Seagrasses of Australia

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Preface

Australia: State of the Environment 1996 (the first ever independent and comprehensive assessment of the state of Australia's environment) was presented to the Commonwealth Environment Minister in 1996. This landmark report, which draws upon the expertise of a broad section of the Australian scientific and technical community, was prepared by seven expert reference groups working under the broad direction of an independent State of the Environment Advisory Council. While preparing the report, the former Department of the Environment, Sport and Territories, on behalf of the reference groups, commissioned a number of specialist technical papers. These have been refereed and are now being published as the State of the Environment Technical Paper Series. Reflecting the theme chapters of the report, the papers relate to human settlements, biodiversity, the atmosphere, land resources, inland waters, estuaries and the sea, and natural and cultural heritage. The topics covered range from air and water quality to seagrasses and historic shipwrecks.

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Drs Di Walker, Rob Coles and Scoresby Shepherd reviewed the manuscript and offered many improvements.

Abstract

This paper describes the nature of seagrasses and explains their importance in the marine environment and their relationships with other marine habitats. The body of the paper is split into three parts: the **state** of seagrasses in Australia; the **pressures** that are put on to seagrass habitats by people and nature; and the **response** that people can make to preserve and restore seagrass meadows. The extent, diversity and abundance of seagrasses are described for separate regions in Australia. There are about 51 000 sq km of seagrass meadow in Australia.

The damage to and loss of seagrass meadows in Australia is recorded, and the way that this decline has occurred is described with examples from various places. People's activities have caused the loss of about 450 sq km and natural events have caused damage to the extent of 1000 sq km in the past ten years. Any recovery from these pressures is described. An issue is made of the poor recovery of many temperate seagrass meadows and some tropical ones. The vulnerability of seagrass meadows is pointed out and the importance of considering their ability to recover after being damaged is emphasised. The ecological values of seagrass meadows should be estimated on a case by case basis as species differ in their abilities to support faunal communities and provide the other values for which they are respected.

It is apparent throughout this paper that more research needs to be carried out just to be able to record losses. Mapping, inventories of diversity and abundance and background data on seagrasses need to be collected. Further research on ameliorating damage to seagrass meadows and accelerating the restoration processes needs to be properly funded and carried out. The legislation drawn up to protect seagrass habitats, relevant to each State, is listed.

Finally, some recommendations as to further research and ways that seagrass meadows can be preserved are presented.

1 Introduction

Seagrasses are first noticed as heaps of decaying plant material on ocean or estuarine beaches. Where does this large amount of plant material come from? Closer examination underwater shows meadows of grass-like plants relevantly called seagrasses. Although these plants look like grass, they are not closely related. They originated from saltmarsh plants which evolved, through time, to tolerate saline water and live in the sea. Some of the characteristics of terrestrial plants still remain but seagrasses are now well adapted to marine life (Larkum & den Hartog 1989).

Seagrasses are marine flowering plants which reproduce by producing flowers fertilised from pollen, producing seeds or seedlings. There are about 30 different species from 12 genera of seagrass in Australia (Table 1). Only one genus is not represented in Australia. There is a distinction between tropical and temperate seagrasses and the general latitude for the change between the two is Moreton Bay in the east and Shark Bay in the west.

Seagrass meadows grow in estuaries, in the lee of islands and in sheltered bays around Australia. Mostly, seagrasses are found in estuaries such as Oyster Harbour at Albany, Westernport Bay in Victoria, Moreton Bay near Brisbane or Trinity Inlet and Hinchinbrook Channel, near Cairns and Cardwell respectively in North Queensland. Along the coast from Shark Bay south, seagrasses are found in enormous meadows along the Western Australian coast through to South Australia, into Spencer Gulf and Gulf St Vincent. In Western Australia alone these meadows occupy the same area as rainforests in the whole of Australia (22 000 sq km).

Seagrasses usually grow on sandy or muddy substrates; they depend upon their rhizomes or underground stems for anchorage. Their distribution is dependent upon temperature and exposure to wave action but most importantly upon light. At Esperance, Western Australia, seagrasses have been found to 47 m whereas, in many estuaries, around 2 m is their depth limit.

Great care by environmental managers is taken to ensure that seagrass meadows are not damaged or lost. Seagrass meadows are held in such high esteem because they are important for a number of reasons which are presented in the next sub-section.

In 1989 many of the pre-eminent scientists working on seagrass biology, ecology, taxonomy and biogeography collaborated to produce the definitive book on seagrasses in Australia (Larkum et al. 1989).

In January 1996, sixty-five researchers from fourteen countries attended a workshop on seagrass biology at Rottnest Island near Perth in Western Australia. Forty-nine peer reviewed papers were published in the pre-workshop proceedings and of these 17 were on Australian seagrasses (Kuo et al. 1996).

1.1 Importance of seagrass

Seagrass meadows are the nursery grounds for many of Australia's commercial fish and crustacean species. The juveniles come into the seagrass meadows for protection against predators, to feed on the epiphytes growing on seagrass plants and to feed on the organic detrital rain that falls into the meadow from the water above. For example, in the Gulf of Carpentaria, the east coast of Queensland and north-eastern Arnhem Land, juvenile tiger prawns (*Penaeus esculentus* and *P. semiscatus*) and endeavour prawns (*Metapenaeus ensis* and *M. endeavouri*) have seagrass meadows as their nursery grounds (Staples et al. 1985; Poiner et al. 1987; Coles et al. 1993). Post-larvae of both tiger and endeavour prawns settle from the water column into the shallow inshore seagrass meadows and, as they grow, they move into and through the deeper meadows. After a cyclone four years ago, the banana prawn industry suffered badly because seagrass meadows were destroyed. The loss of 183 sq km of seagrass in the Gulf of Carpentaria has resulted in a loss of between 250 t/yr and 300 t/yr of tiger prawn production (Poiner et al. 1993).

The juveniles of the western rock lobster forage in seagrass meadows close to the reefs in which they shelter (Joll & Phillips 1984). With the loss of seagrass meadows in Westernport Bay came a decline in commercial fishing (Bulthuis 1983).

Seagrass leaves act as a filter; the strap-like leaves of seagrass plants slow the overlying water thus allowing any sediment that is suspended in the water to fall out into the seagrass meadow. This sediment is made up of silt and inorganic and organic particles from the breakdown of plants and animals (Bulthuis et al. 1984a).

The extensive rhizome systems of most seagrass meadows stabilise the underlying sediment and prevent sediment movement. Many beaches, channels and sandy bottoms are stabilised by seagrass rhizomes.

Seagrass meadows play an important part in the cycling of nutrients and in the food web of these inshore coastal areas. The leaves and stems, in the case of *Amphibolis*, support numerous and abundant epiphytes which are fed upon by amphipods and snails (Jernakoff & Neilsen, in 1997). The discarded leaves and epiphytes are broken up by wave action and bacteria, and a large suite of detritovores fill the base of a complex food web. Commercially, this is important because the western rock lobster forages in detritus and consumes fauna and plant material (Jernakoff 1987).

Seagrass leaf and epiphyte detritus are important components of the food web in coastal ecosystems. Leaves are lost in storms or are replaced by new leaves, epiphyte turnover is very high and the epiphytes also contribute to the food web.

Seagrasses are not fed upon by many herbivores. However, of significance, in the tropics, the dugong (*Dugong dugon*) ingests leaves and rhizomes, and the green sea turtle (*Chelonia mydas*) eats leaves. In warm temperate seagrass meadows, seagrasses are fed on by a few fish, notably hemiramphids and monacanthids, but grazing is most usual on the epiphytes and carried out most commonly by molluscs and amphipods (Klumpp et al. 1989).

1.2 Relationship with other environmental habitats

Generally, seagrass meadows fringe the shorelines of many coastal areas. The meadows cannot withstand great energy from swell or waves so they are usually found in sheltered bays, estuaries or within the lee side of reefs or other barriers. The shallower edge of seagrass meadows is limited by water depth and the ability of plants to withstand breaking waves. The deeper edge is limited by light; in some places this means that seagrasses grow no deeper than one or two metres whereas in ocean water seagrass plants have been found to grow at depths of 56 m in the Great Barrier Reef Lagoon (Rob Coles, QDPI Land Use and Fisheries).

In the tropics, where substrate allows, seagrass meadows may reach into the mangrove forest. Walker and Prince (1987) refer only to *Halophila ovalis* reaching into the mangroves in their description of seagrasses on the north-west coast. Seagrasses in the tropics often reach into intertidal mudflats (e.g. Moreton Bay, Trinity Inlet, the Gulf of Carpentaria and Cape Flattery). Species of *Halodule* and *Halophila* are usually well represented and these areas contain significant numbers of commercial juvenile prawns.

Coral reefs are synonymous with oligotrophic waters (water with very low concentrations of nutrient); water is low in plankton and attenuation of light is low. Seagrass may grow in sandy lagoon areas between reefs, offshore in deeper water, or in lagoons fringed by coral or coral rubble that retain water although the tide has receded well below the lagoon level.

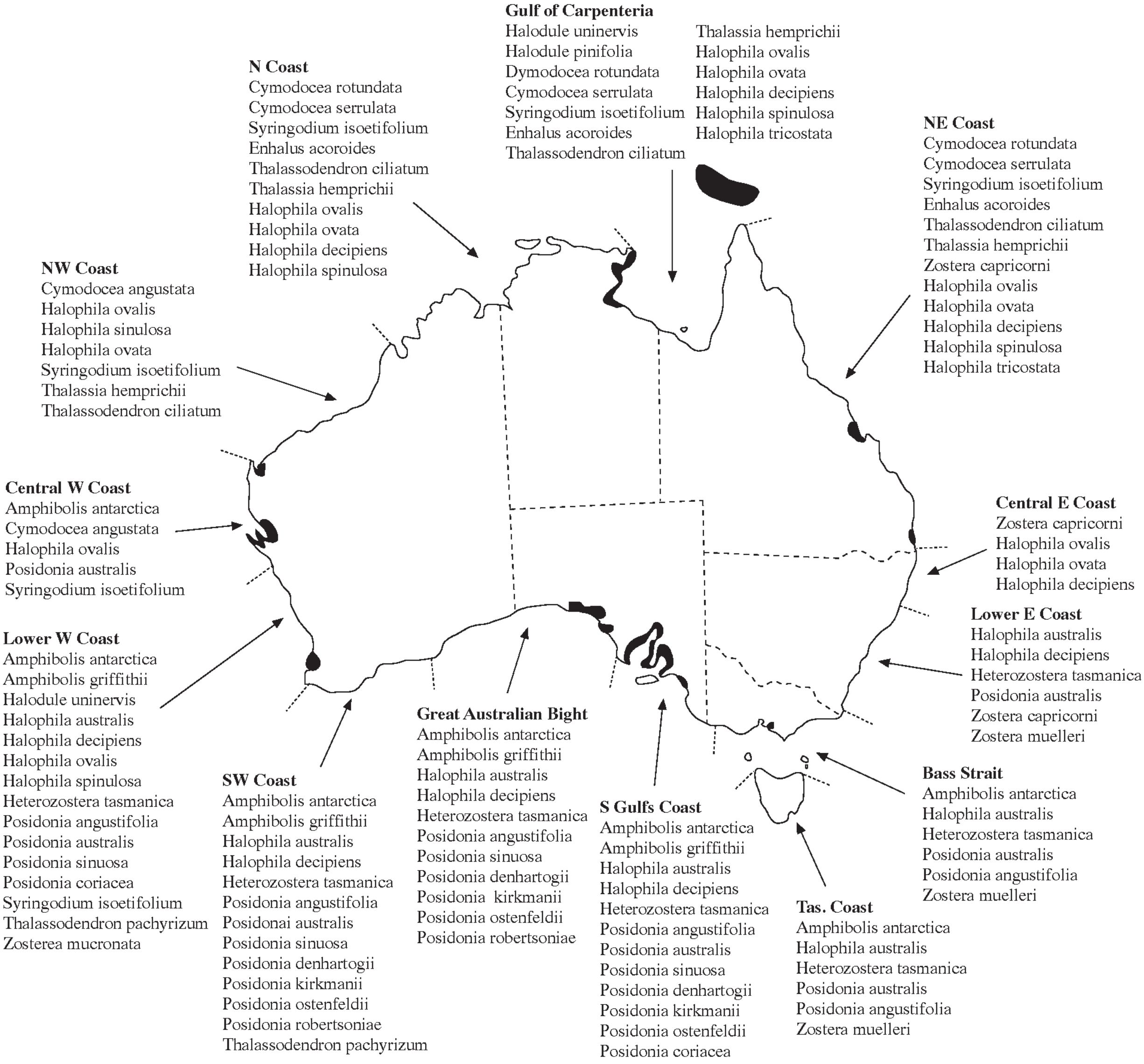
Beaches may or may not be fringed by seagrasses depending upon the aspect and exposure of the beach. Exposed beaches with surf usually do not have seagrasses offshore, but beaches protected from the prevailing swell by headlands have well developed seagrass meadows. These meadows reduce sand erosion or accretion and maintain high water quality. The seagrass meadows are often considered a nuisance by local councils because of the drift plant remains that accumulate on the nearby beaches. These detrital wracks are the source of nutrients for offshore communities and support part of the food web of this marine environment (Robertson & Hansen 1982).

Seagrass meadows are often protected from the full force of open ocean swell and waves by offshore reefs. Many of the vast seagrass meadows of Western Australia are there because they are protected from swell by shallow offshore limestone reefs. A few seagrasses have adaptations to live on rock. Both species of *Thalassodendron* are only found on reefs and both *Amphibolis* species in temperate regions and *Thalassia* in Queensland can grow on reefs as well as sand.

2 State

Seagrass plants require sufficient light to make enough carbohydrates to meet their growth and respiration requirements. The depth to which seagrass grows is partly determined by the amount of light it receives. At the shallow edge of the seagrass meadow, growth is determined by wave action and exposure time at low tide. There are many morphological forms of seagrass and some have the ability to withstand more water movement than others, some have a lower compensation light level than others, and some have the ability to colonise and regrow rapidly when disturbed.

Locally, water temperature does not make a great difference to the distribution of seagrasses, but on an Australia-wide basis seagrasses are divided into tropical and temperate species. On the east coast, tropical and temperate species meet at Moreton Bay, while on the west coast this transition region is wider and stretches between Perth and Shark Bay, probably because of the warm, south-flowing Leeuwin Current (Larkum & den Hartog 1989; Walker 1991).



Gulf of Carpenteria
Halodule uninervis
Halodule pinifolia
Dymodocea rotundata
Cymodocea serrulata
Syringodium isoetifolium
Enhalus acoroides
Thalassodendron ciliatum
Thalassia hemprichii
Halophila ovalis
Halophila ovata
Halophila decipiens
Halophila spinulosa
Halophila tricostata

N Coast
Cymodocea rotundata
Cymodocea serrulata
Syringodium isoetifolium
Enhalus acoroides
Thalassodendron ciliatum
Thalassia hemprichii
Halophila ovalis
Halophila ovata
Halophila decipiens
Halophila spinulosa

NE Coast
Cymodocea rotundata
Cymodocea serrulata
Syringodium isoetifolium
Enhalus acoroides
Thalassodendron ciliatum
Thalassia hemprichii
Zostera capricorni
Halophila ovalis
Halophila ovata
Halophila decipiens
Halophila spinulosa
Halophila tricostata

NW Coast
Cymodocea angustata
Halophila ovalis
Halophila sinulosa
Halophila ovata
Syringodium isoetifolium
Thalassia hemprichii
Thalassodendron ciliatum

Central W Coast
Amphibolis antarctica
Cymodocea angustata
Halophila ovalis
Posidonia australis
Syringodium isoetifolium

Central E Coast
Zostera capricorni
Halophila ovalis
Halophila ovata
Halophila decipiens

Lower E Coast
Halophila australis
Halophila decipiens
Heterozostera tasmanica
Posidonia australis
Zostera capricorni
Zostera muelleri

Lower W Coast
Amphibolis antarctica
Amphibolis griffithii
Halodule uninervis
Halophila australis
Halophila decipiens
Halophila ovalis
Halophila spinulosa
Heterozostera tasmanica
Posidonia angustifolia
Posidonia australis
Posidonia sinuosa
Posidonia coriacea
Syringodium isoetifolium
Thalassodendron pachyrizum
Zosterea mucronata

SW Coast
Amphibolis antarctica
Amphibolis griffithii
Halophila australis
Halophila decipiens
Heterozostera tasmanica
Posidonia angustifolia
Posidonai australis
Posidonia sinuosa
Posidonia denhartogii
Posidonia kirkmanii
Posidonia ostenfeldii
Posidonia robertsoniae
Thalassodendron pachyrizum

Great Australian Bight
Amphibolis antarctica
Amphibolis griffithii
Halophila australis
Halophila decipiens
Heterozostera tasmanica
Posidonia angustifolia
Posidonia sinuosa
Posidonia denhartogii
Posidonia kirkmanii
Posidonia ostenfeldii
Posidonia robertsoniae

S Gulfs Coast
Amphibolis antarctica
Amphibolis griffithii
Halophila australis
Halophila decipiens
Heterozostera tasmanica
Posidonia angustifolia
Posidonia australis
Posidonia sinuosa
Posidonia denhartogii
Posidonia kirkmanii
Posidonia ostenfeldii
Posidonia coriacea

Tas. Coast
Amphibolis antarctica
Halophila australis
Heterozostera tasmanica
Posidonia australis
Posidonia angustifolia
Zostera muelleri

Bass Strait
Amphibolis antarctica
Halophila australis
Heterozostera tasmanica
Posidonia australis
Posidonia angustifolia
Zostera muelleri

Figure 1: Distribution of seagrass species along the Australian coastline divided into CONCOM regions

Note: Seagrass meadows are the shaded areas along the coast and the lists are of seagrass species found in each CONCOM region.

The distribution of seagrass species is shown in Figure 1; the coastline of Australia is divided into those regions recognised by the Council of Nature Conservation Ministers (CONCOM). A very broad-scale map of seagrass distribution is also shown in Figure 1. The distribution and boundaries of the ranges of seagrass species are tabled in Table 1. Total areas of seagrass by States are shown in Figure 2. It can be seen from this that Western Australia and South Australia have the largest areas of seagrass meadow and that there is an enormous area of seagrasses in the Torres Strait. Not all seagrass meadows in Australia have been surveyed and this figure will undoubtedly change as mapping and surveying continues. Ongoing surveys that will add to the areas in Figure 1 are likely to be in Queensland, Western Australia and Tasmania.

2.1 Seagrasses of New South Wales, Tasmania and Victoria

These States are probably the least well represented in seagrass diversity and abundance of the Australian coast. Ten species of seagrass are represented here. *Zostera* and *Heterozostera* are the most common genera with *Zostera capricorni* growing from Queensland to Mallacoota, where it is replaced by *Zostera muelleri*; there is an area between Jervis Bay and Mallacoota where the species coexist. *Heterozostera tasmanica* grows as far north as Port Stephens in New South Wales and is more likely to be found in oceanic water than in estuarine water. *Zostera muelleri* is more tolerant of exposure than *Heterozostera tasmanica* and is slowly replacing some areas in Western Port Bay where *H. tasmanica* once grew. Three species of *Halophila* grow in New South Wales and Victoria but only two, *H. ovalis* and *H. australis*, cover large enough areas to be considered as meadows. The range of *H. ovalis* and *H. decipiens* extends the length of the New South Wales coast, while *H. australis* is present between central New South Wales and all of Victoria and Tasmania. *Halophila* has a wide habitat range but is usually found growing in small patches with other seagrasses. Its biomass is less than other species and it has marked seasonal growth.

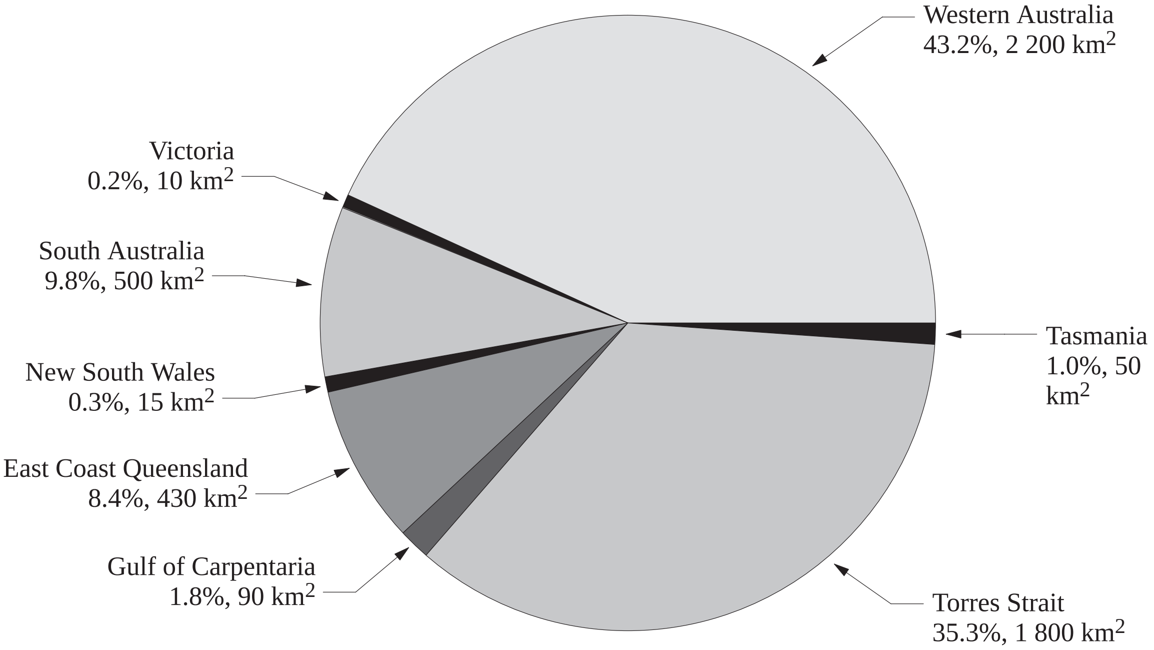


Figure 2: Estimates of seagrass areas

Note: Percentage shows contribution of each state area to the total area of seagrass in Australia (5100 square kilometres)

Posidonia australis has a northern most range at Wallis Lake, New South Wales, but is widely distributed in southern Australia. *Posidonia australis* occupies fewer habitats than does *Heterozostera*, *Zostera* and *Halophila* along the southern and eastern coasts of Victoria and New South Wales, where it avoids hyposaline conditions and unstable sediments, but is more tolerant of wave action than are the other taxa (West et al. 1989).

Recently, the large beds of *Posidonia* on the north-west coast of Tasmania and those between Flinders Island, Cape Barren Island and Clarke Island in eastern Bass Strait were found to consist mainly of *P. angustifolia* and not *P. australis*. This extended the range of *P. angustifolia* from Adelaide to Flinders Island.

The high-energy coastline of south-eastern Australia restricts seagrass to estuaries and protected bays. The distribution and dominance of the four seagrass genera (*Heterozostera, Halophila, Zostera* and *Posidonia*) are dictated by the occurrence and nature of those coastal features which offer a suitable growth habitat for them. The majority of the coastal features where seagrass grows in New South Wales are estuarine. *Zostera* occurs in 93% of estuaries, *Halophila* in 66% and *P. australis* in 43% (West 1983).

Estuaries have been classified into three basic types according to their entrance characteristics: drowned river valleys, barrier estuaries and coastal lagoons (Roy 1984). Distribution and occurrence of seagrasses vary between types of estuary and are also affected by the age, catchment area and stability of each estuary. In general, there is a higher coverage by seagrass about 3 km back from the estuary entrance, although *Zostera* may be found in feeder creeks and cut-off bays further upstream. The species' distribution also depends on substrate type and stability. All four genera occur predominantly on marine sand. At Port Hacking, New South Wales, *Zostera* and *Halophila* will readily recolonise seaward-facing sands subjected to frequent disturbance by storms. *Posidonia australis* recolonises less readily; in Botany Bay, for example, large areas that once supported *Posidonia* are now occupied by *Halophila* and *Zostera* after the *Posidonia* was removed by human disturbance and wave action.

Coastal lagoons also harbour seagrasses which are affected by the frequency with which the lagoon entrance is broached by the sea. In Smiths Lake in New South Wales, for example, the coverage by *Zostera* and *Halophila* is greater during marine conditions when the bar is open than during less saline periods. Hyposaline conditions do not suit *Posidonia*, which is absent from intermittently open lagoons. There are also several open bays in New South Wales containing seagrasses. Those at the mouths of large estuaries may undergo periods of high turbidity and low salinity (e.g. Botany Bay and Batemans Bay). Bays which experience high wave energy are likely to support *P. australis* (e.g. Twofold Bay and Batemans Bay) (West et al. 1989). *Posidonia* grows as patches of only a few hectares in these bays sometimes hundreds of kilometres apart from the each other. One hypothesis to explain the disparate distribution is that these patches are relic communities left over from a sea level rise that occurred about 5000 years ago. Much larger meadows existed then but disappeared when the depth increased beyond the light compensation level for *Posidonia australis*.

Using aerial photographs, West et al. (1985) reported that a total of 155 sq km along the New South Wales coast was covered with seagrass. The largest area of seagrass occurred in Wallis Lake (3078 ha) where there is no *Halophila*–only *Zostera* and *P. australis*; followed by the Clarence River, 1907 ha of *Zostera* and *Halophila*; and Lake Macquarie, 1339 ha of *Zostera, Halophila* and *Posidonia*. There is little information on eastern Victoria although large areas of seagrass are known to exist at Mallacoota Inlet, Gippsland Lakes and Corner Inlet. In 1965, it was estimated that there were 11 900 ha of *Posidonia australis* growing in Corner Inlet as well as *Zostera* and *Heterozostera* (Morgan 1986).

In Victoria, Port Phillip Bay and Western Port Bay have large *Amphibolis antarctica* meadows at their entrances. This species has Wilsons Promontory as its easternmost range in Victoria. Western Port Bay has 7200 ha of *Zostera muelleri* and *Heterozostera tasmanica* remaining after a 70% reduction in coverage since the early 1970s. Port Phillip Bay also contains large areas of *Zostera* and *Heterozostera*, particularly in Swan Bay and Corio Bay.

Tasmanian seagrasses have not been well studied or explored. *Amphibolis antarctica* extends to Maria Island on the east coast and it is found on the north coast. *Posidonia australis* and *P. angustifolia* grow in extensive meadows on the north coast and in sheltered bays among the Bass Strait islands such as Flinders Island (Rees 1993). Their range extends to Little Swanport on the east coast. *Heterozostera tasmanica* and *Zostera muelleri* form dense communities in shallow sheltered bays along the east coast, Derwent Estuary and Port Davey.

2.2 Seagrass decline in New South Wales, Tasmania and Victoria

A number of seagrass communities have been studied in detail due to concerns that an apparent decline in the extent of seagrass meadows has taken place or, in the case of Jervis Bay, New South Wales, as background before development of the area. In 1953, the area of seagrasses in Port Macquarie was estimated at 2548 ha as part of an investigation into declining fish stocks. By 1985 the area of seagrass had declined by 1131 ha to 1417 ha. The decline in seagrass coverage was probably due to increased turbidity in the lake from human activity (King & Hodgson 1986).

Botany Bay is a shallow bay covering 4600 ha, with extensive areas of seagrass. Aerial photographs taken between 1942 and 1986 show a loss of 58% of the *Posidonia australis* meadows, an area of about 2500 ha. Reasons contributing to this loss may include: increased wave climate and erosion due to dredging; major storm events in 1974 and 1975; eutrophication due to sewage input; and grazing by the sea urchin *Heliocideris erythrogramma* (Larkum & West 1990). Prawn trawling on seagrass meadows may also have compounded some of these events (Kirkman, pers. observation). Larkum (1976) suggested that once degradation in *P. australis* begins it may be self-perpetuating: there has been no regrowth of *P. australis* over the 44 year period. *Zostera capricorni* has replaced much of the *P. australis* and covers an estimated 309 ha. However, this species has a lower surface area than *P. australis*, and therefore fewer epiphytes, infauna and associated animals. Both *Zostera* and *Posidonia* meadows in Botany Bay house a diversity of juvenile fish species, and at least five species of commercially important fish use *Zostera* meadows alone (Bell & Pollard 1989). The current development of the third runway for Sydney airport in Botany Bay will probably cause further loss of seagrass from the Bay. There is an estimated loss of 50% of *Zostera capricorni* communities from the estuaries of northern New South Wales. It is thought that the 60% losses from the Clarence and Tweed Rivers over 30 years are due to increased turbidity associated with a general decline in water quality.

There have been unquantified reports of the decline of *Posidonia australis* in Corner Inlet, Victoria, and a reduction in the number of fishermen operating there from 30 in the 1960s to 16 in 1978. No cause could be pinpointed although human changes are implicated (Poore 1978). Western Port Bay, Victoria, supported extensive seagrass meadows when it was first explored in 1899. In the early 1970s, 37% of the area of Western Port (25 000 ha) supported seagrass and macroalgae (Anon. 1974). *Heterozostera tasmanica* dominated in terms of productivity (50%), with *Zostera muelleri*, *Amphibolis antarctica* and the macroalga, *Caulerpa cactoides*, also present. By 1984 only 7200 ha of seagrass and macroalgae remained, with a 90% loss of *Heterozostera tasmanica* (Bulthuis et al. 1984b). Among the surviving seagrass there was a 50% decline in the above-ground biomass, resulting in an 85% decrease in the standing crop of Western Port. Such a decline appeared to be due to an increase in fine silt coming into the bay from river run-off, and this adhered to the seagrass leaf blades, blocking off light. Initial losses of plants caused further erosion of mud banks and an increase in turbidity and the decline became self-perpetuating (Bulthuis 1983).

Because there is no early map of seagrass distribution in Bass Strait or Tasmania there can be no record of seagrass area decline. Human activity is probably less in this area so not as great a decline is expected here as has occurred in parts of Victoria and New South Wales.

2.3 Seagrasses of South Australia

Species with warm temperate affinities in the genera *Posidonia* and *Amphibolis* decline in number from west to east, with a corresponding decrease in ocean temperatures. Encounter Bay is the eastern limit of *Amphibolis griffithii*; Lacepede Bay of *Posidonia sinuosa*; Rivoli Bay of *P. coriacea* and *P. denhartogii*; and Port MacDonnell of *P. angustifolia* and *P. australis*. The cool temperate species *Halophila australis* is distributed throughout this region, as are *Amphibolis antarctica*, *Heterozostera tasmanica* and *Zostera muelleri* and *mucronata*.

The distribution of seagrass is a function of the coastal topography, bathymetry and environment. The most extensive seagrass meadows are found in Spencer Gulf and Gulf St Vincent, with a total of over 5000 sq km of seagrass. Spencer Gulf and Gulf St Vincent offer large expanses of sheltered, shallow water for seagrass growth. Both gulfs are dominated by *Posidonia* species. In Spencer Gulf there are 3700 sq km of *Posidonia* meadows and Gulf St Vincent has 1530 sq km with *Amphibolis antarctica*, *A. griffithii* and *Heterozostera tasmanica* occupying edges, blowouts and smaller areas. *Halophila australis* is sparse but widespread and *Zostera mucronata* and *Z. muelleri* are found intertidally across the gulfs (Shepherd & Robertson 1989).

The clear waters at the western shore of Spencer Gulf allow plants to grow to considerable depths. Macroalgae are better adapted to low light than are seagrasses but seagrasses can grow to depths of 25–30 metres at the base of exposed cliffs of the eastern Eyre Peninsula, where they are unaffected by swell. However, seagrass distribution along the exposed coast is patchy and restricted to bays or the leeside of reefs and islands. Streaky Bay, Smoky Bay and Fowlers Bay have extensive meadows of *Posidonia sinuosa* and *P. angustifolia*, both species of *Amphibolis*, *Halophila australis*, and *Heterozostera tasmanica*. Fowlers Bay is the western most site containing extensive seagrass meadows before the cliffs of the Great Australian Bight where there is no suitable habitat for seagrasses.

Large seagrass meadows also occur along the south-eastern coast of South Australia. In Lacepede Bay, near Kingston, a very large *Posidonia angustifolia* meadow provides drift leaves that are harvested from the beach for soil conditioner and compost mixes (Kirkman & Kendrick 1997). Seagrasses are also distributed along the coastline in coastal lagoons. The larger ones in South Australia are West Lakes (Adelaide), with *Zostera muelleri*, *Heterozostera tasmanica* and *Halophila australis* at different depth zones, and the Coorong, an extensive lagoon system in the south-east of the State, supporting *Zostera muelleri* and *Ruppia* sp.

2.4 Seagrass decline in South Australia

There has been a well-documented decline in seagrass on the eastern side of Gulf St Vincent. In the northern section of the Gulf, *Heterozostera tasmanica* dominates the intertidal flats and mixed *Posidonia sinuosa* and *Amphibolis antarctica* grow subtidally. By 1949, Outer Harbour (Adelaide) had lost 900 ha of seagrass after construction of retaining walls and groynes and subsequent sediment accretion (Shepherd et al. 1988).

There have also been significant losses of seagrass due to sewage effluent. With the commencement of discharge of sewage sludge from the Bolivar outfall in 1967, loss of *H. tasmanica* around Port Gawler was immediate. By 1976, there were *Posidonia* losses exhibited by a decline in leaf density, weight and length and an increase in epiphytes on the plants. Pre-1978, around the Port Adelaide outfall, 85% of the area was covered with seagrass, comprising 53% *Posidonia sinuosa*, 2% *Amphibolis antarctica* and 30% mixed meadows. By 1981, the *P. sinuosa* was reduced by 50% and by 1982, 365 ha had gone. An even more extensive decline in *A. antarctica* took place, with 1500 ha lost over this period. This suggests that *Amphibolis* may be particularly sensitive to the effects of effluent. In the southern section of the Gulf, where *Posidonia angustifolia*, *P. sinuosa* and *Amphibolis* form extensive meadows, 800 ha of seagrass was lost around the Glenelg outfall between 1935 and 1987. Overall losses for the Gulf amount to more than 6000 ha of seagrass (Shepherd et al. 1989; Neverauskas 1987).

In Spencer Gulf, near Port Broughton, fishermen and locals have complained of widespread losses of *Amphibolis* close to the intertidal zone. This may have occurred through unusual weather patterns coinciding with extreme low tides, but some research into the past history and cause of this loss should be carried out. Insufficient background data in the form of accurate mapping makes it very difficult to compare cover at different times. Also, near Port Broughton, *Posidonia* fibre was harvested by dredges in the years preceding the First World War (Winterbottom 1917). It is not possible to see from aerial photographs going back to 1947 the exact scours left by the dredges, but a large irregularly shaped area of bare sand surrounded by seagrass can be seen. This patch is visible in photographs taken in 1957 (Figure 3) and 1994 (Figure 4) and illustrates the slow recovery of *Posidonia*. Seismic blasts were made in the seagrass meadows near Edithburg, Gulf St Vincent, in the 1960s and these marks can be plainly seen from aerial photography of 1992 (Figure 5).

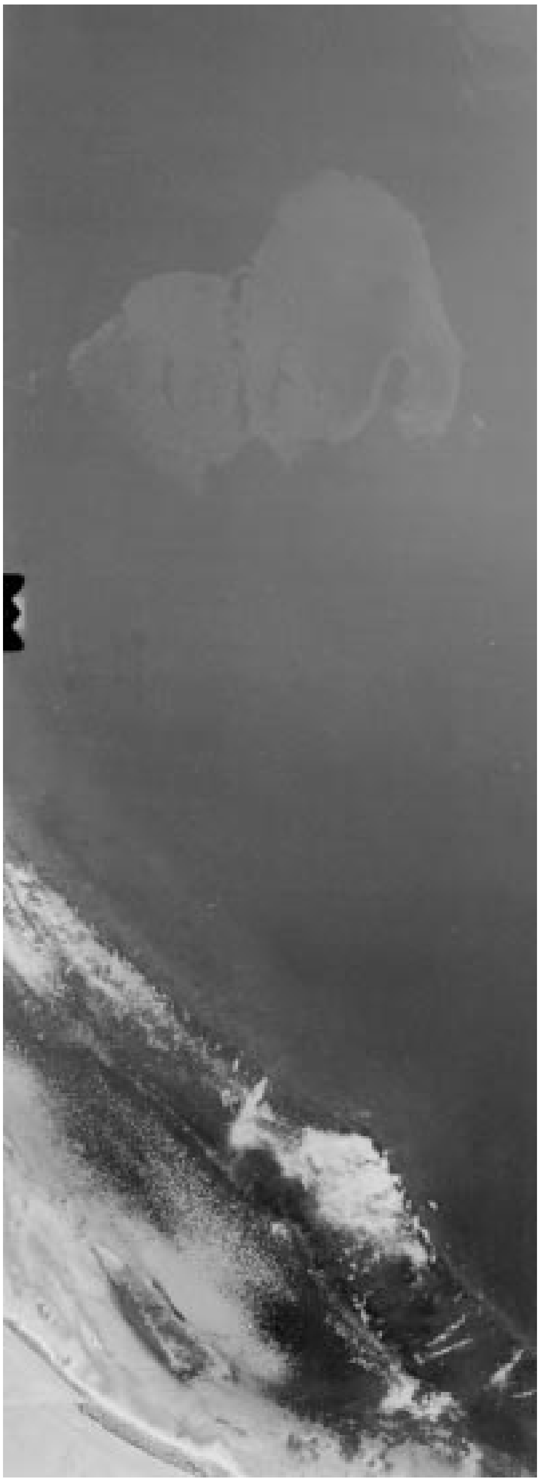


Figure 3: Cleared area in seagrass meadow near Port Broughton, 1957

Note: Aerial Photo 1957

Figure 4: Cleared area in seagrass meadow near Port Broughton, 1994

Note: Aerial Photo 1994

Figure 5: Seismic testing carried out in 1952 near Edithburg

Note: Aerial Photo 1993

2.5 Seagrasses of Western Australia

Southern Western Australia has the largest and the most diverse seagrass meadows in the world. There are about 2200 sq km of seagrasses—the same area that is occupied by rainforest in the whole of Australia (Kirkman & Walker 1989). The coastline of Western Australia extends from 13° S to 35° S with many different habitats and communities occurring over this latitudinal range. There are 11 genera and 26 species represented across this region. Tropical species have their southerly limits on this coastline. *Thalassia hemprichii* and *Thalassodendron ciliatum* extend to 22° S, a latitude which is also the northerly limit of the temperate species *Amphibolis antarctica*. *Cymodocea angustata* extends south to Shark Bay; *Halodule uninervis* and *Halophila spinulosa* extend south as far as 29° S; *Syringodium isoetifolium* 32° S—five degrees further south than its range on the east Australian coast, due to the warm, southflowing Leeuwin Current (Walker & Prince 1987; Walker 1991) (Table 1).

Eight *Posidonia* species are found on the south-western coast of Western Australia. The most widespread species is *Posidonia australis* with a range from Shark Bay in the north to Lake Macquarie in New South Wales and including northern Tasmania. Its range is probably defined by temperature (Kirkman & Walker 1989; Walker 1989).

Despite the wide latitudinal range of the Western Australian coast, the sea temperature range is very small and the distribution of seagrass species reflects the availability of a suitable environment. In the more southerly latitudes, two *Posidonia* seagrass complexes are recognised: *'ostenfeldii'*, including *P. robertsoniae*, *P. kirkmanii*, *P. coriacea* and *P. denhartogii*; and *'australis'*, consisting of *P. australis*, *P. angustifolia* and *P. sinuosa*. Each complex has distinct habitat requirements. *Posidonia* is very abundant along the south-west coast which is more exposed than coasts further north; and here the members of the *'ostenfeldii'* complex, with their deep rhizomes and strong leaves, are most successful.

Israelite Bay, Esperance Bay, King George Sound, near Albany, and Geographe Bay are examples of large areas of seagrasses. Some species may be found at depths of greater than 30 m, depending on the water clarity. *Posidonia australis* and *P. sinuosa* dominate protected habitats, with some *Amphibolis* and other species in small areas. The distribution of species within these bays is a reflection of water movement gradients and depth zonation (Kirkman & Walker 1989, Kirkman & Kuo 1996).

Table 1: Distribution and range limits of Australian seagrasses

Genus	Species	Western Boundary	Eastern Boundary
Halophila	*australis* Doty and Stone	Dongara, WA (south)	Port Macquarie, NSW
	ovata Gaud, in Freycin	Cape York, Qld	
	spinulosa (R.Br.) Aschers.	Dongara, WA (north)	Moreton Bay, Qld
	decipiens Ostenfeld	Perth, WA (south)	Sydney, NSW
	nova sp.	Perth, WA (south)	Augusta, WA
	tricostata Greenwood	Great Barrier Reef, Qld	
Posidonia	*angustifolia* Cambridge and Kuo	Perth, WA (south)	Flinders Island, Tas
	australis Hook.f.	Shark Bay, WA (south)	Lake Macquarie, NSW
	sinuosa Cambridge and Kuo	Shark Bay, WA (south)	Adelaide, SA
	ostenfeldii den Hartog	Augusta, WA (south)	Adelaide, SA
	denhartogii Kuo and Cambridge	Perth, WA (south)	Adelaide, SA
	kirkmanii Kuo and Cambridge	Augusta, WA (south)	Adelaide, SA
	robertsoniae Kuo and Cambridge	Albany, WA (south)	Adelaide, SA
Syringodium	*isoetifolium* (Aschers.) Dandy	Perth, WA (north)	Moreton Bay, Qld
Halodule	*uninervis* (Forsk.) Aschers. in Boissier	Dongara, WA (north)	Moreton Bay, Qld
	pinifolia (Miki) den Hartog		North Qld
Enhalus	*acoroides* (L.F.) Royle	Port Hedland, WA (north)	Townsville, Qld
Thalassia	*hemprichii* (Ehrenb.) Aschers.	Exmouth, WA (north)	Townsville, Qld
Amphibolis	*antarctica* (Labill.) Sonder et Aschers.	Exmouth, WA (south)	Wilsons Promontory, Vic.
	griffithii (J.M. Black) den Hartog	Kalbarri, WA (south)	Victor Harbour, SA
Cymodocea	*rotundata* Ehrenb. and Hempr. ex Aschers.		North Qld
	serrulata (R.Br.) Aschers. and Magnus	Shark Bay, WA (north)	Moreton Bay, Qld
	angustata Ostenfeld	Shark Bay, WA	
Thalassodendron	*pachyrhizum* den Hartog	Kalbarri, WA (south)	Cape Arid, WA
	ciliatum (Forsk.) den Hartog	Port Hedland, WA (north)	Townsville, Qld
Zostera	*capricorni* Aschers.	Jervis Bay, NSW (north)	Cairns, Qld
	mucronata den Hartog	Perth, WA	Melbourne, Vic.
	muelleri Irmisch and Aschers.	Yorke Peninsula, SA (south)	Jervis Bay, NSW
Heterozostera	*tasmanica* (Martens ex Aschers.) den Hartog	Dongara WA (south)	Jervis Bay, NSW

From Geographe Bay north, there are fringing reefs forming coastal lagoons. *Posidonia sinuosa* is the dominant species, covering many hundreds of hectares in the lagoons. Other *'australis'* members occur within the lagoons and *'ostenfeldii'* complexes occupy sandy areas of more turbulent waters. Cockburn Sound is well protected by Garden Island. Here members of the *'australis'* complex with *Amphibolis antarctica* and *Heterozostera tasmanica* are found together to a water depth of 11 m. The Swan–Canning estuary has 5 sq km of seagrass—mainly *Halophila ovalis* with some *Zostera mucronata*. Rottnest Island has some *Halophila ovalis*, but in these clear waters, *Amphibolis* is the most important genus overlying limestone rock. In all, nine species of seagrass are found in the Perth region (Kirkman 1985; Kirkman & Walker 1989).

North of Perth, offshore reefs and islands, tombolas and the shore form many lagoons—an example of which is the sheltered Cliff Head lagoon which has a 50 sq km meadow of dense *Posidonia*. The reefs along this stretch of coast are the centre of the western rock lobster fishery. The seagrass beds are sites of settlement and nocturnal foraging for the juveniles of *Panulirus cygnus* (western rock lobster) with up to 13% of their diet consisting of seagrass and its associated macrofauna, particularly gastropods (Jernakoff 1987; Kirkman & Walker 1989).

Around Dongara further north, Seven Mile Beach is a highly disturbed habitat despite protective reefs. *Halophila ovalis*, *Halodule uninervis*, *Heterozostera tasmanica* and *Syringodium isoetifolium* form communities in the disturbed sands. There are natural seasonal fluctuations in the amount of cover of up to 80%. However, *Amphibolis antarctica* and *A. griffithii* form stable and extensive meadows, which did not fluctuate in area over a six-year study period (Clarke & Kirkman 1989). Large meadows continue to occupy sheltered lagoons from Seven Mile Beach to Geraldton and north to Kalbarri. The Zuytdorf Cliffs are subjected to heavy wave action and seagrass is not abundant until Shark Bay.

At 26° S Shark Bay (with an area of 13 000 sq km) has some of the largest and most diverse seagrass meadows in the world, with seagrass the dominant macroorganism in the Bay. The high diversity is thought to result from a regime of intermediate disturbance and occasional cyclonic events. Shark Bay is also the site of an overlap between temperate and tropical seagrass species. The bay has restricted exchange with high evaporation leading to hypersalinity in its eastern parts. Through sediment accretion and current attenuation, this huge agglomeration of seagrass has further modified its own environment with a subsequent accretion of barrier banks. Behind these, hypersaline conditions exclude seagrasses, and now favour the growth of stromatolites. At the northern limit of its range, *Amphibolis antarctica* is the most abundant species in Shark Bay, with monospecific stands accounting for 3676 km or 85% of the total seagrass beds. Mixed *A. antarctica* and *Posidonia australis* stands are found in the eastern part of the bay; this is also the northern limit for *P. australis*. *Halodule uninervis* is the next most abundant plant. It may form an understorey to *A. antarctica* and *P. australis* or grow on the intertidal flats in sparse mixed stands with *Halophila ovalis* and *H. ovata*. These stands are the preferred grazing area for the large number of dugongs that occur in the bay. North-east and east of the bay, monospecific stands of *Halodule uninervis* are the site of the dugong summer feeding grounds. Other seagrass species in Shark Bay include ‘tropicals’ such as *Syringodium isoetifolium* and *Cymodocea angustata* (which does not occur further south) (Walker 1989). Recently, an area of 129 sq km of *Halophila spinulosa* was found in the north east of Shark Bay. This large area of plants helps sustain the 10 000 grazing dugong said to inhabit Shark Bay (P. Anderson, Calgary University, Canada, pers. comm.; Helene Marsh, James Cook University of North Queensland, Townsville, pers. comm.)

Little is known about the extent of seagrasses north of Shark Bay. Nine genera with 14 species, many with Indo–Pacific affinities, are found here and the coast can be divided into four main habitats. *Thalassia hemprichii* dominates atoll coral reefs, while large meadows of *Enhalus acoroides*, *Thalassodendron ciliatum* and *Cymodocea serrulata* occur on inshore reefs and banks. Offshore islands and sand cays support large populations of *T. ciliatum*. On extensive intertidal–subtidal flats, *Halodule* and *Halophila* dominate (Walker & Prince 1987).

Cymodocea rotundata is absent from Western Australia where it is replaced by *C. angustata*. North of Cape Leveque, however, 1500 km of coastline remains unsurveyed for seagrass. Some areas of the Kimberley coastline are known to be unsuitable for seagrasses but conditions along the rest of the Kimberley coast resemble Queensland seagrass habitat. Here, aerial photographs have revealed banks of *Enhalus acoroides*, *Thalassodendron ciliatum* and *Cymodocea serrulata*, as well as intertidal *Halophila* and *Halodule* communities. More detailed studies are required to accurately map these communities (Poiner et al. 1989).

The extensive and diverse seagrass communities along Western Australia’s coastline may be attributed to the general suitability of the coast which boast a variety of habitats and a range of tropical and temperate species available for colonisation.

2.6 Seagrass decline in Western Australia

Development of heavy industries and the discharge of industrial waste into Cockburn Sound commenced in the 1950s. By 1969 there were widespread losses of seagrasses, and by 1978, 97% of the original 34 sq km of seagrass had been lost (Cambridge & McComb 1984). Examination of the many possible causes showed that increased nutrient loading from effluent had given rise to an explosion in epiphytic growth. As a consequence, there was an overall 63% reduction in light reaching seagrasses in declining meadows. Controls on effluent input have helped to arrest the decline but there is little evidence of regrowth (Cambridge et al. 1986; Silberstein et al. 1986). There have also been losses of seagrass in Princess Royal and Oyster harbours near Albany. These two bays have small mouths and consequently water movement is restricted in them. They offer classical examples of eutrophication. Oyster Harbour has the King and Kalgan rivers running into it; they are rivers from large catchment areas of rich farming land. Princess Royal Harbour has no river entering it but was the dumping ground for local industries and the town sewage flowed back into the harbour from a nearby discharge pipe. There is a 66% loss (over 7 sq km) of seagrass from Princess Royal Harbour and a 46% loss (over 8 sq km) from Oyster Harbour (Bastyan 1986; Walker & McComb 1990).

2.7 Seagrasses of northern Australia

Northern Australia is here defined as the area between the Western Australian border and Torres Strait (Figure 1). This area encompasses three broad geographical regions: Torres Strait, the Gulf of Carpentaria and the north-western coasts of the Northern Territory. Five thousand kilometres of the Northern Territory's coast west of Cape Arnhem is the least well known of these northern regions.

Unlike temperate seagrass species, tropical seagrasses tend to occur in mixed-species stands. Thirteen species from seven genera are found across northern Australia. The region has a greater diversity of seagrass species and communities than elsewhere in the Indo-Pacific. Five *Halophila* species occur in northern Australia: *H. ovata*, *H. ovalis*, *H. spinulosa* and *H. decipiens* and *H. tricostata*. *Halodule uninervis*, *H. pinifolia* and *Cymodocea serrulata* range throughout this region. Other wide-ranging species include *Thalassia hemprichii* and *Enhalus acoroides*. *Thalassodendron ciliatum* is found associated with hard substrates and corals (Poiner et al. 1989).

2.7.1 Torres Strait

Torres Strait is a shallow (30–50 m deep in the east and 10–15 m in the west) body of water approximately 160 km long (north–south) and 220 km wide (east–west). The area has a complex bathymetry with large numbers of islands, shoals and reefs. Two physiographic regions characterise Torres Strait. The first is the western islands which represent the peaks of the drowned ridge extending from Cape York to Papua New Guinea. Coral reefs fringe many of the islands and are well-developed in the shallow water between them. The north-eastern portion of this region is an extensive shallow (less than 10 m) seabed with well-developed sand waves. The second physiographic region encompasses the numerous platform reefs, atolls and barrier reefs in the eastern Torres Strait. The dominant feature of this region is a large, north–south oriented platform reef—the Warrior Reef complex—that almost bisects Torres Strait. Winds are seasonal, with strong south-east trades in the austral winter (May–October) and north-western monsoons in the austral summer (December–February). Strong tidal currents (more than 1 m/s) flow alternatively east and west, but there is no evidence of net current flow through the Strait.

Torres Strait supports one of the largest seagrass areas in Australia. A total of 17 500 sq km of seagrass—supporting habitat associated with 295 km of coastline or reef has been identified and mapped. Twelve seagrass species have been recorded and the area supports a greater diversity of seagrass communities than does the rest of northern Australia. As well as the mixed-species reef-flat communities and depth-zoned open coastline communities similar to those found in the Gulf of Carpentaria, two other communities occur: sparsely distributed mixed-species open ocean communities, and subtidal *Halophila* communities. The open-ocean communities are similar to the diverse mixed-species reef-flat communities but occur subtidally (to around 40 m depth) in the extensive, relatively shallow waters of the north-western and western Torres Strait with *Halophila ovalis, H. spinulosa, Syringodium isoetifolium, Halodule uninervis* and *Thalassia hemprichii* the most common species (Poiner, CSIRO Division of Fisheries, pers. comm.). *Halophila* (*H. ovalis* and *H. spinulosa*) communities are present subtidally off the large continental islands. The open-ocean communities are extensive and especially occur in central and western Torres Strait and include very lush deep-water (more than 30 m) seagrass communities (*Halophila ovalis* and *H. spinulosa*) in south-western Torres Strait. Very little is known about the role of deep water, open-ocean seagrass communities in the tropics (Poiner, CSIRO Division of Fisheries, pers. comm.).

2.7.2 The Gulf of Carpentaria

The Gulf of Carpentaria, a shallow marine embayment with a variety of offshore and coastal features, supports 906 sq km of seagrass habitat along 671 km of coastline. Seventy-four per cent of the seagrass is found along open coastline with depth-zoned communities where *Halodule uninervis* and *Halophila ovalis* dominate intertidally, *Syringodium isoetifolium* and *Cymodocea serrulata* subtidally and *Halophila ovalis* and *H. spinulosa* offshore. Ten per cent of communities occur on reef flats in mixed stands dominated by *Thalassia hemprichii*, 13% consist of a region of monospecific *Halodule uninervis* stands often associated with river mouths, and *Enhalus acoroides* dominates the remainder (Poiner et al. 1987).

2.8 Seagrass decline in northern Australia

Sparse population and lack of development along this coast have meant that there has not been any major anthropogenic-induced loss of seagrass. However, these areas are subject to tropical cyclones and floods. Since 1984, the Gulf of Carpentaria has been the site of a CSIRO study looking at the impact of cyclones on seagrasses.

Poiner et al. (1989) found no noticeable relationship between the strength of cyclones and their impact on seagrass beds. Only one of the four cyclones to have passed through since the study began (Cyclone Sandy, 1985) caused significant long-term seagrass losses. This cyclone removed, undermined or smothered 70% of seagrass cover from the original 183 sq km in the area. Scouring and smothering of the remaining beds caused further seagrass losses, and by 1986 the entire seagrasses area was lost. This represented 20% of the total Gulf seagrass area. Since 1986, recolonisation of the area by *Halodule uninervis, Halophila ovalis, Cymodocea serrulata, Syringodium isoetifolium* and *Enhalus acoroides* took place at relatively slow rates and much of the area had recovered to pre-Cyclone Sandy conditions by 1994. These tropical seagrasses took approximately 10 years to recover.

Poiner et al. (1989) reported that following Cyclone Jason there was a decrease in the above-ground biomass of less than 10 ha in a seagrass bed, but within six months there was no difference between pre- and post-cyclone biomass estimates. This indicates that tropical seagrass beds can recover from minor disturbances, provided there is sufficient structure for re-establishment. This is in contrast with the lack of recovery of disturbed temperate seagrasses.

During 1991/92 several hundred square kilometres of seagrass in north-western Torres Strait disappeared. The actual cause of this loss is not known although it may have been due to high turbidities resulting from flooding of the Mai River in New Guinea. The cause and extent of this loss are currently being investigated by CSIRO.

2.9 Seagrasses of north-eastern Australia

The region of north-eastern Australia encompasses the entire eastern coast of Queensland from Cape York to Moreton Bay. The majority of this coastline is sheltered and supports approximately 4300 sq km of seagrass (Lee Long et al. 1993).

Seagrasses occur near estuaries, in coastal bays, and in areas sheltered from the predominant south-easterly trade winds. Moreton Bay (267 sq km), Hervey Bay (1026 sq km), and the area between Barrow Point and Lookout Point (1566 sq km) support extensive areas of seagrass. A total of eight genera and 14 species are found along this coastline. Three species of *Halophila—H. ovalis, H. tricostata* and *H. spinulos*—are found throughout north-eastern Australia and there are a further two *Halophila* species with more limited ranges. *Halodule uninervis* is perhaps the most widespread of all the seagrasses in the intertidal areas of this region, while *H. pinifolia* is restricted to the area between Cape York and Cairns. Whereas *Cymodocea serrulata* has also been found at most sites sampled along the Queensland coast, *C. rotundata* is not present south of Townsville. *Zostera capricorni* only grows south of 16° S. *Syringodium isoetifolium, Thalassia hemprichii, Thalasso–*

dendron ciliatum and *Enhalus acoroides* are also found at intervals along this coastline (Lee Long et al. 1993). Moreton Bay is the southernmost limit of the ranges of *Syringodium isoetifolium, Halodule uninervis, Halophila spinulosa* and *Cymodocea serrulata* (Young 1978).

2.10 Seagrass decline in north-eastern Australia

In the early 1970s some seagrass species in Moreton Bay experienced a decline or disappeared completely. Aerial photographs showed the loss of a stand of *Syringodium isoetifolium* and decline of a *Zostera capricorni* community at Toorbul Point. In neighbouring waters, there was a dieback of *Z.capricorni* stands, but by 1981 these had returned. Further south at Jumpinpin, a small bed of *Cymodocea serrulata* was lost during 1972/73 and is not expected to return (Kirkman 1978). Increased sedimentation and a rise in substrate levels are thought to be responsible for these losses.

In 1992/93 an estimated 1000 sq km of seagrass in Hervey Bay disappeared. The cause of this loss is not known although it is thought that high turbidities, resulting from flooding of the Mary and Burrum rivers and run-off from two major floods and Cyclone Fran, were responsible (Preen et al. 1993). Nearly two years after the floods there was substantial recovery—apparently from seed germination—in deep water areas (Preen et al. 1995)

3 Pressures

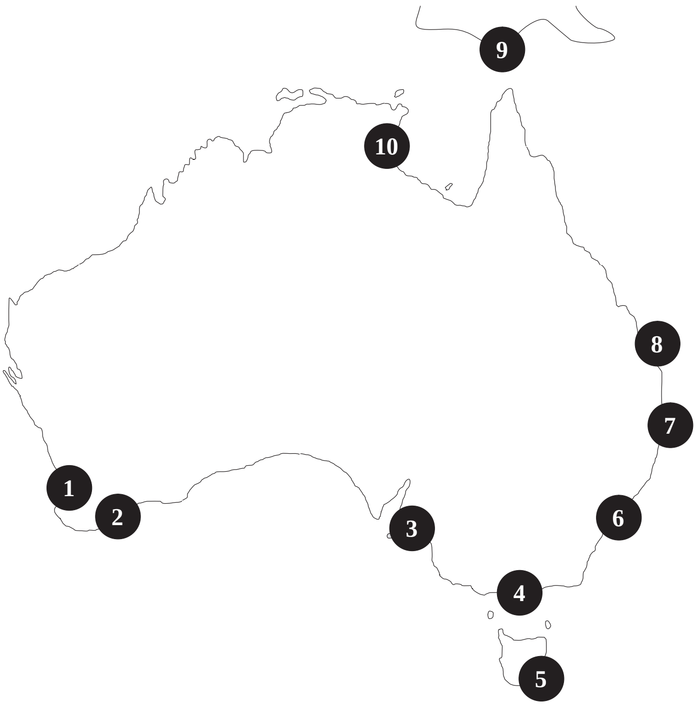
Australian seagrasses are being destroyed. This can occur through both natural and anthropogenic events. Human-induced seagrass losses in recent years have been extensive with over 450 sq km lost (Figure 6). There have also been extensive losses due to natural events such as floods and cyclones, with over 1000 sq km lost. Although the human-caused losses are less in area than natural ones, the seagrasses destroyed by humans are usually those that are least likely to recover quickly, (e.g. *Posidonia*). Most losses, both natural and anthropogenic, are attributed to reduced light intensity due to sedimentation and/or increased epiphytism from nutrient enrichment; but in some cases other factors such as sediment instability, dredging and poor catchment management interact to make the process more complex. Loss of seagrass results in loss of critical habitat for many species, declines in coastal productivity and increased sediment instability (Shepherd et al. 1989).

3.1 Human pressures on seagrass meadows

It was not until the mid-1970s that the extent and importance of seagrass meadows were given any consideration. The importance was highlighted by studies showing seagrass area loss near centres of population and the consequent deleterious loss of nursery grounds and beach erosion (Cambridge & McComb 1984; Kirkman 1978). The losses were blamed on discharges of domestic and industrial effluent to the sea (Cambridge et al. 1986). It was not until then that authorities were made to realise the extent of seagrass meadows in Australia and the damage that some of these meadows were undergoing from human influences.

3.1.1 Eutrophication

An increase in nutrients in the water column is known as eutrophication. As explained earlier, the result of eutrophication is an increase in growth of opportunistic epiphytes which shade seagrass leaves, reduce their photosynthetic capability and thus deplete storage materials. Shading may occur either from increased epiphyte loads on the plants or by increased phytoplankton in the water. Nutrients get into the sea from a number of sources. Sewage, whether treated or not, contains substantial quantities of nitrogen and phosphorus; it is often discharged into the sea through pipes after treatment from a sewage works. Sometimes effluent from septic tanks escapes into the groundwater and this flows to the sea, or sewage is discharged into rivers which make their way to the sea. Nutrients also come from agricultural lands where incorrect fertilising practices cause unused fertiliser to run off into rivers, groundwater or directly into the sea. Another source of eutrophication is the nutrients from the effluent of factories and industry generally (e.g. fertiliser factories, meat works etc.). The 97% loss of seagrasses in Cockburn Sound has been attributed to the bloom of epiphytes growing on seagrass plants stimulated by excessive nutrients, particularly nitrogen (Silberstein et al. 1986). Similarly, in the Albany harbours, nutrients from factories and the sewage works just outside Princess Royal Harbour caused excess epiphyte growth on seagrasses there, and the farmland run-off into the King and Kalgan rivers brought nutrients which helped destroy seagrasses in Oyster Harbour (Gordon et al. 1993; Kirkman 1987).



	Location	Area lost		Probable cause
		(ha)	(%)	
1	Cockburn Sound	3 300	79	Elevated nutrients from factories, sewage and abattoirs
2	Princess Royal Harbour	810	66	Elevated nutrients from factories and sewage
2	Oyster Harbour	720	46	Elevated nutrients from farm run-off
3	Gulf St. Vincent	7 000	?	Sewage and stormwater discharge; coastal works
4	Western Port Bay	17 800	85	Siltation
5	Birch Point	397	?	
5	Ralphs Bar	430	?	
5	Pittwater	1 201	?	
5	Norfolk Bar	2 148	?	
6	Botany Bay	257	58	Erosion, coastal works, elevated nutrients and sea urchin grazing
7	Lake Macquarie	700	44	Increased turbidity
7	Clarence River	445	60	Increased turbidity and general decline in water quality
8	Hervey Bay	100 000	?	High turbidity from flooding of the Mary and Burrum Rivers
9	Torres Strait	>10 000	?	Floods in 1991–1992
10	West Island—Limmen Bight	18 300	20*	Damage from cyclone Sandy, 1985; much of the area had recovered by 1994.

Figure 6: Major areas of seagrass loss in Australia

Note: *This loss represented 20% of the seagrass of the Gulf of Carpentaria

Source: Hamdorf & Kirkman, 1995

Sewage sludge and effluent from Adelaide caused the loss of seagrasses in Gulf St Vincent, probably because of high nutrient loads (Neverauskas 1987). Arguably, in Western Port Bay nutrients from farm runoff, together with high sediment loads have caused the loss of *Heterozostera tasmanica* and, to a lesser extent, *Zostera muelleri* (Bulthuis et al. 1984b). In the case of sediment loads, it is thought that a fine covering of particles from suspended sediment has prevented photosynthesis.

3.1.2 Heavy metals and toxins

Factories and mining developments are often associated with high heavy metal concentrations in nearby waters but there is no record of these levels having a deleterious effect on seagrass meadows apart from very small local areas. Ward (1987) found that there were discernible quantities of zinc in seagrass leaves 16 km away from a lead smelter at Port Pirie. Ward and Young (1982) found that a pattern shown by 20 common species (mostly fish) described decreased frequencies correlated with the concentration of contaminant metals in the sediments. Of course, heavy metal contamination of associated animals—particularly those used for human consumption—is well recorded and of a serious nature in some areas. Princess Royal Harbour was so contaminated by heavy metals (particularly mercury) before 1990 that it was forbidden to take shellfish or fish from the western area (Talbot and Chang 1987). This situation has now been rectified by reducing effluent from harbourside factories (Chris Simpson, DEP of Western Australia, pers. comm.).

3.1.3 Change in hydrology

In Botany Bay, prior to two large storms in 1974 and 1975, configuration dredging to allow container ships through the entrance caused wave heights to increase by 10–20%. After two storms, the *Posidonia* meadow was damaged and waves had almost completely eroded away inshore meadows of *Zostera* (Larkum & West 1990). This evidence suggests that environmental impact statements prepared for dredging should always consider the effects of changes in hydrology on nearby seagrass meadows.

In Gulf St Vincent, when the Outer Harbor revetment was constructed in 1905, 800 ha of seagrasses disappeared. Shepherd et al. (1989) suggest that this was caused by sediment accumulation and progressive shallowing of the water. Further losses occurred in Outer Harbor after construction of retaining walls and groynes and subsequent sediment accretion (Shepherd et al. 1989).

3.1.4 Sediment run-off

Sediment smothering of seagrass or accumulation of sediment and the consequent shallowing of the water are causes of decline in seagrass meadows. Kirkman (1978) reported on seagrasses being smothered by sediment at Toorbul Point in Moreton Bay. Although he did not describe it at the time, sediment possibly came from the catchment area of the Caboolture River which was undergoing considerable land clearing. Recently, a widescale loss of seagrass meadow in Hervey Bay has been attributed to sediment smothering from sediment release during unusually large floods in the Burrum and Mary Rivers (Preen et al. 1993).

Bulthuis (unpublished data cited in Shepherd et al. 1989) estimated that the area of macrobenthic plants in Western Port Bay had declined from 250 sq km in 1973 to 72 sq km in 1984, and that most of the seagrass loss had occurred on the shallow tidal flats. The green alga *Caulerpa cactoides* was the other macrobenthic plant that declined in area. The cause of losses in the tidal flats may have been due to fine sediment covering leaves or to the sediment from the catchment area of Western Port Bay raising the height of the tidal flats and causing the seagrasses to be exposed to air and sunlight beyond their tolerance.

3.1.5 Mining and dredging

A direct cause of losses of seagrass meadow is mining of underlying sediments or dredging. The classic example of the damage done to seagrass meadows occurred in the years before World War I when *Posidonia* fibre was harvested at Port Broughton in Spencer Gulf (Winterbottom 1917). The dredge marks are no longer visible but large cleared areas are probably the results of this dredging. Figure 3 is an aerial photograph taken in 1957 showing a clearing made in the *Posidonia* that can be followed through to 1994 (Figure 4). Other causes of seagrass loss which show a dramatic lack of rehabilitation are the seismic tests in Jervis Bay, NSW (West et al. 1989, p. 250) and the seismic tests made in Gulf St Vincent near Troubridge Island (Figure 5).

Dredging channels in seagrass meadows has the direct effect of removing seagrasses from the dredged areas leaving a hole deeper than the euphotic level for seagrass. The indirect effect of causing plumes of sediment, which may attenuate light beyond the plant's compensation level or cover the leaves of the plant reducing photosynthesis, will also cause declines.

3.1.6 Moorings and boat propellers

Boat moorings produce circular scours in seagrass meadows, as the slack chain from the mooring moves through the seagrass with each wind direction change. Walker et al. (1989) calculated that there were 5.4 ha of seagrass lost due to moorings in the Perth metropolitan waters. Although this is a relatively small area, the scours interfere with the physical integrity of the meadow and the effect is much greater than if an equivalent area were lost from the edge of a meadow (Lukatelich et al. 1987). The scours left by boat moorings are obvious in photographs taken between 1985 and 1992 along the west coast of Tasmania in *Heterozostera tasmanica* meadows (Rees 1993). Rees (1993) also reports on the effects of boat propellers on *Posidonia australis* off Whitemark Jetty at Little Swanport.

Boat propellers on tidal mud flats containing seagrass meadows can have serious impacts. Not only does the propeller cut up the seagrass meadow in tracks for as long as it takes the thoughtless boat owner to get to the ramp, but the tracks become natural channels for incoming and outgoing tides. In 1974, the tracks from boat propellers were obvious in aerial photographs of Rhyll in Western Port Bay. The seagrasses have now gone from these tidal flats and their demise may have been accelerated by the swaths cut by propellers (pers. obs.). On the mudflats of North Queensland, seagrasses have colonised propeller tracks and they are favoured because water collects in them—presenting long strips of seagrass (Coles QDPI, Land Use and Fisheries, pers. comm.). This is reminiscent of the tracks left by feeding dugongs.

3.1.7 Introduced species

There has been no report, in Australia, of introduced species causing a deleterious effect to seagrass meadows. However, a serious warning should be heeded by the example of a macroalgae destroying seagrass habitat in the Mediterranean. *Caulerpa taxifolia* was introduced from the Monaco Oceanographic Museum and has now colonised a 600 km area along the northern Mediterranean coast. The problem is that the green alga over grows the native *Posidonia oceanica* meadows and has destroyed large areas of this seagrass. This alga is known to grow near Broome, Western Australia, and is thought to be sold in Perth aquarium shops as an aquarium plant (Kendrick, pers. comm.). Another *Caulerpa* that was introduced into New South Wales in the 1920s is *C. filiformis*, which is also now reported from Port Phillip Bay and the temperate Western Australian coast. There are no reports of deleterious effects of this plant.

3.2 Natural pressures on seagrass meadows

Occasionally, storms or cyclones may occur that can destroy seagrass meadows. Significant seagrass losses have been recorded following cyclonic events. However, Poiner et al. (1989) found no noticeable relationship between the strength of cyclones and their impact on seagrass beds. They reported that following Cyclone Jason there was a decrease in the above-ground biomass of less than 10 ha in a seagrass bed, but within six months there was no difference between pre- and post-cyclone biomass estimates. Thus, this indicates that tropical seagrass beds can recover from minor disturbances, provided there is sufficient structure for reestablishment.

Other natural causes of seagrass decline are dieback from disease or untimely exposure to hot weather at extreme low tide. There has been much speculation about the catastrophic decline of *Zostera* in the northern hemisphere during the 1930s, where a fungus, *Labyrinthula*, destroyed seagrass meadows. The speculation has been over the cause of the sudden increase in this fungus, which is always present in seagrass meadows (den Hartog 1987). It is thought that an increase in water temperature triggered the bloom. An increase in water temperature, which occurred 60 years ago, may become more frequent if climate change becomes a reality.

Climate change and an increase in frequency of major flooding on the east coast of Australia may cause irrevocable declines in seagrass meadows. The loss of large areas in Hervey Bay in southern Queensland which occurred after major flooding of the Burrum and Mary Rivers offers a good example of what can happen. There is reasonable evidence to suggest that the seagrass meadows of Hervey Bay were destroyed because of a lack of light caused by increased sediment load from the flooded rivers. If the flooding became more frequent, the seed bed in the sediments of the bay would be used up, the new plants would not have enough time to set seed and the meadows could not recover.

The example in Hervey Bay is also a good example of natural forces and human activities combining to increase the damage. Some of the excess sediment in the river arose from poor farming practices and catchment management. Kirkman (1978) reported a loss of seagrass meadow at Toorbul Point in Moreton Bay caused by sediment encroaching on the southern edge of the meadow. At the same time a little further south, *Zostera capricorni* meadows in Deception Bay disappeared. These meadows have returned and it is thought that the damage was done by sediment released by clearing and land development in the catchment of the Caboolture River.

4 Responses

The best way to prevent damage to seagrass meadows is to restrict all human activity that endangers seagrass meadows, and prohibit dumping in the sea. In most cases, this is impossible or impracticable. Thus, a compromise has to be made, to reduce the pressures on seagrass meadows whilst employing an economic alternative means of satisfying human needs.

We have information about the response of seagrasses to changes in the coastal environment but we cannot predict their response and we do not have an assay technique to measure the health of seagrass beds. If the response is a loss of area of seagrass meadow, we do not have suitable maps, along most of the coast, to measure the loss. Recovery and recolonisation from such losses are rare for temperate species and long-term (more than 10 years) for tropical species. Attempts to replant seagrasses have not been successful in Australia (Poiner & Conacher 1992; Kirkman 1989; Kirkman 1992).

4.1 Requirements for inventory and mapping

Seagrass communities are extremely important parts of Australia's coastal ecosystems. To conserve and manage our seagrass resources, we need to know the distribution and composition of the seagrass communities; how seagrasses respond to human-induced changes to the coastal environment; how seagrass systems fluctuate both seasonally, interannually and in the longer term; and whether damaged seagrass systems can be repaired or replanted. Currently, we do not adequately know the distribution of seagrasses in Australia. The distribution of Australian seagrass communities should be mapped at appropriate spatial scales and, in key areas, monitored at appropriate temporal scales. For example, almost nothing is known about the distribution of seagrass communities of the north-west Australian coast between Cape Arnhem and Cape Leveque—a distance of around 6500 km. Much of Australia's coastline has not been systematically mapped for seagrasses nor do we know much about their temporal dynamics.

There are several reasons for mapping seagrass meadows. An inventory of natural resources of the coast must include seagrass. Knowledge of significant areas of seagrass meadows will help with selection of marine parks and reserves. Sensitive areas can be identified in case of oil spills or other pollution events. Decisions about development such as building harbours and marinas will be assisted with knowledge of the extent of seagrass meadows. A scale of 1:250 000 or 1:100 000 is suitable for these purposes. At a finer scale, seagrass meadow mapping can assist managers in deciding whether mitigation of damage in polluted areas has occurred and whether seagrasses are declining from year to year. This level of mapping requires airborne scanning or photography and should be accurate to a few metres.

A project to map Australian underwater habitats including seagrasses began in 1995 and is the first attempt to map these features for the whole of Australia. At a scale of 1:100 000, species distribution has not been included and the only categories for seagrasses are 'dense', 'medium', 'sparse' and 'patchy'. Some detail as to species distribution has been collected and published for southern Western Australia (Kirkman & Kuo 1996), but not for other states. South Australia and all of Tasmania except the mid-north coast is complete, southern Western Australia is complete to Exmouth Gulf and Victoria has been mapped without ground truth. The maps are being prepared in a collaborative project between the

CSIRO Division of Marine Research and the relevant State government departments.

Areas of major population density—such as Port Phillip Bay, Gulf St Vincent, Botany Bay and Moreton Bay—already have more detailed maps of seagrass distribution and abundance. These can be used for management and are useful as historic records of temporal and spatial variability.

In the USA, industries that discharge waste into any environment are compelled to pay into a fund called the Superfund, but it has not been greatly successful due to its complicated structure. In Australia, those companies or State instrumentalities that use the sea or estuaries as dumping grounds for effluents should pay for the monitoring and management of these environments, and, if necessary, pay for their restoration after damage.

4.2 Management

To manage seagrass meadows properly, baseline measurements are needed to document the extent and condition of seagrass meadows. A monitoring program is necessary which will detect, at an early stage, the effects of disturbance and distinguish those effects from natural variation.

Epiphytes have different life histories and preferences for nutrients, light and temperature. Light, nutrients and temperature vary naturally throughout the year and light also varies with depth. Managers need to be made aware, at an early stage, of increases in nutrients from human sources. This is not always possible through analysing water because phytoplankton, epiphytes and other macroalgae may take up the nutrients so readily that they are not detectable by analytical means. If excess epiphyte growth acts as an early indicator of increased nutrient levels in the water, then managers can use this information to act to reduce nutrient input.

Managing the health of seagrass meadows is not restricted to the meadows themselves, but includes the total management of everything that enters the seagrass habitat. From the heads of creeks, through catchments, past saltmarshes or mangroves, over mudflats and algal beds, every input should be monitored and managed. Urban development, sewage outfalls and effluent from industry should be planned and preceded by an environmental impact statement in which strict controls are attached and alternatives to ocean dumping are given a thorough study. Choices on the location of ports, effluent discharge and fishing grounds should be made after consideration of the location of seagrass meadows and the effect that these activities will have on the meadows.

In Western Australia, the Hon. R.J. Pearce the then Minister for the Environment presented a paper at a conference on enclosed seas, in Japan in 1991, on the management of the Perth metropolitan waters (Pearce 1993). He explained the concept of ‘assimilative capacity’ as a philosophical approach to maintain the biological integrity of nearshore coastal ecosystems in Western Australia. This approach relies on the capacity of the receiving environment to disperse, dilute and absorb certain types of pollutants without causing an unacceptable change to the receiving environment. This concept is explained more fully by Masini et al. (1992).

4.3 Methods

At all levels and scales there is a need to standardise procedures and definitions. It is almost impossible to compare and repeat many studies because of different methods used and/or a lack of description of procedures followed. This especially applies to production and distributional studies. Cost-effective, statistically robust methods of mapping and monitoring seagrass habitats need to be developed. Statistical power analysis and good experimental design are essential tools in monitoring seagrass meadows (Cohen 1988; Fairweather 1991).

Some of the methods used to collect baseline data and monitor seagrass meadows so that they can be managed are summarised here. This paper does not identify the problems associated with establishing and quantifying pattern in seagrass meadows. An excellent review of the theory of sampling and the description of spatial pattern is given in Andrews and Mapstone (1987).

Three main types of survey are used for observations of seagrass areas:

- direct field observation and mapping
- mapping from aerial photographs/scanned images of coastal regions
- mapping coastal areas from satellite images.

In effect, these methods are not used exclusively over any others, but mapping from any remotely sensed images always requires verification by some level of field survey. There are obvious cost and time savings in applying the more modern remote techniques, particularly where coverage is required over extensive areas such as Australia's coastal habitat, but all have their own distinct problems and sets of errors. In a gross way, these methods may be seen as providing estimates of seagrass occurrence on a local, regional or national level, respectively, and, while this may be an over-simplified comparison, the main difference between the methods is their degree of resolution. Further, as the resolution of remote techniques increases with refinement of the technology, there will still be a requirement to undertake ground truthing and ecosystem studies at smaller spatial scales.

Kirkman (1995) described some of the methods useful for monitoring and determining the health of seagrasses for gathering an inventory of seagrass abundance. He emphasised the importance of maintaining similar methods throughout Australia so that results can be compared and baseline studies from other areas can be used where relevant. In September 1997, a meeting of managers, scientists and community groups interested in seagrass monitoring was held in Canberra culminating from State meetings of similar groups. The outcome was that it was recommended to Environment Australia that seagrass meadows be monitored, that community groups had a limited role but were an important component of the program and that the Federal Government initiate monitoring.

At least two books have been published concerning seagrass field methodology (Phillips & McRoy 1980; Phillips & McRoy 1990). Walker (1988) reviews the methods of seagrass monitoring in a report from a workshop of Australian seagrass specialists. Useful descriptions of the methods used by Australian researchers are summarised along with lists of available aerial photography and the types of remote sensing carried out at the time.

Walker (1988, Table 1) provides an overview of the status of seagrass monitoring programs throughout Australia. More recently, emphasis has shifted towards incorporating seagrass distribution information with other marine and estuarine databases to develop Geographic Information Systems (GIS) as management tools for the coastal zone.

For these systems to be of maximum benefit, it is useful to establish national standards so that information is compatible between users. Seagrass data standardisation should include such issues as:

- how distributional data is obtained (aerial photography, remotely sensed etc.)
- the degree and accuracy of ground truthing
- temporal variation—availability of area estimates over time
- scales, in terms of mapping
- seagrass health (total biomass, shoots per square metre etc.)
- depth relationships—limitations of techniques in assessing seagrass areas in deeper water or water of low clarity.

The assumption that the deeper edge of seagrass meadows is limited by the plants' light compensation level is often valid and useful for monitoring the deeper extent of the seagrass meadow and thus integrating light availability over the time between measurements. Another simple and useful monitoring tool is the Secchi disc which is used to measure water clarity. As a rule of thumb, the Secchi disc depth is often the same as the compensation depth of many seagrass species. Dennison and Kirkman (1996) developed a simple model using Secchi depth to predict whether a seagrass habitat can support some seagrasses.

Because one of the causes of seagrass death is reduction of light caused by epiphyte blooms, a background knowledge of epiphyte ecology is essential. It is important to know when the epiphyte cover on a leaf has increased beyond the known limits of the background characterisation. Epiphyte cover increases under the effects of eutrophication with the result that, eventually, the seagrass will die. It would be useful to be able to tell, by changes in epiphyte coverage, that eutrophication was occurring. This would give an early indicator that, unless something was done to reduce nutrients, seagrass would die.

4.4 Temporal information

This is an important area that has been neglected. When managing seagrasses, the seasonal variation of the biomass of aboveground plant parts must be known so that early indications of shoot density or leaf biomass reduction can be diagnosed as seasonal variation or as a loss of seagrass health. Epiphytes that live on leaves and stems are very often seasonal in their growth and, at certain times of year, may appear to be smothering seagrass leaves. These epiphyte blooms may be normal and an annual occurrence, but it should be possible to detect at an early stage epiphyte growth, particularly green algae, that is caused by eutrophication.

4.5 Population dynamics

Little is known about the population biology of seagrasses both in Australia and in the rest of the world. Information is required on growth, reproduction and dispersal. With this information it may be possible to model the establishment, growth and spread of seagrasses over various time spans. Simulations offer considerable scope for predictive studies of the effects of varying the environment on seagrass communities and the impact of different management strategies.

4.6 Physiology

There is a need for an understanding of what physiological factors enable a seagrass to occupy and survive at a site. Initially, this work should focus on the physiological and biochemical response of seagrass to reduced light conditions so that managers can set minimum water quality criteria to sustain seagrass growth. An understanding of the critical physiological processes offers managers the possibility of developing an assay technique to measure the health of seagrass beds and an insight into factors that may enhance their ability to restore damaged meadows.

4.7 Restoration

Once destroyed, seagrass systems do not readily recover. The plants require special environmental and substrate conditions which may have been lost with the decline of the seagrass. Therefore, if an area does recover, the time frames are long (years or decades). The possibility of developing cost-effective methods of intervening in the seagrass recolonisation process to speed it up needs to be investigated. These include methods to accelerate the growth of rhizomes, anchoring devices and means of repairing or replacing the environmental and substrate conditions that existed when the seagrass meadow was healthy.

There has never yet been a restoration program that has resulted in a net increase in area of seagrasses (Fonseca et al. 1986). A review of attempts at restoration of seagrass meadows made throughout the world is given in Fonseca (1992) and Kirkman (1992). It is often impossible to restore seagrass meadows. In most cases, where declines have been recorded, there is little evidence of a return. Restoring seagrass meadows is hampered by such problems as:

- finding a suitable propagule
- damaging donor meadows
- preparing and modifying site
- keeping a propagule bank
- attaching the propagules
- the slow rate at which rhizomes spread
- difficulties of large-scale planting.

In Australia, there have been few attempts and little success at restoring seagrass meadows. Poiner (CSIRO Division of Fisheries, pers. comm.) planted *Zostera capricorni* using large machinery and received mixed results with this work. Kirkman was able to keep seedlings of three species of *Posidonia* growing in a sheltered bay for three years but in that time there was no extension of the rhizomes (unpublished data).

Small opportunistic genera like *Halophila* and *Heterozostera* are often washed out of the sediment by seasonal storms and return during calmer seasons (Kirkman & Kuo 1990). Natural recovery of lost seagrass meadows has been demonstrated in Hervey Bay, south-east Queensland, where a thousand square kilometres of seagrass meadow disappeared after two large rainfall events in early 1992. This area had been devastated before (Kirkman, pers. comm.): in 1973, no sign of seagrass was found in Hervey Bay and the dugong were also absent. It is feasible that there is a large seedbank of *Halophila* in the sediments of Hervey Bay which germinates after a disturbance. Preen et al. (1995) have noticed some recovery since 1992.

There is good evidence that *Posidonia*, once removed, does not return in decades:

1. The most popular demonstration of no perceptible recovery is the seismic blasts in Jervis Bay, New South Wales (West et al. 1989, p. 250). Here, a seismic blast was used to determine substrate type in a seagrass meadow. There are more than twenty

of these circular clearings in the *Posidonia australis* meadows—each about twenty metres in diameter. The clearings were made in 1962; the substrate is at the same horizontal level as the substrate on which the seagrass is growing. No recovery has been recorded here (West et al. 1989).

2. From 1910 to at least 1917, *Posidonia* was harvested by dredges from Port Broughton, Spencer Gulf, South Australia (Winterbottom 1917). The seagrass was used for cellulose and provided employment for 2000 people in up to 100 dredges. There are suspiciously large clearings that can be traced from 1947 (the earliest aerial photographs available) to 1994 in the seagrass meadows near Port Broughton; the seagrass has not regrown (Figures 3 and 4).
3. At Marmion, WA, two underwater transects, each 300 m long, have been observed for seagrass presence, absence and density for the past 15 years. The scarp edge of the blowouts, where *Posidonia sinuosa* has been torn away from the meadow by an unusually severe storm, has not changed by one centimetre during the time that the transect has been observed (Kirkman & Kuo 1990, pers. obs.).
4. Natural blowouts in *Posidonia* meadows are unusual occurrences. In recent times, in Western Australia, only one storm large enough to tear rhizomes out has occurred—that was in 1984 along the south coast. The Bureau of Meteorology described this storm as a one in 60–100 year storm (Kirkman & Kuo 1990).

4.8 Legislation and protection

Legislation relating to seagrass protection can be broadly classified into that which offers direct protection to seagrass, (e.g. Section 123 of the *Queensland Fisheries Act 1994)* and that which offers secondary protection by way of protection of important ‘fisheries habitat’, (e.g. *Northern Territory Fisheries Act 1988*). The following is a summary of the relevant State and Commonwealth legislation that relates to preservation of seagrass areas.

4.8.1 Western Australia

(State Law Bookshop, Western Australia)

Fish Resources Management Act 1944—provides for the protection of commercial fish stocks and recreational fish populations, as well as fish habitat including any living marine organism. The Act stipulates the conservation and management of all aquatic animals and plants, which are specifically defined.

Environment Protection Act 1986—an umbrella Act that can override all other ‘resource acts’, operates on Ecologically Sustainable Development principles with a very public Environmental Impact Assessment system, and rates basic producer systems very highly (e.g. seagrasses and mangroves). Pollution control is included–it provides control for effluents into aquatic systems such as industrial and sewage effluents using an assimilative capacity approach, taking account of diffuse sources.

Fishing and Related Industries Compensation (Marine Reserves) Bill 1997—some very large areas of marine habitat are administered by Conservation and Land Management (CALM), but generally it refers control of fisheries to the Minister for Fisheries.

Water Authority—has relevant legislation protecting water quality particularly in rivers and estuaries.

4.8.2 Northern Territory

(Dave Field and Janice Warren, pers. comm.)

Fisheries Act 1988—provides for the protection of fisheries habitat. Liability for prosecution arises (Section 15) if damage is caused to fish or fish habitat from the release of organisms or pollutants without a permit, penalties ranging up to $20 000 (or jail) can be imposed along with the requirement to ameliorate or restore damaged areas.

Waters Act 1992—mainly concerned with quality of fresh and potable waters; however, it does set standards for effluents such as sewage, and requires that effluents do not cause degradation of water quality in fresh and marine systems.

Parks and Conservation Act 1993—extends to marine parks and prohibits taking of flora and fauna in declared areas.

4.8.3 Queensland

(Rob Coles, pers. comm.; Queensland Department of Environment Library)

Queensland Fisheries Act 1994—under section 123, marine plants are protected against removal, destruction or damage, and their removal is only allowed under permit. The Act also includes provisions to issue restoration orders where non-approved removal occurs. Sewage treatment plants receive specific assessment. Port authorities, extractive industries etc. require permits for dredging, sand mining and similar activities.

Where diffuse sources of effluents/sediments impact on marine flora, the approach is taken to document the occurrence, attempt to define the sources and trends, and introduce controls using total catchment management processes to reduce sediment and nutrient fluxes. Currently, there is a considerable amount of work based around Townsville trying to relate nutrient impacts to different nutrients and their sources.

Beach Protection Act 1968—mainly dealing with coastal erosion.

Clean Waters Act—repealed when the *Environment Protection Act 1994* was enacted. There is currently a draft Environmental Policy for Water.

4.8.4 New South Wales

(Jenny Burchmore and Gary Henry, pers. comm.)

Fisheries Management Act 1994—Section 90 provides for protection of ‘sensitive fish habitat’ and ‘productive shallows’ where these have been specified. The Act also provides for review of reclamation and dredging operations (Comment: It is usually fairly effective for local council operations but less so with Commonwealth or State authorities). As well, in ‘recognised fishing grounds’ no structures or other interferences are allowed (Comment: These categories are not well defined and appear to be avoidable by agreement between developers and local fishers).

Marine and Estuarine Protected Areas (MEPAs) and Reserves provide protection for sensitive specified habitat; however, these only apply to approximately 1% of marine habitat.

Clean Waters Act 1970—imposes controls on impacts that cause changes to the environment and is based on water quality guidelines (similar to the Australia and New Zealand Environment Conservation Council (ANZECC) guidelines and these are being aligned wherever possible).

Environmental Offences and Penalties Act 1991—is more frequently used to control actions that cause environmental damage and includes severe penalties and restoration clauses.

4.8.5 Victoria

(Neil Hickman, pers. comm; Steve reilly, Pers. comm)

Fisheries Act 1968—provides for the protection of ‘aquatic habitat’, administered by the Fisheries Division of the Department of Conservation and Land Management (currently under review).

Fisheries Act 1995—one of the purposes of this Act was to repeal the previous Act but the 1988 Act is still assigned to the Minister because there is a two year transition stage, and in that time some provisions of the old act still apply.

Flora and Fauna Guarantee Act 1988—provides for the protection of all native vegetation including aquatic habitat.

Conservation and Land Management Act—provides for the protection of natural habitat. Administered by the Department of Conservation and Land Management.

Environment Protection Act 1970—provides control for effluents into aquatic systems such as industrial and sewage effluents, and generally adopts ANZECC water quality guidelines.

4.8.6 Tasmania

(Howell Williams, pers. comm.; Tasmanian Parks & Environment Library)

Fisheries Act 1959—provides responsibility for all living marine resources (except marine mammals), with powers to ban physical disturbances such as dredging, harvesting, trawling, etc. This has been invoked in the past.

Environmental Management and Pollution Control Act 1994 and the *Environment Protection (Sea Dumping) Act 1978*—provide control for effluents into aquatic systems such as industrial and sewage effluents, and generally adopts ANZECC water quality guidelines.

Forestry Act 1920—has imposed regulations stipulating 'best practices' to avoid run-off and increased sedimentation (similar regulations are planned for agriculture).

4.8.7 South Australia

(Vic Neverauskas, pers. comm.)

Fisheries Act 1982—provides for the protection of 'aquatic habitat', administered by Primary Industries South Australia (Fisheries)

Native Vegetation Act 1991—provides for the protection of all native vegetation including aquatic habitat. Administered by the Department of Environment and Natural Resources with delegation to Primary Industries South Australia (Fisheries) of powers for all vegetation below 'high tide level' (mangroves overlap this zone and require consultation with the Native Vegetation Management Authority).

Environment Protection Act 1993—provides control for effluents into aquatic systems such as industrial and sewage effluents, and generally adopts ANZECC water quality guidelines.

4.8.8 Commonwealth

(Peter O'Hesan and Geoff Williams, pers. comm.)

Great Barrier Reef Marine Park Authority (GBRMPA)—Plants are protected in the park by invoking regulations (Section 66) that govern or prohibit activities that may pollute water or be harmful to marine plants and animals. Plants are defined as any member of the 'plant kingdom' including fungi. Harmful activities include dredging and other physical disturbances plus pollution sources arising within and outside the park boundaries (Comment: Point source effluents are easier to nominate and control, but diffuse sources are more difficult and to date have mainly been addressed cooperatively in conjunction with the Queensland authorities by programs such as total catchment management).

As well, basic management of the park is through zoning plans (these are legal documents) showing detailed uses for specific regions with nominated uses for specific areas.

Torres Strait Fisheries Act 1984—Seagrasses are possibly protected as 'fish', which are defined as 'all natural resources of the sea and seabed, including all swimming species and all sedentary organisms, but does not include cetaceans or minerals'. Taking or possessing 'fish' requires permission under the Act.

5 Conclusions and recommendations

Seagrass communities are critical for the long term sustainability of Australia's coastal zone. Despite the extensive area and species diversity of Australian seagrasses, there have been significant losses of seagrass communities. This loss has occurred through both natural events (e.g. cyclones, floods) and anthropogenic events (e.g. nutrient enrichment, coastal development). Most losses from these influences can be attributed to reduced light intensity. Once destroyed, seagrass systems do not readily recover.

There is a need to develop cost-effective, statistically robust methods of mapping and monitoring seagrass habitats. The ongoing projects to map Australian seagrass communities should be given greater impetus and encouragement to integrate so that a single, uniform scale and categorised map is available with its limitations well documented and readily able to be updated. There is virtually no information about these important habitats along more than 6500 km of coastline of northern Australia. Furthermore, in key regions and sites their condition needs to be monitored on a one to five year cycle because of the potential large scale changes that can occur in the extent of seagrass communities. The possibility of developing an assay technique to measure the health of seagrass beds needs to be investigated.

Cost-effective methods of intervening in the seagrass recolonisation process (to speed it up) should be investigated. Conventional planting and transplanting used for terrestrial plants is not successful with seagrass. More innovative methods should be developed to enhance plant growth. Tissue culture (Loques et al. 1990), hybridisation of *Posidonia* species to obtain advantageous characters of one species with those of another in a fast-growing hybrid and hormone treatment to enhance rhizome growth may help with the restoration process.

Most important of all, however, is the prevention of seagrass meadow loss by correct catchment management, monitored dumping of urban and industrial waste and care in development of nearshore habitats.

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