distance.

This growth pattern differs from a pure stand of *P. australis* which favours conditions of higher sand supply. The shoots tend to be evenly spread through the stand or with gradual changes in density.

In Cockburn Sound, *P. sinuosa* forms almost pure stands with a linear growth pattern on the fringing and barrier banks with very little sediment accretion: *P. australis* forms almost pure stands on the much smaller areas of high sediment accretion on spits and the margin of the meadow adjacent to the beach. This distribution of species related to local availability of sediment is present on the Garden Island fringing bank and was present on the eastern bank from Rockingham to James Point before the loss of seagrass meadows in recent years.

P. sinuosa was the most common species forming extensive monospecific communities on the sheltered peripheral sand platforms with only localised occurrences of *P. australis*.

1.2 (Cont'd)

Other species such as *Heterozostera tasmanica, Halophila ovalis* and occasionally *Amphibolis antarctica* were found only at the upper and lower borders of the *Posidonia* meadows. *Halophila decipiens* has recently been found at one location in Cockburn Sound beyond the lower limit of the *Posidonia* meadow. A greater diversity of species is present on Parmelia Bank (Figure 1.1), the northern barrier bank of Cockburn Sound. Here wave energy is diminished as the westerly swell trains move across the sand bank and a wider range of micro-habitats occur. *P. ostenfeldii* and *Amphibolis* spp. are dominant at the more exposed western zone giving way to *P. sinuosa* meadows. A number of small seagrasses occur grouped around or amongst the dominant stands of *Posidonia* spp. and *Amphibolis* spp. colonising spaces created by loss of the larger species during storms or sheltering beneath their leaf canopies. They include species such as *Heterozostera tasmanica, Halophila ovalis* and *Syringodium isoetifolium.*

The elements of seagrass communities in the sheltered and more exposed sand platforms of Cockburn Sound may be summarised as follows:-

Semi sheltered platforms and barrier banks -

Major *P. sinuosa* Cambridge *et* Kuo
P. australis Hook. *f.*

Minor *Heterozostera tasmanica* (Martens ex Aschers.) Den Hartog
Halophila ovalis (R. Br.) Hook. *f.*
H. decipiens Ostenfeld
Syringodium isoetifolium (Aschers.) Dandy

Exposed barrier banks -

Major *Posidonia* sp. nov. aff. *P. ostenfeldii*
P. ostenfeldii Den Hartog
Amphibolis antarctica (Labill.) Sonder *et* Aschers.
A. griffithii (J.M. Black) Den Hartog

Minor *Heterozostera tasmanica* (Martens ex Aschers.) Den Hartog
Halophila ovalis R. Br. (Hook. *f.*)
Syringodium isoetifolium (Ascher.) Dandy

1.3 The Physical Environment of Cockburn Sound

Cockburn Sound (Figure 1.1) is a sheltered marine embayment on the south-western Australian coast at latitude 32°S. It is an elongate basin 16 km long and 9 km wide parallel to the coastline, lying east of the Pleistocene dune system of Garden Island. It occupies a former inter-dune depression inundated during the Holocene rise in sea level.

Marginal sediment platforms, which range in width from 50 m to 3 km encircle the central basin of the Sound. Beyond the sediment platform the bottom slopes steeply from a depth of about 8 m to the level muddy floor of the basin at 20 m. The sands of the platform were vegetated by dense seagrass communities, predominantly species of *Posidonia* between low water and depths of 10-12 m. The central basin floor consists of a layer of fine grey calcareous mud more than 5 m thick. These muds are thought to be derived from calcareous biota which have been winnowed from the seagrass areas by wave action. This basin is completely devoid of macrophytes but has a rich benthic fauna dominated by detritivores (Wells, 1978 (80)).

1.3 (Cont'd)

The waters of the Sound are marine, with salinity varying between 34-36^{o}/oo. The only freshwater entering the Sound is stormwater drainage and upwelling of groundwater. The Swan River discharges 10 km to the north but intrusion of water from this source is rare.

Tides have a daily range up to 0.6 m and are generally diurnal with one high water and one low water each 24 hours. Similar changes of water level are caused by meteorological and hydrological forces. Water level is generally about 0.3 m lower in summer than winter so that the lower littoral is exposed to air more frequently in summer than in winter (Hodgkin and Di Lollo, 1958 (31)).

Although the west coast is exposed to the full force of westerly cyclonic storms during winter and strong onshore breezes in summer, the waters of the Sound are sheltered. Protection is provided by Garden Island on its western boundary, and shallow sills at the northern and southern ends of the Sound; Parmelia Bank and Southern Flats respectively. These submarine sand banks are 2-5 m deep and were originally vegetated by seagrass. Westerly swells refracted through breaches in the Garden Island ridge are partially dissipated by Parmelia Bank, Southern Flats and the Garden Island Causeway.

Circulation of water over the shallow banks vegetated by seagrass meadows is generally restricted. Even in the deeper water, circulation is much less than that of an open coast and exchange of water across the northern and southern sills is small in terms of the overall volume of the Sound (Steedman, 1979 (71)). The volume of exchange across the shallow sills will affect the degree of dilution of the main volume of water and its pollutant load.

1.4 Development of Cockburn Sound

Before the establishment of the Kwinana industrial complex in 1954 Cockburn Sound was used mainly for recreational purposes and by professional fishermen.

The establishment of an oil refinery at James Point on the eastern shore of the Sound in 1955 initiated the zoning of other sections of the shore for an integrated industrial complex. As the industries developed, increasing quantities of effluents were discharged into the Sound.

Seawater coolants and process waters containing a wide spectrum of waste chemicals (Murphy, 1979 (52)) are released on or close to the beach, so that they pass over the shallows before reaching deep water. Contamination of water also occurs through accidental spillage of cargo during loading and unloading of ships.

Other human activities, in addition to those of industrial developments, include discharge of primary treated sewage into the northern end of the Sound since 1966, and construction of a rockfill causeway across the southern entrance of the Sound in 1971-73. This connects Garden Island to the mainland and is broken by two bridges, the trestle bridge of 305 m and the northern bridge of 610 m which allow limited exchange of water between Cockburn Sound and the ocean.

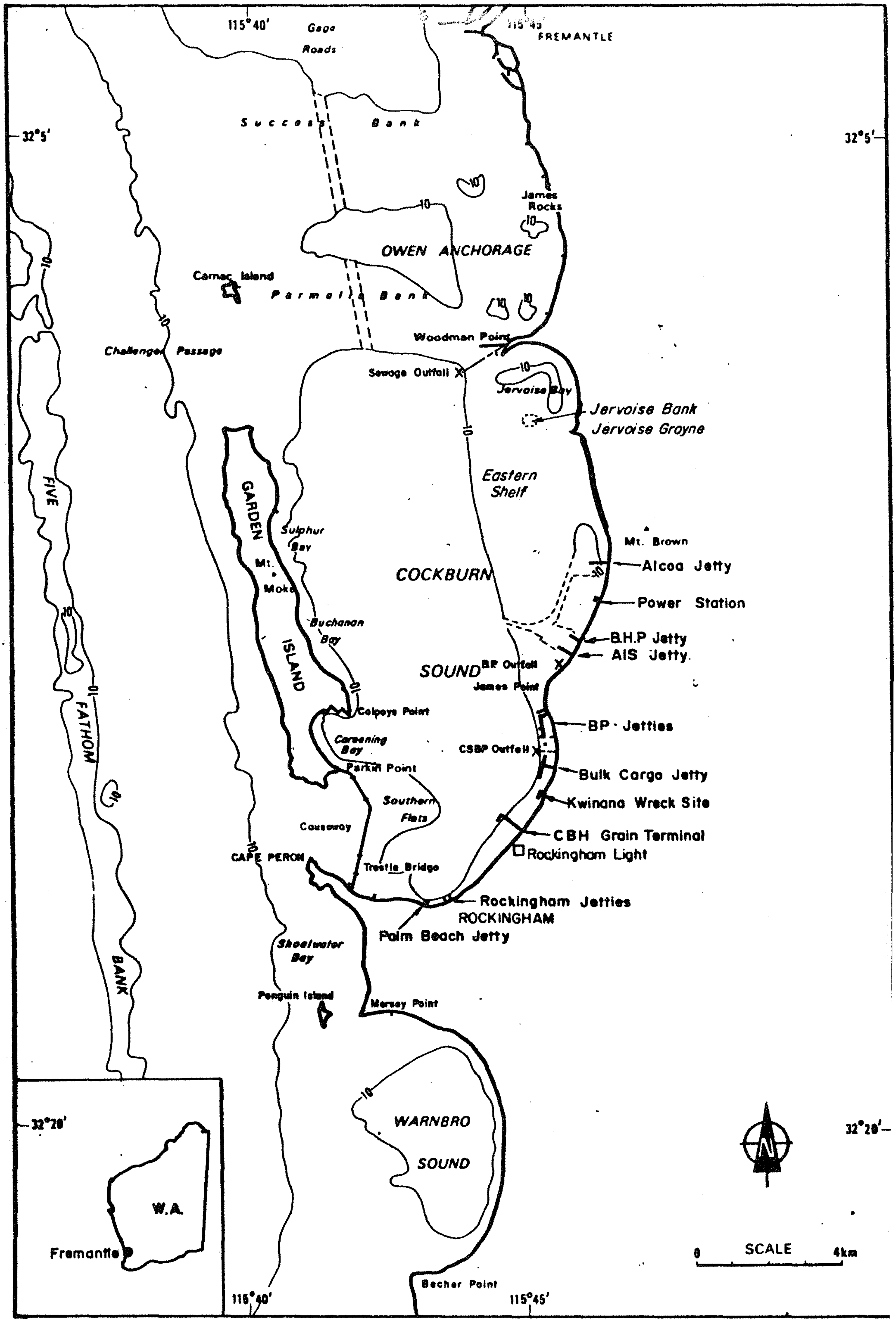


FIGURE 1.1

The study area

2. DETERMINATION OF THE PAST AND PRESENT DISTRIBUTION OF SEAGRASS

2.1 Photointerpretation

Surveys were made by diving using SCUBA equipment to examine the stages of deterioration ranging from a continuous meadow, through the development of patchiness to the final bare substrate thus allowing interpretation of aerial photographs. Aerial photographs, mostly black and white mosaics, covered only the eastern mainland of Cockburn Sound excluding the Eastern Shelf. The earliest complete mosaic of the eastern shore was prepared from aerial photographs taken in 1942 but, as underwater penetration was generally very poor, these were of limited use. The 1954 photographs had excellent water penetration enabling the original distribution of seagrass meadow before industrial development began to be plotted. Annual runs since 1954 to the present by the Western Australian Government Department of Lands and Surveys provided good coverage of the eastern shores. The quality was variable owing to sunflares and poor water penetration obscuring underwater detail, as the original purpose of the photographs was to record terrestrial features.

The Garden Island shore, Parmelia Bank and Southern Flats have been photographed less frequently than the eastern mainland shore. The distribution of the seagrass communities in these areas and along the eastern shore was recorded from sets of aerial photographs listed in Table 2.1.

2.2 Presence of Seagrass on the Eastern Shelf

In Cockburn Sound a rhizome mesh of varying thickness has formed beneath living *Posidonia* meadows as a result of upward growth of the fibrous rhizomes with continued sediment accumulation. Even with the death of the overlying seagrass, the partly decaying rhizomes, or in the longer term, the lignified fibres (Kuo and Cambridge, 1978 (40)) have remained either visible as a fibrous deposit raised above the general level of the substrate or buried beneath a layer of sand.

An investigation of fibre deposits was made for evidence of the existence of *Posidonia* meadows on the Eastern Shore of Cockburn Sound between James Point and Woodman Point, an area too far offshore to be included in the coastal photographic mosaic. Replicate cores of 3 cm diameter and 50 cm depth were taken on the Eastern Shelf (Figure 2.1.). Details of the sediment profile and a description of the seabed are given in Table 2.2.

Fibrous remains of rhizomes covered by varying depths of sand indicated the presence of the old seagrass meadow.

Wilson *et al* (1978 (87)) detail the findings of a survey by the Marine Group of the Western Australian Naturalist Club conducted between 1956-60. The seabed was reported as having a sparse cover of *Posidonia* and density varied with the mixture of substrates. These ranged from sand and shelly rubble to rock surfaces with sponges and living coral at an average depth of 5-10 m.

In view of the observations of Wilson *et al* and the similarity in depth substrates between the areas of coring and those over the entire Eastern Shelf it is concluded that seagrass meadows were present at least until 1960.

2.3 Calculation of Areas Vegetated by Seagrass

Aerial photographic mosaics were overlain by 5 mm or 10 mm square grids and the areas occupied by seagrass were counted and converted to hectares. The smaller grid facilitated counting where seagrass was patchy. Within

2.3 (Cont'd)
each grid square the density of seagrass was categorised on a one to ten scale, so that minimal coverage of seagrass was classified as ten per cent cover and the maximum coverage was classified as 100 per cent cover. Values for each square were then summed to calculate the area vegetated for a meadow and converted to hectares using a scale factor calculated for each set of photographs. This enabled photographs of different scales to be used to compare vegetated areas.

Figure 2.2 and 2.3 show the areas vegetated by seagrass meadows in 1954 and 1978 respectively, on the fringing and barrier banks of Cockburn Sound.

The map of the distribution of seagrass for 1954 is a composite, using aerial photographs from 1954 for the eastern coast, from 1967 for the Garden Island shore and 1970 for Southern Flats as there was no early photographic coverage of Cockburn Sound for areas other than the eastern shore. No photographic coverage exists with penetration of the waters adequate to show details of seagrass distribution along the Eastern Shelf. Records from the Western Australian Museum Survey (Wilson *et al*, 1978 (87)) as well as the presence of *Posidonia* rhizome mesh in sediment cores over the Eastern Shelf were used as evidence for the presence of *Posidonia*.

The areas vegetated by seagrass were as follows; 4 195 ha in 1954 and 889 ha in 1978. It is likely that *P. sinuosa* occupied most of these areas with localised occurrences of *P. australis* in 1954.

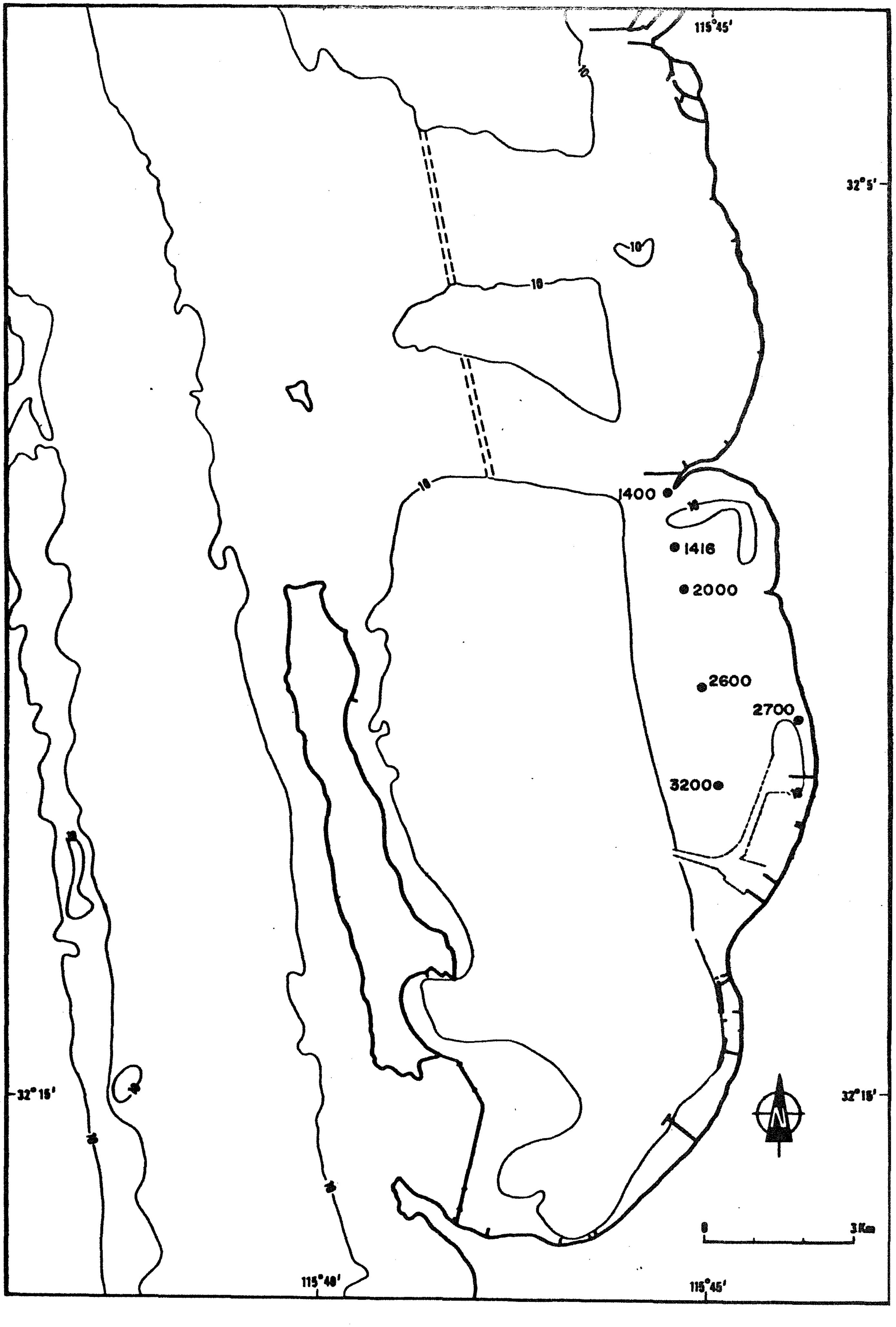


FIGURE 2.1

Sites of sediment cores containing remains of seagrass rhizome along the Eastern Shelf of Cockburn Sound

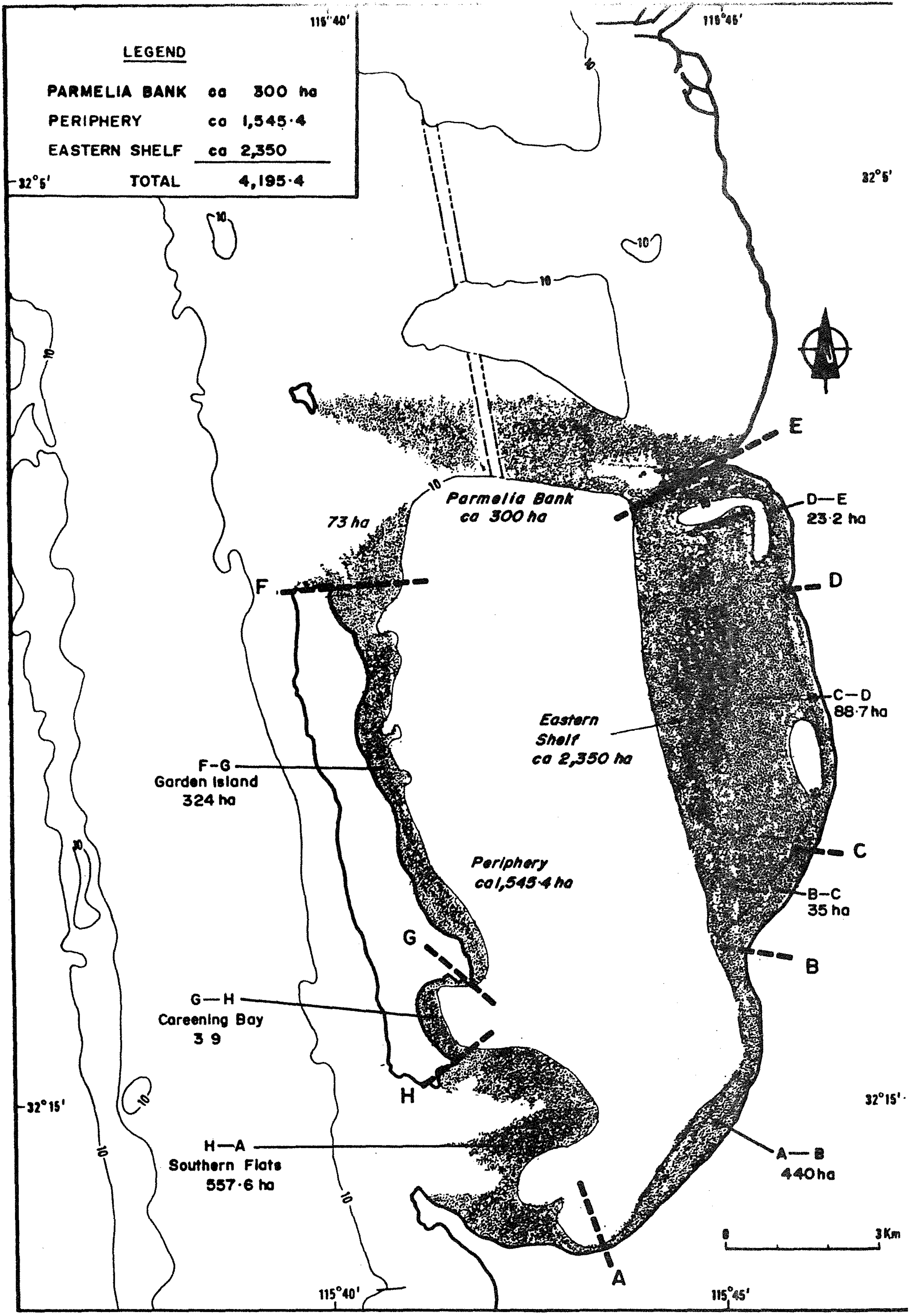


FIGURE 2.2

Diagrammatic representation of distribution of seagrass meadows in Cockburn Sound in 1954

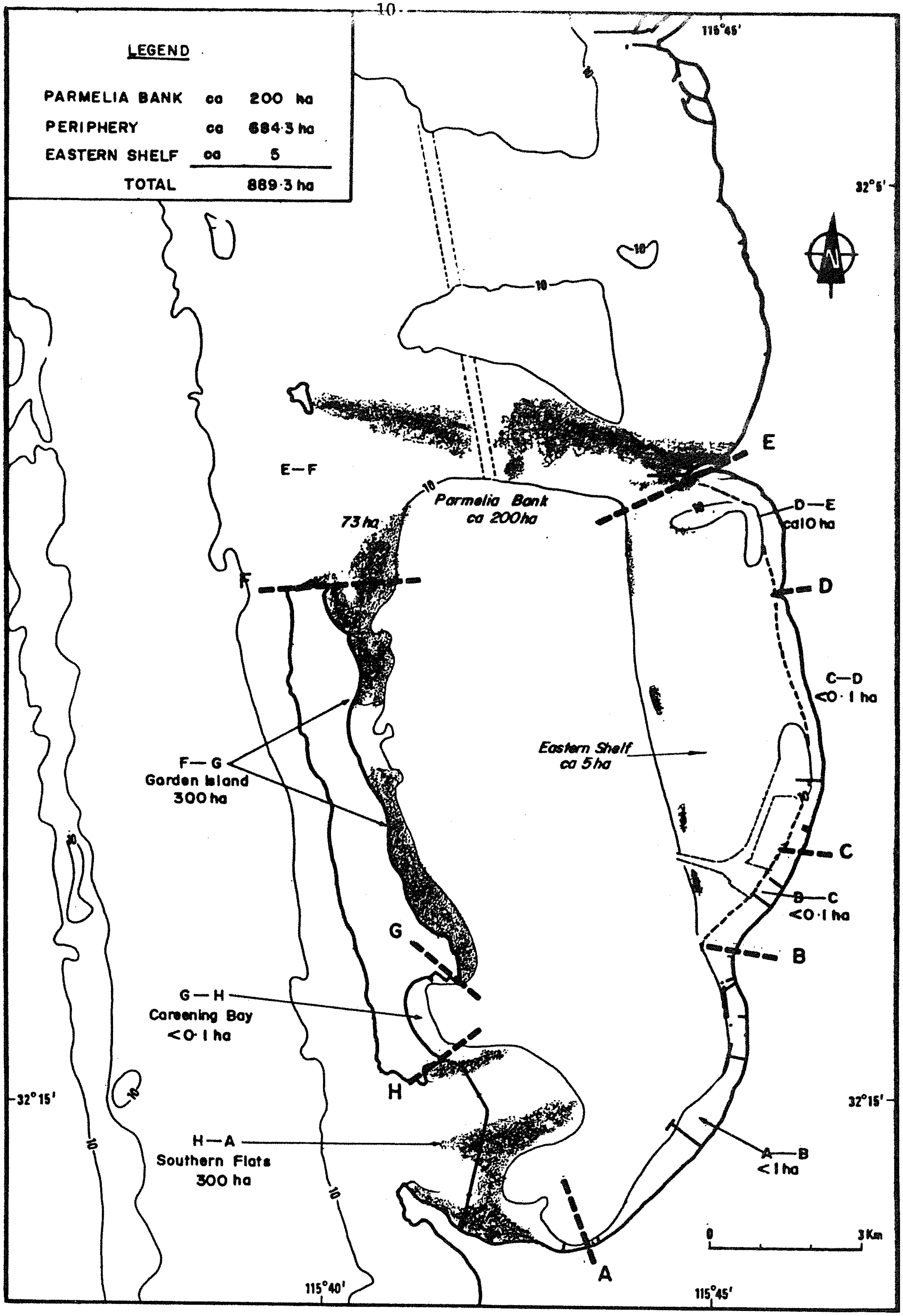


FIGURE 2.3

Diagrammatic representation of distribution of seagrass meadows in Cockburn Sound in 1978

TABLE 2.1

LIST OF AERIAL PHOTOGRAPHS EXAMINED FOR CHANGES IN SEAGRASS DISTRIBUTION 1954-1976

DATE	COLOUR	PROJECT NO.	APPROXIMATE SCALE
Eastern shore of Cockburn Sound			
29.12.1954	B/W	W.A. 154	1:16,000
24.10.1957	B/W	-	1:16,000
-.03.1958	B/W	-	1:14,500
04.03.1960	B/W	-	1:16,000
26.10.1960	B/W	-	1:16,000
23.10.1961	B/W	-	1:16,000
11.10.1962	B/W	W.A. 797	1:16,000
27.10.1963	B/W	W.A. 842	1:16,000
05.03.1964	B/W	-	1:16,000
13.12.1967	B/W	W.A.1039	1:16,000
28.10.1969	B/W	W.A.1199	1:16,000
11.10.1972	B/W	W.A.1417	1:15,840
03.12.1976	C	Seagrass Investigation W.A.1653(c)	1:10,000
Garden Island			
08.07.1967	B/W	Run, 1 W.A.1038	1:9,200
27.03.1973	B/W	W.A. 808	1:15,840 (Underwater detail inadequate for mapping)
14.12.1977	C	SO C96	1:4,000
14.12.1977	C	SO C96	1:12,000
Southern Flats			
12.08.1970	C	APSC 188	1:16,000
12.08.1970	C	APSC 188	1:4,800
03.12.1976	C	Seagrass Investigation W.A.1653(c)	1:10,000
Parmelia Bank			
03.12.1976	C	Seagrass Investigation W.A.1653(c)	1:10,000

TABLE 2.2

DESCRIPTION OF SEDIMENT CORES CONTAINING REMAINS OF SEAGRASS RHIZOMES
TAKEN FROM THE EASTERN SHELF, COCKBURN SOUND: 1977

STATION NUMBER AND DEPTH	CORE DEPTH	SEDIMENT PROFILE
1400 10 m	0 - 5 cm	Sand and rhizome with a thin layer of detritus
	5 - 13 cm	Sand/silt mixture
1416 10 m	0 - 5 cm	Thin layer of worm tubes and detritus fine sand layer
	5 - 12 cm	Sand/silt layer
	12 - 24 cm	Sand/seagrass rhizome material
2000 9 m	0 - 5 cm	Thin layer of detritus on sand
	5 - 15 cm	Sand/silt with shell fragments
	15 - 20 cm	Sand with rhizome material
2600 9 m	0 - 3 cm	Sand with detrital layer
	3 - 12 cm	Light-grey sand and silt
	12 - 17 cm	Sand/silt
	17 - 22 cm	Coarse sand/silt, shell fragments and rhizome material
2700 5.2 m	0 - 2 cm	Algae and detritus with some sand
	2 - 15 cm	Sand/silt layer with rhizome material
3200 9 m	0 - 3 cm	Fine sand/silt
	3 - 12 cm	Light grey silt
	12 - 17 cm	Silt and rhizome material

3. THE DEPLETION OF SEAGRASS MEADOWS IN COCKBURN SOUND

3.1 Signs of Deterioration Coinciding with Seagrass Death

In healthy meadows, the seagrass generally forms a continuous cover producing a dark dense tone in an aerial photograph. Areas of bare sand do occur in healthy meadows in turbulent areas but have a regular shape in the form of crescents aligned with the predominant wave direction (Cambridge, 1975 (12)).

In Cockburn Sound signs of deterioration are evident where *Posidonia* meadows are regressing. There has been a stunting in leaf size and reduction in shoot density (FPA, 1974b (30)), accompanied by heavy growths of epiphytic algae a decline in the quantity of calcareous algae encrusting the seagrass leaves and the appearance of mussels amongst the remaining shoots.

In areas showing partial deterioration, there has been a disintegration of the once continuous cover producing a patchy distribution of areas of reduced leaf canopy next to areas with full leaf density and bare sand. In aerial photographs these areas have been identified by their irregular mottled appearance or simply a paler tone. Where seagrass meadows have deteriorated further the once continuous meadow has been reduced to small residual patches of *Posidonia* often less than half a metre wide. As the decline of the meadow has continued the remnants have disappeared and only the eroding fibre-bed has been left as evidence of a once vigorous seagrass meadow.

The death of seagrass does not seem to have been one of rapid defoliation; rather, the deterioration started as a thinned leaf canopy with occasional bare patches. This has exposed the remaining leaves to increased wave energy and sediment removal. With the reduction of the baffle effect of the leaf canopy, sediment has been scoured out in storms. Some patches remain as extensive islands of seagrass bounded by bare sand or rhizome seagrass mesh, their plateau like appearances marks them as remnants of more extensive meadows. Once the fibre mesh beneath the meadow has been exposed mussels have been able to settle even if some leaves have remained. The mesh supports a sparse benthic algal flora and occasional dense settlements of the edible mussel, *Mytilus edulis*. Algae such as sea lettuce, *Ulva lactuca*, formed a sparse, temporary cover that is torn loose during strong wave action.

3.2 The Pattern of Decline

3.2.1 Interpretation from aerial photographs

Denudation of *Posidonia* meadows progressed along the eastern shore of Cockburn Sound following the establishment of industrial plants at Kwinana (Cambridge, 1975 (13)). The sublittoral banks, once densely vegetated by seagrass meadows dominated by *P. sinuosa*, lost most of their seagrass cover so that bare sand and patches of fibrous rhizome root mesh now remain on the banks in the nearshore zone (Appendix 1).

Figure 2.2 showed the peripheral distribution of seagrass meadows in Cockburn Sound in 1954, prior to any industrial discharge entering the Sound. Examination of aerial photographs from October, 1957 and March, 1958 showed no major changes in the seagrass distribution although a patch of meadow about three hectares in area, south-west of the BP outfall on James Point, was lighter in tone compared with the dense black of the rest of the meadow. This paler area was still present in October, 1961. The photographs of March and October, 1960 were of poor quality, and no underwater detail could be seen from

3.2.1 (Cont'd)

James Point north to Alcoa. Between October, 1961 and October, 1962 (Figure 3.1(a)) a large sand patch was formed about four hectares in area including the original paler toned areas on the northern side of James Point just south-west of the BP outfall (Plate 5032, 11.10.62, W.A. 797). The boundaries of this sand patch remained relatively constant in the photographs up to and including 1969. Definition in the 1960 and 1961 photographs was too poor in those taken north of James Point to allow the boundary of the seagrass to be defined. Seagrass, however, was present at the shallow edge (Plate 5084, W.A. 784) but by 1962 there had been some loss (Plate 5031, W.A. 797). There was also some loss on the narrow northern edge of the bank adjacent to the AIS jetty between 1960 and 1962.

Between October, 1962 and October, 1963 an elongate sand patch of about two and a half hectares in area appeared near the edge of the seagrass meadow in water 5-10 m deep adjacent to the Kwinana Wreck some three kilometres south of the BP outfall (Plate 5034, 11.10.62, W.A. 797 compared to Plate 5032, 27.10.63, W.A. 842).

The December, 1967 photographs (W.A.1039) show that seagrass was present over the full width of the original meadows from just south of James Point south. By 1969 (Figure 3.1(b)), there appears to have been major death of seagrass between the BP jetties south of James Point to just south of the Bulk Cargo jetty across the whole depth range of the fringing bank. The boundaries of this dieback were marked by a zone of patchy seagrass (Plates 5176 and 5177, 28.10.69, W.A. 1 199). Thus the major dieback south of James Point occurred between December, 1967 and October, 1969 (see discussion section for timing of initial discharges by industries).

Between 1969 and 1972 the major portion of seagrass at James Point was lost so that the sand patch formed in 1962 was enlarged to include the rest of James Point (Figure 3.1(c)). Remnant patches were left in shallow water on the two sand spits on James Point and close to the shore (Plate 5086, 11.10.72, W.A. 1 417).

It is not possible to determine the exact period over which seagrass disappeared from the Eastern Shelf. Aerial photographs of the coast flown annually by the Department of Lands and Surveys (W.A.) do not include this area.

Section 2.2 mentions how the presence of seagrass on the Eastern Shelf in 1960 was determined. It is known that dieback occurred within the period of 1960 to 1976. For the purpose of Figure 3.1 the assumption has been that the dieback on the Eastern Shelf was concurrent with the timing of that along the eastern shore north of James Point.

Between 1969 and 1972 the dieback also extended south of the Bulk Cargo Jetty to a zone of patchy seagrass opposite the Rockingham navigation beacon (Plate 5088, 11.10.72, W.A. 1 417). In 1972, during the construction of the Causeway, field observation showed localised scouring east of the trestle bridge and some thinning seagrass east of the central rock fill on Southern Flats. Comparison of colour aerial photographs taken in 1970 before the Causeway construction and in December, 1976 nearly four years after the completion of the Causeway showed that about half of the seagrass was dead or reduced to patches (Figure 3.1(d)).

Seagrass was removed around the site of the Sulphur Bay jetty and on Sulphur Rock to the south of the jetty, early in 1977 by dredging and the effects of dredge spoil. A large chain was also observed being dragged by the

3.2.1 (Cont'd)
vicinity of Sulphur Rock early in 1977 which removed surface irregularities (Figure 3.1(d)).

Posidonia meadows in Careening Bay changed from a continuous band from the low water line to a depth of 6 m in 1971 to a few patches on the shallows at a depth of 0.5-1 m by 1977 (Figure 3.1(d)).

3.2.2 Discussion

The major events in the sequence of dieback can be summarised as follows:

- The loss of a patch of four hectares of seagrass on James Point south-west of BP outfall between 1961 and 1962.
- The loss of seagrass from the narrow northern edge of the James Point bank south of the AIS jetty between 1960 and 1962. with seagrass persisting over the rest of James Point.
- The loss of seagrass south of James Point to the Bulk Cargo Jetty between December, 1967 and October, 1969.
- The loss of the major portion of seagrass on James Point and the dieback south of the Bulk Cargo Jetty to the Rockingham Navigation Beacon between 1969 and 1972.
- The loss of seagrass on the Eastern Shelf at some stage during 1960 and 1976.
- The loss of the seagrass on Southern Flats at some stage between 1970 and 1976.

It is useful to link this sequence of dieback to the time of initial release of effluent from industries along the eastern shore.

BP Oil Refinery	*1955*
BHP Steel Rolling Mill	*1956*
Woodman Point Treatment Plant	*1966*
CSBP Fertiliser Plant	*1970*
Kwinana Nitrogen Company (KNC)	*1968*
AIS Blast Furnace	*1968*
Kwinana Power Station	*1970*

In Section 5.5, enrichment of the water by nutrients, particularly nitrogen, has been implicated as the cause of widespread dieback. Two of the eastern shore industries are major sources of nitrogen; Kwinana Nitrogen Company (KNC) and the BP oil refinery. Between 1958 and 1978, the calculated total nitrogen discharged per annum for BP has ranged from 24 800 kg to 71 700 kg (Appendix 2). Quantities have been variable from year to year with no trend over the 20 years. KNC has released much higher levels from its inception in 1968. Discharge began in November 1968 at about one third of the subsequent discharge rate. In 1969, with full production, 228 000 kg was discharged, rising to a maximum discharge of 813 200 kg in 1973 with subsequent decrease to 639 900 kg in 1978.

The timing of the major dieback events corresponds with the release of effluents high in nitrogen, particularly in the case of KNC when extensive dieback of seagrass on the banks south of James Point rapidly followed discharge beginning in late 1968. The association of release

3.2.2 (Cont'd)

of high nutrient effluent with the death on James Point and to the north is less clear-cut as underwater detail was poor in most of the relevant aerial photographs. The first area of dieback was localised on James Point and appeared suddently between 1961 and 1962 south west of the BP oil refinery outfall, about six years after the first discharge began; other toxic agents, including hydrocarbons (Section 5.4) were being released over the same period and could also have contributed to this localised dieback.

Nitrogen from the Woodman Point sewage outfall calculated as approximately half to two thirds that of the KNC effluent contributed to the nutrient budget of the Sound from 1966 onwards and may have been implicated in the loss of seagrass on the Eastern Shelf, which disappeared at some time during 1960 and 1976. The complete loss of seagrass on the Eastern Shelf as compared with only partial loss in Mangles Bay may be attributed to one or other of a number of factors. The natural conditions before industrial discharge began, may not have been favourable on the Eastern Shelf so that the seagrass was more susceptible to the stress of excess nutrient related problems. Before KNC began discharging in November 1968 the seagrass may already have been debilitated by nutrient inputs from the BP oil refinery and the Woodman Point sewage outfall.

3.2.3 Conclusions

- Rapid dieback on the eastern shores of Cockburn Sound south of James Point is attributed to the release of large quantities of nitrogen compounds* from Kwinana Nitrogen Company which began discharging in November, 1968.

- The progressive dieback, subsequent to 1969, spreading north to include James Point and then south to Rockingham was a continuation of this initial dieback and is attributed to the same cause.

- The cause of the localised dieback before 1969 on and north of James Point is not clear cut. The BP oil refinery was discharging nitrogen compounds, hydrocarbons and other potentially toxic substances which may have contributed to this loss.

- It is probable that the nitrogen added by the Woodman Point Treatment Plant from 1966 onwards contributed to the death of seagrass on the Eastern Shelf which was lost at some time between 1960 and 1976.

3.3 Standing Crop of Seagrass in Study Area: December 1977

3.3.1 Introduction

Standing crop is defined here as the weight of above-ground material. In seagrass, this is the main contributor to detritus production, destined for consumption in the seagrass meadow or export to areas such as the deep basin of Cockburn Sound. The quantity of above-ground material also affects the capacity of the seagrass meadow to modify water movement; the larger the standing crop, the greater the bulk of the leaf canopy and the more effective the shelter for biota and the stabilisation of sediments.

Sampling was carried out in December as the standing crop reaches a maximum in the *Posidonia* meadows during summer (December-January). Growth rates and leaf lengths (Figure 3.2) are highest reflecting the warmer water temperatures, maximum sunlight and relatively calm waters, so that

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*The mechanism by which enrichment leads to seagrass death is discussed in Chapter 5, (Section 5.5.3).

3.3.1 (Cont'd)
standing crop provides an estimate of the maximum quantity of leaf material that may be supported at a site. In turn, this estimate of the maximum weight of leaf material at a site provides some indication of the suitability of the site for seagrass growth, and the variability of the seagrass itself.

3.3.2 Methods

The 21 stations, which represented characteristic seagrass communities in Cockburn Sound and Warnbro Sound are shown in Figure 3.3. General areas were chosen from aerial photographs and bearings noted to define each sampling station. The day before sampling, divers set a steel stake in the substrate to mark the corner of two sampling transects, shown in Figure 3.4.

A float attached to the stake marked the station at the water surface. Accurate bearings were taken after the stake had been placed and were converted to latitude and longitude given in Appendix 3.

To sample the transects a ten metre rope was attached to the central stake and pegged to run due north. A wire frame (quadrat) enclosing an area of $0.33 m^2$ was placed at six, regularly spaced intervals marked on the rope. The seagrass in each quadrat was harvested by cutting level with the sand surface and then placed in labelled plastic bags, N1-N6. When harvesting a mixed seagrass community no attempt was made to separate species. Mussels when attached to seagrass, were included in the harvest and when no seagrass was present within the quadrat the labelled bag was closed and returned. When the northern transect had been harvested, the rope was swung to run due west and the harvesting repeated for another six quadrats, W1-W6. Bags were sealed to prevent drying, but slits in the bags allowed water to drain away.

At a field laboratory, the seagrass in each bag was sorted into species, extraneous material such as mussels and heavy growths of epiphytes were removed and the seagrass wet weighed.

The contents of two bags from each station were retained for decalcification in dilute hydrochloric acid (0.1M) and dried to allow a wet to dry weight conversion. Wet weight data for each quadrat are stored in the Cockburn Sound Study Group Data Repository. Mean wet and dry weights of each species at the sampling stations are given in Table 3.1.

Wet weights of *Amphibolis* spp. included stems and epibiota.

3.3.3 Results -

The results in Table 3.1 have been subdivided into six groups on the basis of location. Within each group values reflect a range of habitats, species and distribution patterns.

Over a range of locations (5, 8, 9 on the Garden Island fringing bank, 19 in Shoalwater Bay and 21 in Warnbro Sound) the dry weight standing crop of pure stands *P. sinuosa* lay consistently in the range of 500-600 g/m^2. At each sampling station the growth pattern was one of linear rows of densely packed roots. It is significant that the Garden Island stations, 5, 8 and 9 sampled within the mid depth range of 2-3 m had similar values to Shoalwater Bay, 19, and Warnbro Sound, 21.

3.3.4 Discussion

The Garden Island Bank now supports the last of the extensive *P. sinuosa* meadows which once vegetated the eastern shore of Cockburn Sound and portions of Southern Flats. These meadows appear to survive because of hydrological conditions which draw ocean water along the Garden Island shore (Steedman, 1979 (71)). The influence of prevailing hydrological conditions upon patterns of water quality are discussed in Chiffings (1979 (16)).

Discussion here will be confined to dry weights rather than wet weights of standing crop. Stations where the standing crop of *P. sinuosa* falls below the 500 g/m^2 may be divided into two groups; those where *Posidonia* meadows have deteriorated recently and those where *Posidonia* is growing in habitats where natural factors are unfavourable. Stations at which *Posidonia* had recently deteriorated included 1 and 2 on Parmelia Bank near Woodman Point, where the plume of enriched water from the Woodman Point sewage outfall passes over the bank; 6, where dredging activity has destroyed the meadows in Sulphur Bay; 10, 11, 12, 13 and 14 on the section of Southern Flats separated from the ocean by the Causeway; 17, in Mangles Bay at the CBH grain terminal jetty where a few remnants of the *P. sinuosa* survive as sparse patches with evidence of sea urchin and fish grazing on the leaves.

Stations 14 and 15 were sited 500 m apart on the eastern and western sides respectively of the Causeway and were sampled to provide a comparison of the *P. sinuosa* meadow on the oceanic and leeward sides of the Causeway. It is reasonable to use the differences in standing crop (217 g/m^2 for the leeward station and 512 g/m^2 for the oceanic station) as an indication of the changes in the seagrass since construction of the Causeway. The meadow on the oceanic side is even and continuous to a point close to the Causeway and examination of aerial photographs prior to the construction of the Causeway show the meadow to have been continuous across and beyond the distance between stations 14 and 15.

Natural factors limit *Posidonia* at station 20 in Warnbro Sound at the interface of the seagrass meadow and unvegetated, rippled sand, where *P. sinuosa* forms a mixed community with *Amphibolis antarctica*. Instability of the substrate, wave action and interspecific competition are the limiting factors.

The standing crop of pure *P. australis* is in all cases lower than that of pure stands of *P. sinuosa*. Its subordinate status in the seagrass community of the two semi-enclosed embayments is indicated both by its lower standing crop and in the infrequency of its occurrence in the samples. *P. australis* tends to be restricted to habitats where sand is accreting.

The highest standing crop of seagrass meadows where all species were included in the total weight was measured on the western sector of Parmelia Bank in the *Amphibolis* - *Posidonia* community 1 300 g/m^2 at station 4. Most of the weight was contributed by *Amphibolis*, a species characterised by a heavy leaf canopy supported by dense, wiry stems.

3.3.4 (Cont'd)

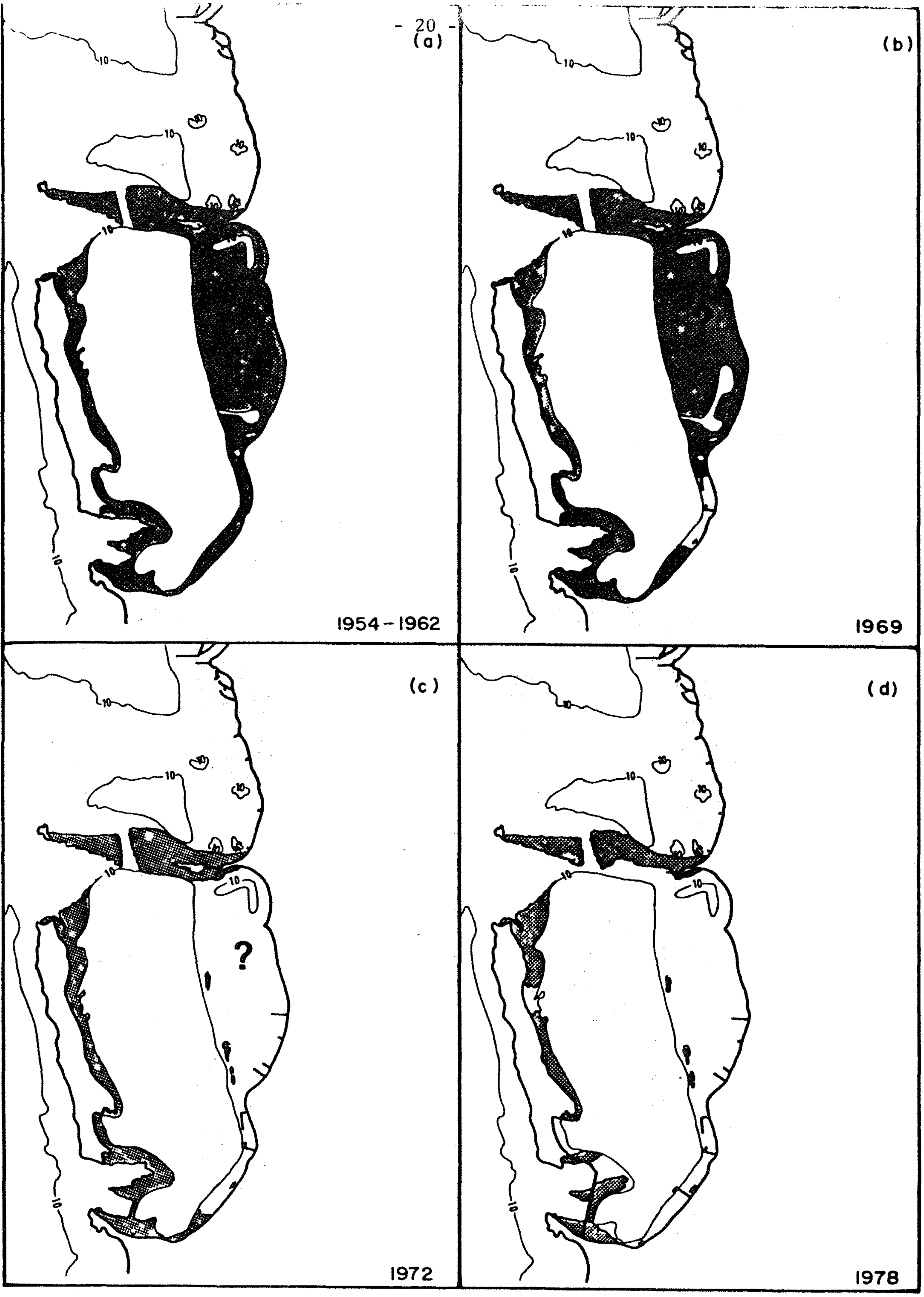
Maximum site standing crop for those species forming the dominant elements in the seagrass meadows of Cockburn and Warnbro Sounds were as follows.

Posidonia sinuosa	ca	600 g/m^2 (pure stand)
P. australis	ca	400 g/m^2 (pure stand)
Amphibolis griffithii	ca	1 000 g/m^2 (in a mixed *Amphibolis* - *Posidonia* community

Measurements of the other species cannot be considered as maximum site standing crops; collection of *Amphibolis antarctica* was made at a marginal site, 20, in Warnbro Sound, and *Posidonia ostenfeldii* was a minor element of the *Amphibolis* dominated community at station 4 on Parmelia Bank.

3.3.5 Conclusions

These results support the findings described in Section 2.3 in which areas vegetated by seagrass were calculated; at stations 1, 2, 6, 10, 11, 12, 13, 14, 16, 17 and 18, there are reduced standing crops compared to 500-600 g/m^2 for healthy *Posidonia* spp. meadows and these stations correspond to the areas of depleted seagrass on Parmelia Bank, in Sulphur Bay and on Southern Flats. These results are also an indication that seagrass is continuing to decline in these areas.



? Indicates time of seagrass loss on Eastern Shelf is uncertain

FIGURE 3.1

Progressive changes in seagrass distribution in Cockburn Sound
1954-1978

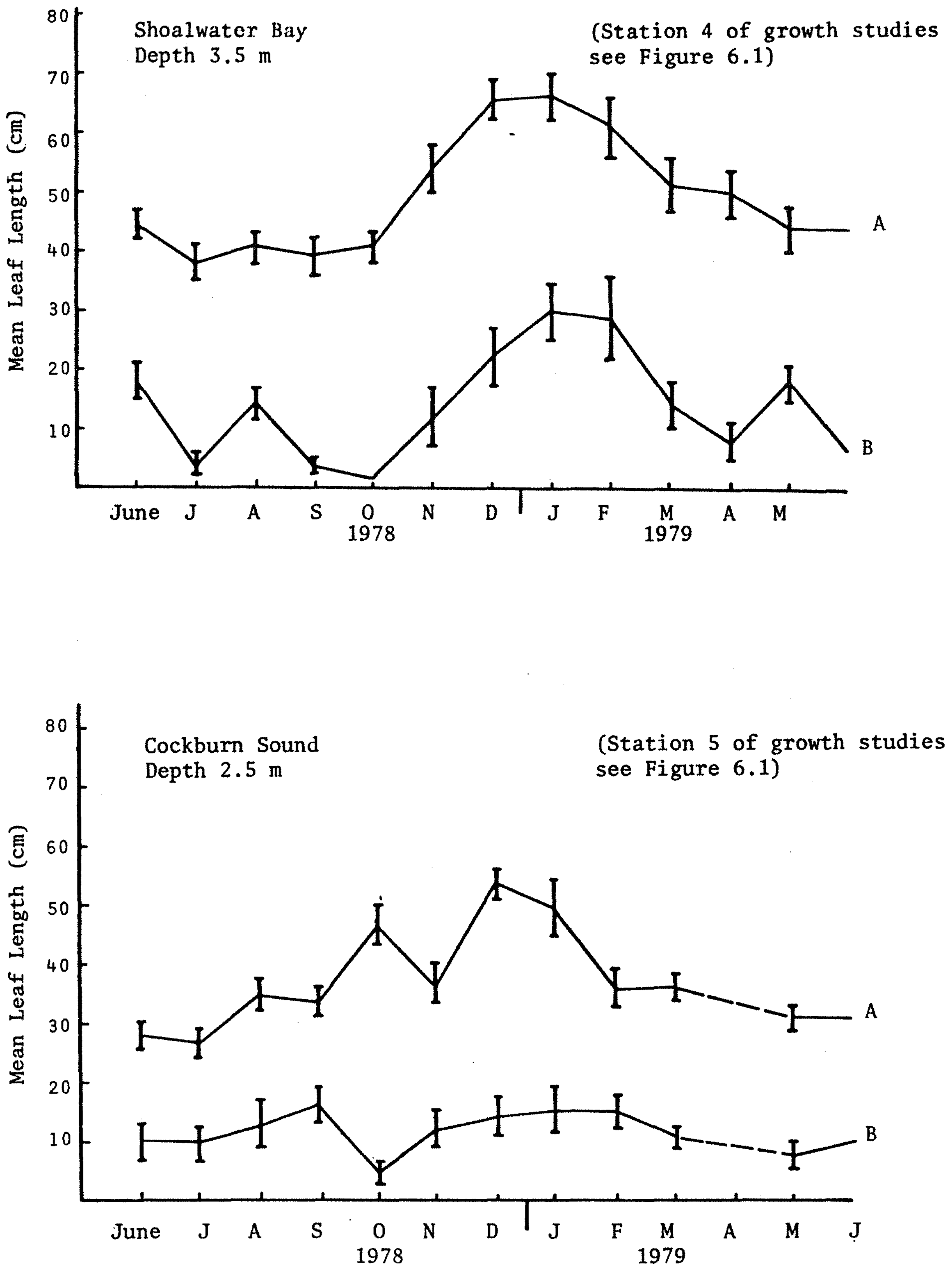


FIGURE 3.2

Leaf lengths in *Posidonia sinuosa*, an annual cycle
(A - Older leaves, B - younger leaves)

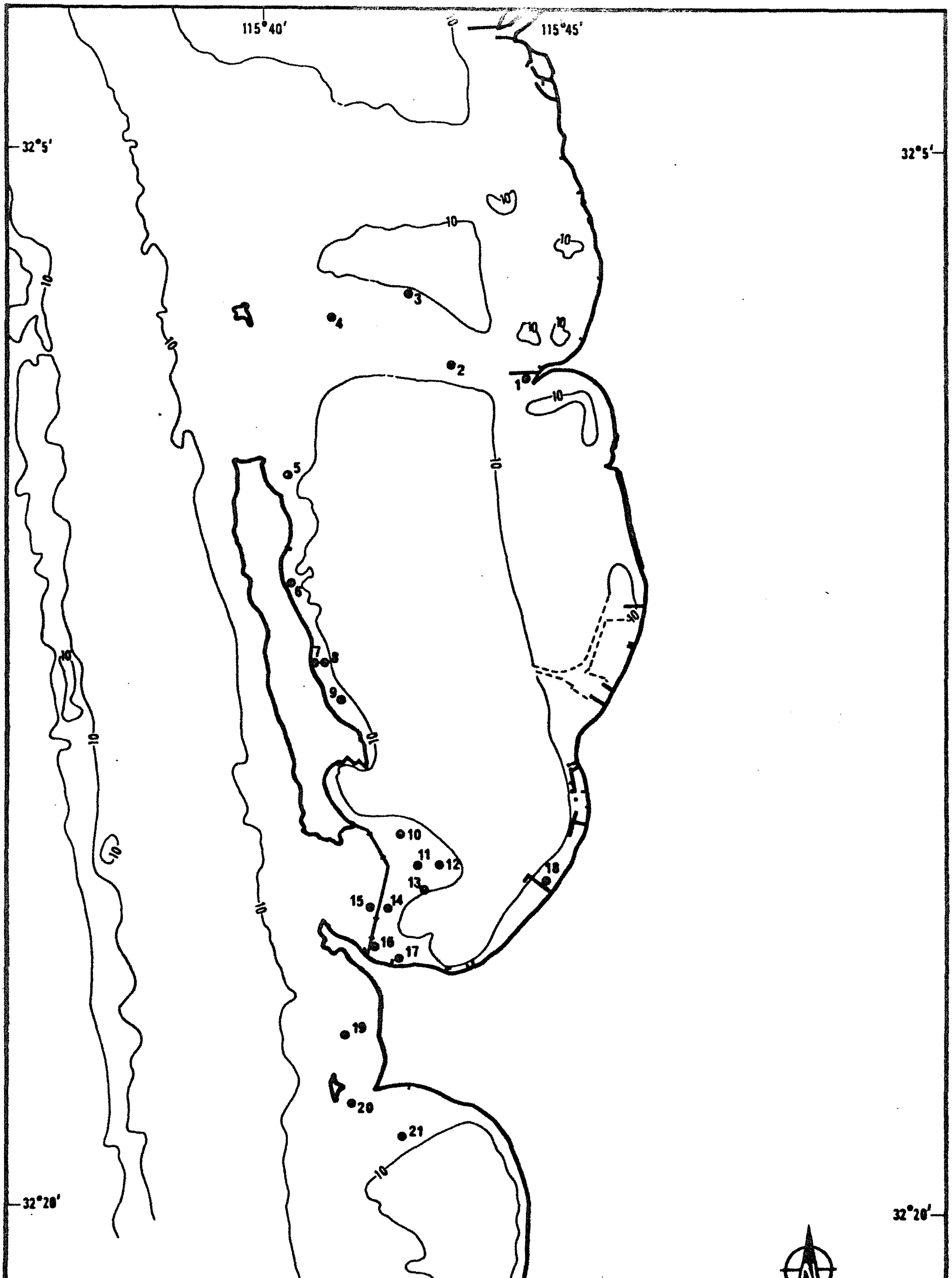


FIGURE 3.3

Stations for sampling seagrass standing crop 3-4.12.1977
(Depths and locations of stations in latitude and longitude
given in Appendix 3)

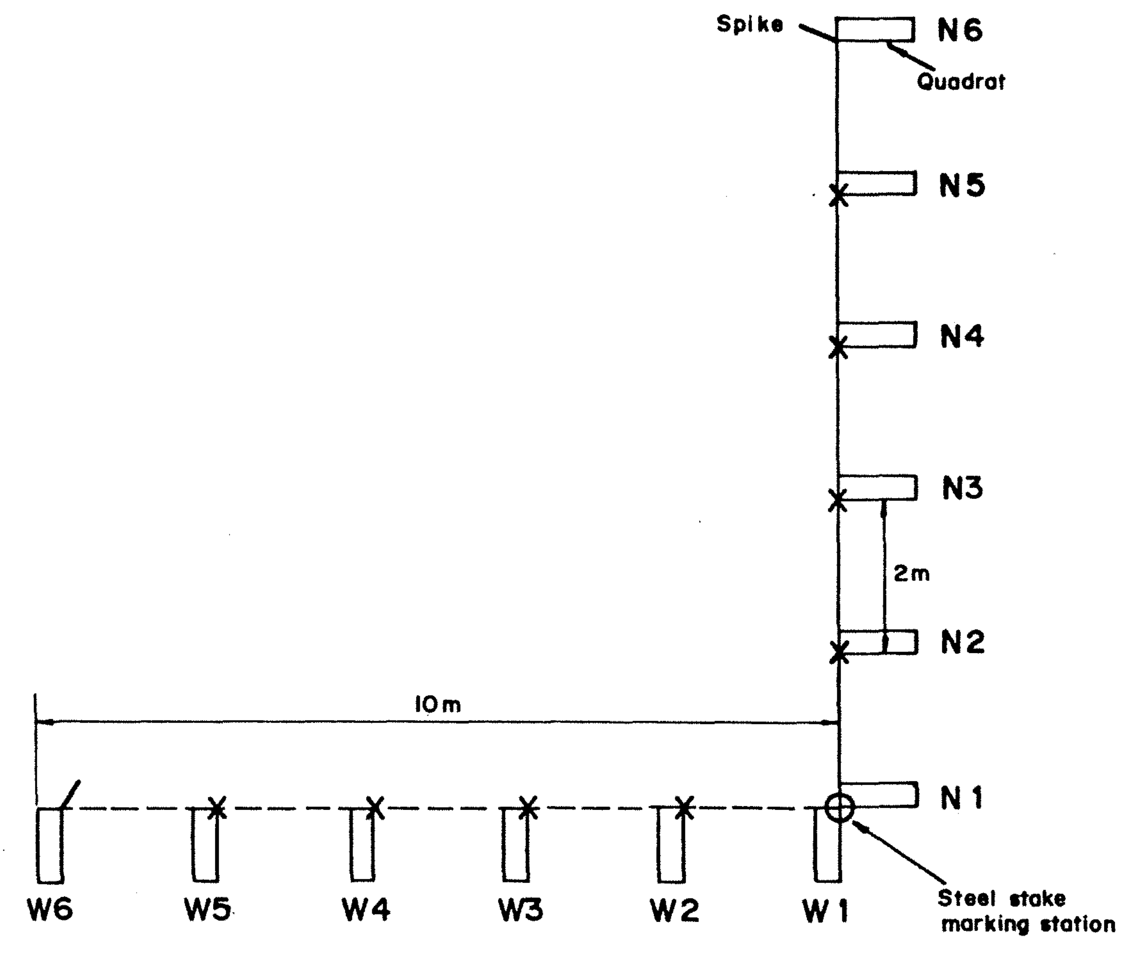


FIGURE 3.4

Plan for sampling seagrass at each standing crop station, 3-4.12.1977

TABLE 3.1

SEAGRASS STANDING CROP: 4.12.1977

Standing crop is a measure of the plant material which may be harvested above ground at one time; for *Posidonia* spp., the weight of the leaf canopy and for *Amphibolis* spp., the weight of stems plus leaves.

Station	Species	g/m² ±s.e.	Dry Weight g/m² ±s.e.
Parmelia Bank			
1.	*P. australis*	1 007 ±219	161.1 ±35.0
	P. sinuosa	850 ±321	136.0 ±51.4
2.	*P. australis*	800 ± 80	128.0 ±12.8
	P. sinuosa	375 ±105	60.0 ±16.8
3.	*Amphibolis griffithii*	3 933 ±528	629.28 ±84.5
	P. ostenfeldii	30 ±3	4.8 ± 0.5
4.	*A. griffithii*	6 170 ±620	987.2 ±99.2
	P. ostenfeldii	1 410 ±173	225.6 ±27.7
	P. sinuosa	540 ±0	86.4 ±0
Garden Island Fringing Bank			
5.	*P. sinuosa*	3 347 ±195	535.5 ±31.2
6.	*P. sinuosa*	1 728 ±208	276.5 ±33.3
	P. australis	170 ± 72	27.2 ±11.52
7.	*P. australis*	2 582 ±281	413.1 ±45.0
8.	*P. sinuosa*	3 510 ±213	561.6 ±34.1
9.	*P. sinuosa*	3 199 ±147	511.8 ±23.5
Southern Flats			
10.	*P. sinuosa*	2 367 ±104	378.7 ±16.6
11.	*P. sinuosa*	2 323 ±434	371.7 ±69.4
12.	*P. sinuosa* and mussels	2 002 ±144	320.3 ±23.0
13.	*P. sinuosa* and mussels	1 465 ± 62	234.4 ±9.92
14.	*P. sinuosa*	1 360 ±163	217.6 ±26.1

TABLE 3.1 (Cont'd)

Station	Species	% Wet Weight g/m^2 ±s.e.	Dry Weight g/m^2 ±s.e.
Southern Flats (Cont'd)			
15.	*P. sinuosa*	3 200 ±151	512 ±24.2
16.	*P. sinuosa*) *P. australis*)	2 370	399.2
17.	*P. sinuosa*	2 104 ±181	336.6 ±29.0
CBH, Eastern Mainland			
18.	*P. sinuosa*	782.4 ±89	125.5 ±14.24
Shoalwater Bay			
19.	*P. sinuosa*	4 150 ±243	664 ±38.9
Warnbro Sound			
20.	*P. sinuosa* *Amphibolis antarctica*	2 183 ±460 3 141 ±485	349.3 ±73.6 502.6 ±77.6
21.	*P. sinuosa* (1% *A. griffithii*)	3 205 ±540	512.8 ±86.4

4. FACTORS OTHER THAN WATER QUALITY AFFECTING SEAGRASS DISTRIBUTION

4.1 Introduction

This chapter considers factors which normally limit distribution under natural conditions, and examines how these may have been significantly altered by industrial activities and marine construction.

4.2 Temperature

4.2.1 Review of Temperature Data

The temperate species of seagrass inhabiting the sand banks of Cockburn Sound grow in waters around the southern half of Australia where maximum sea surface temperatures range from 17°C to 25°C (Rochford, 1974 (63)). Cockburn Sound which lies within the middle of the geographic range of the genera, *Posidonia* and *Amphibolis*, has an annual range in sea surface temperatures from 14.5°C for July to 24.7°C for January, which is the extreme range for monthly means; the highest and lowest temperatures being recorded as 26.7°C and 12.8°C (Hodgkin and Phillips, 1969 (32)). The same range of temperatures were recorded at the South Fremantle Power Station intake for cooling water between 1970 and 1978. In addition, sea surface temperatures were measured at each station on water sampling cruises in Cockburn Sound, Warnbro Sound and an open ocean station, 4 km west of Garden Island, every two months from August 1977 to November 1978 (Chiffings, 1979 (16)). The temperatures for all stations were within the general range of previous records, indicating that there had been no major change in temperature.

The highest summer temperatures recorded for *P. australis* - *Amphibolis* meadows on the Western Australian coast are those from Carnarvon jetty near latitude 26°S. A maximum temperature of 28°C was recorded in March, 1978 by the Western Australian Department of Fisheries and Wildlife (J. Penn, pers. comm., 1979). *Posidonia* spp. including *P. australis* have been observed growing vigorously at Carnarvon so the Cockburn Sound seagrasses lie well within the extremes of temperature experienced over the geographical range.

Elevations in temperature due to the release of thermal effluents from outfalls emptying at the waters edge are very localised on the eastern shore. For example, Figures 1 and 2, pp 80-82 (FPA, 1970 ( )) show the zone of heating limited to less than 100 m from an outfall with a layer of warm water floating above the cooler water. Heated effluent released at 31°C on 27 September,1970 into the nearshore shallows was detectable as a wedge 0-1 m deep. At the surface, elevated temperatures extended over an area 40 m offshore, 100 m north and 10 m south of the point of release. At a depth of 1 m, the elevated temperatures could be detected for only 5 m either side of the point of release. With warmer ambient temperatures and less wave induced turbulence, the surface plume of heated water on 29 November, 1970 extended for 100 m north and south of the point of release and at 1 m depth 50 m north and south.

Additional data collected by the Cockburn Sound Study Group also showed the localised influence of heated effluents in elevating water temperatures. For example, a transect due west of the BP outfall on 29 December, 1978 showed an elevation of 2°C above the ambient temperature of 23°C 100 m from the outfall at .01 m depth and 0.6°C at 1 m depth. This was well within the range normally found over *Posidonia* meadows.

4.2.1 (Cont'd)
Relatively large variations in seasonal and daily temperature occur in shallow waters during summer, particularly on windless days. Turbulence tends to minimise fluctuations by mixing warm waters heated in the shallows with cooler water. However, the range on 4 January, 1978 was 7°C measured near the shallow banks in Warnbro Sound where water depths were only 0.5-1 m.

The mass mortality of *Zostera marina* on north Atlantic coasts between 1931-33 has been attributed to a temporary elevation of the Gulf Stream temperatures which changed ambient temperatures and fostered the invasion of seagrass tissues by a fungus (Rasmussen, 1977 (60)). The *Zostera* mortality occurred over most of the Northern American and European Atlantic coasts over two years. Individual leaves had black patches which spread over the whole plant and a fungus was isolated. Depletion of the Cockburn Sound seagrasses may be compared with this incident. In contrast, dieback of *Posidonia* spp. has been confined to the eastern half of Cockburn Sound from the early 1960's to the 1970's and has spread north and south along the eastern shore. Examination of plants from deteriorating *Posidonia* meadows from 1970 to the present day has not shown any evidence of disease. Rapid depletion has not occurred in other areas outside Cockburn Sound. There has been no documented change in water temperature over the time scale of the depletion; the absence of extensive mortality outside Cockburn Sound would preclude regional changes such as might be attributed to weather or water temperature changes.

4.2.2 Conclusion
Temperature does not appear to have been significant in causing the extensive death of seagrass in Cockburn Sound either from natural seasonal fluctuations, or elevation of temperature by discharge of industrial effluents. At most, the thermal effluents could have contributed to loss of *Posidonia* from a small zone around the points of discharge but their possible effects have been masked by the more widespread depletion.

4.3 Salinity

4.3.1 Review of Salinity Data
Seagrasses in the nearshore ocean waters of southern Australia grow in water of near constant salinity, of 35.75 °/oo, with 3-10 year variations of 0.5-1.5 °/oo. Only estuaries and gulfs (designated as marine by Rochford, 1975 (63)) provide conditions where salinity extends above or below 35.75 °/oo.

In large semi-enclosed marine embayments such as Cockburn Sound, salinity may be reduced by river water or, on a more local scale, by groundwater upwellings. In Cockburn Sound two sites of upwelling near the northern tip of Garden Island and in Mangles Bay have been reported by members of the public but were not substantiated by the Study Group.

Small quantities of groundwater flow into the nearshore shallows through beach sands from groundwater reserves (Layton Groundwater Consultants, 1979 (42)). There is no information on the effects of dilution of interstitial waters in the substrate around the roots of *Posidonia*.

River water during the winter flows of the Swan River does not contribute to more than 1.0 °/oo change (Australian Department of Works, 1972 (6)).

4.3.1 (Cont'd)
Chiffings (1979 (16)) measured salinity at water sampling stations in Cockburn Sound, Warnbro Sound and the open ocean. Salinities did not vary more than 1 ^{o}/oo from the prevailing oceanic salinities of 35.75 ±1.5 ^{o}/oo.

On the New South Wales coast, *P. australis* grows in estuaries where salinity ranges from 20-35 ^{o}/oo (New South Wales State Pollution Control Council data). Kirkman (pers. comm.) recorded the tolerance of *P. australis* to a 15 ^{o}/oo lowering of salinity for two days duration in Port Hacking. Less information is available for *P. sinuosa* at salinities lower than marine 35 ^{o}/oo but it has been observed growing vigorously with *P. australis* in waters of 46 ^{o}/oo on the northern end of Spencer Gulf, South Australia.

4.3.2 Conclusions

Salinities in Cockburn Sound have no major variations from adjacent oceanic salinities, and are well within the range of *P. australis* and *P. sinuosa* recorded elsewhere. Thus changes in salinity are discounted as a cause of the widespread death of seagrasses in Cockburn Sound.

4.4 Light Penetration

4.4.1 Introduction

In Cockburn Sound, *Posidonia* meadows once grew down the slopes of the peripheral sand banks to a depth of 10-12 m indicated by the fibrous remains of *Posidonia* rhizomes under the sand surface.

Although seagrasses have receded into shallower water, no data on light attenuation have been collected previous to this study although there is some comment by residents on increased turbidity. Warnbro Sound was selected as a 'control' site as it is the next marine embayment 4 km south of Cockburn Sound where *Posidonia* meadows extend down to 11 m.

4.4.2 Methods

Light measurements were made using a LI-COR Lambda LI-185 Quantum Radiometer/Photometer, through the water column at 0.5 m intervals. Quanta meters measure the number of quanta per unit horizontal area within the wavelength range 350-700 nm available for photosynthesis in the sea. The vertical attentuation coefficient is a measure of the extent to which a given body of water reduces photosynthetically active radiation (PAR) by scattering and absorption. Theoretical considerations are discussed in detail by Kirk (1977 (36)), but it is emphasised here that a high attenuation coefficient corresponds to a large reduction in light intensity as the light passes through the water. Light readings were made at approximately two monthly intervals at the sampling stations used for water quality studies in Cockburn and Warnbro Sounds, in the open ocean 4 km west of Garden Island, and over four seagrass growth plots in Cockburn Sound, Warnbro Sound and Shoalwater Bay to show the annual variation in light attenuation. Twenty six stations (Table 4.1) were sampled around the periphery of Cockburn Sound on 4 May, 1978 to estimate variation at one time. These measurements were confined to stations over and adjacent to the seagrass meadows.

4.4.3 Results

The mean light attenuation coefficient averaged over Cockburn Sound is generally twice that of the open ocean (Table 4.2). The mean attentuation coefficient in Warnbro Sound was similar to that of the open ocean in summer, but higher in winter probably due to the increased particulate matter suspended from the shallow banks by increased wave energy from storms and westerly swell.

Light attenuation measured over seagrass meadows in both Cockburn Sound and Warnbro Sound (Table 4.3) was generally greater than the mean attenuation averaged for the water body (Table 4.2).

Chlorophyll concentrations were measured as an indication of the amount of phytoplankton in the water column; phytoplankton may form a large proportion of the particles which decrease light intensity with increasing water depth. Chlorophyll concentrations (Table 4.4) in Cockburn Sound were consistently higher than in Warnbro Sound where chlorophyll concentrations were generally similar to those of the open ocean.

There was considerable spatial variation in light attenuation at the 26 stations around the periphery of Cockburn Sound on 4 May, 1978 (Table 4.1), compared to the mean attenuation coefficient of 0.15 for Cockburn Sound overall (Table 4.2). Highest values were present in the plume from the BP outfall and from suspended sediments from dredging on Parmelia Bank (0.46 and 0.26 respectively). High values were also recorded at some stations on Southern Flats (stations 2, 4 and 25) (Table 4.1).

4.4.4 Discussion

Plants use sunlight as a source of energy, converting light energy to chemical energy which can be stored for future use. Underwater plants can grow only to a depth where the light energy trapped by the green leaves is more than the overall needs of the plant for metabolic energy. Thus, the reduction or attenuation of light intensity by the water column through the seasons (and life cycle of the plant) and the ability of the leaves to trap light, determine the depth to which a plant species can grow in an area. Seagrasses have the same pigments as land plants and can grow to relatively shallow depths, e.g. 50 m in clear oceanic waters.

Solar energy has a spectral range of 290-3 000 µm. When this energy passes through the surface of the sea it is attenuated by a combination of two processes; absorption, whereby the light is converted to other forms of energy, mainly heat, and scattering, in which the light is diverted from its original path by particles and by water molecules. Coastal waters are characterised by varying amounts of particulate and humic substances produced from decaying plant matter, and concentrations of phytoplankton which increase scattering of incident light and absorb in the blue end of the spectrum, producing a yellow-green colour in the water (Jerlov, 1966 (34)).

On the Australian coast, the water is normally very low in plant nutrients, particularly nitrogen and phosphorus compounds (mean summer surface inorganic phosphate-phosphorus <0.1 µg/l) and usually have a low concentration of phytoplankton (Rochford, 1975 (63)). There is on the whole little river runoff to add silt and humic substances to the nearshore waters on the temperate Western Australian coast.

4.4.4 (Cont'd)
As a general rule, aquatic plants are considered to colonise suitable substrates down to a depth where the light intensity is only one to four per cent of the average intensity at the surface of the water. The practical difficulties in attempting to determine this depth limit arise from variations from site to site; in the colour of the water, which may be yellow or brown due to organic matter derived from the substrate or pollutants; in the concentration of suspended organic and inorganic particles suspended in the water column and affected by turbulence and the flow of pollutants; and in seasonal changes in phytoplankton and zooplankton.

A decrease in the depth limit over time is often an indication that light attenuation has increased; Larkum (1976C (41)) suggested that turbidity has decreased the depth range of *P. australis* in Botany Bay. Based on historical records and aerial photographs taken in the last years this species appears to have formed far more extensive meadows than at present. The remnants of these meadows extend only to 2.5 m compared with Pittwater some 80 km north, where *P. australis* meadows extend to 7 m, and the large marine embayment to the south, Jervis Bay, to 9 m.

The leaves of the plant may be shaded either by particles in the water or on the leaves. These particles may be either inorganic such as silt, or organic such as phytoplankton, bacteria and fungi, epiphytes or blanketing filamentous algae. If the particles are suspended through the water column, the seagrass meadow will contract vertically, as plants die at the deeper limit. However, if particles such as silt or algae coat the leaves consistently over a time, then plants are likely to die throughout the depth range depending more on the density of the coating than the incident light intensity.

In general, attenuation coefficients in the shallow (1-3 m) waters over the seagrass (Table 4.3) were higher than the mean values (Table 4.2). This may have been a product of sediments suspended by the increased wave activity over the shallow banks, or chlorophyll products and humic substances released from the seagrass meadow. The turbidity at the Cockburn Sound seagrass growth station CS3 on 30 May, 1978 (Table 4.3), where fine calcareous sediment that accumulates in the lee of the Causeway is rapidly suspended in the shallow water (1 m deep) during storms. Five days of storms proceded the light readings, resulting in milky turbid water with an attenuation coefficient of 0.94.

Comparison of light in Cockburn and Warnbro Sounds shows similar values during winter (Table 4.2); however, during summer transparency is less in Cockburn Sound than Warnbro Sound. This reduced light availability may be significant in the reduction of the seagrasses at the deeper end of their range. It is likely that carbohydrate reserves are laid down after seeding in early December so that shading during summer may be critical for the survival of the deeper meadows. It is also during summer, with calms, maximum sunlight and water temperatures that phytoplankton blooms develop in Mangles Bay, on the Eastern Shelf and around the Woodman Point sewage outfall.

Shading by epiphytes as a cause for seagrass dieback at shallower depths (3 to 5 m) is discussed in Section 5.5.

4.4.5 Conclusions

Light reaching seagrass meadows in Cockburn Sound is reduced by phytoplankton blooms, which may occur over wide areas, and by localised suspensions of either particulate matter from industrial outfalls, or sediment.

Shading by these agents is likely to have been a major cause of the decline of seagrass meadows of Cockburn Sound in deep water, where light was already a limiting factor.

4.5 Wave and Current Action

4.5.1 Review of Wave and Current Action

Water movement in nearshore waters takes two forms; a steady current with some turbulent eddies such as is produced by tidal flows, and orbital movement produced by waves.

Water movement within tolerable limits is important for the effective metabolism of submerged plants, by promoting diffusion of nutrients entering the leaves and metabolites leaving the plant (Sculthorpe, 1967 (69)).

Excessive water movement affects submerged plants by mechanical damage, causing tearing of the leaves or uprooting plants, and by making the substrate too unstable for colonisation. Providing the substrate remains stable or the species have a deep, strong rhizome system, short term storm damage appears to be tolerated; leaves will be torn or sand blasted but in *Posidonia* are quickly replaced.

Water movement over a meadow sufficient to erode the substrate produces crescentic scours orientated to the prevailing wave direction (Cambridge, 1975 (12); Patriquin, 1975 (55)). Sudden changes in patterns of water movement such as those which occurred with the funnelling of swell trains through the Garden Island Causeway's northern bridge have produced scours and zones of erosion and accretion. These are clearly visible in aerial photographs taken after construction of the Causeway when compared to before construction. The solid fill of the Garden Island Causeway has reduced wave and current action across Southern Flats, apart from areas adjacent to the bridges where water is funnelled through the relatively narrow openings. Seagrass deteriorated over much of Southern Flats at some stage between 1970-1976 as discussed in Section 3.2, but this cannot be attributed to a decrease in water movement. Evidence for this conclusion is provided by the vigorous growth of *P. sinuosa* measured in the lee of the Causeway on the Mangles Bay shore at Growth Plot 7, (Figure 6.1) where annually primary production was the highest of all stations measured in the study but where the water is very calm except under northerly wind conditions. The water is shallow (about 1 m) generally and very clear despite the silty substrate, in contrast to the waters of central Southern Flats which are often turbid with phytoplankton blooms.

The erosion and accretion patterns are distinctive and are localised in the areas adjacent to the Causeway channels. Similar patterns have not been observed in other areas of major seagrass dieback. It may, therefore, be concluded that changes in patterns and speeds of water movement have not directly caused the major dieback although they have caused loss on a localised scale on Southern Flats opposite the two Causeway bridges.

4.5.1 (Cont'd)

This section deals only with the physical effects of water movement on the seagrass. An account of the effect of reduced water exchange with the ocean in allowing the build up of nutrients in the water column over the seagrass meadows on Southern Flats upon completion of the Causeway is given in Chapter 5.

The effect of suspended sediment transported by water movement can be assessed adjacent to sites of dredging. Seagrass cover has been removed by dredging from Woodman Point along the sewage pipe alignment, at channel dredging sites on Southern Flats, in the Stirling Channel north of James Point, Sulphur Bay, Parmelia Bank, and limesand dredging sites across Parmelia Bank. At all these sites apart from localised scouring the devegetated areas have not spread. It is unlikely that changes associated with dredging have directly caused the major loss of seagrass.

Turbidity from suspended particles disturbed by dredging is spread by water movement far beyond the dredge site. Although this reduces light penetration, the effects on seagrass vary according to the situation. In deep water, where light is near limiting values, the increased turbidity will cause loss of some or all seagrass depending on the duration of the dredge plume. However, in shallow water the situation may differ, for example, on the eastern side of the Causeway in Mangles Bay. Here, *Posidonia* meadows were exposed to high levels of turbidity during Causeway construction and the settling of the limestone dust has produced a silty substrate. During periods of high winds, the area is still very turbid but the shallow waters are very clear at most other times. The leaves often have a thick coating of silt which is then aggregated by organisms on the leaves. Leaf growth is high as described earlier for Growth Plot 7 (also Table 6.1) so that the effects of the temporary turbidity (probably lasting for less than one year during Causeway construction and then afterwards at intervals for a few days in stormy weather) have not had a detrimental effect in these shallow water meadows.

4.5.2 Conclusions

The widespread dieback of seagrass in Cockburn Sound beginning on the eastern shore cannot be attributed to changes in wave or current action.

Increase in water movement produced by human activities has resulted in localised scouring, the most obvious example being those associated with the Causeway bridges on Southern Flats.

Decrease in water movement from man-made structures cannot be held as the cause of deterioration in seagrass meadows but may exacerbate the problem of nutrient retention in localised areas.

4.6 Grazing by Sea urchins

4.6.1 Introduction

In September and November 1972, during routine sampling of the seagrass the author observed localised denudation of the meadows by the grazing of the sea urchin, *Temnopleurus michaelsenii*, on the eastern shore of the Sound near the present position of the CBH grain terminal jetty. Another outbreak was recorded in Warnbro Sound during routine sampling of seagrass in 1977-78 where the sea urchins were grazing the deep limit of the seagrass.

An underwater survey was made in November, 1972 to determine the extent of the sea urchin infestation and record the densities of animals associated with the various states of seagrass denudation.

4.6.1 (Cont'd)

In November 1972 counts were made by scuba divers at each of the stations shown in Figure 4.1. Quadrats of size 1 m^2 were placed randomly at each station and sea urchins counted.

4.6.2 Results

Confirmation that the sea urchins were grazing the seagrass was obtained firstly by examination of the stomach contents of animals found clustered on damaged seagrass leaves and on the sediment between plants. Microscopic examination of the stomach contents of *T. michaelsenii* collected from damaged seagrass showed a prodominance of *P. sinuosa* fragments. The seagrass species was identified by characteristics of the leaf epidermal cells. Secondly, in sediment patches it could be shown that sea urchins had denuded that section of the meadow. By fanning away the sediment the jagged remnants of leaves and leaf bases could be exposed just below the sediment surface, beyond the reach of the sea urchins.

Table 4.5 shows the densities of sea urchins recorded at sampling stations along the eastern shore of Cockburn Sound in November, 1972. A high density of sea urchins was found at Rockingham Light, station 6. This area was vegetated by patches of seagrass; the last along the sand platform which was once continuously vegetated by *Posidonia* meadows. Sampling stations in the more severely grazed meadows were divided into three categories; the centre of exposed sediment patches, denuded of their seagrass cover; seagrasses at the edge of the sand patches, and seagrass in the centre of vegetated patches. Counts were made in each of these three zones of grazing severity.

Densities of sea urchins were intermediate at $100/m^2$ in areas of active grazing amongst seagrass. In the centre of a meadow, or in patches of seagrass between the denuded areas, leaves were less damaged and densities were lower at 40 and $60/m^2$. In the recently denuded patches, densities of 250 sea urchins/m^2 were recorded.

Reconnaissance beyond the stations 6 and 7 showed the most severely grazed area to be localised, extending from the CBH jetty construction site to one kilometre north of the site. Stations 4, 8 and 9 were sampled on areas of bare sediment and *Posidonia* root mesh, but no sea urchins were found at these locations.

Although the high densities of sea urchins seemed to be short-lived, their effects were permanent for the outbreaks observed. For example, the meadow along the Rockingham shore had been reduced to an island remnant with the dieback of large areas of the eastern shore meadows between 1969-1972. Sea urchins invading in 1972 reduced much of this remnant meadow to bare sand. The high densities of sea urchins observed at station 6 in this area were short lived; only a few animals could be found when the station was visited six weeks later. The leafless plants never revegetated and a visit to the area two years and four years later failed to find any *Posidonia* in this area.

The effects of this sea urchin grazing on seagrass cover could be seen in aerial photographs of the Rockingham foreshore. At the site of most severe grazing, the *Posidonia* meadow formed a band 100 m wide in water 3-5 m in depth, 20 m to 30 m offshore. Although there were originally some bare patches in the meadow, patches of bare sediment increased in area at the time of the sea urchin grazing.

4.6.2 (Cont'd)

Although the outbreak of grazing sea urchins was most severe in the vicinity of Rockingham Light in 1972, a number of records of damaged *Posidonia* leaves and occurrence of *T. michaelsenii* in other areas were made during and after 1972.

For example, on 10 December, 1972 *Posidonia* plants adjacent to the Causeway trestle bridge had leaves with evidence of grazing. Dead sea urchin shells were found amongst the sparse plants beneath the bridge.

Small areas of seagrass with grazed and damaged leaves were observed amongst undamaged seagrass on a small bank of sand-covered reef north of Pinnacle Rock on 4 November, 1972. Low densities of the sea urchin *T. michaelsenii* were present; adjacent to a grazed patch 20-60 animals/m^2, and amongst the undamaged meadow 0-20/m^2 were recorded.

On 25 November, 1973, the effects of severe sea urchin grazing were observed at Careening Bay at a permanently marked station of 3 m depth. The leaves of the seagrass, normally 20-40 cm long, were reduced to 3-5 cm with sea urchins clinging to the leaves. The meadow, vegetating a sand slope down to 5 m depth prior to 1973 had receded to 2 m depth.

Other areas where evidence of sea urchin grazing was observed included Woodman Point (November, 1976). Parmelia Bank (November, 1976) and Oyster Harbour, Albany (November, 1976). Sea urchins were present in low densities in these areas but the *Posidonia* leaves had ragged edges typical of sea urchin grazing and the seagrass was patchy.

Sea urchins were observed at seagrass Growth Plot W1 (Figure 4.1) in Warnbro Sound during February 1978. They had removed all leaves for a distance of some 4 m upslope from the original seagrass-sand interface at the deeper edge of the meadow. In a sequence of three visits to the plot, the sea urchins appeared between 3 February 1978 and 6 March 1978, in densities of 200 animals/m^2. They grazed the edge of the meadow over the distance of 0.5 km surveyed, then disappeared in the four weeks between the second and third visits. During the period of grazing, green leaves were uncovered on 6 March from beneath the sand but by the next month few living rhizome apices could be found and again there was no regeneration of *Posidonia* in the grazed area.

4.6.3 Discussion

The sea urchin, *T. michaelsenii*, (identified by L. Marsh, Western Australian Museum), is small and grey in colour, ranging from 1-3 cm in diameter, with sharp primary spines 3-4 mm in length. Mortensen (1943) (49) found only plant fragments, mainly seagrasses, in the intestines of this species collected from seagrass meadows, indicating a vegetarian diet when plants were readily accessible. He records seagrass meadows as the usual habitat but a survey by the Western Australian Museum found *T. michaelsenii* in abundance on the deep calcareous mud floor of the Cockburn Sound basin and only rarely in shallower water amongst the seagrass meadows bordering the basin (L. Marsh, pers. comm.).

The species has also been previously recorded in considerable numbers from the muds of the deep, central basin of Cockburn Sound during a survey by the Western Australian Naturalist Club from 1958-60 reported by Wilson *et al* 1978 (87)), and despite extensive sampling on the shallow

4.6.3 (Cont'd)
sand and rock platforms vegetated by seagrass bordering the deep basin, no large concentrations of the animal were found at that time. Outside Cockburn Sound, *T. michaelsenii* has been found in sheltered waters from South Australia to Shark Bay (L. Marsh, 1976, pers. comm.).

The high densities of sea urchins in seagrass meadows have been short lived in the areas observed but their effects seem to be permanent. Two factors may account for this. If the leaves from a small area of meadow are removed, for example by clipping, reserves from the surrounding plants are moved to the damaged plants via the network so that the leaves regenerate rapidly (Kirkman, 1977, pers. comm.). Examples of the recovery of the leaf canopy within 6-8 weeks are given in FPA (1971-1974). However, if the leaves are removed from large portions of meadow then reserves from the intact meadow are not available - each rhizome must support its own complement of shoots. If the initial regrowth from reserves in the rhizome is grazed again by either sea urchins or fish such as leatherjackets, reserves will be rapidly depleted. (No information exists at present on the reserves held in the rhizome or the requirements of regenerating shoots). The end result is the death of many of the shoots on the rhizome tips and hence of the meadow.

The second factor may be damage to the leaf sheaths by the sea urchin grazing. The leaf sheaths wrap tightly around the growing points of the rhizome apex; their function in excluding seawater and reducing the salinity of the fluid bathing the rapidly dividing cells of the meristematic tissue has recently been discovered (S. Tyerman, 1979, pers. comm.). The growing tissue is usually bathed in a solution of about one third ambient salinity; if the leaf sheath is damaged or disturbed, then seawater of marine salinity can penetrate to the growing tissue which seems to result in death of the growing point. The removal of sediment with the loss of the sheltering leaf canopy by grazing may also be implicated; if the leaf sheaths are exposed to wave action instead of being buried by sediment, they tend to flex and seawater is able to penetrate the sheath, thus raising the salinity. Therefore, the loss of sediment leads to the death of the growing points.

Instances of overgrazing of submarine macrophytes by sea urchins have been reported from Florida in the turtle grass (*Thalassia testudinum*) beds (Camp *et al*, 1973 (14)), and from California in the kelp (*Macrocystis*) beds (North and Pearse, 1970 (53)).

High densities of sea urchins grazing on the kelp beds have been attributed to the destruction of predators such as sea otters, and abalone, and to the enrichment of nearshore waters by the release of sewage. North and Pearse (1970 (53)) reported that the most severely affected areas were centred around sewage outfalls discharging effluents rich in both organic nutrients and pesticides.

Ogden *et al* (1973 (54)), record the heavy grazing of seagrass by a reef dwelling species of sea urchins in the West Indies. The continuous grazing of all vegetation growing on the sand surrounding patches of coral reef produced halos of white sand around the reefs. The grazed leaves of *Posidonia* observed by the author displayed a jagged apex similar to that described by Ogden *et al* as being typically produced by sea urchins grazing turtle grass in the West Indies and differing from the scalloped edges produced by fish grazing. As in Cockburn Sound the highest densities of sea urchins were associated with bare patches of sand in an otherwise continuous meadow of seagrass.

4.6.3 (Cont'd)

The grazing by the sea urchins around the West Indies reef differs from the Cockburn Sound situation in its localised nature of a grazed strip around the reef, and the small numbers of animals involved. The sea urchins in Cockburn Sound most likely came from the deep basin, migrating up the slope of the marginal sand bank vegetated by seagrass.

The direct grazing of *Posidonia* by sea urchins is one instance where this seagrass is used directly by a consumer. Only one other heavy grazer of *Posidonia* has been recorded in the literature by Bell, Burchmore and Pollard (1978 (7)) who documented the grazing of *P. australis* by leatherjackets (Monacanthidae) near Sydney. They showed that *Monacanthus chinensis* and *Meuschenia freycineti* consume large quantities of seagrass. Both those species have been recorded from Cockburn Sound during the study (Dybdahl, 1978 (18)). Because they are mobile they may be less obvious as potential predators of seagrass than sea urchins which cannot avoid divers. However, the author has observed that leatherjackets leave semi-circular "bite marks" along the leaf margin whereas sea urchins strip the leaf epidermis leaving the leaf in ragged streamers. Only grazing characteristics of sea urchins were observed at the sites under discussion here. Occasional consumption of the leaves by gastropods in Cockburn Sound seems to be incidental as a result of grazing of epiphytes from the leaf surfaces (Scott *et al*, in press (67)).

One factor was common to all the observed instances of overgrazing of *Posidonia* by the sea urchin, *T. michaelsenii*. The seagrass meadow was already patchy, either due to deterioration of a once continuous meadow or to some natural environmental limit such as depth, where the seagrass is sparse and vegetated patches interfere with bare sand.

In Cockburn Sound where sea urchin damage to *Posidonia* leaves was recorded in shallow water, the seagrass had already been deteriorating near chemical or sewage effluent discharge or sites of major construction.

No outbreaks were recorded in a well developed seagrass meadow with a dense continuous leaf canopy. The grazing at Warnbro Sound extended only to the point where the seagrass leaf canopy became dense a few metres from the deeper meadow limit. This indicates that the outbreaks may not be random events striking any part of a seagrass meadow, such as would occur with chance migration of sea urchins from the deep muds through the seagrasses. The fish surveys showed a different fish community in a seagrass habitat compared to sand or mud (Dybdahl, 1979 (18)), from which it was concluded that loss of seagrass induced a change in the composition of the fish fauna. Preliminary surveys on fish resident in seagrass meadows indicate that several species are potential predators of the sea urchins. These include juvenile leatherjackets (Monacanthidae), weed whiting, particularly *Neoodax* (Odacidae) and scorpion fish *Gymnopistes marmoratus* (Scorpenidae). Crabs, particularly *Nectocarcinus* sp. may also be predators (Scott, pers. comm.). Further study is required on the predation of sea urchins by fish resident in dense seagrass, and upon the responses of these potential predators to changes in the habitat.

4.6.4 Conclusions

Aggregations of sea urchins, *T. michaelsenii*, have been observed to graze the leaves of *Posidonia* sp. to the level of the substrate, thus depleting or removing the leaf canopy of a meadow.

4.6.4 (Cont'd)

No obvious factors likely to initiate these aggregations were observed during the periods of grazing.

Sea urchins were observed to graze in *Posidonia* which was already patchy, rather than in areas of continuous dense leaf canopy.

Aggregations were localised extending for several hundred metres but sea urchin individuals were observed singly or in small groups grazing leaves in deteriorating seagrass such as that found on Parmelia Bank north of the sewage plume.

Sea urchins have contributed to localised loss of seagrass meadows on the eastern shore but were not observed penetrating into areas with a complete leaf canopy. It is likely that they can cause the final denudation of a meadow but do not initiate extensive defoliation in a meadow with a complete leaf canopy.

Thus, sea urchins cannot be considered as the primary factor in the dieback of seagrass in Cockburn Sound despite their significance at a smaller scale within meadows and should be regarded as a secondary contributor to depletion once the deterioration has begun.

4.7 Sedimentation

4.7.1 Field Observations

The following observations on the response of seagrass to sediment accretion were made by the author during field studies of *Posidonia* meadows in 1977-78 at growth plots and during general underwater surveys both in Cockburn Sound and other areas on the south Western Australian coast.

- *Posidonia* spp. respond to a certain degree of sediment accretion with vigorous growth.
- Rhizome morphology, growth and root production appear to be affected by the rate of accretion, with each species demonstrating a difference in responses (Kuo and Cambridge 1978 (40)).
- Variations of growth in response to sedimentation affect the vigour and persistence of various species, so that a range of preferences is exhibited, from stable substrates with very little accretion through to rapidly accreting rather mobile substrates, as follows:

  (a) *P. sinuosa* favours substrates with limited to very limited sediment accretion, such as the greater area of the fringing bank along the eastern shore of Garden Island.

  (b) *P. australis* favours substrates with higher sediment accretion, such as those localised areas adjacent to sand spits on the Garden Island shore.

  (c) *P. ostenfeldii* favours a substrate with considerable sediment movement and high wave energy, such as on the western end of Parmelia Bank.

A range of sedimentary environments exist in Cockburn Sound with static non-accreting substrates predominating.

4.7.1 (Cont'd)
During this study plants were excavated using a suction device (air lift) so that sand and fibre could be removed and the underground parts examined. The following more detailed observations were made which illustrate the differences in growth patterns under different regimes of sedimentation:

> At the Buchanan Bay site, (Figure 6.1, Growth Plot 5) on the fringing bank along the eastern shore of Garden Island, there is minimal sediment accretion and generally low wave energy. The growth pattern of *P. sinuosa*, the dominant species is in broken linear rows with accumulation of dead rhizomes leaf bases and roots, very short internodes and very few new roots being formed.
>
> At the Warnbro site on the northern edge of a sand spit at Growth Plot 2 the sedimentary pattern is a complex of accretionary and erosional loci with sediment accreting and high wave energy. *P. australis* is evenly distributed and *P. sinuosa* grows in broad rows. The underground rhizomes of both species had long internodes, a lower density, strongly monopodial and many long, white roots.

There is a point where sediment accretion ceases to be beneficial. The influx of too much sediment results in smothering of seagrass; for example in the development of spits or sand sheets.

Where death of seagrass cover has been extensive, sediment becomes mobile again and forms a source of supply. Migrating sand sheets inundating seagrass meadows have been documented in Shark Bay (Read, 1974 (62), Figure 11d).

Kirkman (1978 (37)) describes the death of beds of small tropical seagrasses over several years in Moreton Bay, Queensland as a result of inundation by a moving sand sheet.

4.7.2 Seagrass Growth Related to Sedimentation

The degree of sedimentation and energy at a site affects both the species and the spatial pattern of distribution. *P. sinuosa* forms almost pure stands with a linear growth pattern normal to the prevailing wave direction on the fringing and barrier banks with very little sediment accretion; *P. australis* forms almost pure stands on the much smaller areas of higher sediment accretion on spits and the margin of the meadow adjacent to the beach. The shoots tend to be evenly spread through the stand or with gradual changes in density. This distribution of species related to local availability of sediment is present on the Garden Island fringing bank and was present on the eastern bank from Rockingham to James Point before the loss of seagrass meadows in recent years.

Under conditions of limited sediment supply the prevailing wave direction, *P. sinuosa* has a linear growth pattern with rows of tightly packed shoot apices interspersed by shallow sand gutters. When viewed from above the seagrass has the appearance of a grain field sown in regular furrows. The width of the vegetated rows and gutters according to the sediment supply usually 30-40 cm wide but the orientation is always in the direction of the prevailing wave trains. The sandy gutters do not seem to be static; the fibrous remains of *P. sinuosa* can usually be found a few centimetres below the sand. The larger scale pattern of the rows is similar to that developed in longitudinal sand ribbons with the rows anastomosing or dividing after a distance.

4.7.2 (Cont'd)
Where vertical growth of rhizomes is restricted by a lack of sediment accretion, particularly in *P. sinuosa*, shorter internodes and more branches of the rhizome produce a lateral infilling of space while still producing new growth points particularly in *P. sinuosa*. This response was described earlier in Section 4.7.1 for plants at Growth Plot 5 in Buchanan Bay, Cockburn Sound. The number of shoots per unit area can be very high with massive shallow branching of the upper portion of the rhizome, but the space between shoots is often tightly packed with a dense fibrous mass from remains of dead rhizome apices and the ensheathing leaf bases.

In areas of higher accretion plants are large, vigorous, development of underground roots is prolific, lengths of internodes between leaf scars are long, and the distribution of shoots above-ground is even rather than clumped, such as described earlier for Warnbro Growth Plot 2.

The growth of *Posidonia* spp. under different conditions of sediment accretion parallels the response of the terrestrial dune grasses. Marshall (1965 (44)) describes how and when sand was accreting on dunes or hummocks, the grasses grew vigorously; plants were large with a fresh green colour, there was an abundance of new root production and free flowering. However, when the dune level was static, the grasses showed a marked decline in vigour; plants were smaller, litter accumulated, new root development was rare and one species exhibited a tussock growth form in comparison with the more uniform shoot distribution in unstable areas.

4.7.3 Present Day Sedimentation in Cockburn Sound

The present state of sedimentation on the sand banks of Cockburn Sound is a product of bank growth during the Holocene rise and fall in sea level summarised in France 1978 (21), Figure 13-19, and the present hydrological environment, which is predominatly influenced by the energy of westerly and north westerly waves impinging on the banks.

The growth of the barrier banks and the joining of Cape Peron to the mainland shown in sequence (Figure 13-19) in France (1978 (21)) reduced the influx sediment during the course of Holocene bank development. Present sediment accretion rates on the fringing banks is a product of this cessation in influx of external sediment. Localised accretion takes place only as a result of reworking of beach sediments and their deposition at the edge of the meadow adjoining the beach or in small spits leading off the beach.

The barrier banks coincide with the interference zones between refracted wave patterns shown in Figure 5 of France (1978 (21)), which are depositional loci characterised by continual sediment influx. However, there has been a reduction in external sediment supply so that the barrier banks are probably only maintaining sediment presently in position.

Recycling of sediment is present in groups of crescentic sand patches whose erosion provides a limited sediment source for accretion on the lee face where seagrass colonisation is usually vigorous (Cambridge, 1975 (12), Figure 2b). Localised cycling of sediment also occurs adjacent to beaches.

Although *Posidonia* spp., respond to sediment accretion within limits by vigorous growth, *P. sinuosa* tolerates very low rates of sedimentation.

4.7.3 (Cont'd)

It is considered that the predominance of *P. sinuosa* on the fringing banks of Cockburn Sound is a product of relatively static sedimentation and that the mixed communities on the barrier banks are a response to the combination of accretionary and erosionary loci, and localised recycling of sediment. The localised occurrence of *P. australis* can be related to recycling of sediment within the meadow or from beaches.

Changes in species takes place with recognisable patterns when sedimentation is altered so as to be unfavourable to a given species; it is emphasised that species change but the seagrass community, although modified, remains. These changes are slow, with a timescale for greater than the two years of the present study.

4.7.4 Conclusion

It is concluded that the major depletion of the seagrass meadows has not been caused either by changes in sedimentation or by the static state of bank development in Cockburn Sound at its present stage of geomorphic development.

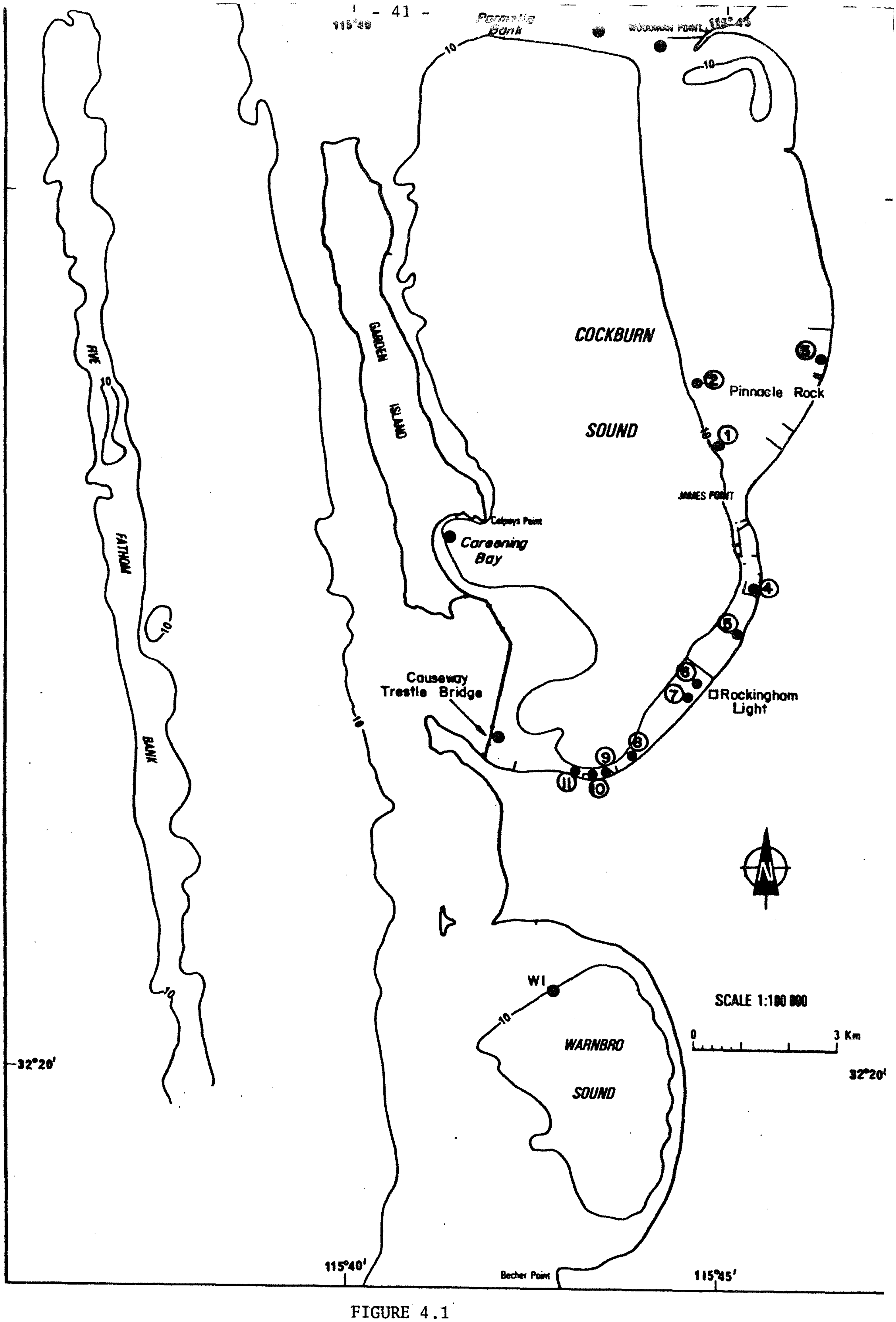


FIGURE 4.1

Observation sites for sea urchin grazing on *Posidonia* meadows 1972-1978

TABLE 4.1

LIGHT ATTENUATION COEFFICIENTS IN COCKBURN SOUND - 4.5.1978

Station No.	Location **	Position	Attenuation Coefficient
1 *	Mangles Bay - edge of bank	115° 42' 58" 32° 16' 21"	0.18
2 *	Mangles Bay (Causeway trestle bridge)	115° 42' 15" 32° 16' 10"	0.24
3 *	Southern Flats (southern edge of bank)	32° 15' 9" 115° 43' 22"	0.19
4 *	Southern Flats Beacon (Fl.Or 6 sec, 5M BnB)	32° 15' 9" 115° 43' 22"	0.28
5 *	CBH jetty (500 m offshore)	115° 44' 39" 32° 15' 39"	0.14
6 *	Kwinana Wreck	115° 45' 15" 32° 14' 53"	0.13
7 *	James Point	115° 44' 54" 32° 13' 20"	0.11
8 *	BP outlet	115° 45' 29" 32° 13' 6"	0.46
9 *	BHP jetty	115° 45' 1" 32° 12' 24"	0.13
10 *	Pinnacle Rock	115° 44' 25" 32° 11' 36"	0.08
11 *	Alcoa jetty	115° 46' 21" 32° 11' 35"	0.14
12 *	Calista channel lead beacon (F.R. 20m 11M)	115° 46' 9" 32° 10' 33"	0.13
13	Woodman channel beacon	115° 43' 58" 32° 9' 19"	0.11
14 *	South Jervoise lead beacon (South Woodman Point beacon)	115° 44' 54" 32° 8' 20"	0.09

TABLE 4.1 (Cont'd)

Station No.	Location	Position	Attenuation Coefficient
15	Woodman groyne	115° 44' 29" 32° 8' 22"	0.15
16 *	Parmelia Bank (in turbid zone from limesand dredging)	115° 42' 50" 32° 7' 57"	0.26
17 *	Parmelia channel beacon (FIR 3 sec 3 m "I" BnR	115° 42' 11" 32° 7' 54"	0.11
18	Dolphin (northern Garden Island)	115° 40' 36" 32° 9' 14"	0.19
19	Second Head (northern Garden Island	115° 40' 24" 32° 9' 57"	0.13
20	Sulphur Bay	115° 40' 30" 32° 10' 53"	0.16
21	Mt. Moke (turbid littoral drift adjacent shore)	115° 40' 44" 32° 11' 34"	0.25
22	Buchanan Bay	115° 41' 12" 32° 12' 36"	0.16
23 *	Colpoys Pt.	115° 41' 55" 32° 13' 38"	0.14
24 *	Careening Bay	115° 42' 21" 32° 14' 12"	0.11
25 *	Southern Flats (central)	115° 41' 40" 32° 15' 4"	0.21
26 *	Palm Beach jetty	115° 43' 36" 32° 16' 30"	0.17

* Reading made near depleted seagrass meadows

** Location from "Gage Roads and Cockburn Sound" chart, AUS 117

TABLE 4.2

MEAN LIGHT ATTENUATION COEFFICIENTS COCKBURN AND WARNBRO SOUNDS, AND OPEN OCEAN, 19779-1978 (AFTER CHIFFINGS 1979)

(Data collected from water sampling grids on cruises at approximately two monthly intervals)

(Details of grid location in Chiffings, 1979 (16))

Date	Cockburn Sound	Warnbro Sound	Open Ocean 4 km west of Garden Island
24. 8.77	0.10[1] ±.04 (.04)	.11 (0)	.07
20.10.77	.10 ±.03 (.03)	-	-
7.12.77	.13 ±.06 (.06)	.06 (0)	.06
25. 1.78	.12 (.03)	-	.06
30. 3.78	.15 (.05)	.08	.08
18. 5.78	.15 (.03)	.12 (.02)	.07
27. 7.78	.16 (.03)	-	.08 (0)
22. 9.78	.16 (.02)	.10 (0)	.05 (0)
16.11.78	.13 (.03)	.06 (0)	.06 (0)

[1] each mean is accompanied by its standard error

\- No data

TABLE 4.3

LIGHT ATTENUATION COEFFICIENTS AT FOUR SEAGRASS STATIONS IN COCKBURN AND WARNBRO SOUNDS, 1977-1979.

(Location of Stations shown in Figure 6.1)

DATE	STATION AND DEPTH			
	Warnbro Sound W3 2.5 m	Shoalwater Bay S1 3 m	Cockburn Sound CS1 2.5 m	Cockburn Sound CS3 1.0 m
12.12.77	.14 (.06)[1]	.17 (.06)	.18 (.13)	.32 (.13)
26. 1.78	.18 (.06)	.24 (.06)	.18 (.12)	.26 (.12)
31. 3.78	.26 (.08)	.14 (.08)	.18 (.15)	.24 (.15)
30. 5.78	.40 (.07)	.25 (.07)	.39 (.15)	.94 (.15)
1. 8.78	.22 (.08)	.17 (.08)	.30 (.16)	.20 (.16)
29. 9.78	.08 (.05)	.12 (.05)	.11 (.16)	.21 (.16)
16.11.78	.09 (.06)	.13 (.06)	.11 (.13)	.14 (.13)

[1] Each mean is accompanied by its standard error

TABLE 4.4

MEAN CHLOROPHYLL 'a' CONCENTRATIONS (μg/L) FOR COCKBURN AND WARNBRO SOUNDS, AND OPEN OCEAN 1977-1978 (AFTER CHIFFINGS, 1979 (16)).

	Aug. 1977	Oct.	Dec.	Jan. 1978	March	May	July	Sept.	Nov.
Cockburn Sound	2.9 (1.0)[1]	4.8 (3.1)	1.8 (0.9)	3.1 (2.3)	1.8 (1.0)	2.7 (2.0)	3.8 (0.2)	4.2 (2.4)	2.4 (1.3)
Warnbro Sound	1.2 (0.2)	0.3 (0.1)	0.3 (0.1)	0.4 (0.4)	0.7 (0.2)	0.9 (0.2)	2.6 (0.3)	0.5 (0.2)	0.3 (0.1)
Open Ocean 4 km west of Garden Island	0.4 (0.1)	0.2 (0)	0.1 (0)	0.3 (0)	0.5 (0.3)	0.5 (0.1)	0.6 (0.2)	0.3 (0.2)	0.4 (0)

TABLE 4.5

DENSITY OF SEA URCHINS IN RANDOM 1 m^2 QUADRATS AT SURVEY STATIONS ALONG THE EASTERN SHORE OF COCKBURN SOUND, NOVEMBER 1972

Station No.	Depth (m)	Number of sea urchins /m^2		
		Seagrass meadow		Denuded sand patches
		Centre	Adjacent to denuded sand	
1.	4	0,0	0,0	0
2.	2	0,2	6,6,2	0
3.	3	6,4	1,2	0
4.	1-2	No	seagrass	0
5.	2-5	8,4	3,3	6
6.	4	40,60	100,106	206,250
7.	4	8,11	10,12	11
8.	2.5	No	seagrass	0
9.	2-3	No	seagrass	0
10.	1.5	0,0	0,0	0
11.	1	0,0	0,0	0

5. WATER QUALITY AND THE DECLINE OF SEAGRASSES

5.1 Introduction

It has already been concluded that temperature, salinity, turbidity, wave and current action, grazing by sea urchins and sedimentation are not in themselves responsible for the widespread loss of seagrass. The possibility remains that a deterioration in water quality is involved. Two aspects of water quality were examined; the direct effect of oil refinery effluent and the likelihood of shading by phytoplankton in the water column and epiphytic algae on the leaves.

The effect of oil refinery effluent was examined because the first loss of seagrass occurred at James Point close to the BP refinery outfall and also because of the quantities of hydrocarbons, including aromatics and alkanes (Murphy, 1979 (52)) which are released into the nearshore zone. Some of these hydrocarbons are known to be toxic to aquatic organisms (Chegwidden, 1979 (15)).

Shading by phytoplankton which developed in response to nutrient enrichment was higher in Cockburn Sound than external areas except during winter (Section 4.4). Furthermore, the possible importance of proliferation of epiphytic algae on deteriorating seagrass required examination.

5.2 The Relationship between Sites of Decline and Water Quality

Discrete water bodies, with a high nutrient input and dense populations of phytoplankton were observed regularly within the larger mass of Cockburn Sound (Chiffings, 1979 (16)), as a result of consistent patterns of water movement (Steedman, 1979 (71)). The influence of weather patterns on the distribution of high nutrients and phytoplankton is discussed in depth by Chiffings (1979) and so will not be discussed further in this report. However, it is significant that the areas where high phytoplankton densities were observed (along the eastern shore, in Mangles Bay and over Southern Flats), also coincide with the areas of depleted or deteriorating seagrass. It is suggested that the remaining seagrass meadows along the eastern shore of Garden Island, on the western sector of Parmelia Bank and pockets of seagrass at either end of the Causeway are likely to have survived because of intrusions of oceanic water which probably dilute or displace nutrient rich waters.

5.3 Field Transplants

Addy (1947a (1)), reported the first attempts to transplant seagrasses. Recently extensive reviews of transplants have been published by Phillips (1974 (57)), Thorhaug (1974 (75)), and Ranwell *et al* (1974 (61)). By transplanting seagrasses, information may be gained on their tolerance to disturbances such as chemical pollutants, temperature and salinity changes.

Two field transplants of seagrass were carried out in the Cockburn Sound area to assess the effect of water quality on seagrass growth. The first was in summer 1977-78 (October-March) and the second in 1978 (November-December). These will be referred to as Transplants 1 and 2 respectively.

5.3.1 Field Transplant 1 (October to March 1977/78)

This investigation was undertaken to assess the suitability of water quality for seagrass growth along the eastern shores of Cockburn Sound. Three trial stations and one control station were established in

5.3.1 (Cont'd)

2-3 cm water depth. The stations, shown in Figure 5.1 were sited as follows:

- 100 m south of the Alcoa jetty where small patches (0.5-1 m diameter) of *P. australis* were present in a narrow band following the 2-3 m contours of the sand bank slope.
- 250 m offshore from the BP oil refinery wastewater discharge where no seagrass was present, although a dead seagrass rhizome mat remained from the once healthy meadow.
- 100 m north of the CBH grain terminal jetty where large patches of *P. australis* and *P. sinuosa* were present. The leaves of these were grazed at the tips and margins, probably by leatherjacket fish (Monocanthidae) and sea urchins (*T. michaelsenii*), observed at the station before the start of the transplant.
- Warnbro Sound control station at Mersey Point set in a small sand patch amongst a mixture of seagrass species, predominantly *Posidonia* spp. and *Amphibolis* spp.

Field Procedures -
Seedlings aged about ten months from the same seed crops of *P. australis* and *P. sinuosa* were collected from Mersey Point, Warnbro Sound during 26-28 October, 1977. A solid-walled plastic tube, 20 cm in length and 6 cm in diameter, was pushed around each seedling. The base of each tube was capped with a plastic cap before it was removed to reduce root disturbance.

Seedlings of each species were transplanted to each of the four stations which were marked by steel pickets and subsurface floats. The numbers of seedlings in each trial are given in Table 5.1. The seedling leaf areas were measured before transplanting and the plants checked each month during the five month trial. Leaf area measurements were taken again at the end of the trial.

Survival of seedlings -
The percentage of plants which survived the trial are shown in Table 5.1. No data were obtained from the Alcoa station owing to vandalism at that station.

The survival was highest for both species at the Warnbro station. Fewer *P. sinuosa* survived at the BP station. A comparison of Table 5.1 with Table 5.2 shows that, although half the seedlings at the CBH station survived, only one *P. sinuosa* and three *P. australis* seedlings retained the above-ground portion of their leaves. At the BP station only three of the surviving seven seedlings of *P. australis* and none of the *P. sinuosa* seedlings retained their leaves. The living plants still retained the green bases of the leaves beneath the sand so that the status of these leafless plants was determined by destructive harvesting at the end of the trial.

Leaf areas of surviving seedlings -
Table 5.3 presents a summary of the data on leaf areas before and five months after the trial. All 12 surviving plants at the Warnbro station retained their leaves and 83 per cent of these increased their leaf areas over the five months, whereas only one plant at the CBH station and none at the BP station gained in leaf area. The change in mean leaf area per

5.3.1 (Cont'd)
surviving seedling for each trial is illustrated in Figure 5.2. There was a substantial net gain in leaf area for *P. australis* ($11.53\ cm^2$) and *P. sinuosa* ($13.32\ cm^2$) at the control station in Warnbro Sound, whereas considerable net losses occurred at the BP station (*P. australis* - $12.44\ cm^2$; *P. sinuosa* - $27.15\ cm^2$ where $n = 1$) and the CBH station (*P. australis* - $13.30\ cm^2$; *P. sinuosa* - $13.12\ cm^2$).

Discussion -
Two points emerge from the trial; firstly more *P. sinuosa* seedlings died at the BP station than *P. australis* seedlings. Secondly loss of leaves from surviving seedlings was considerable at the CBH station and the BP station.

The loss of leaf area from surviving plants at the CBH stations may in part be attributable to the grazing by herbivores. Before the trial began seagrass leaves in the area showed characteristic signs of grazing. Sea urchins, although not observed during the monthly checks of the trial, had been seen previously on the eastern banks (Section 4.6). Some of the surviving plants at the BP station also appeared to have been grazed.

At the termination of the trial the sediment within the capped cores had become blackened and anaerobic. This may have inhibited the growth of a healthy root system which in turn could affect leaf growth. A more satisfactory arrangement would allow the free exchange of water into the base of the cores.

The sample size for the trial was found to be too small. Within a population of transplanted seagrass seedlings the stress of transplanting, particularly to those plants with poor root systems, would be responsible for a proportion of the deaths. It was concluded that a larger sample was therefore required to minimise this factor and to enable a more statistically sound comparison to be made between the experimental and control areas.

The influence of grazing herbivores on surviving seedlings also added difficulty to the interpretation of the data.

A general conclusion, however, may be made; that environmental conditions, whether natural (grazing herbivores) or man-made (lowering of water quality) were unfavourable for growth of *Posidonia* on the eastern bank of Cockburn Sound.

5.3.2 Field Transplant 2 (November/December 1978)
The second series of transplant trials aimed to provide information concerning the general conclusions reached by the previous trial and to eliminate the natural (herbivore grazing) environmental influence encountered in that experiment.

Specifically the trial was designed to investigate seagrass growth where the dominant influence on water quality was likely to be that from effluent carrying hydrocarbons and so complement laboratory trials carried out by Brittan, 1979 ( ) (Section 5.4).

The two locations chosen for the transplant stations are shown in Figure 5.1.

5.3.2 (Cont'd)

- The Kwinana experimental station was located in 2 m depth of water 150 m north-north-west of the BP refinery effluent outfall in an area where the dead seagrass rhizome mat still remained. Before industrialisation of the eastern foreshore this area supported a healthy *P. sinuosa* meadow.

- The Warnbro Sound station was situated in a healthy *P. sinuosa* meadow and protected from excessive wave action. The depth of water was approximately 2.5 m.

Field Procedures -
Because of limited time and resources the trial was confined to *P. sinuosa*, as this was originally the dominant species on the eastern shores of the Sound.

As insufficient first year seedlings could be found, 80, two-to-three-year-old seedlings of *P. sinuosa* were taken from site A in Warnbro Sound (Figure 5.1). An air-lift was used to remove sediment from around the roots of each plant and any with a stunted, blackened root system were discarded. Each healthy seedling was then placed underwater (using local sediment to cover the roots) into a plastic tube 8 cm diameter (3 mm walls) and 30 cm long, the base of which was covered with terylene gauze held by a rubber band. The gauze allowed free movement of water through the sediment in the tubes. Care was taken to select comparable plants with an average of two to three shoots per plant, and comparable leaf area.

Twenty plants were selected, replanted into tubes, measured for leaf area and the tubes resited on the same day. This operation was repeated on each of four days giving a total of 40 plants transplanted to the Warnbro control station and 40 to the Kwinana station. At each station four tubes were placed in the centre of each of five protective cages (see below), staged in a line at 5 m intervals. The 20 uncaged plants were placed along a line parallel to the cages, also in groups of four, each marked by a tagged picket. Each plant could be identified by a number and the sites were marked with both subsurface and floating markers.

The cages were designed to prevent the grazing which had occurred during Transplant 1. Each cage consisted of a frame 50 cm square and 35 cm deep. The sides were covered with 0.5 cm plastic mesh and the hinged lid with 1 cm chicken wire. The open base was placed over the plants and the sides sunk 5 cm deep into sediment and pegged down with 0.5 m length steel pins. At the Kwinana station additional 1 m pins were required to keep the cages in place.

The size of the cage was designed to minimise breaking of leaf ends owing to contact with the sides of the cage. The mesh size was chosen to prevent entry through the sides of the cages of sea urchins more than 0.5 cm in size.

The leaf lengths and widths were measured once a week. The cages at the Warnbro Sound station were brushed clean of marine growth each week whereas those at the Kwinana station required cleaning twice a week, although daily cleaning would have been more satisfactory because of the rapid growth of filamentous algae. Irradiance measurements were made on three occasions inside and outside cleaned and uncleaned cages using a LI-COR 185 photometer. The general condition of the plants and the extent of epiphytic growth on the leaves was noted each week.

5.3.2 (Cont'd)
Six weeks after transplanting and following the final measurement of leaf area, each plant was extracted from its core to examine the health of the root system. The epiphytic growth was gently scraped from the leaves and a 100 g sample of leaf tissue from each of the two stations was kept for analysis of hydrocarbons.

Results -
Leaf areas, as a measure of biomass, of all 20 plants within each group (Warnbro caged, Warnbro uncaged, Kwinana caged, Kwinana uncaged) were summed for each week and are plotted in Figure 5.3.

Measurements of the total leaf area of plants at the start of the trial, one week after transplanting and at the end of the trial are given in Table 5.4. The net change in leaf area from one week after transplantation until termination of the trial is also tabulated. The first 'week' of the trial was considered an acclimatisation period for any recovery of the plants following handling.

At the start of the trial there was no significant difference at the 90 per cent level (Variance = 0.291) between the leaf areas of the plants selected for each group as tested by the anova single classification analysis of variance (Table 5.5).* Using the same test to compare total leaf areas of plants at Kwinana and those at Warnbro at week 6 the difference was found to be highly significant at the 0.1 per cent level (Variance = 67.353 (Table 5.6). A similar significance level was found when the net change from week one to six in leaf area at the two sites was compared (Variance = 70.917) (Table 5.7).

At the Warnbro station there was an average gain in leaf area per plant of 12.37 cm^2 (caged) and 19.54 cm^2 (uncaged) whereas the Kwinana plants lost an average of 15.70 cm^2 (caged) and 9.55 cm^2 (uncaged).

All plants at the Warnbro station survived the trial with 80 per cent (caged) and 90 per cent (uncaged) gaining in leaf area. Growth rates of these were 17 mm^2/shoot/day and 28 mm^2/shoot/day for caged and uncaged plants respectively. At the Kwinana station one plant died but only ten per cent (caged) and 15 per cent (uncaged) gained in leaf area. Growth rates of these were 16 mm^2/shoot/day and 18 mm^2/shoot/day for caged and uncaged seedlings respectively. Thus the growth rate of seedlings at the Kwinana station was reduced compared to the rate at the Warnbro station, particularly for uncaged seedlings (35.7 per cent reduction).

At both sites caged plants grew relatively slowly (Table 5.4). Figure 5.3). Light attenuation measurements taken during the trial (Table 5.8) show that at Kwinana the cleaned cage reduced light by approximately 44 per cent whereas an uncleaned cage reduced light by 67 per cent. At Warnbro, cages reduced light by approximately 31 per cent. It is likely, therefore, that light attenuation was responsible for the reduction in growth of caged seedlings seen at both stations. By chance, uncaged seedlings were not grazed by sea urchins or fish during the trial, so that a fair comparison could be made of growth between caged and uncaged plants.

By the second week of the experiment, leaves of plants at Kwinana were already supporting substantially more epiphytes than those at the Warnbro station. The main epiphytic species colonising the *P. sinuosa* leaves were:-

*After method of Sokal, R.R. and Rohlf, F.J. 1969. "Biometry". W.H. Freeman and Co. San Francisco.

5.3.2 (Cont'd)

Phaeophyta - *Ectocarpus* spp.
Chlorophyta - *Ulva lactuca*
- *Enteromorpha intestinalis*
Rhodophyta - *Polysiphonia* spp. (two species)

By week three the conditions of the Kwinana plants had deteriorated; the leaves were weighed down by long strands of epiphytes and mussel spat and the tips of some leaves were being held and possibly browsed by tubed polychaetes. None of the plants at either site showed evidence of browsing by sea urchins, nor were any observed at any stage during the trial. Leatherjackets were seen occasionally at the Kwinana station, but their specific grazing characteristics on seagrass leaves were not observed.

During week four wave action resulting from strong north-westerly winds caused three cages to be torn from their positions at Kwinana but these were later replaced. The water turbulence broke off most of the senescent leaf ends and their epiphytes from the plants. This is reflected in Figure 5.3; the summed leaf areas of caged plants during week four showed the greatest reduction for any one week period. Rapid build up of epiphytes occurred again before termination of the trial. The contrast in appearance of whole plants after six weeks at the two stations is shown in Plate 5.1. New roots had grown on 90 per cent of the plants at Warnbro as compared with no obvious new growth at Kwinana.

No significant quanties of aliphatic hydrocarbons (3 ppm in both Warnbro and Kwinana samples) were found in the leaves when analysed at the end of the trial, (Alexander *et al*, 1979 (2)).

Discussion -
The results of this field transplant show conclusively that the present conditions over the banks opposite Kwinana (James Point) are unsuitable for growth of *P. sinuosa*. There may be one or several reasons for this:-

- shading due to water turbidity and/or epiphytes
- mechanical stress caused by wave action acting on excessive epiphytic growth
- effect of pollutants on the metabolism of seagrass

A comparison of the attenuation coefficients recorded at Kwinana and Warnbro over seagrass (Table 5.8), shows that considerably less light was available at Kwinana. Particulates from the AIS effluent might contribute substantially to the turbidity of water in this area (Murphy, 1979 (52)) Light levels within the cages may, therefore, be considered inadequate for normal seagrass growth. Nevertheless, the caged seagrass at Warnbro was receiving almost exactly the same light intensity as that received by the uncaged plants at Kwinana, yet the latter had very much lower growth rates. Thus, reduction in light by the water column cannot be important in bringing about the reduced growth of seagrass at Kwinana.

Greater exposure to wave action at Kwinana probably increased the breakage of the senescent leaf ends weighed down with epiphytes; however, the cages afford some protection from wave action. As mentioned above, the dimensions of the cages were chosen to ensure that the leaves were not damaged significantly by contact; however, the caged plants consistently grew less than the uncaged, suggesting that wave action may not, in itself, be very important.

There remains the effect of epiphytes in shading the plants as discussed in Section 5.5.

5.3.2 (Cont'd)

There is also the possibility that pollutants may have affected growth. For example, although concentrations of hydrocarbons in the water at the Kwinana station were probably less than 2 ppm because of dilution, it is likely that lower levels over a longer period of time could inhibit growth rates and so be partly responsible for the results obtained during this field trial. Chegwidden, 1979 (15) discusses the relative toxicity of aromatic and aliphatic hydrocarbons. Although the presence of aromatic hydrocarbons in the seagrass leaves at termination of the trial was not investigated, they are more likely to have inhibited growth rates than the aliphatics.

5.4 Direct Effects of Effluent

5.4.1 Review of Effects of BP Oil Refinery Effluent

Effluent from the oil refinery was chosen for aquarium and laboratory trials because initial loss of the seagrass meadow occurred at James Point approximately seven years after effluent discharge began, and because some of the compounds contained in effluents from similar oil refineries are known to be toxic (Chegwidden, 1979 (15)).

The trials involved:

1. investigations on the growth of *Posidonia* seedlings, cultured in seawater containing different concentrations of effluent,
2. short term laboratory experiments on the effects of phenols on metabolism and senescence of *Posidonia* spp. leaf segments.

The results of these trials are to be found in a report to the Cockburn Sound Study Group on an "Investigation of the effects of oil refinery effluent on the seagrasses *Posidonia australis* and *Posidonia sinuosa*" by C.G. Brittan, February, 1979 (10).

In these investigations *P. sinuosa* showed a 25 per cent reduction of leaf growth rates when subjected to average concentrations of 1 ppm hydrocarbons in a refinery effluent measured by infra red spectrophotometry. Changes in leaf growth rate and senescence rate are pronounced, especially at high concentrations (5 ppm), which caused death in 50 per cent of seedlings of both species within two weeks.

Growth rates of both species were reduced when transplanted into sediments containing low levels of hydrocarbons. Some hydrocarbon uptake may be via the roots.

Although hydrocarbons were used as a measure of the level of pollution, the effluent also contained significant quantities of sulphides and phenols.

The investigation of Tank 3 effluent containing, at dilutions found in the BP effluent pipe (see Murphy, 1979 (52)), 2 ppm phenols (initially) and 3 ppm sulphides (est.), produced up to 40 per cent inhibition of photosynthesis by *P. sinuosa* leaf segments within four days. In view of the relatively less toxic effects of sulphides it would appear that phenol levels of less than 2 ppm could have an adverse effect on photosynthesis of *P. sinuosa*.

5.4.1 (Cont'd)
In summary these results showed that short term exposure of *Posidonia* to effluent at concentrations representative of those expected in the field do not lead to rapid death but do seem to lead to reduced growth. Phenol levels which cause reduction in photosynthesis in leaf segments could be experienced occasionally in the field close to the outfall. Some reduction in growth rate occurred in seedlings growing in sediments with accumulations of hydrocarbons.

5.4.2 Direct Effects of Toxins
Many substances toxic to plants enter the nearshore of the Sound through outfalls and possibly groundwater seepage. Chegwidden (1979 (15)) lists wastes such as heavy metals (cadmium, mercury, zinc, lead, copper, chromium, nickel, arsenic), hydrocarbons (including alkanes and cresols) Alexander *et al* (1979 (2)) and substances likely to be deleterious in "slug" doses, such as sulphuric acid, phosphoric acid, caustic soda and arsenical wastes. Few contaminants could be positively identified during the study as being at levels likely to cause acute toxicity.

Their possible contribution is acknowledged, particularly in the form of low level chronic toxicity, but in the absence of detailed toxicological studies which would require testing for acute and chronic toxicity of a wide spectrum of chemicals, both singly and in combination, no definitive statement can be made. Some identification of the action of toxins is provided by the preliminary work of Brittan (1979 (10)) in which the effect of phenols known to be extremely toxic to organisms, was tested by bioassay of seagrass leaves. No data emerged from this work which would enable the action of a toxin in the field to be defined. Death from toxins or debility from chronic poisoning may be accompanied by morphological changes in the organism; no such changes were ever observed in areas of deteriorating seagrass apart from excessive growth of epiphytes. It is significant that despite the toxins probably released from the oil refinery from the time that effluent release began in 1955, it was seven years before deterioration in the seagrass meadows could be positively identified from aerial photographs in the form of the loss of four hectares of seagrass on James Point between 1961-62. This is in contrast to the major dieback which spread rapidly south of James Point and beyond the KNC/CSBP discharge point from 1969 onwards approximately one year after the KNC discharge commenced.

5.4.3 Conclusion
It is concluded that, while the oil refinery effluent could have caused death of seagrass localised in a small area south west and north of the outfall, the more extensive dieback of the seagrass along the eastern shore cannot be readily attributed to oil refinery effluent. Similarly, localised dieback could have occurred as a result of toxic substances being discharged by other industries.

5.5 Effect of Epiphytes on Light Climate

5.5.1 Introduction
Field transplants of seagrass, discussed in section 5.3, demonstrated that the leaf surfaces of seagrass transplanted to the eastern banks of Cockburn Sound, adjacent to the BP Refinery outfall, were more rapidly and heavily colonised by epiphytic algae than the leaf surfaces of control transplants in Warnbro Sound. The growth of the Cockburn Sound plants was considerably reduced. The author's early records beginning

5.5.1 (Cont'd)
in late 1970 noted the proliferation of filamentous epiphytic algae on declining *Posidonia* (there are no records earlier than 1970). These observations suggested that epiphytes may have been important in the decline of seagrass. Their effect in depressing the growth of *Posidonia* by shading was clearly shown during the transplant trials. The effect of shading was clearly demonstrated by the lower growth rate of the seedlings placed beneath plastic mesh cages (Figure 5.3) which reduced light intensity, compared to the growth rate of uncaged seedlings.

In this section, the effect of epiphytes on the light climate of the seagrass leaves is considered as it is known that an increase in epiphyte cover reduces the light availability, so that a greater proportion of the light energy trapped by the leaves is required for maintenance and less is available for growth.

5.5.2 Field Observations on Algal Epiphytes in Cockburn Sound

Species diversity of epiphytic algae on *P. australis* and *P. sinuosa* was studied on five separate occasions between December, 1970 and November 1972, at a number of sites on the peripheral seagrass banks of Cockburn Sound (FPA, 1971c (35); 1972 (27); 1973 (28)). No measurements were made of biomass; emphasis was placed on documenting the species composition of communities. However, consistent records of heavy growths of red and green algae, particularly reds such as *Achrochaetim* spp., *Polysiphonia* spp., and greens such as *Enteromorpha* spp., and *Ulva lactuca* were made at sampling stations on the eastern shore of Cockburn Sound.

Blankets of fine filamentous benthic algae were also observed; predominantly *Ectocarpus* which in some areas formed a blanket to 1 m thick over the remnants of *Posidonia* meadows, along the south-eastern mainland shore (FPA, 1973 (28)).

The following records from Cockburn Sound note the occurrence of heavy growths of epiphytes and filamentous benthic algae smothering seagrass from 1972-1973.

- November 1972
  Mangles Bay: Old leaves and seed stalks with a heavy growth of bulky brown algae, predominantly *Asperococcus bullosus* and the red algae, *Laurencia* spp. Depth 15 m, adjacent to bare sand, between beach and meadow;

- November 1972
  James Point: Heavy growth of epiphytes on stunted *Posidonia* leaves 15-20 cm long; *Ulva* to 25 cm in length; *Enteromorpha intestinalis*; thick growth of *Polysiphonia*; large plants of *Centroceras* 5 cm x 5 cm.

- 10 December 1972
  Rockingham Light: Blanket of *Ectocarpus* over remnants of *Posidonia* meadow;

- 30 May 1973
  Palm Beach: Heavy growth of epiphytes on *P. australis*.

5.5.2 (Cont'd)

Observations at James Point and Kwinana indicated that the species composition differed from that in other areas of Cockburn Sound. This specialised flora was characterised by the virtual absence of crustose coralline algae such as *Melobesia* and by the presence of green algae such as *Ulva lactuca*, *Enteromorpha intestinalis*, filamentous browns (*Ectocarpus* spp.) and species of red algae (*Polysiphonia* spp., *Centroceras* spp.). Individual plants were frequently large (up to 25 cm in length), dwarfing the stunted *Posidonia* leaves.

Species from stations in declining seagrass adjacent to the Kwinana industrial area changed with different times of sampling (FPA, 1971a, b, c, d (23), (24), (25), (26); 1972 (27)), but were always different from those sampled in areas of the Sound where seagrass meadows were intact.

Subjective estimates of the size and abundance of epiphyte species showed heavy growths of greens, such as *Ulva*, and browns such as *Ectocarpus*. However, seagrass sampled from James Point and Kwinana in September 1973 had relatively few large epiphytes. This may have been a result of storms in the weeks prior to sampling causing the ends of the leaves to break off with the added bulk of the large algal epiphytes.

Observations on the rate of build up of epiphytes was recorded for *P. sinuosa* plants transplanted to James Point. Prior to transplanting the plant's leaves supported no filamentous algae. Within two weeks the leaves were encrusted within two centimetres of the base with the heaviest growths on the senescent leaf ends.

The main species colonising the leaves were: *Ectocarpus* spp. (Phaeophyta), *Ulva lactuca* and *Enteromorpha intestinalis* (Chlorophyta) and *Polysiphonia* spp. (Rhodophyta).

By the third week the leaf surfaces of all plants were thickly coated by epiphytes in contrast to transplants in Warnbro Sound where plants were relatively free of filamentous epiphytes.

At Kwinana strong wave action during the fourth week tore most of the senescent leaf ends and filamentous algae from the leaves. Rapid build up of epiphytes, however, occurred again before termination of the trial at six weeks. This shows clearly, in Plate 5.1 where plants from the two transplant stations are compared.

During field work of the Cockburn Sound Study between 1976 and 1979 heavy growth of epiphytes were observed in two areas where the meadows were in decline, on Southern Flats and the southern sector of Parmelia Bank.

5.5.3 Discussion

Epiphytic algae are always present on *Posidonia* leaves; the algae use the leaf as a settling surface and are not usually parasites. Their proximity to the leaf surface means they are in an ideal position to exploit plant nutrients leaking from the leaf. However, studies detailed in the literature point to the dependence of the growth and development of the epiphyte community on nutrients in the surrounding water rather than those leaking from the leaf; productivity of attached algae on inert substrata has been found to be comparable with that on leaves or submerged plants (Moss, 1958 (50); Pieczyska and Spodniewska, 1963 (59)).

5.5.3 (Cont'd)

In the absence of comprehensive studies on the relationship between reduced seagrass growth and increased epiphyte and phytoplankton growth in Cockburn Sound, the mechanism of this relationship is reviewed here from the literature.

Epiphyte growth and production, the development of filamentous mats of algae are generally less on plants in waters low in plant nutrients than in waters high in plant nutrients, provided sufficient light penetrates to the epiphyte community (Szcepanski, 1968 (73)). The increased nutrient input to Cockburn Sound might be expected therefore to increase the quantity of epiphytes and filamentous algae.

Phillips *et al* (1978 (58)) showed distinct increases in epiphytes in three lakes which had become enriched over the last few hundred years. Examples of similar developments of filamentous algae with artificial enrichment are recorded in Holden (1959 (33)), Moss (1976 (51)) in ponds and lakes, and by Phillips *et al* (1978 (58)) in laboratory tanks.

Fitzgerald (1969 (20)) found that epiphytic development depended on nitrogen availability. Where the water was enriched with nitrogen, epiphytes developed; if nitrogen was scarce, epiphyte growth was poor. Shacklock *et al* (1973 (70)) discouraged epiphyte growth on a red seaweed by reducing nitrate levels in the water column. The discharge of nitrogen into Cockburn Sound is known to be high (Appendix 2).

It is believed that dense epiphytic stands can be a severe stress to aquatic macrophytes such as seagrasses. Mathiesen and Mathiesen (1976 (45)), when reinvestigating Randers Fjord in Denmark found that the previous richly developed submerged vegetation (Mathiesen and Nielsen 1956 (46)), had disappeared from the innermost 17 km, i.e. there had been extensive dieback over some 20 years similar to the time scale of dieback in Cockburn Sound. On the fringe of this zone, the water plants were heavily covered with epiphytes. The transparency of the water had decreased between the first (1954-55) and the second (1974-75) investigations, but not to a decree that could explain the total disappearance of vegetation even from shallow areas. The dieback was thought to have occurred because of dense epiphytic populations, favoured by the high nutrient content in a polluted river which flowed into the landward end of the fjord.

The cause of the severe stress may be explained in terms of direct shading of the macrophytes by the epiphytes. Sand-Jensen (1977 (65)) showed that epiphytes reduced eelgrass photosynthesis by up to 31 per cent at optimum light conditions and ambient HCO_3 concentrations. This substantial reduction became even greater at lower light intensities. Reduced photosynthetic activity leads to reduced growth rates. This was demonstrated by the restriction of growth of macrophytes in laboratory tanks with *Najas marina*, a pond weed, concurrent with growth of filamentous algae. In experiments at two lakes in the Norfolk Broads, disappearance of *Najas* correlated with the appearance of extensive mats of Spyrogyra, a green filamentous algae (Phillips *et al*, 1978 (58)).

5.5.3 (Cont'd)

This work also showed that turbidity of the lake water had not developed sufficiently to prevent macrophyte growth at the time when macrophytes became very scarce in one lake. Only when account was taken of the marked effects of epiphytes in reducing light available at the plant surface could it be shown that the plants were likely to have been sufficiently light-stressed to jeopardise growth the next year. Epiphyte colonisation seemed therefore to have been the critical factor in reducing growth to a low level. It is reasonable to suggest that heavy epiphytic growth on *Posidonia* leaves also reduces photosynthetic activity and hence growth rates by shading. Turbidity from phytoplankton or suspended particles over the shallow parts of the banks is unlikely to have been sufficient to be the main cause of the dieback in Cockburn Sound.

Chiffings (1979 (16)) discusses the occurrence since 1974 of phytoplankton blooms in Cockburn Sound, which are the main cause of increased turbidty of the water. Phillips *et al* (1978 (58)) provide both historical and experimental evidence that phytoplankton development is subsequent to, rather than causative of, the loss of macrophytes.

Moreover, there is some evidence to suggest that organic secretion from macrophytes may actually inhibit phytoplankton growth (Fitzgerald, 1969 (29); Kogan and Chiunova, 1972 (39)).

To summarise the sequence of events likely to have led to the decline of seagrass in Cockburn Sound was as follows:-

- Increased nutrient loading stimulated the growth of epiphytes and filamentous algae dependent on nutrients dissolved in the water.
- Increased epiphytic and filamentous algal growth then reduced the light available to the seagrass leaves.
- A greater proportion of fixed energy was required for maintenance and less for growth of the seagrass.
- Phytoplankton growth continued to increase and hence turbidity increased, further reducing light availability.
- As the 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 widespread death of the seagrass.

Here and in Chapter 3 it is implied that nitrogen is the effluent component which has been particularly important in the seagrass decline. This conclusion rests mainly on circumstantial evidence: (a) the temporal pattern of decline seems to have followed increasing nitrogen load (see Section 3.3.2); (b) the work of Chiffings, 1979 (26) on phytoplankton which shows experimentally that nitrogen is limiting phytoplankton growth; and (c) data from the literature, e.g. Fitzgerald, 1979 (20) which showed that epiphytic algae were nitrogen limited. Thus it is inferred that growth of epiphytes is nitrogen limited in the Sound.

5.5.4 Conclusion

It is concluded that epiphytic growth was and continues to be a major factor in the decline of the seagrass meadows in Cockburn Sound. The evidence for this conclusion lies in the timing of seagrass dieback with release of effluent high in nitrogen into Cockburn Sound, the build up of epiphytes and the occurrence of phytoplankton blooms as well as evidence from the literature of a likely sequence of events.

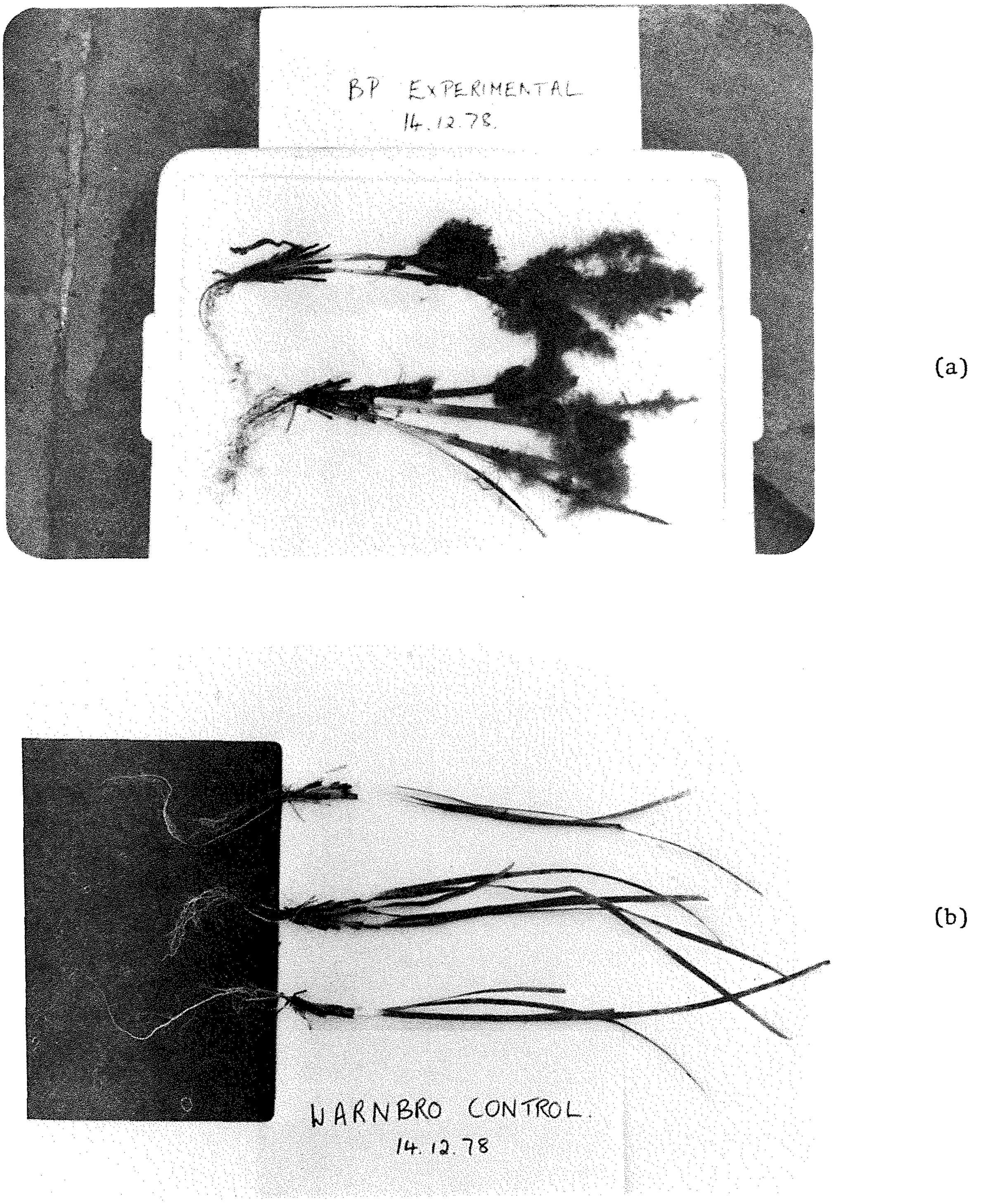


PLATE 5.1

Posidonia sinuosa seedlings, six weeks after transplanting. Transplant 2, December 1978. Plants from the BP Kwinana station (a) have a growth of algal epiphytes on the stunted leaves, and reduced root growth. In comparison, plants from the Warnbro control (b) have longer leaves free of large epiphytic algae and long, white roots indicating vigorous root growth.

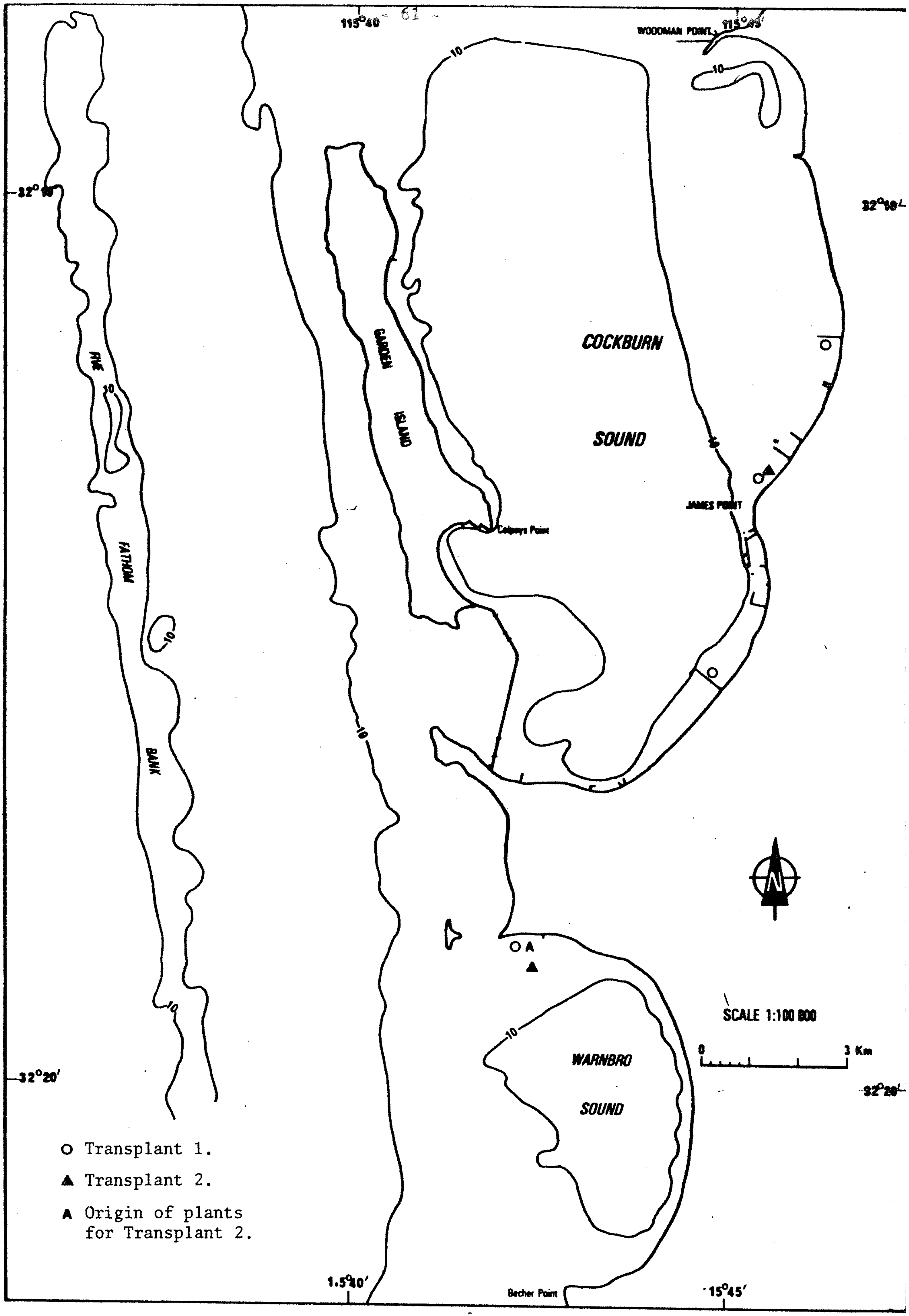


FIGURE 5.1

Seagrass transplant stations

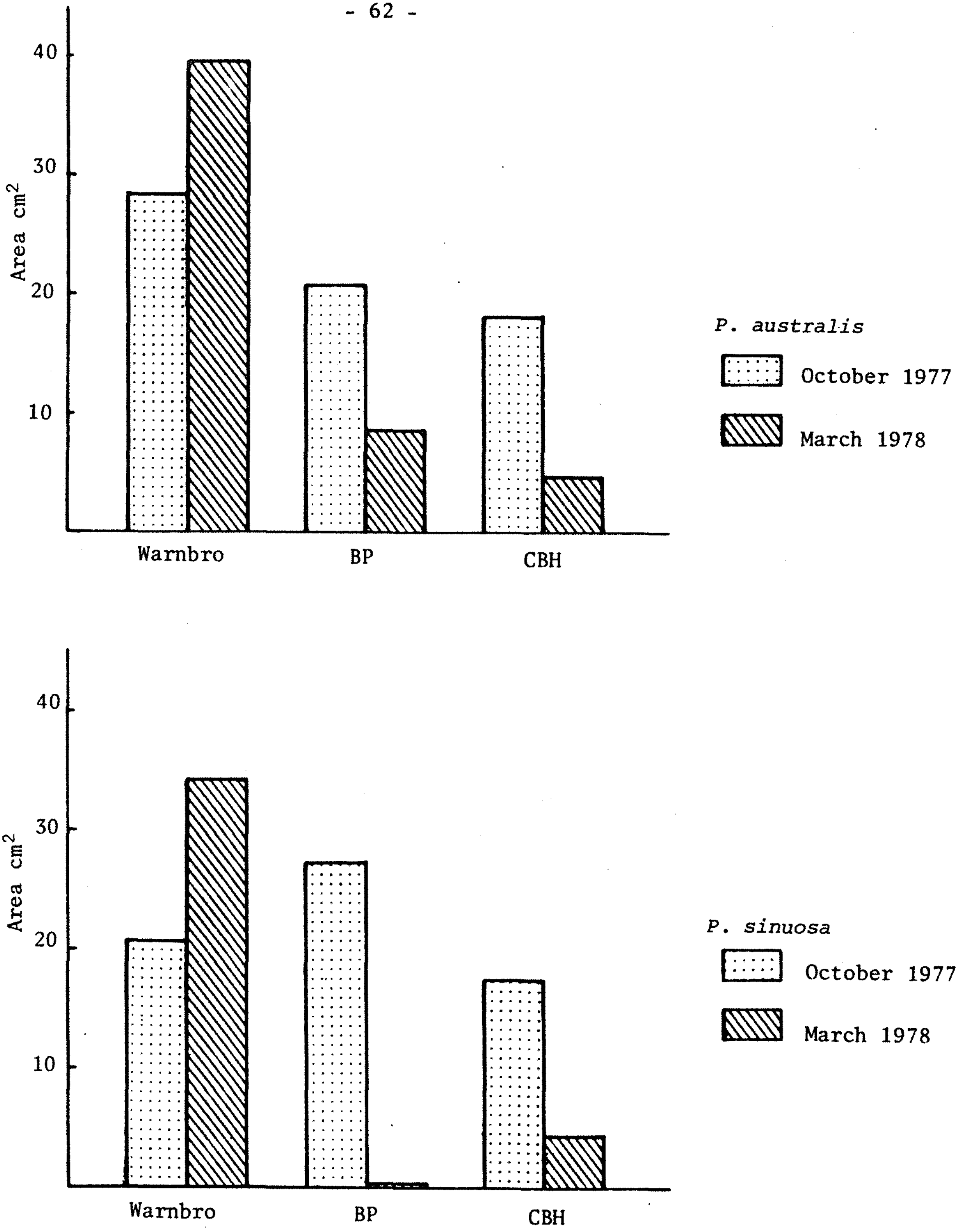


FIGURE 5.2

Change in mean leaf area per plant of surviving seedlings at start and finish of Transplant 2.

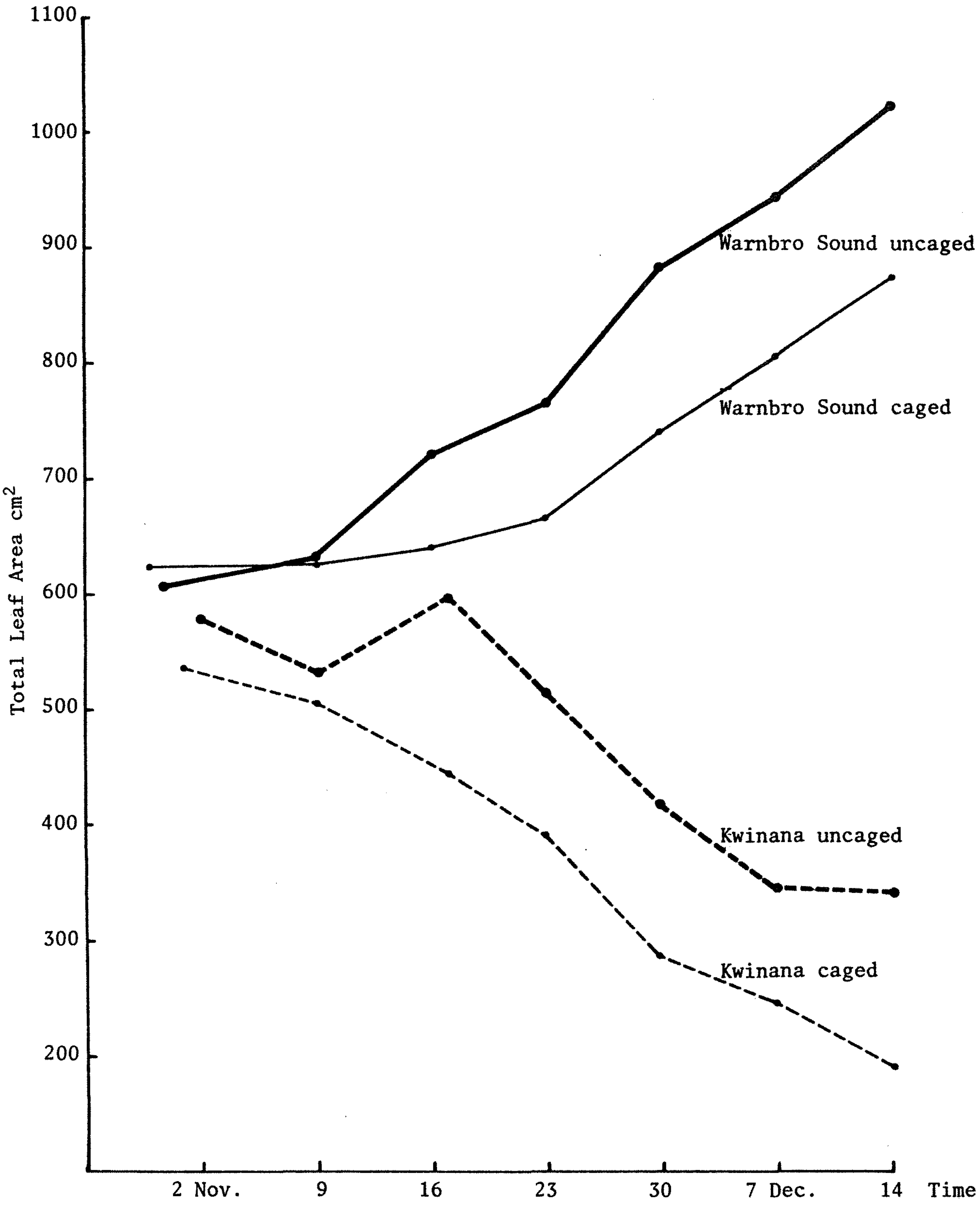


FIGURE 5.3

Leaf areas of *Posidonia sinuosa* seedlings during seagrass Transplant 2.

TABLE 5.1

PERCENTAGE SURVIVAL OF SEEDLINGS FIVE MONTHS AFTER TRANSPLANTING - TRANSPLANT 1.

	Posidonia australis		*Posidonia sinuosa*	
	Initial No.	Survivors %	Initial No.	Survivors %
Warnbro to Warnbro	10	70	9	56
Warnbro to BP	10	70	10	10
Warnbro to CBH	9	44	10	50
Warnbro to Alcoa	No data		No data	

TABLE 5.2

PERCENTAGE OF SEEDLINGS RETAINING LEAVES FIVE MONTHS AFTER TRANSPLANTING - TRANSPLANT 1.

	Posidonia australis %	*Posidonia sinuosa* %
Warnbro to Warnbro	70	56
Warnbro to BP	30	0
Warnbro to CBH	33	10
Warnbro to Alcoa	No data	No data

TABLE 5.3

LEAF AREAS OF SURVIVING SEEDLINGS BEFORE AND FIVE MONTHS AFTER TRANSPLANTING - TRANSPLANT 1.

	Posidonia australis			*Posidonia sinuosa*		
		Mean area (before) cm^2	Mean area after five weeks cm^2		Mean area (before) cm^2	Mean Area after five weeks cm^2
Warnbro-Warnbro control	$\bar{x}$	28.4	39.9	$\bar{x}$	20.7	34.1
	s.e.	±3.0	±10.3	s.e.	±2.3	±9.8
Warnbro-BP	$\bar{x}$	20.9	8.5		27.2	0
	s.e.	±2.2	±3.5		-	-
Warnbro-CBH	$\bar{x}$	18.1	4.8		17.3	4.2
	s.e.	±1.8	±4.1		±4.6	±3.8

TABLE 5.4

TRANSPLANT 2: LEAF AREAS OF *POSIDONIA SINUOSA* SEEDLINGS DURING TRIAL.

(Raw data is given in Appendix 4)

Trial Group	Initial Area cm^2	Week 1 Area cm^2	Week 6 Area cm^2	Net Change Week 1 to 6 cm^2
<u>Warnbro Caged</u>				
Total (N = 20)	722.73	728.85	976.30	247.45
Mean	36.13	36.44	48.82	12.37
s.e. Mean	± 3.58	± 3.31	± 4.47	± 4.48
<u>Warnbro Uncaged</u>				
Total (N = 20)	707.05	731.30	1122.05	390.75
Mean	35.35	36.57	56.10	19.54
s.e. Mean	± 2.98	± 3.31	± 5.89	± 3.21
<u>Kwinana Caged</u>				
Total (N = 20)	637.76	607.37	293.40	-313.97
Mean	31.89	30.37	14.67	-15.70
s.e. Mean	± 4.24	± 3.38	± 2.76	± 3.02
<u>Kwinana Uncaged</u>				
Total (N = 20)	679.75	632.95	441.99	-190.96
Mean	33.99	31.65	22.10	9.55
s.e. Mean	± 2.82	± 3.19	± 2.83	± 2.43

TABLE 5.5

ANALYSIS OF VARIANCE (ANOVA SINGLE CLASSIFICATION) OF LEAF AREAS, TRANSPLANT 2.

(Between the four groups of seedlings, caged and uncaged plants at Warnbro and Cockburn Sounds)

Source of Variation	df	SS	MS	F
Between the four groups	3	2077832	692610.7	0.291 NS
Within the four groups	76	0.1810394E+09	238209.7	
Total	79	0.18131172E+09		

NS = Analysis not significant at p < 0.10

TABLE 5.6

ANALYSIS OF VARIANCE (ANOVA SINGLE CLASSIFICATION) OF TOTAL LEAF AREAS AT KWINANA AND WARNBRO SOUND AT END OF TRIAL

Source of Variation	df	SS	MS	F
Between Kwinana and Warnbro plants	1	0.2369335E+09	0.2369335E+09	67.353***
Within Kwinana and Warnbro plants	78	0.2743873E+09	3517786	
Total	79	0.5113208E+09		

*** analysis significant at p <0.001

TABLE 5.7

ANALYSIS OF VARIANCE (ANOVA SINGLE CLASSIFICATION) OF NET CHANGE IN LEAF AREA FROM WEEK 1 TO WEEK 6 BETWEEN KWINANA AND WARNBRO SOUND, TRANSPLANT 2.

Source of Variation	df	SS	MS	F
Between Kwinana and Warnbro plants	1	0.1641645E+09	0.1641645E+09	70.917***
Within Kwinana and Warnbro plants	78	0.1805598E+09	2314869	
Total	79	0.3447243E+09		

*** Analysis significant at p <0.001

TABLE 5.8

LIGHT ATTENUATION COEFFICIENTS AND MEAN LIGHT INTENSITY RECORDED DURING SEAGRASS TRANSPLANT 2.

Station	Date			Average
	20.11.78	23.11.78	14.12.78	
Kwinana				
Over uncaged seagrass	0.15	0.18	0.21	0.18
Inside seagrass cage (cleaned cage)	0.19	0.31	0.28	0.26
Inside seagrass cage (uncleaned cage)	0.27	N.D.	0.33	0.30
Warnbro				
Over uncaged seagrass	0.12	0.12	0.14	0.13
Inside seagrass cage (cleaned cage)	0.16	0.16	0.18	0.17
Inside seagrass cage (uncleaned cage)	0.15	N.D.	0.19	0.17

MEAN LIGHT READINGS FOR ABOVE DATES IN $\mu Em^{-2}s^{-1}$

	Kwinana	Warnbro
Over uncaged seagrass	717	965
Inside cleaned cage	507	719
Inside uncleaned cage	372	674

6. THE CONTRIBUTION OF SEAGRASS TO THE ECOSYSTEM

6.1 Introduction

The effects of the loss of the seagrass meadows on Cockburn Sound could be gauged to some extent by considering the contribution of seagrasses in general to the ecosystem. This can be summarised from the literature as follows:

- Seagrasses have a high growth rate, producing quantities of leaf material which enter the detrital food chain.
- Few organisms feed directly on seagrass but on the epiphytes and bacteria on living leaves, and the detritus with associated microbes formed from shed leaves is an important and constant source of food for detritivores.
- Seagrasses take up nutrients and release metabolites including oxygen and complex organic compounds through their roots and leaves. The importance of seagrasses to chemical cycles, has been noted, particularly for semi-enclosed waters (Thayer and Phillips, 1977 (74)).
- The underground roots and rhizomes bind the sediments, and with the protection afforded by the leaves, surface erosion is reduced. The leaves of a dense meadow retard wave and current action promoting sedimentation of organic and inorganic materials, and hence the food supply of the resident detritivores.

These considerations suggest that two important attributes of the seagrasses, leaf growth and the generation of detritus, should be described for the Cockburn Sound system in this chapter. France (1978 (21)) considered the other major contribution of seagrass, that of trapping and binding of sediments and their longer term role in modifying sedimentation during the evolution of Cockburn Sound to its present form. There are also complementary studies on fish (Dybdahl, 1979 (18), Scott *et al*, in press (67)), and fauna including those species associated with seagrass (Wells, 1978 (30), Wilson *et al*, 1978 (87)).

6.2 Measurement of Primary Productivity

6.2.1 Introduction

The photosynthetic production of new organic matter (gross production) by plants containing chlorophyll converts part of the sun's radiant energy into a form which can be used by living organisms. Some of the organic matter initially produced is respired by the plant to provide energy for its own metabolism and the rest accumulates in the plant body. That part which is not respired is commonly termed the net primary production, which is contrasted with the initial gross production.

The net production is available for consumption, either before or after the death of the plant, by animals, bacteria and fungi, which are unable to create new organic matter themselves. Definitions below are based on those of Westlake (1963 (82)).

Standing crop - the dry weight of plant material which can be harvested from a given area at one time; in the case of *Posidonia* spp., the above ground portions of the plant are leaves and flowering shoots whereas in *Amphibolis* spp., this also included the above ground stems.

6.2.1 (Cont'd)
Biomass - like standing crop, this is the dry weight on a unit area at a given time but includes all portions of the plant above and below ground.

Primary production - the production of new organic matter measured as the increase in plant biomass (above and below ground) over a period.

Primary productivity - the production rate, that is, the average of short term rates of production; in the case of this study over a period of one month, and then projected for one year.

No attempt was made to measure the component of organic matter leaching from the leaves and underground portion of *Posidonia*. This is a small but readily available contribution to the energy flow of the system: Kirkman and Reid (1979 (38)) measured substantial daily loss of dissolved organic matter from the leaves of *P. australis* in Port Hacking, New South Wales, but did not distinguish between that excreted from the living portion of leaves and that leaching from dead or senescing portions.

The contribution of submerged attached macrophytes, especially the seagrasses, to total primary production in many coastal areas has been acknowledged (Ryther, 1963 (64); Earle, 1972 (19)), but until recently Dillon, 1971 (17); Waite and Mitchell, 1972 (77); Mann, 1973 (43)), seldom adequately quantified. Several techniques have been used to estimate production of macrophytes. Annual macrophyte production has been estimated for measurements of either maximal seasonal biomass or seasonal area biomass changes (Westlake, 1963 (81), 1965 (82); John, 1971 (35); Bellamy *et al*, 1973 (8)). However, such methods are not applicable to plants such as the seagrasses *Posidonia* spp. which show almost continuous production and biomass loss throughout the year.

Two techniques are currently used for investigation of seagrass production. Wetzel (1964 (83), 1965 (84)) first successfully adapted the inorganic ^{14}C uptake technique of Steeman-Nielsen, 1952 (72) for use in the measurement of aquatic vascular plant productivity. Wetzel's modifications have been used in several investigations of marine angiosperm productivity (Brylinski, 1971 (11); Dillon, 1971 (17); McRoy, 1974 (48); Bittaker, 1975 (9)). The method has recently been criticised as underestimating net photosynthetic rates due to possible internal recycling of carbon dioxide in those species with lacunal spaces (McRoy, 1973 (47); Patriquin, 1973 (55); Wetzel and Hough, 1973 (86)).

Zieman (1968 (88), 1974 (89), 1975 (90)) developed a simple and inexpensive staple-marking method involving plant-shoot lengthening as a measure of net leaf production in *Thalassia testudinum* over 4 to 14 day periods. The technique requires long periods of underwater work to staple and measure the plants but despite this disadvantage, it was chosen as the method for production studies on *Posidonia*. The relatively long "incubation" time between stapling and measurement gives integrated production values for the range of environmental variables such as light, temperature and water movement typical of the season. In the following work, an attempt was made to provide production data at a range of habitats over one cycle of the seasons. The number of locations sampled and the regularity of sampling, the need for integration of the effects of environmental variables over long periods, and the need to include the influence of water movement made the use of inorganic ^{14}C uptake techniques impracticable for *Posidonia*.

6.2.1 (Cont'd)
It should be emphasised that the data collection from the growth plots was not a monitoring technique to assess the state of seagrass meadows in Cockburn Sound. Instead, the data was used in reconstructing the original production of seagrass in Cockburn Sound before the dieback to enable comparison with the present levels. Only the Garden Island meadow could be considered relatively intact; the rest of the meadows accessible for regular field work could not be considered representative of the original state of the seagrass. Hence production had to be measured in Warnbro Sound and Shoalwater Bay to provide control situations.

6.6.2 Methods

Seven growth plots on the sublittoral sand banks were selected; three from Cockburn Sound, three from Warnbro Sound and one in Shoalwater Bay between these two embayments (Figure 6.1). The precise locations of the seven stations selected for growth studies are given as magnetic bearings and sextant angles in Appendix 5.

Three sites were chosen in Cockburn Sound; one on the relatively intact meadows on the Garden Island shore, 5, one on Southern Flats opposite the trestle bridge where seagrass meadows have deteriorated, 6, and one in shallow (1 m depth) water in the lee of the Causeway in Mangles Bay, 7. One site, 4, was chosen in Shoalwater Bay as a control site for *P. sinuosa* where a large meadow had developed in the lee of a limestone island.

Three sites were chosen in Warnbro Sound; at the deep edge (11 m) of the *Posidonia* meadow, 1; at the shallow edge of the meadow adjacent to a sand spit in a mixed community 3; and in a mixed community of seagrasses consisting of *Posidonia* spp. and *Amphibolis* spp., 2.

Growth plots were permanently marked underwater by nylon ropes stretched between three steel stakes outlining an equilateral triangle 10 m per side (Figure 6.2). Ropes provided a much wider target for underwater searches in turbid conditions on occasions when the surface float had been lost. They also defined a study area for leaf density transects.

One polyethylene foam float 15 cm in diameter was positioned 1 m beneath the water surface so as to avoid hazard to boats and was attached to one of three stakes. A second float, positioned at the water surface to enable the station to be located from a boat, was attached to a fourth steel stake in the centre of the triangle of rope. Surface floats were frequently vandalised and so were secured independently of the rope-and-stake markers.

Stations were fixed by compass and/or sextant bearings enabling their accurate plotting on charts and aerial photographic mosaics (Appendix 5).

Plants for primary production measurement were marked by a frame of plastic coated steel rod enclosing an area of 0.1 m^2. The frame was anchored by four steel spikes welded to the frame; when the spikes were pressed into the sand they held the frame flush with the substrate level.

Primary production was measured at approximately one month intervals from May 1977 to November 1978 by stapling at the base as outlined by Zieman (1974b (89)).

6.6.2 (Cont'd)

As time progressed staples in the leaves moved towards tips of blades, as growth is confined to the meristem at the base. At the same time erosion occurred at the tips of the leaves so that the leaves could be regarded as moving belts of tissue, producing new tissue at the base and shedding particulate and dissolved organic matter to the environment from the tips.

Leaves within a frame were stapled at the base by divers and harvested one month later as entire shoots with care being taken to retain the young and old leaves in the rhizome apex. After harvesting of the shoots the frame was moved to another area and the leaves within this area stapled for the following month's harvest. The shoots were placed in labelled plastic bags underwater as they were harvested and carried back to the laboratory.

The length increment of leaves for each shoot was measured in cm; leaves were measured and recorded in sequence from oldest to youngest. As the leaves remained attached to their parent shoot after the measuring, new leaves emerging between the period of stapling and harvesting could be included in the primary production measurements.

The leaves were dipped in ten per cent HCl for ten seconds to remove calcareous epibiota and sediment and lightly scraped. Staples were removed and the leaves were cut level with the leaf base of the staple, dividing each leaf into an increment and remainder. The increment was dried in a forced draft oven at 40°C to constant weight and then dry weighted after cooling in a desiccator.

On one occasion the density of shoots per square meter were estimated by harvesting all shoots from transects of 15 contiguous quadrats each 0.1 m^2 in area. Shoots and leaves were counted and converted to number per square meter. Transects were run along one of the ropes marking the growth plots. In areas where more than one species occurred, shoot density of each species was sampled by transects running through a pure stand. Shoot density does not change with season and is relatively constant with time in a mature portion of a meadow so densities were sampled only once. Shoot densities were used to convert length and weight increments of individual shoots to increments per hectare. Density data has been placed in the Cockburn Sound Data Repository.

Annual primary productivity for each *Posidonia* species at each site was calculated from the length and weight increments converted to increment per hectare using the shoot density estimates, and summed for all the growth intervals over a year. Production data are given in Appendix 6a and 6b.

6.2.3 Tables and Discussion

Table 6.1 compares above-ground primary productivities calculated for *P. sinuosa* at seven sites and for *P. australis* at two sites. *P. australis* was sampled consistently only at two sites, where it occurred in well developed stands which could be considered to make a significant contribution and exhibit typical growth forms. Three growth plots (2, 4 and 5) (Table 6.1) which were typical of well developed *P. sinuosa* meadows at mid depth (2-3 m) produced 5.1-6.7 t/ha/y of leaf material. These annual productivities were used to calculate the annual production of *P. sinuosa* for Cockburn Sound overall before the recent depletion of seagrass meadows, using the area once vegetated by seagrass from Figure 2.2

6.2.3 (Cont'd)

Growth plots 1 and 3 enable comparisons to be made between the production of *Posidonia* at the deepest and shallowest limits of the meadow with sparse seagrass at the deep edge of the Warnbro *Posidonia* meadow.

Growth plot 1 at 11 m was producing at a rate of 1.04 t/ha/y. This contrasts with growth plot 3 at the shallowest edge of the Warnbro meadow in 0.5 m depth producing 7.99 t/ha/y, where the leaf canopy was dense and there was maximum light throughout the year, well agitated water, as well as fluctuating temperature and rare exposure by low tides.

Growth plot 7, in shallow (1 m) water, was situated in the lee of the Cockburn Sound Causeway. Although suspension of the fine sediment often produced turbid water, the shallow depth and continual "top dressing" by sediment of the meadow, resulted in a very high growth rate and correspondingly high productivity at 8.06 t/ha/y. This was in marked contrast to growth plot 6 (2 m) lying to the east of the trestle bridge on Southern Flats where seagrass meadows are deteriorating and productivity was esimated at 0.7 t/ha/y. This value is considered to represent that of depleted seagrass meadows, where *Posidonia* although still present, is showing signs of deterioration, with heavy epiphyte growth, stunted leaves, mussel settlement and erosion of sand around the remnant clumps of seagrass.

Comparison of production growth plot 2 and 3 allows comparison of *P. australis* in optimal and suboptimal habitats. Production at growth plot 2 (2.5 m) in Warnbro Sound where growth conditions in terms of light, water agitation and sedimentation were taken to be optimal may be compared with growth plot 3 at the edge of the sand shoal which was exposed by low tides of varying duration and timing were suboptimal (Table 6.1). During early summer the leaves at growth plot 3 were completely burnt and sand was eroded away during the ensuing period of partial defoliation. Thus, despite the relatively high density of plants, growth conditions were considered to be suboptimal and the low productivity (1.3 t/ha/y) was representative of *P. australis* growing in less than favourable conditions.

6.2.4 Annual Primary Productivity for Cockburn Sound Before and After Industrial Development

A reconstruction of the primary productivity of Cockburn Sound before industrial development was based on the area in hectares of seagrass, estimated from aerial photographs in 1954 for the eastern shore and later aerial photographs of Southern Flats, Garden Island and Parmelia Bank, and discussed in detail in Section 2.3. Figures 2.2 and 2.3 show the extent of meadows in 1954 and 1978. The area in hectares and the calculated primary productivity is shown for each major area of seagrass meadow in Table 6.2 for 1954 and 1978.

In 1954, it is estimated that more than 4 000 ha of *Posidonia* produced almost 23 000 t (dry weight) of leaf material each year. This leaf material enters the food chain via the detrital cycle. By 1978, with less than 900 ha of seagrass estimated to remain and a number of areas showing decreased productivity (for example areas of Southern Flats and Careening Bay), it is estimated that about 4 000 t of leaf material were produced.

6.3 Animal Associations and Detrital Food Webs

In the time available for this study, the animal associations and detrital food webs of the Cockburn Sound ecosystem could not be investigated in detail. This section therefore relies mainly on information extracted from the literature. It should be borne in mind that different species of seagrass do offer different habitats, although some generalisations can be made.

Seagrasses can be regarded as a discrete ecosystem, trapping material to enrich the substrate beneath the leaf canopy and exporting plant and animal material to sink areas or the open sea, so that the seagrass ecosystem acts as both a filter and pump.

Thayer and Phillips (1977 (74)) review the literature and conclude that the number of species and the abundance of organisms within seagrass meadows (specifically for *Zostera marina* and *Thalassia testudinum*) are recorded as generally greater than those of adjacent areas devoid of seagrass. This greater variety of organisms and the richness of the animal populations are in part a response to the presence of a variety of habitats and food sources within the grass meadow by their presence on a relatively uniform sandy substrate. Seagrasses create a diversity of habitats and substrates, so that a structured habitat emerges from a structureless one. The animal associations of seagrass beds throughout the world generally can be considered as having several major vertical layers of organisation; animals living on the blades and stems, those swimming among the plants, and those living on and in the substrate (Thayer and Phillips, 1977 (74)). Organisms living on the blades are typically not found, or are found in significantly smaller numbers, in regions devoid of seagrass. On the other hand some of the animals living on or in the substrate may also occur in the benthic communities of adjacent bare substrates. Of the mobile, swimming organisms, some may be members of the seagrass meadow, some are seasonal migrants, and others use the seagrasses for food or protection, moving into the areas at night for example.

The fauna resident on the leaves and on and within the epiphytic coating is very diverse and includes diatoms, encrusting algae, and bacteria. As a group, these animals derive their nutrition from microalgae and detritus (dead matter), and are consumed by small animals which in turn are fed by larger animals. The resident fauna may be divided into five groups:

- Small organisms living in and on the epiphytic coating. This group made up of herbivores (animals feeding on living plants), detritivores (animals feeding on detritus), and carnivore members of the protozoans (ciliates, flagellates and foraminiferans), free living nematodes, small polychaetes and small crustaceans.

- Sessile or attached fauna. These organisms are filter feeders or generally feed on small crustaceans, larval fish, and detritus. Molluscs and different life history stages of larger animals often are found attached to the plant leaves.

- Organisms which move over the blades, represented by snails, polychaete, ribbon worms, amphibods, isopods, and some echinoderms (starfish and urchins primarily).

- Swimming animals able to rest on the leaves. Some species of shrimps, small crabs and certain fish are common members of the fish group.

6.3 (Cont'd)

- Animals attached to stems and roots, notably tube-building polychaetes and amphibods.

The second major category, the mobile animals swimming among and under the leaves, is more easily recognisable because of their larger size. These organisms may be permanent, seasonal, or only occasional residents of seagrass beds. They are for the most part carnivores, feeding on detritivores; they also may feed on detritus. Because they are carnivores, their seasonal and daily movements into and out of seagrass beds may significantly influence the trophic (nutritional) structure of the beds. Representatives of this category are the decapod crustaceans (shrimps and crabs), and numerous species of fish. For some fish, the seagrass beds form significant nursery grounds but often are more important for larval and postlarval stages as seems to be the case for Cockburn Sound (Dybdahl, 1979 (18)).

The third major category, that of animals living on or in the substrate includes sponges, echinoids (sea urchins and starfish), molluscs, crustaceans and worms. Many of these feed on detritus, although algae (including phytoplankton) and small crustaceans may also be consumed.

Members of these categories are not necessarily confined to the seagrass meadow; they can often extend to adjacent bare substrates.

The division of the fauna into these three categories is not rigid; animals may overlap between the boundaries especially at different stages of their life cycle. The animal components of all the strata are linked together by trophic relationships. These relationships plus the great variety of organisms and habitats within eelgrass beds result in a complex ecosystem which functions primarily through herbivorous and detrital feed webs. The herbivorous food chains generally are short, while the detrital chain normally is long and complex. By far the most predominant food pathways in these meadows are: grass → detrital (plus attendant microbes) → detritivores → carnivores.

There are few organisms which feed directly on the living grass blades and, therefore, most of the plant material produced within the bed falls to the substrate or is transported to the shore or sink areas, and is slowly decomposed by bacteria. In Cockburn Sound, the deep basin with a fine calcareous mud substrate at 20 m was probably a major sink for seagrass detritus in the past. Most of the plant material is used by animals as partially decomposed matter, either suspended in the water or deposited in or on the bottom. Different stages of decomposition of the material may correspond with different detrital feeding organisms. For example, sea urchins, crustaceans, and fish may feed on large plant pieces, while some molluscs and polychaetes may feed on fine plant detritus. In addition the leaves support a myriad of organisms, many of which go unnoticed because they are (or nearly are) microscopic. These, in turn, support larger organisms of both ecological and commercial importance. Detritus and whole leaves produced within the meadows are transported to open waters of the Sound and nearshore coastal environment where they may provide an important food source for open-water animals. Animals which feed in the beds and migrate elsewhere also link the beds to the open water environment as food sources for larger animals inhabiting open waters. The living meadows and decomposing detritus produce dissolved organic matter, a complex array of organic chemicals which provide nutrients for bacteria and phytoplankton in the water column as well as those sessile on the substrate or plants.

6.3 (Cont'd)
When a seagrass meadow becomes depleted or dies, the detritus producing system is lost and along with it the complex structured ecosystem outlined above. The dead *Posidonia* meadows in Cockburn Sound have been replaced by patches of algae and sporadic occurrences of mussels. Changes in the fish fauna, with loss of seagrass are discussed in Dybdahl (1979 (18)); fish communities were compared between seagrass meadows and bare sand areas and the differences taken to represent changes in fauna with loss of seagrass.

Wells (1978 (80)) compared the molluscs fauna of the Eastern Shelf recorded by the W.A. Naturalist Club during 1958-60 (reported in Wilson *et al*, 1978 (87)) in areas vegetated by seagrass with the same areas which are now denuded of seagrass. The molluscan fauna typical of the *Posidonia* had disappeared with the loss of the seagrass and was replaced with species characteristic of sand patches or the deep central basin.

Wilson *et al* (1978 (87)) re-sampled the benthic fauna of Cockburn Sound at the same stations as the W.A. Naturalist Club Survey, including a number of stations once vegetated by seagrass where bare sand now forms the substrate. The original community typical of *Posidonia* has changed with the disappearance of the seagrass.

6.4 General Conclusion

There has been considerable loss (estimated to be about 19 000 tonnes per year) of seagrass leaf material, the base of the detrital food chain in Cockburn Sound measured as above-ground productivity. This has and will continue to alter animal associations dependent on the seagrass habitat or on seagrass detritus as discussed in Section 6.3.

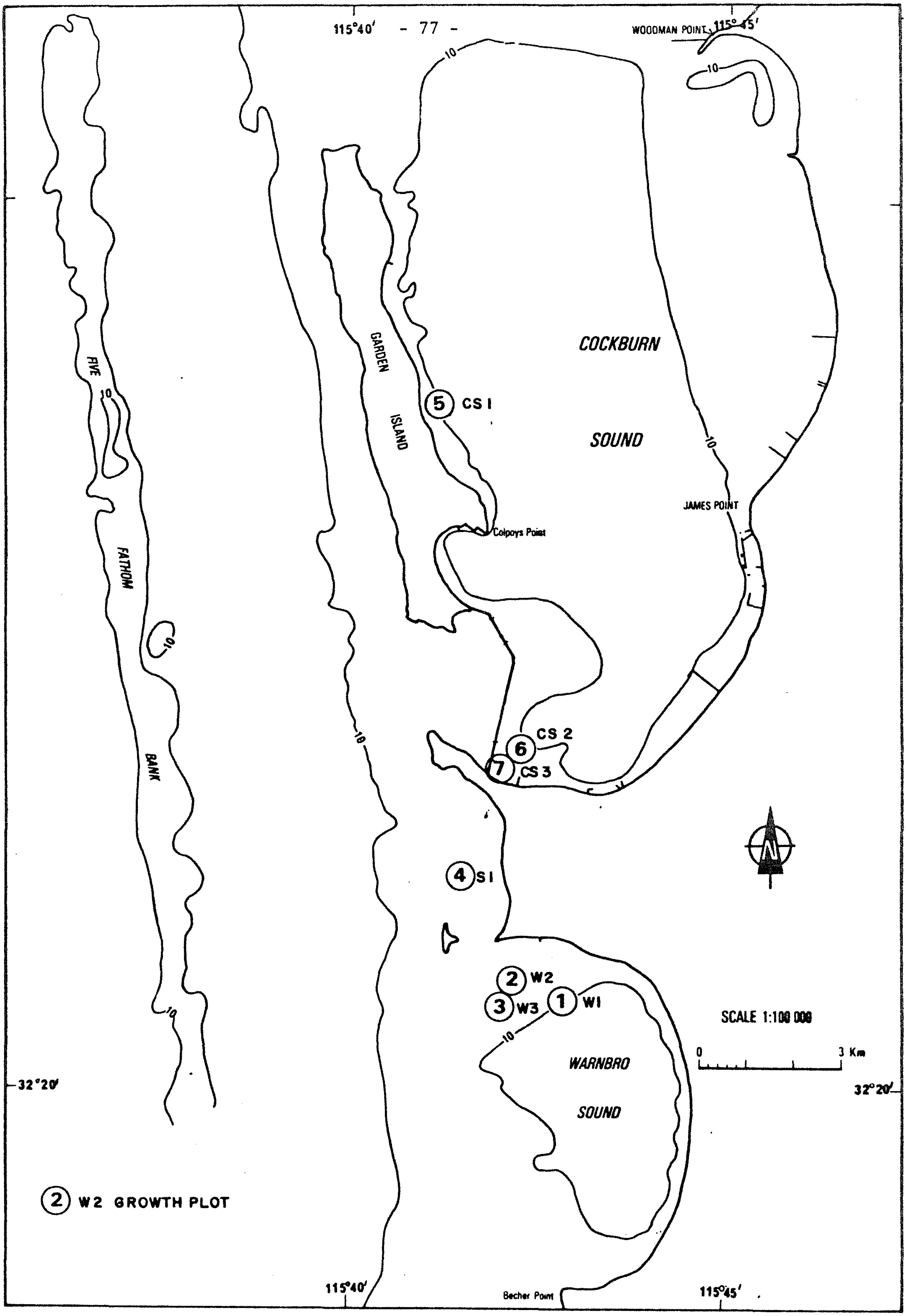


FIGURE 6.1

Growth plots for *Posidonia* spp. primary productivity estimates. Cockburn and Warnbro Sounds 1977-1978

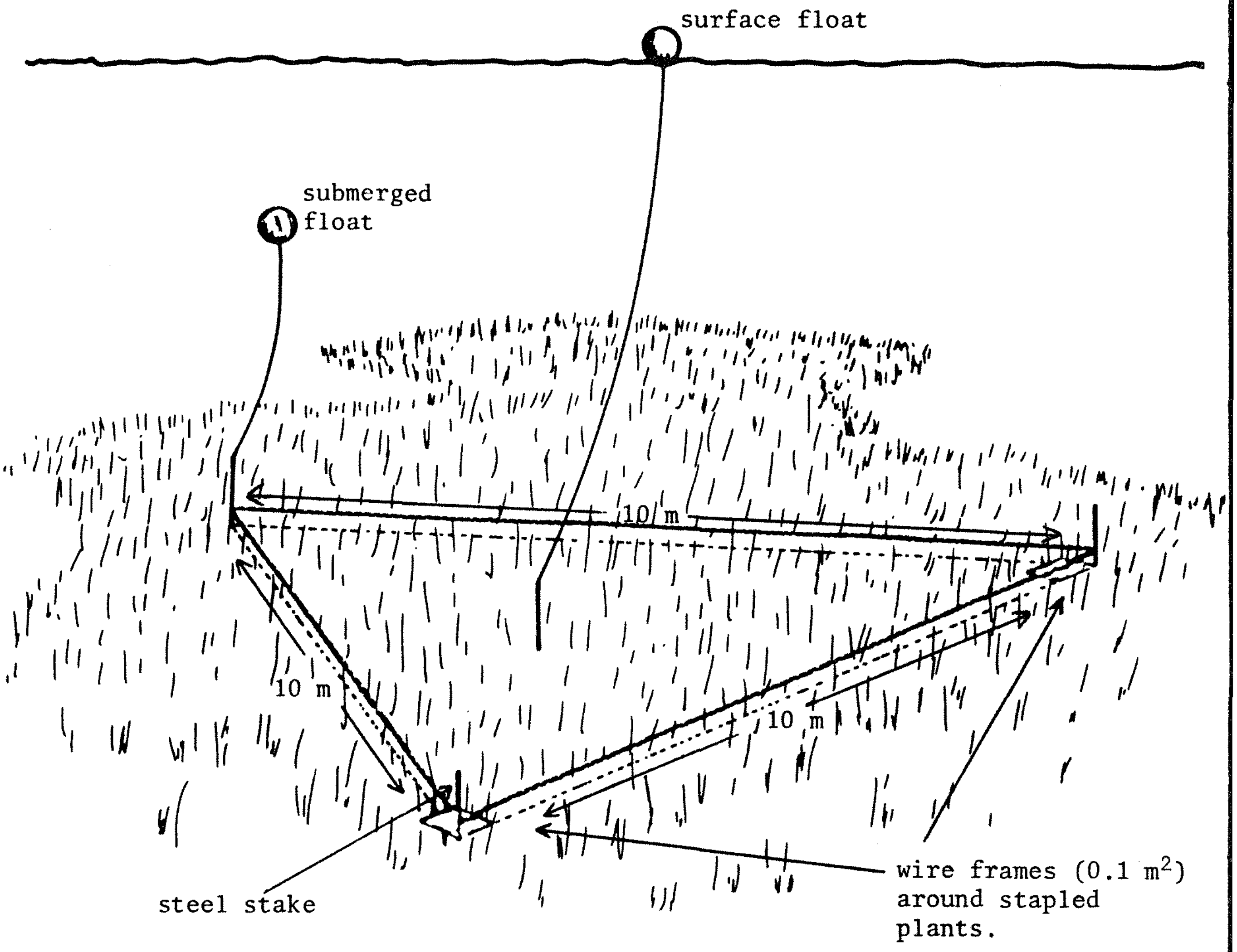


FIGURE 6.2

Permanent underwater growth plot for primary productivity estimates of *Posidonia* spp

TABLE 6.1a

ANNUAL PRODUCTION OF *POSIDONIA SINUOSA*

Station and depth	Production of Leaf Area (cm^2 leaf/m^2)	Primary Production tonnes/hectare dry weight
Warnbro Sound		
1. 11 m	28,281.± 2,129	1.04 ± 0.104
2. 2.5 m	128,261.± 7,803	5.39 ± 0.33
3. .5 m	163,112.±26,162	7.99 ± 1.28
Shoalwater Bay		
4. 3.5 m	139,032.±17,769	6.67 ± 0.86
Cockburn Sound		
5. 2.5 m	111,441.±11,389	5.15 ± 0.52
6. 2 m	14,580.± 2,388	0.70 ± 0.11
7. 1 m	158,119 ±13,976	8.06 ± 0.71

TABLE 6.1b

ANNUAL PRODUCTION OF *POSIDONIA AUSTRALIS*

Station and depth	Production of Leaf Area (cm^2 leaf/m^2)	Primary Production tonnes/hectare dry weight
Warnbro Sound		
2. 2.5 m	242,390.5± 25,400.4	11.39 ± 1.19
3. 0.5 m	25,655.5± 2,962.9	1.30 ± 0.15

TABLE 6.2

CALCULATION OF SEAGRASS PRIMARY PRODUCTIVITY IN COCKBURN SOUND 1954 AND 1978

Location	1954			1978		
	Area (ha)	Primary Productivity (T/ha/year)	Tonnes/year dry weight	Area (ha)	Primary Productivity (T/ha/year)	Tonnes/year
North of Garden Island	73	6.67	487	73	6.67	487
Garden Island shore (Beacon Head - Colpoys Point)	324	5.15	1 669	300	5.15	1 545
Careening Bay	4	5.15	21	<0.1	3	<0.3
Southern Flats	558	6.67	3 722	300	3	900
Rockingham Bank (Palm Beach - north of James Point)	440	5.39	2 372	<1.0	.7	<.1
Nearshore eastern shelf	124	5.39	668	<0.1	.7	<.1
Eastern shelf	2 350	5.15	12 103 7 050	ca 5	.7	3.5
South of Woodman Point	23	50% 7.99 50% 5.39	92 62	ca 10	.7	7
Parmelia Bank	300	5.39	1,617	200	5.39	1 078
TOTAL	4 196		22 813	888		4 021

7. MECHANICAL EFFECTS OF LOSS OF SEAGRASS

7.1 Introduction

Seagrasses modify sedimentation in four ways (Read, 1974a (62)). It may be assumed that these processes occur in Cockburn Sound.

Firstly, skeletal particles from the calcareous biota resident upon the leaves contribute to the existing sediment pile.

Secondly, the leaf canopy of a seagrass meadow acts as an organic baffle, absorbing kinetic energy of waves by impeding the orbital movement of water and dissipating wave height, because of increased bottom friction and the oscillation of the leaves. Wayne (1976 (79)) documents the reduction of 42.2 per cent in wave height across 20 m of turtle grass (*Thalassia testudinum*) on shallow sand banks in Florida and a reduction of 66.6 per cent in wave energy; a gradient of 2.1 per cent and 3.3 per cent per meter respectively. This dissipation of wave energy by the seagrass leaf canopy results in lower energy conditions within the canopy and the formation of a sediment trap where particles entrained in the water column are allowed to settle. Scoffin (1970 (66)) reported that the dense *Thalassia* beds tidal currents of 40 cm s^{-1} measured immediately above the leaf canopy was reduced to zero at the sediment - water interface. The strap-like leaf blade was bent over to form a stream lined cover for the sediment surface. Wanless (1976 (78)) gives an example of the low energy sedimentary environment beneath a seagrass (*Thalassia*) leaf canopy. Seagrass beds in Biscayne Bay modify bottom currents and substrate to permit lime mud accumulation up to a depth of 3 m whereas from purely physical considerations this sediment should be restricted to depths below 5 m in that particular wave climate and bathymetric setting.

Thirdly, a fibrous mesh of rhizomes, roots and fibres remaining after decay binds accreting sediment as the underground portion of the meadow grows vertically. Even when the leaf canopy has been removed and the sand bank surface is exposed to the full effects of wave action the form of the bank is protected against erosion for as long as the rhizome mesh remains relatively intact.

Fourthly, organisms living within the seagrass also modify the sedimentary environment through sediment entrapment (filter feeders and organisms including epiphytes produce mucilaginous films which remove particles from suspension) and textural modification (pellet aggregation) so that fines bound together act as sand sized particles (Wanless, 1976 (78)).

7.2 Sedimentation in Cockburn Sound

Fringing and barrier banks have formed in Cockburn Sound under the biological influence of seagrasses which trapped and bound sediments (France, 1978 (21)). The source of these sediments appears to have been largely external to Cockburn Sound rather than from the deposition of skeletal material derived from organisms resident on or amongst the seagrass. The prevailing influence on the influx of external sediment appears to have been the westerly to south westerly swells refracted through breaches in the Garden Island ridge of islands and reefs. The deposition of these sediments has been localised on a broad scale by the interference of the acute wave trains shown in France's Figure 5. At the smaller scale, thick seagrass meadows promoted deposition and bound the sediments, contributing to the formation and maintenance of banks.

7.2 (Cont'd)

It is reasonable to assume that when the seagrass leaf canopy on the fringing banks of Cockburn Sound thinned and then completely disappeared the following events occurred, particularly along the eastern fringing banks:

- The sand was winnowed by wave action, with loss of fine sediment including the detrital portions which accumulated beneath the leaf canopy.
- Coarser sediments remained but were eventually transported during storm events leaving the rhizome mesh exposed.
- The rhizome mesh eroded at weak points leaving a scarp face on the remaining mesh which eroded slowly in storms.
- Dissipation of wave energy by the seagrass leaf canopy ceased, so that reduction in energy was a product solely of bottom friction on the shelving bank. Thus, more wave energy was expended on beaches.
- More wave energy reached the shallows adjacent to the beaches when the seagrass meadows further offshore were removed. Sediment transported seasonally off the beaches was subject to more wave energy and subsequent currents once the seagrass meadows had been removed. Instead of being held as a reservoir for the next seasons onshore movement, some of the sand was transported elsewhere resulting in change in beach form (France, 1978 (21)). The time scale and size of these changes will vary according to the degree of exposure of the beach. It is not proposed to explore this effect of loss of seagrass further in this report but the dependence of beach morphology on offshore energy and sediment supply is well documented in the literature.

Most of the Cockburn Sound fringing banks lie in relatively sheltered waters protected from the action of swell waves and are subject more to the smaller internally generated areas of shorter wave length which only begin to move sediments in shallow waters.

Known effects on the fringing banks have all been localised (Andrew, 1979 (3)); less is known about the effect of the loss of the seagrass on the stability of the barrier banks and hence the bathymetry of the Sound.

A degree of surface erosion of the barrier banks, Parmelia and Success, depending on the exposure to sediment transport characteristic of each area is likely to be continuing to occur but the form of the banks could be expected to be protected by the capping of seagrass rhizome mesh (described in Section 2.2) which binds the upper leavels and protects the banks. In other areas, sand sheets moving across the bank surface provide a situation of sediment accretion rather than erosion such as is occurring west of Woodman Point.

It is not known how long the rhizome mesh will remain in place, its presence and the relatively sheltered nature of the Sound are expected to be the major influences on the geomorphic stability of the beaches and fringing banks of Cockburn Sound.

7.3 Conclusion

The loss of seagrasses on the eastern sector of Cockburn Sound and on Southern Flats is likely to have only localised effects on shoreline and bathymetric stability because of the relatively sheltered nature of these areas which are disturbed only by storm events. The effects of very severe storms or cyclones could be expected to be more marked with removal of the influence of the seagrass leaf canopy in damping wave energy and trapping and binding sediments. The long term stability will depend on the durability of the seagrass rhizome mesh, at present capping the banks to a depth of up to one metre. This will be particularly important on Parmelia Bank which is exposed to greater wave action and which dissipates some of the energy of storm waves with a westerly and northerly component before they enter the Sound.

APPENDIX 1.

SEAGRASS REMNANTS ON THE EASTERN MAINLAND BANKS OF COCKBURN SOUND

A survey was made in November 1977, to determine the extent and species composition of the few patches of seagrass remaining on the once extensive seagrass meadows on the eastern shore of Cockburn Sound. Underwater sleds manned by divers were used. The original seagrass meadow, predominantly of *P. sinuosa* extend from a depth of 1-2 m to approximately 10-12 m covering an area of nearly 500 ha between Palm Beach in the south and Alcoa jetty to the north.

The four areas surveyed by underwater sled were as follows:-

1. 500 m south of the CBH grain terminal jetty to the jetty itself at depths ranging from 3.5 m - 6.5 m.

2. North of the CBH grain terminal jetty to some 300 m south of the Kwinana wreck at depths ranging from 2.0 - 13 m.

3. From the northern intake of the Kwinana Power Station to south of the Alcoa jetty.

4. North of the Alcoa jetty for a distance of about 1500 m to the southern limit of the coastal cliffs over depths ranging from 2.9 m - 6.5 m.

The area between the Kwinana Wreck and the Kwinana Power Station, including James Point, was not examined because a number of spot dives had been made in this area without observing any signs of living seagrass.

Description of the Areas Surveyed

1. South of the CBH jetty, the occasional patches of seagrass were restricted to a strip approximately 10 m wide and some 500 m long, over depths of 2.5 m - 4 m. The seagrass grew in patches consisting of *P. sinuosa*, the plants having a fresh green appearance.

2. North of the CBH jetty, patches of seagrass occurred over an area roughly triangular in shape, 40 m in width and a length to the apex of approximately 1 200-1 500 m to a point 300 m south of the Kwinana wreck. The average depth of the seagrass was 3 m - 5 m.

   The densest seagrass occurred over a distance of some 300 m adjacent to the CBH jetty. The patches in this area were 0.5 m - 2.0 m in diameter and approximately 1 m - 5 m apart with a percentage cover of between 30 per cent and 50 per cent. Shoots were sparse but appeared reasonably healthy but no flowers were observed. At a distance greater than 300 m from the jetty, the seagrass was sparser, similar to that south of CBH jetty and was much thinner beyond 1 000 m. *P. sinuosa* was the only species present.

3. South of the Alcoa jetty a few patches of seagrass were present over a distance of 250-300 m.

   The patches, were between 0.5 m and 3 m in diameter. *P. sinuosa* and *P. australis* were present but *P. australis* was the more common. The shoots appeared fresh and green, although leaves were short, between 20-30 cm in length.

APPENDIX 2.

TOTAL NITROGEN DISCHARGED PER ANNUM BY BP REFINERY AND KWINANA NITROGEN COMPANY (KNC)

YEAR	BP CATALYTIC CRACKER UNIT Calculated Total Annual Nitrogen Output kg x 10^3	KNC AMMONIUM NITRATE PLANT Calculated Total Annual Nitrogen Output kg x 10^3
1978	42.0	639.9
1977	71.7	626.9
1976	60.8	619.2
1975	49.1	737.8
1974	40.3	747.8
1973	40.5	813.2
1972	35.4	477.2
1971	29.1	195.7
1970	41.3	245.1
1969	41.7	228.6
1968	45.1	*
1967	39.5	
1966	38.4	
1965	24.8	
1964	33.2	
1963	44.2	
1962	50.8	
1961	47.5	
1960	47.6	
1959	37.9	
1958	48.2	

*In November, 1968 6 588 kg were discharged and in December, 1968 5 737 kg were discharged.

N.B. This data is based on throughput of product rather than actual analyses of effluent.

Information supplied by courtesy of BP Refinery on 12.9.79

4. North of the Alcoa jetty was similar to that of Area 1 above. A strip approximately 20 m wide, over a depth range of 2.0 - 4.0 m was vegetated by small patches 0.5 - 2.0 m in diameter, mostly *P. sinuosa*. These patches extended to the coastal cliffs 800-1 000 m north of the Alcoa jetty, the distance between patches varying from 1 m to 50-60 m.

Although these observations did not include measurement of seagrass plants a survey of maximum standing crop in December, 1977 sampled one remnant patch of *Posidonia* near the CBH jetty; mean above-ground dry weight (standing crop) was 125.5 g/m^2 ±14.24 at station 18 (Table 3.1, Figure 3.2) north of the CBH jetty which included the area of densest seagrass along the eastern shore. This value can be compared to 500-600 g/m^2 dry weight for healthy and well developed meadows of *P. sinuosa* in Cockburn and Warnbro Sounds.

The remnant patches of seagrass now occupy a small area of the banks once continuously vegetated by seagrass meadows: the area of the remnant patches is difficult to calculate because of their sporadic distribution and small size, making them generally invisible in aerial photographs. However, by estimating the frequency of patches (i.e. the percentage of the total area covered) within their zone of occurrence, usually a narrow strip at 3-4 m depth, the area now occupied by seagrass is estimated to be less than 1 ha (Figure 2.3).

APPENDIX 3.

LOCATION OF TRANSECTS FOR SAMPLING OF SEAGRASS STANDING CROP SHOWN IN FIGURE 3.3

3-4.12.77

SAMPLING STATIONS COCKBURN SOUND		
Latitude	Longitude	*Depth (m)
1. 32° 8' 16"	115° 44' 21"	1.5
2. 32° 8' 2"	115° 43' 8"	3.5
3. 32° 7' 3"	115° 42' 25"	3.0
4. 32° 7' 22"	115° 41' 9"	3.0
5. 32° 9' 39"	115° 40' 28"	4.0
6. 32° 11' 7"	115° 40' 30"	3.0
7. 32° 12' 15"	115° 40' 54"	1.5
8. 32° 12' 14"	115° 41' 4"	3.0
9. 32° 12' 45"	115° 41' 22"	3.0
10. 32° 14' 45"	115° 42' 26"	2.0
11. 32° 15' 7"	115° 42' 39"	2.0
12. 32° 15' 8"	115° 43' 0"	2.0
13. 32° 15' 30"	115° 42' 48"	2.5
14. 32° 15' 45"	115° 42' 10"	3.0
15. 32° 15' 41"	115° 41' 52"	3.0
16. 32° 16' 18"	115° 41' 56"	1.0
17. 32° 16' 28"	115° 42' 23"	1.0
18. 32° 15' 23"	115° 44' 47"	3.0
SAMPLING STATIONS WARNBRO SOUND		
19. 32° 17' 35"S	115° 41' 30"E	3.0
20. 32° 18' 32"	115° 41' 36"E	2.0
21. 32° 19' 2"	115° 42' 29"E	4.0

* Depths to the nearest 0.5 m

APPENDIX 4.

POSIDONIA SINUOSA TRANSPLANT 2: LEAF AREAS OF INDIVIDUAL PLANTS AT START OF TRIAL, AT WEEKS 1 AND 6; AND NET CHANGE IN LEAF AREA BETWEEN WEEKS 1 AND 6.

Plant No.	Initial Area cm^2	Week 1 Area cm^2	Week 6 Area cm^2	Net Change Week 1 to 6 cm^2
<u>Warnbro Caged</u>				
Control				
A 1	18.75	11.40	30.00	18.60
2	41.25	42.20	36.50	- 5.70
3	31.60	33.75	36.50	2.75
4	24.80	26.70	32.00	5.30
B 5	55.90	58.00	102.45	44.45
6	56.20	49.25	64.25	15.00
7	13.25	15.25	23.75	8.50
8	21.00	24.75	27.45	2.70
C 9	46.25	43.75	52.85	9.10
10	40.75	48.70	58.50	9.80
11	42.50	45.25	51.75	6.50
12	21.80	16.40	43.80	27.40
D13	26.95	31.30	50.25	18.95
14	45.45	62.30	50.10	-12.20
15	38.00	37.50	33.30	- 4.20
16	37.45	44.40	53.20	8.80
E17	23.50	22.80	55.50	32.70
18	81.08	57.20	29.70	-27.50
19	27.75	30.70	88.55	57.85
20	28.50	27.25	56.10	28.85
<u>Warnbro Uncaged</u>				
Control				
F21	18.50	17.75	15.25	- 2.50
22	41.30	48.50	83.30	34.80
23	50.50	56.75	61.10	4.35
24	50.00	50.50	80.30	29.80
G25	24.00	23.40	27.00	3.60
26	16.50	17.75	10.50	7.25
27	29.50	32.25	51.90	19.65
28	55.50	63.90	109.20	45.30
H29	18.55	18.50	28.00	9.50
30	34.40	30.20	64.80	34.60
31	44.15	39.45	49.50	10.05
32	28.00	31.00	45.00	14.00
I33	66.75	68.25	92.80	24.55
34	39.50	40.65	77.40	36.75
35	36.50	38.95	79.20	40.25
36	27.00	26.50	24.75	- 1.75
J37	38.50	39.25	59.40	20.15
38	32.50	33.25	52.50	19.25
39	33.25	32.25	58.25	26.00
40	22.15	22.25	51.90	29.65

APPENDIX 4. (Cont'd)

Plant No.	Initial Area cm^2	Week 1 Area cm^2	Week 6 Area cm^2	Net Change Week 1 to 6 cm^2
Kwinana Caged				
K41	27.60	25.50	9.90	-15.60
42	6.20	7.00	8.25	1.25
43	35.25	42.92	8.40	-34.52
44	55.20	47.90	17.00	-30.90
L45	34.40	27.25	7.25	-20.00
46	25.50	25.60	6.75	-18.85
47	7.60	7.50	4.25	- 3.25
48	23.40	22.50	13.75	- 8.75
M49	12.00	12.00	5.35	- 6.65
50	19.00	22.35	10.35	-12.00
51	11.00	15.20	Died	0
52	25.00	16.80	13.75	- 3.05
N53	35.60	33.75	21.00	-12.75
54	20.00	20.20	9.00	-11.20
55	35.10	28.25	8.25	-20.00
56	71.25	59.15	55.85	- 3.30
057	56.40	41.30	22.80	-18.50
58	29.00	32.50	18.25	-14.25
59	37.96	47.75	28.25	-19.50
60	70.30	71.95	25.00	-46.95
Kwinana Uncaged				
P61	45.00	44.80	9.25	-35.55
62	18.75	14.25	10.00	- 4.25
63	9.75	7.50	23.40	15.90
64	43.80	29.70	37.90	8.20
Q65	21.80	21.40	17.10	- 4.30
66	28.90	16.50	24.55	8.05
67	38.90	29.00	19.85	- 9.15
68	39.50	36.00	31.30	- 4.70
R69	46.50	36.50	18.90	-17.60
70	56.25	51.75	35.55	-16.20
71	37.30	37.20	19.25	-17.95
72	36.65	32.70	22.50	-10.20
S73	38.00	36.50	15.05	-21.45
74	12.80	9.75	8.25	- 1.50
75	24.50	29.40	3.90	-29.50
76	20.00	12.25	1.75	-10.50
T77	43.50	51.60	19.80	-31.80
78	42.80	48.60	44.85	- 3.75
79	46.15	51.55	44.05	- 7.50
80	28.90	36.00	35.60	- .40

APPENDIX 5.

COMPASS BEARINGS AND SEXTANT ANGLES FOR GROWTH PLOTS 1977-1978

(Nomenclature from Admiralty chart AUS 117, "Gage Roads and Cockburn Sound")

1. Deep margin, Warnbro Sound (W1)

Bearings - Magnetic (M)

South point of Penguin Island	-	283°
Becher Point	-	188°
Safety Bay Yacht Club pine	-	324°
Beacon Fl.R.G2,1M	-	224°

An approximate line of approach can be made by running south-south east of the float marking growth plot (W2) on the southern sand spit, to the edge of the bank.

2. Northern Sand Spit, Warnbro Sound (W2)

Bearings (M)

Safety Bay Yacht Club	-	13°
Becher Point	-	176°
Southern end of Penguin Island	-	289°
Beacon Fl.R.G2,1M	-	207°

Sextant Angles

North point Penguin Island Safety Bay Yacht Club	))	62° 35'
Safety Bay Yacht Club Pine to east of orange roof	))	49° 03' 30"

3. Southern Sand Spit, Warnbro Sound (W3)

Bearings (M)

Safety Bay Yacht Club pine	-	320°
Southern end Penguin Island	-	275°
Becher Point	-	182°

4. Shoalwater Bay

Bearings (M)

Southern tip Seal Island	-	234°
Southern end CBH grain terminal silo	-	60°
Kwinana Power Station tallest chimney	-	38°

5. Buchanan Bay, Cockburn Sound (CS1)

Bearings (M)

South Hill, Garden Island	-	258°
Mt. Moke	-	325°
Kwinana Power Station tallest chimney	-	88°
Cliff Head	-	336°

APPENDIX 5. (Cont'd)

5. (Cont'd)

Sextant Angles

Windmill Beacon No. 2 F.R. 21 m 10M)
and)
Kwinana Power Station southern chimney) 60° 34' 30"

and

Kwinana Power Station southern chimney)
and)
Southern end of Bulk Cargo jetty) 26° 37'

6. Trestle Bridge, Causeway, Cockburn Sound (CS2)

Bearings (M)

Southern end of Causeway trestle bridge - 270°
Southern gantry Bulk Cargo jetty - 55°
Lone Pine, Rockingham foreshore - 100°
Southern Flats beacon Fl. or 6 sec 5 m 7M - 45°
Causeway sentry box - 240°
No. 6 Beacon, Minstrel Channel Fl.G 3 sec 3M - 6°

Lines - John Point (Cape Peron) and the eighth pylon from the southern end of the Causeway trestle bridge.

Junction box on the Causeway (between sentry box and trestle bridge) and the north-west corner of the sewage pumping station on Point Peron.

7. Mangles Bay, Cockburn Sound (CS3)

Bearings (M)

Turtle factory (green roof) - 132°
Navy boundary fence (green) - 208°
Causeway sentry box - 338°
Southern gantry Bulk Cargo jetty - 58°

APPENDIX 6a.

LEAF DATA FOR *POSIDONIA SINUOSA* PRIMARY PRODUCTIVITY ESTIMATES

(These data were used to calculate productivity data from growth plots in Cockburn and Warnbro Sounds, shown in Table 6.1-6.3. Sites of the growth stations are shown in Figure 6.1 and bearings given in Appendix 5.

Station No.	Date	Wt/d/m^2*	TL/m^2*	s.e.
1	08.06.77	.751	3976.	852.
1	05.01.78	1.014	10735.	815.
1	31.01.78	.223	5730.	497.
1	01.05.78	4.226	6461.	524.
1	06.06.78	.120	4911.	332.
1	29.08.78	.134	4316.	304.
1	04.07.78	.158	4420.	931.
1	31.07.78	.197	4544.	438.
1	06.11.78	.365	7989.	402.
2	29.08.77	.849	53328.	4230.
2	05.10.77	1.086	45375.	2946.
2	31.10.77	.957	65052.	3180.
2	06.12.77	2.498	89499.	2535.
2	04.01.78	1.938	69688.	7360.
2	31.01.78	2.472	63576.	4750.
2	07.03.78	.896	28044.	3377.
2	01.05.78	.978	33677.	2825.
2	29.08.78	1.723	36309.	2737.
2	31.07.78	.892	25156.	2540.
2	02.10.78	1.579	50120.	2729.
2	06.11.78	1.938	68874.	3510.
3	29.08.77	9.285	60353.	5134.
3	31.10.77	.974	67063.	4095.
3	05.12.77	34.389	50634.	5439.
3	04.01.78	2.456	50404.	3570.
3	07.03.78	2.392	55060	5194.
3	10.04.78	3.970	93728.	5363.
3	01.05.78	2.149	47354.	2664.
3	29.08.78	3.794	63767.	4340.
3	04.07.78	2.062	34027.	7274.
3	02.10.78	2.215	53592.	6802.
3	06.11.78	2.280	62909.	6618.
4	08.06.77	6.497	27900.	3770.
4	29.08.77	.937	25840.	2017.
4	31.10.77	1.268	50272.	2360.
4	06.12.77	2.564	71387.	1679.
4	05.01.78	3.635	80501.	3421.
4	31.01.78	1.770	75670.	5297.
4	01.05.78	1.844	33341.	6823.
4	29.08.78	2.049	47663.	3617.
4	31.07.78	1.269	36009.	4746.
5	07.06.77	1.053	13274.	1010.
5	07.07.77	.815	34792.	2023.
5	03.08.77	.724	29790.	1875.
5	31.08.77	4.179	26623.	2674.
5	04.10.77	1.164	32693.	1789.
5	31.10.77	1.358	31459.	2374.
5	08.12.77	1.750	46377.	3604.
5	06.01.78	1.582	38056.	3281.
5	01.02.78	1.979	47459.	2895.
5	08.03.78	2.132	38142.	2433.
5	07.06.78	7.191	21272.	5056.

APPENDIX 6a. (Cont'd)

Station No.	Date	Wt/d/m^2*	TL/m^2*	s.e.
6	07.06.77	1.176	10796.	1057.
6	07.12.77	.542	9879.	921.
6	06.01.78	.772	9703.	452.
6	01.02.78	.667	9504.	805.
6	11.04.78	.332	7166.	583.
6	02.05.78	.540	6164.	426.
6	05.07.78	.300	4978.	588.
6	28.08.78	.353	7264.	575.
6	30.07.78	.408	7880.	532.
6	03.10.78	.367	8330.	800.
6	07.11.78	.314	6840.	319.
7	07.06.77	3.794	23542.	3286.
7	07.12.77	1.464	42959.	3418.
7	05.01.78	2.167	44222.	3145.
7	01.02.78	2.679	36649.	4572.
7	11.04.78	1.600	33185.	1143.
7	02.05.78	2.291	28267.	2657.
7	07.06.78	2.043	30564.	2410.
7	31.07.78	2.536	32170.	2336.
7	03.10.78	2.901	45085.	3288.
7	07.11.78	4.873	44974.	3760.

APPENDIX 6b.

LEAF DATA FOR *POSIDONIA AUSTRALIS* PRIMARY PRODUCTIVITY ESTIMATES

(As for Appendix 6a.)

Station No.	Date	Wt/d/m^2*	TL/m^2*	s.e.
1	31.01.78	.255	3250.	270.
2	04.07.77	.929	27432.	3164.
2	29.08.77	.	.	.
2	04.10.77	1.726	28011.	2067.
2	06.12.77	3.236	44135.	3321.
2	05.01.78	4.676	39185.	4265.
2	07.03.78	4.908	39519.	2755.
2	01.05.78	1.948	31135.	2026.
2	06.06.78	1.876	18120.	1560.
2	02.10.78	1.510	20083.	1796.
2	06.11.78	2.735	34788.	2097.
3	07.07.77	.160	1462.	111.
3	04.08.77	.296	2274.	178.
3	29.08.77	.185	1852.	127.
3	05.10.77	.208	2913.	281.
3	31.10.77	.305	2416.	220.
3	06.12.77	.125	2965.	259.
3	04.01.78	.685	4893.	312.
3	07.03.78	.607	6572.	622.
3	10.04.78	.347	4342.	363.
3	01.05.78	.217	2678	155.

APPENDIX 6b. (Cont'd)

Station No.	Date	Wt/d/m^2*	TL/m^2*	s.e.
3 (Cont'd)				
3	04.07.78	.145	2184.	359.
3	29.08.78	.202	2241.	180.
3	02.10.78	.273	2398.	197.
3	06.11.78	.378	4128.	282.
6	02.05.78	1.276	21065.	1573.
6	05.07.78	1.435	17658.	784.
6	31.07.78	1.104	15316.	1193.
6	28.08.78	1.390	17455.	1193.
6	03.10.78	1.357	15624.	2063.
6	07.11.78	3.024	34342.	1785.
7	06.06.78	1.061	10432.	1204.

* Wt/d/m^2 - Dry weight of increment per day per square metre.

* TL/m^2 - Total length (cm) of leaf per square metre.

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