Seagrass in Australia

STRATEGIC REVIEW AND DEVELOPMENT OF AN R & D PLAN

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Executive Summary

The FRDC *Seagrass Review* follows the Corporation's *Fisheries Habitat Review.* It reflects a shift from viewing fished species or even fisheries habitats as separate, unconnected entities to viewing them as components of larger ecosystems, and it seeks to develop a comprehensive, ecosystem-based management.

The reviewers were asked to assess

- Gaps in existing knowledge of seagrass ecosystems
- Knowledge of links between seagrass and fisheries
- The state of the art in rehabilitation and restoration of damaged seagrass beds
- Monitoring and assessment of seagrass
- Seagrass and fisheries management

and to prepare a research and development plan to guide FRDC's future investment in the context of FRDC's Ecosystem Protection Program. The review will also guide FRDC's interaction with other agencies who have responsibilities in marine habitat management.

Each of the five areas listed above was reviewed by a separate team of three experts, who co-opted other experts as necessary. The five reports were edited, and the R&D plan drafted, by the principal investigators. The whole report was discussed with the steering committee and reviewed by four independent experts.

Status of Australian seagrass research and knowledge

The authors of this chapter examine the attributes of seagrass communities to determine whether seagrass form provides an indication of function, and hence the significance of particular seagrasses to fisheries.

They examine habitat effects, relationships to water movement and nutrients, and mechanisms of seagrass decline, and discuss what is known about food webs associated with seagrasses, and of the transfer of biological productivity between seagrasses and other components of the marine ecosystem.

The working group identified nine areas of knowledge gaps, and the authors suggest ways to address them. Some examples of gaps are:

1. Northern Australian, turbid-water seagrasses on remote, inaccessible coastlines remain virtually unknown,
2. The importance, as habitat, of seagrasses in wave-exposed conditions and in deep water is not known,

3. Understanding of the dispersal and recruitment characteristics of different seagrass species is inadequate,
4. Comparative studies are needed of the fates and influences of production from the seagrass system — seagrass detritus, plankton, epiphytic flora and fauna, benthic fauna and microphytobenthos.

Seagrass dynamics and fisheries sustainability

This chapter examines the evidence for links between seagrass and fisheries resources. It focuses on the reliability of that evidence, especially on the importance of seagrass beds in fisheries production, and the influence of the extent of seagrass cover, type, or density on fisheries sustainability.

The authors compare the relationships between fish and seagrasses to those of other estuarine and nearshore habitats. Then, more specifically, they explore the relationship of seagrass to fisheries; firstly, those species that are actually fished in seagrass areas, and secondly, those that are fished elsewhere but may have some link to seagrass. The next section examines the related, but distinct, question of the influence of seagrass status on fisheries sustainability.

In conclusion, the working group identifies 17 major gaps in our understanding and future research needs, and recommends specific research to address those gaps. Examples are:

1. Changes in juvenile fish and decapods before and after seagrass loss are poorly understood. Baseline studies of sufficient spatial and temporal intensity are needed to quantify natural variability in fish and decapods in seagrass beds, so useful comparisons can be made after seagrass loss.
2. The importance of exported seagrass detritus to commercially important fish in unvegetated habitats is poorly understood. What is the long-term effect of seagrass loss to these species?
3. The nature of the links with seagrass is still poorly known for many species. Those links might include feeding, protection from predators, or amelioration of physical disturbance. The role of small, non-commercial species in food chains for commercial species is only known in localised areas. Understanding these links is important in predicting the effects of changes in seagrass extent on commercial fish.
4. Research has hinted at the importance of many aspects of seagrass meadows relating to 'landscape ecology'. It is critical to determine the importance of features such as size, shape, and spatial arrangement of meadows, the details of ocean currents over seagrass beds, and relations with other habitats (e.g. unvegetated areas, mangroves, deep water, sand bars).

Review of Australian rehabilitation and restoration programs

This chapter reviews international experience, then concentrates on Australian projects in the restoration and rehabilitation of seagrasses. It identifies the factors that are important to success, although most of these have yet to be investigated for most seagrass species. Consequently, at this time, no projects in Australia can unequivocally demonstrate creation of a permanent, functional seagrass bed out of transplanting efforts. Nor have techniques been tested to the degree that particular methods can be recommended for different seagrass species or habitats.

Nonetheless, enough experience is available to enable the authors to review the issues important to successful seagrass rehabilitation and restoration. In making recommendations for future research the working group argues that restoration and rehabilitation depend on a thorough understanding of the system being restored, and therefore that it would be prudent to undertake restoration programs in combination with well constructed programs of research into the fundamental characteristics of seagrass. The authors give detailed recommendations for a nationally coordinated effort to develop seagrass restoration technology in a variety of conditions.

Monitoring and assessment of seagrass

The authors of this chapter review the current status of knowledge and methods for monitoring seagrass against a defined set of criteria. These criteria address the objectives of the work (including relevance to management in general and FRDC objectives in particular), the monitoring methods adopted, the spatial and temporal scales (and their relevance to the stated objectives), the statistical treatment adopted and the use of explicit data quality processes.

The authors identify specific research priorities, and recommend that a national strategy for seagrass monitoring should be developed. The strategy should be based on a quantitative understanding of the relationship between indices of seagrass distribution and productivity on the one hand, and fish stocks and biodiversity on the other. The authors conclude that the current challenge is twofold: to develop an interim strategy for mapping and monitoring that acknowledges missing and imperfect understanding, and to instigate research that will provide that missing information.

Seagrasses and their management — implications for research

This chapter examines issues confronting seagrass managers, and the information they need. The authors present the requirements presented by managers in response to a questionnaire. These requirements are summarised in the chapter, which stresses that seagrass habitats cannot be considered in isolation.

The research requirements identified by managers have much in common with the findings of the other working groups; in particular, the managers also recognised the needs for inventory; for better understanding of the links between seagrass, fish and fisheries; for better understanding of the habitat and environmental requirements of seagrass species; for conceptual models that would enable the right questions to be asked; for information on natural variation in space and time, at a variety of scales; and for understanding of the links between human activities and seagrass health.

The working group outlines a national action plan for seagrass management.

Such a plan cannot be implemented by FRDC alone, but needs collaboration between many agencies. The R&D plan developed from the *Seagrass Review* does, however, recommend ways in which FRDC can work towards the aims of such a plan.

Research and development plan

The R&D plan is intended to guide FRDC's own future investment in seagrass research and development, and also its interactions with other agencies. The proposed R&D plan is outlined here. The goals of the plan are to enhance our understanding of the ecosystem of which seagrasses are a part, in particular of the linkages between seagrass and fisheries productivity, and to promote research to stop the loss and enhance restoration of seagrass as a habitat that is significant both to fisheries and for other values.

Achieving these goals depends on the active involvement and support of FRDC's stakeholders and researchers, and the beneficiaries of research results. Criteria against which achievement may be measured include: level of knowledge of the status of seagrass ecosystems, changes in rate of loss of seagrass ecosystems, level of seagrass restoration and rehabilitation activity, and availability of sufficient information to develop seagrass ecosystem management plans.

A large number of agencies have management responsibilities that impinge on seagrasses and, amongst those agencies, a significant number have R&D responsibilities. It is essential that these agencies work in collaboration.

The *Seagrass Review* shows a large number of knowledge gaps. On many points the working groups feel that knowledge is not as well-supported as it is commonly believed to be, and in many more areas knowledge is undoubtedly inadequate.

The R & D plan identifies priorities amongst these knowledge gaps under the headings of:

- Inventory and data archiving
- Ecosystem understanding
- Monitoring
- Relationships between seagrass and the productivity of fisheries
- Human impacts
- Protection, restoration and rehabilitation of seagrass beds

These research areas are complex and interdependent.

The most important aspect of the R&D plan is coordination, communication and collaboration between multiple agencies and stakeholders. A variety of communication mechanisms can be imagined. This report proposes one that is readily within the scope of FRDC, but it is the tasks assigned to it that are important. Whatever mechanism is adopted, it must be charged with these tasks. This plan proposes that, within its ecosystem protection program, FRDC should establish a *seagrass ecosystems subprogram*. The plan proposes a number of duties for the subprogram, the first of which is that it should:

- Establish an inter-agency network to facilitate cooperation between the agencies in the funding and coordination of research, the effective use of research outcomes, and the improvement of management

The plan proposes that, having established an inter-agency network, the *seagrass ecosystems subprogram* should address the research areas identified in the *Seagrass Review*. Noting the priorities and current opportunities, the plan outlines a number of strategies directed at particular research aims within those broad categories.

The *Seagrass Review* is concerned with 'R&D', not merely 'R'. This is reflected in the collaborative research strategies it outlines. In addition it proposes that:

- The *seagrass ecosystems subprogram* should facilitate training-based workshops to disseminate knowledge of techniques
- The subprogram should endeavour to improve management models for seagrass fisheries habitats in Australia (a generic plan is proposed in the report)

Finally, the plan includes recommendations for quality maintenance. The R&D plan should be reviewed in five years to assess what gaps have and have not been addressed and to re-focus the plan. The review should use formal performance criteria which are outlined in the report. Annual reviews should take place using those performance measures that can reasonably be assessed on a short time-scale.

INTRODUCTION

Background to the study

The present review was commissioned as part of FRDC's *Ecosystems Protection Program*, which aims to protect the Australian ecosystems upon which fisheries and aquaculture depend. The program has three key areas:

- Ecosystems Status — R&D that will increase knowledge for the protection of ecosystems, including: interrelationships between fish and their environments; impacts of fishing, aquaculture and other marine and land use; biodiversity; fish health; and impacts of exotic organisms.
- Ecosystems Maintenance and Improvement — R&D that will maintain and improve ecosystems, including: protecting, restoring and enhancing habitat; reducing bycatch and impacts on other non-target flora and fauna; and enhancing wild fish resources.
- Ecosystems Management Improvement — R&D that will help to develop and evaluate ecosystems management, including: developing systematic approaches to ESD: determining impacts on ecosystems; and regulating access to ecosystems.

The Review and Synthesis of Australian Fisheries Habitat Research (Cappo *et al.* 1998), which was commissioned as part of the above program, highlighted key issues and questions generic to a range of marine and estuarine habitats. It also identified that seagrasses were a habitat important to fisheries and aquaculture activities.

Seagrasses are flowering plants that live in the sea and are generally restricted to soft sediment habitats. Their leaves and stems are used as an attachment surface by algae and sessile invertebrates and they also shelter many small fish and invertebrates such as crabs and molluscs. Seagrass beds are generally believed to provide nursery areas for many different species of fish and crustacea. It is also believed that they are areas of high productivity, are involved in trapping detritus and cycling nutrients and provide shoreline and substrate stability.

Australia possesses the highest diversity of seagrass species and most extensive seagrass beds worldwide, but it has also experienced significant declines of this habitat over the last 40 to 50 years. For example, Lake Macquarie lost 700 ha, Westernport Bay lost 17,800 ha, Tuggerah Lakes lost 1300 ha, Princess Royal Harbour lost 810 ha, Cockburn Sound lost 3300 ha, Torres Strait lost more than 10,000 ha of seagrass meadows, and there are many more Australian examples.

Seagrass loss is generally blamed on human impacts such as excess nutrients in the water and increased siltation from dredging. However, natural impacts, such as cyclones and storms, also occur. In most cases, seagrass loss has been associated with changing conditions. However, such correlations do not necessarily imply causation; there may be other factors responsible for seagrass loss, such as, dredging, nutrients, climatic change, or a combination of interacting factors. This lack of knowledge of causes and effects and the continued reduction in seagrass distribution has led to a number of recent reports addressing the national and local issues. The Fisheries Pollution and Marine Environment Committee, for example, has produced an issues paper on the status of Australian Seagrass (Hamdorf & Kirkman, 1995); the *State of the Marine Environment Report for Australia* (Zann, 1995) and *Australia: State of the Environment 1996* (see Kirkman, 1997) include sections on seagrasses. Recently, Environment Australia commissioned a number of State workshops that contributed to a national workshop to formulate a national approach to monitoring seagrass (Jacoby, 1997).

Concern over the rate of seagrass decline and determining the causes and ways to reverse seagrass loss are thus of major interest on both local and national scales. Although Australian seagrass research is extensive, the work has not been coordinated, nor directly designed to address these issues and to understand the processes by which fisheries may affect, or be affected by, seagrass loss.

FRDC recognised the need for an integrated approach to such questions, and decided to develop an R&D plan. It commissioned an assessment of the present state of knowledge of the nation's seagrasses, of their interactions with fisheries, and the associated resource and management issues. This report presents that assessment.

Objectives

The objectives of the review were:

1. To assess the status of Australian seagrasses with respect to the following areas:
   - Status of Australian seagrass research and knowledge
   - Review of seagrass monitoring and assessment
   - Review of knowledge of links between seagrass and fisheries sustainability
   - Seagrass and fisheries management
   - Review of remediation and restoration projects
2. To use information from the above areas to develop a strategic R&D plan to help guide future FRDC-funded research on seagrass-related issues.
3. To ensure the project delivered an outcome where all concerned parties in Australia knew what had been done and what needed to be done with respect to seagrass research and its interaction with fisheries.
4. To ensure that other agencies that may have an interest in the work (e.g. Environment Australia) would be involved in the project and so would understand, accept and use the findings wherever possible.

Methods

FRDC contracted CSIRO to coordinate a project to obtain the required information. The framework under which the project proceeded was specified by FRDC.

A steering committee consisting of the working group leaders (see below) and representatives from FRDC, AIMS, Environment Australia, the fishing industry and the principal investigators met in Canberra on 25 March 1998 to discuss and agree on the outcomes and needs of the project prior to its commencement.

Five working groups of seagrass experts from across Australia (each with a designated working group leader) critically reviewed each of the areas under Objective 1. Their starting point was the Review and Synthesis of Australian Fisheries Habitat Research (Cappo *et al.* 1998), plus recent publications on the status of seagrass (Hamdorf & Kirkman, 1995; Kirkman, 1997; Zann, 1995; *State of the Environment, 1996*). However, each group brought its own expert knowledge, and members' own knowledge of the literature, to bear on their topic. In reviewing the status of knowledge, each group specifically identified key issues and knowledge gaps of relevance to FRDC. The five reports of the working groups form the central chapters in this review.

The findings of the report were summarised in brief and knowledge gaps and research recommendations were listed and assigned suggested priorities. An R&D plan was devised, with the aim of guiding FRDC's immediate decisions about allocation of resources to seagrass research, and also of facilitating the coordination of seagrass research at Commonwealth and State levels.

The Plan was discussed in draft among Working Group leaders and Steering Committee members, and then national and international seagrass experts reviewed the report. These reviewers were Professor A.J. McComb (Murdoch University, Perth), Dr K. Heck (University of Southern Alabama, USA) Dr M. Fonseca (National Marine Fishery Service, Beaufort, USA) and Mr V. Neveraskas (Primary Industries and Resources South Australia).

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CHAPTER ONE

Status of Australian seagrass research and knowledge

D. Walker, W. Dennison, G. Edgar

1.1 Introduction

The brief for this section of the report was to:

- review the present state of knowledge of Australian seagrasses and current research
- identify and document gaps in our knowledge

This report critically assesses the information base, identifies gaps and recommends approaches to address these gaps. It is not an attempt to describe encyclopaedically the status of seagrass knowledge. Recent reviews of various aspects of seagrass research have been conducted, as well as a recent review of fisheries habitat research (Cappo *et al.*, 1998). We have attempted to synthesise our understanding of seagrass communities on an Australia-wide scale, within the broad context of world-wide seagrass knowledge. In doing so we have categorised attributes of seagrass communities across all genera of seagrass, to determine whether seagrass form provides an indication of seagrass function, and hence their significance to fisheries.

Seagrass research in Australia was originally focussed in temperate regions, especially in areas close to centres of population. Our understanding of tropical seagrasses has advanced but it is patchy and regions such as the Northern Territory and northern Western Australia are almost unstudied.

1.1.1 Approach taken in this paper

Information on seagrass plant attributes, their ecological function and associated invertebrates was collated from the primary literature, our own background knowledge and by consulting other seagrass biologists around Australia. Previous review documents such as the review by Cappo *et al.*, (1998) were useful, but extensive reference was also made to Larkum *et al.* (1989).

In this chapter we discuss seagrass plants, particularly Australian seagrass knowledge (Section 1.2). Section 1.3 outlines the significance of seagrass as habitat, particularly in relation to water movement and nutrient status. It also outlines mechanisms of seagrass decline. Seagrass food webs (in relation to invertebrates) are discussed in Section 1.4. Section 1.5 outlines gaps in our knowledge and recommends approaches to address these gaps.

1.2 Seagrass plants

Seagrasses are highly specialised marine flowering plants adapted to soft sediments of nearshore environments. Although there are relatively few species of seagrasses globally (< 70 species), these plants have evolved from several lineages of land plants and are adapted to a totally submersed life. Seagrasses are productive, widespread and ecologically significant features of nearshore environments (Phillips and McRoy, 1980; Larkum *et al.*, 1989). Seagrasses indirectly support various coastal fisheries, largely through provision of a nursery habitat for juvenile animals (e.g. Klumpp *et al.*, 1989; Bell and Pollard, 1989). These connections are more fully explored in Chapter 2. Tropical seagrass meadows directly support dugong (*Dugong dugon*) and green sea turtles (*Chelonia mydas*) (Lanyon *et al.*, 1989).

Seagrasses are not a monophyletic group of plants; they are not even true grasses (Poaceae). Rather, 'seagrass' is a functional grouping referring to marine flowering plants living entirely submersed and sharing numerous convergent morphological and physiological characteristics (Larkum and den Hartog, 1989). Recent evolutionary studies using DNA sequences of the chloroplast genome have revealed that the present seagrass diversity probably arose from three separate evolutionary events (Waycott and Les, 1996). Thus, convergence of various characteristics of seagrasses has occurred within and between these three groupings (Cymodoceaceae complex, Zosteraceae, Hydrocharitaceae). The outcome of this convergence is a suite of common morphological and physiological characteristics (including internal gas spaces or lacunae, epidermal chloroplasts, lack of stomata, rapid leaf turnover, reduced respiratory tissue, and salt excretion through the plasmalemma).

1.2.1 Australian seagrasses

Seagrasses are a prominent feature of both tropical and temperate coastlines of Australia. Australia's 32,000 km coastline contains the largest, most diverse seagrass assemblages in the world. The coastline stretches from the tropics (10°S) to cool temperate (44°S), north-south, encompassing 30 degrees of longitude (113°E to 153°E), east-west. Our understanding of the distribution of seagrasses, and of the environments in which they occur varies from species to species and within and between environments. Our knowledge of their functional significance is also fragmentary.

Australia has a unique and rich seagrass flora, with more than half of the world's species, and all but one genus (den Hartog, 1970). Over the past 25 years, various seagrass researchers have investigated Australian seagrasses, and this effort makes up a significant fraction of the world's seagrass literature (Duarte, pers. comm.). In spite of this large research effort, the diversity of seagrasses, as well as of the habitats they provide, have frustrated efforts to synthesise and integrate results. In addition, most seagrass studies overseas have been concentrated on a few temperate species, especially *Zostera marina* and *Posidonia oceanica*, with some on tropical species of the Caribbean, e.g., *Thalassia testudinum*. The extrapolation of these overseas results to other seagrasses, especially the diverse Indo-Pacific flora present in Australia, is inappropriate. The Australian species differ in morphology and have different life histories, so models based on overseas paradigms cannot be applied directly. Our limited knowledge of Australian seagrasses restricts our ability to formulate general models of seagrass ecophysiology, ecology and ecological interactions.

Several features of Australian coastal environments distinguish Australia from other coastal environments in the world. Over geological time scales, Australia has had a relatively stable climate with the northward movement of the Australian tectonic plate compensating for global cooling. The location of the Australian continent towards the centre of the tectonic plate results in little tectonic activity, and the relative sea level along the coastlines is largely controlled by changes in global sea level and eustatic processes, rather than localised tectonic movements. The fact that sea level change has been slow has allowed seagrasses to adapt and migrate. Thus, the high biomass and diversity of Australian seagrasses evident today has probably changed little over the past tens of millions of years.

The position and shape of the Australian continent also contributes to seagrass diversity. Australia straddles the Tropic of Capricorn, so more than one-third of the continent is in the tropics with the remainder in temperate latitudes. The shape of the continent provides extensive east-west coastlines (few contiguous coastlines in the world possess such extensive east-west coastlines). Australia's northern coastline adjoins tropical water masses and the southern coastline adjoins the Southern Ocean, resulting in distinct tropical and temperate seagrass flora.

Australia's seagrasses can be divided into those with temperate and those with tropical distributions. Shark Bay on the west coast and Moreton Bay on the east coast are located at the centre of the overlap zones (Figure 1.1). Temperate species are distributed across the southern half of the continent, extending northwards on both the east and west coasts. These species have been studied most extensively, particularly the large genera *Amphibolis*, *Posidonia* and

Zostera, although species remain that have been little studied. The highest biomasses, and highest regional species diversity, occur in southwestern Australia, where seagrasses occur inside fringing coastal limestone reefs, or in semi-enclosed embayments. Large seagrass meadows are present in protected areas across the Great Australian Bight, and into South Australia and Tasmania. Along the New South Wales coast, seagrasses are confined to estuaries such as Botany Bay, except for the large sheltered embayment of Jervis Bay.

In northern Australia, seagrass species possess tropical affinities, e.g. *Thalassia* and *Cymodocea*. Tropical beds can be highly diverse, but generally possess lower biomasses than temperate zones. While large areas of seagrasses occupy embayments such as Hervey Bay, Queensland, tropical seagrasses are generally confined to intertidal environments, or to deep water (Lee Long and Coles, 1997). The genera *Halophila* and *Halodule* extend beyond the tropics into cooler waters. In the tropics turtles and dugong heavily graze these genera (Lanyon *et al.*, 1989).

Grazing of tropical seagrasses by dugong and sea turtles provides another unique aspect of tropical Australian seagrass meadows. Caribbean seagrass meadows lost large grazing populations of manatees and sea turtles several hundred years ago due to over-exploitation. Indo-Pacific populations of dugong and sea turtles are also increasingly threatened. Because changes in grazing pressure due to local declines in dugong and turtle populations alter seagrass dynamics, paradigms about functioning of tropical seagrass meadows derived from studies in which the macrograzers are missing do not necessarily hold for Australian seagrasses. Tropical Australian seagrass meadows are probably more representative of the natural conditions in which tropical seagrasses evolved.

In areas of northern Australia with a high tidal range, water transparency is often poor, hence conventional remote sensing techniques are of limited value. For this reason, the northwestern quarter of the Australian continent, including the whole Northern Territory coastline, remains largely unexplored for seagrass distribution. Animal communities associated with seagrasses in this region, especially in the area of the Northern Territory prawn fisheries, also remain largely unknown.

The most detailed distributional research in northwestern Australia has been conducted recently in the Kimberley region of Western Australia. Seagrasses in the Kimberleys either occur sparsely in coral reef environments or at moderate to high biomass within intertidal lagoons, where seawater is ponded during the falling tide (Walker, 1997). Environments in this region are otherwise considered too extreme for seagrass survival because of rapid tidal flows, high turbidity (Dennison and Kirkman, 1996), or excessive freshwater runoff in the wet season. Again, the significance of these seagrass communities for any associated fisheries species is unknown.

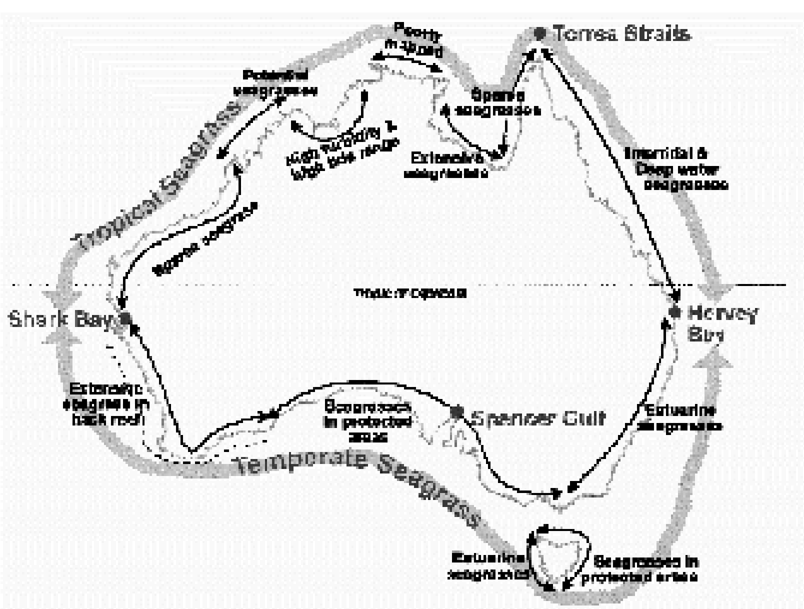
In general, our knowledge of shallow water (down to 10m) temperate seagrass distributions is reasonably good, but our understanding of deep water (down to 20m) seagrasses throughout Australia is rudimentary. Areas subject to more extreme water movement, either tidal or wave-induced, are also poorly studied, compared to seagrasses in more protected areas.

1.2.2 Seagrass form/function model

One useful method of categorising seagrasses is on the basis of their growth forms, which range from small plants with thin leaves (e.g., *Halophila, Halodule*) to large plants with thick leaves (e.g., *Thalassia, Enhalus, Posidonia*). This model, which pools existing fragmentary information and is ultimately related to seagrass rhizome turnover, is proposed and described here (Figure 1.2). Rhizome turnover is a less variable descriptor of size than leaf turnover. As a general trend, there is rapid rhizome turnover in the smaller seagrass genera and slower turnover of persistent rhizomes in the larger seagrasses. This difference may also affect the way large and small seagrasses interact with higher trophic levels, because they are linked through turnover rates. The comparison described in Figure 1.2 encompasses all seagrass genera for completeness, including the genus not present in Australia (*Phyllospadix*) and the genus equivocally classed as a seagrass (*Ruppia*) (Waycott and Les, 1996). The hypothesised gradient from small to large genera is the following: *Halophila* < *Halodule* < *Ruppia* < *Zostera/Heterozostera* < *Phyllospadix* < *Cymodocea* < *Syringodium* < *Amphibolis* < *Thalassodendron* < *Thalassia* < *Enhalus* < *Posidonia*.

This gradient may also reflect different aspects of ecological function, especially in relation to significance to fisheries as habitat. The gradient is not invariant, and some changes within the ordering may occur as more information is gained. However, the grouping of genera at each of the endpoints and the general pattern are likely to remain consistent.

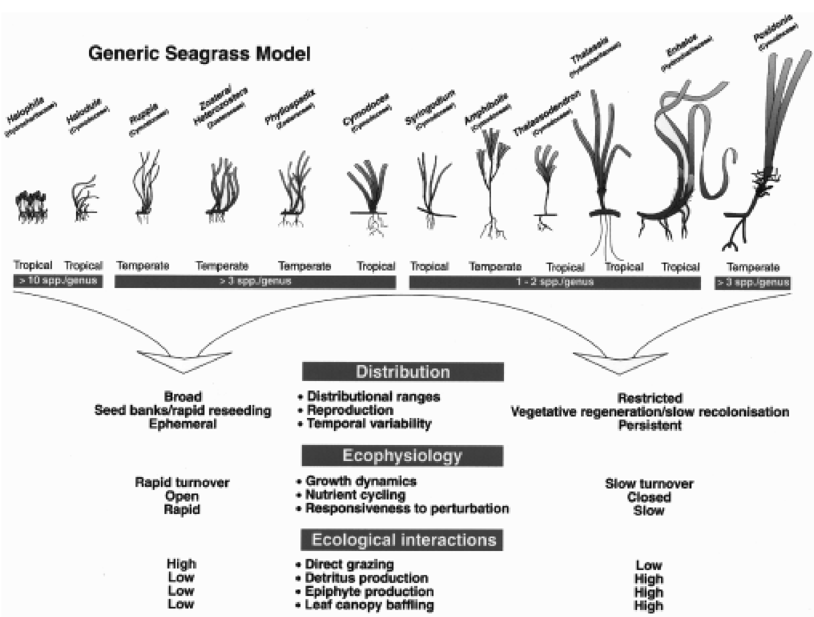
Figure 1.1 Australian coastline showing geographical seagrass distribution



Seagrass responses to disturbances and environmental conditions lead to considerable variability in growth forms for any particular seagrass species. For example, short stunted growth can occur in all seagrasses subjected to environmental stress. The growth form potential that can be achieved for any particular genus, though, is more consistent. For example, *Halophila* plants will be small under all environmental conditions compared with *Posidonia*, *Enhalus* or *Thalassia*. Under different environmental conditions, growth forms of either *Posidonia*, *Enhalus* or *Thalassia* may result in individual plants of each genus being smaller or larger than the other.

The two smallest seagrass genera, *Halophila* and *Halodule*, are the preferred food source for dugong and sea turtle grazing. These two genera have relatively high species diversities, with more than 10 species per genus. This high diversity is probably related to the length of time since the genera evolved, the rapidity of the life-cycle, and frequency of disturbance. Disturbance from repeated grazing of *Halophila* and *Halodule* could lead to more rapid speciation in these genera. *Zostera*, grouped with *Heterozostera* as a result of recent genetic analysis (Waycott and Les, 1996), *Ruppia*, *Phyllospadix* and *Cymodocea* have intermediate numbers of species per genus (>3). The next largest group of seagrasses, *Syringodium*, *Amphibolis*, *Thalassodendron*, *Thalassia* and *Enhalus* have low diversities, with only 1–2 species per genus. In contrast to this trend of decreasing species diversity with increasing seagrass size, *Posidonia* has a high species diversity, with more than 5 species.

Figure 1.2 Seagrass functional form model



Smaller seagrasses tend to have small rhizomes which persist for weeks to months, while larger seagrasses tend to have larger, more persistent rhizomes which exist for months or years. Similarly, the rates of leaf turnover of smaller seagrasses are more rapid than turnover rates in larger species. The potential epiphyte load on seagrass leaves is correspondingly low on fast turnover species compared with high epiphyte loads on slow turnover species. The build up of secondary compounds is higher in species with slower leaf turnover, thus reducing their palatability to grazers. Turtle grazing on *Thalassia* is often a repeated grazing which increases leaf turnover and maintains young, more palatable leaves (Preen, 1995a).

Smaller seagrasses tend to be more responsive to environmental conditions, with faster and more significant responses than larger seagrasses. Photosynthetic responses of *Halophila* are rapid, as shown by relatively rapid chloroplast migration (Drew, 1979), high *in situ* photosynthetic rates (Ralph *et al.*, in press) and rapid fluorescence ratio shift (Dawson and Dennison, 1996). In contrast, the larger seagrasses have low photosynthetic rates (Ralph *et al.*, in press) and slower fluorescence ratio responses (Dawson and Dennison, 1996). Seagrass survival under light deprivation is on the time scale of weeks for small seagrasses (Longstaff and Dennison, 1998; Preen, 1995a), but much longer for large seagrasses (Czerny and Dunton, 1995; Gordon *et al.*, 1994). Small seagrasses recover rapidly from disturbance via seed banks, but large seagrasses can be very slow to recover (e.g., more than 30 years for the seismic explosion craters in Jervis Bay; West *et al.*, 1989). The production of large banks of small seeds in smaller seagrasses contrasts with the production of large seeds that germinate readily in the larger species. This is of significance to dispersal and recruitment of seagrasses, but available data are rare. Growth responses to nutrient addition are higher for small seagrass (*Halodule*) than for larger species like *Zostera* and *Cymodocea* (Udy and Dennison, 1997) or *Posidonia* (Udy and Dennison, in press).

This broad comparison gradient does not correspond to evolutionary relationships, tropical *vs* temperate groupings, geographical (old world *vs* new world) or the potential biomass/architecture obtained by the plants. In terms of evolutionary relationships, species from each of the 3 evolutionary groupings are represented throughout the gradient. For example, *Halophila* and *Thalassia*, both members of the family Hydrocharitaceae, represent examples from both ends of the size spectrum. In addition, no trend is evident in tropical *vs* temperate seagrasses, with interspersed tropical and temperate genera throughout the gradient. The total biomass attained by each seagrass is variable and depends on local environmental conditions. With the possible exceptions of *Halophila* and *Halodule*, any seagrass species can attain high and low biomass values. The canopy architecture is also variable and, again except for *Halophila* and *Halodule*, closed leaf canopies can be obtained, resulting in significant ecological interactions.

The model described above provides a general functional/physiological framework for categorising seagrasses, and should be useful for predicting responses of seagrass species that have not been intensively studied, and responses to disturbance, with their consequent flow-on to higher trophic levels. The usefulness of the model with respect to ecosystem processes nevertheless remains to be assessed. Seagrass cropping rates from large vertebrate grazers, i.e. dugong, turtles and perhaps fish, clearly vary along the described seagrass species gradient; however, the relationship of the model with invertebrate grazing intensity remains completely unknown. Similarly, seagrass meadows composed of species with rapid turnover rates will possess different patterns of nutrient cycling and export than meadows composed of species with slow turnover rates, but again it remains to be determined whether these differences in flux translate to differences in associated fish production.

1.3 Habitat effects

The presence of seagrass physically affects the seabed, leading to major shifts in ecosystem structure as great as changes mediated by the presence of corals, mangroves, salt marshes and macroalgae. As well as transferring energy into food webs, seagrasses provide hard substrata for benthic species, affect water flow, increase rates of sedimentation and larval settlement, provide protection from predators, stabilise sediments, and influence nutrient dynamics.

Seagrasses typically colonise soft sediments, and so often provide the only source of firm substrata that is suitable for colonisation by various macroalgae and invertebrates in many coastal environments. Numerous animals and most plants can only survive attached to firm substrata and so rely on the presence of seagrass along sheltered coasts. Physical structure associated with seagrass also increases the variety of microhabitats available to species, as well as increasing the total area of available substrata. Seagrass leaf canopies can increase the substrata available by 10-fold or greater (Hillman *et al.*, 1989). The overall combination of these factors leads to substantially elevated diversities of plant and animal species in seagrass beds compared to adjacent unvegetated habitats, including increases in numbers of fish species (Howard and Edgar, 1994). Increased heterogeneity of substrata also leads to greater transfer of energy into the food chain because light is trapped by plants at levels above as well as on the seabed, and epiphytes can attach and multiply rather than be disturbed by wave-induced overturn of sediments.

1.3.1 Water movement

Responses of seagrasses to water movement have been studied during the last decade, although studies on Australian species have been confined to investigations of *Posidonia* and *Amphibolis* in southern Australia. Australian studies have also been restricted to sites with turbulent wave motion, rather than sites with bi-directional tidal flow.

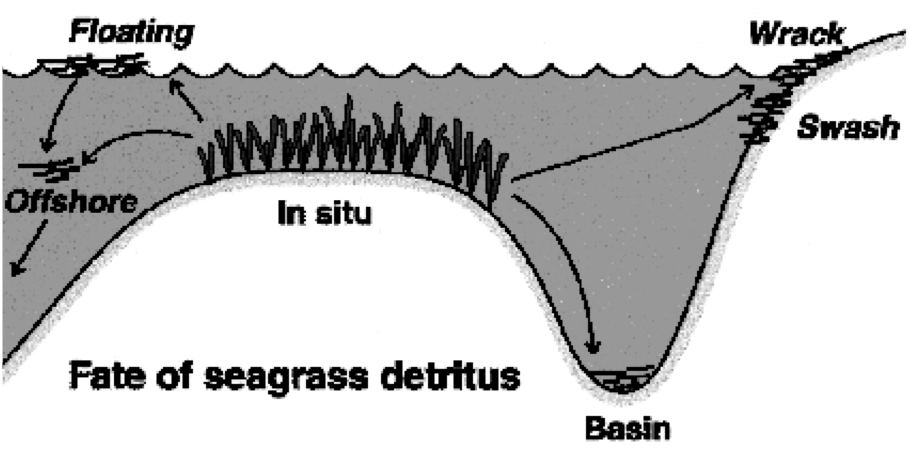
Water movement greatly affects the functioning of seagrass beds (Gambi *et al.*, 1990). Seagrass plants act as baffles to water motion in the nearshore environment. At low plant density, each shoot acts as a barrier to water flow, facilitating the deposition of suspended particles in the lee of shoot (Fonseca *et al.*, 1982). At high plant densities (ratio of shoot area to unvegetated area >12%), the seagrass bed affects water flow as a single unit and deposition occurs in the lee of the bed (Eckman and Duggins, 1993). Amongst the particles deposited are eggs and larval invertebrates, which have frequently been found to differentially settle in seagrass beds and immediately-adjacent sediments (Fonseca and Cahalan, 1992).

In areas subject to large-scale tidal movements, dominated by bi-directional flows (Figure 1.3), seagrasses exercise a complex influence on sediment trapping and binding. This results in higher rates of accumulation of organic matter, including the trapping of old leaves as they are shed and their resulting decomposition *in situ*, which leads to enhanced secondary production (e.g. Edgar 1990a, b, c, d). Abiotic particles deposited in seagrass beds with tidal flows are trapped by roots and rhizomes and rapidly bound into sediments. Seagrass beds therefore act as major sinks for sediments in regions with tidal flows and play an important role in stabilising sediments. Sediment accretion caused by water baffling, and by the deposition of calcareous fragments from epiphytic algae and invertebrates, can lead to substantial rises in seabed levels over historic time scales (Walker and Woelkerling, 1988). Similarly, substantial loss of seagrass beds, such as in Westernport, Victoria, is often accompanied by major erosion of sediment banks and increased water turbidity (Bulthuis *et al.*, 1984).

Under oscillatory orbital flow resulting from high wave energy, this organic matter is more dispersed. The underlying sediments behave as a fluid, resulting in negligible trapping of detritus. Under such conditions, seagrasses may rely on leaf rather than root uptake of nutrients (Pedersen *et al.*, 1997). These generalisations need to be confirmed for different species in a variety of locations.

In addition to its effects on seagrass distribution, water movement also acts directly on seagrass-associated fauna, particularly those species with a planktonic

Figure 1.3 Fate of seagrass detritus



dispersal stage. Local currents greatly affect recruitment of larval fishes (Jenkins *et al.*, 1996), perhaps to the extent suggested by Bell and Westoby (1987) that currents and proximity to sources of larval recruits are the primary determinants affecting the distribution of fishes in seagrass beds.

1.3.2 Nutrients

Background concentrations of nutrients in Australian coastal waters are low compared with most other coasts around the world. The oligotrophic nature of coastal waters is due to both continental and oceanographic features. The Australian continent is relatively old, with reduced topography and well-weathered soils. The nutrient content of Australian soils is generally low, leading to correspondingly low levels of nutrients contained in runoff from undisturbed catchments. As well, no major sources of upwelling of nutrients occur along the Australian coastline. Seasonally warm water poleward currents are present along both Australia's west coast (Leeuwin Current) and east coast (East Australian Current), bringing tropical, nutrient-depleted waters along the coast. Without significant terrestrial or oceanic nutrient sources, Australian seagrasses have evolved in a generally low ambient nutrient environment. This may account for their apparent sensitivity to nutrient enrichment of estuarine and coastal waters, with large-scale seagrass declines linked to nutrient enrichment in many regions.

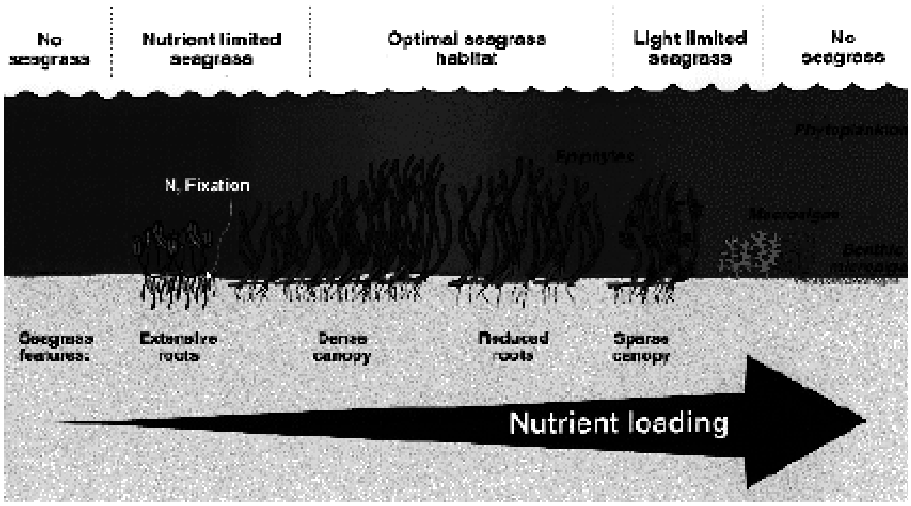
Rainfall is highly variable in Australia, with more seasonal and inter-annual variability than on other continents. Rainfall is also generally low, and Australia is the driest continent, apart from Antarctica. Following European settlement, the catchments of Australian rivers are now poorly vegetated, and low rates of infiltration of rainfall result. Thus, runoff from Australian rivers is highly pulsed; with long droughts interspersed with major flooding events. This flooding typically leads to turbidity and nutrient plumes into coastal waters. Seagrasses subjected to these turbidity and nutrient pulses have a variety of tolerances to withstand the reduced light and potential overgrowth by algae associated with them.

1.3.3 System scale nutrient loading

Australian seagrass systems are generally characterised by low ambient nutrient loadings. The development of seagrass communities requires the acquisition of nutrients, despite the low water column nutrient concentrations. In most Australian waters, phosphorus concentrations, for example, are often below detection limits in the water column. Calcareous sediments, such as in south-western Australia and in tropical reef environments, adsorb phosphorus. The worldwide debate over whether seagrasses are N, P, or Fe limited has not been resolved in Australia, and recent studies implicated N rather than P limitation in a variety of locations (Udy, 1997).

How beds develop under low-nutrient conditions is not well understood, as most seagrass/nutrient research has been carried out in areas of high nutrients.

Figure 1.4 Nutrient loading and the development of seagrass systems



Certain regions of the Australian coastline lack seagrass beds despite possessing apparently suitable conditions, e.g. reef flats in tropical areas such as the Great Barrier Reef and the Dampier Archipelago, and inter-reefal sections in the Great Barrier Reef. Light availability does not appear to restrict seagrass distributions in these areas. An untested hypothesis to explain these gaps is that the low nutrient loadings to such systems prevent seagrass development (Figure 1.4).

As system nutrient status changes, and seagrass biomass develops and increases, increased plant production has been suggested to result in increased flows to the higher trophic levels (Figure 1.4).

The transfer of organic matter from the plankton to the benthos through the suspension-feeding activities of sessile invertebrates represents another aspect of changes to nutrient dynamics facilitated by seagrasses. Seagrasses also directly influence nutrient fluxes through the uptake of nutrients, and through excretion and leakage of cell products. Plant epiphytes and microorganisms associated with the surfaces of seagrass leaves also contribute substantially to the uptake and release of nutrients in coastal waters. Release of oxygen from plant roots can also result in substantial changes to the sediment environment by introducing oxygen into sediments that would not normally receive oxygen from the sediment surface. Oxygen leakage varies greatly between seagrass species, with *Syringodium isoetifolium*, for example, releasing large quantities of oxygen from roots, while *Thalassia* has little effect on sediments (Abal *et al.*, 1994).

In contrast, where nutrient loadings have been increased due to, for example, human loadings, such as at Cockburn Sound, (Cambridge *et al.*, 1986;

Silberstein *et al.*, 1986), seagrasses have been lost. In such situations the system can shift to an alternate stable state that is dominated by other primary producers. These generally take the initial form of epiphytes, with large phytoplankton blooms developing at a later stage (Walker and McComb, 1992). Although such system scale changes have been well documented, the consequent effects on associated fisheries are not well known.

Enhanced nutrient inputs into coastal systems may stimulate secondary production, but the balance between this stimulation of production and other deleterious impacts of eutrophication is not well understood. For example, in Cockburn Sound, a loss of more than 84% of the seagrass beds, resulting from nutrient enrichment from sewage outfalls and industrial fertiliser production waste (Cambridge *et al.*, 1986), did not result in a catastrophic decline in fisheries. The system shifted from a benthic production base to pelagic (phytoplankton) based fisheries.

Other gaps in our knowledge in this area include the effects of water column *vs* sediment additions, and differences between pulsed inflows of nutrients *vs* chronic lower level loadings.

1.3.4 Mechanisms of seagrass decline

Seagrass declines have been well documented both around Australia and elsewhere in the world. A variety of mechanisms can cause seagrass loss; the most ubiquitous and pervasive cause of decline is the reduction of light availability (Walker and McComb, 1992). Seagrasses have high minimum light requirements for survival compared with other plants (Dennison *et al.*, 1993). This requirement for 10–30% incident light is thought to be related to the significant portions of seagrass biomass that can be located in anoxic sediments. Three major factors can cause a reduction in light availability (Walker and McComb, 1992):

- Chronic increases in dissolved nutrients leading to proliferation of light-absorbing algae, either phytoplankton, macroalgae or algal epiphytes on seagrass leaves and stems
- Chronic increases in suspended sediments leading to increased turbidity
- Pulsed increases in suspended sediments and/or phytoplankton that cause a dramatic reduction of light penetration for a limited time

The tolerance to light reduction varies between species. The relative ability of seagrasses to cope with chronic light reductions depends on their minimum light requirement for survival. In contrast, their persistence under prolonged light deprivation controls their relative ability to cope with pulsed light reductions. Minimum light requirements do not appear to be directly correlated with persistence under light deprivation. For example, *Halophila* spp. have low minimum light requirements, as indicated by their ability to colonise to greater water depths than other species at a variety of locations around the world. However, *Halophila* spp. have a limited ability to persist under light deprivation, with survival periods of less than one month, compared with other species which can persist for several months. The ability to persist under light deprivation is probably related to rhizome longevity, and the smaller seagrasses with faster rhizome turnover rates have less reserves and reduced capacity to withstand adverse conditions. The control of minimum light requirements is less obvious and depends on a variety of physiological and morphological adaptations to low light.

The consequences for secondary production under conditions of seagrass decline are not well understood.

1.4 Food webs

The presence of seagrasses affects food webs in Australian coastal waters in two ways:

- Seagrasses modify benthic habitats and so directly alter ecosystem structure
- Seagrasses produce organic matter and assimilate energy into ecosystems

The assimilation of energy occurs either directly, when grazers consume plant material, or indirectly, when detritivores or epiphytic algae utilise dissolved organic matter and nutrients leached from seagrasses.

Assimilation of seagrass matter into food webs occurs not only within the seagrass bed, but, because of drift of seagrass detritus, also within habitats that may be a considerable distance from the parent bed. Depending on wave and tidal action, and currents, seagrass debris can be deposited within the seagrass bed or exported to the swash zone and shores of beaches, to inshore basins or to the deep ocean floor. The extent of this effect of seagrass production on faunal production has not been well quantified.

Very few attempts have been made to quantify the transfer of seagrass production into coastal food webs (*sensu* Robertson, 1984), or to determine the importance of seagrass production relative to primary production generated by other major plant groups (phytoplankton, macroalgae, benthic microalgae, mangroves). In general, direct grazing of seagrass is thought to add relatively little in the way of energy or organic matter to coastal food webs in temperate regions (Klumpp *et al.*, 1989).

In the tropics, direct seagrass grazing by macroherbivores (green sea turtles and dugongs), can provide a major trophic pathway (Lanyon *et al.*, 1989). Macroherbivores consume large quantities of seagrass, generally a low quality food source. The excretion of waste products from these grazers could contribute to coastal foodwebs, a feature largely ignored (except see Thayer *et al.*, 1982). In a similar manner, fish and invertebrates with diel migrations exhibit a transfer mechanism by feeding in seagrass beds during the day and returning to the reef to defecate at night (Meyer *et al.*, 1983).

Dugongs have been found to substantially modify seagrass beds in Moreton Bay by repeated grazing in selected areas, termed ‘cultivation grazing’ (Preen, 1995b). Dugongs and turtles have strong feeding preferences and favour

Halophila and *Halodule* (Lanyon *et al.*, 1989). These species have the most rapid turnover and their new leaf tissue is more nutritious than older leaf material. The effects of grazing need to be tested using consistent methods from a wide variety of locations with different seagrass species. In many tropical locations phytoplankton, mangroves, epiphytes and detritus are all likely to contribute substantial energy input into the base of the food web (Alongi, 1990a, b; Robertson and Alongi, 1992; Robertson and Duke, 1987).

A considerable amount of empirical evidence indicates that direct grazing of seagrass is relatively unimportant in temperate Australian waters. The large number of dietary studies of fish and invertebrates in temperate seagrass beds consistently show an extremely low proportion of species that directly consume seagrass material (Klumpp *et al.*, 1989). The only temperate Australian fish known to ingest large quantities of seagrass are the garfish *Hyporhamphus melanochir* and the leatherjackets *Meuschenia freycineti, Monacanthus chinensis, Meuschenia trachylepis* and *Acanthaluteres spilomelanurus* (Bell *et al.*, 1978a, b, 1987; Robertson and Klumpp, 1983; Edgar and Shaw, 1995b), while the crab *Nectocarcinus integrifrons* is also a seagrass grazer (Klumpp and Nichols 1983; Edgar, 1996).

The presence of seagrass can greatly alter food webs even in the absence of large vertebrate grazers by providing substrata for epiphytic algae such as diatoms and filamentous algae or through the production of detritus. The importance of these seagrass-mediated shifts presumably depends largely on seagrass productivity and the level of primary production in the absence of seagrasses. Thus, the presence of seagrass will greatly increase invertebrate and fish production and alter food webs at exposed low-nutrient sites where primary productivity is low (Edgar and Shaw, 1995c), and in deep basins and the swash zone where seagrass debris accumulates (Lenanton *et al.*, 1982). In contrast, food webs in nutrient-rich estuaries with dense phytoplankton populations and considerable allochthonous inputs of organic matter may be little affected by the presence of seagrasses.

Crustaceans have been found to provide approximately half the total diet of fish in most community studies (Burchmore *et al.*, 1984; Edgar and Shaw 1995a, b). Epiphytic algae, particularly diatoms and other benthic microalgae, are generally inferred to be a major dietary component of crustaceans in seagrass beds (Kitting *et al.*, 1984; Orth and van Montfrans, 1984), hence seagrass food webs in areas lacking large vertebrate grazers appear to be fuelled primarily by epiphytic production. This situation contrasts with pelagic food webs, which are primarily fuelled by phytoplankton, and those occurring below the euphotic zone, which are primarily fuelled by detritus. No consensus exists about the most important primary producers in shallow unvegetated habitats, although seagrass and associated epiphyte detritus are probably both major contributors to food webs and locally enhance invertebrate and fish production, including at locations away from the seagrass beds where the production occurred.

The role of detritus in coastal food webs remains little studied, with virtually no investigations conducted in southeastern or southern Australia on the fate of seagrass or macroalgal debris. The importance of seagrass debris presumably lies primarily in chemical leachates being utilised by bacteria, fungi, microalgae and protozoa, and by the increasing proliferation of microbes on detrital particles as fragmentation occurs, rather than on the direct ingestion of seagrass material (Fenchel and Harrison, 1976; Fenchel, 1977). More protein has been found in surficial microbes than in the decaying seagrass debris with which they are associated (Zimmerman *et al.*, 1979).

Two approaches have been used to disentangle food web structure in the marine environment, with the most common approach the direct observation of dietary linkages through gut content analysis. Indirect analysis of food webs can also be made using dietary tracers that pass from producer to consumer through the food chain, including the use of lipids and other biochemical markers (Klumpp and van der Valk, 1984) and isotopes (Smith *at al.*, 1979). The most common and useful of the indirect procedures involves analysis of the ratio of stable isotopes in animal body tissues to identify the major plant types at the base of the food chain (Nichols *et al.*, 1986). Differences in photochemical pathways used by different plant groups result in consistent variation in the natural abundance of isotopes of major elements (most usefully C, N and S) incorporated into plant tissue (McCleland *et al.*, 1997). The isotopic ratios of elements are transferred conservatively to consumer species. Thus, seagrasses typically incorporate a greater proportion of carbon 13 (^{13}C) relative to ^{12}C into tissues compared to phytoplankton, and this ratio will be transferred to the tissues of seagrass grazers and their fish predators. Analysis of the ratios of ^{13}C, ^{15}N and ^{34}S to the predominant isotope in the tissue of a marine animal will generally provide a clear signal about the primary source of energy utilised by that animal. Unfortunately, such studies have not been conducted systematically in a range of marine habitats around Australia, so the overall contribution of seagrass, seagrass detritus and seagrass epiphytes, relative to other sources of organic matter, to coastal food webs remains unknown.

Seagrass beds can also affect ecosystems through the filtration capacity of filter-feeding invertebrates attached to seagrass leaves. Sponges, ascidians, hydroids and other filter-feeders remove particles from the water column, and then consolidate the particles and eventually deposit them on the seabed in the form of faeces, pseudofaeces and animal bodies. In Cockburn Sound and Marmion Lagoon (WA), the two areas in Australia where estimates have been made on total filtration capacity of seagrass-associated animals, invertebrates were estimated to filter the water column in some seagrass habitats over periods of less than one day (Lemmens *et al.*, 1996; Edgar, unpublished data). Whether these estimates are typical or anomalous remains to be assessed.

Perhaps the most widely cited function of seagrass beds is their role in providing shelter from large fish predators and in acting as nurseries for fish and decapods, including many species of commercial importance (Heck and Orth, 1980; Orth *et al.*, 1984). In contrast to most other aspects of seagrass ecology studied in more detail by Australian workers, this hypothesis has been largely generated and tested overseas, most notably in the United States (Heck and Thoman, 1984; Nelson and Bonsdorff, 1990; Nelson, 1997).

Available evidence supports the nursery bed hypothesis for the New South Wales coast, where luderick, bream and snapper associate as juveniles with seagrass habitat in estuaries (Gray, 1991a, b; Gray *et al.*, 1996). The meagre empirical data available, including a survey along 3,000 km of temperate coast by Edgar and Shaw (1995a, b, c), however, do not support the hypothesis for other sections of the Australian coast (Jenkins *et al.*, 1997), with the possible exception of juvenile prawns associating with seagrass beds in tropical Queensland (see e.g., Heales *et al.*, 1996; Vance *et al.*, 1996), and juvenile baldchin groper associating with coastal seagrass beds along the central Western Australian coast (Howard, 1989). Systematic surveys are urgently required to assess the validity of these hypotheses at a national scale. Surveys are also required to determine whether the primary response of juveniles of the important commercial species in New South Wales is to estuaries or to seagrass habitat within the estuaries.

1.5 Gaps in seagrass knowledge and recommendations to address them

Gap	*Recommended approaches*
Lack of comparative studies: temporal, spatial, component	Fund consortia across geographical scales to undertake comparative scales studies
Standardisation of techniques. Decisions needed for Australian conditions, building on available international methodological manuals	Workshop to define approaches and techniques; funding to undertake methodological studies to identify most useful gear for ecological surveys (fish, macroinvertebrates, plants)
Northern Australian turbid water seagrasses on remote inaccessible coastlines remain virtually unknown, especially Northern Territory	Encourage interaction between agencies and institutions (especially in the Northern Territory) to undertake systematic surveys aimed at filling gaps in our knowledge of biogeographical distributions. These surveys should be tied to other useful data gathering, ie. not mapping in isolation
Exposed/deep seagrasses How important are they as habitat?	Targeted funding to ascertain fisheries importance using standardised techniques at a range of locations. If found to be important, then better mapping at a finer resolution

Gap	*Recommended approaches*
Dispersal and recruitment characteristics of different seagrass species	Studies directed at better understanding of seagrass demography, as it affects recruitment
Clonal biology and genetic structure of seagrass beds: essential for conservation and for improvement of restoration attempts	There is an urgent need to investigate the clonal biology of tropical and temperate species, with emphasis on estimating genetic diversity within and between meadows
Fate and utilisation of detrital, planktonic, epiphytic, benthic microalgae production	Targeted funding at a diverse array of sites using standardised techniques to quantify food webs (gut content analysis, stable isotopes). Studies of seagrass decomposition processes involving microbial food chains
Implications of landscape scale studies i.e. edge vs middle	Studies of patch dynamics implications for fisheries
System scale nutrient loading effects	Literature and modelling exercises to design appropriate experimental techniques to test this hypothesis in a variety of systems
Consequences of eutrophication on seagrass-associated faunal communities	Field surveys using standardised methods (seines or beam trawls and gill nets) to identify consistent relationships between nutrient loadings, epiphyte production and fish density over regional scales

1.6 Acknowledgements

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CHAPTER TWO

Seagrass dynamics and fisheries sustainability

R. Connolly, G. Jenkins, N. Loneragan

2.1 Introduction

2.1.1 Background

Seagrass meadows are renowned worldwide as rich and productive nursery areas for juveniles of economically important fish and crustacean species. Australian scientists have rightly been leaders in research into seagrass as habitat for fisheries species. Australia has a large area of seagrass in all states, and a large number of species (see Chapter 1). With a relatively narrow shelf around most of Australia's coastline, and an absence of major upwelling currents, much of the value of Australian fisheries comes from species harvested in shallow coastal waters. This chapter examines the evidence for links between seagrass and fisheries resources. It especially focuses on the reliability of that evidence, and in particular on:

- the importance of seagrass meadows in fisheries production
- the influence of seagrass status (extent of cover, type, or density) on fisheries sustainability

The aim is to review links between seagrass dynamics and fisheries production to provide clear guidelines for future research directions. The review provides a detailed examination of Australian work, but includes studies from elsewhere where the information helps to highlight what research is needed in Australia.

2.1.2 Approach taken

Information about links between seagrass and fisheries production was gathered from primary literature and by discussing recent work and work in progress with fisheries scientists from around Australia. This capitalised on a previous, more general review of fisheries habitat (Cappo *et al.*, 1998) by focusing solely on seagrass studies except where lessons from other habitats were considered relevant. Results and ideas from all papers and researchers were summarised by geographic location and fishery type. Information relating directly to situations where changes in seagrass status can be linked with fisheries data are shown in Table 2.1. Where relevant, information from outside Australia was also included. This chapter provides a synthesis of that work. Sections 2 and 3 describe what is known (or suspected) about links between fisheries and seagrass dynamics. Section 2 focusses on comparisons between seagrasses and other habitats such as bare sand, mangroves and algae, while Section 3 concentrates on comparisons beween seagrasses of different types. Section 4 lists gaps in our understanding and future research needs. Throughout this chapter, we pursue a clear rationale for future research, and end by summarising our recommendations for future research in Section 5.

Processes linking seagrass with invertebrate production are described in Chapter 1. Literature on fisheries resources and the functionality of restored seagrass meadows is covered in Chapter 3.

The fish and crustacean species discussed in this chapter form the basis of commercial, recreational and indigenous fisheries. Examples of species mainly taken commercially are — most penaeid prawn species; recreationally — whiting, yellowfin bream, flathead (although these species are also taken commercially); indigenous (dugongs, green turtles). Dugongs and green turtles are harvested in small numbers only, and are mentioned here because of their known dependency on seagrasses for food.

2.2 Importance of seagrass beds in fisheries production

2.2.1 Comparison of seagrass with other estuarine/nearshore habitats

Assemblages of fish

Seagrass/unvegetated habitat

A paradigm in seagrass research is that, with few exceptions, diversity and abundance of fishes in seagrass is higher than in unvegetated habitats (Bell and Pollard, 1989). Research in southeastern Australia shows that while this generalisation appears to be true for fish diversity, the results for abundance (or biomass/

production) are equivocal. Diversity of fish in *Zostera* in NSW was higher than over adjacent (<10m) and distant (>100m) unvegetated sand; number of individuals in *Zostera* was also higher than on distant sand, but was similar to adjacent sand (Ferrell and Bell, 1991). Fish diversity in Corner Inlet and Port Phillip Bay seagrass beds was higher than adjacent unvegetated habitats, but abundance and biomass was only higher in subtidal *Heterozostera*. Intertidal *Zostera* had similar abundance and biomass of fish to adjacent unvegetated habitat (Jenkins *et al.*, 1997b). Edgar and Shaw (1995b) found that fish diversity and production was higher in seagrass compared with unvegetated habitat in Westernport, however, when a number of sites across southern Australia were sampled, the production of small (< 1g wet weight) fish did not differ between the two habitats (Edgar and Shaw, 1995c).

In South Australia, three comparisons of fish assemblages from seagrass and unvegetated habitat have been made. In Barker Inlet, a marine-dominated estuary almost surrounded by the city of Adelaide, the study included only intertidal areas, and showed a markedly higher richness and abundance in seagrass (*Zostera muelleri*) than unvegetated patches, over all seasons (Connolly, 1994a). The unvegetated patches were from 5 to 20 metres distance from seagrass. Sampling in Spencer Gulf also showed a higher fish diversity and abundance in seagrass (shallow *Posidonia*/*Amphibolis*/*Zostera*) than unvegetated areas (Seddon, 1997). In contrast, a comparison of *Posidonia*, *Heterozostera* and unvegetated habitats at six sites on the Yorke Peninsula (unvegetated patches up to 30m from seagrass) showed higher species richness in *Posidonia* compared to unvegetated substrates. However, there was no consistent pattern in the total numbers of fish amongst any of the habitats (Jenkins *et al.*, 1996).

A greater diversity and abundance of small fish were found in *Zostera capricorni* patches than over bare sand (with bare sites ranging up to 200 metres from seagrass) in the Clarence River estuary (West and King, 1996) and eight estuaries in northern NSW (Gray *et al.*, 1996). In Western Australia, the total numbers and density of fish caught in *Ruppia* beds varied between dense and patchy beds and bare substratum (Humphries *et al.*, 1992b). The diversity of the fish fauna was lowest, but the total numbers were highest, in dense *Ruppia*.

The physical environment of estuaries is a major controlling factor for both the habitats found within them and the fish and decapods that can colonise these habitats. In southwestern, eastern and tropical Australia, marine species dominate the fish fauna of lower estuaries. They become less dominant with increasing distance away from the estuary mouth, where species capable of completing their life-cycle within the estuary become more important (e.g. Loneragan *et al.*, 1986; 1989; Bell *et al.*, 1988; Blaber *et al.*, 1989; Loneragan and Potter 1990). The distribution of seagrasses is also limited in these systems. For example, in the Swan Estuary, seagrass does not extend beyond the middle reaches of the estuary. In making comparisons between the seagrass fish and decapod fauna in estuaries, it is therefore important to take into account where the sampling was carried out.

Seagrass/algal habitat

Comparisons of seagrass with habitats other than unvegetated sand/mud are less common. In nearshore waters of Port Phillip Bay, fish diversity was highest in seagrass, intermediate in reef with algae, and lowest on unvegetated sand (Jenkins and Wheatley, 1998). Abundance of fishes was typically higher in seagrass than in unvegetated sand, but not significantly different between seagrass and reef/algae (Jenkins and Wheatley, 1998). While the species composition of fish assemblages in seagrass is typically quite different to unvegetated sand (Bell and Pollard, 1989; Ferrell and Bell, 1991; Jenkins and Wheatley, 1998), a number of species previously thought to be strongly associated with seagrass were also common on reef/algae (Jenkins and Wheatley, 1998). Sampling on the Yorke Peninsula, South Australia, showed that fish diversity was higher in seagrass (*Posidonia*, *Heterozostera*, *Zostera*) than in intertidal algae (*Hormosira*), but abundances showed no consistent differences between habitats (Jenkins *et al.*, 1996). A similar result was found for shallow seagrass (*Posidonia*), reef/algae and unvegetated sand in Jervis Bay, with highest diversity in seagrass, intermediate in reef/algae, and lowest in sand; no clear patterns emerged for comparison of abundance amongst habitats (Jenkins *et al.*, 1996).

Both seagrass and algae (*Caulerpa* spp.) provide settlement and nursery habitat for the postlarvae and juveniles of grooved tiger prawns (*Penaeus semisulcatus*) in northern Australia (Haywood *et al.*, 1995). However, the algal beds provide habitat in only the pre-wet season. During the summer wet season, the algal leaves in upstream algal beds disappear with the onset of summer rainfall and the decline in salinities.

Seagrass/mangroves

Comparisons amongst habitats in subtropical waters more often include mangroves, which usually form a forest higher in the intertidal zone, separated from seagrass beds by unvegetated mudflats. Comparisons either within a single study (Laegdsgaard and Johnson, 1995 in Moreton Bay; Small, 1997 in Gladstone Harbour) or over several studies done in adjacent waters (e.g. Blaber and Blaber, 1980; Morton, 1990 in Moreton Bay; Halliday and Young, 1996 and Ian Halliday, QDPI and Rod Connolly, Griffith University, unpublished data, in Tin Can Bay) sometimes show a higher species richness in mangroves and always show a higher proportion of economically important species in mangroves than in seagrass. Laegdsgaard and Johnson (1995) concluded that mangroves form a more important habitat as nursery for economically important fish than seagrass (with unvegetated mudflat intermediate in status). However, it is important to note that all the above comparisons between the fish faunas of mangroves and seagrass are confounded because of: differences in sampling techniques and mesh size and/or differences in water depths. Sampling is often undertaken at slack high tide, at which time even intertidal seagrass is invariably covered by considerably deeper water than mangroves.

Tropical studies

Less is known of the use of seagrass by fish in tropical waters than other regions of Australia. Studies have sampled fish in seagrass (e.g. Coles *et al.*, 1990, 1993) and focused on the predation of prawns by fish (e.g. Salini *et al.*, 1990, Haywood *et al.*, 1998). Relatively few studies have compared the fish fauna in seagrass with different habitats and those that have (Robertson and Duke, 1987; Blaber *et al.*, 1989) have suffered from the problems of confounding outlined above. Whilst no generalisations can be made, one study of fish in different habitats of Groote Eylandt found that in water deeper than 2 m, diversity was higher in the tall, dense seagrass than on bare substrate (Blaber *et al.*, 1992). In addition, most species were more abundant on the tall, dense seagrass than the bare habitat.

Economically important species

Fish

In southeastern Australia, the association of commercially and recreationally important species with seagrass relative to other estuarine/nearshore habitats varies with locality. In Victorian embayments and estuaries, economically important species thought to be linked to seagrass at some stage in their life-cycle include: King George whiting, *Sillaginodes punctata*, rock flathead, *Platycephalus laevigatus*, black bream, *Acanthopagrus butcheri*, blue rock whiting, *Haletta semifasciata*, garfish, *Hyporhamphus melanochir* and six-spine leatherjacket, *Meuschenia freycineti*. Other species which may have links but about which little is known include squid (*Sepioteuthis australis*) and school (*Galeorhinus galeus*) and gummy sharks (*Mustelus antarcticus*).

Two of these species, six-spine leatherjacket and blue rock whiting, are associated with seagrass from settlement to adulthood (Edgar and Shaw, 1995b; Jenkins *et al.*, 1997b). In southwestern Australia, adult blue rock whiting are found in offshore beds of seagrass (*Posidonia sinuosa*) (MacArthur, 1997). It should be noted that juvenile and adult six-spine leatherjackets are also found on reef-algal habitats (Jenkins *et al.*, 1996; Jenkins and Wheatley, 1998). Rock flathead are strongly associated with seagrass as older juveniles and adults, but young juveniles are mainly found on unvegetated habitat (Jenkins *et al.*, 1993a; Edgar and Shaw 1995b; Jenkins *et al.*, 1997b). Juvenile black bream are collected over seagrass in Gippsland lakes (Ramm, 1986) although they can also be collected over other habitats (S. Walker, MAFRI, unpublished data). In the estuaries of southwestern Australia, black bream are found in the middle and upper reaches where seagrasses are either sparse or absent (Holt, 1978; Kanandjembo, 1998).

Adult garfish appear to have a dietary link with seagrass, as evidenced by gut contents and stable isotope analysis (Klumpp and Nichols, 1983a; Robertson and Klumpp, 1983; Edgar and Shaw, 1995a). Gummy and school sharks are thought to pup in bays and inlets of Victoria. Habitat usage by juveniles in bays and inlets is unclear. Edgar and Shaw (1995b) found juvenile gummy sharks widely distributed amongst seagrass, and unvegetated and channel habitats in Western Port. Juvenile gummy sharks had a high proportion of seagrass associated crabs (*Nectocarcinus*) in the diet, while the small number of juvenile school shark collected in the study mainly ate pelagic fish (Edgar and Shaw, 1995a; pers. comm.)

King George whiting have a complex association with seagrass habitat. In Victoria, most sampling has shown that young juvenile King George whiting have a strong preference for seagrass or reef-algal habitat immediately after settlement, but show a shift in habitat to unvegetated sand three to four months after settlement (Robertson, 1977; Jenkins and Wheatley, 1998). However, in one location, Swan Bay, juveniles are associated with unvegetated sediment patches from the time of settlement (Jenkins *et al.*, 1997b). Change to unvegetated habitat in older juveniles is associated with a dietary shift from epifaunal harpacticoid copepods and amphipods to infaunal decapods and polychaetes (Robertson, 1977). Within Barker Inlet in South Australia, more juveniles at all stages from 20 to 100 mm in length were found over seagrass than unvegetated habitat (Connolly, 1994a). Sampling by Jackson and Jones (SARDI, unpublished data), in the same estuary detected reasonable numbers of juveniles at some inner-estuary locations devoid of seagrass. These locations support dense beds of loose macroalgae (*Ulva australis*) at times, and whiting may have been associated with this vegetation. Small whiting can commonly be seen feeding very close to *Ulva* plants in this estuary (Rod Connolly, Griffith University, unpublished data).

In southwestern Australia, on the other hand, King George whiting settle in nearshore sand regions, not in adjacent seagrass (Hyndes *et al.*, 1996, 1998). One of the reasons for this difference between regions may be that in southwestern Australia, the adjacent seagrass is *Posidonia*, not *Heterozostera*. The dense structure of the *Posidonia* canopy may inhibit settlement and the movement of juveniles. An alternative hypothesis is that King George whiting settle into very sheltered regions, whether or not these regions contain vegetation. This is supported by the higher densities in very sheltered than in exposed areas in southwestern Australia (Hyndes *et al.*, 1996, 1998).

A number of species of commercial fish in Victoria have juveniles associated with unvegetated sand habitats. Examples are greenback flounder, *Rhombosolea tapirina*, and long-snout flounder, *Ammotretis rostratus* (Jenkins *et al.*, 1997b). Juveniles of some commercial species, such as yellow-eye mullet, *Aldrichetta forsteri*, and Australian salmon, *Arripis* spp., can be found on a range of habitats from sheltered seagrass to moderately exposed sandy beaches (Robertson, 1978; Jessop, 1988; Jenkins *et al.*, 1996; Jenkins *et al.*, 1997b). The major habitat requirement of these juveniles seems to relate to water depth; they prefer to be near the water's edge moving in and out with the tide, irrespective of substrate type.

In southern NSW, juveniles of four commercial species: sand whiting, *Sillago ciliata*, bream, *Acanthopagrus australis*, tarwhine, *Rhabdosargus sarba*, and sprat, *Hyperlophus translucidus*, were predominantly collected on sand adjacent to seagrass (<10m) (Ferrell and Bell, 1991). This also applies to all species of whiting in Western Australia (Hyndes *et al.*, 1996, 1998, Rod Lenanton, Fisheries WA, pers. comm.). In NSW, one commercial species, luderick, *Girella tricuspidata*, was predominantly collected in seagrass (*Zostera*), while no commercial species was predominant on sand distant (>100m) from seagrass (Ferrell and Bell, 1991). Previous studies had suggested that *Zostera* was an important nursery area for luderick, tarwhine and bream (Middleton *et al.*, 1984). However, only luderick showed a strong affinity to seagrass in the study by Ferrell and Bell (1991); the other species apparently utilise a habitat mosaic of seagrass and nearby sand.

In Tasmania, a recent study compared utilisation of seagrass and unvegetated habitat by commercial species (Alan Jordan, DPI Fisheries, Tasmania, unpublished data). Only older juveniles and adults of sand flathead, *Platycephalus bassensis*, were found in significant abundances in seagrass, although they were also common on sand. Conversely, juveniles of four commercial species: yellow-eye mullet, *Aldrichetta forsteri*, Australian salmon, *Arripis trutta*, greenback flounder, *Rhombosolea tapirina* and long-snout flounder, *Ammotretis rostratus*; were found mainly over bare sand. Relatively few commercial species are found in seagrass beds of southwestern Australia (Glenn Hyndes, Murdoch University, pers. comm.). The paucity of economically important species found in the seagrass beds of Tasmania and southwestern Australia contrasts with higher numbers of such species on seagrass beds in NSW, Victoria and South Australia.

Sampling at two sites within Moreton Bay, Laegdsgaard and Johnson (1995) found that a higher number of economically important species were caught as juveniles in mangrove forest than adjacent seagrass beds (*Zostera*), and that those juveniles were also smaller. They concluded that early recruits predominantly utilise mangroves, slightly older juveniles are found over bare mudflats, while juveniles found in seagrass are older still. Notwithstanding the possibility of a confounding influence of different sampling techniques among habitats, this scenario provides an interesting parallel with the idea that *Zostera* meadows harbour smaller juveniles than adjacent *Posidonia* meadows (Middleton *et al.*, 1984) [see description in Section 2.3.1]. Both patterns can possibly be explained by smaller juveniles being in great abundance in shallower water (mangroves compared to *Zostera*, at high tide; *Zostera* compared to *Posidonia*). Much lower densities of fish (4 to 10 times lower) were found in seagrass than in mangrove lined creeks in the Townsville region (Robertson and Duke, 1987; Robertson and Blaber, 1992). In these cases, the habitat comparisons were confounded with distance from the ocean; the seagrass beds were located at the mouths of creeks and the mangroves were further upstream.

The comparisons of mangroves and seagrass habitats by Laegdsgaard and Johnson (1995) are likely to have overestimated the importance of mangroves given that sampling was only done at high tide. Mangroves are only inundated on the high tide, and cannot be used by most fish species, including all economically important species, at other times of the tidal cycle (more than half the time). Some smaller species, notably gobies, can remain in the mangroves between tides. To properly determine the relative importance to juvenile fish of different habitats in close proximity, we need work which combines sampling at different stages of the tidal cycle, in the same area, over the same period.

Small (1997) compared the same habitats as Laegdsgaard and Johnson (1995) in Gladstone Harbour in one of the few recent subtropical studies aiming to collect data on habitat use by adult and sub-adult fish. In this case, fish sampling techniques were quantitative in seagrass and mudflats but not in mangroves, so quantitative comparisons could not be made between the three habitats. Only the proportion of breeding individuals of economically important species could be compared, and this was found to be considerably higher in mangroves. Thus, mangroves may be a more important site for spawning or recruitment than mudflats or seagrass. However, the data are far too scant to make any firm conclusions.

Decapods

The distribution of early juveniles (postlarvae) of commercially important prawns in Moreton Bay has been thoroughly surveyed (Young and Carpenter, 1977; Young, 1978). The four main species examined (Brown tiger prawns *Penaeus esculentus*, Eastern King prawns *P. plebejus*, Greasyback prawns *Metapenaeus bennettae* and School prawns *M. macleayi*), were all more common in seagrass than in adjacent unvegetated sites. The pattern was equivocal for *P. plebejus*, which was more common at unvegetated sites in some locations. Three species of prawns (*P. esculentus*, *P. semisulcatus* and *M. endeavouri*) were more abundant on seagrass than adjacent bare substrate in the Cairns harbour (Coles *et al.*, 1993). While there is an association between seagrass and juveniles for these species, an even more striking result in Moreton Bay was the lack of prawns in water deeper than about 2m, whether vegetated or not. There was also a strong pattern of differing abundances at different positions within the bay.

Megalopae of blue swimmer crab (*Portunus pelagicus*) settled in shallow, intertidal seagrass in Moreton Bay (Greg Skilleter, University of Queensland, unpublished data). This was also the case for juvenile blue crabs *Callinectes sapidus* in North America which were found in much higher densities on seagrass and in saltmarsh until the 3rd to 5th juvenile instar (Pile *et al.*, 1996). Experiments with seagrass and artificial seagrass in the laboratory, and with seagrass in the field have shown that the postlarvae and juveniles of tiger prawns prefer seagrass to bare sand (Kenyon *et al.*, 1995; 1997; Liu and Loneragan, 1997). In fact, tiger prawn postlarvae were found in bare trays covered with monofilament mesh to exclude predators, which suggests that they respond strongly to structure when settling, not necessarily to seagrass *per se*. Small juvenile blue swimmer crabs were found in much higher numbers on artificial seagrass units than bare units (i.e. controls, Loneragan *et al.*, 1996, Kenyon *et al.*, in press).

Some of the most complete evidence for the use of seagrass by juvenile stages comes from studies of tiger prawns (*Penaeus esculentus*, *P. semisulcatus*) in northern Australia. These species contribute to major fisheries along the east coast of Queensland, the Torres Strait, across northern Australia and in Exmouth Gulf and Shark Bay of Western Australia (Table 2.1). They are found on intertidal and shallow subtidal (< 2.5m deep) beds of seagrass (Coles and Lee Long, 1985; Staples *et al.*, 1985; Turnbull and Mellors, 1990; Coles *et al.*, 1993; Loneragan *et al.*, 1994; 1998) and algae (Haywood *et al.*, 1995). In the Torres Strait, the main nursery grounds for tiger prawns are seagrass on the reef tops of the Warrior Reefs (Turnbull and Mellors, 1990). Endeavour prawns are also important commercial species in the same regions as tiger prawns. While the juveniles of blue endeavour prawns *Metapenaeus endeavouri* are found on similar habitats to tiger prawns (Staples *et al.*, 1985; Coles *et al.*, 1993), those of the red endeavour *M. ensis* are more widely distributed and are found on seagrass, algae and mangrove-lined mudbanks (Staples *et al.*, 1985). In contrast to tiger and endeavour prawns, western king prawns *Penaeus latisulcatus* are found in greater numbers on sandy substrates (Potter *et al.*, 1991).

The fishery for western rock lobster *Panulirus cygnus* is the most valuable single species fishery in Australia. The newly settled or post-puerulus stages are usually found in small cracks and crevices within limestone substrate (reefs and pavement). In all cases, the only potential shelters that are occupied are covered by seagrass and/or algae (Jernakoff, 1990). As the juveniles become older and larger they move to the caves and ledges of limestone reefs and continue to forage amongst seagrass (Jernakoff, 1987). Near Geraldton, the densities of a key prey species were higher in *Halophila* than *Amphibolis* or turf algae (Edgar, 1990).

2.2.2 Knowledge of *in situ* seagrass fisheries

The commercial species most commonly targeted in seagrass habitats of Victoria are King George whiting and rock flathead, with incidental catches of blue rock whiting and leatherjackets. Other species targeted in areas with seagrass, but not specifically over seagrass habitat, include black bream, flounder, garfish, yellow-eye mullet and Australian salmon.

One way to 'test' for links between seagrass and fisheries is to examine the fate of fisheries where seagrass has been lost. The loss of 75% of the seagrass in Western Port, Victoria, over a 15 year period led to major changes in the characteristics of associated fisheries (MacDonald, 1992) (Table 2.1). A parallel decline occurred in catches of King George whiting, rock flathead, blue rock whiting and leatherjackets, while other species such as yellow-eye mullet, Australian salmon and southern sea garfish either showed no change or increased (MacDonald, 1992). It seems unlikely that these changes were a result of fishing pressure because some of the species that declined were only caught incidentally and were of low commercial value (blue rock whiting and leatherjackets), and catches of King George whiting returned to historically high levels in nearby Port Phillip Bay where fishing pressure was higher, but not in Westernport (MacDonald, 1992). It is important to note that the species which declined have the strongest association with seagrass in terms of habitat use and diet, while species that did not change, or increased, had only an incidental association (Jenkins *et al.*, 1993a; Edgar and Shaw 1995b; Jenkins *et al.*, 1997b). Catches of rock flathead have also declined markedly after seagrass loss in Port Phillip Bay and Corner Inlet (Table 2.1).

Large changes in the extent of seagrass and associated estuarine fisheries have also been recorded in the Peel-Harvey estuary of southwestern Australia. Seagrasses in this system were greatly reduced in the 1970s because of massive increases in the biomass of macroalgae (*Cladophora* and *Chaetomorpha*) caused by increased phosphorus in the system (McComb and Lukatelich, 1995). Following the loss of seagrass and an increase in macroalgae, the commercial catches of sea mullet *Mugil cephalus*, yellow-eye mullet *Aldrichetta forsteri* and cobbler *Cnidoglanis macrocephalus* increased by about 100%. Catches in the Swan estuary, where a similar fishery operates and no such increase in macroalgae was recorded, did not increase to the same extent (Lenanton *et al.*, 1984; Steckis *et al.*, 1995). Catches in the Peel-Harvey estuary of western king prawns *Penaeus latisulcatus*, a species whose juveniles use sandy substrates, declined over the same period. In the 1980s, increases in phosphorus led to blooms of cyanobacteria in the spring and summer (McComb and Lukatelich, 1995) and this led to the construction of a new entrance channel in the system. It will be interesting to note whether seagrasses have recolonised and whether the fish and decapod fauna has changed markedly again. Current research at Murdoch University is investigating changes in the fish fauna of the Peel-Harvey estuary associated with the new channel (Glen Young, PhD student at Murdoch University).

A similar comparison between vegetation loss and fishery catch has been made for the Gippsland Lakes, Victoria. From about 1920 to 1960 large seagrass losses apparently occurred from Lakes Victoria and King. Catch data over 100 years shows an extended gap in the catch histories of black bream and luderick for the same period (Table 2.1). Commercial fishing for these species occurs in a number of habitats other than seagrass, however both species are thought to have a strong association with seagrass in the juvenile stage, although the data is more convincing for luderick than it is for black bream (Ramm 1986; Ferrell and Bell 1991; Jenkins *et al.*, 1997b).

A large-scale die-off of seagrass (*Amphibolis antarctica*) at the lower margin of the intertidal shelf in Spencer Gulf in South Australia provided an opportunity to examine differences between assemblages of small fish from healthy seagrass, die-off zones and habitat unvegetated prior to die-off (Seddon, 1997). No data had been collected prior to or during the die-off event in March 1993, but a rigorous sampling program over 12 months, beginning two years after die-off, showed that fish assemblages differed markedly among the three habitat types. Die-off patches had low diversity (similar to bare sand) but fairly high abundance (although not as high as seagrass). Certain species, including the commercially important blue-swimmer crab (*Portunus pelagicus*), were most abundant in die-off areas. It seems that die-off areas will eventually either remain unvegetated with a nekton fauna like that of bare sand, or be recolonised by seagrass (albeit a different species at this stage, namely *Zostera*) and a seagrass fauna will return (Seddon, 1997; University of Adelaide unpublished data).

In northern Australia, two major events have resulted in the loss of seagrass: cyclone 'Sandy' in the Gulf of Carpentaria in March 1984, and major runoff from Papua New Guinea into the Torres Strait in 1992/93 (Table 2.1). Following Cyclone Sandy, 20% of the seagrasses in the Gulf of Carpentaria were lost (Poiner *et al.*, 1989). This led to a marked change in the composition of the juvenile prawn communities in shallow water seagrasses, with tiger prawns being replaced by western king prawns (*Penaeus latisulcatus*) and non-commercial metapenaeid prawns (Poiner *et al.*, 1993). Commercial catches in the southern Gulf of Carpentaria declined, but only by 2 to 5% (Poiner *et al.*, 1993). The seagrasses took about 12 years to return to their original extent and juvenile prawn communities have also returned to their original composition.

Seagrasses affected by the major runoff from Papua New Guinea in 1992/93 were in deeper water and the effect on tiger prawns has not been investigated in detail. However, the loss of seagrasses probably had an effect on painted crayfish (*Panulirus ornatus*) in the region (Pitcher *et al.*, 1994; Darrin Dennis, CSIRO Marine Research, pers. comm.), as no juvenile crayfish were found in the area where seagrass was lost. It is thought that, prior to loss, seagrasses stabilised the sediments around the juvenile crayfish burrows. After the seagrass was lost, sediment filled the burrows, and juvenile crayfish were not able to colonise the area. Once the seagrass recolonised, juvenile crayfish were again found in burrows in the region.

There are very good descriptions of a massive die-off of seagrasses (over 24% of the area of all known seagrass beds in Queensland) in Hervey Bay (Preen *et al.*, 1995) and Great Sandy Strait (Thorogood and Horrocks, 1994). Although this event reportedly led to mass reductions in dugong numbers in Hervey Bay (and an increase in dugong numbers in Moreton Bay, presumably animals that migrated south), we can find no attempt to link the die-off with changes in fisheries catch data. During the same event, die-off of an entire bed of *Zostera capricorni* in Tin Can Bay in 1991 had a strong effect on juvenile fish and prawns, when compared to the same site prior to die-off and with another site within the bay where seagrass did not die-off (Ian Halliday, QDPI and Rod Connolly, Griffith University, unpublished data). Abundances and biomass of trumpeter whiting (*Sillago maculata*), silverbiddies (*Gerres oyeana*) and eastern king prawns (*Penaeus plebejus*) increased significantly after seagrass loss. No commercial species declined significantly in abundance or biomass, although several cryptic non-commercial species did (e.g. hairy pipefish, *Urocampus carinirostris*). Only juvenile fish and prawns were sampled, so we can only infer what effects loss of seagrass might have had on stocks of adult fish. Longer term effects of seagrass loss were not measured; these could be much more detrimental to densities of important fish and crustacean species.

Seagrasses have also been lost from the western side of highly populated Moreton Bay in southeastern Queensland since 1987 (O'Donohue and Dennison, 1997). Unlike the seagrass loss from the Gulf of Carpentaria and Torres Strait, no recovery has been recorded. Changes in the commercial fishery have not been investigated in Moreton Bay.

Overseas, the clearest link between seagrass loss and fisheries decline in the United States was the collapse of the bay scallop, *Argopecten irradians*, fishery in North Carolina and Chesapeake Bay (Virginia, Maryland, Delaware), following the eelgrass wasting disease of 1931-32 when more than 90% of the eelgrass was lost. As eelgrass recovered in North Carolina, the scallops returned but, in Chesapeake Bay, scallops have not returned even though some seagrass regrowth has occurred (Peter Sheridan, US National Marine Fisheries Service, pers. comm.). In a recent study, the pink shrimp, *Penaeus duorarum*, fishery in southern Florida underwent a severe (50%) decline in the late 1980s/early 1990s, at the same time as a 20% loss of seagrass, *Thalassia*, the purported main nursery. However, pink shrimp stocks have since recovered in spite of continued disruption to the seagrass ecosystem (Peter Sheridan, US National Marine Fisheries Service, pers. comm.).

Penaeid shrimp, crab and finfish fisheries in the Seto Inland Sea in Japan declined rapidly during the 1960s at the same time that *Zostera marina* beds were massively reduced by pollution (Kikuchi, 1974). While fisheries information is simple catch data rather than CPUE, the association is impressive. Kikuchi (1974) points out, however, that the pollution that killed the seagrass (increased turbidity, dinoflagellate blooms) might also have had a direct adverse effect on fisheries.

In Barker Inlet, South Australia, an experimental approach was taken to examining the effect of seagrass loss. Patches of *Zostera muelleri* (30m^2) were cleared of above-ground vegetation (Connolly, 1994b) to test the explanation by Bell and Westoby (1986a) that higher fish abundances for some species are the result of those fish actively selecting seagrass rather than unvegetated habitat. Fish abundances were only slightly reduced by the removal of seagrass, and were significantly higher than in habitat unvegetated prior to the experiment. Abundances of key species such as King George whiting were not reduced at all. The experiment had the benefits of being properly replicated (at least along the 1 km stretch of coast under study), with interspersion and randomisation of different treatments. The limitations were the relatively small scale of seagrass 'loss', and the short-term nature of the experiment. Fish were sampled two weeks after seagrass removal, the longest time possible before *Zostera* began to regrow. We note also that Barker Inlet is an exceptionally productive and sheltered region, and results would not necessarily be the same if this experiment was repeated in more exposed seagrass beds. At the time of sampling, invertebrate prey were just as common in plots from which seagrass had been removed as they were in healthy seagrass plots (Connolly, 1995).

A possible explanation for the lack of effect on fish abundances of seagrass removal is that fish abundances are determined by prey availability. For example, one or two months after settlement, King George whiting show a correlation between abundance on a seagrass bed and fullness of the gut, suggesting an important influence of food availability (Jenkins *et al.*, 1996). Research on the role of food availability in determining habitat preference of King George whiting is continuing in Port Phillip Bay (Greg Jenkins, MAFRI, unpublished data).

Another approach for examining the importance of seagrass to fisheries production is to correlate fisheries catch with seagrass cover. In South Australia, seagrass cover within 'fishing sectors' has been shown to be positively correlated with garfish catch within the sector (Karen Edyvane, Lynne Scott, Keith Jones, SARDI, unpublished). The work is at an early stage but shows promise in highlighting links between fisheries species and seagrass.

2.2.3 Links between seagrass and fisheries elsewhere

Juveniles moving from seagrass to other habitats

In NSW, commercial species of fish that occur as juveniles in seagrass before moving to other habitats fall into two categories (Bell and Worthington, 1992):

1. Species whose adults are common in both estuaries, including seagrass beds, and offshore habitats (e.g. yellow-fin bream, *Acanthopagrus australis*, and luderick, *Girella tricuspidata*)
2. Species whose adults are found only in habitats other than seagrass, usually offshore reefs (e.g. eastern blue groper wrasse *Achoerodus viridus*, tarwhine, *Rhabdosargus sarba*, and leatherjackets, *Meuschenia* spp.) (Gillanders and Kingsford 1992; Bell and Worthington 1992).

Species which spend only the juvenile stage in seagrass may be less likely to show correlations between catch and seagrass loss. For example, in NSW, species such as bream and tarwhine spawn offshore from estuaries (or just outside estuaries) and therefore the loss of seagrass from an individual estuary may not have a large impact on the population as a whole. Loss of seagrass across a number of estuaries would, however, be likely to have an impact. The extent to which larvae from coastal spawning are spread amongst estuaries is relatively unknown and deserves further investigation. For many of these species the assumption has been made that most of the adult population is derived from juveniles in seagrass. It has been assumed that coastal populations of blue groper, *Achoerodus viridus*, are derived from juveniles that settled in estuarine habitats including seagrass (Bell and Worthington, 1992). However, work using otolith microchemistry suggests that a significant proportion of the adult population may be derived from juveniles that recruited directly to coastal reefs (Gillanders and Kingsford, 1992).

Results from stable isotope studies have shown that juvenile prawns found on seagrass in the Embley River estuary assimilate carbon that is derived either directly from seagrass or from seagrass epiphytes (Loneragan *et al.*, 1997). Research is currently underway using enriched isotopes to investigate whether seagrass or their epiphytes are the source of carbon assimilated by prawns (Michelle Winning *et al.*, Griffith University, unpublished data). Other studies have dismissed seagrass as a direct source of food for brown shrimp, *Penaeus aztecus* (Kitting *et al.*, 1984). However, brown tiger prawns, *P. esculentus* consume seagrass seeds in large quantities when they are available (Wassenberg, 1990). Seagrass carbon and nutrients could, therefore, contribute directly to the nutrition of juvenile prawns.

Seagrass production sustaining fisheries elsewhere

It may be misleading to consider that only species physically living in seagrass beds derive benefit from them. Juvenile greenback flounder in Port Phillip Bay, Victoria, for example, are found only in unvegetated habitats. Research has shown, however, that unvegetated areas near seagrass are enriched with detritus that results in increased production of the small crustaceans that are the food of juvenile flounder (Shaw and Jenkins, 1992). The detritus was thought to be mainly of seagrass origin as seagrass was the dominant macrophyte in the area. More juvenile flounder were found on unvegetated areas enriched by seagrass detritus, and these flounder had higher feeding and growth rates compared with flounder in other areas (Jenkins *et al.*, 1993b). Seagrass detritus may also contribute significantly to the food web of recently settled and juvenile King George whiting in the sandy habitats (adjacent to the seagrass *Posidonia*) they colonise in southwestern Australia (Glenn Hyndes, Murdoch University, pers. comm.)

Most fish species in Western Port, including a number of commercial species, were supported by a detritus — epifaunal crustacean food chain (Edgar and Shaw, 1995a). This included pelagic species not directly associated with seagrass such as yellow-eye mullet and silver trevally (Edgar and Shaw, 1995a). As Edgar (1995b) noted, most studies of habitat utilisation are carried out on a relatively small scale, while most seagrass production is not utilised *in situ*, but is exported from seagrass beds (Whitfield, 1988). Commercial species that are common in areas with seagrass but do not physically live in seagrass beds may nevertheless benefit from seagrass production through the food chain. The long-term effects of major seagrass loss will be to reduce the detritus in sediments, and therefore reduce the productivity of food for fish in unvegetated habitats. Studies of commercial fish distribution and abundance, feeding rates (including stable isotope analysis) and growth rates should be carried out over a long period and a wide area after an episode of seagrass loss, as the detrital load from seagrass declines.

Simulation studies have been used to estimate the yield and value of three species of prawns (*Penaeus esculentus, P. semisulcatus* and *Metapenaeus endeavouri*) caught in waters offshore from three seagrass beds in the Cairns area (Watson *et al.*, 1993). The yield depends on the density of prawns in different beds and the extent of the beds, while the value is also affected by the price of the different species. The highest yield and value were not from the bed with the greatest area. In fact the highest value was derived from the smallest bed (230ha of seagrass in the western harbour compared with 270ha in the eastern harbour and 376ha in Mission Bay). From stable isotope studies, it has so far not been possible to distinguish whether prawns in offshore waters derive their carbon from exported seagrass detritus, or benthic diatoms (Loneragan *et al.*, 1997).

Seagrass productivity may also benefit fisheries at large distances from the seagrass habitat. Thresher *et al.*, (1992) used stable isotope analysis to show that larval blue grenadier, *Macruonus novaezelandiae* on the west coast of Tasmania, are likely to be supported by a food chain based on the microbial decomposition of seagrass from mainland Australia. Furthermore, the growth rates of larvae were correlated with winter storm events that would lead to export of buoyant seagrass material. In contrast, preliminary results from stable isotope work on food chains leading to demersal trawl fish in eastern Bass Strait indicates that seagrass production is only of minor significance (Nic Bax, CSIRO Marine Research, pers. comm.).

Seagrass beds typically support large numbers of small species with cryptic habits and/or juveniles of larger species (Bell and Pollard, 1989). Non-commercial species in these categories could potentially be an important food source for commercial fish. Some evidence suggests that this is the case. In Corner Inlet, Victoria, seagrass associated fish such as weedfish, *Heteroclinus perspicillatus*, and juvenile leatherjackets, *Acanthalueteres spilomelanurus*, are an important component of the diet of rock flathead (Klumpp and Nichols, 1983b). Diets of juvenile Australian salmon also include small, seagrass associated species such as pipefish, *Urocampus carinirostrus*, blue-spot goby, *Arenigobius bifrenatus*, and weedfish, *Heteroclinus perspicillatus* (Robertson, 1982). In Western Port, the diet of rock flathead and sand flathead consists partly of fish, predominantly small seagrass-associated species (Edgar and Shaw, 1995a). Three commercial species; eastern and western Australian salmon, and tailor, consume mainly pelagic baitfish, although demersal, seagrass associated fish are also included in the diet of Western Australian salmon, *Arripis truttaceous*. A study presently underway has shown that small seagrass-associated species form an important part of the diet of rock flathead and yank flathead, *Platycephalus speculator*, in Port Phillip Bay seagrass beds (J. Hindle, Melbourne University, unpublished data). A species of shrimp (*Palaemonetes australis*) found throughout beds of Ruppia in Wilson Inlet southwestern Australia (Humphries *et al.*, 1992b), is also the main prey species for *P. speculator* in this estuary (Humphries *et al.*, 1992a)

The question of non-commercial fish and shrimp species in seagrass beds becoming food for commercial species has parallels in the recent call by Kneib (1997) for scientists to stop ignoring small, non-commercial species common on saltmarshes. Kneib stresses the need to examine trophic linkages. The overlapping ranges of different sizes and species of fish offers the possibility that fish resident in saltmarshes high in the intertidal zone are eaten directly by slightly larger fish that venture a little way onto the marshes. These in turn might be eaten when they return to deeper water in marsh creeks by fish that spend time in the creeks but also in deeper parts of the estuary. A similar scenario is possibly being played out among the small but abundant fish of shallow *Zostera* beds (e.g. families Gobiidae, Syngnathidae, Ambassidae) and the larger fish caught in deeper seagrass beds and other parts of the estuary.

2.2.4 Summary

1. Fish and decapod diversity in seagrass is generally higher than in unvegetated habitats but this is often not the case for abundance or biomass.
2. Diversity and abundance of fish and decapods in other structured habitats such as reef/algae and mangroves can be comparable to seagrass.
3. A number of important commercial fish and decapod species show a strong association with seagrass at some stage of their life-cycle although there are other commercial species that are associated with unvegetated habitat. Juvenile tiger prawns are always strongly associated with seagrass.
4. The clearest evidence for links between seagrass and fisheries comes from Western Port, Victoria, where the catch of a number of commercial species declined in parallel with seagrass decline. Catches of some other commercial species, however, remained stable or increased over the same period. Such examples are rare on a world scale. Other studies have shown no detrimental effects of seagrass decline on fisheries.
5. There seems to be geographic variation in the proportion of commercial species utilising and caught in seagrass beds: it is lower in Tasmania than in other temperate States.
6. Fish assemblages in seagrass tend to be dominated by small individuals of non-commercial species, but these form part of the diet of some commercial species.
7. A number of commercial species spend their juvenile phase in seagrass but the adults occur partly or wholly elsewhere. For these species the contribution of juveniles from seagrass to future adult populations is unknown, as is the extent of mixing of larvae amongst different bays and estuaries from distant spawning.

8. Although a number of commercial species may be associated with unvegetated habitat, growth and survival may still be enhanced by seagrass detritus increasing benthic productivity.
9. Dietary and stable isotope studies show that direct feeding on seagrass is rare. However, for some species such as garfish and juvenile tiger prawns, carbon from seagrass and/or seagrass epiphytes is assimilated.
10. Sampling methods and protocols (depth, tidal state, time of day etc.) vary widely, making broad geographic comparisons difficult.

2.3 Influence of seagrass status on fisheries sustainability

2.3.1 Seagrass beds: importance to fisheries?

Seagrass beds are not all of equal importance to fisheries, but finding the reasons why is difficult due to confounding factors.

Water depth

In NSW, *Zostera* has been consistently found to support more juvenile fish than *Posidonia* (Middleton *et al.*, 1984; Bell and Westoby, 1986b). Commercial species may be found in *Posidonia* at an older juvenile stage (Middleton *et al.*, 1984). While this difference may relate to morphological characteristics of the seagrass species, it may also simply be a function of water depth. *Zostera* grows in shallow estuarine areas while *Posidonia* is found in deeper marine waters. Depth may be important because pre-settlement larvae of fish have distinct depth preferences which may subsequently be reflected in settlement depth (Bell and Pollard, 1989). Depth is certainly a critical factor in defining the settlement and habitat for juvenile tiger prawns (Young and Carpenter, 1977; Loneragan *et al.*, 1994).

A similar situation occurs in Victoria with intertidal *Zostera* and subtidal *Heterozostera*. Distinct assemblages of fish and decapods are found in each of these species and the assemblages are more similar to those in adjacent unvegetated areas of the same depth than between seagrass species at different depths (Jenkins *et al.*, 1997b). These seagrass species are morphologically very similar and the differences between assemblages most likely relate to physical differences in the intertidal versus subtidal environments. The commercial species that declined most in Western Port were those most closely associated with *Heterozostera*, the seagrass species that showed the greatest decline (Jenkins *et al.*, 1993a).

Even beds of the same seagrass species can support different assemblages of small fish. For example, the abundances of most fish species differed as much between different *Zostera* beds (0.5 to 2 km apart) within an estuary as they did between estuaries (15–300 km apart) along the northern NSW coast (Gray *et al.*, 1996).

Compared with the nearshore, shallow seagrasses, relatively few studies have examined the fauna of deeper water seagrasses, possibly because of sampling difficulties in this habitat. Bell *et al.*, (1992) found that the fauna caught in beam trawls did not differ consistently between shallow (1 to 2 m) and deep seagrasses (6 to 7 m) in Jervis Bay, New South Wales. Current research is investigating the fish fauna of deeper water seagrasses (4 to 9 m deep) in waters offshore from Fremantle, Western Australia (Glenn Hyndes, Murdoch University, pers. comm.).

Seagrass structure

Features of seagrass beds such as leaf density, length and morphology can influence fish assemblages on a local scale. Earlier theory suggested that the main link between seagrass and fish was shelter from predators, leading to the hypothesis that fish numbers would increase with the complexity of seagrass beds up to a threshold when the bed became too dense for fish to move freely (Heck and Orth, 1980). Research has found that fish species respond to structural complexity in seagrass beds, but not necessarily in a way that supports this hypothesis. Bell and Westoby (1986b) manipulated the height of seagrass in *Zostera* and *Posidonia* and found strong responses in abundances of fish and decapods but not all in the expected direction. While some species decreased when seagrass was thinned or shortened, others increased or remained stable. Another study showed a decrease in abundance of fish and decapods when seagrass was thinned, but this happened whether predators were present or not, suggesting behavioural choice was involved (Bell and Westoby, 1986a). Worthington and Westoby (1991) measured settlement into artificial seagrass beds of different leaf densities and found a sharp threshold of increasing settlement at low leaf densities and little change in settlement at higher leaf densities. Similar findings have been reported for postlarvae tiger prawns (Kenyon *et al.*, in press). Jenkins and Sutherland (1997) compared artificial seagrass beds with low and high complexity and found little difference in species richness but a much higher number of some species, particularly pipefish and juvenile leatherjackets, in high complexity beds. None of these studies, however, included significant numbers of juveniles of commercial fish.

These findings on the early life history stages in beds of different structure contrast with preliminary results from deeper water seagrasses in Western Australia. A study there is investigating the fish fauna found in *Posidonia sinuosa* and *Amphibolis griffithii* beds in depths of 4 to 9 m. Major differences are being found in the number of species, total numbers of individuals and the composition of the community between beds of different structural complexity. In addition, the size of individuals of some species differs between beds; smaller fish are being found in beds of *P. sinuosa* than *A. griffithii* (Glenn Hyndes, Murdoch University, pers. comm.).

Studies of the fish fauna and predation rates on prawns in a high biomass (70g/m^2) and a low biomass (7g/m^2) seagrass bed in the Embley River estuary of northern Queensland have shown that of the smaller species (sampled by beam trawl, beach seine and rotenone), 11 species were more abundant on the high biomass bed and three on the low biomass bed (Haywood *et al.*, 1998, CSIRO Division of Marine Research, unpublished data). There were fewer differences for the larger species sampled by gill nets. It should be noted that the differences in both the above studies were confounded by location of the beds and the different habitats were not replicated.

Spatial location of beds and hydrodynamics

Of more interest to managers is whether characteristics of individual beds are important over larger scales. For example, a decision over preservation is more likely to be a choice over different seagrass beds rather than parts of an individual bed. A major concern is whether patterns found for individual beds are important over larger spatial scales. In Botany Bay, NSW, *Zostera* height and density varied among beds but were not correlated with abundance of fish and decapods (Bell and Westoby, 1986c). Patterns seen at the within-bed scale (Bell and Westoby, 1986b) were therefore not reproduced at the larger scale. A similar result was found by Worthington *et al.*, (1992) for a number of NSW south coast estuaries, and in this case some commercial species, such as luderick and tarwhine, were included in the analysis. There was a trend, however, for patterns of fish abundance to be related to distance from the mouth of an estuary, suggesting that the supply of larvae from outside the estuary may influence patterns (Bell *et al.*, 1988).

Position of seagrass bed within estuary

In Victoria, the broad-scale abundance of recently-settled King George whiting has been investigated in Port Phillip Bay. Over approximately 40 km of coastline, abundance of juvenile King George whiting showed no correlation with the structural characteristics of *Heterozostera* beds (Jenkins *et al.*, 1996; Jenkins and Wheatley, 1998). When artificial seagrass beds of constant structure (i.e. density and height) were placed near natural *Heterozostera* of varying structure at locations around the coast, juvenile whiting abundance was highly variable amongst sites but almost identical between natural and artificial habitats. A correlation has been found, however, between whiting abundance and distance from the bay entrance (Jenkins *et al.*, 1996), suggesting a strong influence of larval supply, because spawning of this species occurs outside the bay (Jenkins and Black, 1994). Hydrodynamic modelling has shown that a large amount of the variation in abundance at sites can be explained by two factors: variation in the currents delivering larvae, and exposure of the site to wave action which either kills or retransports larvae (Jenkins *et al.*, 1997a). All this suggests that the location of the seagrass bed within the bay is far more important to King George whiting abundance than characteristics of the seagrass.

Other evidence for the importance of position of seagrass beds within an estuary comes from Barker Inlet in South Australia. Over the whole estuary, fish assemblages differed between the outer and inner parts (Gary Jackson and Keith Jones, SARDI, unpublished data). In the outer part of the estuary, the degree of exposure to open water was a major factor influencing fish abundances, overriding even the strong influence of seagrass presence (Connolly, 1994a).

In northern NSW estuaries, where there is a strong riverine influence on estuaries in general, fish diversity and abundance can be strongly affected by the distance upstream (i.e., amongst other things, degree of freshwater influence).

Seagrass sites just inside the estuary opening are of particular importance to newly recruited fish (West and King, 1996; Gray *et al.*, 1996), but the importance of different positions changes through time (see below, within this section).

In Moreton Bay, Queensland, juvenile prawns of several species all showed habitat preferences based on vegetation and strong affinities for shallow water (< 2 m), but there was also a strong influence of position within the bay (Young and Carpenter, 1977; Young, 1978). Whereas *Penaeus plebejus* occurred all over the bay, *P. esculentus* was found mainly in the middle of the bay, while greasyback (*Metapenaeus bennettae*) and school prawns (*M. maclaeyi*) were found on the western side associated with rivers. The position of seagrass beds is also an important factor in northern Australia where the number of tiger prawn post-larvae passing over seagrass beds was higher in regions where current flow was higher (Vance *et al.*, 1996a; Loneragan *et al.*, 1998).

The 'importance' of a seagrass bed for commercial fish in bays and estuaries may depend on the location of that bed relative to hydrodynamic patterns (McNeill *et al.*, 1992; Jenkins *et al.*, 1997a). This suggests that an assessment of potentially important seagrass beds could be made using hydrodynamic modelling. With a knowledge of bathymetry, sea-level, and wind records, generalised hydrodynamic models can be applied to different bays and estuaries (Black *et al.*, 1993). Because this approach does not require field work in the first instance, it has potential as a rapid assessment tool for evaluating the significance of different seagrass beds to the larvae of fish and decapods.

Another question of relevance to managers is the temporal consistency in the 'importance' of seagrass beds. Earlier suggestions that spatial variation in settlement to beds is 'stochastic' (Bell and Westoby, 1986c) have given way to recognition that certain beds may be of greater importance to juvenile fish depending on their location within a bay or estuary. In NSW, juveniles of commercial fish tend to occur consistently on certain beds within a season (Worthington *et al.*, 1992) and across seasons (McNeill *et al.*, 1992). High recruitment at one site in Botany Bay is seasonal and related to the recruitment of commercial species; the hypothesis was forwarded that stable oceanographic processes resulted in a high supply of larvae to this bed (McNeill *et al.*, 1992). In the same way, certain seagrass beds have large numbers of newly settled King George whiting in Port Phillip Bay consistently across years, suggesting that current and wave exposure patterns mentioned above are relatively stable across time (Jenkins *et al.*, 1997a).

Temporal consistency of the 'importance' of a seagrass bed depends to some extent on whether juveniles continue to stay in the bed they settled in, or whether they migrate to other habitats as they grow. In NSW, there is conflicting evidence with regard to migration from the site of settlement. Some studies argue that little redistribution of settlers to other seagrass beds occurs over a full year of growth (Worthington *et al.*, 1992). Other studies suggest that juvenile fishes will redistribute to alternative habitats within the first year of life (Middleton *et al.*, 1984; Gillanders and Kingsford, 1992). McNeill *et al.*, (1992) found outstandingly high abundances of juvenile commercial fish at one site during the recruitment season, but no significant difference at other times of year. In Victoria, King George whiting juveniles showed an initial settlement pattern related to hydrodynamic patterns, but a month or two after settlement they had redistributed amongst seagrass beds (Jenkins *et al.*, 1996). At this time, a correlation was found between their abundance on seagrass beds and the fullness of the gut, suggesting that juveniles were migrating to areas of high food abundance (Jenkins *et al.*, 1996). Studies of colonisation and turnover of fishes in artificial seagrass in Port Phillip Bay have shown that colonisation of 'new' habitat by juvenile fish (rather than settlers) is very rapid, and that the turnover of fish in a bed from day to day is high (Jenkins and Sutherland, 1997).

In the Clarence River estuary in Northern NSW, *Zostera* sites just inside the mouth of the estuary support high densities of new recruits of several economically important fish species (yellowfin bream, luderick, tarwhine and sea mullet). Older juveniles of these species, however, are common in other habitats and further into the estuary (West and King, 1996; Box 1.4.5.1 in Cappo *et al.*, 1998). For example, juveniles moved up and down the estuary, and between vegetated and unvegetated habitats.

2.3.2 Critical thresholds

The question of critical thresholds in seagrass cover is a difficult one. Bell (1986b) showed that the response to seagrass thinning was uneven and depended on species. Experiments with artificial seagrass of differing densities showed that the density threshold for fish recruitment was very low and suggested that even a minimal amount of seagrass cover may be important for fish recruitment (Worthington and Westoby, 1991). This result was consistent when a subset of commercially important species (yellow-fin bream, tarwhine and luderick) was analysed (Worthington and Westoby, 1991). In a study of broad-scale recruitment of King George whiting juveniles in Port Phillip Bay, most of the variation in abundance was attributable to the location of the bed. No effect of seagrass density or biomass was found, however a small (but significant) trend indicated higher abundance on beds with shorter leaves (Jenkins *et al.*, 1998).

Low cover seagrass beds are also of great significance to postlarval and juvenile tiger prawns. Studies of these early life-cycle stages in the western Gulf of Carpentaria have shown that numbers of prawns did not differ between seagrass beds ranging in biomass from about 5 to 90g/m^2 (Loneragan *et al.*, 1998). However, numbers were higher in seagrass beds where the biomass of seagrass exceeded 100g/m^2. Although these high biomass beds support higher numbers of juvenile prawns, they account for only 6% of the total seagrasses in the Gulf of Carpentaria (Poiner *et al.*, 1987; 1989). In field experiments using fine mesh enclosures, juvenile tiger prawns *Penaeus semisulcatus* grew faster on a high biomass bed (70g/m^2) than on one with low biomass (7g/m^2), which suggests that more food is available for prawns in seagrass beds with high biomass (Loneragan *et al.*, 1998).

The structure of seagrass affects both the behaviour of tiger prawns and rates of predation by fish on them (Laprise and Blaber, 1992; Kenyon *et al.*, 1995). Small juvenile tiger prawns (5mm carapace length — about 2 months old) behave similarly in seagrass with different structures. However, this changes as they increase in size, when they prefer larger seagrass (Kenyon *et al.*, 1995, 1997). Predation rates in the laboratory are greatly affected by seagrass structure. Predation rates were three times lower in tall, dense seagrass than bare substrate, and twice as low in dense seagrass compared with short, sparse seagrass (Kenyon *et al.*, 1995). In the field, however, there was little difference in the numbers of prawns found in guts of fish from dense (*Enhalus acoroides* 70g/m^2) and sparse seagrass (*Halophila ovalis*, *Halodule uninervis* 7g/m^2) (Haywood *et al.*, 1998). Perhaps this is because the densities of postlarvae and small juvenile prawns in seagrass in the field are very low compared with the densities of other crustaceans of a similar size. A two-year comparison of fish and prawns from intertidal *Zostera* beds of differing densities in Tin Can Bay found that faunal abundances were similar, even in beds of strikingly different seagrass densities. However, when seagrass was not present, the abundances of the fauna were much more markedly affected (either increasing or decreasing abundances, depending on species) (Ian Halliday, QDPI and Rod Connolly, Griffith University, unpublished data). In that study, the sparse *Zostera* site had an above-ground dry biomass of around 5g/m^2, 85% lower than the dense site (35g/m^2). This suggests that there is no critical threshold for *Zostera* density in this bay. Seagrass presence is important, but seagrass density is not.

It must be borne in mind that the abundance of several commercially important species (*Penaeus plebejus, Sillago maculata* and *Gerres oyeana* (a bait fish)) *increased* markedly after total loss of seagrass (Halliday, 1995; Ian Halliday, QDPI and Rod Connolly, Griffith University, unpublished data). This study took advantage of a seagrass die-off phenomenon during the survey, but even with such a serendipitous event, limitations of sampling (e.g. a single moon phase, inability to replicate beds of different seagrass densities) limit the confidence of the conclusion. The 'landscape ecology' of seagrasses and its effects on fish and decapods is another relatively new area that needs urgent appraisal. This approach takes into account factors such as size, shape and area of seagrass bed, and position of the bed in relation to other beds. Little attention has been paid to whether seagrass beds have a lower size limit below which the bed is less important for fisheries production. Patches of artificial seagrass as small as 1m^2 placed in unvegetated habitat in Moreton Bay attracted a high number of recruits of commercial species (Hopkins, 1996). It remains for links between high numbers of recruits to such small patches and ultimate contribution to fishery stock to be demonstrated.

Research on mangroves and saltmarshes suggests that landscape ecology is an important area for further development in seagrass research. For example, the linear extent of mangroves was a better predictor of mean average catch of banana prawns in the northern prawn fishery than the total area of mangroves (Staples *et al.*, 1985). Large fish were found in much higher densities in mangroves near the mangrove/water interface than further into the mangrove forest (i.e. away from the interface) (Vance *et al.*, 1996b). Work on saltmarshes, the critical nursery habitat for brown shrimp *Penaeus aztecus*, suggests that as saltmarshes decline in their extent, they break up, or fragment, into smaller units (Browder *et al.*, 1989). For a time, these smaller units increase the length of the interface between marsh and water. Empirical modelling of the relationship between the fragmentation of saltmarshes and brown shrimp catches in Louisiana has shown that as marshes decline in their extent, catches of brown shrimp increase for a time as the interface between marsh and water increases, before catches eventually decline (Browder *et al.*, 1989). This type of modeling suggests that results from short-term or small-scale experiments might not reflect what would ultimately happen after changes in vegetated habitats. Application of landscape ecology to fish assemblages in seagrass of Port Phillip Bay is the focus of a PhD study presently underway (T. Anderson, unpublished data).

Recent advances in information technology and remote sensing mean that it is now possible to map seagrasses at a large scale and place confidence limits on these estimates (see Chapter 4). Such information would allow researchers and managers to better assess links between seagrass and the fisheries they support, to assess changes in the extent and quality of seagrass and the impact this is likely to have on fisheries production. In some cases, joint funding for this type of research might be appropriate, e.g. between FRDC and agencies such as Environment Australia or State agencies.

2.3.3 Summary

1. Seagrass meadows are not all equal as habitat for fish and decapods. In certain estuaries and bays in Australia, there is some knowledge of the way in which meadows differ.
2. Differences in fish and decapod assemblages and abundances between vegetation types (e.g. *Zostera-Posidonia*; *Zostera-Heterozostera*; mangroves-Zostera) are confounded with effects of water depth (shallow versus deeper, in the pairings above).
3. There is very strong evidence that water depth is a major influence on juvenile prawn distribution. Water depth also influences the distributions of juvenile fish in some places, but the importance of water depth remains to be shown in other regions.
4. Small-scale experiments show differing effects of changing seagrass density or height; some fish and decapod species decrease in abundance, others increase, while others are not affected.
5. In general, over whole estuaries/bays or in a series of such waterbodies, no correlation has been documented between seagrass density or height and fish and decapod abundance. An important exception is brown tiger prawns in northern Australia, where juvenile numbers are higher on seagrass beds with high biomass.
6. Regardless of the extent, density or type of seagrass cover, the position of a bed within an estuary or bay is very important in explaining abundances of juvenile fish and decapods. This has been shown in many locations around Australia.

7. Certain beds have high numbers of recruits each year. For some species, these high numbers may not last beyond the recruitment season because of redistribution of juveniles within the estuary/bay.
8. The latest evidence suggests that prey availability is the main factor in determining abundances of some important commercial fish (e.g. King George whiting) once they have redistributed.
9. The important aspects of position of the seagrass bed within the estuary are still to be determined in many places, but seem to be related to currents delivering larvae (i.e. importance of distance to mouth of estuary, or bay opening) and exposure to open water.
10. Studies of inshore, shallow seagrasses indicate that it is the presence of seagrass, rather than its type, density, height or cover, that is important. However, preliminary results from some areas on deeper water seagrasses, show that seagrass type does influence the community structure of fish populations. There is no known threshold of seagrass density, height, or cover, below which fish and decapod abundance shows a marked decrease.

2.4 Gaps in understanding and future research needs

1. Associations between finfish and seagrass in tropical waters are virtually unknown. In view of the proposed developments in the region, further work is recommended.
2. Methods, or more importantly protocols (e.g. stage of tide, water depth, time of day etc.), should be standardised wherever possible.
3. Detailed studies of commercial fish catch trajectories subsequent to episodes of seagrass loss appear to be lacking for many areas. This requires effective monitoring of both seagrass and catch.
4. Changes in juvenile fish and decapods before and after seagrass loss are poorly known. Is the seagrass *per se* important, or are certain estuarine/embayment environments beneficial to both seagrass and fish? Baseline studies of sufficient spatial and temporal intensity are needed to quantify natural variability in fish and decapods in seagrass beds in order to make useful comparisons after seagrass loss.
5. The importance of exported detritus of seagrass (and associated algae) to commercially important fish in unvegetated habitats is poorly understood. What is the long-term effect of seagrass loss to these species? Stable isotope studies can determine whether carbon, nitrogen and sulphur from seagrass beds are being assimilated by species in unvegetated habitats. The population characteristics (growth, survival etc.) for species need to be studied over a significant period and a sufficiently large area after seagrass decline.
6. It is important to study habitat 'mosaics', rather than concentrating on preferences for individual habitat types. Do fish, for example, preferentially colonise mixed habitats such as sand patches amongst seagrass?

7. The nature of links with seagrass (e.g. feeding, protection from predators, and amelioration of physical disturbance) is still poorly known for many species. Understanding these links is important for better prediction of the effects of changes in seagrass extent on commercial fish. Small-scale manipulative experiments are needed, yet they must be conducted over a large enough spatial scale to enable us to make generalisations about the nature of these links.
8. For species in which juveniles are found in seagrass as well as other habitats, the relative contribution of juveniles in seagrass to future adult populations is poorly known; otolith microchemistry shows promise in this area.
9. The older juvenile/subadult life-stage is the most poorly understood in terms of habitat utilisation. A new emphasis on these life stages is needed using new sampling programs and/or advances in tracking technology.
10. The extent of dispersal of larvae from distant spawning locations to different estuaries and bays has implications for whether seagrass loss in an individual bay or estuary will affect populations of commercial fish, such as bream (*Acanthopagrus australis*). Studies using otolith microchemistry and genetic analysis may be useful in this area.
11. The role of small, non-commercial species in food chains of commercial species is only known in localised areas. Further dietary and isotope studies of piscivorous fish are required in many regions.
12. Research has hinted at the importance of many aspects of seagrass meadows relating to landscape ecology. It is critical to determine the importance of features such as size, shape, and spatial arrangement of meadows, proximity to currents, and relations with other habitats (e.g. unvegetated areas, mangroves, deep water, and sand bars).
13. Another important aspect of landscape ecology is position within the habitat patch e.g. edge versus interior. Recent work shows that fish utilise fringing mangroves more heavily than other mangrove habitats. This suggests that edge effects and habitat fragmentation should be studied in seagrass.
14. The aspect of habitat position in relation to larval supply of commercial fish and crustaceans suggests that an assessment of the importance of beds could be made using hydrodynamic modelling. Generalised hydrodynamic models can be applied to different bays and estuaries with a knowledge of bathymetry, sea-level and wind records. Because this approach does not require field work, in the first instance, it has potential as a rapid assessment tool.
15. When considering whether some seagrass meadows are more important than others, it is not only the direct use by fish that needs to be considered, but also the role of beds in nutrient cycling and sediment stabilisation. Collaborative projects with organisations such as EPAs or Environment Australia could be appropriate.
16. What are the important things to monitor in seagrass beds? For some fish and crustaceans, determining the extent of seagrass and the depth of beds is more important than knowing the individual species present. We do not know whether this is the case for all species, particularly those found in deeper water seagrasses.

17. Recent advances in technology (e.g. GPS, GIS) make it possible to map seagrass beds more rapidly, accurately and over much larger areas than ever before. These advances should be taken into account in any future proposals to map seagrass in relation to fisheries production (see also Chapter 4).

2.5 Recommendations for future research

Many conclusions reviewed in this chapter are speculative. Hard data on links between seagrass and fishery species are needed urgently. In some situations, seagrass may be no more important for fish and decapods than adjacent habitats (e.g. bare mudflats in sheltered bays) but it is more vulnerable to loss or degradation than some of these other habitats. The lack of knowledge about links between fisheries and seagrass could result in a weakening of the conservation status of seagrass. Solid research results are necessary to provide coastal managers with arguments for the protection of seagrass.

1. Correlations of large scale seagrass loss with fisheries data and baseline data on the abundance of juveniles are needed.
2. There is a need to understand processes linking seagrass with fish and decapods far better than we currently do to be able to predict the effects of seagrass changes on fisheries.
3. Studies are needed comparing the ecology (e.g. extent of assimilation of food from seagrass beds) of fishery species that spend all or only part of their life associated with seagrass.
4. For all important fish and decapod species, the extent to which early juveniles occurring in seagrass contribute to adult stocks should be determined. Studies of dispersal using modern genetic or otolith microchemistry methods will be useful.
5. Stable isotope studies should be done to trace the contribution of material exported from seagrass beds to fishery species elsewhere.
6. Researchers should aim for standardisation of methods and protocols: e.g. stage of tide, water depth, time of day, frequency of sampling in relation to timing of recruitment.
7. The proximity and nature of habitats adjacent to seagrass beds can be important, and should be incorporated in studies of seagrass fish/decapod assemblages.
8. Large scale mapping of seagrasses by recently developed techniques is needed for fisheries where a demonstrated link exists between seagrass and fisheries production. These studies will help establish a sound baseline for later comparison, particularly if there is a large scale loss of seagrass.
9. Associations between finfish and seagrass in tropical waters need to be established.
10. Habitat utilisation by older juvenile/sub-adult life stages should be studied using new sampling programs and/or advances in tracking technology.

11. The extent of dispersal of larvae from distant spawning locations to different estuaries/bays should be studied. Techniques such as otolith microchemistry and genetic analysis will be useful.
12. In many regions, dietary and isotope studies of piscivorous fish are required to determine the role of small, non-commercial species in food chains of commercial species.
13. The landscape ecology of seagrass beds needs to be studied to determine the importance to fish of features such as size and shape of beds, edge effects and proximity to currents and other habitats.
14. Where the bathymetry, sea-level, wind records and larval supply of commercial fish and crustaceans are known for bays and estuaries, hydrodynamic modelling could be used to assess the importance of beds.
15. Collaborative projects with organisations such as EPAs and Environment Australia should be undertaken to study the role of beds in nutrient cycling and sediment stabilisation.
16. In shallow, inshore waters, the extent of seagrass and depth of beds should be determined rather than studying the individual species of seagrass present. Further work is needed to determine if this recommendation applies to deeper waters.

2.6 Acknowledgements

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Table 2.1 Summary of information about links between changes in seagrass status and fisheries production. Australian cases are listed under climatic zones, ordered by fishery type, then alphabetically by State, then by location.

Location	*Target species*	*Average catch*	*Extent of seagrass*	*# seagrass spp.*	*Evidence for link*	*Impact of loss*	*References*
			Temperate				
Bay, Inlet and Estuary finfish							
Barker Inlet, SA	Whiting (*Sillaginodes punctata, Sillago schomburgkii*), salmon (*Arripis truttacea*), tommy rough (*Arripis georgiana*), yelloweye mullet (Aldrichetta forsteri), garfish (*Hyporhamphus melanochir*): juvenile through to adults.	Total catch for SA of KGW = 600t. (commercial only). Gulf St Vincent small proportion, but big rec catch.	*Posidonia/Amphibolis* in deeper waters, *Zostera/Heterozostera* in shallow parts. Seagrass loss suspected but never quantified.	4	Juveniles and adults closely associated with seagrass habitat. Conclusion that fish differ between inner & outer sectors of estuary, but this virtually matches presence & absence of seagrass.	No change reported over survey period (10 yrs: 1985–94). Instead, shows high interannual variability for ALL spp., no important long term trends.	Gary Jackson & Keith Jones (SARDI, unpubl. data), Connolly 1994a
	" "	" "	*Zostera muelleri*	1	Experimental removal of Zostera (30m^2 patches) followed (2 weeks later) by fish collections.	NONE. Loss of above ground structure did not greatly affect fish abundance (certainly did not reduce it to levels found in bare habitat).	Connolly 1994b

Spencer Gulf, SA	Assemblages of small fish, including economic species of fish (e.g. *Sillaginodes punctata, Arripis georgiana, Aldrichetta forsteri, Hyporhamphus melanochir*) and crustaceans (*Portunus pelagicus*).	For KGW, around half of all commercial tonnage in SA is from Spencer Gulf.	Very extensive in Spencer Gulf, large scale dieback.	8 intertidal spp alone (including *Ruppia* types).	Comparison of die-back areas with healthy *Posidonia/Amphibolis/ Zostera* and bare sand shows fish assemblages of die-back areas more similar to bare sand than healthy seagrass.	Reduced total biomass, although density of some species (e.g. *Portunus pelagicus*) in *Amphibolis* die-back zone.	S. Seddon, University of Adelaide, unpublished data
Gippsland Lakes, Victoria	Black bream, *Acanthopagrus butcheri.*	4–500 declining to 20t.	poorly known.	3	Juveniles associated with seagrass habitat.	Period of seagrass dieback from 1920–60 coincided with historically low catches.	MacDonald, 1992 Ramm, 1986
	Luderick, *Girella tricuspidata.*	70–80 declining to 1t.					
Corner Inlet, Victoria	Rock Flathead, *Leviprora laevigatus.*			1 1	Juveniles associated with seagrass habitat.	Decline in seagrass, mid 70s to mid 80s, concurrent sharp decline in catch.	M. MacDonald, pers. comm.
Port Phillip Bay, Victoria	Rock flathead, *Leviprora laevigatus.*	Dieback of 30 km^2 of *Heterozostera*		1	Adults and older juveniles closely associated with seagrass	Dieback coincided with sharp decline in catch 1982–1990.	M. MacDonald, pers. comm.
Western Port, Victoria	King George whiting, *Sillaginodes punctata.*	60 declining to 10t.	180 km^2 declining 75%.	4	Recently-settled juveniles associated with seagrass.	Major loss of *Heterozostera* between 1970 and 1984 and concurrent major decline in catch not observed in nearby bays.	MacDonald, 1992 Robertson, 1977 Jenkins et al., 1996, 1997 Jenkins and Wheatley, 1998 Connolly, 1994

Location	*Target species*	*Average catch*	*Extent of seagrass*	*# seagrass spp*	*Evidence for link*	*Impact of loss*	*References*
				Temperate			
Bay, Inlet and Estuary finfish		**(continued…)**					
	Rock flathead *Leviprora* (*Platycephalus*) *laevigatus*.	35 declining to 10t.			Adults and older juveniles closely associated with seagrass.		MacDonald, 1992 Jenkins *et al*., 1997 Edgar and Shaw, 1995
	Rock whiting, *Haletta semifasciatus*.	30 declining to 2t.			Juveniles and adults closely associated with seagrass habitat.		
	Six-spine leatherjacket, *Meuschenia freycineti*.	5 declining to 0.1t.			"		
				Subtropical and Tropical			
Bay, Inlet and Estuary finfish							
Tin Can Bay, Qld.	Small fish assemblages.	Region supports 300 commercial fishing operations, landed value $28.8 million p/a, 2nd highest recreational catch and effort of any Qld region.	12 300 ha Great Sandy Straits/Tin Can Bay region. This is more seagrass per unit area than in any other estuarine system on the Qld coast.	6, mainly *Z.capricorni*	Comparison of fish catch (small beam trawl) in dense and sparse seagrass site over 2 yrs. In second year, sparse site lost all seagrass.	Loss of seagrass matched by increase in whiting (*Sillago*) and silverbiddies (*Gerres oyeana*). Non-commercial spp such as pipefish lost completely.	Ian Halliday, QDPI and Rod Connolly, Griffith University, unpublished data
Prawns							
East coast of Qld – tropical and sub-tropical.	Brown and grooved tigers, *Penaeus esculentus, Penaeus semisulcatus.*	2, 300t.	5, 000			1. Loss of seagrass in Hervey Bay – large wet.	Coles *et al*., 1993

	Endeavour prawns *Metapenaeus endeavouri, M. ensis.*	1, 468t.				2. Loss of seagrass in Moreton Bay between 1987 and 1995.	
	Eastern king	> 2, 000t.	"				
Gulf of Carpentaria, Qld	Brown tigers *Penaeus esculentus.*	3, 000t. (tiger prawns)	Gulf of Carpentaria = 1, 000 km^2	11	1. Seagrass defines extent of fishery.	Loss of seagrass in cyclone Sandy (1984).	Poiner *et al.*, 1993 Loneragan *et al.*, 1994, 1998\
	Grooved Tigers *Penaeus semisulcatus.*			"	2. a) juveniles found only in shallow beds of seagrass and algae.	1. Change in composition of juvenile populations.	Vance *et al.*, 1996 Haywood *et al., 1995*
	Endeavour prawns *Metapenaeus endeavouri, M. ensis.*	1, 000t.	"	"	b) juveniles also found on bare substrates.	2. Small reduction in catch.	Liu and Loneragan, 1997
Tin Can Bay, Qld	Eastern King Prawns, *Penaeus plebejus, Greasybacks, Metapenaeus bennettae.*	*P.plebejus* 100t/yr.	12 300 ha Great Sandy Straits/Tin Can Bay region. This is more seagrass per unit area than in any other estuarine system on the Qld coast.	6, mainly *Z. capricorni*	Comparison of prawn catch in dense and sparse seagrass site over 2 yrs. This was matched with associated changes in prawn catch in beam trawl.	Marked increase in *P. plebejus* after seagrass loss, whereas no change where seagrass remained healthy. Pattern for *M. benn.* not so clear, possibly same as for *P. plebejus.*	Halliday, 1995
Torres Strait, Qld	Brown tigers *Penaeus esculentus.*	600t.		5	Juveniles found in reef top seagrasses.	Loss of seagrass from large wet 1992/93.	Turnbull and Mellors, 1990 Derbyshire and Dennis, 1990
	Metapenaeus endeavouri, M. ensis.	900t.			Juveniles found in reef top seagrasses.		Turnbull and Watson, 1992
	Red-spot Kings *P. longistylis.*	40t.			Juveniles on sparse reef-top seagrasses.		Turnbull, pers. comm.

Location	*Target species*	*Average catch*	*Extent of seagrass*	*# seagrass spp*	*Evidence for link*	*Impact of loss*	*References*
			Subtropical and Tropical				
Prawns	**(continued…)**						
	Rock Lobster *Panulirus ornatus.*				No juveniles found after loss of seagrass. Seagrass stabilises sediments and prevents burrows being covered.	Loss of seagrass from large wet 1992/93	Pitcher *et al.*, 1994, Dennis pers. comm.
			Overseas				
Inshore finfish, prawns							
Japan (Seto Inland Sea)	Penaeid shrimp, portunid crabs, estuarine fish.			Mostly *Z. marina.*	Decline in *Zostera* correlated with decline in fisheries catch (total catch, no mention of CPUE).	Markedly reduced fisheries catch.	Kikuchi, 1974
Scallops							
Chesapeake Bay, USA	Scallops *Argopecten irradians.*			*Z. marina.*	Total collapse of scallop fishery after 90% loss of seagrass.	Total collapse of scallop fishery, recovery in N. Carolina as seagrass returned, but not in Chesapeake Bay.	Pete Sheridan pers. comm.

CHAPTER THREE

Review of Australian rehabilitation and restoration programs

D. Lord, E. Paling, D. Gordon

3.1 Introduction

3.1.1 Status of seagrass rehabilitation and restoration

Terminology

It is useful to begin with a definition of the terms 'rehabilitation' and 'restoration'.

The US National Research Council Committee report on aquatic restoration has interpreted 'rehabilitation', 'reclamation', and 'habitat creation' as *putting an area to a new or altered use to serve a particular purpose* (USNRC, 1992). 'Seagrass rehabilitation' is a general term, which has the sense of improving, augmenting or enhancing a degraded or affected area, with the expectation that it will improve through return of seagrass and seagrass ecosystem function. The term 'restoration' conveys the meaning of a return to pre-existing conditions. Since this is acknowledged as being an unlikely outcome in practice, 'restoration' is widely interpreted as returning the ecosystem to a close approximation of its condition prior to disturbance (USNRC, 1992). By that definition, structure and function of the ecosystem are approximately created, but still with the expectation of producing a natural, functioning and self-regulating system integrated with the broader ecological system. While clear distinctions are made between 'rehabilitation' and 'restoration' in terms of the goals and expected outcomes of projects, the term 'restoration' has also been used throughout the report in making general reference to the subject.

The term 'mitigation' is often used to refer to the enhancement or creation of seagrass areas to compensate for permitted seagrass losses.

Complete definitions of all commonly used terms in seagrass transplanting work, such as 'restoration', 'rehabilitation', 'creation', 'success' and 'failure', are presented in a glossary to the report to Cockburn Cement Limited by DM Gordon (1996), given as an appendix to the WWW edition of this review (see http://www.publish.csiro.au/seagrass). The definitions in that glossary have been adopted for this report.

International experience

The status of seagrass restoration at the international level presented here is based largely on an earlier review of international seagrass restoration projects, prepared for Cockburn Cement Limited by DM Gordon, which is given as an appendix to the WWW edition of this review (see http://www.publish.csiro.au/seagrass) and referred to here as Gordon (1996). That review summarised planning, policy and management issues affecting seagrass restoration, planting methods, critical issues confronting successful restoration, and research gaps identified to further develop the technology. It included information from planting guidelines developed for particular species and habitats (e.g. Fonseca, 1994) and issues related to policy, permits, goal setting, performance assessment and monitoring of projects to restore aquatic habitats (e.g. USNRC, 1992). Supplementary reviews have since been conducted (e.g. Fonseca *et al.*, in press; Kirkman, 1997).

Restoration experiments and mitigation projects using different seagrass species have been attempted with varying degrees of success using both temperate and sub-tropical seagrass species, mainly in the USA and Europe. In particular, successes have been achieved in putting back small areas of lost or damaged seagrasses, especially with faster growing species such as *Zostera marina* (eelgrass) and *Syringodium filiforme*. Despite these examples, seagrass restoration is still an evolving technology that remains difficult and challenging.

Early research and transplanting work was done with eelgrass and this has continued. Eelgrass has a history of catastrophic loss through effects of the 'wasting disease' earlier this century in north America and Europe, and through continuing coastal development and pollution (den Hartog, 1987; Short *et al.*, 1991).

At this time, techniques have been tested sufficiently to allow small areas of eelgrass to be restored with reasonable assurance of creating or replacing seagrass cover (Fonseca, 1994). In some cases, unexplained losses of eelgrass several years after planting have focused attention away from planting trials and back to a better understanding of population and patch dynamics. Phillips (1990) pointed out the importance of recognising differences in adaptive tolerance. Pioneer or climax stages in a species development may exhibit differing reproductive and functional behaviour. Phenotypic and genotypic differences in populations may influence how plants respond to stressful environments such as those where transplants are introduced to new areas. Beds planted to replace habitat on a one to one basis often fall short of that goal and, even where successful, have resulted in interim loss of value (Fonseca, 1992). Thus, returns of several hundred hectares of eelgrass through restoration efforts are still to be realised.

Along with eelgrass, the sub-tropical/tropical seagrasses *Thalassia testudinum*, *Halodule wrightii* and *Syringodium filiforme* have been a focus of restoration efforts in the USA (Gordon, 1996). Revegetation studies have been conducted with *Thalassia* seedlings and plugs and sprigs of *Halodule* and *Syringodium*. *Thalassia* is slow to propagate in disturbed areas. Standard issues of lack of adequate seedling availability and destruction to natural beds by plug removal have increased interest in the use of non-destructive seedling-based techniques. Generally, fruit and seed production is highly variable in *Thalassia* and reproductive beds are not always close to restoration sites. In addition, seagrasses exhibit morpho-geographic growth patterns that necessitate a different approach to obtaining and maintaining planting stock (Durako, 1988).

Good survival has been reported, particularly with anchored sprigs while some reported successes with anchored seedlings have been contested. The US experience indicates that *Halodule* and *Syringodium* generally provide faster returns for effort than *Thalassia* and are easier to transplant and grow, to the extent that they are viewed as good species to consider in 'compressed succession' planting programs (Derrenbacker and Lewis, 1982; Fonseca *et al.*, 1987). By that approach, more difficult to grow seagrasses are first planted into colonising beds of faster growing species in an attempt to speed up succession. The analogous approach in Australia would be to plant out *Posidonia* in colonising beds of *Halophila* or *Heterozostera*. A similar approach has been used in France, where shoot bundles of *Posidonia oceanica* were introduced within a *Cymodocea* bed (see below).

Seagrass restoration efforts in Europe have been centred on eelgrass beds in temperate areas as well as seagrass species in the warmer coastal areas of the Mediterranean Sea. A major focus of restoration efforts has been on *Posidonia oceanica*, the single representative of the *Posidonia* genus in the Northern Hemisphere, along with two other species, *Cymodocea nodosa* and *Zostera noltii* and the prairie-forming green macroalga *Caulerpa prolifera*. Restoration projects in this region have been prompted by widespread destruction of seagrass and algal habitat from shoreline development, pollution, anchor damage and trawling.

Research on seagrass restoration in the Mediterranean includes culture studies and transplantation experiments (see Meinesz *et al.*, 1991 and other sources cited in Gordon 1996). While large-scale mitigation transplantation has not been attempted with *Posidonia*, controlled field trials have been undertaken with cuttings of *Posidonia* in sub-tidal habitats in France to examine factors that influence survival and spreading. These include planting interval, season of planting, orientation of propagules on the seafloor, morphology of shoots and differences in leaf bundle numbers per shoot on cuttings used as the planting units. The trials include reciprocal planting experiments that tested effects of depth on the survival and growth of transplants (Molenaar, 1992; Molenaar *et al.*, 1993).

High survival rates were reported after three years with *Posidonia oceanica* cuttings consisting of plagiotropic shoots with three leaf bundles planted out into natural *Cymodocea* beds (Molenaar, 1992). Differing responses were noted in reciprocal transplant experiments, with lower survival and loss of carbohydrate where plants were transplanted from shallow to deeper sites between 3m and 30m.

While *Posidonia oceanica*, like its Australian counterparts, is a notoriously slow spreader, *Cymodocea nodosa*, like eelgrass, has some capacity to spread fast, with rhizomes that can grow several metres long, at rates up to two metres per year and that persist for years (Meinesz *et al.*, 1991). Flowering and fruiting is prolific but seeds are poorly disseminated and often remain buried. Successful transplantation has been reported with this seagrass using clods of seagrass turf also containing *Zostera noltii* and *Caulerpa prolifera*. Trials have been done successfully with *Zostera noltii* using clods. The seeds of this species are small and difficult to collect.

Australian experience

Australian experience with seagrass restoration is summarised in several reviews and articles (e.g. Paling, 1995; Kirkman, 1997; and LeProvost Dames & Moore and Paling 1995). These reviews are supplemented with recent information published in relation to fisheries habitat (Cappo *et al.*, 1998) and with summaries of regional projects contributed for this report and presented in Section 3.2.

Techniques for planting seagrasses have not been widely investigated despite the high species diversity, high degree of endemism, extensive distribution of Australian seagrasses and well-documented accounts of local losses of seagrass related to coastal development, eutrophication and natural storm events (Poiner and Peterken, 1995).

Published accounts of seagrass transplanting experiments include those with *Posidonia australis* in Botany Bay (West *et al.*, 1990). Small exploratory field trials and a range of experimental and pilot studies on seed germination and viability have been conducted over the last few years in Western Australia with species of *Posidonia* and *Amphibolis* in sub-tidal sandy habitats (e.g. Kirkman, 1989; Hancock, 1992; Nelson, 1992; Walker, 1994; Kirkman, 1995; Paling 1995).

Several factors important to restoration have yet to be investigated for most seagrass species. They include acclimation responses to transplanting, spreading and coverage rates, information on longevity of rhizomes and long-term survival of transplants beyond a few months to one or two years. Consequently, no projects in Australia have the data that can unequivocally demonstrate creation of a permanent, functional seagrass bed out of transplanting efforts. Nor have techniques been tested to the degree that particular methods can be recommended for different seagrass species or habitats.

While Australia can learn from the experience gained through restoration projects with eelgrass in the USA and Europe, much of that work has been developed with plants in relatively sheltered and accessible shallow water habitats.

Techniques already developed for eelgrass may be appropriate for many estuarine settings where seagrasses occur in Australia but they are unlikely to be applicable for restoring seagrass beds in higher energy, relatively unprotected sandy environments that form habitat for *Posidonia* and other larger seagrasses on the southern and southwestern coastline. Experience in transplanting *Posidonia oceanica* in sandy, exposed habitats in the Mediterranean region may offer useful background information for developing restoration techniques for seagrasses in physically exposed areas in Australia.

Irrespective of the location and seagrass species involved, seagrass restoration will be assisted considerably by accurate mapping and monitoring data. This will help to develop better understanding of system dynamics and the setting of meaningful restoration goals and performance criteria on restoration projects. To this end, a recent review of Australian seagrasses includes a call for more cost-effective and statistically robust methods of mapping and monitoring seagrasses around Australia (Kirkman, 1997).

3.1.2 Issues important for success

The important issues that need to be addressed in attempting to restore, rehabilitate or create seagrass habitat are:

- selecting suitable sites
- developing methodology appropriate to site conditions
- improving seagrass spreading and coverage rates
- minimising donor bed damage
- overcoming high labour and time costs
- attracting desired functional attributes

The issues are discussed in detail in Gordon (1996). Key points are outlined briefly below from the information sources referred to by Gordon (1996).

Selecting suitable sites

Selecting a suitable site is the foremost issue to be addressed for successful seagrass restoration. Site evaluation is required for several purposes, among them: selecting where to undertake pre-feasibility trials; selecting where to obtain donor planting material; selecting where to plant out the seagrass planting units and selecting relevant reference beds against which performance of the restored area is to be gauged.

The following features should be considered in site selection:

- a physically-stable seafloor
- a relatively protected seafloor (if possible), and especially during the early stages of plant out
- adequate light, with sufficient daily duration at levels that exceed the photo-compensation point
- good water quality (i.e. low levels of contaminants and no eutrophication problems)
- high water clarity (low levels of turbidity)

- adequate area to accommodate the required replacement to loss ratio for seagrass coverage
- a geographic link to reference seagrass beds against which success is to be gauged and to provide pathways for functional and reproductive processes to be maintained

Sites of particular interest for seagrass restoration are those previously affected by poor water quality that once supported seagrass and which have since shown improvements in water quality; and filled areas that have since returned to their original elevation and show evidence of colonisation by pioneer seagrass species.

Areas to be generally avoided in the development of seagrass restoration techniques include sites of active dredging, and shallow areas with heavy boat usage and mooring. The importance of incorporating ecosystem-scale knowledge about systems into site selection for large-scale restoration programs and the risks of planting in 'barren' patches have been amply illustrated. For example, very large and variable changes have been reported in eelgrass density and cover with oscillations from dense growth to barren seafloor and back again within just a few years (LeProvost Dames & Moore and Paling, 1995).

As in terrestrial restoration programs, landscaping issues are an integral part of site selection and site preparation. For example, observations and aerial photographs of eelgrass beds have suggested that habitat continuity cannot be discerned at interspace distances exceeding 50:1. These ratios may differ depending on meadow structure and the species present, however, the patchiness of seagrass beds will have important implications on decisions to restore the site as a single large area or as a group of smaller areas (see Gordon 1996).

Developing appropriate methodology

Technology has now been reasonably well tested for manual planting of sprigs, plugs and turfs of several seagrass species, particularly in shallow, sheltered sites. Different methods are discussed in detail in Gordon (1996).

Techniques that work well in shallow muddy habitats are unlikely to do as well in more energetic sandy habitats. In southern Australia, for example, swell waves will readily erode tethered seagrass propagules unless they are protected.

Success requires methods to be optimised for local conditions, taking into account factors such as planting season, water depth, and planting interval.

A number of mechanical techniques are being developed to provide larger and more stable transplant units, and to allow for higher rates of restoration.

Improving spreading and coverage rates

Seagrass species perform and respond differently to disturbance and in their ability to recover from disturbance. For example, expansion rates of several tens of metres per year are reported for some eelgrass patches in northern Europe. Similarly, populations of the same seagrass in the US that develop from seed annually have also been reported to have expansion rates of several tens of metres per year under suitable conditions (Gordon, 1996).

On the other hand, experimental plantings of detached shoot bundles of *Posidonia oceanica* into sub-tidal seagrass habitat in the south of France have been undertaken with the expectation that coverage will not be fully realised for perhaps several years to decades, due to the slower spreading rates of *Posidonia*.

In general, species with slow spreading features are less attractive for restoration projects, particularly those undertaken as compensatory mitigation for seagrass damage or loss. The slower spreading species are usually also the larger, perennial and climax ones. Consequently, there is considerable interest in promoting seagrass restoration methods that will lead to the most rapid success with climax species.

Growth rate-coverage models have been assembled for some seagrass species and habitats e.g. some of the sub-tropical species in the southeastern USA. Some of these seagrasses, such as *Syringodium filiforme* and *Halodule wrightii* show fast spreading rates. These have predicted coverage rates in the order of tens to hundreds of days while others, such as *Thalassia testudinum*, are notoriously difficult to propagate, spread slowly and have predicted coverage rates of several years (Table 1 in Gordon, 1996).

In order to improve spreading and coverage rates, better understanding is needed of the population biology of seagrasses in different habitats and the mechanisms underlying the inability of seagrasses to re-invade disturbed sites. Beyond inadequate light and pollution problems, the reasons may include factors related to altered chemical and structural properties of sediments as well as intrinsic features of the plants.

Minimising donor bed damage

Reliance on natural seagrass beds as donor sites for planting material will produce damage to these beds. The main sources of planting material for seagrass restoration include harvested rhizomes and fruits, seedlings collected from beds and beach drift, and seagrasses or seagrass parts removed from natural seagrass beds. Availability of material depends on season and species. Availability of propagules of some Australian seagrasses and their requirements for culture and storage have been discussed previously (e.g. Kirkman 1989; 1992; 1995).

Research has been underway in some regions, such as southeastern USA, to develop artificial culture systems and *in vitro* techniques aimed at developing non-destructive, year-round sources of planting material to reduce the reliance on donor beds. *In vitro* propagation and culturing techniques are seen as attractive as they would allow production of uniform planting units in accordance with demand, enabling small-scale stock cultures to be maintained and subdivided for use as required (Durako, 1988). In addition, culturing and sterile techniques provide opportunity to control possible effects of disease and to control problems introduced by use of inappropriate planting stock.

The technology is far from developed and thus there will continue to be heavy reliance on use of natural seagrass beds as a cheap and ready source of planting stock for most restoration projects. An important segment of information required is an understanding of the natural recovery rates of donor beds.

Overcoming high labour and time costs of manual planting

The most desirable outcome of restoration efforts is to obtain rapid seagrass coverage with replacement of function at minimum cost. These goals are best achieved through optimising methodology, utilising the natural attributes of the system as much as possible and using available technology cost-effectively.

Seagrass transplantation relies on labour-intensive, time-consuming and usually costly manual planting methods, making large-scale restoration efforts extremely costly. Several papers have provided estimates of the labour and time costs per unit area and data on timed trials for some small projects (Gordon, 1996 and sources cited therein). Planting conditions differ across species. The costs of manual planting increase considerably where spacing intervals have to be narrow to ensure high survival, as suggested in the experiments with *Posidonia oceanica* planted cuttings in France.

Mechanical techniques offer more cost-effective procedures for large-scale restoration. Mechanical-assisted restoration has obvious potential in two main areas:

- to assist in large-scale salvage of seagrasses
- to produce efficient, fast methods of harvesting, sowing and planting out propagules

There are few published accounts of mechanically-assisted restoration of seagrasses. A boat-mounted mechanical sod remover has been used to remove sods of *Thalasssia* and *Syringodium* in southeastern USA (Gordon, 1996). The machine and boat could only operate in shallow water and the rest of the program relied on manual methods.

As in other parts of the world, seagrass restoration in Australia has relied largely on manual techniques. Mechanical equipment has been employed in a few notable projects, including use of an amphibious mechanical excavator to transplant small plots of *Zostera capricorni* in intertidal habitats, with eventual reported increase in shoot density and seagrass area (Conacher and Poiner, 1991). Some parallel research was undertaken to test germination, storage life and viability of *Zostera capricorni* seeds (Conacher *et al.*, 1994). That particular line of research is lacking for most Australian seagrass species over the range of habitats in which they grow (see Kirkman, 1989).

An innovative submarine vehicle has been developed recently in Western Australia as part of a project to mitigate for seagrass loss from shells and dredging in offshore waters of several metres depth. The machine cuts, removes and stores sods of *Posidonia* from the donor bed, then transplants the sods in lines on the seabed at the receiver site. To date, the technology has been used to salvage seagrass clumps from approved dredging areas to adjacent transplant sites. Monitoring is now underway to determine long-term survival rates of the salvaged plants. The results of this work are discussed in more detail in Section 3.2.

Replacing seagrass function

Return of a functional seagrass bed is the ultimate goal of seagrass rehabilitation and restoration. Ideally, the transplanted site should not compromise existing seagrass function, nor should it reduce the resilience, persistence and diversity of nearby seagrasses (USNRC, 1992). It is also generally recommended that functional attributes be included along with structural attributes in setting performance criteria for aquatic restoration projects (USNRC, 1992).

Suggestions have been made on functional attributes that might be included in assessing the functional equivalence of constructed and natural wetlands. These are also relevant to seagrass systems.

They include data about:

- hydrological function (influence on equilibria for particle and nutrient flux and patch dynamics)
- nutrient supply limitation
- population maintenance and persistence (life history and reproductive strategies)
- persistence of consumer populations (fish and fauna habitat use and feeding, nursery and recruitment sites)
- indicators of population resilience and the capacity of populations to repair and
- resistance of populations to invasion of exotic species, to die-back and to other disturbance

Functional equivalence of restored meadows remains to be demonstrated at the large scale. Present approaches to achieving functional restored seagrass beds point to getting area back first, with function developing with expansion and maturity of the restored meadow. Re-introduction of fauna is then a passive process (Fonseca, 1989).

Promising results have been documented in different projects examining the composition of fish and other fauna in restored areas against those in reference areas. However, other reports comparing particular fauna in reference seagrass beds with two-year-old restored beds suggest that the links between functional equivalence and seagrass cover are still obscure (Gordon, 1996).

3.2 Review of Australian projects

3.2.1 Introduction

Table 3.1 shows a list of known seagrass rehabilitation and restoration projects. For each of these, details on the project is presented in a tabular form in the Appendix to this Chapter. The information has been assembled from interviews with contributors.

Table 3.1 Seagrass rehabilitation and restoration projects undertaken in Australia

Location	*Seagrass Species*	*Date*
Western Australia		
WA1: Success and Parmelia Banks, Owen Anchorage	*Posidonia australis*	1990
WA2: Cockburn Sound (three sites), Warnbro Sound	*Posidonia australis*, *Posidonia sinuosa*	1977, 1978
WA3: Carnac Island	*Posidonia australis*, *Posidonia sinuosa*, *Posidonia coriacea*, *Amphibolis griffithii*	1992
WA4: Shoalwater Bay	*Posidonia australis*, *Posidonia sinuosa*	1986
WA5: Success Bank	*Posidonia sinuosa*, *Posidonia coriacea* (mixed)	1993
WA6: Carnac Island	*Posidonia sinuosa*, *Amphibolis griffithii*	1994
WA7: Rottnest Island	*Amphibolis antarctica*, *Amphibolis griffithii*	1985
WA8: Cockburn Sound/ Warnbro Sound	*Amphibolis antarctica*	1992
WA9: Success Bank	*Amphibolis griffithii*	1997
WA10: Success Bank	*Posidonia coriacea*, *Amphibolis griffithii*, *Posidonia sinuosa*	1996
WA11: Oyster Harbour	*Posidonia sinuosa*	1997
WA12: Cockburn Sound	*Posidonia australis*, *Posidonia sinuosa*, *Posidonia coriacea*, *Amphibolis antarctica*, *Amphibolis griffithii*	1989
WA13: Warnbro Sound	*Amphibolis antarctica*, *Amphibolis griffithii*	1990
WA14: Rottnest Island	*Posidonia australis*, *Posidonia coriacea*, *Posidonia angustifolia*, *Amphibolis antarctica*, *Amphibolis griffithii*	1990
New South Wales		
NSW1: Botany Bay	*Posidonia australis*, *Zostera capricorni*	1988
NSW2: Botany Bay	*Zostera capricorni*	1995
NSW3: Botany Bay	*Zostera capricorni*	1997

(continued…)

Location	*Seagrass Species*	*Date*
NSW4: Botany Bay	*Zostera capricorni*	1997
NSW5: Hastings River	*Zostera capricorni*	1990s
Queensland		
QLD1: Cairns Harbour	*Zostera capricorni*	1990
QLD2: Raby Bay	*Zostera capricorni*	1992
QLD3: Victoria Point	*Zostera capricorni?*	1992
QLD4: Ellie Point, Cairns and Green Island	*Zostera capricorni, Cymodocea*	1998
Northern Territory		
NT1: Western Gulf of Carpentaria	common species including: *Cymodocea, Syringodium, Halodule, Halophila*	1987

The information is presented on a regional basis (State by State), and offers an overview of the fairly significant number of seagrass restoration endeavours that have occurred in Australia.

Two of the most substantial projects are further described in detail in Section 3.2.3. These two projects are:

- restoration of eelgrass (*Zostera capricorni*) in Botany Bay, NSW
- transplantation of *Posidonia coriacea and Amphibolis griffithii* in Owen Anchorage, WA

3.2.2 Detailed reviews of selected projects

The following projects are discussed in detail as they demonstrate use of seagrass restoration principles and use of restoration technology on current projects underway in Australia at a relatively large scale. They also include examples of research and development in practice through innovative engineering and technology used to transplant perennial seagrass species in waters of several metres depth in a relatively high-energy environment.

Sydney airport runway extension, Botany Bay, NSW

Background

Construction of the Sydney airport runway extension in 1994 is an example of a significant recent development in Botany Bay that required replacement of seagrass as compensation for habitat loss. It has been cited as the first large-scale successful transplanting of *Zostera* on the Australian east coast (Gibbs, 1997). Construction of the third runway resulted in various fish habitat changes, including loss of more than 18 ha of the seagrass *Zostera capricorni*. Restoration of seagrass beds and habitat reconstruction were called for as a condition of the runway extension project because of the removal of seagrass and loss of habitat for birds, including the endangered little tern (*Sterna albifrons*) and wading birds (Gibbs, 1997; Smith *et al.*, 1997).

Consent for the development to proceed included a condition that the FAC investigate construction of compensatory bird habitat within Botany Bay. Towra Spit was recommended as a site for relocating the bird habitat and this was addressed in an EIS prepared by the project. The EIS recommended construction of four groynes and the removal and relocation of 33,000 cubic metres of sand to stabilise an island and to create an intertidal habitat. Sand removal and relocation originally represented some 5 ha of seagrass beds (*Posidonia* spp and *Zostera* spp) within the Towra Point Aquatic Reserve.

Requirements for compensating habitat loss as part of the approval for the runway extension included establishment by natural recolonisation, or through artificial propagation, of *Zostera* seagrass meadows on the 30 ha of substrate created between the two runways and on the eastern side of the new runway.

Natural recolonisation by seagrasses in the two created areas has been monitored since January 1995. Following commencement of construction of rock groynes to protect Lady Robinson's Beach from erosion in 1997, the original project was extended to include pilot transplantation of seagrasses from the rock groyne construction area into the created habitats. The pilot project involved the transplanting, in April 1997, of approximately 1.8 ha of seagrass to 16 large plots positioned between the runways and on the eastern side of the runway extension.

Methodology for seagrass removal and transplanting

The original contract specified that seagrasses were to be removed as plugs by hand. Due to cost and time considerations, however, that specification was amended to a combination of mechanical and manual transplanting techniques. The transplantation program was undertaken by Land and Marine Pty Ltd.

To undertake the work, the company developed a mechanical seagrass harvester, known as the 'Dugong' and developed methods to transport and transplant the seagrasses. NSW Fisheries is the permitting agency for the transplantation project and also has had significant input into the overall design of the program. A flexible approach was adopted between NSW Fisheries and the contractors in setting formal conditions on the project to overcome practical difficulties associated with moving unconsolidated marine sediments and to increase the likelihood of success.

A pre-project survey showed that the seagrass bed to be transplanted was not a dense meadow but comprised mainly immature *Zostera capricorni* plants, whose individual shoots had little or no rhizome and only small root systems. Consequently, poor coherence of the sediments often resulted when seagrasses were removed. The problem was reduced by using larger plugs of 300 mm × 570 mm (the size of a small fish box). These larger plugs also ensured that at least some shoots were present in each box for transplanting. In practice, the plants were often distributed in the boxes by hand to ensure a minimum of three plants per box.

The mechanical harvester was in the form of a vessel-towed flat dredge that operates by biting into the seagrass meadow (to a minimum depth of 20 cm) to yield a coherent slice approximately 0.9 m wide and 1.2 m long. The harvester is positioned on the seafloor using differential GPS or sightlines, depending on water clarity and density of seagrasses. Its designers consider it able to carry out harvesting with minimal impact to the surrounding seafloor. The machine collects leaves, shoots and rhizomes immediately surrounding the plants along with sediments, so that the biophysical integrity of the plant and sediment is maintained for rapid colonisation of new areas into which the plants are introduced.

After each bite the dredge is brought up onto the deck of the work vessel and the sediment plus seagrass transferred to the rectangular 'fish boxes'. Initial problems caused by trying to carry loose, unconsolidated sediments in the boxes were resolved by inverting plants and sediments and transporting them this way to the site. This put plants and root systems at the bottom of the boxes and kept the loose material at the top. All boxes were kept covered with seawater during transport from the donor to the transplant sites.

Transplanting sites were specified by NSW Fisheries and indicated by reference to marks made on the airport runway seawalls. Lines were drawn out from the seawalls using buoys and divers and the boxes placed end to end along each line, creating rows.

Initially, samples were brought over right way up and then lowered to the sea floor, placed in rows, tipped onto a plastic slate upside down, then the slate plus inverted sediment plus seagrass mass was rolled over once again to form the final rows of planted grasses on the sea floor surface. This method had three main problems:

- during transport, sediments consolidated and packed down in the boxes leaving the root bole exposed
- double turning of sediments on the sea bed led to unacceptable loss of fines with excessive turbidity and loss of quality control of the work area
- following final placement, after turning over the grasses were often left with their roots exposed

The transfer procedure was modified in a way that reduced root exposure and problems of fines being lost at the plant-out site. The plants were transported inverted, the trays were lowered to their sites on the sea floor then turned over (upright) once only. Problems with fines were reduced by not removing the trays manually, but leaving them in place until gravity pulled the sediment mass to the bottom. The trays then lifted off the sea floor with minimal loss of fines. A significant advantage of this procedure was that the reduced turbidity allowed divers to inspect the plant-out site immediately the trays surfaced and make any necessary adjustments, e.g. pushing any exposed root systems into the sediment mass and releasing any buried shoots. The single obvious disadvantage of the method was that it was unknown how long the seagrasses could survive upside down and smothered in sediment. So, the removed grasses were immediately transported and planted.

Stapling or pinning samples into the sediments proved fruitless. Pinning is preferred if samples are sufficiently consolidated, but no samples were advanced enough to make it work in practice.

Artificial seagrass units (ASUs) were used in some of the plots to provide protection and to reduce wave action, which can be considerable at the transplant sites between the runways. At each ASU site, the artificial units were carefully lowered over the transplanted seagrass. They were then pushed down into the sediment and all the grass blades carefully teased through the ASU mesh. Individual plants located under the mesh were replanted into it.

Outcomes and conclusions

Outcomes of the habitat restoration efforts for the airport extension runway project in Botany Bay are summarised in the tables presented elsewhere in this Chapter, based on information and articles supplied by NSW Fisheries. At the time the project ceased, when more than 90% of the seagrass had been removed, there was no additional grass available for transplant to the site.

The following points are highlighted, based on information in the contractor's final report and additional information supplied by NSW Fisheries from their ongoing monitoring of the created habitats (Gibbs, 1997):

- Daily collection and placement summary sheets (vital to good record keeping in seagrass restoration projects) were produced as part of the project documentation, including statistical data on mean daily hauls of boxes converted to coverage rates per day.
- Nine of the 29 working days taken to do the job were lost through bad weather (an important consideration in budgeting necessary time and resources for field work for seagrass restoration projects).
- Transplanting was undertaken from 12 March to 9 April 1998. NSW Fisheries and the Sydney Ports Corporation (SPC) made a site visit with Ward Civil Engineering in early April; SPC and Fisheries NSW representatives dived on several of the eastern and western sites and Fisheries NSW made a video of the transplants. The contractor's report indicated that at that time all visited sites supported viable and healthy seagrasses.
- Some differences occurred between specified transplanting targets and actual coverage achieved. This was due to several factors, including weather constraints; a lack of transplant material near the end of the program, which meant that some coverage targets could not be met at some sites; and the use of unsuitable methods for placing boxes in the early stages. At two sites additional boxes were placed next to the original sites, with care taken to avoid any original transplants which had been successful.
- The contractors deemed the seagrass transplantation project 'completely successful' on the basis of the 'after' survey at the donor site plus the outcomes of the inspections made of the transplant sites on 9 April. However, it should be noted that a full evaluation of success must come out of longer-term results, as indicated in the tables.

- The monitoring project conducted by the Coastal Conservation Research Branch at NSW Fisheries indicated that three months after the 16 large plots were transplanted, *Zostera* was present at all eight sites on the eastern side of the runway. No seagrass remained at two sites between the runways while the other six sites had a few scattered clumps and some isolated individual plants. This was considered positive, given the losses incurred from a storm in late April 1997, which uprooted or buried much of the transplanted seagrass.
- Artificial seagrass units (ASUs) used to stabilise some experimental plots and to reduce wave action did not appear to greatly assist the transplants. After three months, the ASU plots contained only small amounts of seagrass, possibly the result of abrasion by the artificial seagrass blades heavily fouled by epiphytes (Gibbs, 1997). However, the surviving seagrass plants in the plots appeared longer, denser and less grazed than the other surviving transplants.
- Natural colonisation of the two created areas was dominated by *Halophila*, with some significant meadows developed, especially on the eastern side of the runway (Gibbs, 1997).
- A census of fish that are using the created habitats showed that, in addition to bream, flathead, ambassids, and crabs, some seagrass-associates such as leatherjackets and pipefish were also present in low numbers (Gibbs, 1997).

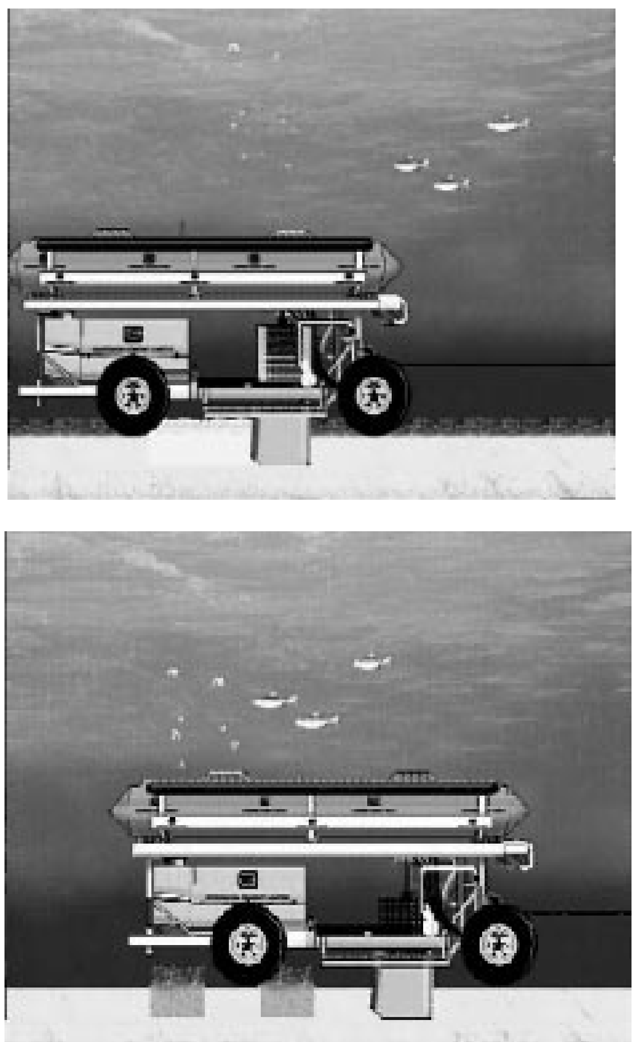
Seagrass transplantation: Success Bank, Owen Anchorage, Western Australia

A series of unconsolidated carbonate sand deposits off the coast of Western Australia are the source of calcium carbonate for the production of lime by Cockburn Cement Limited (Cockburn). Cockburn removes this material by dredging, and presently is operating on Success Bank, approximately 5 km south-west of the port of Fremantle. Some areas on the top of Success Bank contain seagrasses, dominated by *Posidonia coriacea*, and *Amphibolis griffithii*, both separately and in mixed meadows, with *Posidonia sinuosa* on bank edges. In 1994, Cockburn was required to implement a comprehensive Environmental Management Program (EMP), which required the development of seagrass transplantation techniques.

At that time, little success had been achieved in Western Australia with manual transplantation (see summary tables). This was due to loss or removal of transplanted seagrass by hydrological forces, epiphyte growth, fungal attack and/or grazing by sea urchins. Of the 7,500 transplant units that have been placed within the Perth metropolitan area, most have been lost due to water motion. The most long-lasting manual transplants were ones that used large cores (15 cm in diameter) containing roots, rhizome and sediment material. To make restoration feasible, larger transplant units were necessary (to ensure high survival rates) along with the capability of restoring a sufficiently large area. The only feasible option therefore was to construct a mechanical device to extract and plant seagrass.

An underwater seagrass harvesting and planting machine (ECOSUB I) was designed with the specific parameters that a large seagrass 'sod' (0.25 m^2 in area, 0.5 m deep with a mass of 300 kg) could be extracted and planted with minimal disturbance to the leaves, roots and rhizomes contained within it. A prototype was developed and tested (by Ocean Industries WA) by the end of September 1996 and transplantation commenced in November 1996. The machine, which is operated by three divers, consists of a frame with four wheels that is self-winched across the ocean floor. It contains a cutting head with forward vibrating teeth, powered by a hydraulic ram (hydraulics supplied by a support boat). The cutting head is fitted with an open-ended cartridge which, when filled with seagrass, is extracted and placed into an onboard hopper. The hopper stores nine

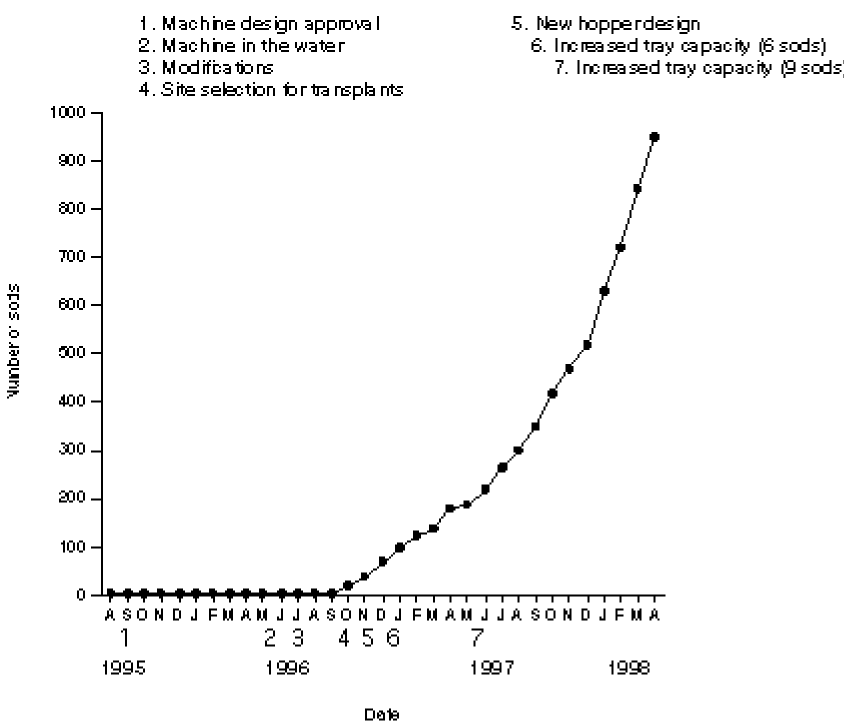
Figure 3.1 Schematic representation of ECOSUB I extraction and planting process.



sods before the machine is raised on its own buoyancy tanks and moved to the planting site. Figure 3.1 shows a schematic representation of the extraction and planting procedures. Sods can be placed in a variety of configurations but are usually laid in rows as this is most efficient. The prototype has undergone major modifications since its first deployment and it is now capable of cutting and extracting a seagrass sod in less than 10 minutes. One thousand sods have successfully been extracted and planted since November 1996 (Figure 3.2). A range of species has been transplanted; monospecific *Posidonia sinuosa*, *Posidonia coriacea*, *Amphibolis griffithii* and a mixture of the latter two species.`

Approximately 85% of the mechanically transplanted sods had survived after five months, and this value remained unchanged after 15 months (Figure 3.3). Shoot densities in general showed a decline in winter followed by an increase in the following summer (Figure 3.3). Percentage change in shoot densities in the transplanted sods exhibited a greater variation (from 10–70%, measured every three months) in comparison to control beds of *Posidonia coriacea* and *Amphibolis griffithii* (5% and 40% respectively over 15 months).

Figure 3.2 Cumulative number of sods planted mechanically, up to the end of May 1998. Major machine milestones are shown. (Approximately 1000 sods have been planted up to the end of May 1998).

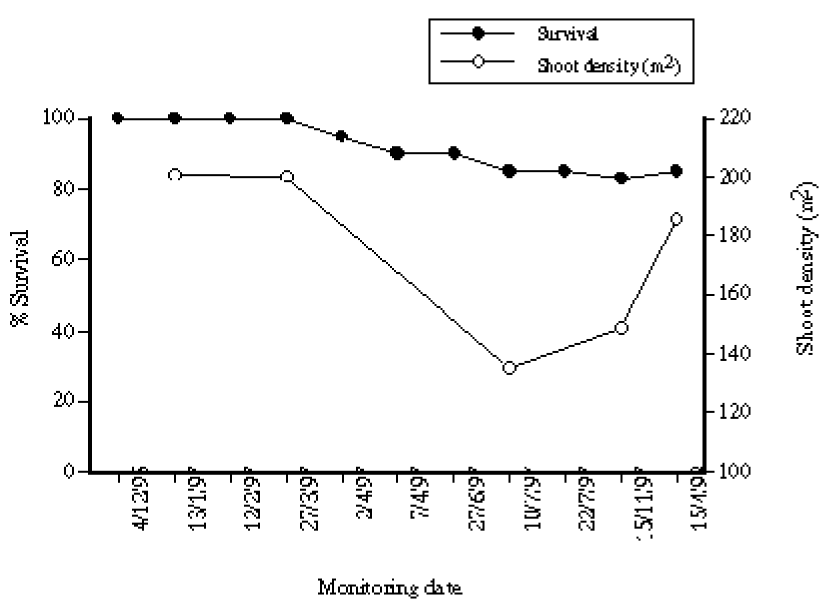


Spreading was observed in *Posidonia sinuosa* sods at the recipient site. In some cases rhizomes up to 30 cm in length were recorded. A subsample of 80 sods was randomly selected from the 230 sods planted (35% of the population), these being the sods that had been the longest in place (between 10 and 17 months). Of these 80 sods, 28 (35%) showed signs of spreading, with a mean rhizome length of 10.4 cm. Taking into account the individual variation, the standard deviation of the extension rates was 6.8 cm. This equates to a range of monthly extension rates of 0.5–1.76 cm per month or 6–21 cm per year.

Numerous *Posidonia sinuosa* seedlings were observed at the recipient site in April 1998. Approximately 1000 seedlings were found amongst transplanted sods in all parts of the site, but not in adjacent bare sand areas. It is not possible to accurately determine the age of the seedlings, however it is estimated that they are at least 10 months old. Some seedlings had three or four leaves present, to a length of approximately 20 cm, and root lengths of 10–20 cm were observed. Most seedlings appeared well anchored within the sediment, and were identified as seedlings only by the presence of a testa, at some depth below the sediment level.

As the transplantation process has been refined, the rate of planting has increased. The current planting rate (prior to winter 1998) is approximately 100–120 sods per month, equivalent to 25–30 m^2 actual seagrass area (at 100%

Figure 3.3 Percent survival and shoot density in mechanically transplanted sods



cover). Developments in the machine technology used for transplantation have been important in increasing transplantation efficiency and, despite reduced planting time due to poor weather in winter, it is clear that the rate of transplantation continues to increase. This rate can be expected to stabilise over the winter period with no further development of the machine technology expected until the launching of ECOSUB II.

ECOSUB II is already under construction and should be operational in early 1999. It will comprise two units each dedicated to a single transplant operation, the first designed specifically to take up sods, and the second to plant them. Sods will be transported by barge from donor to recipient site. This technology will be capable of transplanting sods of seagrass of approximately 0.5 m^2 in size, at a nominal rate of 40 m^2 per day. The increased transplantation rate possible with the new machine, combined with increases in seagrass area through spreading and seedling settlement between transplanted sods, will improve the overall performance of the mechanical transplantation program in relation to the targets outlined in the EMP.

3.3. Recommendations for research

3.3.1 Introduction

Only limited research and development is being undertaken in Australia that can assist seagrass restoration. Few large mitigation projects have been undertaken and most restoration ventures are of an *ad hoc* nature rather than having the ultimate goal of developing a feasible restoration technique. In most cases, experimental restoration programs have not been conducted for a sufficient time to allow for optimising techniques and for success to be properly monitored.

A purposeful seagrass restoration program in Australia should be based on the acceptance that success can only be achieved by a sufficiently substantial program that should last at least five years as a first stage. This amount of time is needed to allow for sufficient development of techniques, and also to sensibly monitor the success of any operation.

The recommendations presented here for research and development of seagrass restoration techniques are restricted to considerations of technique development, and do not include the necessary additional requirements of obtaining a sound knowledge of seagrass ecosystem function and seagrass dynamics. Clearly it would be prudent to undertake seagrass restoration programs in concert with well constructed programs of research into the fundamental characteristics of seagrasses.

It is also assumed that the principal objective of seagrass restoration is to get seagrasses to establish and grow on the understanding that, if area is restored, ecological function will also be restored.

Seagrass restoration is expensive and, to ensure an efficient use of resources, it is recommended that Australian seagrass restoration research focus on three major environments and the dominant species within them. These environments, described in Table 3.2, represent the major species coverage, habitat types and likely areas to be degraded.

Table 3.2 Three major seagrass environments recommended for restoration research

	Northeastern Australia	*Eastern Australia*	*Western Australia*
Climate	sub-tropical	temperate	temperate
Tidal regime	intertidal subtidal	subtidal	subtidal
Environment	estuarine open ocean	estuarine	open ocean
Energy	high energy	low energy	high energy
Sediment	mud	sand	sand
Suggested species	*Halodule uninervis* *Cymodocea sp.* *Zostera capricorni*	*Posidonia australis* *Heterozostera tasmanica*	*Posidonia australis* *Posidonia sinuosa* *Posidonia coriacea* *Amphibolis*

There is a degree of overlap between species around the coast and information gained on *Heterozostera* could be applied to the western, southern and eastern coasts of the continent. Similarly, *Amphibolis* data could be applied to the western and southern coastlines. Northeastern Australian estuaries are superficially similar to those on the American east coast. It is envisaged that successful transplant techniques could be directly transferred.

The program of research and development that is implemented should have national coordination, to ensure:

- effective exchange of information and experience
- standard protocols are employed for assessment site characteristics and selecting restoration sites
- standard procedures are developed and used for measuring the success of restoration

3.3.2 Specific recommendations

The development and implementation of a purposeful seagrass restoration program in Australia should be based on the following considerations:

- Identification of a range of key representative seagrass habitats around Australia, which can form the basis for a nationally coordinated effort to develop appropriate seagrass restoration technology in habitats that display differing environmental features, e.g. differing sedimentary and energetic regimes; the representative habitats should also be selected to take account of the degree to which regional seagrasses are presently threatened, or likely to be threatened in the future, by development activities

- Identification of local sites within each representative habitat type where features and environmental conditions dictate that experimental seagrass restoration efforts could be successful, and therefore warrant support now, or be capable of being supported in the near future
- Development of a protocol and procedures for assessing the most appropriate techniques for transplanting or planting seagrasses under the different conditions experienced within sites selected in each regional representative habitat
- Implementation of pilot trials to provide information on the most appropriate seagrass species for use in restoring or rehabilitating seagrass habitat within representative habitat types
- Implementation of programs to monitor and evaluate the performance and success of pilot and experimental seagrass restoration efforts within each representative habitat
- Implementation of research on seagrass biology specific to the development of seagrass restoration techniques

These points are discussed further below.

1. Identification of a range of key representative seagrass habitats around Australia, which can form the basis for a nationally coordinated effort to develop appropriate seagrass restoration technology

   It is recommended that a program of research and development be based on the recognition of the three broad habitat types described in Table 3.2. These habitat types provide examples of seagrass ecosystems experiencing different climatic, tidal and sedimentary conditions, and different suites of species. The program would be directed towards developing appropriate restoration techniques that, once tested, can be applied more widely to similar habitats around Australia.

   It is anticipated that for higher energy environments, such as those in southern and southwestern Australia, greater emphasis might be placed on developing mechanically-based techniques to harvest and plant out some of the perennial seagrass species that occur in deeper, more physically-exposed waters and under more energetic and sandier environments than occur in estuarine or shallow, intertidal areas. Similarly, the shallower, intertidal areas and estuaries of the east coast may warrant development of both manual and mechanical techniques.

2. Identification of local sites within each representative habitat type where features and environmental conditions dictate that experimental seagrass restoration efforts could be successful, and therefore warrant support now, or

be capable of being supported in the near future. The main local issues that need to be addressed include:

- identifying reasons for loss, or absence, of seagrasses at the site
- historical information on changes in seagrass cover around the site
- degree of sediment stability
- hydrodynamic features affecting stability and biological processes
- existing and future water quality

A set of site selection criteria have been proposed for seagrass restoration projects in the USA. These are similar to those recommended for Australia, although the USA criteria provide stronger emphasis on the close proximity of similar seagrass assemblages. The USA experience also recognises that small transplantation units are more subject to failure due to bioturbation. As yet there is not sufficient experience in Australia to confirm a similar trend.

Finally, in the USA significant emphasis is placed on maintaining the genetic diversity of seagrass beds, with the recognition that the conservation of existing natural stocks and the avoidance of geographic isolation of seagrass populations are long-term management goals. As a result, harvesting of transplantation stock is required to be from as wide an area as feasible within a water body.

All of these issues will need to be considered in Australian waters, and the importance of each of these matters assessed according to the natural features of the area.

In Western Australia, potential sites for developing restoration techniques include:

- Owen Anchorage (Success and Parmelia Banks)
- Cockburn Sound (Eastern Flats and western shore of Garden Island)
- Albany (Princess Royal Harbour, Oyster Harbour, Two People's Bay)

In eastern Australia, potential sites for developing restoration techniques include:

- Botany Bay
- Hastings River

In northeastern Australia, potential sites for developing restoration techniques include:

- Ellie Point, Cairns
- Green Island
- Raby Bay

In northern Australia, potential sites for further evaluating natural recolonisation and for developing restoration techniques include:

- Western Gulf of Carpentaria

Other sites with potential for successful seagrass restoration are likely to exist in each of the broad regions.

3. Development of a protocol and procedures for assessing the most appropriate techniques for transplanting or planting seagrasses under the different conditions experienced within each regional habitat.

   This will include an assessment of both mechanical and manual techniques, making use of some of, or all of, the following planting units:

   - sprigs
   - rhizomes
   - cores
   - sods/turfs
   - seeds

4. Implementation of pilot trials to provide information on the most appropriate seagrass species for use in restoring or rehabilitating seagrass habitat within each representative habitat type.

   The representative regions support different suites of seagrasses and display different degrees of seagrass diversity. Requirements for seagrass growth and survival, and for population maintenance, across such broad regional areas will differ, so that pilot testing of selected or preferred species may be required in some or all regions, in order to select the most appropriate species for particular restoration techniques.

   The development and application of the 'Dugong' in planting out *Zostera* in Botany Bay, NSW and the development of the 'ECOSUB' to transplant *Posidonia* in Western Australia are examples of pilot stage development of technology using different species.

   Pilot studies, should, preferably, run for a minimum of three years to allow for modification of the techniques and for collection of sufficient data to reasonably assess success or failure.

5. Implementation of programs to monitor and evaluate the performance and success of pilot and experimental seagrass restoration efforts within each representative habitat.

   Monitoring and assessment should include:

   - development and use of standard protocols and indicators for evaluating and measuring success
   - observations on natural dynamics of the adjacent seagrass beds and seafloor, to integrate with any research being done on seagrass physical dynamics
   - evaluation of the effects of seagrass removal on donor beds

6. Implementation of aspects of research on seagrass biology that are specifically related to the development of seagrass restoration techniques.

   Additional areas of investigation that warrant consideration include:

   - development and testing of site augmentation procedures (landscaping, filling, re-profiling) and their role in improving survival, growth and spreading rates of seagrasses at restoration sites

- development of seagrass propagation techniques to promote faster spreading rates
- development of culture techniques to provide appropriate planting stock to overcome the present reliance on natural seagrass beds as a source of seagrass planting units
- development of genetic techniques to develop faster growing propagules
- role of carbonate sediments and iron in influencing the availability of phosphorus to seagrasses, as well as the use of artificial fertilisers to stimulate seagrass regrowth

Finally, it is recommended that a national, coordinated program to develop seagrass restoration technology in Australia be undertaken through close cooperation between industry, government and the developers of the technology, in both economic and technical aspects of the program. This will also require due consideration of the intellectual property rights involved in the development of such technology.

There is little doubt that a national, coordinated program of this kind would ensure that Australia is at the forefront of this particular field of marine habitat restoration and would provide a greater technically-based capacity to reduce the negative impacts on seagrasses associated with many development activities around Australia's coastline.

3.4 Acknowledgements

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Appendix 3.1 Summary of seagrass rehabilitation and restoration projects in Australia

Western Australia

WA1: Success and Parmelia Banks, Owen Anchorage, 1990	
Objective of project	Research (transplant technique)
Seagrass species used	*Posidonia australis*
Planting methods	Seedlings in Growool pots 7–20 m; ~2,700 seedlings in total
Plant spacing and density	350–550 seedlings per depth
Size of areas planted	?
Project duration	8 months
Assessment of relative success or failure	% survival, growth
Date and other comments	January 1990
Hydrodynamic characteristics:	
• water depth	7–20 m
• wave climate and characteristics	High to medium energy
• tidal features	Orbital, 1 m
Sediment characteristics:	
• sediment type	Sand to fine sand
• sediment depth	>1 m
• level of contamination	1–2
Water quality characteristics:	
• water clarity/light attenuation	Medium to high
• trophic status	Oligo to meso
Physical protection/alteration of site	None
Monitoring:	
• what attributes, how frequently, and for how long	% survival, growth; 2 monthly for 8 months
• findings	4–50% survival after 2 months. No survival after 8 months.
Performance criteria (details of the relevant requirements that were established and needed to be met)	N/a
References	LEC, 1990
Research/development/ demonstration project descriptions	No information supplied

WA2: Cockburn Sound (3 Sites), Warnbro Sound, 1977, 1978	
Objective of project	Research (eutrophication)
Seagrass species used	*Posidonia australis*, *Posidonia sinuosa*
Planting methods	Seedlings in PVC tubes with intact sediment (~150)
Plant spacing and density	?
Size of areas planted	<5 m
Project duration	5 months
Assessment of relative success or failure	% survival, growth
Date and other comments	October 1977, November 1978
Hydrodynamic characteristics:	
• water depth	2–3 m
• wave climate and characteristics	Medium
• tidal features	Orbital, 1 m
Sediment characteristics:	
• sediment type	Sand
• sediment depth	>1 m
• level of contamination	1–3
Water quality characteristics:	
• water clarity/light attenuation	Medium to high
• trophic status	Oligo to meso
Physical protection/alteration of site	None
Monitoring:	
• what attributes, how frequently, and for how long	% survival, growth; monthly for 5 months
• findings	0–70% survival after 5 months
Performance criteria (details of the relevant requirements that were established and needed to be met)	N/a
References	Cambridge, 1980
Research/development/ demonstration project descriptions	No information supplied

WA3: Carnac Island, 1992	
Objective of project	Research (transplant techniques)
Seagrass species used	*Posidonia australis, Posidonia sinuosa, Posidonia coriacea, Amphibolis griffithii*
Planting methods	Seedlings in Growool blocks (90 total); rhizome bundles (70 total)
Plant spacing and density	0.5 m
Size of areas planted	<5 m
Project duration	12 months
Assessment of relative success or failure	% survival, growth
Date and other comments	February 1992
Hydrodynamic characteristics:	
• water depth	3 m and 11 m
• wave climate and characteristics	High to medium

WA3: Carnac Island, 1992 (continued…)	
• tidal features	Orbital, 1 m
Sediment characteristics:	
• sediment type	Sand, fine sand
• sediment depth	>1 m
• level of contamination	1–2
Water quality characteristics:	
• water clarity/light attenuation	High
• trophic status	Oligo
Physical protection/alteration of site	None
Monitoring:	
• what attributes, how frequently, and for how long	% survival, growth; monthly for 10 months
• findings	0–90% survival after 2 months, 9–15% survival after 4 months for seedlings; 13–75% survival after 6 months with rhizomes
Performance criteria (details of the relevant requirements that were established and needed to be met)	N/a
References	Hancock, 1992
Research/development/ demonstration project descriptions	No information supplied

WA4: Shoalwater Bay, 1986	
Objective of project	Research (below ground production)
Seagrass species used	*Posidonia australis, Posidonia sinuosa*
Planting methods	Rhizome staples + tethering 30 per species
Plant spacing and density	<1 m
Size of areas planted	<1 m
Project duration	3 years
Assessment of relative success or failure	% survival, shoot density, rhizome growth
Date and other comments	February 1986
Hydrodynamic characteristics:	
• water depth	5 m
• wave climate and characteristics	Calm
• tidal features	Orbital, 1 m
Sediment characteristics:	
• sediment type	Sand
• sediment depth	0.5 m
• level of contamination	1
Water quality characteristics:	
• water clarity/light attenuation	High
• trophic status	Oligo to meso
Physical protection/alteration of site	None
Monitoring:	
• what attributes, how frequently, and for how long	% survival, shoot density, rhizome growth
• findings	0% survival after 30 days

WA4: Shoalwater Bay, 1986 (continued...)	
Performance criteria (details of the relevant requirements that were established and needed to be met)	N/a
References	Paling E., 1992
Research/development/ demonstration project descriptions	Water motion/sediment stability

WA5: Success Bank, 1993 (continued...)	
Objective of project	Research
Seagrass species used	*Posidonia sinuosa, Posidonia coriacea (mixed)*
Planting methods	Protected 15 cm cores on depth gradient
Plant spacing and density	10 cm apart (~24/m^2) meshed, 10 cm apart unmeshed
Size of areas planted	<2m^2 per site
Project duration	Ongoing (>3 years)
Assessment of relative success or failure	% survival, spreading
Date and other comments	March 1993; seagrass transplant survival vs protection and depth, 6 months into project a 1 in 50 year storm event occurred
Hydrodynamic characteristics:	
• water depth	5–12 m
• wave climate and characteristics	High energy
• tidal features	Orbital, 1 m
Sediment characteristics:	
• sediment type	Sand
• sediment depth	>1 m
• level of contamination	1
Water quality characteristics:	
• water clarity/light attenuation	High
• trophic status	Oligo
Physical protection/alteration of site	Meshing
Monitoring:	
• what attributes, how frequently, and for how long	Survival, spreading, shoot density; 3 monthly for 3 years
• findings	40–60 % survival, greater survival in mid-depth areas
Performance criteria (details of the relevant requirements that were established and needed to be met)	N/a
References	Nelson, unpublished
Research/development/ demonstration project descriptions	Reduction of energy with depth

WA6: Carnac Island, 1994	
Objective of project	Research (transplant techniques)
Seagrass species used	*Posidonia sinuosa, Amphibolis griffithii*
Planting methods	Cores (40 × 5 cm, 40 × 10 cm, 30 × 15 cm); rhizome staples (units of 1, 2, 5 and 10, 20 replicates per treatment and number
Plant spacing and density	~0.5 m apart
Size of areas planted	5 × 5 m
Project duration	18 months plus
Assessment of relative success or failure	% survival
Date and other comments	Meshed and unmeshed cores and rhizome units
Hydrodynamic characteristics:	
• water depth	6 m
• wave climate and characteristics	High energy
• tidal features	1 m
Sediment characteristics:	
• sediment type	Sand
• sediment depth	>1 m
• level of contamination	1
Water quality characteristics:	
• water clarity/light attenuation	High
• trophic status	Oligo
Physical protection/alteration of site	Meshing
Monitoring:	
• what attributes, how frequently, and for how long	% survival/spreading/leaf turnover; monthly (12 months), 6 monthly (3 years)
• findings	40–80% survival plus spreading in largest cores, complete site was covered by 1 m of sand after 3 years. Less survival than Amphibolis griffithii unless planted in sediment stabilised areas (i.e. Heterozostera bed); all rhizome units lost within one month
Performance criteria (details of the relevant requirements that were established and needed to be met)	N/a
References	Walker C., 1994
Research/development/ demonstration project descriptions	Water motion, develop larger transplant units

WA7: Rottnest Island, 1985	
Objective of project	Research
Seagrass species used	*Amphibolis antarctica, Amphibolis griffithii*
Planting methods	Seedlings woven into rope on grids (880 in total)
Plant spacing and density	1 × 1 cm
Size of areas planted	5 × 5 m
Project duration	18 months
Assessment of relative success or failure	% survival

WA7: Rottnest Island, 1985 (continued...)	
Date and other comments	July 1985
Hydrodynamic characteristics:	
• water depth	Variable <6 m
• wave climate and characteristics	Medium to high
• tidal features	Orbital, 1 m
Sediment characteristics:	
• sediment type	Sand
• sediment depth	>1 m
• level of contamination	1
Water quality characteristics:	
• water clarity/light attenuation	High
• trophic status	Oligo
Physical protection/alteration of site	None
Monitoring:	
• what attributes, how frequently, and for how long	% survival; 6 monthly? for 11 months
• findings	Variable survival: 20% survival after 5 months; <15% survival after 11 months
Performance criteria (details of the relevant requirements that were established and needed to be met)	N/a
References	D. Walker, pers. comm.
Research/development/ demonstration project descriptions	No information supplied

WA8: Cockburn Sound/Warnbro Sound, 1992	
Objective of project	Research
Seagrass species used	*Amphibolis antarctica*
Planting methods	Seedlings woven into rope on grids (1,000 in total); 30 cores (15 cm)
Plant spacing and density	2.5 cm grids
Size of areas planted	<1 m
Project duration	18 months
Assessment of relative success or failure	% survival, growth
Date and other comments	July 1992
Hydrodynamic characteristics:	
• water depth	<6 m
• wave climate and characteristics	Medium energy
• tidal features	Orbital, 1 m
Sediment characteristics:	
• sediment type	Sand
• sediment depth	>1 m
• level of contamination	1–2
Water quality characteristics:	
• water clarity/light attenuation	Medium to high
• trophic status	Oligo to meso
Physical protection/alteration of site	None

WA8: Cockburn Sound/Warnbro Sound, 1992 (continued...)	
Monitoring:	
• what attributes, how frequently, and for how long	Survival/growth; 6 monthly over 18 months
• findings	0% survival after 1 month in Cockburn Sound (seedlings and cores); 100% survival of both methods in Warnbro Sound
Performance criteria (details of the relevant requirements that were established and needed to be met)	N/a
References	D. Walker, pers. comm.
Research/development/ demonstration project descriptions	No information supplied

WA9: Success Bank, 1997	
Objective of project	Research
Seagrass species used	*Amphibolis griffithii*
Planting methods	15 cm cores (630 over 5 treatments)
Plant spacing and density	0.5 m
Size of areas planted	10 × 10 m
Project duration	Ongoing
Assessment of relative success or failure	% survival, growth, shoot density
Date and other comments	February 1997
Hydrodynamic characteristics:	
• water depth	5–15 m
• wave climate and characteristics	High to moderate energy
• tidal features	Orbital, 1 m
Sediment characteristics:	
• sediment type	Sand, fine sand
• sediment depth	>1 m
• level of contamination	1
Water quality characteristics:	
• water clarity/light attenuation	High
• trophic status	Oligo
Physical protection/alteration of site	None
Monitoring:	
• what attributes, how frequently, and for how long	% survival, growth, shoot density; 3 monthly ongoing
• findings	40% survival after 15 months
Performance criteria (details of the relevant requirements that were established and needed to be met)	N/a
References	Paling, unpublished
Research/development/ demonstration project descriptions	Wave energy

WA10: Success Bank, 1996	
Objective of project	Research/Mitigation
Seagrass species used	*Posidonia coriacea, Amphibolis griffithii, Posidonia sinuosa*
Planting methods	Mechanical transplanted units (0.5 m^2)
Plant spacing and density	0.5 m
Size of areas planted	50 × 50 m
Project duration	Ongoing
Assessment of relative success or failure	% survival, growth, shoot density
Date and other comments	November 1996
Hydrodynamic characteristics:	
• water depth	5 m
• wave climate and characteristics	High energy
• tidal features	Orbital, 1 m
Sediment characteristics:	
• sediment type	Sand
• sediment depth	>1 m
• level of contamination	1
Water quality characteristics:	
• water clarity/light attenuation	High
• trophic status	Oligo
Physical protection/alteration of site	None
Monitoring:	
• what attributes, how frequently, and for how long	% survival, growth, shoot density; 3 monthly ongoing
• findings	95% survival after 18 months
Performance criteria (details of the relevant requirements that were established and needed to be met)	1,000 m^2 with greater than 3 years survival, 0.1 ha with greater than 1 year survival
References	Paling, unpublished
Research/development/ demonstration project descriptions	Wave energy, density effects on energy

WA11: Oyster Harbour, 1997	
Objective of project	Research
Seagrass species used	*Posidonia sinuosa*
Planting methods	Rhizomes (>50)
Plant spacing and density	~0.5 m
Size of areas planted	10 × 10 m
Project duration	Ongoing
Assessment of relative success or failure	% survival, growth, shoot density
Date and other comments	February 1997
Hydrodynamic characteristics:	
• water depth	5 m
• wave climate and characteristics	Moderate energy
• tidal features	Unidirectional, 1 m
Sediment characteristics:	
• sediment type	Sand

WA11: Oyster Harbour, 1997 (continued...)	
• sediment depth	>1 m
• level of contamination	1
Water quality characteristics:	
• water clarity/light attenuation	High
• trophic status	Oligo to meso
Physical protection/alteration of site	Meshing and anchorage
Monitoring:	
• what attributes, how frequently, and for how long	% survival, growth, shoot density; 3 monthly ongoing
• findings	>50% survival after 2 years; rhizome growth
Performance criteria (details of the relevant requirements that were established and needed to be met)	N/a
References	Bastyan, unpublished
Research/development/ demonstration project descriptions	No information supplied

WA12: Cockburn Sound, 1989	
Objective of project	Research
Seagrass species used	*Posidonia australis, Posidonia sinuosa, Posidonia coriacea, Amphibolis antarctica, Amphibolis griffithii*
Planting methods	Various; Aa and Ag in geotextile mats and growool; Pa, Ps and Pc in jiffypots and growool; Aa rhizomes in geotextile (4,805 in total)
Plant spacing and density	Various
Size of areas planted	5 × 5 m
Project duration	~27 months
Assessment of relative success or failure	% survival, growth
Date and other comments	May to August 1989
Hydrodynamic characteristics:	
• water depth	~5 m
• wave climate and characteristics	High to moderate energy
• tidal features	Orbital, 1 m
Sediment characteristics:	
• sediment type	Sand
• sediment depth	>1 m
• level of contamination	1–2
Water quality characteristics:	
• water clarity/light attenuation	Medium to high
• trophic status	Oligo to meso
Physical protection/alteration of site	None
Monitoring:	
• what attributes, how frequently, and for how long	% survival, growth; monthly for ~7 months
• findings	Variable; 0–30% survival after 18 months (Aa, Ag); 0–8% survival after 19 months for Pc and Ps; 0% survival after 7 months for rhizomes

WA12: Cockburn Sound, 1989 (continued…)	
Performance criteria (details of the relevant requirements that were established and needed to be met)	N/a
References	Kirkman, 1995
Research/development/ demonstration project descriptions	No information supplied

WA13: Warnbro Sound, 1990	
Objective of project	Research
Seagrass species used	*Amphibolis antarctica, Amphibolis griffithii*
Planting methods	Various; Aa and Ag in geotextile mats and growool (265 in total)
Plant spacing and density	Various
Size of areas planted	5 × 5 m
Project duration	7 months
Assessment of relative success or failure	% survival, growth
Date and other comments	August to November 1990
Hydrodynamic characteristics:	
• water depth	~5 m
• wave climate and characteristics	High to moderate energy
• tidal features	Orbital, 1 m
Sediment characteristics:	
• sediment type	Sand
• sediment depth	>1 m
• level of contamination	1
Water quality characteristics:	
• water clarity/light attenuation	High
• trophic status	Oligo
Physical protection/alteration of site	None
Monitoring:	
• what attributes, how frequently, and for how long	% survival, growth; monthly for ~7 months
• findings	0–47% after 7 months
Performance criteria (details of the relevant requirements that were established and needed to be met)	N/a
References	Kirkman, 1995
Research/development/ demonstration project descriptions	No information supplied

WA14: Rottnest Island, 1990	
Objective of project	Research
Seagrass species used	*Posidonia coriacea, Posidonia australis, Posidonia angustifolia, Amphibolis antarctica, Amphibolis griffithii*
Planting methods	Various; Aa and Ag in geotextile mats and growool; Posidonia growool (850 in total), no growth
Plant spacing and density	Various
Size of areas planted	5 × 5 m
Project duration	~27 months
Assessment of relative success or failure	% survival, growth
Date and other comments	May to August 1990
Hydrodynamic characteristics:	
• water depth	~5 m
• wave climate and characteristics	High to moderate energy
• tidal features	Orbital, 1 m
Sediment characteristics:	
• sediment type	Sand
• sediment depth	>1 m
• level of contamination	1
Water quality characteristics:	
• water clarity/light attenuation	High
• trophic status	Oligo
Physical protection/alteration of site	None
Monitoring:	
• what attributes, how frequently, and for how long	% survival, growth; ~monthly for ~2 years
• findings	Variable; 0–70% survival after 19 months (Ps, Pc); 0–5% survival after 25 months (Aa, Ag), no growth
Performance criteria (details of the relevant requirements that were established and needed to be met)	N/a
References	Kirkman, 1995
Research/development/ demonstration project descriptions	No information supplied

New South Wales

NSW1: Lady Robinson Beach, Botany Bay, 1988	
Objective of project	Pilot project to rehabilitate *Posidonia australis* beds lost after a 12% increase in wave action due to harbour construction and entrance dredging
Seagrass species used	*Posidonia australis* and *Zostera capricorni*
Planting methods	Units were anchored with pegs. Protection provided with artificial seagrass. Some plants fertilised. Some plants with growth hormone added.
Plant spacing and density	Groups of shoots planted at 30 cm intervals. For *Posidonia* 2–3 shoots used, for *Zostera* 20–30 shoots used. 1,800 units altogether.
Size of areas planted	0.02 ha planted within a much larger site
Project duration	4 months but area has been monitored a number of times over past 10 years (1988)
Assessment of relative success or failure	Transplanted seagrasses were washed away in major storms. Prior to storms, *Zostera* had shown initial expansion and growth but *Posidonia* had not shown lateral extension, although leaves were growing. Overall site not considered suitable for transplanting *Posidonia*.
Date and other comments	Much of the site is now occupied by naturally recolonised *Zostera* and *Halophila* beds
Hydrodynamic characteristics:	
• water depth	1 m, 2 m and 3 m below ISLW
• wave climate and characteristics	Site subject to increased wave climate after dredging of the entrance to Botany Bay, NSW
• tidal features	~2 m diurnal tide
Sediment characteristics:	
• sediment type	Sand
• sediment depth	>2 m
• level of contamination	1
Water quality characteristics:	
• water clarity/light attenuation	Good
• trophic status	?
Physical protection/alteration of site	See previous; note that artificial seagrass was used in attempt to counter increased wave action
Monitoring:	
• what attributes, how frequently, and for how long	Historical distribution at site. Survival, number of transplanted shoots and expansion of planted area were monitored monthly for 4 months. Area has been visited since and mapped from aerial surveys and site visits.
• findings	Transplanted seagrasses were washed away in major storms. Prior to storms, *Zostera* had shown initial expansion and growth but *Posidonia* had not shown lateral extension, although leaves were growing. Overall site not considered suitable for transplanting *Posidonia*.

NSW1: Lady Robinson Beach, Botany Bay, 1988 (continued…)	
Performance criteria (details of the relevant requirements that were established and needed to be met)	Considered that the site was probably no longer suitable for *Posidonia* beds but that *Zostera* would probably establish naturally. Since that time, *Zostera* and *Halophila* beds have established over much of the area.
References	West *et al.*, 1990; West, 1995; R.J. West, pers. comm.
Research/development/ demonstration project descriptions	No information supplied

NSW2: Botany Bay, 1995	
Objective of project	Pilot transplants to offset losses around new runway at Sydney Airport
Seagrass species used	*Zostera capricorni*
Planting methods	Sods of plants each containing several hundred shoots
Plant spacing and density	1 m spacing
Size of areas planted	Areas around newly constructed runway
Project duration	Inspected over 12 months (1995)
Assessment of relative success or failure	Some expansion of *Zostera* sods. Groups of plants joined into continuous patches, however they were grazed extremely heavily. During course of experiment changed from long leaf lengths to extremely stunted plants with short leaves.
Date and other comments	This project was overtaken by much larger project involving NSW Fisheries (Dr Philip Gibbs), refer to NSW4.
Hydrodynamic characteristics:	
• water depth	
• wave climate and characteristics	Moderate wave climate
• tidal features	~2 m diurnal tide
Sediment characteristics:	
• sediment type	Sand
• sediment depth	>2 m
• level of contamination	1
Water quality characteristics:	
• water clarity/light attenuation	Good
• trophic status	?
Physical protection/alteration of site	Newly dredged sands; range of alterations
Monitoring:	
• what attributes, how frequently, and for how long	Survival and expansion
• findings	Some expansion of *Zostera* sods. Groups of plants joined into continuous patches, however they were grazed extremely heavily. During course of experiment changed from long leaf lengths to extremely stunted plants with short leaves.

NSW2: Botany Bay, 1995 (continued...)	
Performance criteria (details of the relevant requirements that were established and needed to be met)	Transplanted *Zostera* at some locations were just surviving, indicating a larger scale transplanting might succeed. Very mixed success depending on site characteristics, which varied greatly between locations.
References	R.J. West, pers. comm.; no publications
Research/development/ demonstration project descriptions	Effects of a range of factors (species selection, shoot morphology, nutrient addition, desnity of planting, distance from established meadows) on transplanting success being investigated by Ron West's FRDC funded PhD student (Alex Meahan). Project FRDC 97/220. Natural recolonisation rates of seagrass (Alex Meahan). Project FRDC 97/220. Historical changes in seagrass distribution (Alex Meahan). Project FRDC 97/220. Selection of indicators (Alex Meahan). Project FRDC 97/220.

NSW3: Botany Bay, 1997	
Objective of project	Monitoring of seagrass recolonisation into modified substrates to compensate for habitat losses related to construction of the Sydney airport runway extension
Seagrass species used	*Zostera capricorni*
Planting methods	N/a
Plant spacing and density	N/a to natural colonisation into created substrate between two airport runways and on the eastern side of the new runway
Size of areas planted	30 ha of created substrate available for recolonisation
Project duration	Monitoring since January 1995
Assessment of relative success or failure	Regrowth of seagrass to replace habitat loss, which included 18.75 ha of *Zostera capricorni*
Date and other comments	
Hydrodynamic characteristics:	
• water depth	
• wave climate and characteristics	Site is influenced by storm activity e.g. significant storms in late April 1997 uprooted or buried much transplanted seagrass. Artificia Seagrass Units (ASUs) were used in some experimental plots to stabilise sediments and reduce wave action.
• tidal features	
Sediment characteristics:	
• sediment type	Shallower end of transplant site generally harder sands; deeper end of site with muddy and softer sediments
• sediment depth	

NSW3: Botany Bay, 1997 (continued…)	
• level of contamination	1 ?
Water quality characteristics:	
• water clarity/light attenuation	
• trophic status	?
Physical protection/alteration of site	ASUs were used to stabilise sediments and reduce wave action. After 3 months these contained only small amounts of seagrass, possibly due to abrasion by ASU blades fouled by epiphytes. Seagrass present in ASU plots were longer, denser and appeared less grazed than other surviving transplants.
Monitoring:	
• what attributes, how frequently, and for how long	Initial monitoring survey to evaluate site suitability, check depth profiles and light availability; three levels of survey originally proposed and used previously for same purpose: First level a site overview by diver tow; second level of monitoring, identification of individual seagrass patches but no 'success' assessment; and third level undertaken only when colonisation success can be tested through data on cover, species composition, average shoot density, seasonal variation in cover and shoot density and biomass of seagrass colonised in the FAC created bed.
• findings	Natural recolonisation of the two areas has been monitored since January 1995. The two areas have shown differing responses, with successful colonisation by a few scattered patches of *Zostera* on the eastern side of the runway but not between the runways. *Halophila* has colonised both areas. Poor success between the runways is attributed to reduced probability of seedlings entering the gap between the runways and higher background wave action reducing successful attachment and survival of propagules in the created substrate area.
Performance criteria (details of the relevant requirements that were established and needed to be met)	Fish habitat compensation through recolonisation or transplantation. Criteria of 50% biomass or shoot density relative to reference data from baseline sampling at specified locations.
References	P. Gibbs, pers. comm.; Gibbs, 1997
Research/development/ demonstration project descriptions	No information supplied

NSW4: Botany Bay, 1997	
Objective of project	Experimental pilot transplanting and monitoring to replace seagrass habitat smothered through construction of rock groynes used to protect the beach from erosion
Seagrass species used	*Zostera capricorni*
Planting methods	Airport runway project enhanced through transplanting of seagrass into 16 large plots obtained from the rock groyne construction site at Lady Robinson Beach. A combination of manual methods and use of a mechanical harvester (towed flat dredge) were eventually adopted to transplant the seagrasses. Poor coherence of sediments required use of large plugs, 300 × 570 mm, (= the size of a small fish box) to give from 3–40 shoots in each box. The mechanical harvester removed slices to a minimum depth of 200 mm. Footprints of each slice were generally 0.9 m wide and 1.2 m long. 'Fish boxes' were placed end to end along several transect lines at pre-determined points out from runway seawall.
Plant spacing and density	The mean daily haul was 318 boxes collected from the donor area, or about 72 m^2 per day. Daily placement rate was 208–515 boxes per day, with a mean placement of 329 boxes, or 74 m^2 per day.
Size of areas planted	Transplanting of 1.8 ha of seagrass into 16 experimental plots. After planting survey indicated 90% of available seagrass was transplanted. Minimum requirement of 1,060 m^2 was to be removed to yield 1,272 m^2. In fact, 5,366 boxes were used, representing an area of 1,214 m^2 removed and transplanted, (about 92% of the total bed area).
Project duration	The project was completed over 20 working days during March–April 1997
Assessment of relative success or failure	
Date and other comments	The contractors who did the transplanting noted several practical and logistical considerations and constraints in relation to the adopted methods used for transplanting. Thus there were some differences in what was originally proposed and agreed, and what was actually undertaken in the field, in terms of some aspects of the methodology, as well as the final coverage and layout of the planted out beds.
Hydrodynamic characteristics:	
• water depth	
• wave climate and characteristics	Refer to NSW3
• tidal features	
Sediment characteristics:	Refer to NSW3
• sediment type	

NSW4: Botany Bay, 1997 (continued…)	
• sediment depth	
• level of contamination	
Water quality characteristics:	
• water clarity/light attenuation	
• trophic status	
Physical protection/alteration of site	
Monitoring:	
• what attributes, how frequently, and for how long	
• findings	Pilot transplantation of *Zostera capricorni* at 16 experimental sites. Inspection of transplant sites 3 months after transplanting indicates *Zostera* present at all 8 sites on the eastern side of the runway. No seagrass remained at 2 of the other 8 sites, while the remaining 6 sites had a few small scattered clumps generally less than 0.025 m^2 and some isolated individual plants.
Performance criteria (details of the relevant requirements that were established and needed to be met)	No information supplied
References	West *et al*., 1990; West, 1995; P. Gibbs, pers. comm.; Gibbs, 1997
Research/development/ demonstration project descriptions	No information supplied

NSW5: Hastings River, 1990s	
Objective of project	Small scale project to assess feasibility of planting seagrasses in an established canal estate where seagrasses had not established naturally
Seagrass species used	*Zostera capricorni*
Planting methods	Sods of plants containing several hundred of shoots each
Plant spacing and density	1 m spacing
Size of areas planted	Small areas in 2 arms of a canal estate
Project duration	Inspected over 12 months (1990s)
Assessment of relative success or failure	*Zostera* transplanted to canals with established seagrass beds survived and spread quickly to form continuous bed. *Zostera* transplanted to canals with no seagrasses were quickly consumed, apparently by amphipods.
Date and other comments	
Hydrodynamic characteristics:	
• water depth	1–2 m below ISLW
• wave climate and characteristics	Very little wave action
• tidal features	~2 m diurnal tide
Sediment characteristics:	
• sediment type	Mud-sand
• sediment depth	>2 m
• level of contamination	1

NSW5: Hastings River, 1990s (continued...)	
Water quality characteristics:	
• water clarity/light attenuation	Good
• trophic status	?
Physical protection/alteration of site	Established canal estate, well protected
Monitoring:	
• what attributes, how frequently, and for how long	Survival and expansion
• findings	*Zostera* transplanted to canals with established seagrass beds survived and spread quickly to form continuous bed. *Zostera* transplanted to canals with no seagrasses were quickly consumed, apparently by amphipods.
Performance criteria (details of the relevant requirements that were established and needed to be met)	Transplants to control sites, where *Zostera* had been able to establish naturally, survived well. Transplants to bare areas within the canal estate did not survive.
References	R.J. West, pers. comm.; no publications
Research/development/ demonstration project descriptions	No information supplied

Queensland

QLD1: Cairns Harbour, 1990	
Objective of project	Experimental Trial
Seagrass species used	*Zostera capricorni*
Planting methods	Cores in bunded pools at upper tidal zone
Plant spacing and density	1 core/m^2 (approx 350 shoots/m^2 each)
Size of areas planted	2 × 10 m^2 experimental blocks
Project duration	3 months
Assessment of relative success or failure	Survival of transplants, but no evidence of expansion; natural regeneration of meadow occurred in following year
Date and other comments	Transplant effort not cost effective; recommend management of water quality and shore topography to maintain conditions for natural growth
Hydrodynamic characteristics:	
• water depth	0.5 m above MSL
• wave climate and characteristics	Sheltered bay; up to 0.3 m waves on windy days
• tidal features	Upper range of seagrass zone; tide range 3 m
Sediment characteristics:	
• sediment type	Terrigenous mud
• sediment depth	>1 m
• level of contamination	Low, 1 ?
Water quality characteristics:	
• water clarity/light attenuation	Exposed at each low tide
• trophic status	Mesotrophic

QLD1: Cairns Harbour, 1990 (continued...)	
Physical protection/alteration of site	Mud flat pools very dynamic, moving between years
Monitoring:	
• what attributes, how frequently, and for how long	Shoot density, monthly, but not completed
• findings	Survival of transplants, but no evidence of expansion. Natural regeneration of meadow occurred in the following year.
Performance criteria (details of the relevant requirements that were established and needed to be met)	Experimental trial only to test ability of transplants to survive
References	QDPI unpublished; W. Lee Long, pers. comm.
Research/development/ demonstration project descriptions	Experimental and larger-scale trials to develop cost effective seagrass transplanting technologies (otherwise always remains better to minimise direct and indirect losses from development, and instead ensure topography and ecosystem health is suitable for seagrass survival). Focus on species most likely to be at risk from human impacts (W. Lee Long).

QLD2: Raby Bay, 1992	
Objective of project	Research
Seagrass species used	*Zostera capricorni*
Planting methods	20 tonne amphibious excavator
Plant spacing and density	~4 m^2 turfs
Size of areas planted	
Project duration	18 months
Assessment of relative success or failure	After 14 months there was no difference in density between transplanted turfs and unmoved controls
Date and other comments	Netting was used to stabilise the turfs-this killed the seagrass
Hydrodynamic characteristics:	
• water depth	Intertidal
• wave climate and characteristics	Sheltered embayment
• tidal features	2 m semi-diurnal
Sediment characteristics:	
• sediment type	Mud
• sediment depth	
• level of contamination	1
Water quality characteristics:	
• water clarity/light attenuation	<1 m average sechhi depth
• trophic status	Oligotrophic
Physical protection/alteration of site	Nil; plants were in pots; controls not in pots

QLD2: Raby Bay, 1992 (continued…)	
Monitoring:	
• what attributes, how frequently, and for how long	Shoot density, leaf length and width, area of seagrasses every two months for 18 months. Shoot density per pot, biomass, maximum leaf length and leaf width (5 leaves), area of seagrass, generative shoots, percent cover, proportion of pots dominated by *Zostera* and *Halophila* per pot. Monitored 2 monthly: November 1989 to May 1991 and 6 monthly May 1991 to June 1992.
• findings	
Performance criteria (details of the relevant requirements that were established and needed to be met)	Survival and expansion of transplanted turfs
References	Poiner and Conacher, 1992; Conacher et al., 1993; Kenyon, pers. comm.
Research/development/ demonstration project descriptions	Reproduction from seeds, population dynamics for deepwater seagrass species in Queensland; establishment of new seagrass beds from seeds rather than transplanting plants. This minimizes damage to existing beds (see Thorogood *et al.*, 1990; Poiner *et al.*, 1993) (C. Conacher). Long-term population dynamics of tropical seagrasses, effects of natural and man-induced disturbances. Distribution and dynamics of tropical deepwater seagrasses (C. Conacher). Long-term monitoring and publication of project findings. Comparison with other seagrass species. Investigation of physiological change within the plants associated with reciprocal depth transplanting (R. Kenyon).

QLD3: Victoria Point, 1992	
Objective of project	Refer to QLD2
Seagrass species used	Refer to QLD2
Planting methods	
Plant spacing and density	
Size of areas planted	
Project duration	
Assessment of relative success or failure	
Date and other comments	
Hydrodynamic characteristics:	
• water depth	Intertidal
• wave climate and characteristics	Refer to QLD2
• tidal features	Refer to QLD2
Sediment characteristics:	
• sediment type	Muddy sand
• sediment depth	
• level of contamination	1

QLD3: Victoria Point, 1992 (continued...)	
Water quality characteristics:	Nil
• water clarity/light attenuation	
• trophic status	Oligotrophic
Physical protection/alteration of site	
Monitoring:	
• what attributes, how frequently, and for how long	Refer to QLD2
• findings	Transplants from subtidal to intertidal survived accompanied by a change in leaf morphology and shoot density.
Performance criteria (details of the relevant requirements that were established and needed to be met)	Survival and morphology of inter-tidal/sub-tidal cross planting. Statistical comparison with intertidal and subtidal control pots and unpotted controls.
References	Poiner and Conacher, 1992; Conacher *et al.*, 1993; Kenyon, pers. comm.
Research/development/ demonstration project descriptions	Refer to QLD2 (R. Kenyon).

QLD4: Ellie Point, Cairns and Green Island, 1998	
Objective of project	Research on recovery and succession of tropical seagrasses
Seagrass species used	*Zostera capricorni, Cymodocea*
Planting methods	
Plant spacing and density	
Size of areas planted	
Project duration	
Assessment of relative success or failure	
Date and other comments	
Hydrodynamic characteristics:	
• water depth	
• wave climate and characteristics	
• tidal features	
Sediment characteristics:	
• sediment type	
• sediment depth	
• level of contamination	
Water quality characteristics:	
• water clarity/light attenuation	
• trophic status	
Physical protection/alteration of site	
Monitoring:	
• what attributes, how frequently, and for how long	
• findings	
Performance criteria (details of the relevant requirements that were established and needed to be met)	

QLD4: Ellie Point, Cairns and Green Island, 1998 (continued...)	
References	Cappo *et al.*, 1998 citing M. Rasheed, Northern Fisheries Centre; QDPI, Cairns
Research/development/ demonstration project descriptions	Proposed project to investigate recovery and succession of tropical seagrasses *(Zostera, Cymodocea)* with the benefit of establishing mechanisms for recovery of intertidal and subtidal tropical seagrass communities (M. Rasheed cited in Cappo *et al.*, 1998).

Northern Territory

NT1: Western Gulf of Carpentaria, 1987	
Objective of project	Monitoring natural regeneration of seagrass beds following large-scale cyclone damage
Seagrass species used	Common tropical species: (10 species, including species of *Cymodocea, Syringodium, Halodule* and *Halophila*
Planting methods	N/a
Plant spacing and density	N/a
Size of areas planted	N/a
Project duration	12 years
Assessment of relative success or failure	Assessment of re-establishment of seagrass to pre-cyclone state on substrates denuded by cyclones
Date and other comments	
Hydrodynamic characteristics:	
• water depth	0–10 m
• wave climate and characteristics	Tropical, exposed coastline, prone to cyclones
• tidal features	~1.5 m
Sediment characteristics:	
• sediment type	Sand to mud, depending on location
• sediment depth	0.5–1.0 m, depending on location
• level of contamination	1
Water quality characteristics:	
• water clarity/light attenuation	0.5–15 m, depending on location
• trophic status	Oligotrophic
Physical protection/alteration of site	Nil
Monitoring:	
• what attributes, how frequently, and for how long	Shoot density per species, leaf morphology, above-below ground biomass, sediment particle size, seed density in the sediment

NT1: Western Gulf of Carpentaria, 1987 (continued...)	
• findings	Cyclone Jason, in 1987, reduced 10 ha of above ground biomass, removed almost all above ground parts in deeper water and buried rhizome in sediments. Growth was visible less than 3 weeks after the cyclone and the total area of seagrass did not change. Cyclone Sandy, in 1985, ran parallel to the coast, extensively exposed shallow seagrass beds, which were damaged by currents, wind and exposure. The cyclone completely removed the inshore seagrass beds; deeper water beds were severely disturbed, with leaf damage and thick mud layers over the beds in many areas. A total 151 km^2 of the original 183 km^2 of habitat was either removed, undermined or smothered. By 1988, about 20% of the affected area had recolonised, mainly with species of little habitat value to commercial prawns. In 1989, the extent of seagrass had not changed but there was an increase in shoot density and species diversity, with expanding areas of more useful species to prawns (*Cymodocea, Syringodium*). In one area that did not recolonise, the sediments became unconsolidated sands, shifting with water movement. Monitoring from 1987–1989 of damaged beds and undamaged areas indicated that the effect on juvenile prawns was to replace commercially-important species with commercially-unimportant species not dependent on seagrasses.
Performance criteria (details of the relevant requirements that were established and needed to be met)	Increase in shoot density, shoot biomass and percent cover; comparison with control site undamaged by the cyclone
References	Poiner *et al.*, 1987; Thorogood *et al.*, 1990; R. Kenyon, pers. comm.
Research/development/ demonstration project descriptions	Transplant/growth trials with tropical seagrass species. Comparison among species with respect to ease of transplantation. Publishing results of the Western Gulf of Carpentaria study (R. Kenyon).

CHAPTER FOUR

Monitoring and assessment of seagrass

M. Thomas, P. Lavery, R. Coles

4.1 Introduction

4.1.1 Background

Extensive areas of seagrass beds occur throughout the coastal waters of all Australian States. Most States have regulatory machinery designed to protect seagrass and other marine plants. Seagrass is protected partly for economic reasons (because of an assumed role as juvenile fish habitat), and partly for conservation purposes (an assumed importance in maintaining biodiversity).

Because of this regulatory process, and because of general scientific interest, there has been considerable investment in monitoring seagrass habitat throughout much of Australia. The purpose of this chapter is to:

- Identify the current state of expertise in seagrass monitoring and assessment
- Identify gaps in our existing knowledge and technology
- Propose a strategy for the development of seagrass monitoring in Australia that will be relevant to the mission and objectives of FRDC

4.1.2 Approach taken

Existing work is reviewed against a defined set of criteria. These criteria address the objectives of the work (including relevance to management in general and FRDC objectives in particular), the monitoring paradigm adopted, the spatial and temporal scale (and their relevance to the stated objectives), the statistical treatment adopted and the use of explicit data quality processes.

The review covered both journal publications and consulting reports (where available). Much of the monitoring/mapping literature is grey literature and our publication list may not be exhaustive. We have reviewed all those reports which we discovered, and which satisfied our inclusion criteria (*vide infra*); many of the entries in our bibliography are consulting reports from private sector organisations or State agencies. Publications describing a specific monitoring or assessment study were included if they were Australian, but methodological papers were included whatever their geographical focus.

The review specifically excluded papers reporting on short-term studies that were undertaken for physiological or other purposes not related to conservation, habitat inventory or assessment.

Section 4.3 lists gaps in our knowledge, and issues which are significant for monitoring including both fundamental knowledge necessary for the design of locally focussed monitoring and broad scale gaps in our knowledge of seagrass distribution. Section 4.4 provides recommendations for future research — justified by the gaps identified in the previous section.

4.2 Critical review of existing literature

4.2.1 Objectives of monitoring/assessment

The monitoring and assessment studies that have been published have had many objectives. These can be classified into three major types: general background studies of conservation relevance (including mapping and monitoring), highly specific objectives (often linked to specific contracts or development projects), and method development and/or review papers.

Background studies of broad relevance to conservation

These papers are of two general types: resource mapping and descriptions of changes in specific seagrass meadow variables. Resource mapping of this type is typically broad scale (km^2) and low precision. Large-scale examples (thousands of km^2) of this type of study are Kirkman and Walker (1989), Poiner *et al.* (1989), and Lee Long *et al.* (1993). Smaller scale examples (in single bays) are Coles *et al.* (1995c), Híllman *et al.* (1995a), and Larkum and West (1990).

The largely unpublished work of Kirkman in mapping seagrass distribution along much of the Australian coast is possibly the most significant example of this type. Its value lies in providing background information that takes accounts of seagrass change and extent out of the anecdotal domain and into the scientific literature. These studies have direct conservation relevance and will serve to identify changes which occur across thousands of square kilometres. It is, however, critically important that the limitations of this type of study are recognised. Firstly, the precision of the broadest scale maps is largely un-quantified. Local change (at the scale of tens of km^2) is indistinguishable from map error; and significant real change at this scale will be missed. Only major changes in resource could be detected. These studies provide no basis for attributing any observed change to a specific impact (they were not designed to do so). Linkages to ecological value or fisheries significance have not been attempted.

A second set of papers has the objective of describing and measuring spatial or temporal change in some component of seagrass ecosystems, but this measurement is not clearly linked to any specific monitoring objective or fisheries relevance. Examples of this type include seasonal changes in biomass, shoot or epiphyte characteristics of a seagrass species (McKenzie, 1994; Kendrick and Burt,1997; Lanyon and Marsh, 1995). This type of study provides a broad scientific context for our emerging understanding of seagrass processes, but has little direct linkage to fisheries or other resource management issues. From a resource management perspective, a disappointing feature of much of this work is that it does not identify the relevance of these seasonal or broad-scale changes.

Community monitoring

Interest is emerging in community monitoring of seagrass condition (and other environmental indicators), which is not documented in the scientific literature. Outcomes from these endeavours are mixed. Our experience of community-based monitoring with insufficient scientific input suggests that it may suffer from one or more of the following problems: lack of a formal sampling plan (with opportunistic and unstructured sampling); inadequate or missing data management procedures (with data stored on sheets of paper); and little or no attempt to analyse or integrate data.

In contrast to this experience is a study being funded by the NHT under the clean seas initiative. This study is a collaborative venture between Queensland Department of the Environment, Queensland Department of Primary Industries (the seagrass ecology group) and community groups in the Whitsundays. A sister project involving the same State agencies is starting in Hervey Bay. Project management and technical direction are provided by the State agencies, which are also organising a substantial volunteer training program. The volunteer groups will take most of the field records. The study will have a strong design, with specific and clearly defined objectives based on detailed scientific knowledge of the biology of the region. It has a high probability of success. Data provided by the volunteers will be integrated onto the QDPI seagrass GIS (with an appropriate meta-data statement) and will be used in the generation of management plans. QDPI intends to provide simple Web-based 'front ends' to the GIS to enable the community groups to enter data directly. The volunteers will be able to see GIS based representations of their data, and will understand the way in which these data drive policy.

Maintaining the energy and involvement of a community group is a key factor in success (Ashworth, pers. comm.). Coastcare facilitator with the Department of Environment at Townsville, Tanya Ashworth identifies several factors that are important in maintaining community involvement, the main one being regular feedback of data and information, to demonstrate the impact of the group's data on management decisions.

Another excellent example of a community monitoring program is occurring in Nepean Bay, Kangaroo Island. The program, developed by Edyvane (1997), is based on a comprehensive review of catchment structure and existing monitoring (diverse and multi-agency) leading to identified data gaps and monitoring needs. The monitoring program involves a well-designed sample plan, defined data management processes (including establishment of a GIS) and a sound approach to analysis. It clearly identifies the roles of the different agencies and community groups. The community volunteers have received extensive training from Edyvane.

Community monitoring is unlikely to produce the volume or quality of data required to produce defensible inputs to policy formation and management without strong scientific input. This has to take the form of properly budgeted contributions from appropriate agencies. The two excellent programs described above have benefited enormously from the leadership of researchers with established reputations in the area. According to Edyvane (1997):

> *Marine habitat and water quality monitoring offer ideal opportunities for community participation in the proposed Nepean Bay Environmental Monitoring Program (NBEMP). However, there is a clear need to acknowledge the limitations of community-based monitoring and the need for complementary scientific studies to establish the framework for a scientifically defensible environmental monitoring program. In this respect, community monitoring is not a substitute for scientific studies but rather a tool for acquiring broadscale and cost-effective environmental information (and also, raising community awareness).*

The need for professional involvement in developing community-based monitoring programs is broadly recognised. For example, the South Australia Central Region Coastcare operation has made involvement of the relevant agency (South Australian Research & Development Institute) a prerequisite for funding — although they have not provided funding for that input. It has been suggested that recent developments in information technlogy (essentially Web-based interfaces to GIS map servers and computer servers) may have a substantial impact on community monitoring. While such tools are certainly useful — and indeed are being developed in the Hervey Bay and Whitsundays monitoring project, they do not obviate the need for scientific direction. Study design calls for a broad scientific understanding that is impossible to encapsulate in software.

It is essential that community project budgets make appropriate provision for funded expert direction. Successful community monitoring projects have received large hidden subsidies from State research agencies, and such subsidies will not — and should not — continue. The NHT Coasts and Clean Seas initiative is a major step forward in this direction. It is very gratifying to see that excellent community action projects like those in the Whitsundays and Hervey Bay have already been funded with appropriate provision for scientific direction.

Specific monitoring objectives

These papers, and more commonly contract reports, have a strong management focus. This might be concerned with specific baseline studies (Hillman *et al.*, 1990; Lee Long *et al.*, 1997a; Lee Long *et al.*, 1997b), determining (and responding to) specific impacts of existing or anticipated disturbances (Hilman *et al.*, 1994;

Westera and Paling 1994; Long *et al.*, 1996), or with specific large scale management decisions such as defining marine park boundaries or designated fish habitat areas (Coleman, 1997; Burt and Anderton, 1997; Danaher and Stevens, 1995). A recent study of this type attempted to define the scale of natural temporal variation in seagrass cover to provide a baseline for impact assessment (CCL, 1998). Few of these objectives relate specifically to fish management, or identify the impact on any fish species.

Few of the reports or papers reviewed identified specific management actions associated with a monitoring program. Although situations could be identified in which management action had taken place following a decline in seagrass cover, in most cases monitoring had been instigated as part of a management response. That is, monitoring was not a trigger to management action, rather it was part of that action. To that extent, this review was able to identify very few situations in which formal monitoring actually made a difference! Hilman *et al.* (1990) provides one example of monitoring triggering management intervention.

A number of broad-scale mapping studies have had clear management consequences in the definition of protected areas (Coleman, 1997; Burt and Anderton, 1997; Danaher and Stevens,1995) but these are not classical monitoring studies. That is, they are concerned with identifying the current state of seagrass over a broad scale, rather than with detecting change in seagrass distribution.

Method development and review

A relatively small number of papers have the objective of developing and evaluating techniques for monitoring and assessment of seagrass resources or analysing monitoring data. They include papers on visual assessment (Mellors, 1991), aerial photography, satellite imagery (Armstrong,1993), acoustic techniques (Lee Long *et al.*, 1997b), videography (Norris *et al.*, 1997), physical sampling (Long *et al.*, 1994; Hillman *et al.*, 1994) and observer bias (Inglis and Lincoln-Smith, 1995). Methods papers are extremely valuable in building the inventory of techniques, and it is surprising how few critical evaluations of methods can be found in the literature.

Sampling designs include a range of approaches: random and fixed transects, locations and aerial photography, or remote sensing. The choice of technique is scale and site dependent, and is strongly influenced by the objectives of the study. Aerial photography and remote sensing have been used for larger-scale studies. Fixed locations (Lanyon and Marsh, 1995; Abal and Dennison, 1996; Kirkman, unpublished; Lavery and Westera, 1998) have some attractions when attempting to detect change. The ability to return to exactly the same location appears to remove some of the monitoring problems associated with spatial variability. However, difficulties arise in interpreting these transects. Firstly, it is not clear how the values from a single fixed transect may be generalised to the study area, and secondly, fixed transects may be appropriate for monitoring only if the natural state is static. If the undisturbed system is dynamic, with the location of seagrass beds moving in response to changing topography, then a fixed transect may give a false signal. Certainly, topography in the tropics can change rapidly and CCL (1998) shows similar changes for some temperate species of seagrass.

Hundley *et al.* (1994, abstract only) claim successful application of sonar techniques for seagrass monitoring, but their abstract contains no substantiating information. Lee Long *et al.* (1998) provide a critical evaluation of a 420 KHz acoustic survey of seagrass beds in Cairns, using vertical incidence and 45° conical beam techniques. They conclude that acoustic techniques require further development before they can be used reliably to map seagrass biomass in the tropics.

Videographic techniques are being used to improve the spatial coverage and cost-effectiveness of mapping and for more pragmatic occupational health and safety reasons. Norris *et al.* (1997) describe a method that integrates video footage with differential GPS data to produce spatially explicit imagery, subsequently used in mapping. This technique is now applied routinely by the Department of Primary Industries in Queensland (Coles, pers. comm.) partly because of its cost-effectiveness and also because of its safety advantages in deep or low visibility area or known crocodile habitats.

Long *et al.* (1994) describe a rapid sampling technique involving a grab lowered from a boat. This appears to offer significant advantages over diving in some situations, particularly where diving is not feasible due to low visibility or risks of crocodile attack. The use of grabs allows for the generation of spatially dense samples — a prerequisite for detailed mapping at the local scale. While clearly effective in some circumstances, the performance of the grab depends on the combination of bottom type and species. The method may introduce bias for large-scale surveys covering a range of bottom types, and it may be inappropriate for some purposes (for example sampling *Thalassia* on a reef top, where the grab will not penetrate the substrate).

Aerial photographic interpretation is clearly the dominant method applied to most studies of large-scale changes in seagrass cover. The degree of sophistication of aerial photograph-based mapping has increased considerably in recent years. Studies in the late 1970s and early 1980s were typified by a lack of spatial rectification and manual photo interpretation (i.e. discrimination of seagrass versus other features) (e.g. Cambridge & McComb, 1984; Silberstein, 1985; LSC, 1986; Silberstein *et al.*, 1986). More recent studies have devoted significant effort to spatial rectification of images, using density slicing to discriminate seagrass from bare sand (e.g. Lavery, 1994; CCL, 1998).

Aerial photography is extremely useful, but it must be tailored to the specific study area. The choice of filter, height, water conditions, atmospheric conditions and subsequent analysis (rectification and digitisation) can have a substantial impact on the quality of the results. Most papers give no indication that these factors have been considered. These issues become more acute when attempting to use archival material for historical reconstruction of seagrass distribution (e.g. Lavery, 1994). Although opportunistic and archived aerial photographs may provide valuable background information, aerial photographs not commissioned specifically for the purpose of identifying seagrass beds should be treated with extreme caution in any quantitative assessment.

Irrespective of these problems, there are regional constraints in using aerial photography for baseline mapping of seagrasses. While the approach may be appropriate for mapping large bed-forming species, such as *Posidonia* spp., in clear waters, it is quite inappropriate for areas of turbid water and/or high tidal range like those experienced in much of the tropical north. The approach is also inappropriate for mapping or monitoring small species such as *Halophila* spp. or areas that have been heavily cropped. In these situations an aerial photograph may provide biased and inaccurate mapping. While not specifically a methods development paper, CCL (1998) provides a comprehensive account of approaches to using aerial photography to estimate changes in seagrass cover. This report also makes recommendations on a standardised procedure for such mapping and introduces a useful comparison of manual and automated density slicing methods for estimating areas of seagrass on photographs. Density slicing on grey scale or a single colour band is strongly recommended.

Hart (1997) provides an account of the use of digital orthophotography to map changes in the extent of sand and seagrass off the Adelaide coast. Orthophotographic images were classified using a variety of techniques including filtering and density slicing. Changes in sand or clay extents were measured, and these were assumed to take place at the expense of seagrass. This is an excellent report with clear statements of assumptions and limitations, and a recognition of the need for ground truthing.

The dearth of papers on satellite remote sensing may confirm anecdotal evidence that this approach has been less than helpful in Australian waters. Several conference presentations report the results of remote sensing studies for seagrass mapping (e.g. Ong *et al.*, 1994) but few of these are published in peer-reviewed literature.

Remote sensing for seagrass may induce biases towards shallow water and large species. This technique requires extensive ground truthing to prevent unquantifiable errors, especially in turbid tropical waters. Armstrong (1993) provides an example of a study aimed at mapping *Thalassia testudinum* using Landsat TM data. There is no account of validation. Lennon and Luck (1990) describe an attempt to map the distribution of seagrass using Landsat TM over the Great Sandy Strait (southern Queensland). They report an unsupervised analysis based on a wide collection of clustering methods and the assumption that one or more of the spectral classes represent seagrass. Validation was attempted by comparison with aerial photography and there was good agreement between the techniques — although both the aerial photography and the Landsat analyses involve a great deal of subjectivity. These researchers also undertook a limited ground truthing exercise.

Other studies have attempted to address issues of water column/depth interference with raw data and to provide algorithms for enhancing contrast between different benthic substrate types (Bierwirth *et al.*, 1993). Good results (checked by ground truthing) were obtained for the Shark Bay area of WA, but there are mixed reports about the transferability of these algorithms. The relationship between interpretations of satellite data and ground truthing was also shown to be strong off Roebuck Bay, WA (Hick, 1997). However, others report little success in applying the algorithms at the Abrohlos Islands (Wyllie, pers. comm.).

Hick (1997) found exactly the inverse relationship when he applied the algorithm at Geographe Bay, WA. This algorithm seems typical of many developed from remotely sensed data; they are rarely universally applicable and are usually best applied in conditions very similar to those in which they were developed.

In separate studies, Hick (1997) and Lavery *et al.* (1990) have shown that different algal and seagrass types cannot be readily distinguished using spectrophotometric data. Both studies concluded that remotely sensed data would be of limited value in distinguishing between different benthic plant types.

An alternative to satellite platforms appears to be aerial imaging radiometers, such as the Compact Airborne Spectrographic Imager (CASI) system or Geoscan Multi Spectral Scanner (BBG, 1994; Ong *et al.*, 1994; Bajjouk *et al.*, 1996). These systems can overcome some problems associated with satellites, such as interference by high altitude cloud. Bajjouk *et al.* (1996) tested CASI in Brittany (France) and found it discriminated between major types of benthic plant habitats. However, as with satellite platforms, the technique may be of low value in turbid waters and requires extensive ground-truthing to provide essentially site-specific empirical algorithms. Also, as with satellite based measurements, it remains to be proved that the algorithms being developed are transferable, since few studies provide adequate validation.

Whether studies involve satellite sensors or airborne hyperspectral sensors such as CASI, they will be successful only if they combine highly developed expertise in remote sensing with equivalent knowledge of the ecology and environmental characteristics of the target site. Remote sensing studies that do not have access to both areas of expertise should be discouraged.

There appear to be few critical review papers for mapping and monitoring. Reviews tend to list standardised methods without detailed analysis of strengths and weaknesses of techniques (Coles *et al.*,1995a; Kirkman, 1996). Coles *et al.* (1997b) provide a critical review of information requirements for dugong management.

Jacoby (1997) reports the outcomes of the National Seagrass Workshop, the culmination of a series of State workshops which were tasked with outlining a concerted national approach to seagrass monitoring. The broad consensus was that seagrass monitoring is important and that it must be linked to specific management triggers, which are key elements in the design of a monitoring process. The workshops did not reveal any common quantitative understanding of the role of seagrass in maintaining fishery production or biodiversity (nor could they, since that understanding is a critical gap in our knowledge). Perhaps for that reason, they contained no indication of how economic or conservation values could be factored into a national monitoring program.

4.2.2 Monitoring paradigm

There is no clear unifying paradigm for monitoring seagrass in Australia. As one might expect, differences in monitoring approach reflect the differences in resource availability, availability of specialist advice and monitoring objectives.

Where the monitoring has sought to identify specific impacts it tends to be quantitative and based on a BACI or repeated measures design (Long *et al.*, 1996; Hillman *et al.*, 1994; Lee Long *et al.*, 1997e; Rasheed *et al.*, 1996).

Most monitoring focuses on the seagrasses themselves rather than their ecological or functional value. It has not generally been concerned with seagrass function, and therefore is unable to link long-term descriptions of seagrass variability to fisheries management.

Monitoring exercises are rarely based on a conceptual model of the system being monitored. The seagrass parameters quantified or described tend to be based on convenience rather than any analysis of either the ecological determinants of seagrass distribution or the ecological role of seagrass meadows. In some cases this may reflect cost constraints that prevent process oriented monitoring; in other cases it possibly reflects a lack of awareness of the value of these types of study.

At least four studies are comprehensive enough to demonstrate the value added to resource management by a more conceptual approach. They are: the Brisbane River/ Moreton Bay Waste Water Management Study (Dennison *et al.*, 1998), the Perth Coastal Waters Study (Lord and Hillman, 1995), the Cockburn Cement Environmental Management Program (CCL, 1998), and the Port Phillip Bay Study (Harris *et al.*, 1996). This conceptual basis at least offers the potential to link seagrass function to secondary production such as fisheries.

In the case of the Perth Coastal Waters Study, a conceptual model was constructed as the building block for a numerical coastal ecological model (COASEC). The conceptual model clearly exposed the pathway of interactions between nitrogen, phytoplankton, epiphytes and seagrasses as the key concern of managers. It linked increased sewage loading, conceptually, to changes in water quality and biotic variables that could have negative effects on seagrasses. This process in turn identified variables for which information was lacking or for which more extensive monitoring was required. The model thus clarified the monitoring needs and resulted in projects to develop appropriate monitoring techniques for variables such as epiphytes, periphyton biomass and seagrass grazers (Hillman *et al.*, 1994) which have subsequently been incorporated into ongoing monitoring programs (Kinhill, 1997). These programs are based on a sound understanding of variability and incorporate sufficient replication to allow impacts of meaningful magnitude to be detected with reasonable statistical power. Equally importantly, the process resulted in the elimination of some potential monitoring variables (such as seagrass grazers) from the program as they were shown to be too variable to be useful.

In the case of Cockburn Cement Ltd's management program, a conceptual model was developed to describe the alternative states of seagrass ecosystems in relation to the company's dredging operations (CCL, unpublished). The model alternated ecosystems between a 'seagrass' state and a 'bare sand' state and identified processes that allowed one state to cross into the other. Natural regrowth was identified in the model as a process which allowed bare sand to return to a vegetated state based on rhizome extension of adjacent seagrasses.

At the beginning of the project it was generally accepted that the seagrasses being examined would not show significant rhizome extension. However, the conceptual model required detailed mapping and monitoring to investigate this assumption. So, a ‘landscape’ monitoring approach, not normally applied to seagrass ecosystems, was adopted. It revealed significant inter-annual variation in seagrass cover that could be accounted for by rhizome extension into bare areas. This has resulted in significant ‘landscape’ description and ongoing monitoring of seagrass patches and landscapes. Monitoring units are 4 ha patches and monitoring covers changes in both the density and coverage of seagrass at a number of scales within the patches. From a resource management perspective it has clearly altered the notion that seagrass ecosystems are static, and has forcibly demonstrated that seagrass loss is not irreversible.

The Brisbane River / Moreton Bay wastewater management study (Dennison *et al.*, 1998) is based on a well-developed conceptual model for the study area. The model identifies a range of key processes and functional zones for the bay area. Functional zones include the tidal estuary, a river plume zone and an oceanic zone in the eastern bay. The researchers monitor the depth range of seagrass meadows, because they are concerned to identify biological impacts of changing sediment load and turbidity. They also monitor $\delta^{15}N$ concentration on seagrass as an indicator of the extent to which nitrogen from sewage outfalls is biologically available. In this case two different characteristics of seagrass are monitored to address two key issues arising from a conceptual model: long term changes in sediment properties, and the boundaries of the sewage plume. The seagrass itself is not of primary concern, rather its distribution and $\delta^{15}N$ content are used as indicators of ecosystem health.

In contrast, a large body of monitoring research is qualitative or of low precision and driven by resource managers’ concerns about long-term trends. This provides background information, often at a large spatial scale. It may serve to alert managers to large-scale or long-term changes in resource; subsequent policy development would depend on more detailed process-oriented studies. This broad-scale qualitative work is the only type of monitoring activity identified in this review as generating management action. The Albany Harbours management strategy is an appropriate example of qualitative broad-scale monitoring which triggered detailed studies resulting in policy development (Hillman *et al.*, 1990).

4.2.3 Spatial scale

Monitoring and inventory projects typically operate at two spatial scales: regional studies which tend to be qualitative or deal only in hectare scale changes in cover (e.g. BBG, 1994), and local studies which are quantitative, focussing on biomass or other attributes (e.g. McKenzie, 1994). Larger regional-scale studies, which are relevant to fisheries management, have generally been qualitative rather than quantitative. Some of these studies have had a specific fisheries management objective, and have typically been used to delineate boundaries for coastal and fisheries management (Coles *et al.*, 1987a and 1987b). Broad-scale monitoring is not used for quantitative fishery management, either because the maps are of low precision, or because they lack the detailed production information that would be required for this purpose. Specifically, it is difficult to infer quantitative changes in fish stock from changes in seagrass cover at a regional scale. This is in no sense a criticism of this work, since quantitative fishery management was never its objective.

Local studies typically involve sample sites within one or a small number of meadows, and separated by distances of tens or hundreds of metres. Spatial analysis of these local studies has been largely restricted to irrelevant analysis of variance — identifying unsurprising differences between sites — or worse still, failing to find differences because of low statistical power. While technically acceptable, these analyses have not attempted to characterise the spatial or temporal variation in any way which is meaningful for the efficient design of monitoring studies. Although, with sufficiently high sampling effort, these local-scale studies may be useful in detecting specific impacts, none of those have had a specific fisheries management objective. Consequently the monitoring is of limited value for this purpose.

At an even larger spatial scale Kirkman and Walker (1989) describe indicative maps of the distribution of seagrass throughout the coast of Western Australia. The precision of this work is difficult to evaluate, and it was not intended to provide a basis for quantitative fisheries management.

Only a few published monitoring works seek to characterise seagrass meadows using the concepts of landscape ecology. Two examples of landscape-scale monitoring have been reported from Western Australia. Kendrick *et al.* (in press) have monitored changes in seagrass cover between 1965 and 1995 while Hyndes *et al.* (1998) monitored fish assemblages in seagrass landscapes at a range of temporal scales. Both these studies used spatial scales in the order of several hectares with landscapes defined by the predominant mosaic and patchiness of different seagrass habitats.

Obvious opportunities exist to describe meadows in terms of their spatial-temporal variation in edge to area ratios, patch size, and three-dimensional structure. These factors are likely to significantly influence the value of meadows as fisheries habitat. Ongoing studies in the Success Bank region of Western Australia are beginning to address these issues (CCL, 1998; Kendrick, unpublished; Section 4.2.2, and other chapters of this report). The constraints of traditional BACI analysis of biomass, percentage cover and epifauna in detecting changes in seagrass habitat are outlined below. In light of these constraints, landscape and other spatially related approaches to monitoring may offer better alternatives.

4.2.4 Temporal scale

Several of the studies reviewed in this Chapter contain long-term monitoring that extends over a period of several years. These include Birch and Birch (1984), Cambridge and McComb (1984), Hillman *et al.* (1990) Larkum and West (1990), Hillman *et al.* (1995a), Lee Long *et al.* (1997e), CCL (1998) and Lavery and Westera (1998). These studies tend to be opportunistic and irregular (reflecting the difficulty of obtaining funding for regular long-term monitoring) or hind casting (essentially historical reconstruction based on archival material). Such long-term studies invariably focus on area of seagrass beds or biomass, and contain no production information that might be relevant to quantitative fisheries management.

Other studies are presented as providing a baseline for future comparison (Walker *et al.*, 1991; Kirkman and Manning, 1993; Danaher and Stevens, 1995), although it is likely that in some cases the data has not been archived in a form suitable for time-series comparison. Even such 'baseline' studies must contain information on spatial variation, temporal variation and spatial-temporal interaction before they can be used to assess changes. In many cases it has not been possible to follow up initial samples with the intended sequence of repeat samples.

Many other studies focus on seasonal changes in seagrass meadows, typically running for less than three years (Mellors *et al.*, 1993; McKenzie, 1994; Lanyon and Marsh, 1995; Híllman *et al.*,1995b). Postgraduate students frequently undertake these studies, and the length of the studentship determines the duration of the study. They almost uniformly show seasonal variation, but since the studies are invariably short term, seasonal effects are not characterised with any degree of reliability over years. This seasonal variation is usually not incorporated into the design of longer-term monitoring.

4.2.5 Statistical treatment

Much of the reviewed work (especially that concerned with broad-scale mapping) contains little or no statistical treatment. Methodological studies, background studies (especially those attempting to demonstrate spatial or temporal differences) and monitoring studies have generally included statistical analyses based on BACI (Long *et al.*, 1996) or repeated measures analyses (Híllman *et al.*, 1994; McKenzie *et al.*, 1996; Lanyon & Marsh, 1995).

Several of these studies (Long *et al.*, 1996; Híllman *et al.*, 1994; Heidelbaugh and Nelson, 1996) contain detailed power analyses based on analysis of variance applied to random sampling of seagrass parameters. Very intensive sampling produces designs with low power, because of the inherently high variation in space and time (Híllman *et al.*, 1994; McKenzie *et al.*, 1996). The implication is that even very intensive (and expensive) sampling will be insensitive to large and potentially important changes in features of seagrass habitats. The problem is especially severe when monitoring is based on faunal or epiphytic components of the seagrass ecosystem. High variability makes sampling for BACI designs impractical using these sampling techniques. Monitoring exercises based on this approach are likely to be ineffective — both design and analysis should take explicit account of the spatial structure of samples. Few of the studies include sufficient detail to allow an assessment of the adequacy of the statistical analysis. Many studies include comments about transformations chosen to stabilise variances, but given the distributional properties of seagrass data (often involving point mass at zero biomass or percentage cover) the success of this approach is questionable. This review did not find any analyses based on generalised linear models or generalised linear mixed models (which explicitly model the distributional properties — especially the mean variance relationship).

It is more important to focus on the widespread over-reliance on the significance test than the technical details of the analysis. Many studies have set up null hypotheses that are known *a priori* to be false: is there a difference between control and impact sites? Is there a difference between sample stations? Is there a difference (seasonal or otherwise) between sample times? There are, of course, differences — variability is a defining characteristic of all biological systems. The important issue is not whether such differences exist, but how large they are, where they occur and when they occur. The dominance of the significance test reflects both the current dogma in ecology and the regulatory framework or client expectations that shape most contract work. Presentation of interval estimates of differences or change would be much more informative. Such interval estimates would provide information about the maximum credible change, given the observed data.

This issue is even more important when spatially dense samples are available. Several local-scale publications include maps of quantitative seagrass parameters such as cover or biomass (Hillman *et al.*, 1990). However, these publications do not include a satisfactory analysis of uncertainty. Typically they provide maps of biomass or cover distribution based on interpolation between a small number of sampled points. These maps are then compared for different years to produce estimates of change. The approach introduces two sources of error — one in the precision of the mapping and another in the interpolation process. Precision tends to be treated in terms of the location of the sample points or the scale of the map — not in terms of the impact of spatial correlation on the interpolation. This lack of an appropriate treatment of spatial uncertainty becomes more serious when one attempts to map change over time. No studies include both maps of change, and spatial analysis of the uncertainty of change estimates. That is, although workers have mapped change, signal to noise characterisation is poor, which reduces the ability to assess the probability that the change is real. Dennison *et al.*, (pers. comm.) are conducting such analyses. Recent work (CCL, 1998) has provided maps of error associated with seagrass cover maps for individual years. However, even in this case, the study did not provide comparable error estimates for the maps showing change between years.

Fonseca (1996) describes an explicit spatial analysis of factors associated with seagrass distribution. His analysis is based on geostatistical approaches, and is restricted to water depth, which is a continuously changing variable. In particular, the study does not include a spatial analysis of the distribution of seagrass biomass, which is more difficult to model using spatial statistics, because it is typically not continuous. In many studies, seagrass is recorded as present or absent, and where continuous measurements of seagrass biomass are made, the distribution of biomass typically has a large point mass at zero. Spatial analysis of seagrass biomass requires an appropriate distributional model (or at least an appropriate variance–mean relationship).

Diggle and Tawn (1998) describe a more sophisticated approach to spatial analysis, involving generalisation of model-based geostatistics to embrace non-Gaussian spatial processes. Their approach generalises earlier non-Gaussian spatial techniques developed by Besag and Green (1993). It is based on a Markov random field, and an implementation of the Markov Chain Monte Carlo approach using the Metropolis Hastings algorithm (Smith and Roberts, 1993).

4.2.6 Data quality/data management

Emerging GIS technology provides a much better mechanism for maintaining and archiving data. Work currently in progress is likely to take advantage of this opportunity, resulting in increased accessibility of data across studies using standard GIS structures. This accessibility, however, will require the widespread use of meta-data statements. Meta-data are 'data about data'. Typical elements of a meta-data statement include: where, when, what, who and how data were collected. Hillman *et al.* (1990), BBG (1994), Lee Long *et al.* (1997c), Burt and Anderton (1997) and Coleman (1997) describe the GIS structures and include a meta-data table, but this is the exception rather than the rule. As yet, very few of the reviewed publications have any of these elements.

Some papers provide details of the location of herbarium specimens (Híllman *et al.*, 1994). Other workers routinely lodge herbarium specimens, but this is rarely reported in the final paper. Likewise, some studies have quality assurance systems in place, but no published studies provide any details of data quality assurance.

Much mapping and monitoring relies on accurate taxonomic identification. General seagrass taxonomic skills and professional taxonomic support are inadequate. The authors have encountered this problem in their own research and are aware of other instances where data quality may have been degraded.

4.3 Gaps in understanding of monitoring issues

- Kirkman and others have produced broad-scale maps of seagrass distribution for most of subtropical Western Australia, South Australia, and Tasmania. These maps are implemented in ArcInfo. Maps have been produced but not yet ground-truthed for Victoria and NSW. The Queensland Department of Primary Industries has maps of seagrass distribution for the east coast of Queensland and CSIRO Marine Research has seagrass maps for much of the Gulf of Carpentaria. There is, however, a gap in our resource assessments along the north and north-west coasts of Australia. Furthermore, both the accuracy and precision of these maps needs further evaluation, and, depending on the species, is almost certainly variable.
- The emphasis on monitoring cover or biomass of seagrass as an end in itself stems from a lack of any conceptual model or quantitative knowledge of the

role of seagrass in maintaining fish production or ecological health. In the short term, managers are unlikely to wish to move beyond these indices. But we may expect to see environmental lawyers challenge the scientific basis for monitoring based only on cover or biomass. Effective protection of fishery resource or environmental values will then require a more conceptual knowledge of the role of seagrass.

- Long-term monitoring has been difficult to maintain; funding has often been piecemeal, producing fragmented outcomes. This is due to funding on a short-term, project basis instead of program funding — although before committing funds to long-term monitoring one would expect to see more attention to defining and justifying monitoring objectives.
- Modern GIS and image analysis systems will allow researchers to present and compare sequences of maps of biomass or percentage cover over time. They will even allow differences to be mapped on a pixel by pixel basis (e.g. CCL, 1998). Unfortunately, these systems are unsatisfactory for mapping the errors involved in this process. There is a risk of 'over interpreting' the changes — especially since the interpolation algorithms will generally produce smooth maps. This problem of interpolation errors is more likely for maps of biomass, percentage cover or other variables of seagrass ecosystems than for area maps, since these variable maps tend to rely on interpolation algorithms to 'fill' spaces between intensively sampled areas. Uncritical use of GIS technology may hide inadequacies in sample intensity, ground truthing, scale dependence and classification methodology. It is important that these issues are addressed in metadata statements. There has been exciting research in this area (Kiiveri and Caccetta, 1997) but application of the techniques still requires a sophisticated understanding of Bayesian conditional probability networks.
- One further limitation of these GIS products is that they are fundamentally static. It is not easy to incorporate, for example, the outputs of physicochemical or oceanographic models (which are fundamentally dynamic) into a standard GIS. If seagrass monitoring is to be based on process understanding and used as a tool for quantitative management, then it will be necessary to generate decision support systems that have precisely this combination of spatial and dynamic capability. New advances in spatial information technology (Abel *et al.*, 1997; Abel *et al.*, in press) for urban water management have illustrated the opportunities in this area. But it must be recognised that this work is still an active area of information technology (IT) research, and is not accessible without the active collaboration of IT researchers.
- Data quality protocols are not documented and may be missing. Existing data may or may not be accompanied by appropriate meta-data, and data security and distribution mechanisms are ill defined. Much of the material on seagrass monitoring is in the form of consulting reports, and is not widely available.
- Inadequate taxonomic resources are available to support the extent of seagrass research in Australia. There are few taxonomists, and no readily useable taxonomic guides.
- There is a similar shortage of statisticians and IT specialists who can both develop and use modern statistical techniques, and communicate effectively

with marine researchers. Most marine scientists have no means of bridging the gap between what is possible (as described in the statistical and IT literature) and what is available in standard packages for non-specialist use.
- Successful community monitoring programs have relied on substantial input from State and other agencies. This input has been provided either *gratis*, or at completely uneconomic rates and thus represents a hidden subsidy to community projects which is not sustainable. This is especially dangerous since it may lead to overestimation of the independent capability of community groups.

4.4 Recommendations for strategy and future research

It is desirable to develop a national strategy for seagrass monitoring. Such a strategy should specify where monitoring should take place around the Australian coast, the indices to be monitored, appropriate physical sampling techniques and the spatial and temporal intensity of sampling. The objectives of such a strategy should be to protect the economic resources of Australia's fisheries, to protect biodiversity and to protect seagrass as having intrinsic value. Ideally, the strategy should be developed from a quantitative understanding of the relationship between indices of seagrass distribution and productivity on the one hand, and fish stocks and biodiversity on the other. That is, if we cannot quantify the effect of seagrass loss on fisheries or on conservation values, then we cannot identify how much seagrass must be preserved, where and in what condition it must be preserved. Developing this knowledge must be a priority for seagrass research. At present, we are not even able to identify the Australia-wide distribution of seagrass to a defined precision, let alone quantify its importance.

The current challenge is twofold: to develop an interim strategy for mapping and monitoring that acknowledges missing and imperfect information about key dependencies, and to instigate research that will provide the missing information.

In this context we suggest the following research directions, which should be pursued concurrently with research into the economic and conservation role of seagrass:

- Completion of broad-scale resource assessments
- Continued local-scale mapping and monitoring in high risk areas
- Research into the techniques for the integration of spatial data
- Establishment of a meta-database of existing monitoring and inventory assessments.

Each of these issues is addressed below.

4.4.1 Broad-scale assessments

Although there may be very few clear, quantitative relationships between seagrass resource and fisheries production, there are strong anecdotal accounts of cases in which removal of seagrass habitats has been accompanied by a reduction in fish stocks (e.g. Cockburn Sound) (see Chapter 2). A minimum information requirement is therefore a comprehensive broad-scale map of seagrass habitat. Proposals for mapping should take account of the peculiar difficulties of mapping seagrass in the tropics: turbid waters and small non-bed forming seagrass species. Proposals for aerial photography and satellite remote sensing may be highly attractive in terms of cost per hectare, but they have low feasibility in this context. On the other hand, they may be highly appropriate in clearer waters, given that sufficient error estimates are applied.

Work seeking to extend the range of broad-scale mapping should be accompanied by a critical assessment of the precision and reliability of existing broad-scale seagrass maps.

4.4.2 Continued local mapping and monitoring

This review has identified many of the problems of constructing scientifically designed, formal monitoring schemes: lack of detailed knowledge of the role and value of seagrass making it difficult to construct monitoring objectives; sampling difficulties; and high spatial variability which makes classical monitoring designs ineffective. We have failed to identify any situations in which such classical monitoring has actually triggered managerial action. Nonetheless, there are many informal observations of seagrass decline leading to management action. It may not be possible to quantify the fisheries, environmental and social costs of such seagrass decline, but the precautionary principle clearly warrants action in the face of changes of considerable magnitude if uncertain impact.

4.4.3 Techniques for the integration of spatial data

The third area of strategic research is in techniques for the integration of spatial data — particularly in the form of temporal sequences of spatially referenced data for the same region. *Ad hoc* analyses based on the spatial displays of proprietary GIS systems are totally inadequate — they provide no information about the reliability of change maps. Neither can we rely on continuing research in the statistical literature. Much of this work is either narrowly theoretical or focused in the area of geostatistics for mining resource assessment. From a practical monitoring perspective, the most exciting statistical developments are in the area of Causal Probability Networks (CPNs) (Kiiveri *et al.*, 1997; Evans *et al.*, 1996; Evans *et al.*, 1998). These techniques have been pioneered in the interpretation of temporal sequences of satellite images and have an immediate application to monitoring problems. FRDC should consider funding method development work on spatial integration of sequences of seagrass monitoring data. This work should be undertaken in the context of a 'live' resource assessment issue, so as to ensure relevance and applicability. The current WA Northwest Shelf study might provide a valuable opportunity for progress, or such work could be undertaken in the context of the broad-scale mapping proposed above.

4.4.4 Data quality and meta-databases

The fourth area for immediate consideration is a detailed inventory of existing monitoring or resource distribution data. The Environment Australia 'Blue Pages' database is a significant move in this direction, and should be encouraged. FRDC should consider requiring lodgement of meta-data with Blue Pages as a condition of funding.

In order to protect the value of future investment, FRDC should also require appropriate data quality protocols as a condition of funding. These protocols should address the level of meta-data required, data security and data access issues, and data validation concerns.

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CHAPTER FIVE

Seagrasses and their management — implications for research

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5.1 Introduction

5.1.1 Background

Scientific research has demonstrated that, within the uncertainties described in previous chapters, seagrasses have value for both fishery and biodiversity conservation. Responsibility for managing human impacts on seagrasses so as to maintain or enhance these values rests with a number of agencies representing all levels of government.

Managers require accurate and timely information about seagrasses at varying spatial scales. For example, planners may require information on seagrass distribution at a regional scale whereas a person evaluating a development application may require very site-specific information.

Those agencies with a legal responsibility to manage seagrasses also provide information to a wide variety of interest groups including the community at large, industries, local governments and other agencies. Managers also have to specify to developers (private and public) and their consultants the studies required for evaluating environmental impacts and the efficacy of impact mitigation measures.

Linking the information needs of managers to the supply of such information from researchers is the theme of this chapter.

Two notes of caution

Although not raised specifically by Cappo *et al.* (1998), the management of fish habitats such as seagrasses raises some major questions for the FRDC in regard to determining where its responsibilities for funding lie. These questions arise from the fact that, although fish habitats are important to FRDC and its stakeholders, the factors which impact upon them, and the jurisdictional responsibility for them, commonly lie outside of fisheries management agencies. We suggest mechanisms for dealing with this in Section 5.6.

A second point that needs to be made is that, although seagrasses are important, they are but one component of a wider system of fish habitats. This report is directed to seagrass managers and researchers but its recommendations, while focused on seagrasses, are also applicable to other habitats. We thus advocate a broader interpretation of these recommendations.

5.1.2 Approach taken

This chapter aims to provide the FRDC with an insight into the type of information about seagrasses that environmental managers require. Such an insight is vital as managers commonly express dissatisfaction with the information provided by seagrass researchers; it rarely addresses the situations which these managers face on a day-to-day basis.

The primary means of gaining information for this chapter was through a questionnaire sent to organisations and individuals involved in the management and research of seagrasses. Appendix 5.1 shows a copy of the questionnaire. The authors followed up any issues raised in the questionnaire that required clarification.

Selected legislation and policy documents were reviewed by conducting searches of the Australasian Legal Information Institute's databases of Australian legislation (www.austlii.edu.au).

Two key papers were also considered: (Cappo *et al.*, 1998; and Hamdorf & Kirkman, 1995).

Finally, the personal experience of the authors was also utilised to structure the approach to the analyses and fill in gaps where necessary.

The information for this project was difficult to obtain, due to the complexity of decision making structures. In addition, the existence of both duplication and gaps with respect to responsibilities made it hard to find out who was responsible for seagrass management in any given State. The complexity of decision making in the coastal zone has been pointed out on many occasions (e.g. Anon, 1992; and Anon, 1993). It would appear that these complexities remain.

The results below need to be interpreted with some caution because the questionnaire may not have reached everyone in Australia involved in seagrass management and some managers did not respond.

Respondents to the questionnaire raised three main, interrelated concerns:

- Lack of coordination of the actions of managers with responsibility for the various pressures on seagrass, particularly on a local scale (within estuary), but also on a broader scale (within and across jurisdictions)
- Lack of sufficient and appropriate information on which to base management decisions with confidence on a day-to-day basis
- Inadequate links between managers and researchers to allow for demand driven prioritisation of research effort

After outlining our findings on the issues that concern managers (Section 5.2), responsibilities, methods and tools for management (Section 5.3), and the information needs perceived by managers (Section 5.4), suggestions are offered for assessing the effectiveness of management (Section 5.5). In Section 5.6 a national plan of action is proposed to improve seagrass management, which would involve many participants but in which FRDC could invest significantly.

5.2 Issues confronting seagrass managers

Pressures on seagrasses — human-induced (directly or indirectly) and natural — are discussed in Chapters 1–3. To give context here, the main 'pressures' on fish habitats presented in Cappo *et al.* (1998) are summarised in Sections 5.2.1 to 5.2.5.

5.2.1 Natural dynamics and environmental variability

Sudden and major variations may occur in the distribution and abundance of seagrass as a result of events such as episodic floods, storms or grazing by herbivores. Climatic variation can also operate over longer time scales to influence seagrass. The natural dynamics in seagrass systems and environmental variability need to be understood to underpin all management of human impacts. The natural dynamics of seagrasses and environmental variability produce uncertainty in the prediction of environmental impacts. This may have significant consequences for management decisions, outcomes and risk analysis. The current understanding of natural seagrass dynamics and environmental variability is inadequate (See Chapters 1 and 2).

5.2.2 Changes to drainage and alteration of habitat

Effects on seagrass may result from river regulation and from alteration to land management practices in catchments. Potential seagrass habitat can be degraded by structural, chemical, thermal and biological barriers. In addition, sedimentation leads to mangrove expansion, increased turbidity resulting in seagrass retreat into shallows ('narrow-banding'), and seagrass blowouts and erosion.

Direct disturbance or destruction of plants or their habitat affects seagrass. Examples of activities include sand mining, extraction of fill material, dredging for navigation, filling, and placement of structures.

5.2.3 Nutrient and contaminant inputs

According to Cappo *et al.* (1998) most seagrass losses, whether natural or caused by human activities, are directly attributable to reduced light intensity due to turbidity, increased epiphytism, or both. (This general hypothesis is believed to be inadequately tested, see Appendix 6.1 and Chapter 1). Poor catchment management, sediment instability and dredging interact to make the process of seagrass dieback a complex one.

Major sources of pollutants are:

- runoff from agricultural land of fertilisers, animal wastes and soils
- point source discharges from industrial plants, stormwater and sewage drains
- effluent runoff from mariculture ponds, racks and sea cages
- possibly, wind-blown agricultural chemicals

5.2.4 Effects of harvesting on ecosystems and biodiversity

Commercial and recreational harvesting of fish, invertebrates or algae may directly affect seagrasses or their habitats by damage from trawling and hauling gear, digging implements, boats, and foot and vehicular traffic. Indirect effects may result from food chain alteration through removal of predators or forage species. Collection of live seagrass plants and dead seagrass material can also have an impact.

5.2.5 Introduced and translocated pests and diseases

Cappo *et al.* (1998) identified the potential for displacement of seagrass by the Asian mussel *Musculista senhousii* or by introduced species of green algae of the genus *Caulerpa*, and the presence of the seagrass pathogen *Labyrinthula* sp. in southeastern Queensland.

5.3 How is seagrass managed?

5.3.1 Who manages seagrass?

Commonwealth, State and local natural resource management agencies that have a role in seagrass management in Australia are generally of the following types:

- **Fisheries** agencies that are generally concerned with the maintenance of sustainable use of fisheries resources. They may have powers to control direct disturbance or destruction of seagrass with the aim of maintaining a viable fish habitat. They also regulate fishing activities in seagrass beds. They generally have little legislative control over activities that have indirect effects on seagrass.
- **Environment protection** agencies that generally have powers to control environmental harm caused by pollution (e.g., discharges), construction (e.g., sea walls) or maintenance works (e.g., annual dredging).
- **Parks, flora and fauna** agencies that are generally concerned with conservation of biodiversity and ecological integrity.

- **Land and water conservation** agencies that are generally concerned with management of soil, water and/or vegetation.
- **Land use planning and development control** agencies (especially local government and State government planning departments) that control developments and activities in catchments, waterways and coastal zones.
- **Ports/harbours/airport/defence** authorities that may have powers to carry out developments and/or activities in or near seagrass, often in limited defined areas.

The actual placement of each of these management agencies in an administrative structure varies from jurisdiction to jurisdiction. Further, the primary functions ascribed above may be amalgamated in various combinations within each jurisdiction. For example, fisheries management and biodiversity conservation are both functions of the Victorian Department of Natural Resources and Environment (although these two functions are delivered via separate divisions within the department). The detailed administrative structure for each jurisdiction is not described as it is likely to be out of date soon.

Across the nation, there are varying degrees of overlap in management objectives, sharing of responsibility, and cooperation in seagrass management. These links are between agencies, advisory groups and management committees at any level of government and community/ industry sector. While this report documents some successes in seagrass management and improvements in models of management, the shortcomings of past and present management regimes are expected to continue for many years. Ongoing seagrass degradation results from inadequate legislative protection of seagrasses in some jurisdictions, inadequate policy setting and implementation in others, as well as inadequate impact assessment and day-to-day decision making that is based on limited information.

Increasingly, opportunities exist for education to give broad community impetus and political support for implementing formal seagrass habitat protection measures.

5.3.2 Tools used for managing seagrasses

Seagrasses can be managed either via the enforcement of laws or by the provision of information that encourages people to take voluntary action.

Laws may specifically protect seagrasses or may protect them indirectly by protecting linked habitats (e.g. protecting all fish habitats in an area) or by addressing threatening processes such as pollution.

Laws that do not absolutely protect seagrasses generally give managers some latitude to allow for conditions to be placed on any activity that may potentially affect seagrasses. For example, such conditions may seek to regulate certain activities and/or mitigate potential impacts.

Whereas laws generally prescribe what may *not* happen they may be effected via the provisions of policies and guidelines. Guidelines in particular aid developers and others to understand what *may* be done to make an activity or development more compatible with seagrasses.

Providing information to the public is an important component of seagrass management. Information enables individuals to take actions to reduce their own impacts and enables developers to design activities/developments around the needs of seagrasses and other sensitive habitats.

This section describes tools used by seagrass managers in Australia and how they are used. Examples come from various jurisdictions.

Legislation

Legislation relevant to the protection of seagrasses falls into the following categories:

1. *Acts that include specific protection for seagrasses*
   An example is the NSW Fisheries Management Act, 1994 which provides specific protection for seagrasses under Sections 204 and 205. Damage to all seagrasses is prohibited unless permitted under licence. In addition the Act has been recently (1997) amended and strengthened to include special protection of species identified as threatened. This could provide increased protection to *Posidonia australis* (for example) and its habitat in NSW.

2. *Acts that address activities which may affect seagrasses or other biotic communities*
   A large number of pieces of legislation are included in this category. They address the 'pressures' listed by Cappo *et al.* (1998). Much pollution control legislation, for example, aims to ensure that water quality in waterways is sufficient to maintain plants and animals. In South Australia, loss of seagrass is included in the definition of environmental harm. Some fisheries acts (amongst others) include provisions for the control of activities such as dredging and reclamation, which may affect seagrasses.

   Impact assessment legislation, such as the Commonwealth's Environment Protection (Impact of Proposals) Act, 1975, is used in all States to evaluate the potential impacts of specific development proposals.

   In general these acts are reactive in that they are triggered by a particular development or activity proposal. Practitioners administering such acts need to be aware of the existence and needs of seagrasses in the area affected by the proposal in order to invoke protective or impact amelioration mechanisms.

3. *Acts which proactively protect seagrasses from classes of activities*
   Legislation providing for land use planning and protected areas can protect seagrasses in several ways. For example, it may provide for the protection of all seagrasses wherever they occur, making it the responsibility of anyone who may affect seagrasses to seek a permit. An example is Habitat Protection Plan Number 2 which was promulgated under the NSW Fisheries Management Act, 1994. The Queensland Fisheries Act (1996) also provides strong legislation specific to protection of all seagrasses and other marine plants (see Appendix 5.2).

   A second way of protecting seagrasses through legislation is to zone particular areas as protected. Many such areas are set aside under conservation legislation (as national parks for example), planning legislation (by being zoned under council planning schemes) or under fisheries legislation (in marine protected areas). In general, any activity which may directly affect seagrasses would be prohibited, as would indirect activities occurring within the protected area. For activities occurring outside the protected area which may affect seagrasses inside, coercion and pressure may be used, although these tactics may not necessarily be successful. The Great Barrier Reef Marine Park Authority is just one agency that has problems dealing with activities outside the park boundaries that affect the park itself.

Hamdorf and Kirkman (1995) presented a State-by-State assessment of legislative protection for seagrass. A substantial amount of natural resource management and environmental protection legislation has been created since that review and an update is provided in this report (see Appendix 5.2).

Information requirements for legislation

Managers dealing with legislation need many types of information. Locational information (inventory and mapping) is always important but accuracy becomes more of an issue for specific development proposals than for large-scale planning exercises.

For development proposals managers may need quite detailed information on the potential consequences of the development itself. In general, potential consequences can only be predicted on the basis of an understanding of the ecology of the seagrass and its relationship to other components of the overall ecosystem. Such understanding is not generally available (see Chapters 1 and 2) and is rarely supplied by the proponents of developments.

Policy

Policies are designed to guide the implementation of legislation. Whereas legislation may apply to all aquatic vegetation, the special needs of seagrass may be highlighted by the preparation of a policy.

Policies themselves may have a legislative base and thus 'have teeth' or they may be a guide for the responsible department and others as to how the legislation will be interpreted. As with legislation, policies may address seagrasses directly or indirectly and may address threatening processes rather than the habitats themselves.

Information requirements for policy

Policies deal with information at a greater level of detail than legislation and therefore more information is required. For example, the policy on *Posidonia australis* for NSW Fisheries implies knowledge that its status is at risk and that there is a reasonable amount of knowledge about the types of activities that may be of concern to the policymakers.

Guidelines

Guidelines are generally 'how to' documents that may present developers, proponents of proposals subject to environmental impact assessment, and the general public with information on how to carry out activities/developments in a way which will either enable a permit application to be successful or, if a permit is not necessary, to avoid prosecution. They can provide greater certainty of outcome and ensure consistency of approach.

The WA Environmental Protection Authority has produced draft EIA guidance statements on protection of seagrass and other benthic primary producer habitats (Anon., 1998a, b). NSW Fisheries has also produced guidelines on how applications will be assessed for approval of activities that may detrimentally affect seagrass (Smith and Pollard, 1997).

One opportunity for increased use of guidelines and codes of practice is in the fishing industry itself, where improvements in fishing practice can reduce direct habitat damage and bycatch. It is within the jurisdiction of fisheries managers to develop this area.

Information requirements for guidelines

Guidelines tend to be highly detailed documents and thus require detailed information. For example, guidelines may provide advice about how far a development should be from a seagrass bed or the maximum depth of dredging which will allow seagrasses to recolonise. For example, the recently released NSW Fisheries habitat guidelines state that dredging must go no deeper than 2m if seagrasses are to recolonise. Knowledge of the distribution and light limitation aspects of seagrasses are needed to generate such guidelines.

Guidelines designed to reduce habitat damage and bycatch also require specific information on the effects of fishing practices and on the effectiveness of various amelioration techniques, such as bycatch reduction devices.

Education and provision of information/advice

Some management models have made extensive use of education as a tool to facilitate and motivate improvements in land and coastal zone use for seagrass conservation. Dedicated education programs are most effective, but respondents to our survey suggest that even these require further resources. The day-to-day legislation and policy-based management, during interactions with stakeholders and proponents, has been seen as a front-line and critical form of education.

Seagrass management that includes dedicated education programs exists in some States, for example, those run by Queensland Department of Education, GBRMPA and NSW Fisheries. Dedicated education programs are thought to be an effective mechanism for achieving broad-based community impetus and political support for implementing formal seagrass habitat protection measures. The contribution of such education programs to slowing or reversing seagrass decline would be difficult to assess and, to our knowledge, this has not been done.

Information requirements for education and provision of advice

Most agencies and authorities appear to follow their own assessment in choosing the most appropriate education tools, but there may be advantages in identifying the types and styles of education that are most effective for particular circumstances and desired management outcomes.

Works

Physical works may be carried out to protect seagrass from specific threats or to restore or rehabilitate seagrass in areas where it has been lost or degraded.

Information requirements for works

This aspect is dealt with in detail in Chapter 7.

5.3.3 Approaches to seagrass management

As indicated above, a number of approaches to seagrass management are possible, from a reliance on strong and prescriptive legislation to weaker guidelines and policies. More than likely a mix of approaches is used but to the authors' knowledge, the effectiveness of different approaches has not been evaluated.

A second major area where approaches vary is whether agencies are proactive or reactive in their protection. Proactive approaches tend to involve the use of planning powers whereas reactive approaches involve intervening in situations after a problem is detected or an application to affect seagrasses is made. As with the legislation/guidelines split, commonly a mix of proactive and reactive approaches is used and neither approach is necessarily better than the other in isolation.

Finally, seagrasses can either be addressed as part of a wider, system-based management program, such as integrated catchment management, in which all aspects of the system are considered, or they can be managed in isolation. Although examples of both approaches can be found, there is no doubt that the complexity of systems approaches makes for some serious difficulties and a mix of integrated management with foci on special problem areas such as seagrasses is becoming more common.

Planning

Three approaches to planning can be found amongst those agencies that practice proactive seagrass protection, namely:

- All seagrasses protected
- All seagrasses as mapped are protected
- Seagrasses within a wider protected area are protected

Few States fully protect all seagrasses although partial protection is achieved via legislation or policies that put more stringent requirements on those wishing to affect seagrasses than those who do not. Such an approach shifts the burden of information supply from the agency to the person/agency wishing to affect the seagrasses in that the applicant must find out about the existence of seagrasses in the area they want to develop and also the potential impacts of their development.

In comparison to some terrestrial habitats (e.g. wetlands, littoral rainforests), there are few cases where seagrasses have been mapped and the mapped areas given stringent protection. In northern Queensland, broad-scale mapping of seagrasses in the 1980s led to the drawing of boundaries for trawl area closures and some localities mapped in the early 1990s were gazetted as Fish Habitat Areas. In New South Wales seagrasses were mapped in the early 1980s and the maps used as the basis for policy decisions but the maps are now out of date and the policy has changed. In Queensland, the Fish Habitat Areas commonly protect seagrasses as part of larger habitat complexes and such areas are given reasonably stringent protection. Mapping seagrasses as a prelude to protection has a number of problems (see Chapter 4), not the least of which is its intensive use of resources, the often fickle nature of seagrass distribution over time and problems relating to scale (e.g. long linear beds are often missed by remote sensing).

In a number of marine and estuarine protected areas seagrasses are afforded quite strict protection. Such reserves exist in Queensland, New South Wales, Victoria, South Australia and Western Australia. Reserves tend to require relatively high levels of detail due to public scrutiny and tend to be used to set aside either special or representative areas. They are therefore not appropriate for protecting the large areas needed to support fisheries.

Information requirements for planning

McNeill (1996) suggests that information on the following characteristics of seagrass beds and associated communities needs to be considered when designing marine protected areas:

- Spatial variability among and within estuaries
- Areas of consistent recruitment
- Links with other habitats, including information on the type, quality and proximity of adjacent habitats and the processes that maintain the linkages.
- Resilience to disturbance

Knowledge about location is the most critical information required for spatial planning approaches to seagrass protection.

Integrated management

Integration of the activities of the many stakeholder groups in catchments is an elusive goal. There are examples where legislative approaches are being used to achieve coordination of managers (for example, Queensland Integrated Planning Act, New South Wales Catchment Management Act) as well as policy approaches such as the coastal policies of New South Wales and Tasmania and the use of 'whole of government' decision making.

The Integrated Planning Act (IPA) in Queensland intends to provide a Statewide planning system for dealing with developments which affect coastal habitats. It will include obligations to set Desired Environment Outcomes (DEOs) and to monitor selected performance indicators. Developments will be assessed by all relevant management agencies.

1. Land based — e.g. catchment management

Integrating/coordinating bodies such as catchment, river, estuary or harbour management committees are generally concerned with bringing together the activities of the natural resource managers within a geographical unit (catchment, sub-catchment, lake, river, estuary). Membership of these integrated management bodies usually includes stakeholder groups and expert/technical advisory agencies.

Information requirements for integrated land-based management

Such committees always require locational information and commonly require more detailed information on 'response to impacts'. However, they are rarely decision-making bodies in the sense that they may issue and place conditions on permits. Such responsibilities still lie with agencies who are the ultimate users of such information.

2. Water-based — estuary, fishery etc

The Albany Waters Management Authority (AWMA) aims to manage for a sustainable environment in the Albany Waters Region. AWMA is one of five major regional management authorities in the south west of Western Australia that evolved from local community groups (on catchment issues) and are now under the umbrella of the WA Waters and Rivers Commission.

Seagrass health is by far the most important indicator of the success of management of the Princess Royal Harbour and Oyster Harbour area. AWMA facilitates management of other environmental parameters, but these are all intended to lead to improvement and maintenance of seagrass systems. AWMA has limited legislative powers, but it is the major organisation facilitating agencies and community groups to implement environment protection and rehabilitation initiatives for the region.

Many fisheries management advisory committees either consider seagrasses, or have the capacity to consider seagrasses, as part of their deliberations.

Information requirements for integrated water-based managment

As with the land-based committees, the information needs are primarily locational and can be more detailed. In most cases jurisdiction and thus decision making powers rest with agencies.

Impact assessment

Most agencies with jurisdiction over seagrasses are required to conduct some form of environmental impact assessment in regard to applications to conduct an activity or development that may affect a seagrass bed. Such an application may be required as part of a permit process or part of a more formal application to be accompanied by an Environmental Impact Statement (EIS).

Depending on the 'level' of the application (i.e. permit versus EIS) the amount of information required can be highly variable. Small permit applications for a jetty for example may only require locational information coupled with information on how the jetty may avoid shading. However, an EIS for a major marina will require much more detail and be subject to greater scrutiny. For both types of applications, fine scale locational information is required and, in the case of the marina, it is likely that detailed information on dredge depths, responses of seagrasses to turbidity and pollutants, as well as impact mitigation strategies will be required.

Information requirements for impact assessment

In addition to locational information, impact assessments require the identification of essential physical, chemical and biological conditions under which seagrasses live. Such detail is commonly not available, especially on a site specific basis, and so managers need to know what to ask of applicants so that the appropriate information can be obtained.

5.4 Information needs for better seagrass management

5.4.1 Sources and recipients of information

Information relevant to seagrass management is presented in highly specialised language and format (results of scientific research, legislation), as well as in more accessible interpretation, simplification and clarification of this technical information (guidelines, educational material). The information is produced and presented by researchers, management agencies, advisory committees, community/interest groups, and private businesses (e.g. developers, tourism operators). All of these groups are also recipients and users of information, as are schools and the general public. Obviously the nature of the target audience is a major consideration in the format of the presentation.

Primary sources of information produced by researchers on seagrass biology, ecology and responses to perturbations, are scientific journals and books, and technical reports of research organisations. Integrating much of the information available on seagrass through vehicles such as Environment Australia's National Marine Information System would be of great value to many seagrass managers. Comprehensive databases (e.g., those of Australasian Legal Information Institute, www.austlii.edu.au) already exist for legal information, including legislation and court and tribunal proceedings.

Interpretation of the information and extension to decision makers and resource users is an essential second step. Indiscriminate availability of information through the Internet will be of little use to managers. If there is to be effective use of the information, it needs to include addresses of sources of advice/interpretation, for example, reference or links to such services as the Australian Marine Sciences Association's directory of experts. Strategic communication and extension of existing R&D knowledge into processes and structures which have common visions for fisheries outcomes is an important role for FRDC.

5.4.2 What the managers say they need

Answers to the five strategic questions posed by Cappo *et al.* (1998) will provide information that will contribute to effective management of seagrass. We have used these questions to help guide the interpretation of responses received from managers to the questionnaires and we have rephrased the questions to apply specifically to seagrass:

1. What are the major seagrass habitats and where are they located?
2. What is the role of seagrasses in providing and maintaining fisheries production?
3. What is the role of seagrasses in maintaining ecosystem integrity and biodiversity as a basis for long-term ecosystem health, and what are suitable indicators and monitors of this health?
4. What are the natural dynamics of seagrasses, and how are they affected by fishing, aquaculture and other human activities?
5. What linked mitigation, monitoring, scientific assessment, and management strategies will provide the seagrass protection necessary to achieve ecologically sustainable development of fisheries and aquaculture?

1. What are the major seagrass habitats and where are they located?

Knowing what seagrasses occur where in Australian waters, *or where they might occur*, is basic to many aspects of fisheries management and biodiversity conservation (see examples in Section 5.3). This information need was the most commonly mentioned in responses to our questionnaire. Respondents to our questionnaire identified needs for information on the location of seagrass, the species and proportions present, as well as biomass.

Details of distribution of all habitat types, including seagrass, are necessary for fisheries and marine park zoning purposes. This is exemplified in the conflicts which arose in the GBRMPA Dugong Management Plan, where boundaries of dugong protection areas were being negotiated to minimise impacts on both dugongs and the commercial gill-net fishery. This required seagrass habitat maps more detailed than the present broad-scale maps.

Without adequate baseline information on seagrass resources, we will remain ignorant of losses that may occur in unsurveyed areas. Inventories and mapping of seagrass resources (by species and habitat type) have been reviewed in Chapter 4. Seagrass has never been mapped for some parts of Australia, such as the Northern Territory (although seagrass distribution there can be derived to some extent from information on dugong distribution).

2. What is the role of seagrasses in providing and maintaining fisheries production?

See answer to fifth question, below.

3. What is the role of seagrasses in maintaining ecosystem integrity and biodiversity as a basis for long-term ecosystem health?

See answer to fifth question, below.

What are suitable indicators and monitors of this health?

Respondents considered that elucidation of physical and biological links between seagrass, fish and fisheries would allow them to make better decisions in management of seagrass. They considered that this information was often unavailable or more difficult to obtain than the 'what/where' information on seagrass.

Some respondents believed that translating the value of seagrass for fisheries production into economic terms would be useful to counter arguments for particular activities that would degrade seagrass. It is our view that using arguments based strictly on economics is a risky path to follow as they may not always result in the protection of seagrass.

Respondents identified information needs in relation to the value of specific areas for habitat, uniqueness and naturalness. In the absence of detailed knowledge of the different productivity or conservation values of each seagrass area, agencies assessing impacts of development and runoff will make uninformed and possibly inappropriate assessments of what may be sacrificed to development. However, having detailed information for all areas is probably an unrealistic goal. A possible application for research is the development of models that ask the right specific questions so that answers can be obtained about each area with a minimum of new effort.

Respondents specifically identified a need for information on:

- utilisation and interaction with and by vulnerable species such as turtle and dugong (areas of highest priority are dugong protection areas (DPAs) and the southern GBR)
- fish utilisation of 'productive' seagrass meadows (e.g., potential yield from seagrass meadows of commercially important species)

Proposals for monitoring ecosystem health using seagrass have suggested the measurement of many different variables, but generally without a conceptual basis (see Chapter 4). No standard set of parameters has been established, and it is likely that the most suitable parameters for monitoring management effectiveness will be project-specific depending on why and where the monitoring is being conducted. While management is targeted to maintenance of habitat and plant health for fisheries productivity, parameters which reflect these goals should be measured first. No survey respondents mentioned socio-economic parameters for monitoring effectiveness of seagrass management programs. These would be low priority, but not unimportant, considerations in an assessment of the effectiveness of a fisheries habitat management program.

The money available for monitoring is always likely to be less than is required to measure a comprehensive set of parameters. Identification of strengths and weaknesses of measurable parameters, including information of their relative costs, would be a valuable resource. This could include recommendations on the combination of parameters that would be most appropriately used to identify stresses resulting from particular pressures, as well as advice on the value of parameters in identifying responses at various scales. (See Chapter 4 for additional comments on monitoring).

4. What are the natural dynamics of seagrasses, and how are they affected by fishing, aquaculture and other human activities?

Many respondents identified a crucial need for information on natural variation in space and time and at a variety of scales. Variation would be between and within (such as phenotypic differences in tolerances to environmental conditions) species of seagrass. Understanding of natural dynamics in seagrass systems and environmental variability is needed to underpin all management of human impacts.

Chapter 4 comments on the limitations of broad-scale seagrass mapping exercises at one point in time. For example, maps of seagrass in the Shoalhaven River on the south coast of NSW, prepared by West *et al.* (1985) from 1979 air photographs and 1982 field surveys, show scattered areas of *Zostera capricorni* between Broughton Creek and Nowra. Local fishermen (G. Usher and J. Wilson, pers. comm.) report that most of the seagrass disappeared from sand flats and channels in a large section of the estuary in the early 1990s, possibly as a result of one or two flood events. Since that time *Zostera* has recolonised the sand flats and channels to an extent 'not seen in living memory' and it now occupies a considerably larger area than shown on the 1985 maps.

Clearly, managers need to consider such temporal variability. It is a particular problem when mapping the location of seagrass. This is often done on a needs basis, e.g., mapping seagrass in a particular part of an estuary that is the subject of a development proposal. But, information on patterns of temporal variability in seagrass distribution and abundance is needed for all spatial scales, so that these can be related to changes in secondary productivity.

One way of taking into account temporal variation in the distribution and abundance of seagrass is to identify potential seagrass habitat. An alternative is to map the location of seagrass more frequently. Mapping potential seagrass habitat would require identification of essential physical, chemical and biological conditions under which seagrasses can live (Chapter 3 addresses this possibility). This information could be used in combination with the extensive observations made over many years by users (such as commercial and recreational fishers) of particular waterways. Many respondents to the questionnaire identified quantitative research aimed at identifying the habitat requirements of seagrasses as an important information need. Such information would not only be valuable for identifying potential seagrass habitat but is also essential for predicting responses of seagrass to human-induced changes in environmental conditions.

Temporal variability in seagrass habitats may affect fisheries productivity, but still little has been done to establish the strength of this relationship and whether it should play a significant role in fisheries management. Although causality may be difficult to establish, if studies of seasonal or year-to-year changes in seagrass and their influence on fisheries productivity were designed to collect corresponding information on the factors relating to the physical environment which contribute to seagrass changes, then some light may be shed on the relationship between natural and human impacts.

Respondents identified the need to more clearly define pathways linking human activities with seagrass health. Information on the following was specifically identified as being necessary to assist in management of human impacts on seagrass:

- Habitat requirements for continued seagrass viability
- Determination of the sources of nutrients, sediments or other human induced impact on seagrass
- Responses to changes in habitat quality (such as reduced light intensity, increased suspended solids, increased nutrients, increased temperature) resulting from jetties, dredging, catchment inputs

Other questions specifically posed by respondents were:

- What are the critical levels (area, density) required for sustaining seagrass habitat?
- How might seagrass respond to geological evolution of estuaries?
- What is the capacity of seagrass to recover from loss or be rehabilitated?
- What are the time-frames for recovery?
- What is required for successful restoration?

Possible impacts of fishing gear on seagrasses is a perennial issue in management of seagrasses and fisheries in some parts of Australia, but little research has been conducted to date, and this should be noted as a priority.

5. What linked mitigation, monitoring, scientific assessment, and management strategies will provide the seagrass protection necessary to achieve ecologically sustainable development of fisheries and aquaculture?

Adaptive management relies on monitoring system performance and changing those management activities that are ineffective. The integration of information and effort among researchers, managers and industry is of utmost importance.

The coastal zone has multiple impacting agents and competing users of resources, who together influence the fate of seagrasses. Cappo *et al.* (1998) identified the problems of coastal zone habitats and fisheries being managed separately — while some States do much to manage and protect seagrass through fisheries legislation alone, there are generally problems in safeguarding fisheries values in our fragmented coastal management.

5.4.3 Summary of information requirements identified by managers

The information requirements identified above are very similar to the knowledge gaps identified in Chapters 1–4. Managers stressed the need for inventory and mapping, noting problems of accuracy and the importance of spatial and temporal variability. They needed ecosystem understanding and knowledge of ecological processes, ecological requirements and tolerance, and particular species, links between seagrasses and other components of the ecosystem, the mechanisms for the impacts of human-induced pressures, and development of monitoring methods. All of this can be found in more detail in Chapters 1–4.

Managers also sought information on the effectiveness of management tools, and of educational tools, a need not identified in the preceding chapters. They called for greater accessibility of scientific information (e.g. by referring to it on Web sites) but pointed out the strong need also for services that can interpret technical information so that managers can use it.

Since complete understanding of seagrass ecosystems at all sites is unlikely to be obtained in advance of need, this Chapter suggests the idea of developing models that would enable the right specific questions to be asked in particular cases. The seagrass form/function model proposed in Chapter 1, and the research program which it implies, might be an approach to this proposal.

5.5 Assessing the effectiveness of seagrass management

Chapters 2, 3 and 4 give some indication of the effectiveness of past management. Early examples of foresight and some successes are evident, for example:

The annual reports of the fisheries management agency in New South Wales make reference to the need to protect seagrasses in the 1960s and 1970s, i.e. before provisions were created in the Fisheries and Oyster Farms Act, 1979, to manage activities such as dredging and reclamation. More formal management of seagrasses for their fish habitat value began in the 1980s. For example, the Towra Point Aquatic Reserve was established in 1987 to protect the mix of seagrasses, mangroves and saltmarshes on the southern shore of Botany Bay. Another example, was the 1990 closure to trawling of inshore seagrass areas so as to protect juvenile prawns (with indirect benefits of minimising possible physical damage to meadows from trawl gear) in the northern prawn fishery.

However, even following large-scale losses of recognised fish habitat areas (e.g., Westernport Bay, Vic; St Vincents Gulf, SA; Cockburn Sound, WA) formal management of these habitats has grown sporadically. A number of environment agencies took on some responsibility for seagrass habitat management in the 1980s.

Some major advances in seagrass management have occurred in the 1990s. Some State fisheries and other agencies have recently begun to develop very progressive models of seagrass management for fisheries sustainability. For example, in Queensland and New South Wales, legislation specifically provides for protection of seagrass from direct disturbances, and Queensland has a policy of no net habitat loss. In South Australia, loss of seagrass is included in the definition of environmental harm.

There are few examples of management actions designed specifically to deal with natural impacts on seagrass. In the mid-1980s action was taken to reduce numbers of sea urchins grazing on seagrass in Botany Bay, NSW after the number of urchins had increased greatly in a relatively short period. It was argued that they threatened to remove large areas of *Posidonia australis*, that this species would be extremely slow to recover, if at all, and that there had already been major losses in the bay as a result of human activities. Divers removed urchins by hand.

Notwithstanding these examples of action, there is no consistent approach amongst agencies to assess the effectiveness of seagrass management programs. Some authorities audit the activities of other agencies; for example, the Western Australian Marine Parks and Reserves Authority audits the management plans for marine protected areas implemented by the Department of Conservation and Land Management. Legislation generally allows for approvals to pollute or disturb seagrass to be conditional on monitoring of environmental effects; a synthesis and analysis of information from such programs would no doubt provide useful insights on which to base future management actions.

An example of broad-scale assessment of the effectiveness of management is the review by McNeill (1996) of seagrass and marine protected areas in New South Wales. McNeill found that the current system of marine protected areas in New South Wales is inadequate in the area and range of seagrass species protected. She demonstrated that seagrass communities have not been the target community for protection when the boundaries of protected areas were established.

In general, assessment of the actual success of management is a task in *monitoring*, discussed in Chapter 4, and we address only the jurisdictional aspects here.

5.5.1 Who should monitor?

It has been extremely difficult for any authority to implement formal, institutionalised programs to monitor even the location of seagrasses, let alone any more sophisticated assessment of the effectiveness of seagrass management.

Most legislation that provides for approvals to pollute or disturb seagrass also allows for that approval to be conditional on monitoring of environmental effects. Where this condition is applied it is frequently the polluter/developer that carries out the monitoring and this may or may not be audited by the regulatory agency.

In 1993, the Ports Corporation of Queensland initiated its own monitoring of seagrass bed status (among other parameters of ecosystem health), to assess its port development environment management plans (McKenzie *et al.*, 1996; Rasheed *et al.*, 1996). So too has the Federal Airports Corporation been monitoring the impacts of runway construction on seagrasses in Botany Bay.

More efficient and effective monitoring of the impacts of human activities on seagrass (or more generally the natural environment on which fisheries depend) may result from co-operative efforts that result in pooling of resources and minimising overlap. An example of such a co-operative effort is the Cumulative Impact Monitoring Program in Jervis Bay, New South Wales.

5.6 Suggestions for improvement of seagrass management

One of the outcomes of this review is questioning of the role of FRDC in seagrass management. There are many things that need to be done to improve seagrass management in Australia, but they may not all be the responsibility of FRDC. In our view, a key action is for FRDC to identify, in association with its client groups, what the boundaries are for FRDC action. We offer some suggestions for improving the situation for seagrass management.

5.6.1 A National Action Plan

Complex mazes of legislation and jurisdiction vary from State to State. While a national standard of seagrass management might attempt to rationalise processes for achieving seagrass fisheries habitat protection, the multiplicity of political powers, agencies, interest groups, their objectives and location-specific management issues will forever create an impediment to enforcement of a national standard on seagrass management. Each State and region will almost always need to develop management models most suited to 'local circumstances'.

A national action plan for seagrass management, however, could maintain an overview perspective of where seagrass management models are successful or unsuccessful. A national action plan also provides a guide to fisheries managers on how to better facilitate improvements in seagrass habitat management in their State or region.

Key areas for action to improve seagrass management in Australia are listed and then expanded on below.

Because the management of seagrasses is inextricably linked with management of fish habitat in general, many of these suggestions are couched more generally than if seagrass was being considered in isolation. As mentioned in the introduction to this chapter, these suggestions should be read to include fish habitats in general and not just limited to seagrasses.

5.6.2 Action plan for seagrass management in Australia

This plan attempts to address the information gaps (Section 5.4) and makes suggestions for improving management models for seagrass fisheries habitats in Australia. It is generic and recognises there are location- and State-specific differences in management issues, etc. FRDC would be one of the many partners in this plan, and could take a significant role in facilitating the whole plan (see Chapter 6). The FEHC or the ASFB's habitat group could review the plan annually and provide a major review of seagrass management every five years.

The plan contains the following key actions:

- Establish/improve and maintain links between managers and researchers
- Develop networks for information sharing
- Develop collaborative research, development and extension
- Improve standards for impact assessment and rapid area assessments
- Improve standards for assessment of seagrass management programs

Establish/improve and maintain links between managers and researchers

"The over-riding challenge facing fisheries stakeholders with all the downstream effects of agriculture and development is to identify and implement better ways to transform scientific expertise and knowledge into information relevant to natural resource management — and to ensure this information produces outcomes that safeguard fisheries values" (Cappo *et al.*, 1998). We suggest that an equally important challenge is to involve the managers in setting and prioritising the research questions.

One suggestion is to provide a forum every three to five years for managers to come together on a national basis to place their needs on the table and thus help drive the research agenda from a demand perspective.

Develop networks for information sharing

Formalise exchanges between fisheries managers and between States

Fisheries management agencies from each State could conduct formal annual or biannual meetings or regular e-mail /video-conference discussion groups to exchange information on the management of seagrasses and other fish habitats. These exchanges could also ensure the national perspective is maintained on a regular basis and examine where and when opportunities exist for improving management mechanisms.

Establish a directory of fish habitat management organisations

A first step for any national or State-wide management strategy is to identify all agencies and stakeholder groups which have formal influence on seagrass/fish habitat management. A directory of these bodies and their level of involvement (e.g., the geographical scope and nature of their management tools) should be constructed to provide a means of improving links between agencies with common intent. The directory will serve to facilitate better communication of management successes and facilitate networks for transfer of information on improving management models.

The directory should also make provision for the inclusion of non-government stakeholders with an interest in the management of seagrasses and fish habitats.

Develop collaborative research, development & extension

Catchment based problems are not only complex but resource hungry and beyond the reach of fisheries agencies to make substantial progress. By necessity, collaboration will be needed if the resources are to be made available and the will and the commitment of non fisheries stakeholders obtained.

Some suggestions include:

- Further collaborative ventures between FRDC and other R&D organisations such as Environment Australia, Land and Water Resources R&D Corporation and Dairy, Sugar and Grazing R&D Corporations in order to deliver research outcomes
- Use of R&D outcomes to facilitate progress on management decisions needed to protect, manage and/or rehabilitate seagrasses and other important fish habitats
- FRDC has recently upgraded its commitment to the extension of research project outcomes and this should be reinforced. Joint ventures with other R&D corporations, agencies, educational institutions and the private sector are again appropriate

Detailed investigations should be conducted within States to identify existing vehicles where fisheries research information can be used to help deliver 'on the ground' achievements and outcomes for seagrass management. Vehicles such as integrated catchment management, landscape-scale modeling initiatives in bays and estuaries, adaptive environmental assessment and management in catchments — all include processes and structures with common visions for fisheries outcomes, and existing fisheries R&D knowledge could be very effective if communicated to these vehicles.

A few warnings must be given in relation to proposals to work with 'local' coordinating bodies within the States. Firstly, there are many of them. Secondly, they are variable in their make up in terms of the stakeholder groups represented but more importantly in terms of the individuals' skills and their commitment to the goal of balance in natural resource use and conservation. Thirdly, although all of the local bodies report to or are coordinated by a coordinating body, such as the NSW State Catchment Management Coordinating Committee, and work within some overall policy or legislative framework, they do not all share the same priorities.

A two-pronged approach is recommended:

- Firstly, fisheries information would go to the State coordinating bodies, where they exist, for dissemination to the local bodies. Where fisheries stakeholders are directly involved with local groups, they would of course ensure that use is made of relevant information
- Secondly, collaborative projects should be initiated through local bodies, but they should be suitably chosen (noting the above caveats) to ensure success

It is unrealistic to expect that fisheries management agencies would ever administer primary laws that deal with upstream disturbances. Cappo *et al.* (1998) conclude that the greatest challenge facing fisheries stakeholders is to harness forces outside their control to conserve and rehabilitate key features of entire catchments, such as helping farmers to get rate relief or tax incentives for silt/nutrient retention programs, wetland construction or rehabilitation, and replanting of riparian vegetation. A further challenge is to convince port users, city planners and industries upstream that seagrass management should be a priority and that their actions influence seagrasses. Although economic incentives are an important element in modifying people's behaviour, other strategies are also important to address widespread ignorance of the consequences of poor catchment- and land-use. Modification of activities by regulation and education are also important strategies.

The importance of harnessing political forces should not be under-estimated as a way of bringing about better implementation of R&D results in environmental management. Powerful agents in this area are the fishing lobbies. Other processes and structures with a strong community component such as estuary management committees and catchment management committees are valuable. In Adelaide, the EPA has shown leadership in getting the solution to seagrass loss identified as not merely one of regulating point sources; the problem is now widely 'owned' by the public, local government, catchment management boards, recreational fishers and others.

Improve standards for impact assessment and rapid area assessments

Planning studies, environmental impact statements and related documents are a common source of information on seagrasses and fish habitats, but the information contained in many of them is extremely poor. One reason is that there is no accreditation system in place for those who conduct the studies, a situation beyond the scope of FRDC, although in the longer term FRDC could work with bodies such as the Environment Institute of Australia to establish accreditation systems. However, it is also true that no 'standard methods' manuals are available to provide guidance to consultants and others as to how such surveys and studies should be conducted. In the shorter term, FRDC should consider investing in such manuals as they would have application throughout Australia.

Many managers identified locational information as an important information need. Further development of rapid area assessments needs to be facilitated to enable such locational information to be provided at a suitable cost. A collaborative venture with an agency providing such spatial information would be productive.

Improve standards for assessment of seagrass management programs

Identify parameters which best monitor effectiveness of seagrass management (e.g., habitat status; fisheries productivity or yield)

Rarely has the effectiveness of seagrass management programs been assessed. No standard set of parameters has been established (see above), and it is likely that the most suitable parameters for monitoring management effectiveness will always be locality-specific. While management is targeted to maintenance of habitat and plant health for fisheries productivity, parameters which reflect these should be measured first. Social and economic parameters would be of lower priority but not unimportant in assessing effectiveness of a fisheries habitat management program.

Where possible, make assessment of management effectiveness a compulsory part of management programs

Some new legislation makes it obligatory for proponents to monitor their impacts on habitats (e.g., Queensland's proposed Integrated Planning Act; the NSW Fisheries Act and the South Australian EPA). This should be encouraged where possible in seagrass management models. However, it is important that monitoring is not only done to comply with the requirements of permits, but that it provides meaningful data with which to assess change (See Chapter 4).

5.7 Conclusions

Managers responding to our questionnaire had three main concerns:

- Lack of coordination of the actions of the various managers with different but interacting responsibilities
- Lack of adequate information on which to base day-to-day management
- Inadequate links between managers and researchers to allow for demand driven prioritisation of research effort

The information that managers require from researchers is very similar to the knowledge gaps identified in Chapters 1–4. Like those chapters, this one stresses the need for:

- inventory and mapping
- ecosystem understanding (knowledge of ecological processes, ecological requirements and tolerance, and particular species, links between seagrasses and other components of the ecosystem, and mechanisms for the impacts of human-induced pressures)
- development of monitoring methods

But managers added some requirements to those identified in Chapters 1–4; they sought:

- information on the effectiveness of management tools
- information on the effectiveness of educational tools
- greater accessibility of scientific information
- services to interpret technical information so that managers can use it
- a model structure that would enable the right specific questions to be asked in particular cases

A national action plan is proposed, to improve the effectiveness of management and the links between management and research, not only for seagrasses but for fish habitats more generally.

5.8 References

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Appendix 5.1 Questionnaire to seagrass managers

Questionnaire

Review of seagrass and fisheries management in Australia

The Fisheries Research and Development Corporation (FRDC) is reviewing seagrass research, monitoring and management in Australia so that a research and development plan can be established which will enable the corporation to determine funding priorities and to make decisions about research grant applications.

I am on a working group that is reporting on current models of seagrass management in Australia and how they have been integrated into fisheries management strategies and activities. The aim of this working group is to identify the information needs of managers who have an involvement with seagrasses.

Other groups are reviewing

- our present state of knowledge of seagrasses
- monitoring, assessment and mapping projects
- seagrass dynamics and the sustainability of fisheries
- seagrass remediation and rehabilitation.

To assist in compiling the report on seagrass management, I would greatly appreciate your considering the questions below and sending answers to me, either by:

Email: [*insert email address*] OR

Fax: [*insert fax number*] OR

Telephone: [*insert phone number*].

FRDC wants the review finished in time to guide the 1998 grant applications and so the deadline is tight. I need to receive your response by 8th May 1998.

Don't hesitate to telephone me if you want to discuss.

Feel free to make more space for your answers if you need to.

What is YOUR NAME?

What is your ORGANISATION?

What is the aim of your organisation with respect to seagrass management?

What management strategies (legislative and policy mechanisms) are employed by your organisation when dealing with direct impacts of human activities on seagrass? Please specify and attach relevant documents, if possible.

[Activities that result in direct impacts could include, but are not limited to, dredging, filling, placement of structures, fishing, boating. Management strategies include:

- protect areas, species or habitats
- require permits for disturbance
- assess impacts on a case by case basis require mitigation/compensation
- plan for dealing with accidents (eg oil spills)

- compliance through education and enforcement
- involvement in statutory planning laws
- combinations of the above or other approaches.]

What management strategies are employed by your organisation when dealing with indirect impacts of human activities on seagrass?

[Indirect impacts could include, but are not limited to, nutrient enrichment of surrounding waters, increased sedimentation, rise in sea level. Management strategies include:

- involvement with catchment management committees (or similar)
- community education work
- provision of technical information and advice to agencies, consultants etc.]
- What government agencies do you provide information or advice (formal or informal) on seagrasses to? What types of information do you provide (technical, general information etc)?
- How important are the issues of spatial scale and temporal variability in the provision of that advice? How important are issues relating to individual species and the degree of stress in the environment?
- What management strategies (legislative and policy mechanisms) are employed by your organisation when dealing with impacts on seagrass from natural events such as floods, storms, grazing by herbivores?
- What information would allow you to make 'the best' decision when you are implementing each of these strategies? How much of that information is available to you each time you make a decision? What is the source of your information (research organisation, proponent/consultant, management agencies, advisory committees)? For what issues do you commonly find gaps in information availability?
- What research into the effectiveness of seagrass management strategies do you know about? Does your organisation audit the results of management decisions and, if so, what information is used or would be of value in conducting such audits?

Any other comments?

Appendix 5.2 Legislation and seagrass management

Searches of the Australasian Legal Information Institute's databases of Australian legislation (www.austlii.edu.au) revealed that, in relation to fisheries and environmental interests, direct reference to seagrass/es occurs in only seven acts or regulations. These are:

Commonwealth Federal Airports Corporation Regulations — Schedule 1 1993 (deals specifically with environmental management in Botany Bay for Sydney Airport)

New South Wales Environmental Planning and Assessment Regulation 1994 — Schedule 1

New South Wales Fisheries Management Act 1994

New South Wales Fisheries Management (General) Regulation 1995 — sect 73

Territory Fisheries Act

South Australian Environment Protection (Marine) Policy 1994 — Reg 4

South Australian Fisheries Act 1982 — sect 52

Other legislation, such as the Queensland Fisheries Act 1994, refers more generally to marine plants or to fish habitat but does not refer to seagrass specifically. Our search strategies were not designed to detect references to seagrasses by genus or species names.

The following is a summary of the provisions of Australian legislation that affects seagrass. The name of the primary organisation that administers the act is in parentheses following the title of the act.

New South Wales

***Fisheries Management Act 1994* (NSW Fisheries)**

It is an offence to cut remove, damage or destroy marine vegetation (including seagrass) without a permit. Permits are also required for dredging and reclamation.

Provides for declaration of seagrass as threatened species; and creation of aquatic reserves.

A small number of existing aquatic reserves contain some seagrass. Fish Habitat Protection Plan Number 2, created under this act, deals with seagrass management.

***National Parks and Wildlife Act 1974* (National Parks and Wildlife Service)**

Provides for creation of nature reserves and national parks; a few of which contain seagrass

***Marine Parks Act 1997* (Marine Parks Authority/NSW Fisheries/NPWS)**

Provides for creation of marine parks: Jervis Bay and Solitary Islands have been declared and management plans are in preparation and will provide for seagrass protection

***Environmental Planning and Assessment Act 1979* (Dept Urban Affairs & Planning)**

Provides for land use planning through State Environmental Planning Policies, Regional Environmental Plans and Local Environmental Plans

Provides for impact assessment of development proposals and activities (an environmental impact statement is generally required for dredging in seagrass)

New South Wales (continued...)

***Clean Waters Act 1970* (Environment Protection Authority)**

A licence is required to place any material in waterways. Water quality objectives are currently being developed for NSW waterways.

***Environmental Offences and Penalties Act 1991* (Environment Protection Authority)**

Provides for control over actions that cause environmental damage

Allows for enforcement of clean up and restoration programs

***Catchment Management Act* 1989**

Establishes a State Catchment Management Coordinating Committee

- Provides for creation of Catchment Management Committees for specific geographic areas that function to, inter alia:
- promote and coordinate the implementation of total catchment management policies and programs
- advise on and coordinate the natural resource management activities of authorities, groups and individuals
- provide a forum for resolving natural resource conflicts and issues
- facilitate research into the cause, effect and resolution of natural resource issues

Northern Territory

***Fisheries Act* (Dept of Primary Industries and Fisheries)**

Provides for creation of aquatic reserves; no existing reserves contain seagrass

Provides for control of harvesting of aquatic life (including seagrasses) and for protection of fish habitat from release of organisms or pollutants without a permit

Parks and Wildlife Conservation Act (Parks and Wildlife Commission)

Provides for creation of marine parks

Draft plan of management for Coburg Marine Park specifies protection of seagrasses.

Waters Act 1996

Sets standards for effluents such as sewage and requires that effluents do not cause degradation of water quality in fresh and marine systems.

Queensland

***Fisheries Act 1994* (Department of Primary Industries)**

Refers to ‘marine plants’ and ‘fisheries habitats’ which includes mostly mangroves, seagrasses, algae, saltmarshes and other tidally influenced wetlands. Provides for declaration of Fish Habitat Areas, management of declared Fish Habitat Areas, protection of fisheries resources in declared Fish Habitat Areas, protection of marine plants, and executive powers to request rehabilitation or restoration of fisheries habitat or restore land or waters

Developers, government agencies and authorities, extractive industries and researchers, etc., require permits to remove, damage or destroy marine plants.

Queensland (continued...)

***Environment Protection Act 1994* (Department of Environment)**

Used in regulating any point source discharge (eg., volumes, composition and method of discharges) from shipyards, resorts, farms, waste treatment plants

***Nature Conservation Act 1992* (Department of Environment)**

Provides the basis for conservation of species of particular conservation value, eg., dugongs and sea turtles

Conservation of these species requires protection of their seagrass feeding habitats.

Harbours Act 1955

Provides for enforcement and regulation of works in tidal waters, e.g., dredging, construction of walls, or other structures, where direct and indirect impacts on seagrasses may occur. Permits are required for works to proceed.

***Marine Park Act 1982* (Department of Environment) and *Great Barrier Reef Marine Parks Act 1975* (GBRMPA)**

Provide for identification and zoning of areas which require special protection from human impacts or use

Marine Park permits are required for activities which may affect seagrasses, conservation of other flora and fauna, or have impacts on the physical environment (e.g., water quality) in a marine park. Impacts from outside marine parks can also be regulated (e.g., prawn farm runoff, dredge operations and spoil dumps, structures which could cause shading.)

Deeds of Agreement can be written into Marine Park permits as conditions or obligations on impact mitigation, habitat compensation or habitat recovery. Bonds may be held in trust to help ensure these conditions/obligations can be fulfilled. These are not often used and there appears to be no formal policy within the Queensland Department of Environment on revegetation or replenishment of seagrass habitat.

Coastal Protection and Management Act 1995

Allows for development of a Statewide coastal management plan as well as regional coastal management plans, and can include measures to protect seagrass habitats necessary for dugong and sea turtle populations

Integrated Planning Act 1997

Intends to provide a State-wide planning system for dealing with developments which affect coastal habitats

Includes obligations to set Desired Environment Outcomes and to monitor selected performance indicators

Developments to be assessed by all relevant management agencies (Integrated Development Assessment System).

South Australia

***Fisheries Act 1982* (Primary Industries and Resources - Fisheries)**

Provides for control of fisheries (including commercial harvesting of seagrass), aquatic reserves, marine parks and disturbance of the sea floor and associated biota

Flora can be protected in marine parks. A person must not engage in an operation involving or resulting in removal of or interference with aquatic or benthic flora and fauna of any waters.

Native Vegetation Act 1991

Limits the destruction of any native vegetation including seagrass

Delegates responsibility for marine vegetation to Director of Fisheries

South Australia (continued...)

Local Government Act 1934

Empowers councils to make by-laws regulating, controlling or prohibiting the removal of sand, shells, seaweed or other material from foreshores

Development Act 1993

Controls planning and approvals for developments

***Environment Protection Act 1993* (Dept for Environment, Heritage and Aboriginal Affairs, Environment Protection Agency)**

Under this Act, the Environment Protection (Marine) Policy 1994 sets out transitional licensing arrangements, defines environmental harm to include loss of seagrass, sets water quality criteria which are derived from national guidelines, and, for nutrients, requires specifically that no discharge will cause loss of seagrass after March 2001.

Dredging is also licensed under this policy. Operations must use best available technology in dredging and monitor their effects during operations. The policy requires that spoil be brought ashore, unless exempted. No exemptions have been granted to date.

The Act provides for licensing of ports, marinas, and similar boating facilities, which are required to have an environment management plan.

Tasmania

Living Marine Resources Management Act 1995

Marine Farming Planning Act 1995

Environmental Management and Pollution Control Act 1996

State Policies and Projects Act 1993

The State Coastal Policy is a policy created under this Act. The central objective of any State policy is sustainable development. This means that it must address the use, development and protection of natural and physical resources together with the objectives relating to public involvement and the sharing of responsibility in resource management and planning as well as those relating to economic development. The policy establishes the State Coastal Advisory Committee, which is supported by the Coastal and Marine Program in the Department of Environment and Land Management.

Seagrass will be considered for inclusion in protected environmental values under the State Water Quality Management Policy.

Land Use Planning and Approvals Act 1993

Provides for land use planning and development control

To ensure integration between planning schemes and other plans affecting the coastal zone, the Coastal Policy requires all planning authorities (including local councils, Marine Boards, the Secretary of the Department of Primary Industry and Fisheries and other agencies developing plans which cover all or any part of the coastal zone) to consult with the Marine Resources Division (Department of Primary Industry and Fisheries) the Marine Board responsible for the area subject to the plan and the Department of Environment and Land Management. The assessment of impacts on seagrass is required for coastal development application.

Victoria

***Fisheries Act 1995* (Dept of Natural Resources and Environment, Fisheries Division)**

One of the objectives (Section 3(b)) is to protect and conserve fisheries habitats and ecosystems: this includes seagrass. Fisheries Victoria is the lead advocate for fish habitat management. Fisheries can only control directly fishing and aquaculture based impacts on seagrass. This can be done two ways:

- declaration of an area as a Fisheries Reserve under Part 5, Division 3
- list seagrass as protected aquatic biota under Part 5, Division 1

Fisheries Victoria will look to influence other agencies responsible for control of other human activities that can impact on seagrass, e.g. Environment Protection Authority.

Flora and Fauna Guarantee Act 1988 (Dept of Natural Resources and Environment, Flora and Fauna Division)

Provides for creation of marine parks in areas that support seagrasses

Management plans for these protected areas can specify actions designed to protect seagrass.

***Environment Protection Act 1970* (Environment Protection Authority)**

Provides for creation of State Environment Protection Policies (SEPPs)

These identify the environmental segment to be protected, beneficial uses of the environment, environmental indicators and objectives to protect the uses. They can also identify potentially threatening processes and an attainment program to prevent environmental damage or restore systems.

Beneficial uses are defined as uses of the environment or any element or segment of the environment which:

- is conducive to public benefit, welfare, safety, health or aesthetic enjoyment and which requires protection from the effects of waste discharges, emissions or deposits or of the emission of noise
- is declared by a State Environment Protection Policy to be a beneficial use

Beneficial uses in SEPPs relevant to seagrass protection are:

Waters of Victoria

- maintenance of natural aquatic ecosystems and associated wildlife

Waters of Far East Gippsland

- maintenance of aquatic ecosystems and associated wildlife
- scientific and educational use

Waters of Western Port Bay and Catchment

- maintenance and conservation of marine ecosystems and wildlife habitats
- maintenance and preservation of littoral zones, foreshores, salt marshes, mangroves, seagrasses and other vegetation
- production of edible fish, crustacea, shellfish and other aquatic life

The breaching of SEPP requirements is included in the definition of pollution, which is an offence. Enforcement action specifically for seagrass systems has not been common.

In assessing works approvals and in developing licence conditions it is mandatory to include SEPP requirements. In developing monitoring programs the potential for impacts on systems such as seagrass is considered. For operations such as dredging it must be demonstrated that there would not be significant impacts.

While not specifically prohibiting resource use activities in an area, SEPPs ensure that activities are undertaken in a manner that prevents impacts or likely impacts on beneficial uses.

Planning and Environment Act 1987

Western Australia

Fisheries Resources Management Act 1994 **(Fisheries WA)**

Seagrasses are included in the definition of fish. The objects of the act are to conserve, develop and share the fish resources of the State for the benefit of present and future generations.

Seagrass is protected by creating areas closed to trawling and by prohibiting aquaculture above seagrass beds. Fish Habitat Protection Areas are established.

Conservation and Land Management Act 1984 **(Dept of Conservation and Land Management)**

Provides for creation of Marine Nature Reserves and multiple use Marine Parks

Environmental Protection Act 1986 **(Environmental Protection Authority/Dept of Environmental Protection)**

Provides for protection of the environment through the prevention, control and abatement of pollution

Requires environmental impact assessment of proposed activities

There is an intention toward integrated multiple use management in the marine park legislation administered by CALM, whilst EPA/DEP are working towards the use of environmental protection policies which will have an integrating effect and will aim for Environmental Quality Objectives.

CHAPTER SIX

Research and Development plan

Chapters 1–5 indicate key issues and knowledge gaps in Australian seagrass research related to fisheries habitat and productivity. The following R&D plan addresses these gaps and issues. The plan will allow FRDC to confront the issues and gaps in a coordinated way. It should also assist other agencies in their seagrass related research, and it suggests ways that FRDC and other agencies, such as Environment Australia, could interact to provide maximum synergy for seagrass research.

The R&D plan has been divided into the following sections:

- Roles of funding agencies and their R&D responsibilities
- Suggested structure to maintain the R&D linkages between organisations
- Key issues and knowledge gaps
- Goals of the R&D plan
- Priorities for seagrass R&D
- Strategies to implement, maintain and develop the R&D plan
- Communication and coordination strategies

This review and R&D plan falls within FRDC's *Ecosystems Protection Program* (see Section 6.1.4 below).

The review and synthesis of Australian fisheries habitat research by Cappo *et al.* (1998), which was commissioned as part of the above program, highlighted key issues and questions generic to a range of marine and estuarine habitats. It also identified seagrasses as a habitat important to fisheries and aquaculture activities. This review and R&D plan draws extensively on the findings of Cappo *et al.* (1998).

Cappo *et al.* (1998) concluded that five strategic questions are common to all issues and impacts on marine habitats, and our review asked essentially those questions about seagrasses. The questions were:

1. What are the major habitats of the coastal fringe and Exclusive Economic Zone and where are they located?
2. What is the role of these habitats in providing and maintaining fisheries production?

3. What is the role of these habitats in maintaining ecosystem integrity and biodiversity as a basis for long-term ecosystem health, and what are suitable indicators and monitors of this health for these habitats?
4. What are the natural dynamics of the major marine habitats, and how do the fishing and aquaculture industries and other human activities affect them?
5. What linked mitigation, monitoring, scientific assessment, and management strategies will provide the habitat protection necessary to achieve ecologically sustainable development of fisheries and aquaculture?

Cappo *et al.* (1998) derived a set of R&D priorities for their generic questions. These priorities were that:

- natural dynamics in fisheries and habitats and environmental variability underpin all the other human impacts in fisheries habitat research. Without better understanding of this issue, there are uncertainties in identifying human-induced effects to help develop appropriate management strategies
- the major threats and disturbances are clearly specific to region and habitat type, and must not be considered in isolation — they are linked and interact with one another in coastal zones to aggravate habitat degradation
- high risks are generally perceived for the human disturbances, but the effects and impacts, or hazards, are often poorly documented — especially for introduced pests and diseases
- ultimate causes of many disturbances in the coastal zone are outside the direct sphere of influence of FRDC and its stakeholders — but there is much common interest with many other agencies in addressing them
- FRDC will have the lead role in providing R&D for the various effects of aquaculture and harvesting on fisheries habitats — these are not limited to the widely publicised bycatch and benthos damage in some trawl fisheries

This review derived similar findings. Thus, the R&D plan must address not only research issues, but also communication and management issues so as to solve the important problems in the relationship between seagrasses and the ecologically sustainable management of fisheries.

6.1 Roles of funding agencies and their R&D responsibilities

Chapter 5 indicates that several Commonwealth and State agencies have overlapping responsibilities for seagrass habitats. However, agencies that provide most of the funds for seagrass related work are those discussed below.

6.1.1 Department of Education, Training and Youth Affairs

The Australian Research Council (ARC) provides advice to the Minister for Employment, Education, Training and Youth Affairs through the National Board of Employment, Education and Training on national research priorities and the coordination of research policy and related matters. It advises the Minister on the allocation of resources for research under a range of approved programs. As part of new Government initiatives it will soon be set up as an independent body.

The Council's mission is to provide advice on research funding and research policy, and to promote the conduct of research and research training of the highest quality for the benefit of the Australian community.

The Council has a special responsibility for advice on basic research, and on research and research training in the higher education sector. The Council emphasises the importance of placing the higher education sector's research in the wider context of the research undertaken in government laboratories and in industry. A major proportion of the marine research work in Australia is in fact done in universities.

To facilitate its advisory and funding functions, the Council seeks representation from other government agencies and departments and from industry on its committees and panels. The Council also has a program of consultations with several peak research and academic organisations.

Research grants are provided to support high quality research in all research areas, except clinical medicine and dentistry. Large Research Grants (above $20 000 or $30 000 a year, depending on the research field) are recommended by the Research Grants Committee with the assistance of the Discipline Panels. Small Grants (above $5000) are determined by individual institutions, acting as agents of the Council, from block grants allocated to eligible institutions. The Department estimates that in 1997–98 its portfolio provided about $0.4 billion directly to researchers and institutions through research grants, fellowships, centres, scholarships, infrastructure grants and grants to the learned academies and the Anglo–Australian Telescope Board. In 1997–98, the Large Research Grants Scheme provided $104.7m and the Small Research Grants Scheme $26.6m. In the past ARC has supported thematic areas, but this practice ceased in 1998.

6.1.2 Agriculture, Fisheries and Forestry Australia

Although not specifically directed towards seagrass, the *Fisheries Action Program* being administered within Agriculture, Fisheries and Forestry Australia (AFFA) (formerly DPIE) is highly relevant because its responsibilities cover seagrasses as a fisheries habitat and it funds seagrass R&D.

The *Fisheries Action Program* is a component of the *Natural Heritage Trust*. It aims to rebuild Australia's fisheries to more productive and sustainable levels through:

- fish habitat restoration and protection
- encouraging community participation in activities to improve fisheries ecosystems
- aquatic pest control
- ensuring that fishing by commercial and recreational fishers is sustainable and responsible
- raising community awareness

- promoting related research encouraging integrated approaches to fisheries resources management and habitat conservation

The key objectives of the *Fisheries Action Program* are to:

- develop an awareness amongst all resource users and the wider community of important fisheries issues, the sources of fisheries habitat problems and the actions required to remedy them
- develop a sense of ownership and responsibility amongst all user groups for the sustainable use of the resource
- encourage participation, particularly by the direct users of fisheries resources, in habitat rehabilitation, aquatic pest identification and other Fisheries Action Program activities
- enhance sustainable resource use by fishers and 'upstream' groups by ensuring that impacts on fish resources and habitats are considered in their actions, processes and plans
- integrate habitat considerations into fisheries management strategies
- encourage development and use of sustainable fishing practices
- integrate fisheries issues with regional planning

The *Fisheries Action Program* gives priority to practical projects in freshwater, estuarine and marine environments that address the causes of the degradation of fisheries resources rather than the symptoms. These causes could include: fishing practices (both recreational and commercial), 'upstream' factors (nutrients, pollutants and poor planning), and loss of marine and estuarine habitat and related coastal development.

Although the *Fisheries Action Program* is run by AFFA, it is carried out in close co-operation with State and Territory governments and community groups. The program meshes with existing State and Territory fishcare activities.

Applications for *Fisheries Action Program* funding are assessed by community based assessment panels assisted by fisheries technical advisory panels. The program is closely integrated with other Federal Government programs such as Landcare and Coastcare.

The *Fisheries Action Program* is funded for $9.75 million over the life of the *Natural Heritage Trust*. It will provide matched funding for projects on a dollar for dollar basis.

6.1.3 Environment Australia

The Portfolio Marine Group covers a number of areas within Environment Australia that are relevant to seagrasses. The objective of the Portfolio Marine Group is to promote ecologically sustainable management of Australia's coastal and marine resources. The Group has responsibility for implementation of the *Commonwealth Coastal Policy.* It was the lead agency in development of the *Oceans Policy* announced in December 1998 and is now commencing its implementation. In addition, it is responsible for the coordination of all coastal and marine programs delivered by Environment Australia.

The focus of the *Coasts and Clean Seas Program* is on protecting the marine environment from the negative impacts of human activities. It tackles pollution problems, addresses threats to marine biodiversity and habitat degradation, and ensures the sustainable use of Australia's coastal and marine areas. The *Coasts and Clean Seas* funding package is $125 million over four years starting in 1996/97.

The *Clean Seas Program* will support projects that have a direct effect on reducing pollution and degradation of the marine environment, particularly projects targeting discharges directly into estuaries or the sea. The program will promote: innovative management of wastewater and stormwater, including increased reuse and recycling, development of new Australian technologies for rehabilitation of polluted areas, reduction of erosion and sediment discharge in runoff, coastal urban design and development, incorporating sustainable water management.

The *Marine Species Protection Program* aims to ensure that community and industry groups, fisheries managers, marine management and research agencies, and governments, work together for the conservation and sustainable use of living marine resources. The program's funding package is $8 million over four years starting in 1996/97 and it targets on-ground activities which:

- identify and reduce threats to vulnerable marine mammals, seabirds, turtles and fish species (including sharks)
- address adverse environmental impacts of commercial and recreational fishing
- control impacts from other commercial and recreational activities
- reduce impacts caused by habitat degradation
- address the effects of environmental changes on marine species and habitats from a whole-of-ecosystem perspective

The *Coastal Monitoring & Vulnerability Assessment Program* will provide more than $4 million to improve coastal and marine managers' capacity to recognise, monitor and understand the combined impacts caused by nature and people. Monitoring will provide a basis for improving our approaches to integrated coastal zone management. This program has a strong interest in seagrass habitats.

This program will assist in the strategic targeting and evaluation of *Coasts and Clean Seas* programs and projects. The program will support:

- a coastal monitoring network to improve monitoring of key sites and issues
- a national directory of coastal and marine monitoring activities
- development of response strategies for coastal impacts of climate change for key areas and ecosystems
- local managers and planners in assessment of, and response to, potential coastal impacts of climate change, including identifying and reducing public liability and insurance risks

The Commonwealth will directly fund State and local government authorities, as consortia or in partnership with community groups, to expand the national network of monitoring nodes or contribute to the national monitoring networks.

6.1.4 Fisheries Research and Development Corporation

FRDC's mission is to increase economic and social benefits for the fishing industry and the people of Australia, through planned investment in research and development, in an ecologically sustainable framework.

FRDC funds projects that have objectives consistent with:

- FRDC's strategic priorities, as reflected in the R&D program
- fishery, industry sector or region-specific priorities determined from time to time by consultation (through the network of Fisheries Research Advisory Bodies (FRABs)) with fisheries managers, industry representatives and researchers

FRDC supports a network of FRABs located in each State and the Northern Territory. The Australian Fisheries Management Authority is the FRAB for Commonwealth fisheries. The role of FRABs is to set R&D priorities, to encourage R&D applications to address those priorities, to identify appropriate funding sources (including FRDC), and to advise FRDC on the priority and appropriateness of applications attributing benefit to their related fisheries or industry sectors. The FRABs generally represent all sectors of the fishing industry, researchers and fisheries managers.

The goal of the *Ecosystems Protection Program* is to protect the Australian ecosystems upon which fisheries and aquaculture depend. FRDC works towards achieving this goal by investing in the following key areas:

- *Ecosystems Status*
  R&D that will increase knowledge for the protection of ecosystems, including: interrelationships between fish and their environments; impacts of fishing, aquaculture and other marine and land use; biodiversity; fish health; and impacts of exotic organisms

- *Ecosystems Maintenance and Improvement*
  R&D that will maintain and improve ecosystems, including: protecting, restoring and enhancing habitat; reducing bycatch and impacts on other non-target flora and fauna; and enhancing wild fish resources

- *Ecosystems Management Improvement*
  R&D that will help to develop and evaluate ecosystems management, including: developing systematic approaches to ESD; determining impacts on ecosystems; and regulating access to ecosystems

6.1.5 Commonality in R&D scope between funding organisations

Several funding bodies, such as FRDC, EA, AFFA and State organisations have common interests in a number of the knowledge gaps identified in this report, and have common, or deeply overlapping, management interests. The knowledge gaps of widest common interest relate to the current distribution and health of seagrass meadows, whether they are changing over time, and factors causing the change. Studies related to mapping and monitoring fall within this category, but it should be noted (see Chapter 4 and cf. Chapters 1 and 2) that adequate approaches to mapping and monitoring depend strongly on the development of better conceptual models linking what is measured to the processes of real concern, whether they be concerns about biodiversity conservation or fisheries productivity.

Thus, although these agencies also have different interests and emphases, this report recommends the establishment of an effective mechanism to maintain communication between them regarding seagrass R&D. This should, minimally, keep them informed of each other's activities, but ideally should go further and promote synergy, efficient use of resources, and minimal duplication of R&D effort. A suggested structure is outlined below; many variations are possible to achieve the main goal of efficiently and effectively maintaining communication and cooperation between the agencies with common interests.

6.2 Suggested structure to maintain R&D links between organisations

This report recommends the establishment of a *Seagrass Ecosystems Subprogram* within FRDC's *Ecosystems Protection Program*. This is not the only possible mechanism to achieve the primary aim, which is coordination, cooperation and collaboration between all the funding agencies, management agencies, stakeholders and researchers; a variation is suggested in Chapter 5, and this point is discussed further below. For simplicity, however, only the FRDC subprogram is described here. The manager of that subprogram should be supported by, and should make use of, an inter-agency network comprising a number of working groups. At Commonwealth level, an inter-agency committee should comprise representatives from FRDC, EA and AFFA (and others as necessary). At the State level, similar groups would have representatives from FRABs and State environmental and fisheries departments. The *Seagrass Ecosystems Subprogram* would be charged with establishing a high level of cooperation and communication between these groups, and with other research funding agencies. Collectively, the *Seagrass Ecosystems Subprogram* and its network would:

- confirm and clarify organisational responsibilities for seagrass
- identify large projects of common interest, e.g. mapping of northern Australian waters, that could be jointly funded by the various organisations and directed by a steering committee
- follow through on the recommendation of the EA seagrass workshops and those of Chapter 4; e.g., setting up a series of research projects aimed at addressing monitoring issues

- communicate with other research funding agencies (e.g. ARC) to ensure, even though their priorities and criteria may be different, that they are aware of the research needs of the agencies concerned with seagrass management. An aim would be to achieve adoption of a common set of objectives for R&D as set out in this report

The subprogram would facilitate this by taking leadership. FRDC would not own the subprogram, rather it would be a contributing partner.

6.3 Key issues and knowledge gaps

6.3.1 Key issues

These formed the topics of Chapters 1–4. The issues were:

- the status of seagrass research and knowledge within Australia
- knowledge of the links between seagrass dynamics and fisheries sustainability
- the ability to rehabilitate and/or restore areas where seagrass had declined or had been lost
- knowledge of how to monitor and assess the state of seagrass and seagrass research
- seagrasses and their management — what are the implications for research?

6.3.2 Knowledge gaps

The key issues lead to the identification of broad knowledge gaps. At the outset of this review, the knowledge gaps could be expressed informally as a list of questions that were being asked around Australia by people concerned with management, whether of fisheries or of other environmental values. They were:

- What are the key seagrass species/assemblages and are they important in maintaining fisheries productivity and ecosystem function?
- What are the important links between seagrass and fisheries production?
- What are the important links between seagrass and ecosystem function?
- What is the current distribution and abundance of seagrasses and how accurate and precise is the estimate?
- What measurement methods should be used to assess seagrass extent and health?
- Are there any early warning indicators of seagrass change?
- Over what time and space scales should measurements be taken?
- What is the rate of seagrass change?
  - Naturally
  - Under human influences
- What are the key factors influencing seagrass survival?
- What factors are critical to successfully restoring and/or rehabilitating seagrass beds?

- How do we know when key seagrass ecosystem parameters have been restored?
- What impact do aquaculture activities have on seagrasses and, if it is negative, can the effects be reversed?

There has, of course, been much research on seagrasses. At least partial answers to the above questions are available and are being acted upon in some cases. But it was important, in this review, to assess the extent and quality of our knowledge and the authors of Chapters 1–5 were asked to do that in a fearlessly, but constructively critical way. We then attempted, on the basis of the reviews in those chapters, to assign available knowledge of Australian seagrass systems and their relationships to fisheries into three broad categories:

1. Things we know — where the data are good, the hypotheses well tested and alternatives eliminated. Management actions can be based on these, and they would not appear to be (current) high priorities for FRDC's research expenditure.
2. Things we think we know — frequently quoted pieces of popular wisdom — but where the data are not so good or alternatives have not been properly evaluated. Also, areas of research where results from a specific location or time have been widely extrapolated without adequate justification. These are likely to be high priority areas for FRDC research funding.
3. Things we don't know. These questions currently remain unanswered. If relevant to fisheries and their management these, too, are likely to have high priority for future research.

Appendix 6.1 uses a table to consolidate the research needs identified by the working groups, to arrive at priorities, although it does not, itself, indicate priorities. Entries appear in something close to the order of their appearance in Chapters 1–5, not in priority order. Appendix 6.1 is included as a convenient quick reference to the many research needs identified by the working groups. It is noteworthy that many more items appear in columns 2 and 3 than in column 1, and also that many of them — even those from the more 'practical' chapters concerned with rehabilitation, monitoring and management — call for studies leading to greater understanding of the ecosystems of which seagrasses are a part.

Appendix 6.1 highlights many areas identified in Chapters 1–5 where beliefs and conclusions about seagrass and related issues are based on inadequate or insufficient data; they cannot be critically and objectively supported. These 'myths' are usually a result of extrapolating the results from specific to general situations, for two kinds of reasons. Firstly, researchers may fail to read the original research paper and instead may cite the opinion or interpretation of another scientific paper that cites the original. If that secondary source was in error or simply presented a misleading emphasis, then a false conclusion could develop and proliferate. Secondly, the lack of information on a particular subject or region may have forced researchers or managers (without evidence) to assume that the results from other areas/species apply to their situation; later, people may forget about this assumption, and the extrapolation may become accepted as 'knowledge'.

Unfortunately, if management decisions and policy are based on incorrect scientific assumptions, or inadequate data, the risk is that management will not have the intended outcomes. Further, almost regardless of its outcomes, it may be open to challenge. If Australian coastal development, fishing and environmental protection follow the path of those in the Northern Hemisphere, the trend for litigation will increase. Management actions will have to be scientifically defensible in litigation cases. If managers (and scientists) rely on propositions from the middle column of Appendix 6.1 (i.e. propositions that are believed, with insufficient data to support the belief) the implications may be severe if challenged in litigation. Thus, a strong case exists for doing the necessary solid science to support the management decision or policy.

6.4 Goals of the R&D plan

The goals of the R&D plan are to enhance our understanding of the ecosystem of which seagrasses are a part, in particular of the linkages between seagrass and fisheries productivity, and to promote research to stop the loss and enhance restoration of seagrass, both as a significant fisheries habitat and as a habitat with intrinsic value.

Achieving these goals depends on the active involvement and support of FRDC's stakeholders and researchers, and the beneficiaries of research results. Criteria against which achievement may be measured include: level of knowledge of the status of seagrass ecosystems, changes in rate of loss of seagrass ecosystems, level of seagrass restoration and rehabilitation activity, and availability of sufficient information to develop seagrass ecosystem management plans.

6.5 Priorities for seagrass R&D

The research areas listed under 'knowledge gaps' (Section 6.3.2) highlight the scope of the R&D Plan — in other words, the authors of Chapters 1–5 could not find acceptable, complete answers to any of those questions. Thus, Chapters 1–5 have identified a long list of knowledge gaps and needs for action to take care of seagrass habitats and to improve the relationship between seagrasses and fisheries sustainability. Everything noted in Appendix 6.1 has some priority and research on those areas would be worthy of support. Clearly, however, they cannot all be supported immediately, and some will have higher priority than others.

Although the primary focus of this report was on the relationship between seagrass and fisheries (and FRDC is generally understood to be concerned with fisheries), this emphasis must be broad. FRDC is concerned with: fisheries in all categories (traditional, recreational and commercial); ecosystem protection; and the 'intrinsic' values of a habitat (such as seagrass) as part of a functioning, complex marine system, as habitat for countless non-commercial and non-exploited species, and thus as something of high aesthetic value. Generally, the research priorities we identify from the viewpoint of fisheries (in the broad sense — all three classes), are priorities also for 'intrinsic' reasons.

The identified requirements can be grouped into six categories:

- Inventory and data archiving
- Monitoring
- Ecosystem understanding
- Relationships between seagrass and the productivity of fisheries
- Human impacts
- Protection, restoration and rehabilitation of seagrass beds

The highest priority research areas under those headings and suggested ways to approach them, are addressed below. Some topics can be addressed simultaneously, and synergistically, by addressing several kinds of questions in the same system, and most can be approached by collaboration with other agencies. Some topics are prerequisite for others.

6.5.1 Inventory and data archiving

Throughout the working group reports, in a variety of ways, there are calls for more inventory of seagrass. It is clear that we do not yet have a satisfactory answer, for seagrasses, to the question posed by Cappo *et al.* (1998):

> *What are the major habitats of the coastal fringe and Exclusive Economic Zone and where are they located?*

This is especially true in tropical Australia. Thus our first priority is:

- Broad-scale resource inventory of seagrass distribution in the tropics

Several chapters, however, made it clear that some doubt exists about the precision and reliability of mapping techniques used in temperate Australia and that, in any case, those techniques (dependent on remote sensing) will not work in the tropics. As well, more sophisticated and appropriate ways of storing, retrieving and interpreting the data are needed (Chapter 4). Finally, the development of data management techniques should be targeted towards the eventual development of decision support systems. Not all of these requirements fall under the heading of 'inventory' and they are returned to below. However, the following list of developments are equal in priority to the above item and must be addressed simultaneously with it.

- Mapping techniques for turbid waters
- Development of methods for mapping and monitoring; including:
  - methods for critically examining inventory techniques and assessing reliability of maps
  - appropriate statistical approaches and appropriate treatment of spatial uncertainty especially for mapping change over time

- techniques for handling meta-data; protocols for handling and archiving data including storage of adequate meta-data about field methods (which, themselves, should be standardised where desirable and feasible)

6.5.2 Monitoring

The above priorities refer simply to the kind of broad-scale inventory that already exists in southern Australia. All five working-group reports, however, called for a better understanding of spatial and temporal variation, and this must be given very high priority. Chapter 4 especially stressed that much of the existing mapping and monitoring is of unknown reliability and precision and is, in any case, only a static picture at one time. It will not be possible for managers to interpret changes in a system, hence decide how to act, until they have both a statement of 'natural' variation in space and time against which to assess any observed changes, and monitoring methods capable of detecting and estimating the sizes of such changes, with understood reliability and precision.

Since this is fundamental to assessment of the effects of fishing, aquaculture, terrigenous inputs of nutrients or toxins, climate change, etc., it has a high priority. It will require:

- development of new monitoring techniques
- techniques to integrate spatial data and temporal data
- data quality protocols for use in time-series analyses
- protocols for handling and archiving data including meta-data

These methods, however, need to be based on a conceptual understanding of the system; that understanding tells what variables are important to monitor.

Mapping and monitoring techniques that meet the above needs will position us to tackle some additional high-priority questions identified by the groups, which straddle the border between mere *description* and the *understanding* of ecosystem processes. These concern a knowledge of natural variability of seagrasses and their biota in space and time.

But description, however precise and reliable, even with statements of spatial and temporal variation, is insufficient to permit understanding of how the system works, hence how it will react to changes and how to manage it. In fact, Chapters 4 (monitoring and assessment) and 5 (management), as much as Chapters 1 and 2 (ecological processes) contain strong calls for a conceptual model of the functioning of seagrass systems. Chapter 4 makes it clear that such a model is a prerequisite for the design of a monitoring system, and Chapter 5 called not only for testing and standardisation of accurate, precise monitoring techniques but also for a well-founded understanding of how and what to monitor.

Thus, our next section has equal or higher priority than the above descriptive items.

6.5.3 Ecosystem understanding

The review stresses that many doubts remain about the way in which seagrass ecosystems function, and their linkages to other systems. Chapter 1 proposes a framework (in terms of seagrass growth forms) within which better understanding may be sought, and Chapter 3, in suggesting three 'environments' in which to investigate restoration, encompasses the same range of growth forms (Table 3.1). We suggest therefore that FRDC should foster a research program (not entirely funded by FRDC — see below) aimed at answering process questions in several, selected locations. These locations should have the attributes noted in Table 3.1 and also be selected for economic or other attributes which would justify their choice.

The aim of this work would be to develop and test

- Models of seagrass ecophysiology, ecology and ecological interactions applicable to several, selected growth forms of seagrass and several, selected physical/climatic situations

Such models would provide a well-founded basis for choice of parameters in monitoring exercises.

A number of issues raised by the working groups, with obvious direct or indirect management implications, would be encompassed by such conceptual models. A judgement would have to be made as to which of them should be investigated in detail in each case, and a mechanism is suggested below. These issues include:

- Trophic pathways linking with seagrass beds
- Critical light level values for specific seagrass species
- Effects of fluctuating light regimes on seagrasses
- Quantitative estimates of the role of seagrass detritus as a food source (compared with other sources of primary productivity) and critical tests of hypotheses, including not only fisheries but also the conservation value of seagrass productivity
- Consequences for secondary production under seagrass decline
- Investigation of the roles of habitat size on habitat diversity, function and survival
- Knowledge of natural variability of seagrasses and their biota in space and time; this need identified by several groups, refers not only to description of patterns but also to variability in ecological processes — dynamics of populations, fluxes of nutrients, etc., all must be described with measures of spatial and temporal variation
- Role of spatial patterns and interactions (landscape ecology) in explaining seagrass distribution and abundance
- The relationship between landscape ecology and fisheries
- Investigation of stability and persistence of natural seagrass beds — compilation of seagrass population growth and coverage rates for defined ecological regions

The high priority of these 'process' studies must be stressed. There is an understandable tendency to view process studies as a luxury. However, both predictive and decision support models rely on knowledge of processes in order to be effective and accurate. Increasingly, management will rely on these models, so it is important to have the appropriate type of process study . That is why our working groups repeatedly call for studies leading to greater understanding of ecosystems.

None of them, however, suggests delaying management while those studies are done! Management action and further development of understanding must proceed together. This is an R&D plan, and its aim is to propose ways in which research and development can proceed hand-in-hand. The important point, however, is that in the case of managing natural systems it will always be inescapably the case that part of the research is quite fundamental — directed at understanding the system better — even though it may be done hand-in-hand with immediate practical application. We indicate below how this can be achieved.

6.5.4 Relationships between seagrass and the productivity of fisheries

The research priorities outlined above bear indirectly on the relationships between seagrasses and fisheries but some more specific questions were also raised and should be recorded. Despite the widespread acceptance of the importance of seagrasses to fisheries, understanding of the nature of that importance is still limited. Working groups identified as knowledge gaps:

- Mechanisms explaining relationships between fish and seagrass — hence ability to predict effect on a fishery of seagrass loss
- Fisheries utilisation of 'productive' seagrass meadows (e.g. potential yield from seagrass meadows of commercially important species)
- An important idea that needs special attention within the R&D plan is the need to establish empirical links between specific seagrass species and fisheries production. This refers not to mechanisms (e.g., juvenile whiting feed in seagrass beds) but to observed correlations (e.g., loss of x ha of seagrass was coincident with a drop of y in CPUE). It is suggested below that the R&D Plan should enable opportunities to be seized when they arise, but this will have to be done rigorously, with an emphasis to allocate effort where comparative baseline data is available.

6.5.5 Human impacts

Chapter 5 shows that there is some knowledge, some poorly supported belief and many questions about the relationships between human activities, especially addition of nutrients, and seagrass beds. Some specific questions are noted in Section 6.5.3 but other questions raised by managers are worth noting because they cover larger-scale issues and a number of influences:

- What are the system-scale effects of nutrient loading?
- What are the critical nutrient levels to initiate shifts in community composition?
- What are the responses to changes in habitat quality (such as reduced light intensity, increased suspended solids, increased nutrients, increased temperature) resulting from jetties, dredging, and catchment inputs?
- What are the impacts of introduced pests, e.g. Asian mussels, on seagrass?
- What are the impacts, if any, of trawling gear on seagrasses?
- What are the impacts of aquaculture on seagrasses?

It is suggested below that these questions be addressed at the target areas chosen for the 'understanding' studies noted above.

6.5.6 Protection, restoration and rehabilitation

Protection

Questions like: 'What is the minimum size for Marine and Estuarine Protected Areas?' beg the useless answer 'It depends'. A useful response to such questions requires creative use of the data called for by Chapters 1 and 2. Those chapters did not explicitly say how to tackle a question like this, nor how to answer the more sophisticated versions posed by our managers (Chapter 5). These include: How much seagrass must be preserved? Where must it be preserved? and In what state must it be preserved? Is it better to protect all habitats in a defined, mapped area, or all habitats of a particular type? A suggested approach uses the conceptual models sought in Section 6.5.3 as a framework. Within that framework, specific questions (such as, how far particular species disperse, whether certain sites are sources or sinks because of their hydrology, etc.) would be refined. Ideally, a decision-support system (DSS) based on such a conceptual model would guide the refinement of the question. This would be the same kind of DSS used in ongoing management of a given area, for which purpose it would have to be linked to appropriately-interpreted, quantitative monitoring, and would have to combine spatial and dynamic capability.

Restoration

In conservation circles generally (not just concerning seagrasses, nor only marine systems), there is a strong view that the proper approach is to avoid destroying habitat, rather than to hope that we can later restore it. Nevertheless, given the extensive seagrass loss around Australia, there is increasing interest in the possibility of restoring damaged seagrass areas. Chapter 3 shows that experience is so far limited, but advances are being made and the relevant research questions clarified. Successful restoration attempts, like monitoring and management, require understanding of ecological processes, such as the relationships between particular seagrass species and light, nutrient levels, or sediment stability; thus, much of the 'process' research proposed above is germane to successful rehabilitation efforts.

A program of restoration research is outlined in Chapter 3 (Section 3.3.2). In brief, its key points are:

- Identification of a range of key representative seagrass habitats around Australia, which can form the basis for a nationally coordinated effort and selected to take account of the degree of threat to regional seagrasses
- Identification of local sites within each representative habitat type where experimental seagrass restoration efforts could be successful
- Development of a protocol and procedures for assessing techniques for transplanting or planting seagrasses
- Implementation of pilot trials

- Implementation of programs to monitor and evaluate the performance and success of pilot and experimental restoration efforts
- Implementation of research on seagrass biology specific to the development of seagrass restoration techniques

Adoption of the program is recommended, in the first instance, at locations selected for large-scale, multi-faceted, cooperative studies (see below).

6.6 Strategies to implement, maintain and develop the R&D plan

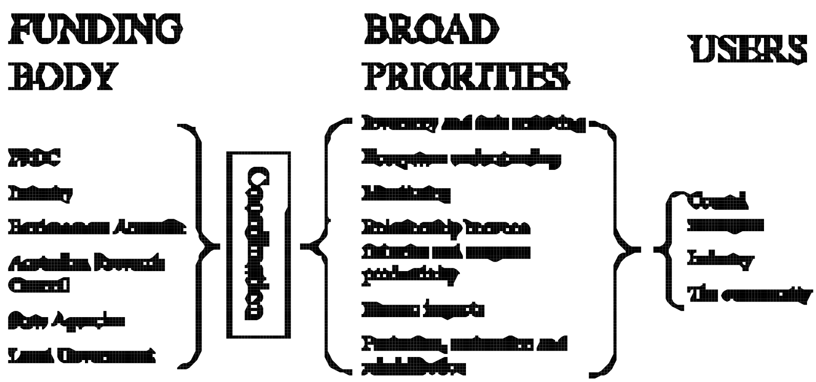
The over-riding strategy proposed for this R&D Plan is cooperation and collaboration. It is clear that there are many agencies whose responsibilities include seagrass, many agencies who might fund research, and many stakeholders who will use the results (directly or indirectly). Our chief proposal is that FRDC should facilitate an effective relationship between these players. The complexity of possible relationships is illustrated in Figure 6.1. Any of the agencies in the left-hand column (and some of those entries are themselves collective) may be interested in several, or most, of the research priorities in the central column. In turn, various stakeholders (right-hand column) are concerned with multiple research topics. The reader can imagine a version of Figure 6.1 with a very large number of connecting arrows joining every agency separately and independently to every one of its research interests!

In fact, however, a number of the agencies and stakeholders have common interests in particular topics, and their funds may be limited so it may be necessary to pool their resources to accomplish their respective goals. The key to success is a coordinating agent of some kind, indicated by the rectangle in Figure 6.1, who will bring together the responsibilities, interests, and funding capacities of the players, so that they can effectively address the priority research topics, without dissipating their resources.

This chapter proposes a *Seagrass Ecosystems Subprogram* within FRDC's *Ecosystems Protection Program*. This is suggested because it is a mechanism that FRDC itself can establish. However, variations on this theme could be devised. Whatever the detailed form of the coordinating mechanism, its function is crucial because:

- FRDC cannot set priorities in detail from the management perspectives of other organisations — this must be a matter for interaction between all those with management responsibilities. (In the case of a single-species fishery with an identified industry exploiting it, a FRAB can give FRDC this kind of advice; a habitat category like seagrass is far more complex.)
- Similarly, priorities will vary according to the interests of different 'stakeholders' (in the broadest sense) or 'users', so the priorities in this plan must remain very broad, relying on the communication mechanism to arrive at the detailed priorities by interaction with the stakeholders.

Figure 6.1 Agencies with an interest in seagrass management and research, and a capacity to fund research, are shown in the left-hand column. Priority research topics are in the centre and 'clients' or 'stakeholders' (users of research) in the right-hand column. Different agencies and users may be concerned with different subsets of the list of research topics, but there will be many common interests, leading to opportunities for collaboration. For these opportunities to be realised, there needs to be some kind of agent for coordination.



- Funding will frequently have to come from multiple sources and in some cases the research will be expensive, so communication will have to be facilitated between funding agencies, management agencies, researchers and stakeholders to establish and fund the research and to manage it through its lifetime. Our communication mechanism may not do all this (particular large studies will have their own steering groups, technical groups, and stakeholder liaison mechanisms) but it should facilitate the creation of the necessary links.
- It must be recognised that the writing of an R&D plan like this one is not a definitive exercise; the communication mechanism will be needed to continually review the state of knowledge, to enable priorities to be revised and to monitor performance.
- Priorities will vary according to geographical location and the management concerns pertinent to those locations.

Figure 6.2 broadly indicates the interests of the different groups in funding, or using the results of research, but it is clear that these interests may shift, and also that there would need to be much discussion of detail (more than a mere recognition of common interest in, say, monitoring) before joint funding arrangements could be achieved.

The coordination agent will need to:

- Identify subsets of agencies and stakeholders with common interests, probably based around geographic locations
- Possess sufficient scientific understanding to build on this review and to ensure that further R&D on seagrass advances from the level of expertise that was drawn together for this review
- Maintain a strategic focus despite short-term pressures
- Take initiative to draw together the agencies and users and to exploit opportunities as they arise
- Involve the community and contribute to the improvement of extension of research outcomes to the community
- Ensure proper recording and dissemination of effort — e.g., to ensure that all projects record meta-data
- Ensure continuous management interaction with research, and develop new ways of extension of research outcomes to management

Constant, iterative communication will be required, and the communication agent must ensure this. Although other mechanisms could be envisaged, the Steering Committee felt that it was important that a single person be charged with this responsibility. For simplicity, a *Seagrass Ecosystems Subprogram* is the mechanism referred to here (although it would depend crucially on a complex network, it would have a single person as leader) but FRDC, in consultation with other major research funding and management agencies, should explore alternatives. With that caveat, we propose the following R&D plan.

Figure 6.2 Common interests of the various funding agencies and research users.

Broad priorities

		Inventory and data archiving	Ecosystem understanding	Monitoring	Relationships between fisheries and seagrass productivity	Human impacts	Protection, restoration and rehabilitation
Potential funding bodies	FRDC	✓	✓	✓	✓	✓	✓
	Industry				✓	✓	✓
	Environment Australia	✓	✓	✓		✓	✓
	Australian Research Council		✓				
	State agencies	✓	✓	✓	✓	✓	✓
	Local government					✓	✓
Users	*Coastal managers*	●	●	●	●	●	●
	Industry				●		●
	Community groups			●			●

- FRDC should establish a subprogram for seagrass ecosystems research
- The subprogram leader should be required to establish and maintain liaison broadly as indicated in Section 6.2 with a view not only to communication but also to active collaboration in funding and carrying out joint research projects
- The subprogram should address the following areas identified as fundamentally important in this review:
  - Inventory, especially in northern Australia, and data archiving
  - Ecosystem understanding — development of conceptual models of seagrass ecosystem function
  - Monitoring
  - Ultimately, based on the above three areas, development of decision support systems linked to appropriate monitoring and capable of handling spatial and temporal patterns in the context of a conceptual model
  - Relationships between seagrass and the productivity of fisheries
  - Human impacts
  - Protection, restoration and rehabilitation of seagrass beds
- The research areas listed above are complex and interdependent. For example, inventory of northern Australian seagrasses depends on the development of techniques for mapping in turbid water (Chapter 4); 'development of conceptual models' implies a suite of more specific research projects about ecosystem function and about relationships between seagrasses, other habitats, fish and fisheries (Chapters 1 and 2); 'techniques for effective monitoring' depend on the availability of an acceptable conceptual model (Chapter 4).
- To facilitate the inventory of northern Australia, the *Seagrass Ecosystems Subprogram* should call for expressions of interest, and should evaluate whether those expressing interest are technically prepared for a large-scale resource inventory. If the technical capacity is not yet adequate, then it should immediately commit funds to accelerate the development of the necessary capacity. If it appears that there is already adequate capacity, then FRDC should liaise with EA and relevant State agencies, to establish the funding for a systematic resource inventory of northern coasts.
- To facilitate the 'ecosystem understanding' aims of this Plan, the *Seagrass Ecosystems Subprogram* should identify, from amongst the priorities highlighted in this review, those cases where:
  - It should immediately fund certain research projects
  - It should contribute to pre-existing projects so as to add value and to ensure that the questions of importance to FRDC are addressed
  - It should encourage other agencies with different priorities and decision criteria from its own (e.g. ARC) to fund certain work

In particular, it should urgently liaise with the managers of existing or forthcoming large-scale integrated studies in seagrass areas, namely Brisbane River/Moreton Bay, Adelaide Coastal Waters, Perth Coastal Waters and the North-west Shelf, to determine ways in which FRDC could collaborate to add value to those studies.

- The *Seagrass Ecosystems Subprogram* should seek an opportunity to similarly approach a multidisciplinary, multi-agency study in the tropical north. Since there are no well-advanced studies comparable with the temperate and subtropical cases, FRDC may have to be more proactive in promoting this, and may have to initiate contact with LWRRDC, and State/Territory Governments as well as with its own FRABs to identify opportunities.
- To facilitate the 'monitoring techniques' aims of this plan, the *Seagrass Ecosystems Subprogram* should, again, make use of liaison with the major ongoing or forthcoming integrated studies. Further, it should liaise closely with Environment Australia. That agency has a mandate to achieve Australia-wide monitoring and reporting but Chapter 4 makes it clear that this will be of little value unless it is properly conceptually based, and rigorously done. It is also clear that the Coasts and Clean Seas (CCS) Program is directed at establishing a monitoring program, rather than funding the research necessary to develop the required conceptual models or to develop new techniques for data handling, storage and temporal and spatial analysis. Yet EA clearly has an interest in such research, to maximise the value of the CCS Program. Therefore, FRDC and EA should form a partnership in this area. As an early priority, the *Seagrass Ecosystems Subprogram* should fund development work in the area of monitoring design, data handling and techniques for spatial and temporal analysis. Emphasis should be placed on data formatting and storage appropriate for dynamic, GIS databases. Next, as monitoring programs become established, FRDC (in close liaison with EA) should support an emphasis on collecting data on spatial and temporal variability in seagrass ecosystems, rather than on static description. Emphasis should be placed on database archiving, including certain standard parameters (e.g. latitude/longitude, date of sampling), and agreed meta-data protocols (cf. the Auslig protocol used in the ERIN Blue Pages).
- Several working groups noted the need for comparative studies and, if the results of such studies are to be useful, a need for standardised techniques. The *Seagrass Ecosystems Subprogram* should facilitate training-focussed workshops to disseminate the necessary skills. These might be run in collaboration with professional societies such as the Australian Marine Sciences Association and the Australian Society for Fish Biology, particularly by arranging workshops with those societies' conferences. FRDC should seek opportunities to support such workshops. They might concern, for example:

  - Fish sampling in seagrass areas
  - Macroinvertebrate sampling
  - Mapping techniques for turbid water
  - Methodology for study of food webs — e.g. stable isotope techniques
  - Use of the ERIN Blue Pages
  - Techniques for handling meta-data
  - Spatial statistics
  - Uses and limitations of Geographic Information Systems
  - Enhancing communication between managers and researchers, to link what managers want and what researchers can deliver

- The *Seagrass Ecosystems Subprogram* should be prepared to act opportunistically in the event of significant changes (e.g., major seagrass die-offs) and when such events occur it should consider interceding to ensure that appropriate data are collected at the time of the event (e.g., on correlation between seagrass loss and fisheries productivity). If necessary, FRDC should fund the collection of data on such occasions. The subprogram should be especially alert for opportunities to learn more about the relationship between deepwater seagrasses and offshore (relatively wave-exposed) seagrasses and fisheries. However, the mere recording of events after a major change will yield little understanding (correlation does not imply causation). In general, the results will be impossible to interpret unless good 'before' data of the right kinds are available, collected on the right temporal and spatial scales. Thus, the subprogram should not support opportunistic research unless it is making critical tests of useful hypotheses; the subprogram needs to be convinced that the inferences to be made from the results will be rigorous and defensible.
- The *Seagrass Ecosystems Subprogram* should facilitate a program of research on seagrass rehabilitation and restoration (see Chapter 3). It should do this initially by encouraging and supporting projects associated with major studies at a few selected localities (above), so as to achieve both experience in rehabilitation and restoration and the necessary process research (which may also have priority for purposes other than rehabilitation and restoration). It should, further, liaise with the major funding agencies and stakeholders to develop these locality-specific efforts into a national, coordinated program to develop seagrass restoration technology in Australia, through close cooperation among industry, government and developers of the technology. This would require due consideration of intellectual property rights, because such understanding and experience should be transportable to other locations and will contribute to a marketable, national body of expertise in this area. A national, coordinated program would ensure that Australia is at the forefront of this particular field of marine habitat restoration. FRDC should be alert for opportunities to encourage its use and potential commercialisation, overseas as well as in Australia.
- The *Seagrass Ecosystems Subprogram* should use its leadership to improve management models for seagrass fisheries habitats in Australia. Chapter 5 proposes a national action plan, recognising that there are location- and State-specific differences in management issues and conditions. The main elements of the plan (see Chapter 5) are:
  - Establish/improve and maintain links between managers and researchers
  - Develop networks for information sharing
  - Develop collaborative research, development and extension
  - Improve standards for impact assessment and rapid area assessments
  - Improve standards for assessment of seagrass management programs

  Where it refers to research, the proposed national action plan has major elements in common with the role proposed for the *Seagrass Ecosystems Subprogram*. There is no contradiction, but in addition to what is proposed here for research, networks need to support the extension of research results to the community and to managers, and to support the development of management methods. This ultimately goes beyond the responsibilities of FRDC, but the *Seagrass Ecosystems Subprogram* should be charged with brokering and facilitating elements of the proposed action plan to the extent possible, using the networks that it will establish for its primary responsibilities. Thus, the subprogram should keep in mind that managers called for the following areas of development, and be alert for ways of furthering them:

  - Coordination between managers
  - Links between managers and researchers
  - More effective access to scientific information and to services for its interpretation
  - A conceptual (model) structure that would enable the right specific questions to be asked in particular cases
  - Information on the effectiveness of management tools
  - Information on the effectiveness of educational tools

- Each project funded under the *Seagrass Ecosystems Subprogram* should have clearly defined outputs and outcomes with realistic deadlines
- Outcomes of each contract should be reviewed at agreed milestones (which will vary with the nature of the research topic) to determine how they address the proposed conceptual model and how they fill the knowledge gaps they are intended to address
- The R&D plan should be fully reviewed and refocussed after five years. The review should use clear performance indicators. A set of indicators is suggested below, but this should be discussed, altered if required, and agreed to at the commencement of the *Seagrass Ecosystems Subprogram*. Some of the indicators relate to the goals of the plan (reduction in knowledge gaps; actual improvement in status of seagrass), which will not be measurably achieved in a short time. Others relate to actions taken in pursuit of the plan, and these can reasonably be accounted for at short intervals, e.g., annually. Therefore, we propose a full review after five years but annual progress reviews to confirm satisfactory operation of the plan. Indicators suggested are:

Primary indicators — measures directly related to goals of the plan

The goals of the R&D plan are (in brief): to enhance our understanding of seagrass ecosystems and their linkages, and to promote research to stop the loss and enhance restoration of seagrass. Ideally, performance indicators will directly reflect achievement of those goals. A way of assessing the improvement in knowledge (in understanding both of ecosystems themselves and of the links between seagrass and other ecosystem components, including fisheries) is proposed:

- Record the number of refereed reports, papers published in refereed scientific literature or refereed books that have appeared since this review and been facilitated in some way by the *Seagrass Ecosystems Subprogram*

- Commission a mini-review by expert referees, who will build on this review, note the above record of publications etc., and report on the extent to which the knowledge gaps identified in this review have in fact changed

Regarding the reduction of loss, or restoration of seagrass, FRDC should:

- Ask each FRDC-supported restoration/rehabilitation project to report on its success (areas re-established, measures of function, etc., the measures of success are themselves a research topic here!)
- Commission, or collaborate with other agencies in commissioning, a mini-review of the status of recovery of seagrass. This could, for example, be achieved in association with State-of-Environment reporting by the States and Commonwealth

The above indicators are as close as we can come to a sustainability indicator for seagrass at this stage of our knowledge. The situation should change, of course, as a result of the parts of this R&D plan that concern monitoring, etc.

Secondary indicators — measures of actions under the plan

The primary goals (above) will be difficult to assess, and success may be slow in coming even if the R&D plan is progressing well. However, meaningful measures of the effort going into the program should also be used to indicate performance and they can be used in the shorter term. These include:

- The number of collaborative projects established by the efforts of the sub-program
- The number of individual projects funded by the program
- Records of the achievement of their milestones by each of those projects
- The number of people who have completed training courses in, for example, monitoring techniques, meta-data techniques, and statistical methods
- The number of successfully-established management plans covering seagrass systems
- The level of support for seagrass research projects from FRABs.

6.7 Communication and coordination strategies

FRDC's own communication strategy covers the needs for the present seagrass R&D plan.

1. Develop and maintain effective media for communication and consultation between FRDC, its stakeholders and researchers. Performance indicators are:
    - To be communicating and consulting regularly with stakeholders and researchers
    - To be regarding the views of stakeholders and researchers in developing the R&D Plan and program management procedures

2. Ensure that stakeholders and researchers have a clear understanding of FRDC's objectives and R&D priorities, and program management procedures. The performance indicator is:
   - To be disseminating information in a timely manner on FRDC's objectives and R&D priorities, and other information on FRDC's program management procedures
3. Ensure that R&D results are widely known. The performance indicator is:
   - To be widely and effectively disseminating R&D results and their availability

   Specifically FRDC could disseminate the R&D plan and its results through its own newsletter, through seagrass research newsgroups, and though other newsgroups such as those used by Environment Australia. It has been argued that FRDC's communication strategy is still largely one-way, and that there is a need for more effective feedback, with a real influence on R&D priorities. In this particular case, the proposed *Seagrass Ecosystems Subprogram* would have its own significant responsibilities (outlined above) for communication with researchers, other research agencies, and immediate stakeholders. It is anticipated that this communication would take a variety of forms, and would not be confined to formal meetings or scientific reports.

6.8 Summary

1. The goals of the R&D plan are to enhance our understanding of the ecosystem of which seagrasses are a part, in particular of the linkages between seagrass and fisheries productivity, and to promote research to stop the loss and enhance restoration of seagrass as a significant fisheries habitat, and as a habitat with intrinsic value.
2. Achieving these goals depends on the active involvement and support of FRDC's stakeholders and researchers, and the beneficiaries of research results. Criteria against which achievement may be measured include: level of knowledge of the status of seagrass ecosystems, changes in rate of loss of seagrass ecosystems, level of seagrass restoration and rehabilitation activity, and availability of sufficient information to develop seagrass ecosystem management plans.
3. There are a large number of agencies with management responsibilities that impinge on seagrasses and, amongst those agencies, a significant number with R&D responsibilities. It is essential that these agencies work in collaboration.
4. Our assessment of the state of knowledge of seagrass systems and their relationships to fisheries sustainability shows a large number of gaps. On many issues the working groups feel that knowledge is not as clear, or as well-supported, as it is commonly believed to be (column 2 of Appendix 6.1); and in many more areas knowledge is undoubtedly inadequate (column 3 of Appendix 6.1).

Priorities amongst these knowledge gaps are identified under the following headings:

- Inventory and data archiving
- Ecosystem understanding
- Monitoring
- Relationships between seagrass and the productivity of fisheries
- Human impacts
- Protection, restoration and rehabilitation of seagrass beds

5. The most important aspect of the R&D plan is coordination, communication and collaboration between multiple agencies and stakeholders. A variety of communication mechanisms can be imagined. The one proposed here is the FRDC Subprogram, which is readily within the purview of FRDC, but it is the tasks assigned to this subprogram that are important. Whatever mechanism is adopted, it must be charged with these tasks. We propose that, within its Ecosystems Protection Program, FRDC should establish a *Seagrass Ecosystems Subprogram*. The subprogram should:

- Establish an inter-agency network to facilitate cooperation between the agencies in the funding and coordination of research, the effective use of research outcomes, and the improvement of management
- Address the following research areas that this review has found to be of fundamental importance (and which are complex and interdependent):
  - Inventory, especially in northern Australia, and data archiving
  - Ecosystem understanding — development of conceptual models of seagrass ecosystem function
  - Monitoring
  - Ultimately, based on the above three, development of decision support systems linked to appropriate monitoring and capable of handling spatial and temporal patterns in the context of a conceptual model
  - Relationships between seagrass and the productivity of fisheries
  - Human impacts
  - Protection, restoration and rehabilitation of seagrass beds
- To facilitate the inventory of northern Australia, the *Seagrass Ecosystems Subprogram* should call for expressions of interest, assess them and then either commission necessary technical development, or liaise with EA and relevant State agencies to establish a systematic resource inventory of northern coasts.
- To facilitate the ‘ecosystem understanding’ aims of this plan, the *Seagrass Ecosystems Subprogram* should identify, from amongst the priorities highlighted in this review, those cases where:
  - It should immediately fund certain research projects
  - It should add value to pre-existing projects
  - It should encourage other agencies with different priorities and decision criteria from its own to fund certain work

- In particular, the *Seagrass Ecosystems Subprogram* should urgently liaise with the managers of existing or forthcoming large-scale integrated studies in seagrass areas (all of which happen to be in temperate or subtropical areas), to determine ways in which FRDC could add value.
- The *Seagrass Ecosystems Subprogram* should explore and create an opportunity to similarly establish a multidisciplinary, multi-agency study in the tropical north.
- To facilitate the 'monitoring techniques' aims of this Plan, the *Seagrass Ecosystems Subprogram* should liaise with the major ongoing or forthcoming integrated studies. Further, it should liaise closely with Environment Australia. The *Seagrass Ecosystems Subprogram* should fund development work in the area of monitoring design, data handling, and techniques for spatial and temporal analysis. As monitoring programs become established, FRDC (in close liaison with EA) should support an emphasis on collecting data on spatial and temporal variability in seagrass ecosystems, rather than on static description. Emphasis should be placed on improved database archiving.
- The subprogram should facilitate training-based workshops to disseminate knowledge of techniques, for example in:
    - Fish sampling in seagrass areas
    - Macroinvertebrate sampling
    - Mapping techniques for turbid water
    - Methodology for study of food webs
    - Meta-data techniques
    - Spatial statistics
    - Uses and limitations of GIS
    - Enhancing communication between managers and researchers, to link what managers want and what researchers can deliver
- The *Seagrass Ecosystems Subprogram* should be prepared to act opportunistically in the event of significant changes (e.g., major seagrass die-offs); it should consider interceding to ensure that appropriate data are collected at the time of the event, to take the opportunity to advance knowledge, but only if this can be done rigorously (generally, where suitable 'before' data exist). If necessary, FRDC should fund the collection of data on such occasions.
- The subprogram should facilitate a program of research on seagrass rehabilitation and restoration, initially by supporting projects associated with major studies at a few selected localities, and then by liaison with other agencies to develop a national, coordinated program to develop seagrass restoration technology, both for use in Australia and for marketing overseas.
- The subprogram should use its leadership to improve management models for seagrass fisheries habitats in Australia; a generic plan is proposed in Chapter 5 of this report.

6. Research funded under the *Seagrass Ecosystems Subprogram* should have clearly defined outputs and outcomes with realistic deadlines. Outcomes of each contract should be reviewed at agreed milestones (which will vary with the nature of the research topic) to determine how they fill the knowledge gaps they are intended to address.
7. The R&D plan should be reviewed in five years to assess what gaps have and have not been addressed and to re-focus the plan. The review should use formal performance criteria which are outlined in this report. There should be annual reviews using those performance measures that can reasonably be assessed on a short time-scale.
8. In addition to the specific responsibilities for communication and liaison noted above, the *Seagrass Ecosystems Subprogram* should follow all elements of the FRDC Communication Strategy.

6.9 References

Cappo, M., Alongi, D., Williams, D., and Duke, N. (1998). A review and synthesis of Australian fisheries habitat research. 3 volumes. (AIMS, Townsville) FRDC project # 95/055.

Appendix 6.1 Research needs identified by working groups

This Table was a tool used by the principal investigators in consolidating the research needs identified by the working groups, and in arriving at priorities. It does not, itself, indicate priorities. Entries appear in something close to the order of their appearance in Chapters 1–5, not in priority order. Items marked by ** appeared as priorities in more than one chapter. We suggest that items marked with '(opportunistic)' be carried out if an opportunity occurs e.g. if seagrass die off occurs there may (subject to critical methodological considerations) be an opportunity to investigate the relationship between seagrass and fisheries productivity. We include the Table here as a convenient quick reference to the many research needs identified by the working groups. It is noteworthy that many more items appear in columns 2 and 3 than in column 1.

The five concerns identified by Cappo *et al.*, (1998) are listed in italics in the table within the section on 'Seagrasses And Their Management — Implications For Research', in italics. The specific knowledge gaps of concern to managers are all subsumed in those five general questions, and are almost all covered, often in critical detail, in Chapters 1–4 (see above in this Table). However, we include here the ones mentioned in Chapter 5 to indicate the particular concerns that were expressed by managers.

1. Status of knowledge of seagrass

Known	*Believed — insufficient critical data for Australia*	*Not known*
Temperate seagrass distribution at broad spatial scales	Role of seagrass as nursery sites for commercial species	Seagrass distribution in the tropics
General community compositional shifts under eutrophication	Seagrass functional form models	Role of spatial patterns and interactions ('landscape ecology') in explaining seagrass distribution and abundance**
General seagrass response to light levels	Responses of seagrass to water movement (dependent on site and physical conditions)	Importance of seagrasses in deep water (>20m)
Knowledge of invertebrate grazing impacts on seagrass epiphytes in southwest Australia	Sediment trapping and binding roles of seagrass	Comparative studies of the range of natural variability in seagrass attributes in space and time
Conceptual food web processes	Other interactions between seagrass and sediment dynamics	Models of seagrass ecophysiology, ecology and ecological interactions**
	Interactions of seagrass, epiphytes and fauna with nutrient elevation	System scale effects of nutrient loading**
	Seagrass persistence times in low light regimes	Critical nutrient levels to initiate shifts in community composition**
	The role of seagrass detritus in nearshore ecosystems	Impacts on seagrass of water column vs sediment nutrient addition
	Grazing impacts on seagrasses and their epiphytes by fish and large mammals	Impact on seagrass ecosystems of pulsed vs chronic nutrient loading
	Filter feeding rates within seagrasses	Conditions for leaf vs rhizome nutrient uptake

Other aspects of food web flux	Eutrophication effects on seagrass-associated faunal communities (including fished species)
	Critical light level values for specific seagrass species
	Effects of fluctuating light regimes on seagrasses
	The top-down role of predators in affecting seagrass faunal and floral composition
	Consequences for secondary production under seagrass decline
	Role and flux rates of microbiological production
	Quantitative, comparative estimates of the role of seagrass detritus as a food source and critical tests of hypotheses**

2. Seagrass dynamics and fisheries sustainability		
Known	*Believed — insufficient critical data for Australia*	*Not known*
The presence of seagrass rather than abundance or density is important for fish presence	General links between seagrass and fisheries production (best knowledge in temperate Australia especially around Western Port in Victoria)	Empirical links between specific seagrass species and fisheries production (opportunistic)
Fish diversity and presence in seagrass vs bare areas	Latitudinal patterns in fish utilisation of seagrass beds — fish abundance/biomass/production and seagrass presence	Relationships between seagrass die-off and fisheries catch data (opportunistic)
	Stage of lifecycle and habitat association	Are there critical thresholds in seagrass cover and fisheries abundance? If so, need to measure them
	Knowledge of natural variability of seagrass and their biota in space and time	The role of seagrass structure in creating fish habitats especially in the tropics
	Role of non-commercial species in food chains affected by seagrass decline	Diets of fish; associations between prey and seagrass habitats
	Importance of location of seagrass beds	The use of seagrass by fish in tropical waters
	The role of seagrass detritus in increasing benthic productivity	Temporal consistency of fish composition and seagrass habitats
	Standardisation of sampling protocols	The relationship between landscape ecology and fisheries**
	Testing and standardisation of sampling methods	Mechanisms explaining relationships between fish and seagrass — hence ability to predict effect on a fishery of seagrass loss**
		The influence of seagrass on larval recruitment
		Trophic pathways linking with seagrass beds

3. Seagrass rehabilitation and restoration		
Known	*Believed — insufficient critical data for Australia*	*Not known*
	Seagrass transplantation techniques	The response of different seagrass species to rehabilitation/transplantation
	The faunal and floral composition of normal, fully functional seagrass ecosystems	Successful planting techniques and key components necessary for seagrass rehabilitation and restoration
		The role of habitat size on habitat diversity, function and survival**
		The stability and persistence of natural seagrass beds — seagrass population growth and coverage rates for defined ecological regions**
		Innovative methods to accelerate restoring seagrass (propagation and genetic techniques)
		The practicability of using mixed and/or substitute seagrass species for meeting restoration objectives
		Rate of recovery of fauna into restored seagrass beds
		The effects of surface and subsurface geology and current patterns on seagrass meadow shape and size **
		Site augmentation procedures to speed up successful seagrass recolonisation and transplantation

3. Seagrass rehabilitation and restoration (continued...)

Known	*Believed — insufficient critical data for Australia*	*Not known*
		Vegetation transplanting techniques appropriate to site conditions
		Recovery rates of donor beds
		Accurate and precise monitoring techniques **

4. Monitoring and assessment of seagrass

Known	*Believed — insufficient critical data for Australia*	*Not known*
Lack of continuity of funding for long-term monitoring projects	Precision and accuracy of remote sensing seagrass maps	A conceptual model to focus the monitoring goals and parameters**
	Validated and scientifically peer reviewed remote sensing seagrass mapping methods	What spatial scales are biologically appropriate?**
	Methods for critically examining inventory techniques	How and what to monitor, based on the above**
	Appropriate statistical approaches — estimation of differences and measures of uncertainty rather than simply detection of significant differences	Decision support techniques for integrating spatial and temporal process understanding and management needs
	Techniques for handling meta-data	Reliability of maps — accuracy and precision estimates
	Seagrass cover and biomass is widely accepted for monitoring (without consideration of appropriateness to conceptual models of seagrass and fish production and ecosystem health)	Statistical rigour and assumptions of remote sensing algorithms to display spatial and temporal data
		Appropriate treatment of spatial uncertainty especially when one attempts to map change over time

		Techniques to integrate spatial data and temporal data
		Data quality protocols for use in time-series analyses
		Completion of broad scale resource assessments (especially northern Australia)**
		Mapping techniques for turbid waters**

5. Seagrasses and their management — implications for research

Known	*Believed — insufficient critical data for Australia*	*Not known*
Inconsistency in approach between agencies at local, State and federal levels	The role of nutrient and contaminant inputs in affecting seagrass survival	*1. What are the major seagrass habitats and where are they located?*
No single agency or department that independently regulates seagrass protection and use; much is outside the purview of FRDC and its stakeholders	Impacts of fishing gear on temperate seagrasses	*2. What is the role of seagrasses in providing and maintaining fisheries production?*
		3. What is the role of seagrasses in maintaining ecosystem integrity and biodiversity as a basis for long-term ecosystem health, and what are suitable indicators and monitors of this health?
		4. What are the natural dynamics of seagrasses, and how are they affected by fishing and aquaculture and other human activities?

5. Seagrasses and their management — implications for research (continued...)

Known	*Believed — insufficient critical data for Australia*	*Not known*
		5. What linked mitigation, monitoring, scientific assessment, and management strategies will provide the seagrass protection necessary to achieve ecologically sustainable development of fisheries and aquaculture?
		Spatial variability among and within estuaries**
		Patterns of recruitment, in relation to location**
		Links with other habitats, (including the type, quality and proximity of adjacent habitats and the processes that maintain the linkages)**
		Resilience of seagrass beds to disturbance
		The impact of introduced pests e.g. Asian mussels, on seagrass
		Impacts of land management practices e.g. drainage changes
		Minimum size for MEPAS and geographic/ biological ranges.
		Conservation value of seagrass productivity
		Utilisation and interaction of seagrass with and by vulnerable species such as turtle and dugong
		Potential yield from seagrass beds of commercially important species**
		Relationship of secondary production to spatial and temporal patterns of variability in seagrass distribution and abundance

The importance of physical environmental processes in affecting seagrass distribution and abundance compared with human influences
Habitat requirements for continued seagrass viability**
Identifying the sources of nutrients, sediments or other human induced impact on seagrass**
Responses to change in habitat quality (e.g. reduced light intensity, increased suspended solids, increased nutrients, increased temperature) resulting from jetties, dredging, catchment inputs**
The critical levels (area, density) required for sustaining seagrass habitat**
The response of seagrass to geological evolution of estuaries
The capacity of seagrass to recover from loss or be rehabilitated**
Recovery times for seagrass**
The requirements for successful restoration**
Possible impacts of trawling gear on seagrasses in NE Australia**
Assessing the effectiveness of seagrass management programs (including choice of parameters)**
Aquaculture impacts on seagrasses**

Appendix 6.2 Composition of steering committee and working groups

Principal Investigators

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Appendix 6.3 Acronyms

AFFA — Agriculture, Fisheries and Forestry Australia

ARC — Australian Research Council

ASFB — Australian Society for Fish Biology

ASIC — Australian Seafood Industry Council

ASU — Artificial Seagrass Unit

BACI — Before After Control Impact

CASI — Compact Airborne Spectrographic Imager

CCL — Cockburn Cement Limited

CCS — Coasts and Clean Seas

COASEC — Coastal Ecology Model

CPUE — Catch per unit of fishing effort

CSIRO — Commonwealth Scientific and Industrial Research Organisation

DPA — Dugong Protection Area

DPIE — Department of Primary Industries and Energy (a former Commonwealth Department, now AFFA)

DSS — Decision Support System

EA — Environment Australia

EMP — Environmental Management Program

ERIN — Environmental Resources Information Network

ESD — Ecologically Sustainable Development

FAC — Federal Airport Corporation

FEHC — Fisheries Environment Health Committee

FHA — Fish Habitat Area

FRAB — Fisheries Research Advisory Body

FRDC — Fisheries Research and Development Corporation

GBR — Great Barrier Reef

GBRMPA — Great Barrier Reef Marine Park Authority

GIS — Geographical Information System

GPS — Global Positioning System

Ha — hectare

IT — Information Technology

LWRRDC — Land and Water Resources Research and Development Corporation

MAFRI — Marine and Freshwater Resources Institute

MEPA- Marine and Estuarine Protected Area

NIWA — National Institute for Water and Atmospheric Research

NSW — New South Wales

NSWFRI — New South Wales Fisheries Research Institute

NT — Northern Territory

NTDPIF — Northern Territory Department of Primary Industries and Fisheries

QDoE — Queensland Department of Education

QLD — Queensland

QDPI — Queensland Department of Primary Industries

R&D — Research and Development

Recfish — The Australian Recreational and Sport Fishing Confederation Inc.

SA — South Australia

SARDI — South Australian Research and Development Institute

SPC — Sydney Ports Corporation

SPCC — State Pollution Control Commission (NSW)

SEPP — State Environmental Protection Policy

TAS — Tasmania

USNRC — US National Research Council Committee

VIC — Victoria

WA — Western Australia

www — World Wide Web