Seagrass Degradation in Australian Coastal Waters

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Australia has large areas of seagrass, rich in diversity, which flourish in clear, relatively low-nutrient coastal waters. Seagrass losses in recent years have been extensive with over 45 000 ha lost. The major widespread human-induced declines of seagrass, from 11 sets of locations around Australia, are summarized. The reasons for these losses are discussed, most being attributable to reduced light intensity, but in many cases, other factors interact to make the process of loss more complex. These declines result in loss of habitat and productivity, and increased sediment mobility. Recovery and recolonization from such losses are rare; thus, the destruction of seagrass has long-term consequences. Increasing awareness of the risks and better understanding of seagrass systems is leading to better management practices.

Australia has the largest seagrass beds in the world and has the largest number of seagrass species (Walker & Prince, 1987). There are extensive, diverse areas of tropical species in northern Australia, which are associated with large populations of dugongs and turtles and support major prawn fisheries (Poiner et al., 1989). In Western Australia and South Australia, there are large, mainly monospecific meadows of southern Australian endemic species. These meadows have high biomasses (500–1000 g m⁻²) and high productivities (>1000 g m⁻² yr⁻¹; see Hillman et al., 1989). Southern Australian seagrasses are unusual in that they occur in water bodies exposed to relatively high rates of water movement—in most of the world, Zostera and other seagrasses are confined to estuaries and lagoons. Nevertheless, Australian species also occur where there is some protection from extreme water movement and most are found in habitats with extensive shallow sedimentary environments, sheltered from the swell of the open ocean, such as embayments (e.g. Shark Bay and Cockburn Sound, Western Australia; Spencer Gulf, South Australia; Westernport Bay, Victoria), protected bays (e.g. Geographe Bay and Frenchman’s Bay, Western Australia) and lagoons sheltered by fringing reefs (e.g. the western coast from 33° to 25°S). The seagrass meadows in this lagoonal area on the west coast provide foraging grounds for the largest single-species fishery in Australia, the Western rock lobster Panulirus cygnus George. The annual catch has a value of about SA200 million and is largely taken between latitudes 28° and 32°S on the west coast (Phillips et al., 1991).

The significance of seagrasses is well reported in the literature, and the importance of seagrass habitats to fisheries is well documented (Bell & Pollard, 1989). Seagrasses have other attributes aside from the provision of habitat. Seagrass meadows play a significant role in the processes and resources of near-shore coastal ecosystems, as they have physical, chemical and biological effects on habitats. These include reduction in water movement (Fonseca et al., 1982) and hence prevention of erosion, the trapping and binding of sediments (Scoffin, 1970) and organic detritus (Walker & McComb, 1985); provision of a stable surface for colonization by epiphytes (Harlin, 1975); high rates of production (Hillman et al., 1989); contributions to detrital foodchains (Harrison & Mann, 1975); contribution of calcium carbonate by epiphyte deposition to sediments (Walker & Woelkerling, 1988); and essential roles in nutrient trapping and recycling (Hemminga et al., 1991).

Recent destruction of seagrass meadows is a worldwide phenomenon. This loss may result from natural events, e.g. ‘wasting disease’ (den Hartog, 1987) or high energy storms (Patruquin, 1975), but most seagrass loss has resulted from human activities, e.g. from eutrophication (Orth & Moore, 1983; Bulthuis, 1983; Cambridge & McComb, 1984; Neverauskas, 1987a) or land reclamation and changes in land use (Kemp et al., 1983).

The major human-induced declines of seagrass in Australia are summarized in Table 1, with suggested principal causes—in most cases, other factors interact to make the process of loss more complex. A more detailed review of losses is given in Shepherd et al. (1989). The general hypothesis for all these instances of seagrass decline is that a decrease in the light reaching seagrass chloroplasts reduces effective seagrass photosynthesis. The decrease may result from increased turbidity from particulates in the water, or from the deposition of silt or the growth of epiphytes on leaf surfaces or stems. Seagrass meadows occur between an upper limit imposed by exposure to desiccation or wave energy, and a lower limit imposed by penetration of light at an intensity sufficient for net photosynthesis. A small reduction in light penetration through the water will therefore reduce the depth range of seagrass meadows (e.g. in Botany Bay between 1942 and 1970; Larkum & West, 1990), while particulates on leaves
TABLE 1
Summary of major human-induced declines of seagrass in Australia. The principal apparent cause is given, but in almost every case other factors are implicated.

<table>
<thead>
<tr>
<th>Place</th>
<th>Seagrass community</th>
<th>Extent of loss</th>
<th>Cause</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Westernport, Victoria</td>
<td>Heterozostera tasmanica</td>
<td>17 800 ha lost</td>
<td>Fine muds settle on leaf-blade, blocking light</td>
<td>Bulthuis (1983)</td>
</tr>
<tr>
<td>Numerous estuaries of NSW</td>
<td>Zostera capricorni</td>
<td>50% loss of area of seagrass beds</td>
<td>Light reduction</td>
<td>West (1983)</td>
</tr>
<tr>
<td>Lake Macquarie, NSW</td>
<td>Zostera capricorni Halophila ovalis Ruppia megacarpa</td>
<td>700 ha lost</td>
<td>Light reduction</td>
<td>King &amp; Hodgson (1986)</td>
</tr>
<tr>
<td>Tuggerah Lakes</td>
<td>Zostera capricorni Halophila ovalis Ruppia megacarpa</td>
<td>1300 ha lost</td>
<td>Light reduction</td>
<td>King &amp; Hodgson (1986)</td>
</tr>
<tr>
<td>Cockburn Sound, Western Australia</td>
<td>Posidonia sinuosa P. australis</td>
<td>3300 ha lost</td>
<td>Increased epiphytism blocking light</td>
<td>Cambridge &amp; McComb (1984)</td>
</tr>
<tr>
<td>Princess Royal and Oyster Harbours, Western Australia</td>
<td>Posidonia australis Amphibolis antarctica</td>
<td>8.1 km² lost (46%) 7.2 km² lost (66%)</td>
<td>Decreased light, increased epiphyte loads</td>
<td>Bastyan (1986)</td>
</tr>
<tr>
<td>Holdfast Bay and off Bolivar, South Australia</td>
<td>Posidonia sinuosa P. angustifolia Amphibolis antarctica</td>
<td>5222 ha lost 620 ha partial loss</td>
<td>Increased epiphytism blocking light (and other contributing factors)</td>
<td>Neverauskas (1985a,b)</td>
</tr>
<tr>
<td>South of Outer Harbour, Holdfast Bay, South Australia</td>
<td>Posidonia sinuosa</td>
<td>100 ha lost; replaced by sparse Halophila australis</td>
<td>Accretion of sediment</td>
<td>Sergeev et al. (1988)</td>
</tr>
<tr>
<td>Holdfast Bay, South Australia</td>
<td>Posidonia sinuosa P. angustifolia</td>
<td>800 ha lost</td>
<td>Sediment instability induces blowout expansion</td>
<td>Sergeev et al. (1988)</td>
</tr>
<tr>
<td>Botany Bay, New South Wales</td>
<td>Posidonia australis</td>
<td>257 ha lost (58%)</td>
<td>Poor catchment management, uncontrolled effluent disposal and widespread dredging</td>
<td>Larkum &amp; West (1990)</td>
</tr>
<tr>
<td>Moreton Bay, Queensland</td>
<td>Zostera capricorni</td>
<td>Smothering by sediment</td>
<td>Smothering by sediment</td>
<td>Kirkman (1978)</td>
</tr>
</tbody>
</table>

could eliminate meadows over extensive areas of shallower water (e.g. Princess Royal Harbour, Western Australia; Bastyan, 1986).

The turbidity of water above seagrasses may increase directly, by discharge or resuspension of fine material in the water column (e.g. from sludge dumping, or dredging). Indirect effects occur through enhanced nutrient concentrations, from the discharge of sewage and industrial wastes, or from agricultural activity in catchments, increasing phytoplankton biomass to levels which reduce light penetration significantly (Chiffings & McComb, 1981; Lukatelich & McComb, 1986). The extent of phytoplankton blooms associated with nutrient enrichment will be determined by water movement, and mixing will dilute nutrient concentrations. Deeper seagrass beds further from the sources of contamination may show no influence of turbidity (e.g. Holdfast Bay, South Australia; see Sergeev et al., 1988).

The cause of early loss of seagrass in Westernport Bay, Victoria, is still uncertain, but human activity around and on the Bay increased greatly during the major period of seagrass loss, and fine sediment and epiphytes have been implicated (Bulthuis, 1983; Bulthuis & Woelkerling, 1983; Bulthuis et al., 1984).

**Epiphytes**

Nutrient enrichment can lead not only to enhanced phytoplankton growth, but also to enhanced growth of macroscopic and microscopic algae on leaf surfaces (Neverauskas, 1987b). Nutrients are required for seagrass growth, but the concentrations in tissues are lower than in macroalgae. C:N:P ratios for seagrasses are greater than 700:35:1, and are lower than 550:30:1 for macroalgae (Atkinson & Smith, 1983), and small filamentous algae may approach phytoplankton ratios (e.g. 265:38:1 for the small green alga Cladophora sp. compared to 106:16:1 for phytoplankton—the Redfield ratio). Macroalgae dominate over seagrasses under conditions of marked eutrophication, both as epiphytes and as loose-lying species (e.g. the genera Ulva, Enteromorpha, Ectocarpus) which may originate as attached epiphytes (Bastyan, 1986). Increased epiphytic growth results in shading of seagrass leaves by up to 65% (Silberstein et al., 1986), reduced photosynthesis and hence leaf densities (Walker & McComb, 1988; Larkum & West, 1990). In addition, the epiphytes reduce diffusion of gases and nutrients to seagrass leaves (Borowitzka & Lethbridge, 1989).

**Sediment**

Settlement of suspended fine material on leaf blades of seagrasses seems to have been important in Westernport Bay (Bulthuis et al., 1984). Such deposition is likely to be significant only in low wave energy environments where fine sediments can settle out. The morphology of the plant may also be significant, as flat-
bladed genera such as *Posidonia* and *Heterozostera* are more likely to be blanketed by a rain of fine sediment and hence be shaded more heavily than those with other morphologies such as *Amphibolis*.

Larger volumes of sediment may also be important. Seagrasses may survive temporary inundations of sediment for several months but not longer periods (Clarke & Thomas, unpublished data, 1989), and the smothering of seagrass by large amounts of sediment was observed off Bolivar, South Australia (Neverauskas, 1988) and at Moreton Bay, Queensland (Kirkman, 1978).

Further losses of seagrass often follow the initial decrease in seagrass area, as the removal of seagrass canopy may result in large volumes of fine sediment being resuspended. These increased losses have been referred to as ‘auto-catalytic’ (Larkum, 1976) where increasing turbidity results in increasing seagrass decline as sediments are winnowed and deposited elsewhere. This may have been a major factor accelerating the decline in Westernport Bay, Victoria (Bulthuis et al., 1984).

Sediment imbalances in seagrass beds may be caused by activities such as harbour and groyne construction, which change the wave energy regime. Increased wave or current energy may increase sedimentary erosion and lead to fragmentation of seagrass beds and loss of the rhizome matt. The dredging of Botany Bay, New South Wales appears to have precipitated this effect in the *Posidonia* beds within the Bay (Larkum & West, 1990). If the wave energy regime is decreased by man-made structures then deposition of sediment is probable, with a potential reduction in seagrass leaf production. Enhanced protection may in some cases lead to seagrass establishment (Harrison, 1987).

Changes in the redox potential of the surface sediments by rapid addition of oxidized material (Thayer et al., 1975) or even toxins released from suspended sediments may also be involved in seagrass loss, but the most conservative and traditional hypothesis is the reduction of light availability.

Grazing by sea urchins may also be a secondary cause (Cambridge et al., 1986; Larkum & West, 1990). Increased grazing by sea urchins has been associated with the decline of seagrass beds, but increases appear to be associated with meadows that are already declining for some other reason.

The inter-relationship between grazing invertebrates and epiphyte abundance on seagrasses has also been suggested as a potential cause of seagrass loss (Howard & Short, 1986). Toxic effluents could reduce grazer population densities, reduce grazing pressure and allow increased growth of epiphytes. Other studies of seagrass decline have shown an impoverishment of the mobile epifauna, which includes many grazing species (Orth et al., 1984; Virstein & Howard, 1987a,b; Sergeev et al., 1988). For Cockburn Sound the simpler hypothesis has been accepted as sufficient to account for the losses of seagrass; epiphyte abundance increases, in response to enhanced nutrient concentrations. Enhanced nutrient levels were observed, differences in grazing were not observed on plastic seagrass between healthy and deteriorating meadows, and the filamentous algal species which grew are not those which are readily grazed (Silberstein et al., 1986).

Epiphytes and sediment deposits could interfere with carbon or nutrient uptake by seagrass leaves, and sometimes toxins may affect growth. However, the simpler hypothesis of shading, known to be significant in reducing seagrass photosynthesis, should not be abandoned because other more complex possibilities can be suggested which give rise to light reduction. This hypothesis can also be tested experimentally.

**Consequences of seagrass loss**

Additional nutrients can stimulate productivity, but in seagrass systems the community shifts from a three-dimensional benthic structure to a phytoplankton-dominated system, which does not provide additional habitat. Although seagrass losses in Australia are well-documented, the consequences of loss are less well understood. Recent work in Princess Royal Harbour, Western Australia, where up to 80% of the seagrass biomass has been lost since 1960, showed that there were 40 times more benthic invertebrates associated with seagrass than with adjacent bare sand (Walker et al., 1991; Hutchings et al., 1991; Wells et al., 1991). Fish and macro-crustacean populations showed similar patterns (Kirkman et al., 1991).

When there is no longer an intact seagrass canopy, sediments are more easily resuspended, so that light availability remains low, even if the original source of nutrients/cause of seagrass loss has been removed. This is at least partially why little recolonization seems to occur in areas where there has been widespread seagrass loss. Various other factors have been suggested, such as changes in the sediment biogeochemistry, e.g. involving disruption to the rhizosphere bacterial communities. Whatever the reason, there are reports in the literature of long-term persistence of damage to seagrass beds, e.g. in Jervis Bay, New South Wales, circular depth-charge scars from 1940 are still visible, as are scars from the mining of *Posidonia* rhizome fibres for paper-making in 1911 in Spencer Gulf, South Australia (Kirkman & Parker, 1978). It has been suggested that recolonization takes place over an 80–200 yr period (Clarke & Kirkman, 1989). Thus any large-scale losses persist for extremely long time periods and it cannot be assumed that seagrass losses will be made up by increased natural growth. Smaller-scale losses in areas, such as those brought about by boat moorings (Walker et al., 1989) may well be recolonized over shorter time scales, although it is clear they persist for several years and re-invasion has not been documented.

Seagrass restoration has been attempted in several locations around Australia, but such attempts are expensive, time-consuming and so far have not been successful (Larkum & West, 1983; Lewis, 1987). It is particularly difficult for species such as *Posidonia australis*, which have a slow rhizome growth rate. Other difficulties include problems of transplanting under the high energy conditions which prevail on much of the
Australian coast, and the possibility that unless seagrasses are established over reasonably large areas, sediment movement and fish or sea urchin grazing may lead to establishment difficulties (Kirkman, 1989). Nevertheless, experimental work in this area may lead to better understanding of the conditions necessary for the establishment of meadows and the time scales over which invasion may occur.

Increased awareness of seagrass losses around Australia has lead to constructive attempts by government agencies to implement integrated catchment management (Wallis, 1992, pers. comm.). Rates of degradation seem to have slowed, and for example, management changes to Cockburn Sound have resulted in an increase in water quality (Hillman, 1986). However, sheltered water bodies around the Australian coast are still viewed as having a ‘beneficial use’ to the community as receivers of industrial waste (Western Australian EPA, pers. comm.). Developers in the state of Queensland are by law required to replace any area of seagrass they remove, with an equivalent area elsewhere. As transplantation is not guaranteed to succeed, this policy may not be effective in the long term. Increased awareness of the potential risks and long-term consequences should help protect Australia’s remaining seagrass resources.

Bastyan, G. R. (1986). Distribution of seagrasses in Princess Royal Harbour and Oyster Harbour on the southern coast of Western Australia. Technical Series 1, Western Australian Department of Conservation and Environment, Perth.
Kirkman, H. (1989). Restoration and creation of seagrass meadows with special emphasis on Western Australia. Environmental Protection Authority Technical Series No. 30, Perth, Western Australia.


