Marine Pollution Bulletin xxx (2013) xxx–xxx

Contents lists available at SciVerse ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Seagrass meadows globally as a coupled social–ecological system: Implications for human wellbeing

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ARTICLE INFO

Keywords:
Ecosystem services
Human wellbeing
Seagrass meadows
Coupled social–ecological system
Ecological systems
Social processes

ABSTRACT

Seagrass ecosystems are diminishing worldwide and repeated studies confirm a lack of appreciation for the value of these systems. In order to highlight their value we provide the first discussion of seagrass meadows as a coupled social–ecological system on a global scale. We consider the impact of a declining resource on people, including those for whom seagrass meadows are utilised for income generation and a source of food security through fisheries support. Case studies from across the globe are used to demonstrate the intricate relationship between seagrass meadows and people that highlight the multi-functional role of seagrasses in human wellbeing. While each case underscores unique issues, these examples simultaneously reveal social–ecological coupling that transcends cultural and geographical boundaries. We conclude that understanding seagrass meadows as a coupled social–ecological system is crucial in carving pathways for social and ecological resilience in light of current patterns of local to global environmental change.

1. Introduction

There is growing understanding of the links between ecological systems and social processes. The dynamics of these intrinsically linked, ‘coupled’ systems are seen to be determined by the feedback loops operating among them (e.g. Holling, 1973; Folke et al., 2010). While there are different understandings of how the term ‘coupled’ can be understood, the term can, in the first instance, be used to refer to the links between natural and social systems. This is where the properties of social systems are in some sense linked to the properties of natural systems *on which the social system depends* (Adger, 2000). This understanding has been used to explore social systems that depend on a single ecosystem or a single natural resource, such as a mining or fishing community. Research has explored vulnerabilities in resource dependent economies and societies and exposed the links between natural resource depletion over time and economic decline within communities. This has highlighted the link between community decline and unsustainable methods of natural resource management (Adger et al., 2005; Baker, 2006; Liu et al., 2007).

Policy makers have also taken note of the relationship between ecological systems and social processes. The UN Millennium Ecosystem Assessment (MEA, 2005) and the more recent UK National Ecosystem Assessment (NEA, 2011), for example, have highlighted human dependence on ecosystems for life support, wellbeing and socio-economic development. Such reports have also stressed how vulnerable these systems are to change and degradation caused by certain human activities. The more recent focus on ecosystem services and their accompanying ecosystem assessments resonate with the perspective that society depends on natural systems, providing a way of looking at this relationship in economic terms. Despite advances in the understanding of the links between social processes and ecological systems, more in-depth, theoretical and empirical investigation is required.

It is well known that coastal and island communities provide a clear example of the interactions between societies and nature, where people both depend on the marine environment to provide their basic life needs and where the marine environment is proving to be highly vulnerable in the face of social pressures. However, less is known about seagrass meadows as examples of this coupled relationship. In addition, seagrasses are valuable ecosystem service

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0025-326X/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.marpolbul.2013.06.001

providers which are often marginalised or missing from the global conservation agenda (Kenworthy et al., 2006; Duarte et al., 2008; Unsworth and Cullen, 2010; Nordlund, 2012). Therefore, in this paper, we shift empirical focus from a general discussion on the marine environment to a particular examination of the coupled social and ecological functions of seagrass meadows.

Seagrass meadows are important for their ecological functions and ecosystem services such as their role in food web dynamics, seascape interactions and ecological resilience potential (e.g. Duarte, 2002; Moberg and Rönnbäck, 2003). Coastal communities across the globe rely on seagrass meadows directly for food and livelihoods (de la Torre-Castro and Rönnbäck, 2004; Nordlund et al., 2010; Unsworth et al., 2010), but indirect services also include the cultural benefits obtained from seagrass meadows (Felger et al., 1980; Wyllie-Echeverria and Cox, 2000; de la Torre-Castro and Rönnbäck, 2004; Shokri et al., 2009). From temperate to tropical climates, seagrasses have been shown to create supportive conditions for other marine habitats and fisheries, stabilise the sea floor as well as effectively sequester carbon (Jackson et al., 2001; Orth et al., 2006; Fourqurean et al., 2012). The nearshore and inter-tidal location of seagrasses generally enables easy human access and multiple uses as well as exposing seagrass meadows to both terrestrial and marine based threats.

This paper explores the multi-functional role of seagrasses in their provision of services fundamental to human society. We apply a coupled view of the interactions between social systems and ecological processes as they relate to seagrasses, identifying both the social and ecological values of seagrass meadows and the dynamic interactions between them. This enables us, in turn, to identify the unintended consequences arising as a result of often externally driven stressors that cause imbalances in this relationship. Specifically we address the importance of seagrass meadows for food security and economic development across a range of local communities with varying levels of dependence on marine resources. We discuss resilience of this coupled social–ecological system, taking account of the management status of seagrass ecosystems and exploring the local to global implications of their conservation status. We argue that the dynamic relationship between society and ecosystems creates a variety of opportunities and problems for diverse communities in different places and times. To explore these interactions we present seven regional case studies, each of which highlights the intricate relationships between seagrasses and people.

2. Methods

This exploration uses a range of case studies conducted by the authors from 2001 to 2013, in different locations across the globe. The case studies are geographically, politically and culturally diverse and include tropical, sub-tropical and temperate seagrass systems from both developed and developing countries (Fig. 1).

The case studies used mixed, qualitative methods of data collection, including household surveys, elite and key informant interviews, focus groups, participant observation, market surveys, gleaning surveys, and seagrass habitat, invertebrate and fish assessments. The authors have been conducting detailed research at all of the locations (except Turks and Caicos and Inhaca Island) for at least 2 years. The Turks and Caicos Islands have been studied by the authors in detail during 2013 only and Inhaca, in detail, during 2005/2006. The authors have worked in the Wakatobi since 2004, Zanzibar since 2007, Green Island since 1992, Porth Dinllaen since 2011, and Laucala Bay, Fiji Islands since 2001.

3. Case studies

3.1. Wakatobi, Indonesia

The Wakatobi National Park (WNP) is centred in the Coral Triangle and comprises a range of marine ecosystems with high marine biodiversity (e.g. Pet-Soede et al., 2003; Unsworth et al., 2009) but suffering extensive anthropogenic overexploitation (Unsworth et al., 2010). Marine resources in WNP are heavily relied upon for food, raw materials and income (Cullen-Unsworth et al., 2011). The area has extensive reef and seagrass systems and is heavily exploited by a variety of fishery activities (Cullen, 2007; Cullen et al., 2007). Seagrass covers at least 1000 ha and is dominated by *Thalassia hemprichii*, *Enhalus acoroides*, *Syringodium isoetifolium* and *Halophila ovalis*.

WNP is home to a culturally diverse population of approximately 80,000 people including both islanders (known locally as *Pulo*) and traditionally nomadic sea people (known locally as *Bajo*). *Pulo* and *Bajo* communities have different cultural backgrounds, beliefs, values and levels of dependence on natural resources (Sather, 1997; Tomascik et al., 1997; Cullen et al., 2007; Pilgrim et al., 2008; Cullen, 2009). A forced shift from traditional nomadic lifestyles to a more sedentary lifestyle meant that *Bajo* peoples developed semi-permanent settlements in the shallow intertidal or subtidal areas in coastal regions but they remain predominantly fisher people and intertidal gleaners with highly limited livelihood alternatives (Cullen, 2007). In the WNP *Bajo* settlements are specifically located over shallow subtidal to intertidal seagrass meadows.

Seagrass in WNP is of high economic importance; particularly for its provision of critical habitat for fish and invertebrate species of subsistence, commercial and recreational value, as well as the provision of habitat for endangered Dugong and Green Turtle. At low tide intertidal seagrasses are exploited by men, women and children gathering a major portion of their daily nutrition. The reliance of fishers in WNP on seagrass meadows demonstrates their importance for both income and food security, but they also represent a source of spiritual fulfilment, with lives and lifestyles intricately interlinked to the seagrass system. Seagrass areas are also used for seaweed cultivation.

Data highlights that seagrass meadows represent a reliable and accessible fishing resource when other resources, such as coral reefs, are inaccessible (e.g. during poor weather). Most invertebrate gleaning (e.g. clams, sea cucumber and conch) activity (82%) is conducted within the intertidal and shallow subtidal seagrass meadows, but the role of gleaning is changing rapidly. A household survey in 2005 (Cullen, 2007) outlined gleaning as a supplementary food gathering or recreational activity with no households dependent on gleaned products as their main food source. Conversely in 2012, several *Bajo* households stated gleaned products as their primary source of protein with seagrass gleaning also viewed as a "backup livelihood" when food or money is scarce. Survey data from 2005 to 2006 demonstrates that 60% of invertebrate collectors utilise seagrass habitat, with seagrass remaining the preferential habitat for finfish for 40% of fishers (Unsworth et al., 2010). Approximately 70% of households preferentially consume fish from seagrass habitats; this is in contrast to around 20% who preferentially consume reef fish (Cullen, 2010; Unsworth et al., 2010).

Seagrass meadows in WNP are an essential resource base for local people contributing significantly to their wellbeing through the provision of fishing grounds, substrate for seaweed cultivation, nutrient cycling and, for the *Bajo*, a place to live. But these habitats are suffering from increasing anthropogenic pressures. Destructive fishing practices and overexploitation, particularly the use of static

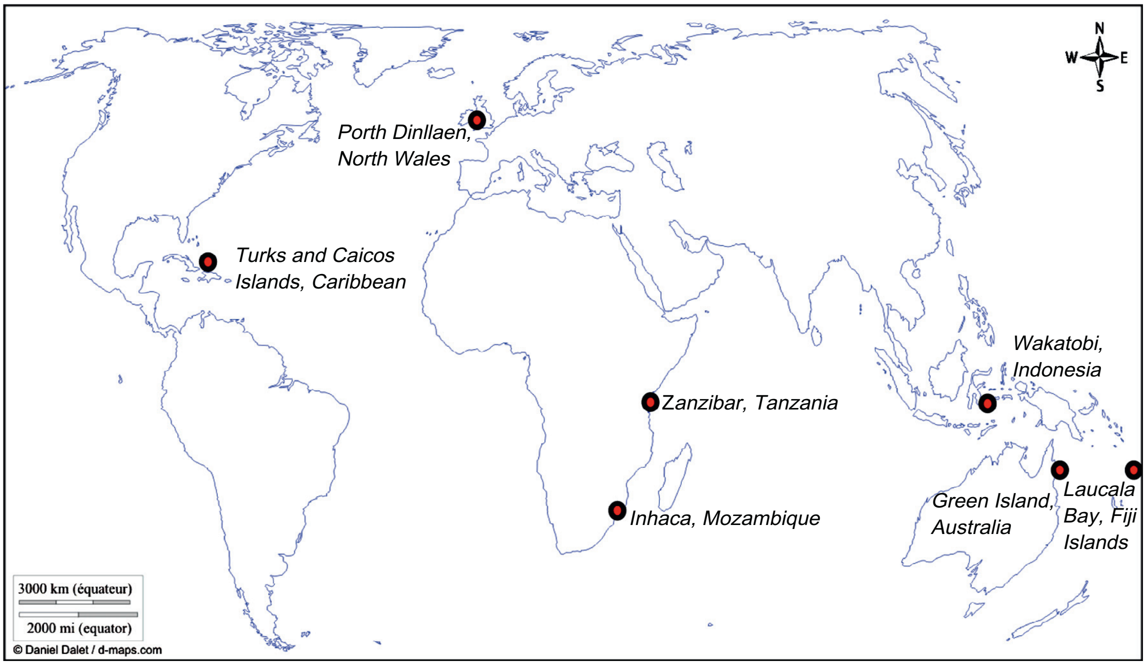

Fig. 1. World map with the locations of the case studies. *Source of map*: www.d-maps.com

fishing gear such as fish fences, are of concern, however, household surveys, focus groups and visual observations conducted in 2012 outlined disturbing evidence of new and significant threats. These threats include mining for coral rock beneath the seagrass meadow, use of poison to remove seagrass from fish fences and pens, and physical removal of seagrass from seaweed cultivation areas. Large areas of seagrass have been lost or have species and/or density decreases. While the *Bajo* are more acutely aware that seagrass meadows are suffering from increased sedimentation (largely due to mangrove removal) and decreasing water quality, both *Pulo* and *Bajo* peoples feel, in the face of these threats, unable to act to protect their lifeline habitat. The WNP suffers from a lack of capacity for formal enforcement of management regulations and limited alternative sources of food and income.

3.2. Zanzibar, Tanzania

Zanzibar is located off the Tanzanian coast of East Africa and has a population of over 1 million in 2012. The tidal range is over 4 m, creating extensive exposed areas during spring low tide that contain dense seagrass meadows comprised of eight species (*T. hemprichii*, *Thalassodendron ciliatum*, *Cymodocea serrulata*, *Cymodocea rotundata*, *H. ovalis*, *Halodule* sp., *E. acoroides*, *S. isoetifolium*). These meadows are extensively fished, during high tide it is mostly men that fish for fish, cuttlefish and octopus using hook and line, nets, spears and traps; while during low tide it is mostly women gleaning invertebrates with very basic or no fishing gear (Nordlund et al., 2010; Håkansson et al., 2012). Women also cultivate seaweed in several seagrass areas around the island (Fröcklin et al., 2012). Seagrasses have aesthetic, instrumental and religious values and traditionally some seagrass plants are used for medicinal purposes; the seagrass also functions as an information service, i.e. navigation aid for fishermen (de la Torre-Castro and Rönnbäck, 2004).

Intertidal invertebrate collection within seagrasses in Zanzibar has a strong gender aspect and a long tradition with almost exclusively women harvesting/collecting (Nordlund et al., 2010). There is also a tradition of older relatives teaching the young how to collect, what to collect and to be careful about the environment. This inter-generational transfer of knowledge is likely important for the preservation of the intertidal zone, representing an informal management strategy. Invertebrate gleaners have experienced a decline in seagrass distribution (Nordlund et al., 2010). The majority of those surveyed said that the invertebrate species abundance had decreased locally but reported a noticeable decline only during the last decade. The number of collectors has been limited due to small village populations, but in the last 10–15 years the population has increased, tourism has grown, and inward migration, or settlement of people, has increased, which has resulted in, for example, more coastal construction, and increased stress on the intertidal zone. Invertebrate collection is predominantly a subsistence activity, but sometimes represents a commercial activity, some collectors selling parts of their catch. Collection from seagrass occurs most commonly during low spring tides. This is a multi-species fishery with more than 270 species targeted.

Interviews demonstrated that the main reasons for the decline in seagrass distribution and fauna were thought to be too many invertebrate collectors, engine scars, strong winds, and digging (Nordlund et al., 2010). Biological inventory data showed that an unexploited remote site had higher invertebrate density, biomass and species richness and diversity than other exploited sites. If seagrass fish and invertebrates decrease dramatically, or even disappear, an important food and income source will be threatened resulting in negative impacts on local people's wellbeing and livelihoods. It is not only overexploitation of invertebrates that is a threat to seagrass ecosystems around Zanzibar; additional threats include lack of sewage treatment, coastal construction and population growth (Jiddawi and Öhman, 2002; URT/World Bank workshop, 2012). These threats combine with a general failure to appreciate the social and ecological value of the intertidal zone, and a lack of institutional capacity to effectively manage seagrass resources (de la Torre-Castro and Rönnbäck, 2004; Nordlund, 2012).

3.3. Inhaca, Mozambique

Inhaca Island is located off southern Mozambique, and has a subtropical climate. The island has semi-diurnal tides with a range of 3.5 m (Tabela de Mares do Porto de Maputo). The small population on Inhaca directly or indirectly depends on the marine environment. In general, men work with fin-fisheries and cattle, while women farm and glean invertebrates in the seagrass dominated intertidal zone at low tide (de Boer and Longamane, 1996; de Boer, 2000; de Boer and Prins, 2002). Men tend to use fishing gear while women use their hands or sometimes a stick when harvesting invertebrates. Tourism is not widespread on the island and it only has a few small hostels and one hotel. Recently large cruise ships have occasionally started to stop by the island bringing tourists to the reserve Ilha dos Portugueses. The seagrass meadows around the island are extensive and commonly composed of *T. hemprichii*, *T. ciliatum*, *Halodule* sp., *Zostera capensis*, *C. rotundata*, *Cymodocea serrulata*, *S. isoetifolium*, and *H. ovalis.*

A study by Nordlund and Gullström (in Nordlund, 2012) compared the community composition in three different seagrass areas with different types of human exploitation. One area is protected (Ilha dos Portugueses), one is harvested by women and the third area is a harbour at Inhaca Island. The study compared *T. ciliatum* dominated meadows and investigated seagrass characteristics, invertebrate abundance, biomass and community structure through biological inventory and observations. The results showed that the protected site, without direct anthropogenic disturbance, was by far comprised of the highest invertebrate density, biomass and species richness compared to areas with invertebrate gleaning and harbour activity. Observations of shell middens showed that mollusc size has decreased over time and some shells (*Perna perna*) can no longer be found in the intertidal zone (de Boer et al., 2000; pers. obs.).

Seagrass at Inhaca supports extensive fisheries. This provides a direct example of the contribution of seagrass to human wellbeing, in this case though through the provision of food and livelihoods. At Inhaca, invertebrate harvesting is mostly for subsistence use, probably due to low tourism and limited export capacity. The fin-fishery is largely subsistence but fishers also sell to other islanders. More research is needed to investigate the sustainability of the seagrass fishery, as well as to investigate other potential threats to seagrass ecosystems. With an increasing population and increasing tourism activity; intensified fishing, sewage, harbours and costal construction will likely increase the pressure on the seagrass resource. To deal with these problems management plans need to be developed and put in place as there are currently no formal and only limited informal management strategies.

3.4. Laucala Bay, Fiji Islands

Located on the south eastern corner of Fiji's largest island (Viti Levu), Laucala Bay borders the northern shore of the largest city in the Pacific islands, Suva. Seagrass meadows cover much of the intertidal reef platforms and mudflats surrounding Laucala Bay and four of Fiji's five seagrass species are reported from the locality (Skelton and South, 2006; Waycott et al., 2011). A barrier reef system encloses the Bay, where seagrasses are widespread in the back reef regions, and dense *S. isoetifolium* meadows fringe the channels between the reefs. *Halodule uninervis*, *Halodule pinifolia* and *H. ovalis ssp bullosa* are also found on the reef flat and back reef, often in a mosaic of patchy meadows.

Seagrasses in the bay have high biological productivity, are efficient in nutrient cycling and support a large biomass of consumers, especially those of fisheries importance. The intertidal and shallow subtidal seagrass meadows surrounding the Bay provide diverse marine food resources of major subsistence and commercial importance (Thaman, 1990). Fiji's coastal fisheries productivity depends greatly on the islands' more than 16.5 km^2 of seagrass habitats (Waycott et al., 2011), which have helped sustain Fijian people since first arrival over three thousand years ago. Almost daily, Suva residents, particularly low income families, glean their protein needs from the intertidal meadows. People glean for almost anything edible and of almost any size. Echinoderms, crustaceans, molluscs, anemones and many other invertebrate species are popular food gleaned from seagrass meadows during low tide (Munro, 1999; Dance et al., 2003). They are collected by women and children for family consumption or sold in local markets.

Of the shellfish, the ark shell or kaikosa (*Anandara cornea*), which is easily collected at low tide in Laucala seagrass meadows, is the most commonly consumed and marketed marine shellfish (Butler, 1983). Other species of local subsistence and commercial importance include: the green seahare (*Dolabella auricularia*), spider conch (*Lambis lambis*), sandfish (*Holothuria scabra*), mangrove shrimps (*Palaemon* sp.), octopus (*Octopus* sp.), rock lobsters (*Panulirus* sp.) and sea urchin (*Tripneustes gratilla*) (Lewis, 1985; Richards et al., 1994; Thaman, 1990). The seagrass meadows of the bay are also important nursery habitat for the regions fisheries. For example, juvenile Emperors (*Lethrinus nebulosus*, *Lethrinus atkinsoni*, *Lethrinus harak*) live in the shallow, inshore seagrass and mangrove areas before moving to deeper water as adults where they are fished on Reefs by gill net (Richards et al., 1994). Seagrass is also a nursery habitat for the witch prawn (*Penaeus canaliculatus*) before they move offshore at the age of 5 months and help for develop adult stocks (Choy, 1982).

Fiji's seagrass meadows also provide foraging habitat for over half of the adult green turtles in the central South Pacific (*Chelonia mydas*) (Craig et al., 2004). Until recently, green turtles were actively hunted and commonly sold in municipal markets and to restaurants and tourists resorts as a delicacy (Thaman, 1990). However since 1997, the Fiji Department of Fisheries has enacted a moratorium on harvesting all turtle species (Paclii, 2013) and the need to protect seagrass foraging areas is becoming widely recognised as a critical part of sea turtle conservation.

Despite limited knowledge of the spatial extent of seagrasses and data on their ecological and socio-economic roles it is clear that these meadows play a supporting role in fisheries production. This provides a direct example of their contribution to wellbeing through their provision of food and a source of livelihoods. Such support also serves to empower local communities though access to foods otherwise not affordable. However, rapid population growth and urbanisation has put increasing environmental pressure on the region. The greatest threats to seagrass are development, improper methods of disposal of solid waste, sewage pollution, coral harvesting, and siltation of coastal areas as a result of agriculture and forestry runoff (Vuki et al., 2000; Vuki, 1994). Long-term studies of seagrass meadows on Suva Reef revealed that losses occurred in some years because of major disturbances (e.g. tsunami, cyclones) and high turbidity/siltation from foreshore reclamations (Vuki, 1994). These impacts are also affecting the seagrass associated fauna and the population of Suva are often advised not to eat the local shellfish because of the danger to human health, such as the risk of hepatitis. Nevertheless, Laucala Bay remains a major source of food for low-income residents underlining the need to secure the survival of the remaining seagrass meadows to protect community food security.

3.5. Turks and Caicos Islands, Caribbean

The Turks and Caicos Islands (TCI) – a UK Overseas Territory in the Caribbean – are a group of islands lying at the south-eastern extremity of the Bahamas Archipelago. The islands are limestone with outlying coral reefs. The six larger islands and two (of the forty) smaller islands are inhabited. The 2012 census reports a population of 31,458 which represents a steady growth from 12,000 reported in 1990. Like other small island states in the Caribbean, the TCI are vulnerable to characteristic shocks such as extreme weather, their dependence on imported goods and lack of fertile soil. Seagrass meadows in TCI are extensive covering large coastal areas and are present across the Caicos Bank (WCMC 2013). These meadows are dominated by three species (*Thalassia testudinum*, *Syringodium filiforme* and *Halodule wrightii*).

The main export sector on TCI is fishing, with other primary industries currently minimal and there is no value added fisheries production, such as canning. Tourism and offshore finance are the most important economic sectors, in terms of both revenue and employment. The role of seagrass in supporting both fisheries production and tourism on TCI is clear. Seagrass associated species (such as Conch, Lobster and Nassau grouper) help supply seafood to hotels, and seagrass supplies interesting habitat for snorkel and kayak tours. The abundance of Green Turtles in the seagrass meadows of TCI provides a potential source of value to tourists and the tourism industry, however Green Turtles are also important as a traditional food item, still consumed across the islands (Godley et al., 2004).

Key informant interviews with administrative and political elites, environmental organisations and activists, charities, fishermen and community members and key stakeholder focus groups highlight the importance of seagrass meadows to local communities across TCI, in particular the role of seagrasses in supporting tourism and fishing based livelihoods as well as household protein requirements. Data also highlighted the perceived threats to seagrasses, and crucially, the economic stressors and fishing practices underlying these threats, as well as the social and cultural processes threatened by degraded seagrass meadows.

The development of the tourism industry of TCI depends heavily upon their high-quality marine habitats. However, the development of this industry presents threats to its longevity through dredging, poor water quality and boat damage. In some locations seagrass meadows are removed to make way for the easy passage of tourists from beach to water (Zuidema et al., 2011). While threatening the survival of the biodiversity that underpins tourism on TCI, the decimation of seagrass meadows also has impact on fishing based livelihoods. As both a threat and opportunity for boosting wellbeing, the careful balance to be held between ecological and social processes becomes paramount.

While there is limited data to establish the status of conch, lobster and fin-fish fisheries on TCI extensive anecdotal observations suggests these fisheries are in decline. Aspirations of a shift to pelagic fishing represent recognition of the decline of coastal fisheries across TCI. Local peoples of the TCI commonly fish from the shore to catch food for household consumption. In addition, on the large spring low tide invertebrate gleaning is known to occur within the extensive coastal seagrass meadows surrounding TCI and highlights a complex dynamic relationship between people and the marine environment. They are both dependent upon it, but prove central to its decline for example, increasingly, lobster and other invertebrates are caught using bleach.

Interviews with community reveal a shift in food habit driven by necessity. As food prices rise, and the price of local fish is driven up by the shortage of supply and high demand from hoteliers wishing to supply tourists with local fish, an important source of low fat protein is perceived as no longer available to local peoples. Crucially, this social and cultural practice of local fish consumption is considered to no longer be within reach of those that value this as a source of food and cultural fulfillment. The role of seagrass in supporting fisheries on TCI provides the most direct example of their contribution to wellbeing through their provision of food and a source of livelihoods, they support empowerment of local communities though access to foods otherwise not affordable.

This case study highlights the complex and dynamic interaction of processes affecting biodiversity loss in marine environments across TCI. With a high dependence on imports, lack of fertile soil, and weak enforcement of the legal and policy arrangements governing the marine environment, TCI's marine resources are increasingly under threat, with devastating consequences for local livelihoods and food security.

3.6. Green Island, Far North Queensland, Australia

Green Island is a vegetated coral cay, located approximately 27 km north-east of the tropical city of Cairns, within the Great Barrier Reef Marine Park and World Heritage Area (GBRWHA), Australia. The cay is surrounded by a platform reef with a shallow and indistinct lagoon on the lee of the cay that deepens to the back-reef slope with coral isolates. The reef flat and lagoon comprises coral reefs and extensive shallow water seagrass meadows of eight species (*C. serrulata*, *C. rotundata*, *H. uninervis*, *Halophila minor*, *H. ovalis*, *S. isoetifolium*, and *T. hemprichii*). The seagrass covers an area of approximately 151 ha (Mckenzie, unpublished data) and extends from the intertidal reef flat to back reef slope at 15 m. Additionally the deeper waters surrounding Green Island contain extensive low density seagrass comprised of three species (*Halophila capricorni*, *Halophila decipiens*, and *Halophila spinulosa*). The location has been a fishing "no take" area since 1974 when it was declared a marine national park (Baxter, 1990). In 1983 the site was protected as a Green Zone within the Great Barrier Reef Marine Park; which prohibits recreational and commercial fishing but allows for a small level of indigenous fishing. Endangered Green Turtle (*C. mydas*) juveniles are commonly observed at the site, feeding primarily on *T. hemprichii* (Fuentes et al., 2006), and although sightings of threatened dugongs is rare, evidence (feeding trails) of their presence is common in the *H. ovalis* meadows (personal observation). Seagrasses at Green Island and in Queensland waters are specifically protected under the Queensland *Fisheries Act* (1994).

The economic value of the seagrass at Green Island is easily observed as tourists are attracted to the abundance of Green Turtles and fish to be seen at the site. Green Island has been a major tourist attraction for over 70 years and is a very popular day trip tourist destination for those living in the Cairns region. The shelter of the leeward side of the Island creates an ideal anchorage zone for small to medium sized vessels; boats use a combination of dropped anchors and permanent moorings typically placed in the seagrass. Numerous pontoons also moor in this area and provide a range of tourist attractions (e.g. SCUBA diving, sea walking and parasailing). Recreational fishing in Queensland is also very popular on inshore and coral reef areas.

The Island and surrounding seagrass is of further significant cultural value for the wellbeing of its Aboriginal traditional owners. It forms part of the cultural 'Sea Country' of the Gungandji people. Historically the Gungandji used the seagrass for fishing and the hunting of Dugong and Green Turtle (Fuentes et al., 2006), this practice continues today but is regulated by and restricted to the Traditional Owners.

Surveys of the fish communities of seagrass within the locality reveal that they have significance as nursery areas for the support of numerous coral reef and coastal species, particularly key functional groups that support coral resilience (e.g. Hoey et al., 2013) and species of economic importance (Watson et al., 1993). Abundance of adult fishes has been reported to be greater at Green Island reef than on neighbouring reefs (Baxter, 1990). Due to the local nature of the fisheries (landed in Cairns) economic gain from this productivity is important.

Seagrass throughout the Great Barrier Reef is under threat from the cumulative impacts of poor water quality, industrial development and the increasing frequency of natural disturbances (Grech et al., 2012; McKenzie et al., 2012). Analysis of seagrass tissue nutrients reveals historic trends of decreasing water quality (McKenzie et al., 2012); arguably at Green Island this may have increased the prevalence of seagrass due to previous nutrient limitation (Udy et al., 1999). This is in contrast to many locations closer to the coast where seagrass is rapidly deteriorating in health and distribution. Seagrasses such as those at Green Island may provide an indirect source of wellbeing by supporting the Coral Reefs of the GBRWHA through their extensive filtration of sediments and nutrients (de Boer, 2007).

3.7. Porth Dinllaen, North Wales

Porth Dinllaen is a small natural harbour located on the Llŷn Peninsula on the North West coast of Wales, United Kingdom (UK). It is protected by a headland to the north, sheltering the bay from all except north-easterly winds, creating an environment well suited for seagrass growth. This intertidal to subtidal environment encapsulates one of the largest seagrass beds in Wales (28 ha), and is located within the Pen Llyn a'r Sarnau EU Special Area of Conservation (Boyes et al., 2005). The site is also designated as a 'Site of Special Scientific Interest', due in part to the presence of the extensive *Zostera marina* seagrass meadow. This is the only seagrass species at the site.

In addition to the sheltered location of the bay providing appropriate environmental conditions for seagrass it also creates an ideal anchorage zone for small to medium sized vessels on what is otherwise a very barren coastline. As a result of the shelter, the harbour has historically been a significant port for UK coastal shipping, local ship building and regionally important ferries. The bay remains a small commercial fishing port that is a popular anchorage for recreational vessels throughout the summer period. It has also become a focus of tourist interest as a sheltered spot to walk and swim and due to the presence of an historic Public House close to the beach. The site is also a favoured location for divers during poor weather. This is because the sheltered seagrass contains diverse fauna for recreational divers to observe and remains a potential dive site in most conditions. Additionally, sea kayaking tours sometimes utilise the bay and observe the seagrass for the same reason of shelter during poor weather.

The potential value of the seagrass meadow in providing wellbeing is through the indirect role the seagrass plays in enhancing the numerous functions of the bay for tourism and anchorage though filtering water, reducing wave action and stabilizing the sea bottom, making the site more affable for tourist activities. In this way the seagrass enhances the physical security of the location and contributing to material wealth provision by assisting local business. But these benefits are also the cause of habitat destruction, for example anchors and moorings damage the seagrass.

The structure that the seagrass provides as habitat also supports an abundant invertebrate fauna, and as a result Porth Dinllaen is popular as a site for recreational collection of shrimp with push nets. This role is largely an emotional affiliation to the site due to its natural beauty, and fishers will only visit during summer months for short periods. Informal discussions with a number these fishers highlight that they are long-term repeat visitors who fished for shrimp at the site as youngsters. The seagrass is also used for the placement of holding cages for Lobster, Brown Crab and Whelk prior to sale by fishermen. It is however unlikely that the seagrass has a role other than providing a location for this activity.

Detailed seasonal fish surveys reveal the importance of the site for 10 species of juvenile fish of commercial importance throughout the region (Cod, Saithe, Bib, Pollock, Whiting, Mullet, Bass, Plaice, Brill, Herring) (Unsworth, unpublished data). Evidence from other areas of the Atlantic reveal that juvenile fish living within *Z. marina* grow faster and have better long-term survival rates than those living in other nearshore habitats (Tupper and Boutilier, 1996). Although these fisheries are of economic and food security importance in the region and currently in an overexploited state (Kelly et al., 2006) they are largely not exploited by Welsh fishermen but instead by foreign fleets, and hence their contribution to local economic activity through fisheries support is likely minimal.

The integrity of the seagrass meadow at Porth Dinllaen has been defined as being in an unfavourable state by the local government bodies responsible for its environmental management. This relates to the increasing degradation of the seagrass by permanent boat moorings, extensive anchor use and the driving of tractors and four-wheel drive vehicles over the meadow. Estimates of the damage caused by the permanent moorings suggest at least 10% of the meadow has been lost by this activity alone (Egerton, 2011). Improving the integrity of the seagrass meadow at Porth Dinllaen through effective management implementation – enforcement, compliance, and monitoring is of potential benefit to the wellbeing of users of the system but requires consideration of users as an integral part of a linked social–ecological system. The Special Area of Conservation (SAC) seagrass steering group at Porth Dinllaen have commenced stakeholder engagement with local fishermen, residents and businesses in order to develop a pathway to management for the seagrass at the site but efforts are limited by insufficient financial support to the SAC.

4. Results and discussion

The case studies demonstrate a range of place specific and cross-cultural reliance on seagrass meadows for a variety of ecosystem goods and services across various regions of the globe. In each of the case studies seagrass meadows have been shown to support the wellbeing of local societies. As a foundation species for marine biodiversity, seagrasses represent a source of food security through subsistence and commercial fishing activity. The importance of informal (subsistence or unregulated) fishing activity to food supply, however, remains poorly understood and not well documented. In the developing regions highlighted, the economic value of seagrass meadows is largely direct through the fisheries that they support. Through this support of fisheries, seagrasses were also shown to add higher level, economic contributions through trade and in particular exports. In the more developed regions there is additional sectoral value through the tourism that seagrass meadows support and in direct food security roles due to their nursery habitat provision for major fisheries. The case studies also highlight the direct and significant threats to seagrass meadows driven by increasing anthropogenic activity which has seen traditional practices replaced by more environmentally damaging behaviour. Research also reveals that seagrass meadows are afforded limited protection in practice, even in cases where formal legislation remains strong (see summary Table 1).

4.1. Seagrass and food security

Achieving food security requires that we pursue culturally appropriate goals of food sustainability, availability and accessibility. In terms of both production and delivery, the food system needs to be ecologically sound such that resource exploitation enhances the productive capacity of the ecological system, while at the same time building human capacity and skills to live sustainably over time (Lawrence et al., 2011). As a foundation species for marine biodiversity, seagrasses are crucial to food security in five of our seven case studies, and in all but the UK case study, there is evidence of the direct exploitation of seagrass fish and invertebrates for food. In the UK shrimp are collected but only as a novelty 'holiday food'. However in most cases, our study has recorded declining catches and decreases in seagrass habitat quality. In Indonesia there is worrying evidence of fishing down the chain

Table 1
Summary of case studies conducted including specific localised threats to seagrass meadows and their management status.

Case study	Socio-cultural and economic context	Methods for data collection	Locally acknowledged values of seagrass	Seagrass exploitation methods	Purpose of exploitation	Target species	Resource changes	Management Status	Threats
Wakatobi, Indonesia	Tropical developing region, cultural diversity, some poverty	Household survey, key informant interviews, market surveys, biological inventory, observation	Source of food and livelihoods (fisheries), accessible fishing ground, protection from storms, cultural value (Bajo)	Fish fence, seine net, gleaning (day and night)	Subsistence and commercial value	Sea cucumber, urchin, all species of fish, anemones	Declining fisheries, all species	Marine protected area but limited enforcement due to lack of capacity.	Overexploitation, destructive exploitation methods, physical removal, mining, declining water quality, sedimentation
Zanzibar, Tanzania	Tropical developing country, widespread poverty	Interviews, biological inventory, observation	Source of food and livelihoods (fisheries), accessible fishing ground, cultural value	Net, seine net, spear gun, snorkelling (day and night), gleaning (day time)	Subsistence and commercial value (local sales)	Everything you can eat or sell	Declining fisheries	Limited understanding of seagrass importance, scarce management, limited enforcement, Seagrass not a priority. Invertebrate harvesting considered harmless.	Overexploitation, nutrient enrichment, declining water quality
Inhaca, Mozambique	Sub-tropical developing country, severe poverty	Biological inventory, observation	Source of food and livelihoods (fisheries), accessible fishing ground	Nets, low tide gleaning (day time)	Subsistence	Common edible species	Decreases in species size, some species locally extinct	Formal management strategies scarce, informal strategies for invertebrate collection present in some parts. The reserve in the study is mainly terrestrial, surrounding intertidal (seagrass) not prioritised	Potential over exploitation of fish and invertebrates. Threats largely unknown
Laucala Bay, Fiji Islands	Tropical developing country, low incomes	Biological inventory, observation	Source of food and livelihoods (local commercial fisheries)	Net, seine net, spear gun, snorkelling (day and night), gleaning (day)	Subsistence and commercial value (local sales)	Fish and multiple invertebrate species	Declining seagrass and invertebrates fisheries stocks	Limited formal understanding of seagrass importance, limited management, and traditional, community-based resource use methods, enforcement at village level, seagrass not a priority. Invertebrate harvesting considered harmless.	Overharvesting, coastal development, waste disposal, coastal water quality (sewage pollution, and agriculture and forestry runoff from adjacent catchments)
Turks and Caicos Islands, Caribbean	Tropical, UK Overseas Territory, tourism based development, social/cultural/economic diversity	Elite, stakeholder, key informant interviews, observation, biological inventory	Source of food and livelihoods (fisheries), accessible fishing ground, safeguard against erosion, water quality, cultural value	Free-diving, hand nets, line fishing	Primarily commercial, limited subsistence	Queen conch, rock lobster, snapper	Declining invertebrate fisheries	Formal management of marine protected areas, limited enforcement. Limited understanding of values and threats within lay community	Overexploitation, destructive fishing, development, dredging, propeller damage, storms, water quality, increasing temperatures
Green Island, Queensland, Australia	Tropical developed country	Biological inventory, observation	Cultural value	Indigenous line and spear fishing	Subsistence	Turtle	No change	Formal management of area through marine protected area status.	Coastal water quality, storms, climate change
Porth Dinllaen, North Wales	Temperate developed country	Biological inventory, observation	Fisheries support, cultural value	Hand nets, line fishing	Recreational	Shrimp and fish	Declining seagrass	Formal indirect protection of seagrass	Local physical destruction and damage, climate change, poor water quality

of preference for food types and income, and fishing down the food chain, seagrass fisheries are largely now based on the exploitation of undersize and juvenile individuals. Similarly, invertebrate gleaners in Zanzibar are noticing a decrease in catch per unit effort due to deceased abundance of resources, and the conch fishery in TCI is believed by many to be on the verge of collapse.

4.2. Seagrass meadows and tourism

The links between seagrass and tourism is an area of research that needs to be investigated further. There are indications that seagrass can be valuable in the tourism sector, however their value here is often indirect, underappreciated and not quantified. In Green Island, Australia, the easily accessible seagrass attracts tourists due to the density of turtles, in Porth Dinllaen, UK, seagrass snorkel trails are being developed and in Chumbe Island, Zanzibar, tourists are participating in educational walks in seagrass meadows, showcasing potential for seagrass related tourism and ecotourism (Nordlund et al., 2013). Developing seagrass tourism can be particularly important for small island developing states, as tourism is a main contributor to national economies (Rogerson, 2007). However, the links between seagrass meadows and tourism are not always positive. In TCI for example, few people recognise the valuable role of seagrasses, and they can be seen as an aesthetic affront to the pristine white sands that represent the Caribbean ideal, as promoted by tourist interests and as expected by the tourists themselves. In this context, tourism development has gone hand in hand with the deliberate removal of seagrass meadows in the intertidal and shallow subtidal zones. In Green Island, tourists appreciate the turtles but again do not necessarily make the connection between the presence of turtles and healthy seagrass meadows.

4.3. Threats to seagrasses

Seagrass ecosystems face increasing threats and degradation globally, predominantly because of increased anthropogenic activities (Waycott et al., 2009). The environmental effects of excess nutrients or sediments are commonly considered the most widespread and significant causes of seagrass decline, however, recently, greater attention has focused on the role of top-down control in seagrass declines and outlined the impact of overfishing (e.g. see Unsworth and Cullen, 2010). In addition to the direct and immediate anthropogenic impacts are the complex and inter meshed impacts from threats related to climate change. These include impacts related to rising sea levels, changing tidal regimes, UV radiation damage, sediment hypoxia and anoxia, increases in sea temperatures and frequency and intensity of storms and flooding events (Björk et al., 2008). These issues are likely to operate differently based on species and location.

Within the case studies presented here coastal development and associated impacts such as increased sedimentation and decreasing water quality were recognised threats at all case study locations. Destructive fishing practices and overexploitation were recognised as major threats in all but two case studies (Porth Dinllaen and Green Island). Specific localised threats included coral rock mining and coral harvesting (WNP and Fiji), poison and bleach fishing (WNP and TCI), and direct mechanical damage by physical removal (WNP), boat and propeller contact (Tanzania, TCI and Porth Dinllaen), digging (WNP and Inhaca), and mooring scar, anchor use and terrestrial vehicles (Porth Dinllaen). Loss has also been reported in Fiji, Tanzania, Inhaca, and Green Island due to natural disturbances (storm action). Regardless of the threats faced, to improve the situation for seagrass ecosystems in any region in the face of direct threats, including the potential threats from climate change, effective management efforts at local, national and regional levels are required. This in turn requires further development of more robust governance processes.

4.4. Governance and conservation of seagrasses

In all of the case studies seagrass meadows generally have unregulated use and there are clear requirements for recognition of their ecological and social importance and for improved management. In WNP, for example, strategic fisheries management is urgently required to halt the declining fisheries, which is also more generally the case for the Indo-Pacific region (Unsworth et al., 2007). The case studies have revealed a deficit between policy formulation, in particular the development of management plans, and implementation, including monitoring and enforcement. In the WNP, Zanzibar and TCI case studies, the designated marine protected areas remain largely ‘paper parks’. As shown in this study, there is a lack of administrative capacity for research, monitoring and management of seagrass ecosystems, with a tendency for this to be scarcer in developing regions such as East Africa and Indonesia, although the system of public administration in TCI was also shown to lack the administrative, technical and financial capacity for effective intervention. In addition, sectoral policy integration, that is, the integration of environmental considerations into sectoral planning, in particular with respect to fisheries and tourism development, remains weak. Furthermore, most designation processes for the selection of marine or terrestrial reserves do not consider the interactions between the terrestrial and marine environments (Stoms et al., 2005), which is unfavourable for seagrass as they are often are located nearshore and affected by both changes to land and sea use. Seagrass conservation is a relatively new policy concern, which might be another reason why effective local and global strategies often are lacking. Coupled with limited public awareness of the value of seagrass meadows this results, in many areas, in declines going unnoticed and undocumented. In East Africa (for both Zanzibar and Inhaca) there is also limited formal understanding of the importance of seagrass meadows, but high local ecological knowledge among resource users (de la Torre-Castro and Rönnbäck, 2004; Nordlund et al., 2010).

The prominent location of seagrass meadows in the intertidal and shallow subtidal zones creates challenges in terms of responsibilities and decision making in developing areas whereby responsibilities for management are not always clear (Nordlund, 2012). Therefore community driven programmes to raise awareness and take measures to protect the seagrass resource are a favourable option. Community participation can, in turn, support the development of locally appropriate adaptive measures that recognise place specific stresses and opportunities. Local engagement has long since been recognised as essential if the capacity of natural resource management regimes to conserve resources is to be improved (McClannahan et al., 2006). Furthermore, increasing public support though raising awareness of the value of seagrass meadows is crucial to their long-term survival, not least in terms of ensuring more sustainable methods of seagrass use are adopted by local communities. In this context, bottom up, local and community engagement in both the development and implementation of conservations strategies has the potential to contribute to more successful conservation efforts.

4.5. Local to global implications

The case studies presented use examples from across the globe describing the importance of seagrass meadows to local communities with varying levels of dependence on marine resources. For example, for the local peoples living directly from the seagrass resources in the Indo-Pacific degradation and decline of seagrass have obvious and crucial implications, while in more developed areas the direct effects are less obtrusive. All of the case studies reveal the importance of seagrass meadows to the local economy, but the implications of resource loss vary depending on the availability of alternative livelihoods and the extent to which their exploitation is embedded in higher level economic activities, such as trade and exports.

In developing countries coupled social–ecological systems are commonly looked at with respect to livelihoods, where the coupled relationship is seen to be nested across scale. These nested relationships can see primary resource users (e.g. fishers) subject to either positive feedback loops or downward spirals of negative feedbacks (Cinner et al., 2011). In this view, behaviour of primary resource users is intrinsically linked with wide-scale processes such as globalisation. This reveals the negative relationship between resource exploitation at the local level and processes of globalisation and trade or the association between the loss of local ecological resources and global environmental change. Primary resource users, the fishers in our case studies, are linked with processes such as globalisation though, for example, accessibility to international markets to sell high value items. This has, however, increased demand and fishing pressure locally, and in the WNP and Zanzibar, for example, this has resulted in overexploitation of high value species. This has further implications locally as the loss of ecological resources results in changes to local diets and behaviour closely associated to the seagrass system. Removal of grazers and bioturbators also has wider implications for the health of the system as a whole.

At the global scale seagrass meadows act as major global carbon sinks (Duarte et al., 2010), they contribute to global nitrogen cycling (Costanza et al., 1997), as well as providing productive habitat supporting world fisheries (Jackson et al., 2001; Unsworth and Cullen, 2010). The recent recognition of seagrasses within climate mitigation strategies as carbon capture and storage systems adds to their global value, along with recognition that seagrasses may represent a source of food security in a rapidly changing global environment (Unsworth and Cullen-Unsworth, 2013).

4.6. Seagrass meadows as a coupled social–ecological system

Recognition of the system as a coupled social–ecological system points to the appropriateness of an ecosystems approach to management. The seagrass resource is important; and its decline has significant implications for society and for the resilience of the coupled social–ecological system. The dynamic relationship between society and seagrass meadows creates a variety of opportunities and problems for diverse communities in different places and times. In all of the case studies, temperate to tropical climate and developed to developing region, seagrass meadows represent a source of livelihoods both directly and indirectly through the goods and services that they provide. The interactions between society and the natural environment are many and varied within the seagrass ecosystem where, in the developing case studies, local society depends directly on seagrass meadows for sustenance and income. In all of the case studies seagrass meadows represent a source of spiritual fulfilment. However, in all of the case studies it is clear that seagrass meadows are highly vulnerable to threats driven largely by anthropogenic pressures. While threatening the survival of the biodiversity that underpins fisheries production, the degradation of seagrass meadows also has impact on fishing based livelihoods. The highly accessible nature of seagrass meadows makes them ideally placed for multiple and not necessarily compatible human uses, whilst at the same time exposing them to threats originating from both the land (e.g. increased erosion and run-off) and ocean. The direct relationship between seagrass systems and social processes will likely affect the resilience of both.

5. Concluding remarks

This paper draws attention to the dependence of people on seagrass systems across the globe. The linkages between society and ecology in the seagrass system are described and we suggest that as such seagrass meadows represent a clear example of a coupled social–ecological system. The threats to seagrass meadows are not only threatening an important resource, in many areas they are also threatening a way of life for those people closely associated with the system either directly or indirectly.

Many studies describe the decline of seagrass meadows; here we describe seagrass as a coupled social–ecological system considering the impact of a declining resource on the wellbeing of peoples. In particular, understanding the importance of seagrass systems in provisioning food security is important to understanding the declining capacities of communities for resilience. There have been few, if any, cross cultural and quantitative studies describing the changing status of seagrass as a coupled social–ecological system or the potential impact of seagrass loss on dependent human communities and further quantitative assessment is required. Understanding seagrass meadows as a coupled social–ecological system is crucial in carving pathways for social and ecological resilience in the face of current patterns of local to global environmental change.

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Please cite this article in press as: Cullen-Unsworth, L.C., et al. Seagrass meadows globally as a coupled social–ecological system: Implications for human wellbeing. Mar. Pollut. Bull. (2013), http://dx.doi.org/10.1016/j.marpolbul.2013.06.001