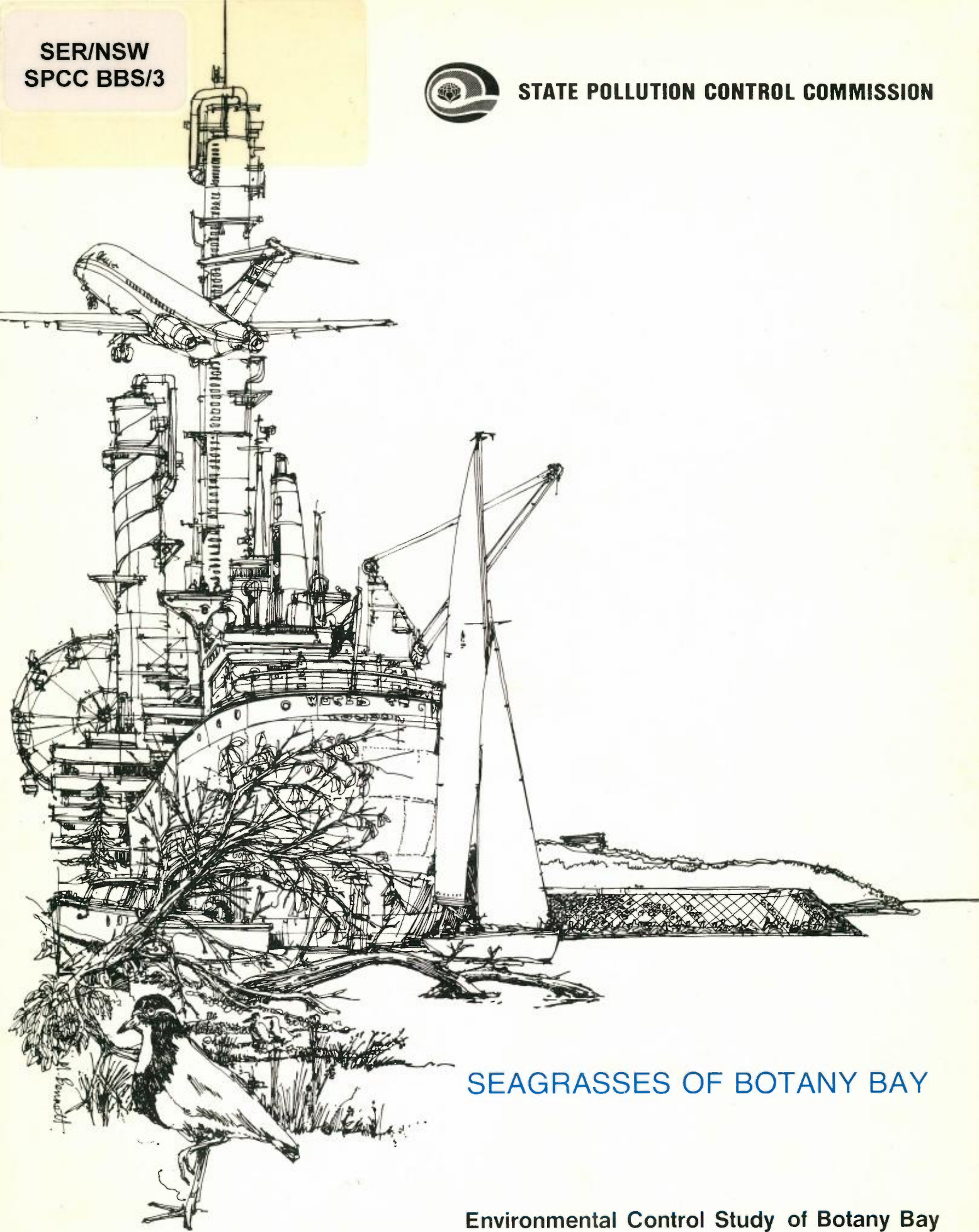


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STATE POLLUTION CONTROL COMMISSION



SEAGRASSES OF BOTANY BAY

Environmental Control Study of Botany Bay



STATE POLLUTION CONTROL COMMISSION



SEAGRASSES OF BOTANY BAY

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Environmental Control Study of Botany Bay

BBS 3
ISBN 0 7240 3971 6

Sydney, Australia
September, 1978

PREFACE

Arrangements were made in 1975 for the State Pollution Control Commission to carry out an environmental control study of Botany Bay and its tributaries. The study, which began in January 1976, developed from initiatives of the Maritime Services Board of New South Wales and the Board has contributed substantially to it.

The study primarily is of water and water-associated environments, so it covers land-based activities within the catchment only to the extent that these have an impact specifically on the water environment.

The State Pollution Control Commission is responsible for management of the study and for making recommendations developed from it, with advice from its Technical Advisory Committee. Throughout the study period, however, the Commission has been assisted by willing cooperation and communication with many other departments and authorities.

Particular elements of the study are being carried out by State Government instrumentalities, universities and consultants. Major elements are supported by technical consultative committees.

Investigations have aimed first to identify and describe the water-associated resources and the activities responsible for environmental change. The effects of activities on important resources can then be assessed and appropriate control measures indicated.

These investigations have led to a series of technical papers on specific aspects, of which this paper is one. Other papers in the series are listed below.

One of the principal objectives of the study is to recommend to the Government a comprehensive water-resource management plan for the Bay and its tributaries. These technical papers will contribute to that objective.

This report has been prepared within the Commission's study team.

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1 INTRODUCTION

Seagrasses are aquatic angiosperms completely adapted to the marine environment. They commonly form extensive meadows in sheltered bays and estuaries along the Australian coastline. Of the six species reported to exist in New South Wales (den Hartog 1970), four occur in Botany Bay : Posidonia australis, Zostera capricorni, Halophila ovalis and Halophila decipiens. The dominant species in Botany Bay are P. australis and Z. capricorni.

Heterozostera tasmanica has been reported to exist in the Sydney district but probably does not occur in Botany Bay (Jacobs personal communication). Zostera muelleri was thought to occur in Botany Bay and elsewhere along the mid New South Wales coast (Wood 1959b) but, as a result of taxonomic revision, is now known to occur only as far north as Sussex Inlet (Jacobs personal communication).

Another aquatic angiosperm, Ruppia sp, has been reported to occur in Cooks River (Hamilton 1919) but this is no longer the case. It has a wide distribution in New South Wales coastal lagoons and estuaries (Aston 1973) and may occur in Georges and Woronora Rivers above the limits of Z. capricorni.

The importance of the Sydney region as a transition zone for many seagrass communities has been stressed by Larkum (1977). Both P. australis and H. tasmanica are near their northern limit here. H. tasmanica extends to Pittwater (Sydney) and P. australis extends to Lake Macquarie (den Hartog 1970). H. decipiens is presently reported only for Port Jackson and Botany Bay (den Hartog 1970).

Although the seagrass community is an essential and significant component of the Botany Bay aquatic ecosystem many activities threaten its existence. For this reason this paper will assess the extent and significance of seagrasses in Botany Bay, present condition, importance and opportunities for maintenance.

2 SEAGRASS ECOLOGY

2.1 Environmental Requirements and Tolerances

Environmental conditions recorded for seagrass species found in Botany Bay are summarized in Table 1.

. Posidonia australis

The depth limit of P. australis in both Port Hacking and Botany Bay is shallower than elsewhere along the New South Wales coast (Table 1). Phenotypic variation due to proximity to the northern limit of P. australis seems an unlikely explanation as P. australis occurs to a depth of 7 m at Pittwater in the Hawkesbury River, 45 km north of Botany Bay.

Larkum (1976b) has suggested that increased turbidity may have decreased the depth limit of P. australis in Botany Bay. He is examining further the relationship between occurrence at depth and water turbidity (Section 3.2). Local and overseas workers have shown that the depth limit of seagrass can be effected by turbidity. Higginson (1970) demonstrated a correlation of turbidity and light penetration in Tuggerah Lakes; McRoy (1974) and Backman and Barilotti (1976) have shown the dependence of seagrass growth on adequate light penetration.

The salinity tolerance of P. australis is not known. It appears to be less tolerant of salinity fluctuations than Z. capricorni, being found only in the marine waters of estuaries where salinity is predominantly high. Available data relate only to the range of salinity at localities where P. australis is known to grow; for example, salinity in Quibray Bay ranges from 20 to 35 parts per thousand (State Pollution Control Commission data), though P. australis is known to tolerate a salinity drop to 15 parts per thousand for up to two days (Kirkman unpublished data).

P. australis is near its northern limit in Botany Bay, so probably is susceptible to temperature fluctuations. As for salinity, the available data only record the range of temperatures at a known locality.

P. australis is found on sandy bottoms with a positive redox potential (den Hartog 1970) and prefers to grow in coarse sand (Larkum personal communication). It is not

Table 1. Depth, Salinity and Temperature Ranges, Substratum Preference and Tolerance to Water Movement for Seagrasses Occurring in Botany Bay

Species	Depth below M.L.W. (m)	Substratum and Redox Potential	Salinity Range (%)	Temperature Range (°C)	Water Movement : Currents and Wave Action
<u>Posidonia australis</u>	2 - 10 generally (1) 0.2 - 2 suboptimally (1) 0.5 - 10 NSW (2) 0.2 - 3 Botany Bay(3) 0.2 - 3 Port Hacking (4) 0.2 - 9 Jervis Bay(3) 0.2 - 7 Pittwater (3)	Sloping, sandy with positive redox potential (1) Preference for coarse sand (14) Chiefly on sandy bottom (8)	20 - 35 Quibray Bay (16,17,18) 'Quite tolerant' (1)	13 - 23 Botany Bay (16,17,18)	
<u>Zostera capricorni</u>	0 - 6 and not common in intertidal (1) 0.5 - >7 (5) 0 - 2 Lake Illawarra (6) 0 - 4 Tuggerah Lakes entrance (7)	Sand to Mud (9,10, 11,12) Reduced sand or mud (1) No apparent correlation with sediment type in Lake Illawarra (6)	Euryhaline (1) 3 - 34 Tuggerah Lakes (13) 2 - 30 at upper Georges limit (16) optimum 20 - 35 (6) Tolerate rapid and prolonged salinity fluxes (6)	10 - 40 Lake Illawarra (6)	2 knots Lake Macquarie (5)
<u>Halophila ovalis</u>	"midtide" to 12m (1) More abundant at depth (5)	Almost any (1) Adapted to unstable bottoms (1) Associated with reduced muds (5) On dark organic sediments (3)	5 - 35 Swan R. W.A. (15)	tropical to cold temperate waters (1)	
<u>H. decipiens</u>	Usually 10 - 30 m and excluded by <u>H. ovalis</u> in upper 10 m (1) But 1.0 m below L.W.S. in Botany Bay (1)	Soft muds in Botany Bay (1) Amongst <u>P. australis</u> beds (1)	Euryhaline (1)		

- (1) den Hartog (1970)
 (2) Larkum (1977)
 (3) Larkum (1976b)
 (4) Kirkman (unpublished data)
 (5) Wood (1959b)
 (6) Harris (1977)
 (7) Higginson (1965)
 (8) Aston (1973)
 (9) Day (1975)

- (10) Hutchings and Recher (1974)
 (11) Larkum (1976c)
 (12) Weate (1975)
 (13) Higginson (1970)
 (14) Larkum (personal communication)
 (15) Bayly (1975)
 (16) SPCC (internal study data)
 (17) CSIRO (1943 - 1954 data)
 (18) Goodwin (1970)

known, however, whether a reduced substrate is a prerequisite for P. australis colonization or growth.

. Zostera capricorni

The depth to which Z. capricorni occurs in New South Wales coastal waters varies, possibly because of different turbidity levels in those waters. Harris (1977) compared depths for Z. capricorni communities in Lake Illawarra and found a correlation with water turbidity, seagrasses being limited to shallow depths in more turbid waters.

No published data are available for salinity and temperature tolerances of Z. capricorni; however the wide ranges of salinity and temperature values reported by Higginson (1968) and Harris (1977) indicate that it is both eurythermic and euryhaline.

Z. capricorni shows no preference for substratum type (Harris 1977) and grows on both mud and sand in Botany Bay. It is usually associated with reduced sediments.

2.2 Colonization and Succession

Posidonia is regarded as a climax plant, in the sense of terrestrial plants (den Hartog 1971, Young and Kirkman 1975, Larkum 1977). In Botany Bay, Z. capricorni is considered to be an early colonizer, leading to a P. australis climax except in situations where P. australis is at a competitive disadvantage (Larkum 1977). Thus, in the intertidal zone, where P. australis cannot grow due to its low tolerance to desiccation Z. capricorni forms a fringe above the P. australis. H. ovalis is often the first seagrass to pioneer an area as it is adapted for life on unstable sediments (den Hartog 1970). It cannot, however, stabilize sediments. P. australis may require a reduced substratum for initial growth whilst Z. capricorni does not. Although Z. capricorni is thought to reduce oxidized sands thus making them suitable for Posidonia growth no supportative data is available.

2.3 Seagrass Propagation

Table 2 summarizes available Australian phenological data for the seagrasses occurring in Botany Bay.

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Table 2. Phenological Data for Seagrasses found in Botany Bay

Species	Flowering	Fruiting
<u>Posidonia australis</u>	June to Oct (1)* Nov to Dec Port Hacking (4)	Nov - Dec (8)
<u>Zostera capricorni</u>	Sept to March (1) Sept to July Lake Illawarra (6)	Oct - March (1) Oct to June Lake Illawarra (6)
<u>Halophila ovalis</u>	Jan to Feb (1)	Jan to Feb (1)
<u>Halophila decipiens</u>	All year, peak Jan to April (1)	

* See Table 1 for references

Earlier workers considered that both flowering and fruiting of Zostera and Posidonia were irregular events in New South Wales and that flowering communities exhibited extreme patchiness (Wood 1959a, b). Larkum (1976b) thought flowering of P. australis to be an irregular event in Botany Bay. Observations in Botany Bay and other estuaries indicate that flowering of both species, although extremely patchy, does occur annually. There is no evidence of seedling establishment in Botany Bay. These data have led to speculation that propagation of seagrasses in Botany Bay is mainly achieved by vegetative mechanisms.

McMillan (1974) summarized information available for North American seagrasses and suggested that salinity may be a limiting factor for flowering. He postulates that the broad distribution of seagrasses, which entails wide salinity tolerances, must be enhanced by utilization of a large gene pool.

Vegetative reproduction has been indicated by Waisel (1972) as being a more efficient method for seagrass dispersal. Seed dispersal by seawater is a slow process because of the scarcity of seed production, lack of buoyancy, short distance drift of disseminules and poor survival of seedlings.

2.4 Seagrass Disease

There has been no report of seagrass decline due to disease in Australia.

A fungus Labyrinthula macrocystis, originally thought to be associated with the catastrophic decline of Z. marina in the United States and Europe in the 1930's ('wasting disease') has been identified on Z. capricorni and Ruppia sp in Tuggerah Lakes (Weiner unpublished data). Kirkman (unpublished data) has found another disease organism on P. australis in Port Hacking.

Cottam and Munro (1954) categorized the theories for the United States seagrass decline as :

- . Localized effect (these theories have been discarded as not applicable to widespread decline)
- . Bacterial disease (conclusions could not be confirmed)
- . Fungus or fungus like organisms (association of Labyrinthula with 'wasting disease')
- . Environmental factors (mainly temperature).

Rasmussen (1977) has reviewed the literature regarding 'wasting disease' and concludes there is no evidence for mass destruction by bacterial or fungal disease, rather "the primary cause of mass destruction can be found in changed temperature conditions, so that the higher water temperature generally weakened the eelgrass, and thereby directly or indirectly contributed to its destruction; directly by destroying metabolism (heat rigor) and indirectly by weakening the Zostera plants so that the ever-present bacteria, slime moulds, fungi, etc., could complete the destruction".

This theory is partly based on the narrow and critical temperature ranges of Z. marina and the existence of ecological races each with different temperature preferences. Until the temperature ranges and existence of ecological races for local Zostera communities are known, 'wasting disease' must be considered a potential threat.

Harris (1977) noted that the degeneration of Zostera in Munmorah Lake and Lake Illawarra may be a consequence of hot water discharging from the Munmorah and Tallawarra Power Stations. Although degeneration in deeper areas could result from a decrease in compensation depth due to increased metabolic rate of seagrass subjected to sublethal temperatures, this has not been proven for these discharges.

3 SEAGRASS DISTRIBUTION IN BOTANY BAY

3.1 Present Distribution

Seagrasses cover an area of 680 ha in Botany Bay (Figure 1), the major beds (approximately 600 ha) being along the southern shores, between Inscription Point and Pelican Point (including Quibray and Weeney Bays).

In the southern part of the bay, P. australis is the major species, with Z. capricorni usually forming a distinct landward zone. In contrast, the northern beds of seagrass consist almost exclusively of Z. capricorni. (Posidonia does not occur in these beds.) Halophila ovalis occurs in small patches throughout all the seagrass beds and forms a small monotypic bed off Sutherland Point. Isolated plants also occur in the calm waters of Congwong Bay. Small patches of Z. capricorni fringe Yarra and Frenchmans Bays and Lady Robinsons Beach.

Quibray and Weeney Bays support the most luxuriant beds of seagrass, and all four species recorded in Botany Bay occur there. P. australis forms monotypic stands from +0.2 to about -3 m (ISLW)* with Z. capricorni fringing both the shallower and deeper margins. H. ovalis and H. decipiens are found amongst the deeper beds of Zostera. Larkum (1976b) suggests that the comparative isolation of these bays from the river systems and from wave action has meant there has been less change in these communities than for the rest of the bay.

Posidonia does not occur westward of Pelican Point. Zostera occurs in a fringe along the eastern and western sides of Woollooware Bay, but not on the southern side or in Botany Bay. Zostera and Halophila are both found in patches on the mud flats of Kogarah Bay, but only Zostera penetrates the river system to any extent. Isolated patches of Zostera occur to the tidal limit at the Needles in the Woronora River and to East Hills in the Georges River.

Cooks River does not support any seagrasses.

3.2 Changes in Seagrass Distribution

3.2.1 Botany Bay

Larkum (1976b, c) suggests that the distribution of seagrasses in Botany Bay was formerly much more extensive than it is today. He bases this argument on comparison of the present seagrass distribution in Botany Bay with that of other less developed estuaries, historical records and, over the last 40 years, aerial photographic records.

* Indian Spring Low Water

Larkum considers early declines in seagrasses from Botany Bay were largely due to commercial dredging of mud oysters for lime during the 1880's. These operations probably damaged seagrass beds and de-stabilized sediments, making these areas less suitable for recolonization. The decline possibly was accentuated by increased water turbidity restricting the depth to which seagrasses could grow. This suggestion is consistent with the relatively shallow depth limit of P. australis in Botany Bay (2.5 m), compared with Pittwater (7 m) and Jervis Bay (9 m), but not with Port Hacking (about 3 m).

The declines of seagrasses from different areas in the estuary are discussed below.

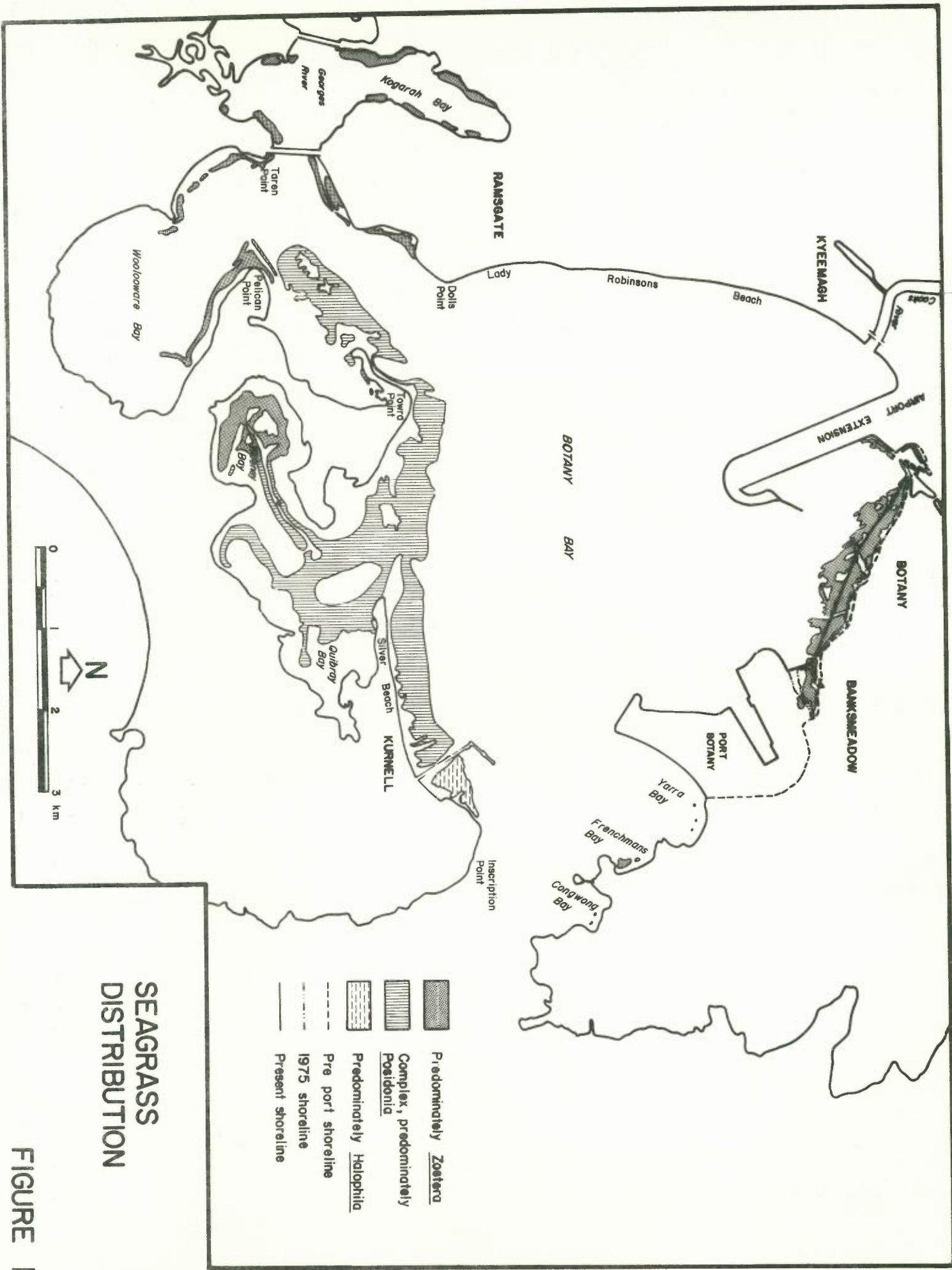
. Northern Beds

The zonation of P. australis and Z. capricorni which presently characterizes the southern beds of seagrasses in Botany Bay is thought also to have once existed in the northern seagrass beds. Zonation is apparent in 1930 aerial photographs (Larkum unpublished data). P. australis has since disappeared from the northern meadows, leaving only Z. capricorni.

Larkum hypothesizes (1976a, b, c) that the decline of P. australis from the northern seagrass beds has largely been due to pollutants from Cooks River and the Botany industrial complexes.

The last bed of P. australis on the northern shore (a strip about 2 m wide off Frenchmans Bay) disappeared between 1974 and 1975. Larkum (1976c) noted that the rhizomes of these plants were still intact indicating that mechanical damage due to storms could not account for the losses, and suggests that the plants may have died as the result of an oil spill at the Single Buoy Mooring.

The construction of the north-south airport runway extension and the armoured revetment wall created a shallow stable-bottomed backwater with a small fresh-water input. This resulted in the colonization of inshore waters by Z. capricorni and an overall increase in Zostera beds (Larkum unpublished data). By 1976 there were at least 87 ha of Zostera on the north shore (Watkins 1976).



**SEAGRASS
DISTRIBUTION**

FIGURE 1

Recent reclamation and dredging for Port Botany and foreshore roadway have covered about 68 ha.

. Southern Beds

The seagrass beds off Towra Point have been subject to alternate erosion, accretion and regrowth over many years (Larkum 1976a, New South Wales State Fisheries 1976, Watkins 1976). Since 1972 however, erosion of these beds has increased dramatically. The Simblist Inquiry (1976) accepted that increased wave action, due both to configuration dredging of the bay entrance and to two particularly severe storms in 1974 and 1975, resulted in accelerated erosion of seagrasses from Towra Point. This loss is continuing.

Most damage to seagrasses has been due to erosion, though further losses have resulted from smothering by sand. Between 50 and 100 ha of seagrasses (mainly Zostera) had been destroyed by mid-1976 (New South Wales State Fisheries 1976, Watkins 1976, Larkum 1976a, c). Larkum (1976c) suggests that a form of autocatalytic decline may now be in progress in which initial losses accelerate further declines.

Construction of groynes along Silver Beach has also caused some loss of seagrasses. In particular, scouring of the inshore region adjacent to the western-most groyne has produced mobile sands which are smothering seagrasses off Bonna Point.

Wind-blown sand from the Kurnell dunes has destroyed seagrasses in the southern end of Quibray Bay. Since 1970, 5 ha have been smothered.

3.2.2 Georges River

The present wide but disjunct distribution of Z. capricorni in Georges River may be indicative of an earlier more extensive river distribution. Aerial photographs over the last 25 years show declines during this period.

Sand mining and urban development disturbed much of Georges River, destabilizing bed sediments over large stretches and contributing heavy silt loads to the system (Warner and Pickup 1977). Further losses would also have resulted from foreshore reclamation, localized pollution and manual removal of seagrasses.

3.2.3 Cooks River

Ruppia sp was reported from Cooks River by Hamilton (1919). Seagrasses are also evident in 1949 aerial photographs of the old Cooks River entrance. Cooks River was dredged to Canterbury during the 1960's and parts have been reconstructed; seagrasses no longer grow in Cooks River.

3.2.4 Woronora River

Results of sampling done by the Australian Atomic Energy Commission and aerial photographs indicate Z. capricorni beds in the Woronora River appear to have been stable since at least 1950.

4 SEAGRASS PRODUCTIVITY

4.1 Primary Productivity

Seagrass ecosystems are amongst the most productive aquatic ecosystems. However, "in spite of considerable sophistication in chemical methods, our knowledge of seagrass productivity is not much advanced beyond what Petersen learned more than sixty years ago" (McRoy and McMillan 1977). This poor knowledge is in large part due to the complexity of the seagrass community. McRoy and McMillan (1973) listed six components of the plant community (Table 3) which need both individual and collective study.

McRoy and McMillan (1977) found that estimates of standing crop and productivity for seagrasses were very wide, and grouped seagrasses into either high or low biomass categories corresponding to the growth form classification of den Hartog (1977).

Thus, meadow-forming grasses such as Zostera and Posidonia can attain average seasonal biomass of 0.5 to 1.5 kg/m² (dry weight of total plant) and the smaller patchy grasses such as Halophila 100 to 100 g/m².

Productivity estimates for seagrass and other plant components of the seagrass ecosystem are tabulated in Table 3.

Most data on Australian seagrass production are not directly applicable to Botany Bay because of either different species e.g. Z. muelleri and H. tasmanica in Westernport or geographical isolation e.g. P. australis in Western and South Australia. However, several estimates for Z. capricorni and P. australis standing crops are available for the New South Wales coast (Table 4). Work on seagrass productivity is current in Port Hacking by H. Kirkman (CSIRO Division of Fisheries and Oceanography) and in Botany Bay by A. Larkum (Botany Department, School of Biological Sciences, Sydney University).

There is a distinct seasonal cycle in biomass and productivity for both Z. capricorni and P. australis in Botany Bay.

West and Larkum (unpublished data) measured the variation in biomass of P. australis in Botany Bay. P. australis above-ground parts (leaves, shoots and flowering parts) reach a maximum biomass of 300 g/m² (dry weight) at the end of summer then biomass decreases through autumn and winter until the next growing period. The below-ground parts (roots and rhizomes) retain a fairly constant value of about 1000 g/m² throughout the year.

Kirkman (unpublished data) found that the biomass fluctuation for P. australis in Port Hacking occurred predominantly in above ground parts of the plant but is uncertain whether productivity fluctuation is due to a varying growth rate or grazing pressure.

Larkum et al (unpublished data) have also measured the variation in Z. capricorni biomass in Botany Bay. The average above-ground biomass (dry weight) is less than 200 g/m² and can reach a maximum of 250 g/m² at the top of the growing season. As with P. australis, below ground parts show little variation throughout the year and average 300 g/m².

The biomass of Z. capricorni may fluctuate widely because of interactions between regular seasonal changes and irregular climatic changes (Jacobs personal communication). Seasonal changes result in loss of erect flowering stems at the beginning of autumn and decrease in growth rate through winter (possibly due to reduced insolation, Sand-Jensen 1975).

Winter dieback of Z. capricorni is marked in Botany Bay (Larkum unpublished data) because, for example, prolonged exposure to very cold air during low tide or sudden and prolonged exposure to cold freshwater accentuates normal winter decline.

Annual production data* show considerable variation due to different assumptions regarding seasonal variation of standing crop and turnover-time made because of inherent measurement difficulties, particularly turnover-time of below-ground (root and rhizome) components (Sand-Jensen 1975). However, as turnover-time for roots and rhizomes is long compared with above-ground parts, annual production based on biomass now is generally limited to above-ground parts.

Turnovers of above ground parts for both Z. capricorni and P. australis have been measured in Botany Bay. Z. capricorni produces six crops (Larkum et al unpublished data) and P. australis three to four crops per year (West and Larkum unpublished data).

*
$$\text{annual production (g/m}^2\text{/yr)} = \frac{\text{annual turnover (g/yr)}}{\text{average standing crop (g/m}^2\text{)}}$$

annual turnover = number of crops per year

turnover-time = time taken for standing crop biomass to double itself

Table 3. Biomass and Annual Productivity (Dry Weight)
(from McRoy and McMillan 1977, Sand-Jensen
1975)

Group	Species/ Habitat	Standing Stock (Total plant) Maximum seasonal (g/m ²)	Above Ground Productivity (g/m ² /yr)
Seagrass (i) Meadow- forming	<u>Zostera</u>	500 - 1 500	1 300
	<u>Posidonia</u>		
(ii) Small, patchy	<u>Halophila</u>	100 - 200	-
Associated algae	Macro and micro epiphytes	Seagrass biomass	Average 20% of seagrass productivity
	Macro benthic algae	11-14% of Seagrass biomass	-
	Micro benthic algae	-	1% of seagrass productivity
	Phyto- plankton	-	-

Note : The following conversion factors were used in comparing data.

Wet weight to dry weight 10:1

Carbon weight = 38% of dry weight

A photosynthesis quotient of 1.25 yields the following conversion for oxygen figures.

0.3 x mg O₂ = mg carbon

Table 4. Biomass and Productivity, New South Wales (dry weight)

Author	Species	Region	Standing Crop (g/m ²)	Productivity (g/m ² /yr)
Australian Museum 1974	<u>Posidonia australis</u>	Wagonga River (Narooma)	345 (2)	-
Larkum 1976b	"	Jervis Bay	360 - 1 200	-
Kirkman (unpub. data)	"	Port Hacking	600 - 800 (1)	-
Kirkman (unpub. data)	"	Port Hacking	160 (2)	410 (2)
Larkum (unpub. data)	"	Botany Bay	300 (2) maximum at end of summer 1 000 (3) relat- ively constant throughout the year	
Australian Museum 1974	<u>Zostera capricorni</u>	Eurobodalla Shire	144 (2)	
Kirkman (unpub. data)	"	Port Hacking	210 - 300 (1)	
Larkum (unpub. data)	"	Botany Bay	250 (2) maximum 300 (3) relat- ively constant	1 200 (2)(4)
Australian Museum 1974	<u>Halophila ovalis</u>	Eurobodalla Shire	57 (1)	

Notes : (1) Total Plant

(2) Above ground parts only (leaves and shoots)

(3) Below ground parts (rhizomes and roots)

(4) Based on turnover times for growing season only.

The 680 ha of seagrass in Botany Bay therefore contribute 5 660 t of dry organic matter annually. Current research (West and Larkum unpublished data) indicates that the Zostera contribution to annual productivity in Botany Bay may be higher than that indicated in Table 4 and total bay seagrass productivity may be 6 500 t annually. Associated algae productivity is unknown for Botany Bay but is said to be significant (West and Larkum unpublished data). In contrast to the productivity contribution by seagrasses, the 397 ha of mangroves in Botany Bay contribute about 2 400 t of leaf and twig litter annually (Allaway personal communication).

4.2 Nutrient Cycling

High productivity systems such as seagrass communities show high nutrient demand, high dynamic cycling of trace metals and transfer of other compounds involved in plant growth (vitamins, hormones, etc). Thus, the return of nutrients and other compounds from sediments to the water column and mechanisms for filtering of material from the water column must be efficient.

Pomeroy et al (1965) demonstrated the dynamic interaction of phosphorus between the water column and the upper few centimetres of surface sediments. Similarly McRoy et al (1972) demonstrated an active phosphorus exchange between seagrasses, sediments and the water column. The exchange is reversible and seagrass can act as either a source or sink for dissolved phosphorus. Active uptake of phosphorus from the rhizosphere means that phosphorus absorbed onto sediments from the water column and trapped in sub-surface soils can be recycled. However, the cycling of phosphorus by Australian seagrasses has not been demonstrated. Work by Kirkman (unpublished data) in Port Hacking indicates that P. australis does not cycle phosphorus.

Fenchel (1973) reviewed the mechanisms of phosphorus cycling and linked biological interactions to physico-chemical interactions (Figure 2), although cycling between the seagrass and algal components were not included. Epiphytic algae contribute to the dissolved organic phosphorus and sediment detrital pools and probably cycle phosphorus with the seagrass host (McRoy et al 1972) and this has been incorporated into Figure 2. Similarly, associated algae probably cycle nutrients.

Fenchel (1973) summarized the cycling of nitrogen between seagrass, water column and sediments (Figure 3). Epiphytic algae (mainly blue-greens) fix nitrogen, making it available for the seagrass plant community as dissolved organic nitrogen (Goering and Parker 1972). This pathway has been incorporated into Figure 3.

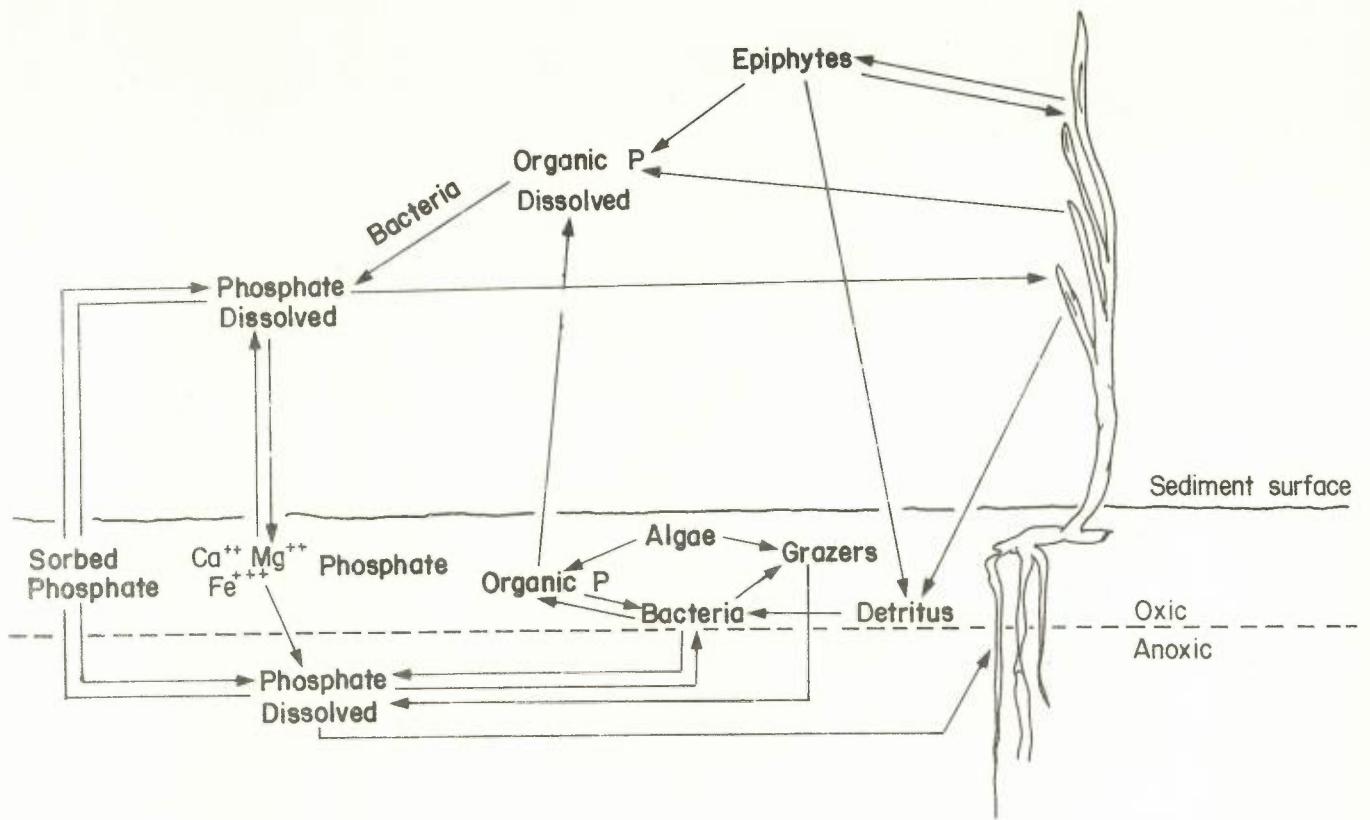


FIGURE 2. Circulation of phosphorus in seagrass ecosystems

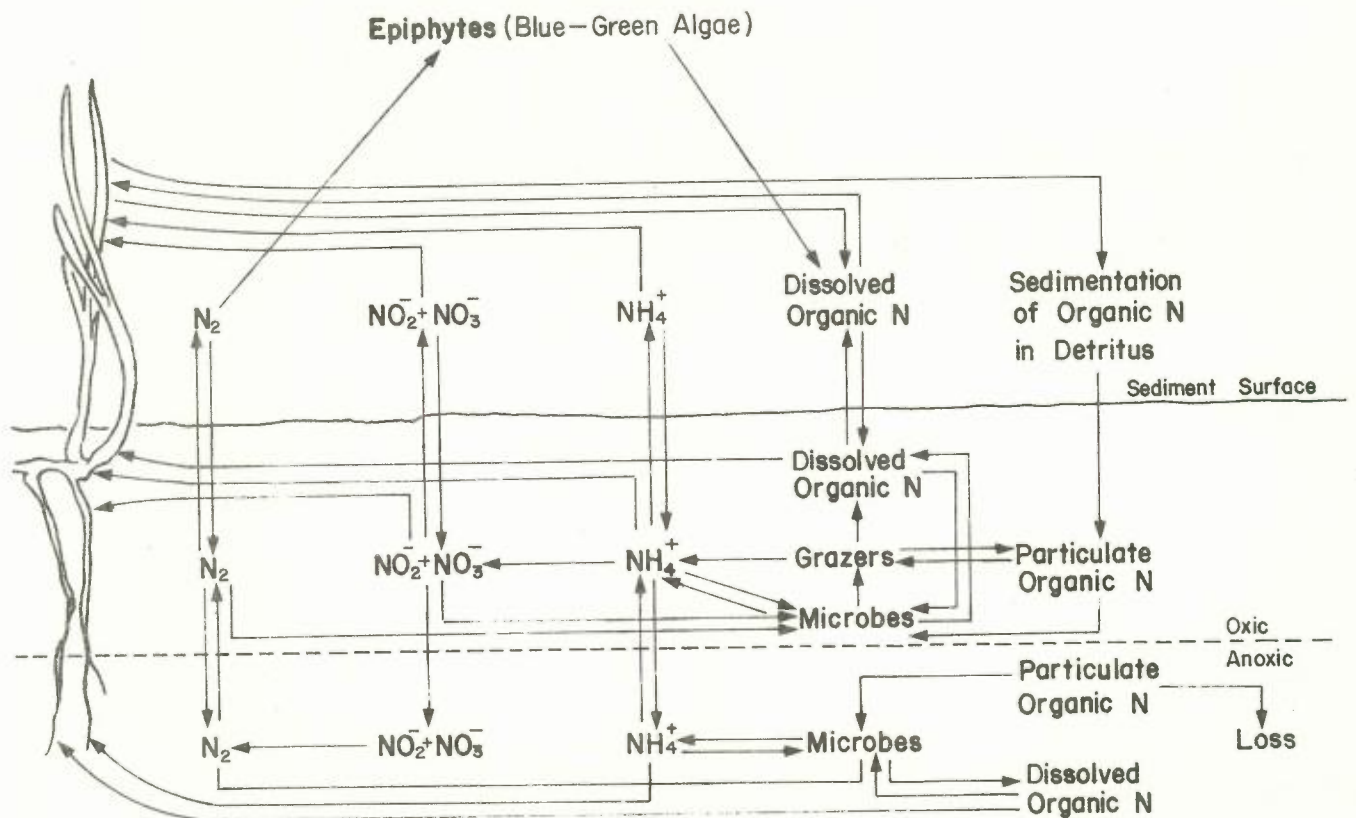


FIGURE 3. Circulation of nitrogen in seagrass ecosystems

Harlin (1975) has suggested another pathway for nitrogen cycling via parasitic algae whereby free nitrogen is fixed by bacteria in the seagrass rhizosphere, taken up by the seagrass, utilized by parasitic algae and, finally, released as dissolved organic nitrogen.

Carbon, as dissolved organic carbon (DOC), is an important energy source utilized either directly or indirectly by many aquatic organisms (Brylinsky 1977). Although the DOC contribution from living plant material to the water column is low, generally less than 10 per cent of total fixed carbon, (Penhale and Smith 1977), and typically 1 to 4 per cent for seagrass (Brylinsky 1977), the significance of DOC as a food source is high. Assimilation of DOC by heterotrophic organisms is typically 20 to 30 per cent and can reach 40 per cent (Brylinsky 1977).

Ephyphytes are another important source of DOC.

5 SEAGRASS FOOD CHAINS

Seagrass and associated algae standing crops comprise a large food source. Total primary production of seagrass systems is made available to faunal communities and other systems through several pathways (Kikuchi and Peres 1973, Odum and Heald 1975):

- . Direct Utilization
 - Plant material → higher consumers
- . Formation of Dissolved Organic Matter (DOM)
 - Plant material → bacterial and fungal breakdown → higher consumers
 - DOM (leached) → micro-organisms → higher consumers
 - DOM (leached) → sorption on sediment particles → higher consumers
- . Energy Transfers
 - Plant material → other systems (export of primary production)
 - Faunal material → other systems (export of secondary production)
 - Transfer of energy among different trophic units of consumers in the system. This includes both direct transfers and feedback mechanisms

5.1 Detritus-based Food Chain

Most animals are incapable of directly utilizing (digesting) structural carbohydrates, so detritus is the important link between primary and secondary production in shallow water. (The inability of animals to digest structural carbohydrates such as cellulose and phenolics may be due to the low nutritional value of seagrasses arising from low tissue nitrogen content and subsequent high carbon/nitrogen ratios - Shapiro 1975.)

5.1.1 Formation of Detritus

Organic detritus is not clearly defined but is known to be of heterogeneous nature and to harbour rich microbial communities (Fenchel 1970). It is separated by particle size into dissolved organic matter (DOM) and particulate organic matter (POM). Efficiency of detrital utilization increases with decreasing particle size ie increasing surface to volume ratio, so DOM is the end product of detrital formation.

Sources of DOM have been functionally separated into three categories (Fenchel 1973, Harrison and Mann 1975):

- . Growing seagrasses, which secrete photosynthates and release various cellular components during regulation of osmotic balance
- . Senescent seagrasses, which lose cytoplasmic DOM both rapidly by cell breakdown (lysis) and slowly as decomposing plant material
- . Degradation of POM to DOM by bacterial metabolism.

The last category represents an important mechanism whereby the heterogeneous assembly of organic and inorganic molecules locked up in POM can be recycled. Recycling is achieved by release during bacterial metabolism of DOM formed by aerobic and anaerobic degradation of POM.

Anaerobic processes generally are inefficient when compared with aerobic processes, though in shallow seagrass beds anaerobic respiratory processes involving sulphate reduction and regeneration of sulphate by chemo- and photoautotrophs in the aerobic zone may be as efficient or even more efficient than aerobic processes (Fenchel 1973). (See Figure 4 for summary of aerobic and anaerobic pathways.)

5.1.2 Utilization of Detritus

As shown above, primary decomposers of dead organic material are microbes (bacteria and fungi) which break down structural carbohydrates and which, because of their small size, can utilize DOM efficiently. These can be considered the real primary producers for aquatic detrital food chains (Fenchel 1977).

Two pathways from primary decomposers to higher trophic levels are recognized (Fenchel 1973, Kikuchi and Peres 1973). These are :

- . bacteria - microfauna - macrofauna
- . fungi - nematodes - macrofauna.

The bacterial flora of anaerobic decomposition, together with the chemo - and photoautotrophic bacteria which utilize the end products of anaerobic decomposition, are utilized by a suite of distinct assemblage of microfauna from that which utilize other bacteria (Fenchel 1973).

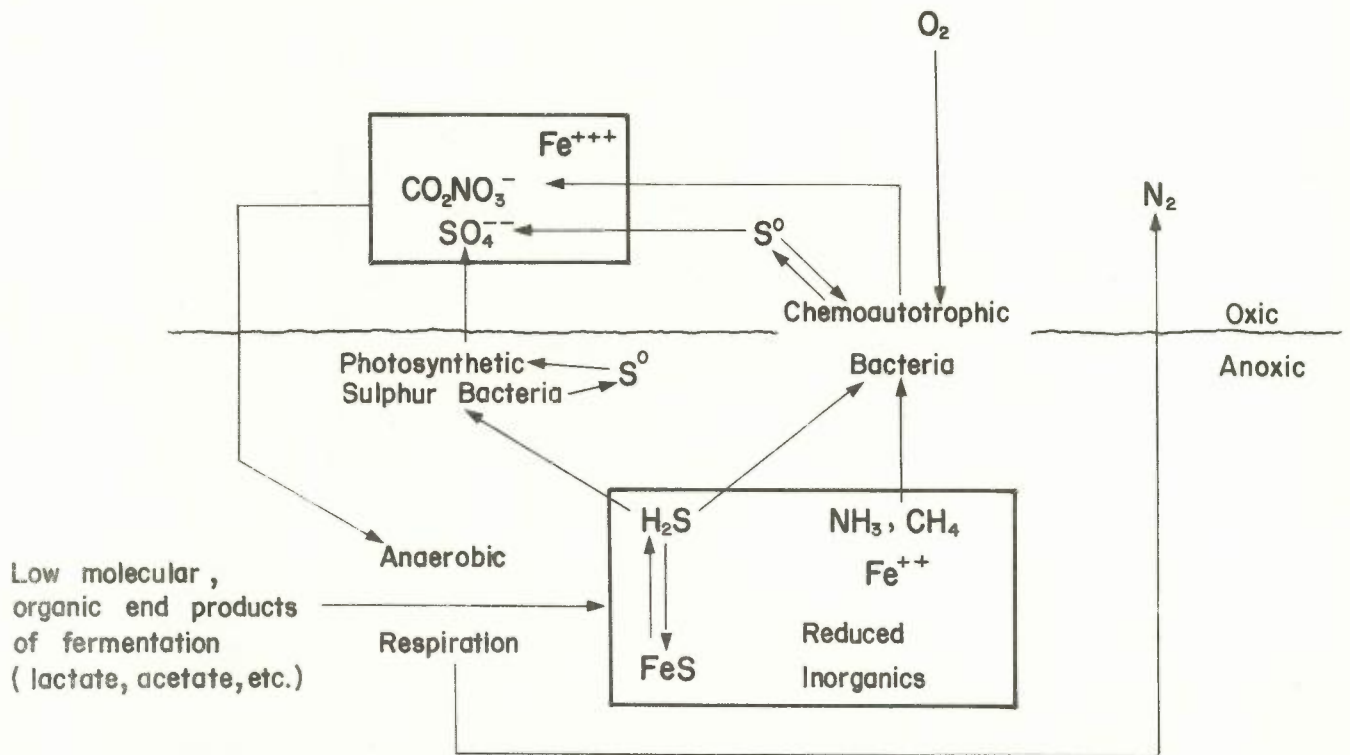


FIGURE 4. Oxic and Anoxic detrital decomposition in sediments of seagrass beds

The detrital system has characteristics of mature stages of ecosystem successions (Fenchel 1977) :

- . Complexity of food interrelationships and resulting high degree of stability. Food chain complexity and controlled decomposition of POM by leaching and saprophytic decay (probably limited by the rate of decay of structural carbohydrates, Harrison and Mann 1975) assures a regular source of energy for heterotrophic organisms throughout the year.
- . Feedback mechanisms. These enhance the breakdown of POM and so increase the efficiency of DOM production. Protozoans continually graze the micro-organisms thus maintaining them in an active metabolic state (or "physiological youth", Odum and Heald 1975) which increases the rate of saprophytic decay (Harrison and Mann 1975). For example, amphipods break up large POM, strip off microbes for food and produce faecal pellets. These pellets are recolonized quickly by microbes and the organic material becomes available again to amphipods. Thus, continual breakdown of POM also increases the efficiency of saprophytic decay (Fenchel 1970)
- . A high species diversity and high degree of structural complexity at the microscopic level
- . Relatively closed mineral cycles (Section 4.2).

5.2 Communities Within Seagrasses

The seagrass community is one of the most diverse aquatic communities known, rivalling coral reef communities in species diversity and animal abundance (Thorhaug and Austin 1976).

Seagrass animal communities have been subdivided (Kikuchi and Peres 1977) using micro-habitat structure and mode of life of the biota :

- . Biota on green leaves :
 - ephiphytic felt flora and micro- and meiofauna living in it (many protozoans - ciliates, flagellates, foraminifers, foraminifers - free living nematodes, minute polychaetes, rotifers, tardigrades, copepods, and ostracods)

- sessile fauna (hydrozoa, actinians, bryozoa, tube-building polychaetes, and compound ascidians)
- moving epifauna creeping and walking on the leaves (gastropods, polychaetes, turbellarians, nemertines, crustaceans, and some echinoderms)
- swimming animals which rest on leaves (mysids, hydromedusae, small squids, and special fishes, eg syngnathid fishes).
- . Biota attached to stems and rhizomes :
 - nest-building polychaeta and amphipoda
- . Mobile species living under the leaf canopy :
 - decapod crustaceans, cephalopods and fishes
- . Biota living on or in the sediment :
 - polychaetes, bivalve molluscs and echinoderms
- . Biota of leaf material washed up onto beaches (windrows) :
 - amphipods, isopods, some gastropods, polychaetes, some halophilous insects and millepedes; anaerobic sulphide systems can develop in large windrows to form the basis of further detrital food chains. This decay mechanism does however lead to unpleasant odours and organic sludges (Higginson 1970).

5.2.1 Algal Communities

May et al (1978) listed 57 species of algal epiphytes from P. australis and Z. capricorni in Botany Bay. Larkum (1977 and personal communication) noted more than 100 species of epiphytic and benthic algae associated with seagrasses in Botany Bay, the most common (by weight) being Ulva lactuca, Colpomenia sinuosa, Ectocarpus confervoides and Laurencia obtusa. P. australis, presumably because of its larger leaf area consistently shows a greater diversity of epiphytic algae (May et al 1978).

A hypothesis for nutrient conservation between seagrasses and epiphytes (Harlin 1975) may be applicable to Botany Bay epiphytes. As seagrasses decay in autumn, epiphytic algae bloom, possibly in response to increased availability of nutrients, and blanket the seagrasses. The algae eventually break away from the deteriorating host and die in late winter and early spring, releasing nutrients which become available for phytoplankton blooms and finally for new seagrass growth.

Larkum (1976b) found that C. sinuosa and E. confervoides completely blanket seagrass beds during July - August and August - September, respectively. These months correspond with the winter low productivity period when the bay seagrasses are not utilizing nutrients at their normal spring and summer rates.

Seagrasses provide an enhanced substratum for algae, including suitable light and nutrient exchange conditions; vitamins and hormones may also be available and some carbon exchange possibly occurs.

Penhale and Smith (1977) have suggested that epiphytes provide some protection from desiccation for the seagrass host.

5.2.2 Benthic and Infaunal Communities

Studies of seagrass fauna in New South Wales have not discriminated between phytal epifauna and sedimental epi- and infauna. Benthos of Zostera beds, Posidonia beds and adjacent non-grassed areas have been studied, the most extensive being that of Hutchings and Recher (1974) for Careel Bay where 136 species were collected over a two-year period (Table 6).

Two current studies are relevant to Botany Bay :

- Benthic data collected over a number of years by the New South Wales State Fisheries and the State Pollution Control Commission are being collated and analysed
- Epibenthic communities in Port Hacking are being studied within the CSIRO Estuarine Project. In this context, Young and Wadley (1976) have compared the fauna of Posidonia beds and adjacent bare areas, with regard to both seasonal and rainfall variation.

Several other studies along the mid-NSW coast provide species lists and comparison of grasses and ungrassed areas (Table 5). All studies concluded that species diversity and population numbers were greater on grassed than on ungrassed areas (Table 6).

MacIntyre (1959) noted that the seagrass benthos was dominated by filter feeders rather than browsers and deposit feeders.

Weate (1975) concluded that species composition at Myall River was similar to that at Careel Bay. She correlated species diversity and abundance with Zostera density and found both were minimal in ungrassed areas. Areas both of decaying grass and of sparse coverage have greater numbers of species and individuals. The densest Zostera beds supported the greatest number of species and individuals.

Table 5. Studies of Benthic Fauna, mid-New South Wales Coast
(Comparing Benthos of Seagrass Beds with Ungrassed Areas)

Author	Area
Day 1975	Tuncurry Creek and Wollamba River
Weate 1975	Myall River
MacIntyre 1959	Lake Macquarie
Powis 1975	Tuggerah Lake
Hutchings and Recher 1974	Careel Bay
Harris 1977	Lake Illawarra
Australian Museum 1974	Eurobodalla Shire (South Coast)

Powis (1975) sampled Z. capricorni benthic infauna over a six-month period (July to December) and noted relatively constant species composition but changes in species abundance linked to spring spawning periods and settlement of new generations.

Weate and Hutchings (1977) surveyed the benthos of non-grassed areas in several barred coastal lagoons in the Gosford region. These lakes had reduced estuarine faunas similar to those in Tuncurry Creek (Day 1975) and the lower Myall River (Weate 1975), in contrast to that of Careel Bay which is almost fully marine. The total number of species from the Gosford lagoons is greater than from Careel Bay ungrassed areas (Table 6) but is less than from Careel Bay grassed areas.

Studies of seagrass benthic fauna in Botany Bay include :

- Watkins (1976), who recorded 67 species from Zostera beds along the northern shore of Botany Bay near Banksmeadow
- Australian Littoral Society (1978) survey of benthos at Towra Point
- University of New South Wales, School of Zoology undergraduate surveys collated and lodged in the University Library.

Several of these studies, when comparing the three most abundant animal groups - polychaetes, crustaceans and molluscs, confirm that seagrass areas support a greater diversity of benthic organisms than comparable ungrassed areas (Table 6). Another conclusion, not apparent from the table but apparent from compiled species lists, is that the fauna common to grassed and ungrassed areas is less abundant on ungrassed areas. Kikuchi (1974), in a review of Japanese seagrass research, noted that infaunal species of seagrass beds are also distributed widely throughout similar muddy environments, though the density and biomass of seagrass infauna generally is higher.

The herbivorous opisthobranch mollusc Aplysia sp (sea hare) occurs commonly in seagrass beds. Populations vary seasonally reaching maximum density in spring and early summer (Hutchings and Recher 1974). Although they were thought to eat seagrass, their main dietary component appears to be the associated algae (Kikuchi and Peres 1977).

Sea urchins are major consumers of seagrass (Kikuchi and Peres 1977) and are known to consume P. australis in Cockburn Sound, Western Australia (Cambridge unpublished data). Sea urchins, however, have not been reported from eastern Australian seagrass beds.

Kirkman (1976b) reports heavy grazing of seagrasses by amphipods in laboratory cultures but notes that normally amphipod populations are probably kept low by predation.

Few comparisons have been made of the faunas of Posidonia and Zostera beds. The only extensive survey to date (Hutchings and Recher 1974), of Careel Bay, shows Zostera to have a more diverse fauna than Posidonia but this conclusion is uncertain because the species were sampled by different methods. Hutchings and Recher acknowledge the difficulty of sampling Posidonia beds and state that the Posidonia zone "was not well sampled".

Posidonia, with wider and longer leaves (average 330 mm compared with 170 mm for Zostera) supports a greater epiphytal biota (May et al 1978). Similarly, the greater bulk of a Posidonia bed may provide a greater diversity of micro-habitats and hence lead to greater species diversity (Kikuchi and Peres 1977).

5.2.3 Nektonic Communities

The mobile fauna (nekton) of seagrass beds comprises fish, crustaceans (principally prawns and crabs) and cephalopods (squid).

Table 6. Comparison of Benthic Fauna in mid-New South Wales Estuaries

Author and Location	Benthic Fauna of :-											
	Bare Areas				<u>Zostera</u> Communities				<u>Posidonia</u> Communities			
	P*	C*	M*	T*	P	C	M	T	P	C	M	T
Day (1975) Tuncurry Creek		1		1	7	5	8	20				
Weate (1975) Myall River					14	16	12	42				
Weate & Hutchings (1977) Gosford Lagoons	10	11	23	44								
Watkins (1976) Botany Bay								67				
Weate ** Botany Bay								30				13
Hutchings ** Wallis Lake					32							
Hutchings & Recher (1974) Careel Bay	10	8	12	30	36	23	20	79	28	18	14	60

Notes : * P = polychaetes, C = crustaceans, M = molluscs and T = total. Numbers of species.

** Unpublished data reported by Hutchings and Recher (1974)

Few systematic studies of nekton living in, or utilizing, seagrass beds have been made in Australia. Hoese (1978) has recorded 80 to 100 fish species living in southern New South Wales seagrass beds. Most benthic studies discussed above (Table 6) contain fish netting results but none of these studies are quantitative.

Any systematic study of seagrass nektonic communities must account for different residence times of mobile animals in the seagrass beds, reasons for entry and exit, partitioning of food and effects of nekton upon the sessile seagrass biota. Kikuchi (1974) in a review of Japanese seagrass consumer ecology, classified the mobile fish and decapods into four residence classes. These are, with reference to the Botany Bay nekton :

- . Permanent residents, usually small, non-commercial species - gobies, syngnathids (pipe fish and seahorses), fortescue and hardyheads
- . Seasonal residents, including :
 - those which enter for spawning - portunid crabs, processed shrimp, squid, river garfish and flathead
 - juveniles and subadults, which are the majority of seasonal residents - tarwhine, leather jackets, bream, groper, luderick, old wives, silver biddy, striped perch and mullet (Hoese 1978)
- . Temporary visitors - forage in a wider area than the seagrass beds - toado, flathead, whiting, adult bream and luderick
- . Occasional migrants - tailor and sharks.

The mobile invertebrate fauna of seagrass beds can also be divided on the basis of residence time. Most smaller animals (eg caridean shrimp, amphipods) are more or less permanent residents but show pronounced seasonal population changes. The rest (mainly portunid crabs and penaeid prawns) are seasonal residents or temporary visitors utilizing seagrass beds while passing from tidal flats to deeper water.

Young (1973) initially considered that juvenile king prawns (Peneaus plebejus) recruited preferentially onto seagrass rather than on bare substrate. Later studies (Young and Wadley 1976) indicated that post-larvae showed no preference between seagrass and bare substrates rather both mortality and emigration rates

are less in seagrass areas, resulting in an observed greater number of post-larvae. In contrast, Young and Wadley (1976) noted a consistent preferential recruitment of tiger prawns (P. esculentus) onto seagrass meadows.

Partitioning of food among fish species occurs in various ways :

- . Different seasonal abundance and food requirements of fish during their development (temporal differences)
- . Differing morphological adaptations of fish lead to different prey preferences (morphological differences)
- . Limitation of vertical swimming capacity (spatial differences).

In addition, Kikuchi (1974) has shown that food-chain relationships of fishes inhabiting seagrass beds change seasonally. Dynamic seasonal variation is caused by :

- . Presence or absence of some trophic link by the migration of seasonal residents and transients
- . Progressive change of food requirements accompanying ontogenic development of predators
- . Seasonal change of feeding habits of predators relative to food abundance.

De Sylva (1975) has reviewed the literature on nektonic detritus-based food webs (Table 7). These do not include the inter-connecting links and feedback mechanisms which exist between the various pathways.

Major prey items in seagrass beds are moving epibenthos, especially crustaceans (Kikuchi 1974). Infaunal benthos is not generally consumed by permanent or seasonal residents but is by temporary visitors. Several fish species such as leather-jackets and luderick consume epiphytic algae but few fish species consume seagrasses directly.

Kikuchi (1974) notes that few true piscivores occur within seagrass beds, presumably because of shelter afforded to potential prey species. Hoese (1978) notes that piscivores such as tailor only enter seagrass beds where the grass is sparse although, in Botany Bay, tailor and flathead commonly are found in or near seagrass beds (Bell personal communication).

Table 7. Detritus-Based, Nektonic Food Webs
(de Sylva 1975)

detritus	→	benthos (epifauna)	→	benthophagous fishes
detritus	→	benthos (infauna)	→	benthophagous fishes
detritus	→	benthos	→	benthophagous fishes → large fish → predators (sharks)
detritus	→	small benthos	→	larger invertebrates & small benthic fishes → large fishes
detritus	→	large detritivorous fishes (mullet):	"telescoping" of food chain	
detritus	→	benthos	→	large predators
detritus	→	micronekton	→	intermediate predators
detritus	→	zooplankton	→	small fishes and invertebrates
detritus	→	zooplankton	→	small fishes and invertebrates → larger fishes

Consumption of seagrass and epiphytal organisms has been discussed in several papers. Kirkman (1976c) found that 3 per cent of standing P. australis was consumed by fish. Thompson (1957, 1959) has shown that garfish consume Zostera. Bell et al (in press) found gut contents of leatherjackets Monacanthus chinensis, Meuschenia freycineti and Meuschenia trachylepis consisted of 45, 75 and 69 per cent P. australis fragments respectively. They suggest that leatherjackets consume seagrass for ectoprocts and epiphytes. Luderick eat filamentous algae and Zostera, and mullet eat diatoms (Thomson 1959). Cobblers (catfish) eat seagrass for the nest-building polychaete Spirorbis on the leaves (Thomson 1957). Several fish species including yellow tail accidentally ingest grass whilst snapping at fast moving prey (Thomson 1957).

The cosmopolitan sea mullet, Mugil cephalus has been studied by Odum (1970) and is representative of a class of fish which 'telescope' the detrital food chain by directly consuming primary decomposers. The benefit of unlimited food supply thus gained is balanced by a need for continuous foraging to make up the fishes' energy requirements.

Fish species entering seagrass beds as juveniles and sub-adults have common development characteristics, i.e. have pelagic larvae, which, on reaching a specific body length, move to the bottom and settle into the seagrass beds. Sub-adults, on attaining a further specific body length, move out of seagrass beds to other ecosystems (such as rocky shores) or utilize a wider range of ecosystems including the seagrass beds, i.e. they then become temporary visitors.

The specificity of food organisms for the commercially important black rock fish Sebastes inermis inhabiting Zostera marina beds in Japan has been extensively studied and exemplifies the partitioning of food among the numbers of a species (Table 8).

Comparable Australian studies, although only covering portions of the life cycles of some estuarine species, show similar trends, i.e. migrations are closely related to ecological demands of the species, which are in turn dependent on ontogenic development.

Table 8. Food of Black Rock Fish (Sebastes inermis)
during Ontogenic Development (Harada 1963)

Period	Developmental Stage	Prey Items	Region
Early Spring	larva	zooplankton	surface water
Spring	early juvenile 10 - 20 mm	copepod species 1	surface water
	late juvenile 20 - 25 mm	copepod species 2	in seagrass bed
Early Summer	early sub-adult	mysids + gammarid amphipods	under leaf canopy
Autumn	late sub-adult	mainly small shrimp with some mysids and gammarids	under leaf canopy
Spring	adult 1-2 yrs	goby juveniles*	in seagrass bed
Summer	adult 1-2 yrs	shrimp*	

* The alteration of principle food for large fish is determined by seasonal changes in the relative abundance of available prey.

Maclean (1971) showed a change of diet with ontogenic development for winter whiting (Sillago maculata) in Moreton Bay. Fish need to attain a length of 150 mm to eat molluscs, 165 mm to eat Glossobalanus (acorn worm - a hemi-chordate) and 170 mm to eat brittle stars. He also noted a change of feeding strategy; juveniles eat epifauna (mysids and amphipods) from the seagrass and adults eat infauna (mainly polychaetes) from a wider range.

Robertson (1977) showed a similar change in diet and range for juvenile King Georges whiting (Sillaginodes punctatus) in Western Port. Juveniles move into seagrass beds in mid-November and for their first five months eat harpacticoid copepods, mysids and gammarid amphipods. Juveniles up to the 2+ year class forage widely over seagrass and associated mud flat areas, their preferred food being ghost shrimp (Callinassa australiensis) larvae when in season and several species of polychaetes at other times. The 3+ year classes move out of the seagrass beds and utilize a wider diet consisting mainly of polychaetes (Thompson 1957).

Bell et al (1978) studied foreshore (Centropogon australis) from Posidonia beds in Port Hacking and found only one length class within the beds (14 - 68 mm). The younger sub-adult Fortescues are highly dependent on crustaceans of Posidonia beds whilst older fish (52 - 78 mm) appear to migrate from the seagrass beds to adjacent rocky shores.

Pollard and Bell (1976), comparing nekton from various habitats in Port Hacking, recorded 26 species on seagrass (P. australis), 22 on rocky shores, 21 on sand, 6 on mud and 13 pelagic species. They compared fish gut contents with benthic samples from a Posidonia habitat on a seasonal basis and found a "significant dependance upon Posidonia beds and their associated invertebrate fauna for food resources by the Posidonia fish community".

Several other studies provide fish species lists and catch data from seagrass areas (Tables 9, 10 and 11).

5.3 Use of Seagrass Beds for Protection

The provision of shelter for juvenile fish and crustaceans within seagrass beds is thought to be of prime importance (Hoese 1978). Young and Wadley (1976), in a study of king prawns (P. plebejus) in Moreton Bay, found that prawns which are sheltered by seagrass beds show reduced mortality when compared to those which settle on adjacent bare areas.

Table 9. Fish and Crustacean Species found on Seagrass Beds in Estuaries along the Mid-New South Wales Coast

Author and Location	Seagrass Species	Number of Species		
		Adult Fish	Crustaceans	Juveniles (fish)
Day (1975) Tuncurry Creek	<u>Z. capricorni</u>	17	8	5
Weate (1975) Myall River	<u>Z. capricorni</u>	13	4	-
Hutchings and Recher (1974) Careel Bay	<u>Z. capricorni</u> and <u>P. australis</u>	20	-	6
Pollard (1973) Jervis Bay	<u>Z. capricorni</u> and <u>P. australis</u>	22	-	9+
Pollard and Bell (unpublished data) Port Hacking	<u>P. australis</u>	40	-	20+

Table 10. Juvenile Fish Species Captured in Seagrass Beds

Fish species (common name)	Author		
	Day (1975)	Hutchings & Recher (1974)	Pollard (1973)
Blackfish	x	x	x
Garfish	x	-	x
Mullet	x	-	x
Trumpeter	x	-	-
Flounder	x	-	x
Trevally	-	x	x
Bream	-	x	x
Tarwhine	-	x	-
Whiting	-	x	x
Leatherjacket	-	x	-

x = present; - = not known

Table 11. Prawns Netted in Seagrass Beds

Species	Author and Time of Study		Number of Gravid Females in Sample
	Day (1975) June 1973	Weate (1975) Feb 1974	
<u>Palaemon serenus</u> (edible prawn)	*	*	15% to 50% (Weate)
<u>Macrobranchium</u> <u>intermedius</u> (edible prawn)	x	x	
<u>Metapeneaus</u> <u>macleayii</u> (school prawn)	x	x	large proportion (Day)
<u>Penaeus plebejus</u> (king prawn)	x		large proportion (Day)
<u>P. esculentus</u>	x		

* Occurred in large numbers

x = present

Several fish (e.g. leatherjacket, Monacanthus chinensis) have cryptic camouflage for seagrass and juveniles are seldom found outside seagrass areas (Bell personal communication). The use of seagrass for shelter is further supported by the almost complete lack of true piscivores in dense seagrass beds (Kikuchi 1974, Hoese 1978).

5.4 Utilization of Seagrass Beds by Other Animals

Birds are temporary visitors to, and not dependent on, seagrass communities. Black swans and black ducks pull out whole plants (Wood 1959b, Braithwaite 1975, Harris 1977), but this damage is not significant in Botany Bay.

Birds may be major predators on fish in seagrass beds (Hoese 1978). The three most common fishing visitors are cormorants (mainly the little pied cormorant Phalacrocorax melanoleucas), seagulls (Larus novaehollandiae) and the Australian pelican (Pelecanus conspicillatus). Cormorants and seagulls are present all year whereas pelicans are seasonal. Pelicans and cormorants are mainly piscivorous whilst seagulls are omnivorous, 'paddling' for polychaetes, scavenging among uncovered Zostera beds at low tide and fishing in shallows.

Wading birds using mud flats will also use shallow-water seagrass beds at low tide.

Sea turtles are known to graze on seagrasses and have been observed in Botany Bay, although their numbers are too small to have significant effect.

5.5 Nutrient Export

Kikuchi and Peres (1973) suggested that nutrients may be exported from seagrass communities to other ecosystems along four pathways:

- . Intact detached leaves
- . Particulate organic matter
- . Dissolved organic matter
- . Migration of animals.

Kirkman (1976c) measured the loss of intact leaf litter and calculated that about 0.025 per cent of P. australis standing crop is exported to other systems with each tide.

Studies of Western Port seagrasses (Bulthuis and Brand 1976) indicate that nutrients in the form of particulate organic matter, nitrogen and phosphorus are not exported. Migration of animals is treated in Section 5.3.

6 THE HYDRODYNAMIC EFFECTS OF SEAGRASSES

Burrell and Schubel (1977) reviewed the literature on hydrodynamic effects of seagrasses, and indicate three major effects:

- . Increased sedimentation rates
- . Preferential concentration of finer particles
- . Stabilization of deposited sediments.

These effects are brought about by interaction of three mechanisms.

- . Direct and indirect extraction of fine water-borne particles

The dense carpet of seagrass blades baffles the water currents, creating a layer of water into which fine sediments settle. Algal epiphytes, particularly the blue-greens, have a mucilaginous sheath to which fine sediment particles and nutrient laden colloidal particles adhere (Ginsburg and Lowenstam 1958). Leaf roughness due to calcareous tubes, nests and skeletons of epiphytic fauna (polychaetes, bryozoans etc.) also damps water movement and entrapping more fines.

Baffling efficiency depends on leaf structure (length, breadth) and plant density (Wood et al 1969). This affects not only the mean size but also the sorting (dispersion), skewness, roundness and shape of trapped sediment particles (Burrell and Schubel 1977).

Impedance of water circulation by seagrasses can create problems for thermal water discharge from power stations (Higginson 1970).

- . Formation and retention of particles produced locally within seagrass beds

As epiphytic fauna and infauna die, and as plant material falls to the sediments, calcareous and siliciferous skeletal parts combine with the sediments. Baffling results in less water-induced crushing and grinding and the mineral particles remain larger than in ungrassed areas.

- . Binding and stabilization of the substratum by seagrass rhizome and root systems

Seagrasses, unlike algae, have a true root system and so are able to consolidate and bind soils. Their rhizome system allows horizontal growth and, in some cases, vertical growth.

Binding efficiency also is dependent on species and plant density. The leaf blades reduce wave motion and hence minimize scour, while density and depth of roots affects binding.

Halophila, with a small leaf, shallow root system and creeping rhizome system with few roots, is at some disadvantage with regard to binding and stabilizing of soils (den Hartog 1970). On the other hand, Posidonia with large leaves, a deep root system and rhizomes capable of both horizontal and vertical growth, is very efficient at binding soils (Kikuchi and Peres 1977). Posidonia rhizomes are resistant to decay and can therefore form long-lasting 'mattes' of soil and rhizome material. Mattes have been reported to depths of 3 m within the bed sediments beneath South Australian waters and about 0.5 m in Jervis Bay (Larkum 1973).

Zostera, with smaller leaf size and only horizontal rhizome growth, is not as efficient as Posidonia. Nevertheless, the capacity of Zostera to bind sediments was demonstrated when its destruction by 'wasting disease' along the Atlantic coast of the United States and Europe resulted in stable sediments being replaced by shifting sands (Cottam and Munro 1954).

In Australia, opening of the Gippsland lakes to the sea in 1889 caused rapid changes to the salinity and temperature of the lakes resulting in destruction of Zostera (Rochford and Newell 1974). This led to rapid erosion of the formerly stabilized sediments and loss of the associated seagrass community. The sediments were replaced by unstable tidal sands which made the area unstable for recolonization.

7 EFFECTS OF HUMAN ACTIVITIES ON SEAGRASS BEDS

Thayer et al (1975) point out that seagrass beds have aesthetic value but can be incompatible with some water-oriented recreation such as boating and swimming and that amateur fishermen generally are aware of the importance of seagrass beds to their fish catch. However Higginson (1970) noted that seagrasses interfere with fishing and prawning.

Since 1972 about 150 ha of seagrass (almost 20 per cent of 1972 total) has been destroyed in Botany Bay, mostly due to man's activities either localized or outside of the seagrass beds (Table 12). Since these activities are continuing further damage can be expected.

7.1 Localized Activities

. Trawling

The effects of prawn trawling with otter trawls on the southern seagrass beds are unknown. Amateur fishermen attest to large amounts of grass being torn up by trawlers. Ruello and Henry (1977) are "not aware of any evidence which indicates that sein or trawl nets cause extensive ... damage ... to seagrass beds", but present no evidence. However, Peres and Picard (1975) documented damage by otter trawling to Posidonia beds near Marseille and recovery of these beds after prohibition of trawling.

. Boat Damage

Passage of propeller driven boats through seagrass shallows can produce erosion channels. This has been well documented overseas (Thayer et al 1975, Zieman 1976) and in Western Port (Shapiro 1975). The extent of this damage in Botany Bay is unknown but tyre tracks left by amphibious vehicles off Silver Beach can still be recognized as erosion channels after at least 20 years (Larkum unpublished data).

. Bait Digging

Fishermen dig up both Zostera and Posidonia plants in shallow nearshore seagrass beds, particularly in Quibray Bay, to obtain animals, mainly worms, for bait. This has caused considerable damage to the southern seagrass beds. Bait digging within the southern seagrass beds became illegal in January 1978.

The long term effects of both bait digging and damage by motor boat on Botany Bay seagrasses are unknown, but could be of importance.

Table 12. Seagrass Losses in Botany Bay from 1972 - 1978 Caused by Human Activities

Location	Activity/Cause of Damage	Loss to 1977 (Total in 1976 = 700 ha)	Will Loss Continue?
Banksmeadow (Northside <u>Zostera</u>)	dredging and reclamation for port	70 ha	yes, could result in complete loss
Towra Point	trawling	unknown; said to be significant by amateur fishermen and in the literature (see below)	unknown
	bait digging	unknown, thought to be seasonally significant	unknown
	recreation (Boat damage)	unknown, said to be significant in the literature (see below)	yes
	smothering and physical damage caused by increased and realigned wave action due to configurational dredging	60 ha	yes, as realignment continues
Bonna Point	as above	2 ha	yes, as realignment continues
Silver Beach	as above (Wave realign- ment has increased and groyne erosion from both end of groyne field)	unknown	yes, as realignment continues
Bonna Point and Silver Beach	recreation - boat damage	as for Towra Point	yes
Quibray Bay	smothering due to mobile sands from Kurnell sand dunes	5 ha	yes
	bait digging	1 ha	
Georges River	turbidity due to sand dredging and river construction	no estimate at this time	unknown

. Reclamation and Dredging

The only seagrass areas reclaimed in Botany Bay are those of the north-west corner. Construction of the north-south runway extension to Kingsford Smith Airport smothered a small patch of inshore grass (probably Z. capricorni).

The present reclamation for a port and roadway has smothered about 70 ha of shallow water Zostera bed, about 10 per cent of the total bay seagrass area. Preliminary investigations by the New South Wales State Fisheries indicate this area was even more productive for juvenile fish of commercial interest than the Posidonia beds of Quibray Bay.

The fate of the remaining 30 ha of Z. capricorni is being examined; smothering by silts washed off the reclamation has been noted but the final condition is uncertain.

No seagrass beds have been dredged in Botany Bay, though dredging is thought to have contributed to the decline of seagrass in Georges River.

7.2 Activities Outside the Seagrass Beds

. Dredging

The full indirect effects of dredging activities are unknown but likely effects are :

- . Changed wave energy resulting in erosion and deposition
- . Increased turbidity which may reduce light penetration and so reduce photosynthetic rate
- . Changes in redox potential of sediments and rapid addition of oxidized materials to the water column (Thayer et al 1975) which may retard recolonization (Wood 1959b)
- . Release of plant toxins from disturbed sediments
- . Release of mineral nutrients from disturbed sediments enhancing subsequent growth (Odum 1963).

Configuration dredging in the entrance channel of Botany Bay has led to a change in wave energy regime within the bay. One effect has been progressive realignment of beaches along the southern shore. Associated loss of seagrasses has occurred and probably will continue. The total loss may be offset by recolonization of new areas.

Control of realignment by interruption of sand movement, would reduce future losses around Towra Point. However, replenishment of beaches repeated at intervals of 3 to 5 years would prevent recolonization by seagrasses of both the borrow and replenish areas.

If the groyne field along Silver Beach is extended west to minimize further damage to Prince Charles Parade, erosion west of the new groyne would result in mobile sand which, under the influence of long shore drift, could smother seagrass further to the west. This loss might be offset to some extent by recolonization in the newly stable area created between the two end groynes.

. Effluent Disposal

The addition of waste materials to estuarine ecosystems usually impinges more directly upon the animal than upon the plant components (Thayer et al 1975). However industrial effluents from an oil refinery, a phosphate fertilizer plant and a blast furnace have destroyed P. australis beds in Cockburn Sound, Western Australia (Cambridge 1975). Similarly, industrial effluents on the northern shore of Botany Bay are thought to have destroyed seagrasses there (Larkum unpublished data). At present there are no industrial effluent outfalls within the Georges River - Botany Bay system which would effect seagrass beds.

Monitoring of Z. capricorni in Woronora River downstream from the Australian Atomic Energy Commission Reactor at Lucas Heights has shown no concentration of radio isotopes (Davy and Dudiatis 1974).

The effects on Botany Bay seagrasses of sewage are unknown. Sewage may contain both nutrients and toxins, and may increase turbidity; these can have different effects on seagrass and algal components. Increased nutrients may enhance epiphytic algal growth and seagrass growth (May personal communication), although imbalances may occur. Treated sewage effluent is thought to have destroyed seagrass beds near Adelaide (Larkum 1977).

. Agricultural and Urban Runoff

The effects of pesticides, chlorinated hydrocarbons, heavy metals and petroleum derivatives have been documented for many organisms but not for seagrass (Thayer et al 1975). The accumulation and cycling of these compounds between the seagrass and other components of the estuarine ecosystem are unknown.

- Cooling Waters

The effects of thermal pollution are considered above (Section 2.4). The loss of seagrasses near the Bunnerong Power Station cooling water outlet in the late 1930 would have been due to thermal effects (Larkum unpublished data). The only important thermal discharge to Botany Bay at present is from Australian Oil Refinery Ltd, Kurnell, which is licensed to discharge a maximum of 400 000 m³/day at a maximum temperature of 42°C. Measurements done by the State Pollution Control Commission indicate that mixing is rapid, and thermal effects upon adjacent seagrasses would therefore be minimal.

- Oil and Chemical Spills

Oil spills cause lasting damage to seagrasses (Thayer et al 1975); however results of the few Australian studies have not yet been published.

Oil spills have occurred at the single buoy mooring in Yarra Bay and at the Australian Oil Refinery Ltd berths at Kurnell. Larkum (1976c) has suggested that an oil spill at the single buoy mooring in 1974 killed the last remnant of P. australis on the north side.

No information is available from which to assess the effects on seagrass of pollution following spillage of various toxic chemicals.

7.3 Importance of Seagrass Loss

Kikuchi and Peres (1977) have summarized the significance of seagrass loss :

- Erosion and topographic and sedimental changes, leading to infaunal changes
- Drop in phytal biota unless other plants (e.g. algae) are available
- Decline in fish diversity and abundance due to decline of food and shelter for juveniles and decline in food for subadults and adults.

Two occurrences of seagrass loss have contributed to our understanding of the value of seagrasses and the significance of their loss.

The catastrophic decline of Z. marina (eelgrass) along the Atlantic coasts of the United States and Western Europe in the 1920's and 1930's has been well documented (Cottam and Munro 1954). Rasmussen (1977) reviewed work on faunal changes observed after seagrass decline and concluded that "not only the mobile fauna of the Zostera (crustaceans and certain fishes), but also the immobile animal life depend on the eelgrass beds only as a shelter and a substratum with better water movement, i.e. better conditions for respiration and feeding (plankton- and diatom-grazing) than on a level sea floor, and that it is a matter of vegetation or no vegetation more than the kind of vegetation."

However, when seagrass vegetation is not replaced, animals formerly associated with it disappear (Stauffer 1937). Similarly, Kikuchi (1974) in a review of Japanese research found a positive correlation between the decline of inshore fishes and decline of eelgrass beds.

Destruction of Gippsland Lakes seagrass beds following the opening of the lakes in 1889 towards the end of the last century is reported to have resulted in a drastic decline in the bream fishery (Dunstan 1968).

8 SEAGRASS RECOLONIZATION AND TRANSPLANTS

The slow recolonization of disturbed seagrass areas has been well documented overseas (Zieman 1975, Thayer et al 1975) and for Botany Bay (Larkum 1976b and unpublished data). Cleared Posidonia areas in Quibray Bay have shown no growth after two years and in Jervis Bay show very little growth after one year.

On the other hand, colonization of new areas can be rapid, as occurred with Z. capricorni on inshore areas in northern Botany Bay after reduction of wave action (Larkum in press).

Phillips (1974, 1976), Thorhaug and Austin (1976) and Kirkman (1976a) have reviewed the literature on transplanting of seagrasses. Overseas work cannot be related to Australian grasses and conditions (Kirkman 1976a). The only Australian work using Posidonia was successful on a small scale (Larkum 1976c) and included transplants in Botany Bay.

SUMMARY

Local and overseas research has shown that seagrass communities are important components of estuarine ecosystems. This is supported by work done in Botany Bay :

- The contribution of seagrasses to total primary production is greater than any other component within the bay ecosystem. Botany Bay seagrasses produce about 5 000 t of dry matter annually; in contrast, the 400 ha of mangroves in Botany Bay produce about 2 400 t annually
- Seagrass beds stabilize soils, contain erosion, baffle water currents and clear turbid waters
- The diversity of microhabitats and shelter on and under the leaf canopy and the provision of food via an extensive and sophisticated detrital based food web means that seagrass beds support a larger benthic and nektonic community than surrounding ungrassed areas
- Seagrass beds are particularly important as nursery areas for many fish species and Botany Bay seagrasses (particularly Z. capricorni) accommodate commercial species such as bream, luderick, leatherjackets, king prawns and blue swimmer crabs.

Four species of seagrass occur in Botany Bay. The dominant species are strapweed, Posidonia australis and silkyweed, Zostera capricorni.

500 ha of P. australis and about 100 ha of Z. capricorni occur along the southern shores of Botany Bay from Inscription Point to Taren Point. A large bed (100 ha) of Z. capricorni occurred in the northern port area before reclamation for Port Botany and a port road.

P. australis occurs from mean low water (mean low water + 0.2 m) to -3 m (Indian spring low water). Z. capricorni occurs as a fringe above and below P. australis in the southern bays and occurs from MLW to -2 m (Indian spring low water) in northern Botany Bay. Z. capricorni occurs in the Georges River system, but seagrasses no longer occur in Cooks River.

Seagrass beds are subject to continuing changes:

- Storms and sand movement continue to cause damage to the beds off Towra Point and Silver Beach. Current considerations to mitigate the effects of storm damage and beach

realignment to Silver Beach and Towra Point should consider the effects upon seagrass of each proposal.

- . The northern beds off Banksmeadow, now largely removed, should show some recolonization but will be limited, both in extent and density, by depth.

Human activities both within seagrass bed areas and elsewhere within the bay ecosystem have reduced seagrass distribution:

- . Industrial, agricultural and urban effluents appear to have limited the distribution of seagrasses in some places, particularly of P. australis from the northern shores
- . The depth to which seagrasses occur in Botany Bay is less than for these species in other estuaries, possibly because of greater turbidity
- . Configuration dredging of the bay entrance channel altered wave energy and direction over southern seagrass beds, leading to the loss of up to 70 ha since 1972
- . Construction of the port revetment led to expansion of Z. capricorni along the northern (Botany) shore. However reclamation for the port road has eliminated this gain. About 35 ha remain of the 100 ha existing prior to reclamation
- . Bait-digging boat propellers and, possibly trawling caused additional damage to seagrass beds but the extent is unknown.

Proposals for developments need to take account of the effects on seagrasses and the seagrass community. In particular, development proposals in the upper catchment of the Georges River should consider the effects of changed water parameters (e.g. increased nutrient loads or increased water currents) on seagrass beds further down stream.

Other problems such as bait digging and damage by propellers are more amenable to local management by the appropriate government body.

GLOSSARY

- Benthos : Plants and animals living in or on the bottom of a sea, attached or unattached, up to the high-water mark.
- Chemoautotroph : Organisms (generally bacteria) which obtain their energy for carbon dioxide assimilation by chemical oxidation of simple inorganic compounds (e.g. sulphide to sulphur) rather than by photosynthesis.
- Compensation depth : The depth in water at which, because of reduced light penetration, the rate of production of organic material by photosynthesis exactly balances the rate of breakdown of organic material by plant respiration. There is no net production below compensation depth.
- Configuration dredging : Dredging to a pattern calculated to deflect wave energy in a certain specified direction. Configuration dredging of Botany Bay entrance is a V-shaped channel 21 m deep along the centre line, side slopes of 1 in 50 and 1700 m long. It is designed to minimize wave action in the entrance to the port basin.
- End groyne erosion : Recession of the downdrift shore due to the action of a groyne system in trapping longshore drift (c.v.) and reducing the sand supply to the immediate downdrift beach.
- Epibenthos : Organisms living on the substratum surface, either attached or moving freely.
- Epifauna . Animal component of epibenthos.

- Epiphyte : Organisms living on a plant surface (in the case of seagrasses on the leaf surface), either attached or moving freely.
- Euryhaline : Having a wide salinity tolerance.
- Eurythermal : Having a wide temperature tolerance.
- Infauna : Organisms which dig, construct tubes, or burrow into the substratum.
- Long shore drift : The movement of sedimentary material in the littoral zone under the influence of waves and currents. Generally in a predominant direction determined by waves breaking at an angle to the shore.
- Meiofauna : Animals living within the interstitial spaces of a particular substratum.
- Nekton : Swimming organisms able to control direction.
- Photoautotroph : Organisms (generally plants) which obtain their energy for carbon dioxide fixation by photosynthesis.
- Rhizosphere : The section of substratum, including micro-organisms, surrounding the seagrass rhizome.
- Trophic : Concerned with nutrition. An ecosystem has two basic trophic components: An autotrophic (self-nourishing) component in which fixation of energy predominates (eg plants), and a heterotrophic (other-nourishing) component in which utilization and decomposition of complex materials predominate (i.e. most animals).

ACKNOWLEDGEMENTS

Hugh Kirkman (CSIRO, Cronulla), Tony Larkum (University of Sydney), Paul Weiner (Planning and Environment Commission of New South Wales) and Johann Bell (New South Wales State Fisheries) contributed greatly to the literature review and constructive criticism. They are thanked particularly for generous agreement to the use of unpublished data.

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