In: Seagrass: Ecology, Uses and Threats ISBN 978-1-61761-987-8
Editor: Robert S. Pirog

Chapter 9

SEAGRASS ECOLOGY AND THREATS IN THE TROPICAL INDO-PACIFIC BIOREGION

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ABSTRACT

Seagrass meadows are critical components of Indo-Pacific tropical marine environments providing some of the most economically important ecosystem services of any marine habitat. Many coastal traditional ways of life are intricately associated with seagrasses for food, recreation and spiritual fulfilment. These unique marine flowering plants are found mainly in clear, shallow, sheltered, estuarine and coastal waters with as many as 24 of the worlds' 72 seagrass species found in the region. Despite their importance, seagrass meadows are experiencing high rates of loss in some parts of the world. There are many threatening human activities to seagrasses including direct threats such as land reclamation and chemical spills as well as diffuse threats such as water quality and the influence of climate variability. In the Indo-Pacific conservation activity is focused on coral reefs, with little consideration and emphasis placed on inter-connectivity with other marine environments such as seagrasses. In recent years several seagrass monitoring programs have been implemented to monitor change in the Indo-Pacific region. Iconic marine parks such as the Great Barrier Reef Marine Park are a

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focus for developing a more nuanced understanding of change in coastal habitats. We outline the current status of Indo-Pacific tropical seagrass knowledge, the threats to coastal seagrass meadows in this region, and approaches to management that will ensure long-term survival and conservation of these important habitats.

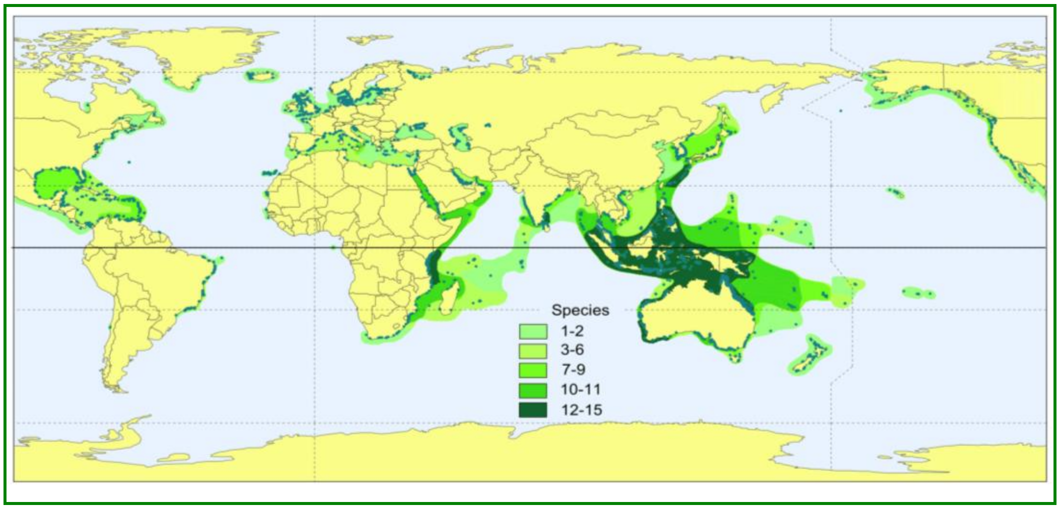
INTRODUCTION

The world's coastal and ocean ecosystems are at risk from anthropogenic activities with as much as 40% of the area impacted by multiple drivers (Halpern *et al*. 2008). Seagrass meadows are one of the critical components (along with coral reefs, mangrove forests and algae beds) of tropical coastal marine environments (Waycott *et al*. 2009). As a basis for primary productivity in coastal waters, seagrasses provide economically important ecosystem services (Costanza *et al*. 1997; Orth *et al*. 2006). They are essential for fisheries productivity. Tropical near-shore fisheries provide protein for up to one billion people (Burke *et al*. 2002). The proportion of this productivity arising directly from seagrass has received limited consideration but seagrass is likely a major contributor to fisheries production and human food security (Unsworth *et al.* 2010a). Seagrasses support numerous charismatic faunal species, including species of turtle, sirenia and seahorse (Gillanders 2006; Hughes *et al*. 2009). Seagrass meadows are an important cultural, economic and ecological resource in tropical regions, with traditional ways of life dependent on them for food and cultural activities. (Coles *et al.* 1999; Coles and Fortes 2001; de la Torre-Castro and Ronnback 2004; and Unsworth *et al*. 2010b).

Seagrass meadows are being lost at a rate which may be as high as 7% of their total global area per year (Orth *et al*. 2006; Waycott *et al*. 2009). Within the Indo-Pacific 'Coral Triangle' there is pressure from government and non-government organisations to understand, limit and attempt to reverse damage to and loss of coral cover and coral reefs (Clifton 2009). But this focus on coral has not emphasised as it should the connectivity to other coastal marine habitats such as seagrasses and the role seagrasses play in productivity and nutrient cycling. Seagrass meadows make a valuable contribution to marine productivity (Coles *et al.* 1993; Unsworth *et al*. 2008) but their role in tropical waters remains poorly understood. The value of this productivity requires consideration at national and international levels and recognition that these vital habitats must be conserved.

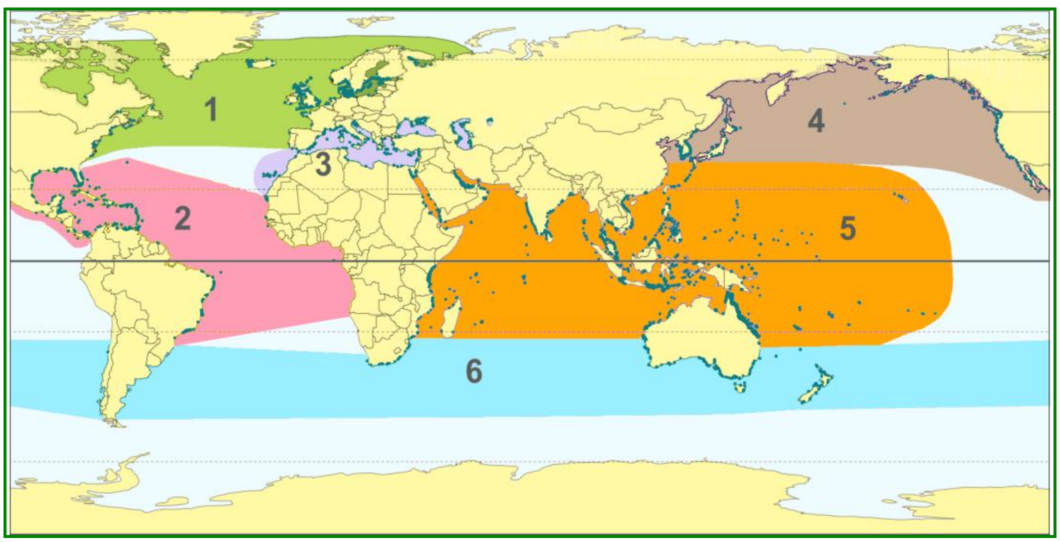
TROPICAL SEAGRASS BIOLOGY

Seagrasses are marine flowering plants that grow in the near-shore environment of most of the world's continents. Most are entirely marine and submerged although some species (such as *Enhalus acoroides*) cannot reproduce unless emergent at low tide. Surviving in a range of conditions from upper estuarine to marine, there are relatively few species globally (about 72) and these are grouped into just 13 Genera and 5 Families.



Global distribution of seagrass species from Short *et al.* 2007.

Seagrass Species



Bioregion 5 – the Tropical Indo-Pacific bioregion defined by Short *et al*. (2007).

The Tropical Indo-Pacific bioregion defined by Short *et al.* (2007) has the largest number of seagrass species worldwide and a high species diversity of associated flora and fauna. Short *et al.* (2001) report 13 species from Papua New Guinea, 16 species from the Philippines and 16 species from northern Australia. Humoto and Moosa (2005) report that eight genera and 13 species of seagrass occur in Indonesian coastal waters. The 24 Tropical Indo-Pacific bioregion species include: *Cymodocea angustata*, *Cymodocea rotundata, Cymodocea serrulata, Enhalus acoroides, Halodule pinifolia, Halodule uninervis, Halodule wrightii, Halophila beccarii, Halophila capricorni, Halophila decipiens, Halophila hawaiiana, Halophila minor*, *Halophila ovalis, Halophila ovata, Halophila spinulosa*, *Halophila* *stipulacea*, *Halophila tricostata*, *Syringodium isoetifolium*, *Thalassia hemprichii*, *Thalassodendron ciliatum*, *Zostera capensis*, *Zostera japonica*, *Zostera muelleri*, and *Ruppia maritima.* Some species such as *Halophila ovalis* are wide spread through the region while others such as *Halophila hawaiiana* have limited distributions. The distribution of seagrass species has been mapped by Green and Short (2003).

Biogeography

A number of environmental parameters determine whether seagrass will occur along any coastline. These include the biophysical parameters that regulate the physiological activity and morphology of seagrasses (such as temperature, salinity, waves, currents, depth, substrate, day length, light, nutrients, water currents, wave action, epiphytes and diseases), the availability of seeds and vegetative fragments and the anthropogenic inputs that inhibit available plant resources (such as excess nutrients and sediment loading). Combinations of these parameters will permit, encourage or eliminate seagrass from a specific location.

The depth range of seagrass is likely to be controlled at its deep edge by the availability of light for photosynthesis. Seagrass meadows in clear tropical waters can be found at up to 61 metres below the sea surface (Coles *et al.* 2009). At the shallow edge, exposure (with associated high temperatures and drying at low tide), wave action and associated turbidity, and low salinity from fresh water inflow determine seagrass species' survival. Seagrasses survive in the inter-tidal zone especially in sites sheltered from wave action or where there is entrapment of water at low tide, (e.g., reef platforms and tide pools), protecting the seagrasses from exposure.

Differences in the life history strategies of tropical seagrasses result in varying species assemblages. *Enhalus acoroides* is a slow turnover, persistent species with low resistance to perturbation (Bridges *et al*. 1981; Walker *et al.* 1999) and is susceptible to disturbance; full recovery from disturbance may take many years (Rollon *et al.* 1998). In contrast, *Cymodocea serrulata*, *Halodule uninervis* and *Halophila ovalis* are more ephemeral (Birch and Birch 1984). *Halodule uninervis* and *Halophila ovalis* are considered pioneer species growing rapidly and surviving well in unstable or depositional environments (Bridges *et al*. 1981; Birch and Birch 1984). *Cymodocea serrulata* is found associated with deeper sediments, and has been linked to increased sediment accretion (Birch and Birch 1984).

Tropical seagrass meadows can be categorised into four habitat types (see Carruthers *et al*. 2002). These include: river estuary, coastal, reef, and deep water. Most seagrass habitats in shallow coastal waters are influenced by high disturbance and are spatially and temporally variable. However, the spatial and temporal dynamics of the different seagrass species and types of seagrass habitat are poorly understood. Each of these four habitat types has a number of dominant processes that influence seagrass growth, survival and community biodiversity.

River estuary habitats contain many seagrass species, and are often highly productive. These habitats are often closely associated with mangrove forests in the tropics and are characterized by fine sediments. The dominant influence of river estuary habitats is terrigenous runoff from wet-season (monsoon) rains. Increased river flows result in higher sediment loads which create potential light limitation for seagrass (McKenzie 1994). Salinity fluctuations and scouring can make river and inlet habitats a seasonally variable environment for seagrass growth. River estuary watersheds in the tropics often support a large range of land uses, including urban and industrial development, agriculture, mining and forestry. These land use practices increase sediment and nutrient inputs.

Coastal habitats support a diverse seagrass assemblage. Physical disturbance from waves and swell (Grech and Coles 2010), associated sediment movement and macro-grazers, all control seagrass growth in coastal habitats. Episodic events such as tropical cyclones (hurricanes) or storms can have severe impacts at local scales, making this a dynamic and variable habitat. Sediment movement due to wave exposure creates an unstable environment for seagrass seedlings to establish or persist. Removal of seagrass by periodic storms can take many years to regrow (Preen *et al.* 1995). *Cymodocea* and *Syringodium* are seen as intermediate genera that can survive a moderate level of disturbance, while *Halophila* and *Halodule* are ephemeral species with rapid turnover and high seed set, well adapted to high disturbance and high rates of grazing (Walker *et al*. 1999). The end result of successional processes, however, will vary with geographic location.

Reef habitats support seagrass communities in shallow lagoon and intertidal reef platforms. Shallow sediment, fluctuating temperature, exposure to wave action and variable salinity in intertidal regions characterise these habitats. Nutrient concentrations are generally low in reef habitats; however intermittent sources of nutrients are added by seasonal runoff and seabirds. Carbonate sediments limit nutrient availability (Short *et al.* 1990; Erftemeijer and Middelburg 1993; Udy *et al*. 1999). Tight nutrient recycling strategies by species such as *Thalassia hemprichii*, aid in survival in the nutrient poor reef habitat (Stapel *et al.* 1997). Bioturbation and herbivory can be so prevalent in some reef environments, particularly lagoon environments, that they significantly alter seagrass productivity (Ogden and Ogden 1982; Tomascik *et al*. 1997; and Unsworth *et al*. 2007).

Deep water seagrasses occur at subtidal depths (greater than 15 m), and are restricted to locations where high water clarity allows sufficient light penetration for survival (Lee Long *et al*. 1993; Coles *et al.* 2009). Deep water seagrass areas can be extensive and often dominated by *Halophila* species (Lee Long, *et al.* 1993; Lee Long *et al.* 1996; Coles *et al.* 2009). Large often monospecific meadows of seagrass occur in this habitat (e.g., *Halophila decipiens*), in contrast with coastal and reef habitats where the seagrass meadows are diverse and mixed (Coles *et al*. 1987). *Halophila* spp. display morphological, physiological and life history adaptations that can assist survival in low light conditions. The distribution of deep water seagrasses, while mainly influenced by water clarity, is also modified by seed and vegetative material dispersal and availability, nutrient supply, and current stress. Deep water seagrass communities are the least studied and understood in the Tropical Indo-Pacific bioregion.

SEAGRASS HABITAT – THREATS AND LOSS

Management Issues

At a global scale there is a clear understanding by seagrass researchers that seagrass habitats and the fauna that they support are threatened by human impacts and by the marine environmental components of climate change (Bjork *et al*. 2008; Unsworth and Cullen 2010b; Hughes *et al.* 2009; Halpern *et al.* 2007;Waycott *et al.* 2009 and Orth *et al.* 2006). This has been translated into a regional scale evaluation in countries with well developed conservation approaches (Waycott *et al.* 2007; Selkoe *et al.* 2008). However through much of the Indo-Pacific there is little in the way of a coordinated program to address issues identified in the literature, or the outcomes of programs are difficult to assess. Action in some locations has focused on the need for an ecosystem based approach and on the need to improve planning concepts, data sources and trend monitoring. While it is important to develop a consensus on the need for action and to act to improve our understanding of the underlining issues and data availability it is also necessary to make a connection between research on biological/ ecological parameters and the social/political management domain where any decisions to address threats will need to be made. Major programs in the region such a the regional South China Seas initiative (UNEP 2004) outline the problems but admit little has been achieved to mitigate or remove the threats. Jurisdiction issues and enforcement ability are commonly cited as reasons why little in the way of threat mitigation has occurred (UNEP 2008: Coles and Fortes 2001). However it is likely that the problems are so complex and poorly understood by governments and agencies with regulatory responsibility that mitigation actions have become mis-matched in scale and time.

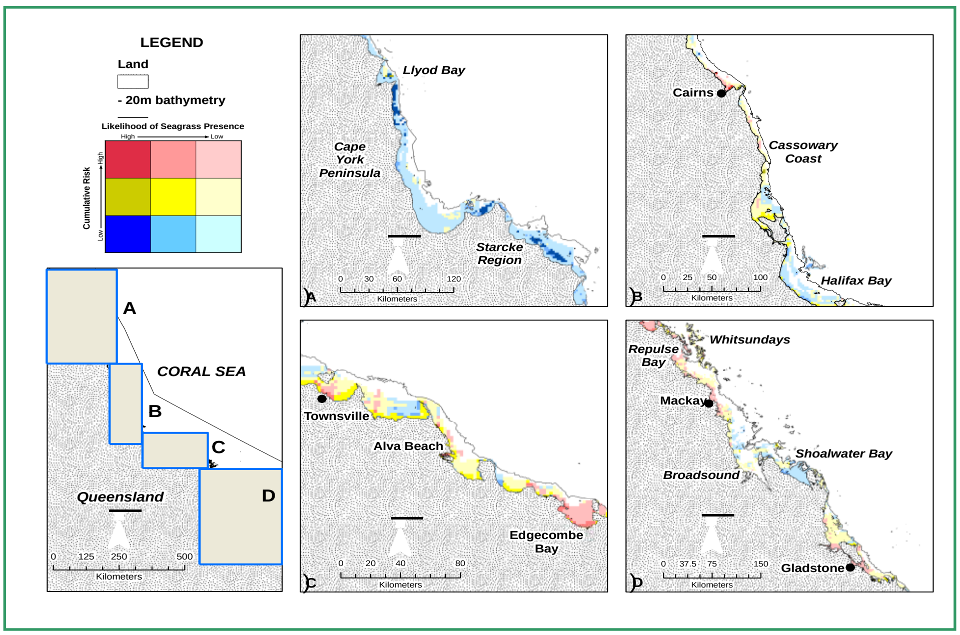
Understanding Threats to Seagrass

The continued growth and health of a seagrass meadow are influenced by a large number of environmental factors and the key ones are well established and generic. The indicators of what is a healthy meadow are more subjective and more likely to be location specific and could change through time– a high biomass may result from a healthy, fast growth rate, or be the result of over fishing of the natural herbivores. Depending on species and location, flowering and seed reserves may be a marker for a healthy, resilient meadow or for a meadow under stress. This subjectivity cascades down to performance indicators for judging success in guiding decision making to mitigate threats. These must also include a component of subjectiveness.

The value biologically and economically assigned to a meadow may also be subjective. Losing a large area is less desirable than a small area. A rare species is of more concern than a very common species. Loss of a meadow when that is the only seagrass along an entire coastline may be rated of greater concern than if the same meadow was damaged but it was only a small fraction of the total seagrass area present.

In prioritising management intervention these three classes of information: the range of threats and their possible impact in space and time; the biological characteristics of the seagrass meadow and species and the indicators of meadow health; and the values assigned to seagrass meadows for the ecosystem services they provide need to be considered.

Coles and Lee Long (1999) listed common threats for the region as disease, excavation, burial, erosion, direct nutrient and oil pollution, and increased land runoff and disturbance (causing excessive nutrient load, high turbidity, reduction in light intensity) without attempting to put those threats in an order of importance. Damage from fishing nets and boats and gleaning and aquaculture discharge are also important (UNEP 2004) as well as the direct and indirect impacts from dredging (Erftemeijer and Lewis 2006). Climate change factors and the possibility of invasive species have also been suggested (Kenworthy *et al.* 2006) as developing threats. Selkoe *et al.* (2008) and Grech (2009) have both used a more sophisticated approach based on Halpern *et al.* (2007) combining an indexed order of threat with the parameters of risk; scale (the area of the impact); frequency (how often a new event occurs); functional impact (how many species are likely to be effected); resistance (the tendency of a biological community to resist change); and recovery time (the time for the biological community to return to its “natural state”). Grech (2009) examined threats specifically to seagrass in the Great Barrier Reef World Heritage Area of northern Australia showing the greatest threat came from agricultural runoff, followed by urban and industrial runoff, urban port and infrastructure development, dredging, shipping accidents, bottom trawling, boat damage and other fishing methods. This list is location specific but the method would identify numerically those threats likely to have the greatest consequence in other locations. Grech (2009) has also mapped overlayed composite threats against known or modelled seagrass areas, giving a spatial “map” of locations of highest risk. The key advantage of this approach is that it can be applied to ecosystem scale planning areas (thousands of kilometres) and can direct limited management resources to locations that are likely to have the greatest return on an investment in prevention or restoration.



Threat map for seagrass in the Great Barrier Reef World Heritage Area, Queensland, Australia from Grech (2009).

Monitoring Changes

To inform management agencies of the need to intervene to ensure the protection of seagrass meadows in the Indo-Pacific it is essential to monitor and quantify changes and declines if they occur. Monitoring programs for indicators of seagrass status and trends are now wide spread through the Indo-Pacific with the development of major global monitoring initiatives supported by the World Seagrass Association such as SeagrassNet and Seagrass-Watch and the development of demonstration sites by the South China Seas project. These seagrass monitoring programs have also been used to identify impacts and trends (Freeman *et* *al*. 2008; Coles *et al*. 2005) and to monitor long term – trends in north eastern Australia (Mellors *et al*. 2008; Coles *et al*. 2007). Because of the expense and logistics of monitoring at the scale of a global region data is limited in the number of locations included and to abundance of species, sediment types and meadow locations. Mapping occurs as part of these programs but there is no coordinated Indo- Pacific mapping program. Resilience and health indicators of seagrasses, such as nutrient status, growth rates and seed banks, are rarely collected systematically and little monitoring occurs in sub-tidal or deep water locations.

It is also necessary in advocating for the protection of seagrasses to quantify the value of seagrass meadows. Ecosystem values of seagrass have become better understood in recent years but may still be locally and regionally specific and calculated for different purposes. Figures used globally for seagrass are as high as US$1.9 trillion per year in the form of nutrient recycling (Waycott *et al.* 2009). For a shrimp fishery in northern Australia seagrasses were valued at A$2 500 ha^{-1} y^{-1} (in 1993 values) (Watson *et al*. 1993), and the economic value of seagrass meadows in China were valued at as much as

US$18 385 ha^{-1} y^{-1} (UNEP 2004). In comparison seagrass fishery standing stocks have been valued recently in Indonesia at less than US$200.00 ha^{-1} y^{-1} (Unsworth *et al.* 2010b). For management purposes seagrasses in the inshore lagoon of the Great Barrier Reef World Heritage Area are valued by Fisheries Queensland at around A$40 000 ha^{-1} y^{-1} when comparing values in determining development alternatives (based on Costanza *et al.* 1997 with exchange rate and annual increase corrections).

There is also an increasing awareness of the role of seagrass in carbon sequestration. Worldwide seagrass may sequester around 12% of the oceans' carbon (Duarte and Cebrian 1996). Rasheed *et al.* (2008) studied a reef in the Torres Strait between Australia and Papua New Guinea and measured an above ground carbon assimilation rate of just under 90 t C day^{-1}. The fate of this carbon is poorly understood but it is likely that as much as 65% decomposes within a meadow with 15% exported, and the remainder grazed or accumulated as a stable refractory pool within the meadow (Mateo *et al.* 2006)

MANAGEMENT AND PROTECTION TOOLS

Coastal management and development polices, and decision making strategies for coastal marine management issues are complex, and much of the information on approaches and methods exists only in local policy and legal documents that are not readily available (Coles and Fortes 2001). There may also be several layers of decision making (International, Federal, State/Regional, Local Government authorities and village level authorities) all of which have control or vie for control over jurisdictions at a variety of spatial scales. Protection of seagrass meadows may also start well away from the coastline with the management of farming and mining activities in river watersheds to prevent chronic pesticide and nutrient levels increasing environmental stress on seagrasses (Schaffelke *et al.* 2005; Lewis *et al*. 2009; Freeman *et al.* 2008).

It is important to match a management approach with the administrative ability of each jurisdiction. An approach including complex laws and active enforcement might have a successful outcome in countries such as Australia and in locations close to urban populations but not be useful in places such as remote Pacific island villages with a reliance on subsistence fishing. Much of the Indo-Pacific bioregion has complex issues of land ownership and indigenous coastal sea rights. These are sometimes overlaid partially by arrangements put in place by colonising powers during and after World War II, leaving the nature and strength of protective arrangements uncertain (Coles and Fortes 2001).

While effective monitoring programs are now established, it is still difficult to separate natural trends and cycles in seagrass parameters that form background levels of change from those of human induced changes for which management intervention is possible - the range of natural variation produces uncertainty in predicting short-term environmental impacts. Presently there is not an adequate understanding of the natural dynamics of change in tropical seagrass habitats. The level of scientific understanding of the basic dynamics of tropical seagrass ecology and requirements for sustained plant growth and survival is also less than ideal for effective management advice. This has significant consequences for scientists who are asked to provide data supporting management decisions intended to reduce impacts on seagrass meadows or to protect areas of seagrass.

Coles and Fortes (2001) list approaches to protection of seagrass meadows as: (1) direct general protection by legislation; (2) protection in Marine Protected Areas; (3) periodic area closures to activities such as fishing; (4) offsets, mitigation and restoration; (5) effective coastal planning; and (6) development of effective environmental management systems. Three main directions may be taken; a prescriptive approach with enforceable laws and regulations; a non –prescriptive approach emphasising education, community, stakeholder or village involvement in decision making and the development of code of practice or guidelines for industry, fishing, aquaculture and agriculture; and a reactive approach seeking to modify and reduce impacts on seagrass meadows by processes such as environmental impact statements, development proposal modification or by improved coastal planning. The underlining science can be either applied science developing tools for implementation of protection regimes and approaches to restoration, or strictly scientific developing and testing hypotheses, syntheses and prediction (Kenworthy *et al.* 2007).

Depending on the social political environment at a particular location a combination of these approaches is likely to be used. The most obvious examples of effective protection are in places such as the Great Barrier Reef where a combination of a multiuse Marine Park and associated closures to some activities, general legislative protection and coastal watershed management aim to protect the biodiversity of the Great Barrier Reef World Heritage Area (Fernandes *et al.* 2009). The Great Barrier Reef World Heritage Area is very large (347 800 km^2), with a well resourced management authority, and not a model for protection of seagrass applicable to most of the Indo-Pacific. Most Marine Protected Areas in this region are small and developed with the support of non government organisations. In these regions an education and guideline based non-prescriptive approach may be more effective. Green and Short (2003) list the marine protected areas with known seagrass in 2003. There are almost certainly many more (see Seagrass-Watch magazine at www. seagrasswatch.org); most quite small and only locally documented, and few developed with seagrass protection specifically as a goal.

The South China Sea initiative is an exception. This large scale regional program designed to reverse environmental degradation in the South China Sea and Gulf of Thailand set up marine environment demonstration sites in China, the Philippines, Malaysia, Vietnam, Indonesia, Cambodia and Thailand four of which are specifically for seagrass (UNEP 2008).

It remains to be seen if this approach is effective in protecting seagrass meadows and in halting losses of seagrass in the region.

Management Needs in the Tropical Indo-Pacific Bioregion

Tropical seagrass meadows have proved resilient to changing environmental conditions in the past, evolving in the warm Tethys seas and surviving sea level rises and falls of as much as 80 metres and temperature changes of as many as 10 degrees (Coles and Lee Long 1999). However multiple environmental stressors in the modern era and the potential speed of changes in the biophysical marine environment from human population increases and climate change may lead to rapid and extensive losses. The Indo-Pacific is the centre of seagrass biodiversity and has extensive seagrass meadows but is fragmented into many jurisdictions making a consistent management approach difficult. Losses of seagrass in this region are likely to be from diverse human impacts each with a small spatial footprint but inevitably resulting in large cumulative losses. Many monitoring sites are now collecting data to assess status and changes (e.g., www.seagrassnet.org and www.seagrasswatch.org) but there is still no coordinated program to map all the seagrass of the region and to document the spatial distribution. Key threats have been identified but priorities for action are difficult to determine at this broad bioregional scale.

We suggest a stepwise approach to present management needs : (1) a comprehensive mapping program of intertidal and sub tidal seagrass meadows in the region to clearly identify the extent of the seagrass resource; (2) research to identify and demonstrate the ecosystem values and connectivity of the region’s seagrass meadows; (3) a more comprehensive analysis of trends in seagrass health for the region; (4) an assessment of threats to seagrass health and how those threats are distributed around the region; and (5) an education program to support local understanding of the values of these key marine habitats. Elements of the South China Seas project (UNEP 2004) and the development of protected zones in north Queensland Australia using biophysical operational principals (Fernandes *et al.* 2009) could be expanded to the greater Tropical Indo-Pacific bioregion as a framework for action.

Conclusion

The Tropical Indo-Pacific region has a high level of seagrass biodiversity and large areas of seagrass meadows covering a variety of environments. The region also has large urban developments, agriculture, coastal infrastructure and coastal development issues leading to poorly quantified threats to these meadows. Losses of seagrass meadows are not being monitored effectively at a regional scale. Management action is complicated by different approaches and resource levels in dollars and in expertise in the many countries and jurisdictions of the region. Major initiatives in the South China Sea and in the Great Barrier Reef World Heritage Area are good models from which to develop a regional approach but outcomes at a scale of the Indo-Pacific are yet to be realised. Global monitoring of seagrass parameters such as by the SeagrassNet and Seagrass-Watch programs are providing indications of trends but requires better support. Dedicated research on the values to the ecosystems of tropical seagrass in this region and of the connectivity to food production in conjunction with applied research and education would ensure the environmental management decisions made in the region are made with the best possible advice regionally. Spatial modelling and spatial risk assessment approaches may be cost effective at the scale of the Tropical Indo-Pacific region.

This region with its many countries, jurisdictions and management approaches requires a coordinated response if effective seagrass management and protection is to occur. It also requires a better understanding of the role and value of seagrass meadows to tropical marine ecosystems and a better tool kit of research based parameters to enable effective management advice.

Appropriate models for management of seagrass communities are available in the region and these models need to be more widely applied.

ACKNOWLEDGMENTS

The authors acknowledge the advice on seagrass management issues from Phil Hales, Manager Planning and Assessment, Fisheries Queensland and assistance with the manuscript by Ms Vanessa Pearson. University of New Hampshire, Jackson Estuarine Contribution **497**

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