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Ecological significance of seagrasses: Assessment for management of environmental impact in Western Australia

D.I. Walker [a,*], K.A. Hillman [b], G.A. Kendrick [a], P. Lavery [c]

[a] *Department of Botany, The University of Western Australia, Nedlands, WA 6907, Australia*
[b] *D.A. Lord & Associates, PO Box 3172, LPO Broadway, Nedlands, WA 6009, Australia*
[c] *Environmental Management, Edith Cowan University, Joondalup Drive, Joondalup, WA 6027, Australia*

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Abstract

Studies to determine the ecological significance of seagrasses in Owen Anchorage, Western Australia, have been undertaken to allow government to assess the effects of dredging proposals that result in the removal of seagrasses. Ecological significance was broadly defined to include physical, chemical, biological and cultural attributes. The study area (Owen Anchorage) is characterised by a mosaic of bare sand and patchy assemblages of a mixture of seagrass species. These seagrass meadows are quite unlike the more prominent monospecific meadows in more sheltered waters. Previously, seagrass research in Western Australia had focused almost exclusively on these monospecific meadows. To assess the effects of short-, medium- and long-term dredging on the ecological significance of the study area, a large study was implemented, with tasks based on the attributes used in the definition. These included detailed spatial and temporal investigations of the primary producers (seagrasses and algae), the secondary consumers (invertebrates and fish), and their interactions. Two techniques were used to assess the ecological significance of the study area. The first involved a matrix of biological characteristics that calculated proportional losses of seagrass meadows relative to the areas left after dredging. Stochastic processes were introduced using @RISK software, with values based on extensive and intensive field measurements. Linkage with an interactive geographic information system database was developed to better represent seagrass dynamics. The second involved defined beneficial uses (i.e. the way society uses or values an area) of the study area. Preliminary results specific to the individual tasks and more general modelling results are presented to show the value of this multidisciplinary approach in addressing the ecological significance of seagrasses. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Shellsand dredging; Environmental approval; Seagrass; Ecological significance

1. Introduction

The role of seagrasses in maintaining ecosystems has been referred to often in the literature (McRoy and McMillan, 1977; Larkum et al., 1989) but has often not been detailed in a rigor-

* Corresponding author. Tel.: + 61-8-93802089; fax: + 61-8-93801001.
E-mail address: diwalker@cyllene.uwa.edu.au (D.I. Walker).

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ous scientific manner. In Western Australia, where seagrasses are important coastal resources, seagrasses have been studied extensively over the past 15 years (Kirkman and Walker, 1989; Poiner et al., 1989; Walker, 1989), but essential data are still not available to assess their significance. Development requires the management of potential impacts, so an understanding of the ecological significance of seagrasses is fundamental to predicting the extent of these impacts.

The loss of seagrass associated with any coastal development in Western Australia is an important environmental issue. Shellsand dredged from Success Bank in Owen Anchorage (Fig. 1) is used in cement and lime manufacturing, and the dredging operations involve some loss of seagrass beds that grow above the resource. In order to gain environmental approval from government, an Environmental Management programme was undertaken. Part of this approval was a requirement to determine the ecological significance of seagrasses. This paper describes the process used to fulfil this requirement.

The objectives of the project were: to define the ecological and cultural functional roles of seagrasses in the Cockburn Sound/Owen Anchorage area; to quantify the loss of ecological and cultural functional roles resulting from historical seagrass losses in the Cockburn Sound/Owen Anchorage area; to determine the loss of seagrass meadow in the Cockburn Sound/Owen Anchorage area that can be sustained without significantly impairing the ecological and cultural functional role of seagrasses; to quantify the loss of ecological and cultural functional role in the Cockburn Sound/Owen Anchorage area resulting from dredging (1972–2021); and to quantify the ecological and cultural functional role of seagrass that can be potentially replaced by mitigation techniques.

The project was staged in phases to allow an adaptive environmental assessment programme,

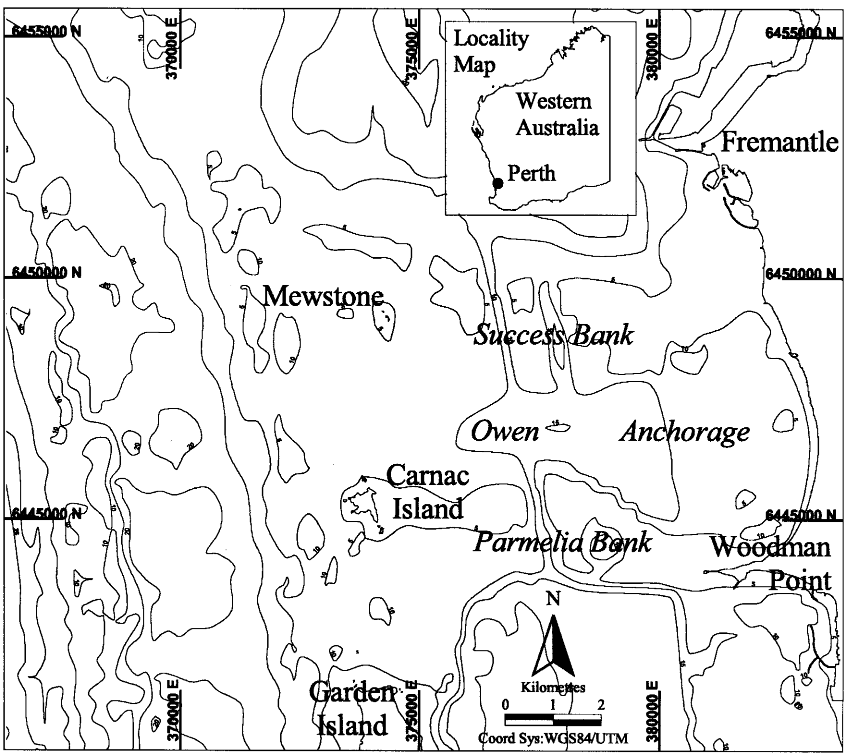

Fig. 1. Location of study area.

where the results were fed back in to the planning of the studies as the work progressed.

2. Methods — the approach used

2.1. Definition of ecological significance

The definition of ecological significance and how it should be determined had to be acceptable to scientists, managers and the public, with a clear demonstration that ecological significance could be measured.

The definition and the measurement system proposed for determining ecological significance was based on accepted environmental management principles, starting with those provided by the World Conservation Strategy. These principles are the maintenance of essential ecological processes and life-support systems, the preservation of genetic diversity, and the sustainable utilisation of species and ecosystems.

These principles were incorporated in the development of Australian Water Quality Policies, resulting in a set of environmental values (ANZECC, 1992) that form an acceptable base for management. Environmental values are the ecological and cultural ways in which society values an area. The term ‘beneficial uses’ is also often used synonymously. The definition of ecological significance used in this study related to this concept of environmental values.

Environmental values for the cultural uses of local coastal waters south of Fremantle (Fig. 1) include direct contact recreation (primary and secondary contact), commercial fishing, harbours and marinas, mineral recovery, navigation and shipping, effluent disposal and marine park.

The four main uses of the Owen Anchorage area are ports and shipping, shellsand dredging, primary and secondary contact recreation based around the Woodman Point reserve, and industry south of Fremantle. These cultural uses, along with relevant ANZECC (1992) environmental values, were used to identify the potential environmental values of the Owen Anchorage area as ecosystem protection, which includes maintenance of ecological function and maintenance of biodiversity, recreation (including commercial activities related to recreation), aesthetics, education, and commercial activities, including mineral recovery, fisheries and shipping.

These environmental values depend, to varying degrees, on the physical, chemical and biological attributes of the area being considered. The ecological significance of the Owen Anchorage area involves existing habitats, seagrass meadows, reefs and unvegetated sediment, and proposed replacement habitats, rehabilitated seagrass. The Owen Anchorage area has a very small proportion, less than 1% of reefs, and the remaining area is a mosaic of approximately two-thirds unvegetated sediment and approximately one-third seagrass meadows, where seagrass meadows are defined as areas with more than 5% seagrass cover (Fig. 2). In relation to the physical, chemical and biological attributes of the area, seagrass meadows are by far the most significant habitats. Dredging will remove seagrass habitat in relatively shallow waters, less than 8 m depth, and replace it with unvegetated habitat at greater depth, ~ 13 m depth. Seagrass habitat and the resulting changes to the physical, chemical and biological attributes will be most affected by shellsand dredging.

The definition of ecological significance therefore placed particular emphasis on seagrasses, although it was also applicable to other habitats in the study area. As the ecological significance of any area resides in the physical, chemical, biological and cultural attributes of the various habitats, it was proposed that the ecological significance of the study area be defined by determination of the following attributes.

These attributes were: the physical attributes, sediment accumulation and stabilisation; wave baffling and other hydrodynamic processes; effects on light climate; and degree of complexity in terms of three-dimensional structure. The chemical attributes included biogeochemical cycling. The biological attributes of the area were considered to be floral and faunal abundance and diversity, primary production, secondary production (including fisheries) and, finally, cultural attributes of the resource, including recreational and commercial uses, educational uses and aesthetics.

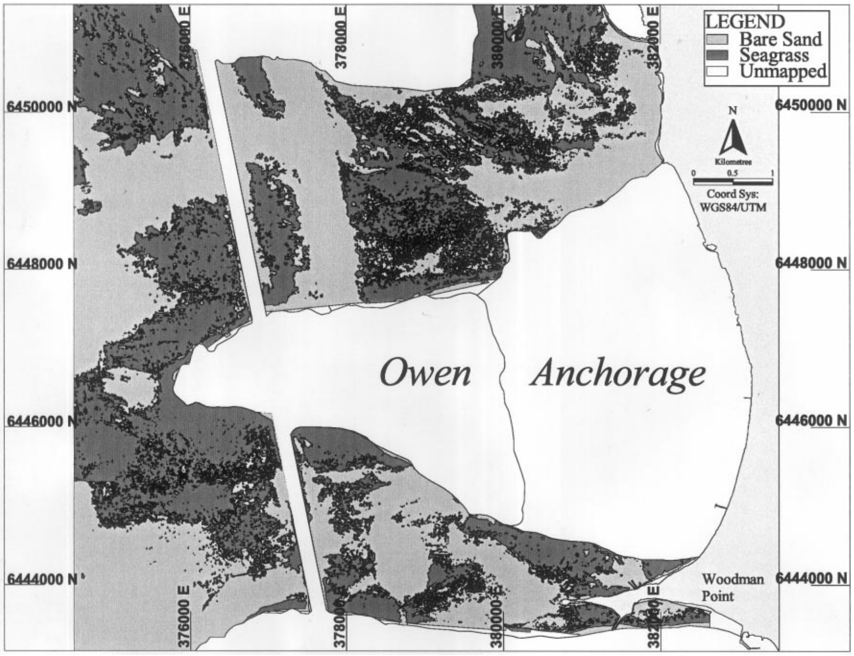

Fig. 2. Habitat map of study area.

The attributes listed in the definition encompass the potential ecological and cultural roles of the various habitats in the study area, particularly seagrass habitats, thus providing a means for assessing the ecological significance of seagrasses. The relative importance of each of the attributes in contributing to ecological significance was determined over the course of the project. Ecological significance was assessed in terms of measurable parameters that represent these attributes, including absolute measurements such as plant biomass, as well as subjective measurements such as aesthetics. Changes in ecological significance caused by shellsand dredging were interpreted by relating these change to the environmental values identified previously.

2.2. Study area and sampling programme

Five habitat types were the subject of detailed ecological studies in this project: three types of seagrass meadow and two types of unvegetated habitat. On Success Bank there are meadows of *Amphibolis griffithii* (Black) den Hartog, *Posidonia coriacea* Cambridge and Kuo, generally less than 30% seagrass cover, containing low biomass of other seagrass species and *Heterozostera tasmanica* den Hartog, as well as unvegetated sediment in shallow waters, < 10 m. In the Owen Anchorage basin there is unvegetated deep sediment in deep waters, > 10 m. Twenty biological parameters were measured in these habitats (Table 1).

As can be seen in Table 1, sampling included macro-invertebrates (> 0.5 mm), fish, seagrasses, and seagrass epiphytes. Fish were sampled using trawls or nets over relatively large areas, whereas the focus for the other organisms was generally at a smaller scale, i.e within habitats. To ensure that cross-comparisons between seagrass, epiphyte, invertebrate and fish data were possible, the western, central and eastern parts of Success Bank (see Fig. 1) were treated as separate regions. Within each region, two major landscapes were recognised: continuous seagrass landscape, with greater than 70% seagrass cover, and fragmented seagrass landscape, with patches of seagrass separated by unvegetated sand. *Amphibolis griffithii* seagrass habitat dominated the former landscape, while *Posidonia coriacea* seagrass habitat, *Heterozostera tasmanica* seagrass habitat and unvegetated sand in shallow waters occurred in the latter landscape. Deep (water depth greater than 10 m) unvegetated habitat also occurs in the Owen Anchorage basin. These provided five habitats, which were sampled.

Measurements were taken at a variety of sites for each habitat type in order to determine the spatial scale of natural biological variation (i.e. variations between sites within an area). Initial studies largely concentrated on the eastern and western regions of Success Bank. Following an appraisal of initial results, it was decided that better regional coverage of the study area would be achieved by sampling in the eastern and western regions, and in a new region at the northern end of Success Bank. Depending on the statistical requirements and logistical constraints of each task, one or two sites per habitat were sampled in each region.

Detailed measurements of the parameters listed in Table 1 were made in the five habitats for two consecutive summers and winters, with additional spring and autumn measurements as needed. This series of measurements determined the scale of natural biological variation within and between years.

Table 1
Parameters used in determination of ecological significance[a]

Above-ground plant biomass
Below-ground plant biomass
Seagrass leaf area index
Macroalgal (epiphytes) diversity
Seagrass and epiphyte nutrient turnover
Phytoplankton/MPB nutrient turnover
Seagrass and epiphyte primary production
Phytoplankton/MPB primary production
Macro-invertebrate density
Macro-invertebrate biomass
Macro-invertebrate diversity
Fish density
Fish biomass
Number of juveniles of resident fish species
Number of juveniles of nursery fish species
Fish diversity
Secondary (fish and invertebrate) production
Total biodiversity index
Calcium carbonate production
Edge-to-area ratio of seagrass meadows

[a] MPB–Microphytobenthos

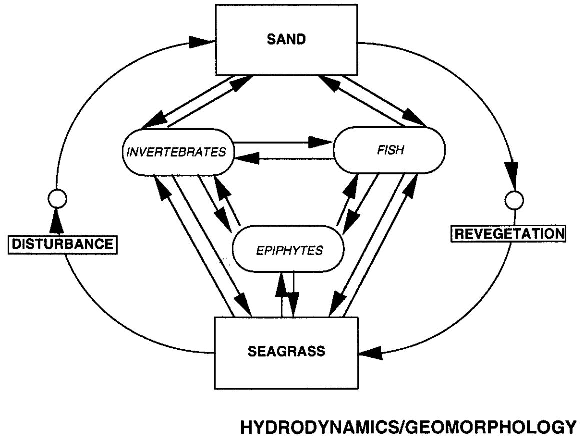

Fig. 3. Conceptual model of the links between the major biological components of the seagrass/sand ecosystem of Success Bank.

Mapping studies indicated that seagrass meadows on Success Bank had undergone considerable changes in distribution, degree of patchiness and seagrass species composition since 1965 (Kendrick et al., 1999). Losses of seagrass meadows occurred due to both dredging and natural patterns of sand migration, and new areas of seagrass became established through natural revegetation, presumably via seedling colonisation and/or lateral extension of existing seagrass meadows. A conceptual model (Fig. 3) was established to represent the dynamic nature of this seagrass meadow/unvegetated sand ecosystem.

In addition to quantifying the major biological components (the boxes in the model) in the study area, and past and proposed man-made losses of seagrass habitat, this project had to quantify the 'natural changes' in the area of seagrass and unvegetated habitats in the study area (i.e. not just the 'man-made losses' of seagrass meadows); and quantify the linkages between the biological components (the arrows in the conceptual model).

Natural changes in meadow distribution, degree of patchiness and seagrass species composition over larger geographical and temporal scales were documented with a detailed interpretation of sections of Success Bank, using historical aerial photography. Detailed monitoring of seedling survival, lateral growth of ramets, and clump and patch dynamics in *Posidonia coriacea* and *Amphibolis griffithii* habitats on the eastern region of Success Bank was also carried out. Studies on linkages between the biological components involved quantifying the role of detached seagrass and reef algae in supplying detritus for food webs, and assessing the value of seagrasses in supplying food and shelter for invertebrates and fish.

3. Results

Research to date has established significant differences between the three seagrass habitats in the biomass and production of their above-ground and below-ground seagrass components, their epiphyte biomass and production, and the number and type of different species of epiphytes present. Results for fish and invertebrates indicated that differences between the three seagrass habitats were less pronounced in terms of the species present, but there were significant differences between vegetated habitats, i.e. seagrass meadows in general, versus shallow and deep unvegetated habitat. Invertebrate density, biomass and production were generally substantially higher in seagrass habitats than shallow unvegetated habitat (deep unvegetated habitat was intermediate), whereas the species composition, abundance and biomass of fish in deep unvegetated habitat differed significantly from all the shallow habitats, but there was less difference between seagrass habitats and shallow unvegetated habitat.

Differences between the three seagrass species in partitioning of above- and below-ground components may reflect their different ecological roles. A pattern of colonisation from unvegetated sand → *H. tasmanica* → *P. coriacea* → *A. griffithii* appears to be occurring on Success Bank. The hypothesis is made that *H. tasmanica* is a coloniser of bare sands, along with *P. coriacea* and, to persist in the semi-exposed, wind-influenced environment of Success Bank, a greater investment in below-ground biomass may be required. *A. griffithii* colonises onto the other species of seagrass, using the characteristic grappling anchor of its seedlings (Ducker et al., 1977) to attach to the leaf sheath and fibre of other seagrass species. This pattern of colonisation has not been reported elsewhere in Australian coastal waters.

In terms of determining the natural changes in the area of seagrass and unvegetated habitats in the study area, the results of detailed analysis of changes in seagrass area at eight selected sites since 1972 are summarised in Table 2. These sites are located in the area between the two shipping channels (the 'Central region'), and immediately at the east of the Second Shipping Channel (the 'Eastern region'), and each site is a square of 40 000 m^2 in area.

These dramatic increases in seagrass area can be explained by seedling recruitment and/or lateral extension of existing seagrass clumps. A review of the scientific literature has identified accepted rhizome extension rates of 20–50 cm/year for *Amphibolis* spp. and 10–20 cm/year for *P. australis* (Clarke and Kirkman, 1989). If these rates are used in a simple model of rhizome spread, it can be shown that increases in seagrass

Table 2
Changes in seagrass area between 1972 and 1993 at eight selected sites on Success Bank[a]

Region/site	Area of seagrass present (m^2)		
	1972	1982	1993
Central region, *Amphibolis* site 1	17 083	36 419	37 132
Central region, *Amphibolis* site 2	5185	26 764	32 464
Eastern region, *Amphibolis* site 1	1036	4904	32 894
Eastern region, *Amphibolis* site 2	2836		31 198
Central region, *Posidonia coriacea* site 1	853	6516	20 294
Central region, *Posidonia coriacea* site 2	7236	17 696	21 242
Eastern region, *Posidonia coriacea* site 1	4326	5920	21 121
Eastern region, *Posidonia coriacea* site 2	890	13 272	27 130

[a] Each site has a total area of 40 000 m^2. Full details are contained in Kendrick et al. (1999).

area at some, but not all, sites (e.g. Eastern region, *P. coriacea* Site 1) can readily be explained by vegetative growth alone. Species specific differences within *Posidonia* may make this assumption invalid but, in the absence of any data for *P. coriacea*, this is a conservative assumption.

Research in local coastal waters has also found that seagrass seedling establishment and survival rates are typically low: 0.5–1.2% of seedlings survive their first year (Kuo and Kirkman, 1996). Seagrass meadows on Success Bank produce large numbers of fruits. Recent measurements indicate around 1400 *P. coriacea* fruit are produced each year in a 100 m^2 area. From these fruits, 119–236 seedlings could become established, indicating that, based on percentages of Kuo and Kirkman (1996), seven to 17 of those seedlings per 100 m^2 could survive their first year. This is a large number of new seedlings.

Knowledge of these measured seedling survival rates coupled with measured extension rates then allowed for the documented increases in cover and density of *P. coriacea* between 1972 and 1993 on the eastern-side of Success Bank to be accounted for by a combination of the lateral extension of existing seagrass clumps and the establishment of seedlings followed by clumping and tillering (extending of rhizomes). Investigations in Two Peoples Bay, Albany, Western Australia; show the same patterns of re-establishment of a similar species of *Posidonia* after major storms. The demonstration of natural establishment and re-establishment of *P. coriacea* initially from seed is a major conclusion of the project to date, and one that modifies existing views.

4. Integration of results

Integrating data to assess changes in ecological significance was as important as the definition of ecological significance itself. Available assessment techniques were reviewed in order to choose the best for the purposes of the project. The three main requirements of the technique were: the ability to handle the natural variability of plant and animal communities in time and space; the ability to deal with quantitative ecological data (on plant and animal communities) and qualitative data (i.e. people's subjective value judgements about cultural attributes); and the ability to deal with stochasticism. Biological parameters cannot be represented by single values: each parameter is best represented by a probability distribution with values largely around some mean value. A stochastic event is any one value in each probability distribution and, however unlikely, there is a chance of it occurring.

Two separate assessments were carried out. One assessment was based strictly on biological parameters that represent (directly or indirectly) the physical, chemical and biological attributes in the definition of ecological significance. The effects of any changes (man-made or natural) that have, or could, occur in the study area were determined by addressing the changes in area occupied by each of the habitats, and then estimating the total accompanying change in ecological function using the selected biological parameters. In this manner, both the effects of natural variability, as well as man-made changes, were estimated. The changes in ecological function were calculated using an ecological matrix that incorporates the biological parameters, the habitats studied and the areas occupied by these habitats. The matrix utilised the computer software package @RISK, which enabled the parameter 'values' to be represented by probability distributions that incorporate the measured spatial and temporal variability. This was then linked to an interactive geographic information system database to better represent seagrass dynamics.

The second assessment involved both ecological and cultural attributes, and therefore both quantitative and qualitative data. The @RISK software was not needed for this evaluation.

5. Conclusions

Our understanding of the seagrass communities on Success Bank and their interactions has been advanced substantially during the investigations of the ecological significance of seagrasses. The synthesis of these multi-disciplinary studies has required the development of new techniques to be able to deal with stochastic processes, in order to produce information useful to environmental and resource managers.

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