Great Barrier Reef (Australia): A Multi-ecosystem Wetland with a Multiple Use Management Regime

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Abstract

The Great Barrier Reef (GBR) covers an area of about 350,000 km^2 on the north-eastern Australian continental shelf. Biological diversity within the GBR is very high and includes coral reefs, large areas of seagrass meadows, many species of turtles, sponge gardens and high species diversity of fish, molluscs, echinoderms, sea snakes and seaweeds. The GBR also has at least 30 species of whales and dolphin and the dugong. The coral reefs of the GBR are in generally poor condition with degradation continuing. Seagrass meadows have declined recently but may recover more easily if acute stressors are removed. Dugong and turtle populations in many parts of the GBR are in very severe decline. The GBR has

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a well-designed management system based on both regulatory measures and voluntary compliance with planning regimes but the net effect of 40 years of management has seen many habitats and species still in decline. Most of the factors leading to decline can be identified as associated with climate change, terrestrial pollutant runoff and fishing. To prevent the further decline of the GBR more stringent measures need to be implemented to reduce the impacts of terrestrial runoff and fishing as well as better global (and Australian) measures to reduce the severity of climate change.

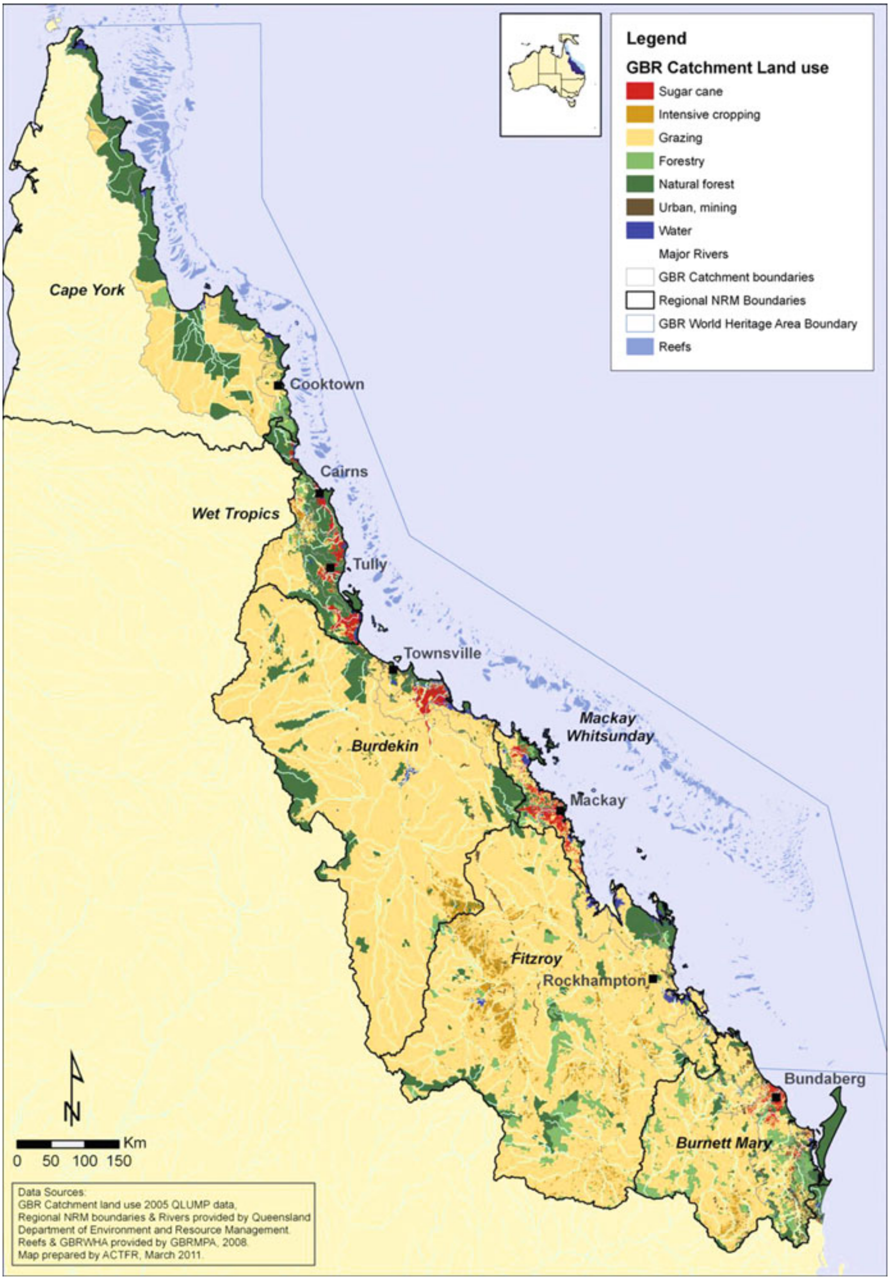
Keywords
Corals · Seagrass · Mangroves · Stressors · Management · Future

Introduction

The Great Barrier Reef (GBR) covers an area of about 350,000 km^2 on the north-eastern Australian continental shelf. It is a long, narrow system stretching 2,000 km along the coast from 25^0 S near Lady Elliot Island and as far north as Bramble Cay close to the Papua New Guinea coast at latitude 9^0 S (Fig. 1). In width it ranges from 100 km wide in the north to 200 km in the south and is generally bounded by the coast on the west and the Coral Sea on the east. The adjacent catchment area covers 400,000 km^2 (Brodie et al. 2012; Great Barrier Reef Marine Park Authority 2014).

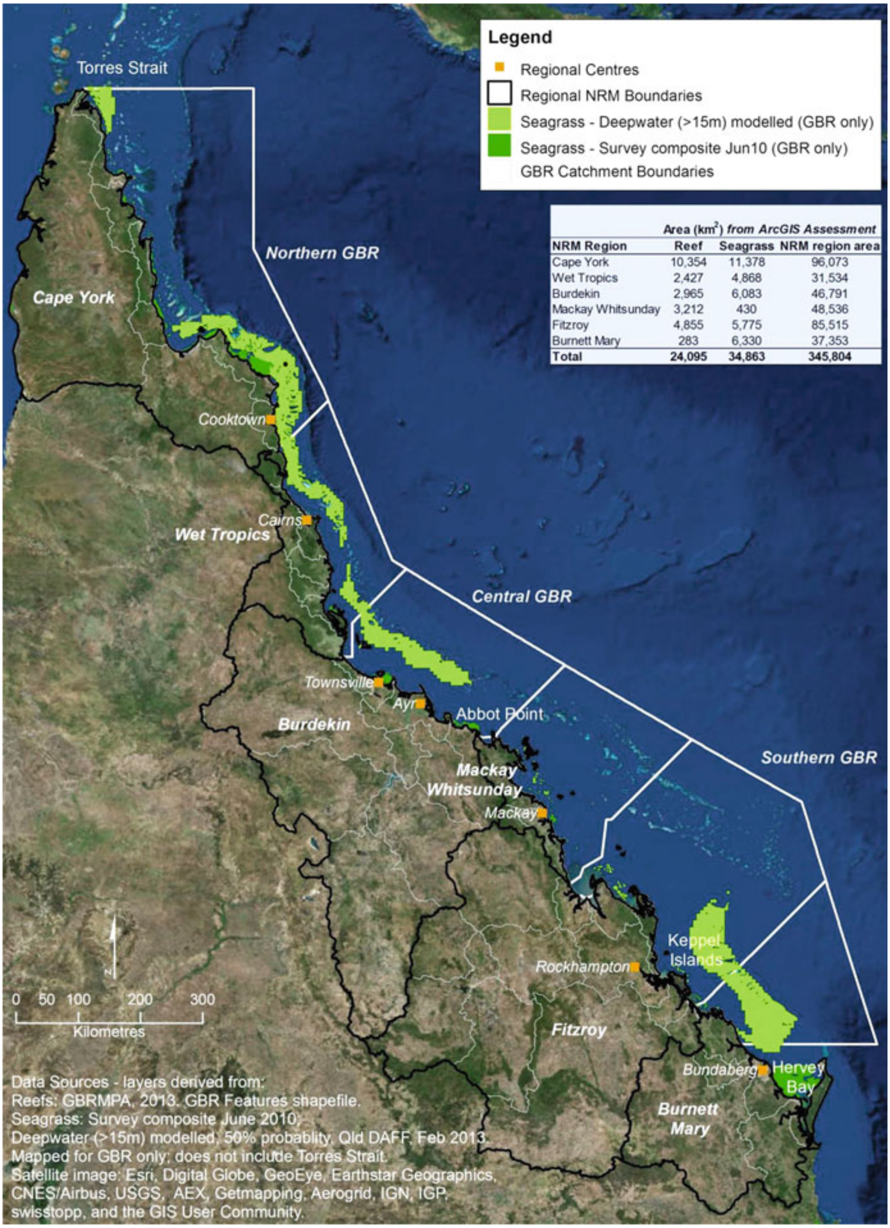
Biological diversity within the GBR includes over 2,900 coral reefs built from over 450 species of hard coral, over one third of all the world's soft coral and sea pen species (150 species), over 43,000 km^2 of seagrass meadows including 23% of the known global species diversity, 2,000 species of sponges equaling 30% of Australia's diversity in sponges, 3,000 species of mollusks including 2,500 species of gastropods, and approximately 500 species of seaweeds (from Day 2011). It also provides habitat for six of the world's seven species of marine turtle including the largest green turtle *Chelonia mydas* breeding area in the world, one of the world's most important dugong *Dugong dugon* populations, more than 1,620 species of fish of which 1,460 are coral reef species, 630 species of echinoderms including 13% of the known global species diversity, and 14 breeding species of sea snakes including 20% of the known global species diversity. The GBR is also a breeding area for humpback whale *Megaptera novaeangliae* with at least 30 other species of whales and dolphins identified within the GBR.

The coastline is dominated by mangroves and saltmarsh interspersed with areas of low energy sandy beach and rocky shores. Immediately offshore, shallow seagrass beds are common and considerable areas of deepwater (>15 m) seagrass are found further offshore (Coles et al. 2015; Fig. 2). The GBR lagoon floor is dominated by soft-bottomed communities of algae, sponges, and bryozoans interspersed with bare sand. In the north, extensive *Halimeda* sp. algal beds occupy the deeper offshore waters, their growth stimulated by nutrient-rich water upwelling from the Coral Sea



Data Sources:
GBR Catchment land use 2005 QLUMP data,
Regional NRM boundaries & Rivers provided by Queensland Department of Environment and Resource Management.
Reefs & GBRWHA provided by GBRMPA, 2008.
Map prepared by ACTFR, March 2011.

Fig. 1 The Great Barrier Reef showing the reefs, catchments and major rivers, and land uses on the catchments and major cities and towns (Map prepared by the Australian Centre for Tropical Freshwater Research (now TropWATER) for general use by staff of TropWATER, James Cook University)



	Area (km^2) *from ArcGIS Assessment*		
NRM Region	**Reef**	**Seagrass**	**NRM region area**
Cape York	10,354	11,378	96,073
Wet Tropics	2,427	4,868	31,534
Burdekin	2,965	6,083	46,791
Mackay Whitsunday	3,212	430	48,536
Fitzroy	4,855	5,775	85,515
Burnett Mary	283	6,330	37,353
Total	**24,095**	**34,863**	**345,804**

Data Sources - layers derived from:
Reefs: GBRMPA, 2013. GBR Features shapefile.
Seagrass: Survey composite June 2010;
Deepwater (>15m) modelled, 50% probablity. Qld DAFF, Feb 2013.
Mapped for GBR only; does not include Torres Strait.
Satellite image: Esri, Digital Globe, GeoEye, Earthstar Geographics,
CNES/Airbus, USGS, AEX, Getmapping, Aerogrid, IGN, IGP,
swisstopp, and the GIS User Community.

Fig. 2 Mapped extent of potential seagrass meadows and coral reefs in the Great Barrier Reef World Heritage Area. *Inset* table shows the area of coral reef, seagrass, and total area of each catchment-based natural resource management (*NRM*) region (Map prepared by J. Waterhouse, TropWATER. Data provided by the Great Barrier Reef Marine Park Authority and the Queensland Department of Agriculture, Fisheries and Forestry, 2013. Satellite image supplied by ESRI)

(Wolanski et al. 1988). The coral reefs of the GBR consist of two main types: the fringing reefs (~760 reefs) which occur on the coast and around the high islands (inner-shelf reefs), and those of the main reef (~2,200 reefs) which occupy a band on the outer part of the continental shelf (mid- and outer-shelf reefs) (Day 2011) (Fig. 2).

Status of Selected Species and Ecosystems of the GBR

Coral Reefs

Coral cover (an indicator of coral reef status) on the GBR has declined markedly in the period since the 1960s from values near 45–55% on mid- and outer-shelf reefs in the 1960s (Hughes et al. 2011) to 28% in 1986 and 14% in 2011 (De'ath et al. 2012). On the inner-shelf reefs, although our record is shorter (8 years), similar declines have been recorded (Thompson et al. 2014). Other indicators of coral "health" have also declined at different areas in the GBR, e.g., between Townsville and Cooktown coral diversity is much lower than expected and ascribed to the impact of terrestrial runoff (Thompson et al. 2014). In addition, calcification rates have declined across the central GBR with the cause mainly attributed to thermal stress on mid- and outer-shelf reefs (Great Barrier Reef Marine Park Authority 2014) with some involvement of ocean acidification, but on inner-shelf reefs terrestrial runoff has also been shown to play a part. There are many causes of the decline, often quite reef-specific, including terrestrial runoff of fine sediment (with associated nutrients) causing more turbid conditions on the inner-shelf and reducing light availability for coral growth, nutrient runoff from soil erosion and fertilizer loss causing crown of thorns starfish (COTS) outbreaks (Brodie et al. 2012), excess algal growth, enhanced sensitivity to coral bleaching, and coral diseases (Brodie et al. 2013); coral bleaching and mortality associated with climate change (Hughes et al. 2007); and increased incidence of category 4 and 5 cyclones which seems to have occurred over the last decade and is predicted to continue under climate change (Walsh et al. 2016). Rainfall extremes are also predicted to increase with an increase in the frequency of La Nina periods and hence more frequent and larger river discharge events (Great Barrier Reef Marine Park Authority 2014).

Seagrass

Seagrass health and abundance is quite variable in space and time in the GBR (Coles et al. 2015). This variability constrains our knowledge of the extent and biomass of seagrass in the GBR at any fixed time, in contrast to coral reefs which are much more structurally stable. Analysis of areas of the GBR suitable for deepwater seagrass (>15 m) using environmental factors has been carried out, and these modeled results are combined with survey results to produce an overall assessment of the likely occurrence of seagrass in the GBR (Coles et al. 2015). The combined area is shown in Fig. 2 (presented as 50% probability of occurrence).

Recently, there is strong evidence that seagrass is declining in parts of the GBR (McKenzie et al. 2015; Coles et al. 2015), particularly in the Townsville, Cairns, and Abbot Point regions and several other locations, associated with a series of severe cyclones and large river flood events (Coles et al. 2015; Devlin et al. 2012). Evidence of this decline are that 38% of sampling sites that are monitored regularly across the GBR are exhibiting shrinking meadow area, a large number of sites have reduced seagrass abundance, and many sites have limited or no sexual reproduction producing seeds that would enable rapid recovery (McKenzie et al. 2015). Degraded light regimes from increased turbidity are the driver of declining seagrass abundance in many sites. For example, the 2011 major river discharge events from many of the GBR rivers associated with the strong La Nina and the effects of category 5 tropical cyclone Yasi have had devastating effects on large areas of GBR seagrass (Devlin et al. 2012). In addition, port dredging may have severe but shorter-term effects on seagrass in locations in the GBR such as at Hay Point near Mackay, where turbidity from dredging is believed to have prevented seasonal reestablishment of deepwater seagrass, although recovery occurred in later years after the dredging ceased (York et al. 2015).

Mangroves

While mangrove forests worldwide are under increasing pressure from a range of anthropogenic threats, mangroves along the whole GBR coast are generally in excellent condition and relatively stable, with only small losses reported, mostly associated with port and urban development (Great Barrier Reef Marine Park Authority 2014). Mangrove and saltmarsh habitats cover an area of approximately 3,800 km^2 along the GBR coast. Given their importance to so many commercial fisheries, it is vital to maintain protection of this asset.

Saltmarsh

Saltmarsh in eastern Queensland has been subject to a range of development pressures due to its position at the interface between terrestrial and estuarine ecosystems, and often on private or leasehold land (Wegscheidl et al. 2015). Since European settlement, around 35 km^2 of saltmarsh has been lost in Queensland, mainly through the construction of ponded pastures, salt ponds, and urban development. The largest losses have been along the GBR coast, including in Fitzroy region (refer Fig. 2), where 17% of estuarine wetlands have been lost, primarily from the construction of tidal levees to create ponded pastures for cattle grazing (Great Barrier Reef Marine Park Authority 2014).

As is the case with mangroves, saltmarsh systems along the GBR coast are exposed to continuing threats from expanding urban and industrial coastal development (Waltham and Sheaves 2015), providing a strong imperative for better management of coastal development, especially given the poor status of many of the ecosystems in the GBR (Grech et al. 2013).

Megafauna

Dugong numbers in the GBR have declined precipitously over recent decades with numbers reducing at a rate of almost nine percent a year between 1962 and 1999. Overall, this is estimated to have reduced dugong numbers from about 72,000 in the early 1960s to 4,000 by the late 1990s. Causes of mortality include incidental netting in fish nets and shark nets, loss of seagrass habitat due to water quality impacts and coastal development, and hunting (Marsh et al. 2005). The combination of severe weather events in 2011 along the entire Queensland coast (Devlin et al. 2012) has also increased dugong mortality and the long-term effects of these events in combination with the existing stresses has yet to be assessed.

Dugong populations are in best condition in Hervey Bay at the southern end of the GBR (Coppo et al. 2014) and in the northern GBR including the Torres Strait (Sobtzick et al. 2014), while there are much lower populations left in the central and southern GBR (Grech et al. 2011). The Torres Strait region between mainland Australia and Papua New Guinea (Fig. 2) supports the largest recorded single continuous seagrass meadow in Australia (Carter et al. 2014) and is the most important dugong habitat in the world (Marsh et al. 2011). Dugongs primarily occur in a large, central area that extends south of Boigu Island to north of Badu and Moa Islands and west of Badu and Muralug Islands (Grech et al. 2011; Sobtzick et al. 2014). The northern GBR region also supports globally significant populations of dugongs (Sobtzick et al. 2014).

The population of “east Australian” humpback whales was as low as 500 animals when whaling ceased in 1963. The population in 2008 was estimated to have been more than 10,000 animals, which is about half of the estimated pre-whaling population size (Noad et al. 2008).

The population structure, distribution, range, and status of the six species of marine turtles found in the region have been well documented (Hamann et al. 2007). All six species are listed as threatened under Queensland and Federal legislation and the International Union for Conservation of Nature and Natural Resources (IUCN) Red List. Long-term census data on green turtle populations indicate that although significant declines in population size are not apparent, other biological factors such as declining annual average size of breeding females, increasing remigration interval, and declining proportion of older adult turtles in the population may indicate populations at the beginning of a decline (Hamann et al. 2007). In Queensland, the loggerhead turtle *Caretta caretta* population has been monitored annually since the late 1960s and has undergone a substantial and well-documented decline in the order of 85% in the last three decades. Long-term monitoring data collected for the eastern Australian population of flatback turtle *Natator depressus* show no signs of a declining population. No leatherback turtle *Dermochelys coriacea* nests have been reported in Queensland since 1996, despite annual nesting surveys for loggerhead turtles that use the same beaches. Mortality of green turtles increased greatly in the year after the large flood and cyclone events of 2011 (Devlin et al. 2012) with many turtles appearing to be starved. *Fibropapillomas* virus is also present in GBR green turtle populations, and studies about the possible causes are continuing.

Management of the GBR

The Management Regime

The GBR has been managed as a national Marine Park since 1975 (*Great Barrier Reef Marine Park Act, 1975*) and was listed as a World Heritage Area (WHA) in 1981 (Day 2011). The overriding objective of the legislation is the conservation of the GBR. The outer boundaries of both the GBR Marine Park (GBRMP) and the Great Barrier Reef World Heritage Area (GBRWHA) lie beyond the shelf break in the east thus enclosing a considerable area of oceanic depth water. The western boundary of the GBRWHA is the low water mark along the coast with the GBRMP boundary similar, except for a few small excluded areas along the coast. It is recognized as a global Large Marine Ecosystem, and the management system is often regarded as the best possible or best in the world and the leading contender for the best example of ecosystem-based management (Brodie et al. 2012). The GBR has been subject to an intensive management regime involving both the Australian and Queensland state governments for 40 years, focussing on managed use and ecosystem protection. The Great Barrier Reef Marine Park Authority (GBRMPA) was established as a statutory authority to manage and protect the values of the GBR in 1975. The human use impacts to be "protected against" include tourism, recreation, shipping, farm and urban pollutant runoff from the adjacent land, fishing and hunting, and climate change related environmental change. The GBRMP is not a park in the same sense as a terrestrial national park; it is a multiple use protected area and many uses, including extractive uses such as commercial fishing, can be licensed to operate with in parts of the park. The one activity which is not permitted in any part of the GBRMP is mining. Activities which occur in the GBRMP include commercial and recreational fishing, aquaculture, tourism, shipping traffic, research, and defense exercises.

Saltmarshes, mangroves, and other marine and estuarine plants in Queensland are protected through a range of legislative measures including the *Fisheries Act 1994*, Ponded Pastures Policy 2001, *Sustainable Planning Act 2009*, and *Environment Protection and Biodiversity Conservation Act 1999*. These mechanisms are vital to minimize or mitigate development impacts on saltmarsh communities; however, stronger policies, planning, and adaptation strategies are needed to ensure that buffers are set aside for anticipated landward migration of saltmarsh with sea-level rise (Sheaves et al. 2007).

The GBRMP Strategic Plan (Anon 1994) attempted to provide hierarchical steps and processes for ecologically sustainable use (ESU) and biodiversity management. It identifies the key issues or objectives in the management of the GBRMP as: (1) the maintenance of the ecology; (2) management to achieve ecologically sustainable use; and (3) maintenance of traditional, cultural, heritage, and historic values. The main 25 year objective was "to ensure the persistence of the GBRWHA as a diverse, resilient, and productive ecological system." However, the Strategic Plan failed to provide unambiguous, scientifically based targets and mechanisms for ESU and biodiversity conservation and does not attempt to define the processes by which ESU may be attained. The plan makes no attempt to identify threatened species; define limits of acceptable change to habitats, proportions of habitat which should be totally protected, or the number, size, and spatial arrangements of protected areas; or specify how representative biological communities can be identified. However, the Strategic Plan recognized that management of potentially damaging activities in the GBR, which may adversely affect conservation values, is spread among a variety of agencies, and GBRMPA attempts to maintain a level of overall coordination.

In 2003, the evidence of the relationship between land use, water quality, and declining GBR ecosystem health led to a national policy response between the Australian and Queensland governments, the Reef Water Quality Protection Plan (Reef Plan) (Department of the Premier and Cabinet 2013). The Reef Plan built on existing government policies, industry and community initiatives with a list of strategies and actions to be implemented by government, industry, and community groups. The initial goal was "*to halt and reverse the decline in water quality entering the GBR by 2013*" (i.e., within 10 years). The Plan was revised in 2009 and again in 2013, with the current long-term goal "*to ensure that by 2020 the quality of water entering the reef from broadscale land use has no detrimental impact on the health and resilience of the Great Barrier Reef.*" The primary focus is to address diffuse source pollution from broadscale land use. The Plan has provided a substantial challenge for the delivery of widespread changes in land use practices and community attitudes, and while some measurable progress has been made, the rate of improvement is not likely to be enough to meet the Plan's goals and targets. To date, the governments have adopted a largely voluntary incentive-based management approach, where agricultural land holders are offered financial support and training (matched by in-kind contributions) to improve management practices. Investment to support Reef Plan implementation has increased from the governments in the last 5–8 years; however, securing resources that are commensurate with the scale of the catchment management issues has been an ongoing challenge.

In more recent times The United Nations Educational, Scientific and Cultural Organization (UNESCO) has expressed concern over the decline of the outstanding universal value of the GBRWHA, their concerns triggered by the rapid industrialization of the Queensland coastline for port, urban, and industrial development, and the recent proposals for expanded development of ports for export of unprecedented amounts of fossil fuels. In response to UNESCO's concerns, the Australian and Queensland governments drafted the Reef 2050 Long-term Sustainability Plan (Reef 2050 Plan; Commonwealth of Australia 2015). The Australian Academy of Science review of the draft Reef 2050 Plan concluded that the plan was inadequate to achieve the goal of restoring or even maintaining the diminished outstanding universal value of the GBR (Australian Academy of Science 2014). The final Reef 2050 Plan, released in March 2015, remains short-sighted given its aspiration to provide an overarching framework for the next 35 years (Hughes et al. 2015). Critically, the revised plan lacks any action on climate change, identified by scientists and the government as the key threat to the GBR owing to the impact of global warming and ocean acidification.

Management Status

Despite this impressive management system, the success of the management regime in halting the decline of many species and ecosystems in the GBR is mixed (summarized in Brodie and Waterhouse 2012; Great Barrier Reef Marine Park Authority 2014). There have been notable successes in recent times after the major rezoning of 2004 with new no-take zones showing increased fish populations (Emslie et al. 2015) but also apparent effects on COTS populations (Sweatman 2008) such that numbers of COTS are lower in the no-take zones. However, major floods have removed much of the positive effects on coral health in the no-take zones in the Keppel Island group (refer Fig. 2; Wenger et al. 2016) showing that integrated management of both fishing and terrestrial pollution (and other stresses) is needed to maintain healthy reef condition. Recent data on turtle populations indicates that numbers are declining, particularly after recent large-scale flooding. Whales (humpbacks in particular) are slowly increasing in numbers again after the cessation of most commercial whaling. There has been little loss of mangroves as a result of strong prohibitions on damaging marine plants under the Queensland fisheries legislation. However, saltmarsh has not been so well protected (Wegscheidl et al. 2015), and coastal wetlands in general are in need of further protection and restoration (Sheaves et al. 2014; Waterhouse et al. 2016).

Sewage effluent discharges from resort islands and mainland cities and towns have been improved dramatically. Strong action on shipping management for compulsory pilotage and navigation equipment may have prevented many shipping accidents but ships still manage to run onto the reef every decade or so. Water quality may have started to improve with recent programs under the Reef Plan policy addressing river pollutant discharges (Brodie et al. 2012, 2013), but the success of the Reef Plan is still uncertain, mainly due to the scale of the management effort required, the associated resource implications, and time lags in the system response from land management change. Current progress under the Reef Plan is summarized in an annual report card (e.g., Department of the Premier and Cabinet 2014). During the first years of more targeted management (2008–2013), the catchment pollutant load modeling, which removes the time lags in management practice effectiveness, indicates that the adoption of improved land management practices was estimated to have reduced loads of suspended sediment by 11%, total phosphorus by 13%, total nitrogen by 10%, and photosystem II inhibiting herbicides (e.g., atrazine and diuron) by 28% to the GBR lagoon (Department of the Premier and Cabinet 2014). However, there is still much to do and a large proportion of agricultural land in priority areas (up to 75–80% in some regions) is still managed below best management practice standards (Department of the Premier and Cabinet 2014).

Many aspects of GBR health and management are less positive; coral cover has declined greatly (De'ath et al. 2012; Thompson et al. 2014), seagrass health in the central GBR is in poor shape, dugong numbers have declined precipitously, shark populations are in serious decline (although perhaps recent management has reduced the rate of decline), many other large fish on the GBR have had large population declines (although data on many are incomplete), and the fourth wave of COTS outbreaks is in progress. Most notably, coral bleaching has become more frequent, widespread, and damaging (Great Barrier Reef Outlook Report 2014), and coral calcification has started to decline due to ocean acidification. Rapid port expansion with large-scale dredging of entry channels (Grech et al. 2013) and associated increases in shipping traffic linked to the growth of the mining industry in Australia raise significant concerns for the long-term health of the GBR (Hughes et al. 2015), with increased potential for fauna strikes and a greater risk of a major shipping incident occurring in the GBR.

The reasons for this apparent failure of effective management are complex but include the need for reasonably "certain" science before management action occurs (and the long times needed to achieve this) (Brodie and Waterhouse 2012). In addition, time lags in recovery after management action are long. For a slow breeding animal like a dugong (one calf every few years), population recovery is a very slow process. Catchment management activities such as reafforestation of riparian areas or rehabilitation of degraded land take decades to reduce erosion and river sediment loads. The likelihood of effective reduction in global greenhouse gas emissions such that temperature change associated with climate change can be limited to a maximum of two degrees also seems remote at the moment although the recent Paris agreements (http://www.cop21.gouv.fr/en/), if implemented, may limit temperature rises to at least less than a catastrophic four degrees.

The Future of the GBR

Based on the information we have outlined above, the long-term viability of the GBR in anything like its current state is in doubt (Hughes et al. 2015). Many species and ecosystems are in decline, and only a few are stable or recovering from past degradation. In addition, the heavy cyclone and flood damage of 2009–2015 and the commencement of the fourth wave of COTS outbreaks raise significant concerns for the long-term health of the GBR (Great Barrier Reef Marine Park Authority 2014). It could be argued that the system has gained some resilience through the current management interventions in water quality management (Brodie et al. 2012; Department of Premier and Cabinet 2014) and the GBRMP rezoning in 2004 which increased the level of protection in a greater proportion of the GBRMP. However, it is unlikely that this management response is adequate to prevent either a large-scale phase shift in the system or just continuing slow decline. Even successful interventions are unlikely to return the GBR to some pristine or pre-disturbance state as has been shown from experience in restoration through management in other systems.

Overall, issues such as the continuing effects of climate change including ocean warming and ocean acidification, more frequent extreme events, continued COTS outbreaks, and accelerating coastal development associated with greatly expanded port and urban development that are not managed in any strategic way raise serious concerns that recovery of many of the key species and ecosystems of the GBR is unlikely (Brodie and Waterhouse 2012). This outcome is despite the fact that the GBR remains one of the best managed coral reef systems in the world.

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