

Climate Change Adaptation in the Great Barrier Reef Iconic National Park System

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THE GREAT BARRIER REEF IS AN ICON UNDER PRESSURE, as outlined in the Marine Park Authority's latest outlook report (GBRMPA 2014). Similar to other iconic parks (see Carter et al., this issue), the Great Barrier Reef (GBR, or the Reef) has been influenced by drivers of change that are external to it, some of which are global in nature. One such driver is climate change, regarded as the major long-term threat to the GBR (GBRMPA 2009a). Climate change is already affecting the Reef and is predicted to have far-reaching consequences in the coming decades. Further, climate change is predicted to interact with other drivers, such as poor water quality from land-based runoff and coastal development (GBRMPA 2014). Together, climate and non-climate drivers can undermine the ability of the GBR to deliver important ecosystems goods and services that underpin regional communities and industries (e.g., tourism and fishing) (Johnson and Marshall 2007). In addition, many of the GBR's heritage values (e.g., aesthetic values, biodiversity, and traditional indigenous practices) are intricately linked to the health of the Reef (GBRMPA 2014). Therefore, responding to drivers, such as climate change, emerges as a key issue requiring urgent attention in the GBR (Fidelman et al. 2013). This will necessarily require addressing the complex nature of the Reef. By using the concept of national park systems (Miller et al., this issue), this article addresses the dynamics between external drivers of change, with a focus on climate change and the GBR's natural, human, and artifactual components. It explores a range of strategies adopted in response to these drivers to gain insights that may be useful to other iconic parks subject to external drivers in a changing climate.

The Great Barrier Reef as an iconic national park system

The Great Barrier Reef of Australia (Figure 1) is a national and international icon. The GBR contains outstanding ecological, social, and cultural values, which have been recognized and protected as a national marine park (since 1975) and World Heritage site (since 1981). In addition, the GBR supports a wide range of socioeconomic activities, contributing significantly to the local, regional, and national economy (GBRMPA 2014).

The basic structure of national park systems (NPSs) consists of natural, human, and artifactual components, which are shaped by internal dynamics and influenced by external

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drivers of change (Miller et al., this issue) (Figure 2). The *natural component* of the GBR comprises the world's largest system of coral reefs. It extends 2,300 km along the state of Queensland's coast and encompasses an area of 344,400 km² (approximately half the size of Texas). In addition to coral reefs, the GBR features a variety of tropical marine habitats, such as beaches, mangroves, and seagrass meadows. It supports a great number and diversity of species, including 600 species of soft and hard corals, more than 100 species of jellyfish, 3,000 species of mollusks, 500 species of worms, 1,625 species of fish, 133 species of sharks and rays, over 30 species of whales and dolphins, and 22 nesting species of birds (GBRMPA 2009a). Some of the GBR species are regarded as being of "conservation concern." These include iconic species (e.g., sea snakes, seahorses, whales, and dolphins), "at risk" species (e.g., most sharks and rays, triton shells, and giant clams), and threatened species (e.g., marine turtles, dugongs, and the sooty albatross) (GBRMPA 2009a). Ecosystem goods and services associated with the GBR are critical to reef-dependent communities and industries. For example, it is estimated that the approximately A\$5.7 billion (US\$5.15 billion) in 2011–2012 to Australia's economy (Deloitte Access Economics 2013).

The GBR is a multiple-use marine protected area, which accommodates a range of uses under the Great Barrier Reef Marine Park Zoning Plan 2003 (GBRMPA 2004), including recreation, commercial marine tourism, fishing, ports and shipping, indigenous traditional use, and scientific research. The *human component* of this NPS comprises a wide range of social actors involved in the use, protection and management of the GBR. These include reef-dependent communities (e.g., indigenous traditional users) and industries (e.g., tourism and fishing), federal and state government agencies, local governments, nongovernmental organizations, and scientists. Protection

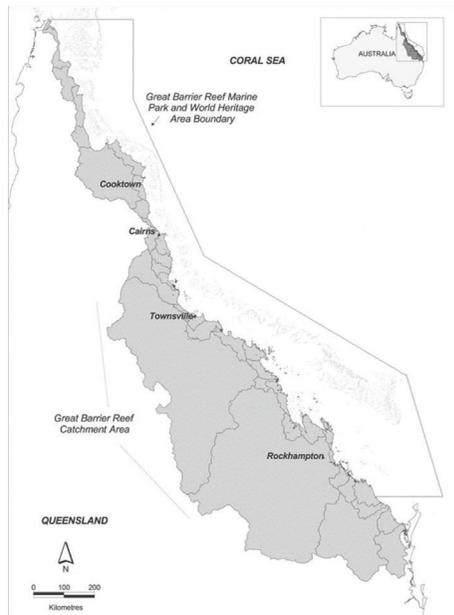
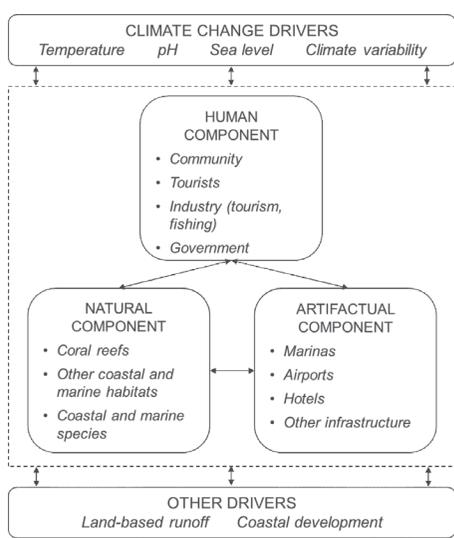


Figure 1. The Great Barrier Reef regions (after GBRMPA).

of the GBR contributed, mostly through tourism,

Figure 2. The Great Barrier Reef iconic national park system (after Miller et al., this issue).



and management of the GBR is shared between the federal and Queensland state governments. Established as a federal agency in 1975, the Great Barrier Reef Marine Park Authority (GBRMPA) has primary responsibility over the GBR Marine Park while the Queensland state government is responsible for the inshore GBR Coast Marine Park. Field management involves partnerships with a number of relevant federal and state agencies. Further, the GBR management is complemented by the contribution of natural resource management bodies, local governments, and community and industry groups (GBRMPA 2009a).

The infrastructure supporting reef-based tourism comprises the *artifactual component*. Much of this infrastructure is concentrated in the Cairns/Port Douglas and Whitsundays areas, which are responsible for about 80% of the tourism in the GBR (GBRMPA 2009a). Such infrastructure includes a wide range of accommodation facilities, restaurants, and shops; airports in the Whitsundays (Hamilton Island) and Cairns serviced with daily flights connecting the GBR with various cities across Australia and some international destinations; and networks of roads (including designated tourist routes) and rail (GBRMPA 2014). The tourism fleet, consisting of approximately 1,500 vessels and aircrafts with permits to operate in the marine park, is the primary means to explore the Reef and islands. In addition, there are approximately 80,000 registered recreational vessels. Tour-operated trips to the Reef involve largely nature-based activities with a focus on corals and other marine life. These activities include snorkeling, scuba diving, and fishing (GBRMPA 2009a).

The GRB is subject to local, regional, national and global *external drivers* (Table 1). The *Great Barrier Reef Outlook Report 2014* indicates that the three major threats to the GBR's environmental, economic and social values continue to be climate change, declining water quality from land-based runoff, and coastal development (GBRMPA 2014).

Climate change is predicted to impact the GBR through increased frequency of severe weather events, ocean acidification, increased air and sea temperature, and sea-level rise. Some impacts of climate change are already being experienced in the GBR, such as coral bleaching due to warmer water temperatures (Hoegh-Guldberg 1999; Done et al. 2003; Berkelmans et al. 2004). The impacts of climate change on the GBR are discussed in more detail in the next section.

Land-based runoff entering the reef system is influenced by land use in the adjacent catchments (watersheds), which area covers approximately 426,000 km². Land use includes farming activities, urban and industrial coastal development, and port expansion. Declining water quality with increased suspended sediments, nutrients, and pesticides can lead to adverse impacts on coral reefs and seagrasses (Brodie and Waterhouse 2012) and has been

Table 1. Main drivers and associated impacts in the Great Barrier Reef NPS.

Climate change	Coral bleaching, ocean acidification, severe weather events leading to loss of coral cover and mortality
Land-based runoff	Sediments, nutrients, and pesticides from land-based runoff can lead to adverse impacts on coral reefs and seagrasses
Coastal development	Loss of coastal habitats
Sources: GBRMPA 2009, 2014; Brodie and Waterhouse 2012; Day and Dobbs 2013.	

linked to coral bleaching, algal blooms, crown-of-thorns starfish outbreaks, and pollution (Day and Dobbs 2013).

Coastal development is related to population growth, economic development and associated infrastructure, and socioeconomic activities. For example, the GBR region is home to a growing population of approximately 1.16 million people (GBRMPA 2014). In addition, mining and industry are driving expansion in port development and shipping activity. Coastal development adversely affects coastal habitats that support the GBR (GBRMPA 2012a).

Given the dynamic nature of NPSs, the drivers addressed above are predicted to interact with each other resulting in synergistic adverse effects. For example, climate change is predicted to compound local and regional non-climate drivers, particularly land-based runoff (see, e.g., Wooldridge 2009).

The Great Barrier Reef NPS under changing climate

As mentioned above, climate change is one of the greatest long-term threats to the health of the Reef (GBRMPA 2009a). A number of climate change variables are already changing in the GBR, and are projected to further and significantly change over the next decades (GBRMPA 2014). Climate change projections suggest increases in air temperature, sea surface temperature, sea level, ocean acidification, and weather variability by 2050 (Lough 2007) (Table 2). These are expected to affect all the components (natural, artificial, and human) of the Great Barrier Reef NPS, as discussed below.

The natural component. Expected impacts of climate change on the GBR include high and enduring sea temperatures, which can result in mass bleaching of coral reefs, and ultimately coral mortality (GBRMPA 2014). There have been various bleaching events due to warmer seawater temperatures in the GBR; some of the most severe occurred in 1998,

Table 2. Climate change projections for the Great Barrier Reef.			
Variable	IPPC 2050 B1 scenario	IPPC 2050 A2 scenario	Certainty of projections
Air temperature	+0.9° C	+2.6° C	High certainty, already observed increases
Sea surface temperature	+1.1° C	+1.2° C	High certainty, already observed increases
Sea level	+13cm	+68cm	High certainty, already observed; may accelerate
Ocean acidification (pH)	-0.15	-0.25	High certainty, already observed decreases
Weather variability	No consensus. Intensity of high rainfall events expected to increase with more extremes. Intensity of tropical cyclones expected to increase	High certainty for increased intensity	
B1 scenario: lower emissions with a global population peak in mid-century, rapid changes in economic structures; clean and resource-efficient technologies introduced. A2 scenario: high emissions with continuously increasing global population and economic growth; fragmented and slow technological change. Sea-level increase is measured relative to a 1961 to 1990 baseline. Source: after Lough (2007).			

2002 and 2006 (Hoegh-Guldberg 1999; Done et al. 2003; Berkelmans et al. 2004). Given the low-lying coastline that characterizes most of the GBR, even small changes in sea level can considerably affect tidal habitats, such as mangroves, beaches, and islands (GBRMPA 2009a). Ocean acidification can have profound effects on coral reefs, decreasing their capacity to build skeletons (De'ath et al. 2009). Lastly, weather variability in the form of more intense tropical cyclones can cause physical damage to coral reefs, and extreme flooding events can affect coral reefs through increased pollution and sediment levels (De'ath et al. 2012).

The human component. Reef-dependent communities and industries are the most vulnerable to the effects of climate change on the GBR. Fenton et al. (2007) suggest that such effects may lead to reduced cultural (e.g., indigenous traditional uses) and recreational (e.g., boating and fishing) opportunities. For example, change in abundance and distribution of traditional marine resources may lead to disruption of customs and practices with likely loss of knowledge, skills, and culture. The reef-based tourism industry is also highly susceptible to the effects of climate change, such as bleaching of coral reefs and change in distribution of iconic species (Fenton et al. 2007). Decline in coral reef and fish biodiversity may cause reef trips by divers and snorkelers to decline by up to 80%. In economic terms, this corresponds to a reduction of A\$103 million (US\$93 million) per year in expenditure by divers and snorkelers on full-day reef trips in the Cairns area (Kragt et al. 2009).

The artificial component. Sea-level rise and extreme weather events, such as floods and cyclones, are potentially damaging to urban and coastal infrastructure that support the GBR reef-based tourism. For example, the GBR region was affected by intense flooding and cyclone activity between December 2010 and February 2011. Tropical Cyclone Anthony (January 2011) and Severe Tropical Cyclone Yasi (February 2011) caused widespread impacts on the region's infrastructure. These included considerable damage to Queensland's road and rail networks, port and airport closures, disruption of water treatment and sewage systems, and loss of power, telecommunication, and Internet (Gooch et al. 2013). Queensland Tourism Council estimated that the losses to the industry caused by the floods and Cyclone Yasi alone totaled A\$1 billion (US\$900 million) (ABC News 2011).

Responding to climate change in the Great Barrier Reef

The future of the GBR will depend on its capacity to respond to a range of climate and non-climate drivers (GBRMPA 2009a). In this context, adaptation is a key societal response to these drivers and can significantly reduce their adverse impacts (Fidelman et al. 2013). In this article, adaptation refers to “the decision-making process and the set of actions undertaken to maintain the capacity to deal with future change or perturbations to a social-ecological system [such as NPS] without undergoing significant changes in function, structural identity, or feedbacks of that system while maintaining the option to develop” (Nelson et al. 2007).

This section draws largely on Fidelman et al. 2013, which examined over 100 examples of adaptation strategies—reports, plans, legislation, policies, studies and assessments—relevant to climate change and the main non-climate drivers (i.e., land-based runoff and coastal development) in the GBR.

In the GBR, adaptation results from a number of organizations pertaining to several, and

in many cases interlinked, sectors (e.g., tourism, biodiversity, fisheries, and water), and governance levels (local, regional, state, and national) with mandates within the GBR Marine Park and beyond. Examples of these organizations include local councils (e.g., Cairns Regional Council), regional natural resource management bodies (e.g., North Queensland Dry Tropics), and state (e.g., Queensland Department of Environment and Heritage Protection Management) and federal (e.g., Department of the Environment) government agencies. These organizations have developed and/or adopted a range of adaptation strategies, including (1) production, synthesis, and integration of information; (2) policies, plans, and programs; (3) planning and natural resource management legislation; (4) organizational structures; (5) tools and guidelines to cope with climate impacts; and (6) establishment of committees and networks (Table 3).

Because adaptation aims to meet diverse socioeconomic goals, it takes place in a context of interacting climate and non-climate changes (Moser and Ekstrom 2010). Accordingly, adaptation strategies in the GBR have been designed as responses to both climate and non-climate drivers (Table 4).

Strategies responding primarily to climate-related impacts include the *Climate Change and the Great Barrier Reef: A Vulnerability Assessment 2007* (Johnson and Marshall 2007), the *Great Barrier Reef Climate Change Action Plan 2007–2012* (GBRMPA 2007) and *Great Barrier Reef Climate Change Strategy and Action Plan 2012–2017* (GBRMPA 2012b). The vulnerability assessment, considered the world’s first comprehensive assessment of climate change risks for coral reef systems, identified key areas of vulnerability and informed the first GBR Climate Change Action Plan (GBRMPA 2012b). The action plan was implemented over the 2007–2012 period with investments of approximately A\$9 million (US\$8.14 million) (GBRMPA 2007). The subsequent GBR Climate Change Strategy and Action Plan (2012–2017) are currently being implemented (GBRMPA 2012b).

Table 3. Examples of main types of adaptation in the Great Barrier Reef NPS.

Information and Research	<i>Climate Change and the Great Barrier Reef: A Vulnerability Assessment</i> examines the vulnerability to climate change of GBR species, habitats and key processes (Johnson and Marshall 2007)
Policy, Plans, Programs	<i>The Great Barrier Reef Tourism Climate Change Action Strategy 2009–2012</i> provides a framework for the tourism industry to respond to climate change (GBRMPA 2009b)
Legislation	The Queensland Great Barrier Reef Protection Amendment Act 2009 aims to ensure the adoption of management practices in catchments to improve the quality of water entering the Reef (State of Queensland 2009b)
Organizational structures	The Climate Change Group within the Great Barrier Marine Park Authority is responsible for developing and coordinating climate change measures on the GBR
Tools and guidelines	<i>Adapting to Climate Change, a Queensland Local Government Guide</i> helps local councils assess the risk of, and respond to, climate change
Committees and networks	The GBR Tourism Climate Change Action Group, consisting of representatives from Great Barrier Reef Marine Park Authority, Queensland government, and the tourism industry, addresses climate change issues
Source: after Fidelman et al. 2013	

Table 4. Examples of adaptation responses in terms of purposefulness.

Climate	Non-climate
Coral bleaching response plans	Caring for our Country Program
<i>Great Barrier Reef Climate Change Strategy and Action Plan 2012–2017</i>	<i>Great Barrier Reef Outlook Report 2009</i>
<i>Climate Change and the Great Barrier Reef: A Vulnerability Assessment 2007</i>	Coastal Protection and Management Act 1995
<i>Implications of Climate Change for Australia’s World Heritage Properties: A Preliminary Assessment</i>	<i>Great Barrier Reef Marine Park Zoning Plan 2003</i>
<i>Australia’s Biodiversity and Climate Change: A Strategic Assessment of the Vulnerability of Australia’s Biodiversity to Climate Change</i>	Great Barrier Reef Protection Amendment Act 2009, Queensland
	<i>Reef Water Quality Protection Plan for Catchments Adjacent to the Great Barrier Reef</i>
	Natural resource management plans
Source: after Fidelman et al. 2013.	

At the core of the GBR climate action plans—and the overall approach of the GBR management—is the concept of *resilience*, understood as the capacity of the Reef system to resist disturbance and undergo change while still retaining essentially the same function, structure, and processes. It refers to the capacity of a changing and dynamic system to return to a healthy state after being subject to a disturbance or impact (GBRMPA 2014). The magnitude of adverse climate change effects on the GBR has been articulated as a function of the rate and extent of climate change and the resilience of the Reef to this change (Johnson and Marshall 2007). Therefore, a key focus has been on maximizing the resilience of the Reef system. This includes minimizing the effects of non-climate drivers, which undermine the resilience of the GBR to climate change. Further, it is assumed that a resilient GBR reduces the vulnerability of dependent industries and communities (GBRMPA 2012b).

Other strategies have been developed to address non-climate drivers, which are nevertheless expected to provide adaptation benefits to the Reef. As discussed above, this is because strategies addressing local and external threats are regarded as important to restore and/or maintain the Reef’s resilience (GBRMPA 2009a). For example, the GBR Marine Park Zoning Plan and the Reef Water Quality Protection Plan for Catchments Adjacent to the GBR (the Reef plan) are major initiatives to help build resilience of the Reef (GBRMPA 2007). The GBR Marine Park Zoning Plan, which came into effect in 2004, defines the activities that are allowed in different parts of the marine park. Its aims include conserving biodiversity, and protecting key functional groups and refugia, all of which are critical to maintaining ecosystem resilience (GBRMPA 2009a). The Reef plan is a joint initiative between the federal and Queensland governments introduced in 2003 to halt and reverse the decline in water quality entering the Reef. Reducing loads of nutrients, pesticides, and sediments from land-based runoff will help enhance the GBR’s resilience in the face of a changing climate (State of Queensland 2009a).

Adaptation in the Great Barrier NPS has been triggered by various factors (Table 5). In addition to climate-related impacts, adaptation has been driven by (1) the management of the marine park, which includes policy and management strategies with a particular focus on ecosystem resilience (Marshall and Johnson 2007); (2) legislation and policy, such as the Great Barrier Marine Park Act 1975 that was amended in 2007 to require the preparation of an outlook report every five years; (3) natural resource management plans and projects, which address many issues of relevance to climate change, such as soil and vegetation management, water quality, and biodiversity conservation; and, (4) planning and management schemes, such as those of local and state governments.

Concluding remarks

The Great Barrier Reef is illustrative of iconic national park systems featuring dynamic interactions between external drivers and the NPS’s natural, human, and artifactual components. In fact, an NPS can be understood as parts of a system within systems and, as such, its components can influence (positively or negatively) change in other components of the NPS (Miller et al., this issue). Addressing the dynamic nature of NPSs is imperative to effectively confront multiple drivers, particularly in the context of a changing climate. In this regard, response strategies need to be sensitive to NPS complexity (Ostrom 1995). For example, the multifaceted and interacting nature of external drivers affecting NPSs requires a variety of response strategies involving a number of sectors with different mandates, which operate at multiple scales and levels. Accordingly, in the GBR these strategies include information and research; policy, plans and programs; legislation; organizational structures; tools and guidelines; and committees and networks. They have been adopted by a range of organizations across several sectors (e.g., tourism, biodiversity, fisheries, and water) and governance levels (local, regional, state, and national) with mandates within the GBR Marine Park and beyond. In sum, responding to key pressing threats to the NPS, such as climate change, requires multi-stakeholder, cross-sector, and multi-level approaches.

The future outlook of NPSs, such as the GBR, will depend to a great extent on the ability of these approaches to deliberately embrace and respond to complexity and interconnectedness. However, it is important to notice that strategies to address external drivers of change may be limited if such drivers are not mitigated (in the context of the GBR, see Bohensky et al. 2011). For example, reducing vulnerability to climate change will require, in addition to

Table 5. Triggers of adaptation in the Great Barrier Reef NPS.	
Trigger	Example
Impacts of climate change	Experienced or perceived climate-induced impacts such as coral bleaching
GBR Marine Park management	Strategies developed for the management of the GBR Marine Park
Legislation	Statutory requirements and sustainable development principles
Natural resource management	Natural resource management issues, such as water quality, biodiversity, and erosion and soil conservation
Planning and management schemes	Coastal management and protection, state planning schemes
Source: Fidelman et al. 2013.	

the adaptation strategies addressed in this paper, strategies to mitigate greenhouse gas emissions. Mitigation measures at the NPS level and beyond should be regarded as a complementary response to reduce risks from external drivers.

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