

Future Scenarios as a Research Tool: Investigating Climate Change Impacts, Adaptation Options and Outcomes for the Great Barrier Reef, Australia

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Abstract Climate change is a significant future driver of change in coastal social-ecological systems. Our knowledge of impacts, adaptation options, and possible outcomes for marine environments and coastal industries is expanding, but remains limited and uncertain. Alternative scenarios are a way to explore potential futures under a range of conditions. We developed four alternative future scenarios for the Great Barrier Reef and its fishing and tourism industries positing moderate and more extreme (2–3 °C above pre-industrial temperatures) warming for 2050 and contrasting ‘limited’ and ‘ideal’ ecological and social adaptation. We presented these scenarios to representatives of key stakeholder groups to assess the perceived viability of different social adaptation options to deliver desirable outcomes under varied contexts.

Keywords Adaptation · Future scenarios · Coastal ecosystems · Governance · Fishing · Tourism · Great Barrier Reef · Australia

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Introduction

Coastal and marine ecosystems provide more benefits to society than many other social-ecological systems (MA 2005a). Climate change is identified as one of the most profound future drivers of change in these systems, encompassing both risk and potential opportunity (Hughes *et al.* 2003; Hoegh-Guldberg and Bruno 2010; Pereira *et al.* 2010). Research into climate change impacts, experiences of adaptation, and projected outcomes for marine environments and coastal industries continues to build knowledge and consensus around our climate change future, e.g., the Intergovernmental Panel on Climate Change (IPCC) 4th assessment (2007). However, impacts, responses, and outcomes are location specific; dependent on how global climate change manifests at regional and local scales and on the vulnerability of the regional, national, and local contexts to these changes (McClanahan *et al.* 2008; Allison *et al.* 2009; Bjarnadottir *et al.* 2011). There is considerable uncertainty about the impacts of climate change for different places and people over time.

In the Great Barrier Reef (GBR) World Heritage Area and Marine Park in Australia, climate change impacts are already evident. Mass coral bleaching was experienced in 1998, 2002, and 2006 in the southern GBR, and sea level rise and ocean acidification have been documented (Hoegh-Guldberg and Hoegh-Guldberg 2004; GBRMPA 2009a; Lough 2012). Ongoing, the GBR region will be affected by air and sea temperature increases, sea level rise, higher concentrations of CO₂, changing rainfall patterns, and increased intensity of storm events when they occur (their frequency is not expected to change) (Lough 2007). Climate change represents the top threat to the reef with major implications for its ecological, economic, and sociocultural values (Johnson and Marshall 2007; Wachenfeld *et al.* 2007). Adaptation to climate change is therefore, at the forefront of research, policy, and management of the region, although strategies and plans are

still broad to account for uncertainty over changing perceptions of climate change.

We present four alternative scenarios to explore multiple perspectives on climate change impacts, adaptation options, and potential outcomes, using the GBR's commercial and recreational fishing and reef-based tourism industries as a case-study. Alternative scenarios are *plausible* descriptions of how the future may unfold (IPCC 2000; MA 2005b) used to scope potential outcomes resulting from different human responses under a range of conditions. They present different choices and suggest potential outcomes resulting from these choices (e.g., Bohnet *et al.* 2008; Bohensky *et al.* 2011). We use scenarios as a research tool to provide a unique analysis of how stakeholders frame adaptation choices within the context of future 'realities'.

Most scenario exercises to date focus on modelling climate change trends and/or impacts (Hulme and Dessai 2008). Increasingly, they are also used to articulate adaptation responses at different scales, from global to local. Typically, scenarios are developed as an end in themselves, for example, the IPCC emissions scenarios (IPCC 2000) and the Millennium Ecosystem Assessment scenarios (MA 2005b). This can occur through expert-driven, scientific processes (Bohensky *et al.* 2011) or through multi-stakeholder policy and action research processes where the learning that occurs throughout scenario development is as important as the final scenarios (Wollenberg *et al.* 2000; Tompkins *et al.* 2008; Cobb and Thompson 2012; Haward *et al.* 2012; Johnson *et al.* 2012). Alternatively, scenarios can be used as a tool to identify future actions. As described by Wilby and Dessai (2010) scenarios are used widely in vulnerability and risk assessment exercises to inform impact models from which scientists, managers and/or resource-users identify adaptation strategies to minimise risk. This often occurs within an adaptation policy and planning context (e.g., the risk and vulnerability assessments underway in Queensland's farming and fishing industries; Brundell *et al.* 2010). Rarely do these processes go on to appraise, evaluate, or implement the adaptation strategies identified (Wilby and Dessai 2010).

Here, we take a similar approach to risk assessment in that our scenarios are not the end goal but a research (as opposed to planning) tool to elicit further information. They provide a future 'vulnerability context' that frames in-depth qualitative data collected on industry adaptation experiences and expectations. We thereby place considerable emphasis on understanding stakeholders' perceptions of a range of adaptation strategies contextualised within the four alternative futures. As Wollenberg *et al.* (2000: 66) note, using scenarios can stimulate "creative ways of thinking that help stakeholders break out of established patterns of assessing situations." Our scenarios contrast moderate and more extreme climate change trends, set against two contrasted adaptation strategies: limited and ideal. They allow us to explore stakeholders' perceptions of: i) different adaptation strategies within four different ecological

and social impact contexts, and ii) projected ecological and social outcomes based on contrasted ideal and limited adaptation pathways.

After detailing our methodology we present our four scenarios. We then explore the diversity of stakeholder responses to them and highlight the adaptation strategies and outcomes that were valued in the fishing and tourism sectors. We conclude with a discussion of the utility of scenarios as a research tool for understanding experiences and perceptions of adaptation.

Methods

Framing the Scenarios

We framed our four scenarios around two climate change trends for 2050 – a best-case and worst-case situation – and two contrasted adaptation pathways – ideal and limited ecological and social adaptation (Fig. 1). This framework allowed us to investigate how adaptation could play out under a range of potential ecological and social impacts. Under best-case climate change trends, air temperatures rise by less than 1.5 °C above 1990 levels (2 °C above the pre-industrial average) and in the worst-case, air temperatures rise by more than 2.5 °C above 1990 levels (3 °C above the pre-industrial average). These projections were adapted from the GBR Marine Park vulnerability assessment (Johnson and Marshall 2007), and align with the regional climate projections developed by the Queensland Climate Change Centre of Excellence (QCCCE n.d.). Ecological, institutional, and economic limits constrain strategies under the limited adaptation scenario (Adger *et al.* 2007). Ideal adaptation is not limited by these factors,¹ and is most effective at reducing vulnerability to climate change.

Developing Plausible Alternative Storylines

We conducted a systematic literature review and broad scientific elicitation to develop our four storylines framed around the axes described above. The literature review consolidated existing knowledge of climate change trends, impacts, adaptation, and potential outcomes in the GBR region. We used the ISI Web of Knowledge to conduct three distinct searches to compile literature related to: i) climate change trends and impacts; ii) adaptation responses, and; iii) limits to adaptation in the GBR, Queensland, or Australia. We reviewed a total of 253 articles in full (see [Supplementary material](#)). For the scientific elicitation, we asked scientists working on climate change in Australia to complete a semi-structured scenario response template that presented information on temperatures, ocean acidification, rainfall patterns, and

¹ Ecological adaptation thresholds still apply but are more optimistic.

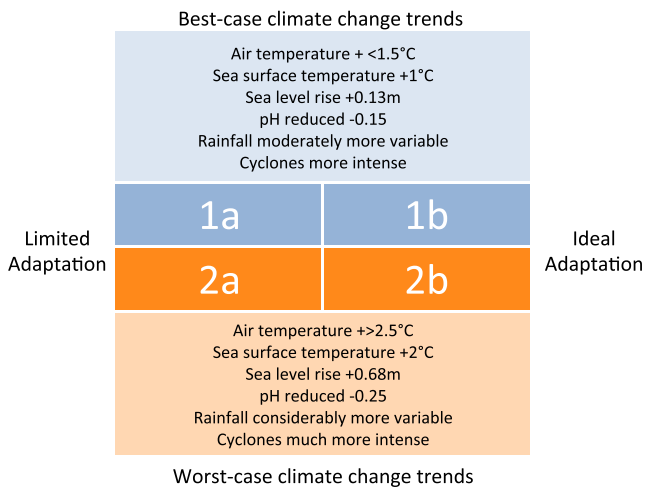


Fig. 1 Scenario framework presenting climate change trends for 2050 along the vertical axis and alternative adaptation pathways along the horizontal axis

extreme events under the moderate and extreme climate change trends for 2050 (Fig. 1; http://dl.dropboxusercontent.com/u/9744348/Scenario_template.pdf). Respondents were asked to outline potential ecological and social impacts from these trends, followed by possible adaptation strategies under a limited and ideal situation. We contacted a broad, ‘non-selective’ sample of scientists and received 27 comprehensive responses to our scenario template. Some were group responses, compiled following brainstorming meetings. Others provided information in the form of papers and project reports, which we included in the literature review. Fish, coral, mangrove, seagrass, turtle, and sea snake specialists, agricultural scientists, environmental engineers, planners, economists and social scientists working on fishing, tourism, agriculture and coastal development responded to the scientific elicitation process. Three project investigators coded the responses and the most frequent trends were combined with information from the literature review to form the alternative storylines. The scenarios focused on the reef, recreational and commercial fishing, and reef-based tourism. Agriculture and coastal development were included, but only where relevant to fishing and tourism.

Eliciting Data on Social Adaptation

We conducted a series of workshops and interviews with GBR stakeholders ($n=26$) to elicit data on industry adaptation experiences and expectations. Representatives of local and state government, fishing and tourism industries, the non-government sector, and research institutions participated in this research phase. Every effort was made to include a wide range of organisations (see [Supplementary material](#)).

First, the four alternative scenarios were presented to participants. In open-ended but facilitated discussion, participants were then asked to reflect on the scenarios and compare the

impact-adaptation-outcome storylines to their knowledge and experience of change in the region, and their expectations for the future. Specifically we wanted to understand: i) whether participants thought the broad, regional scenarios were plausible for different parts of the GBR; ii) whether the adaptation strategies outlined in the scenarios were feasible, possible for different groups of people, and likely to be effective in reducing vulnerability to the range climate change impacts outlined, and; iii) what adaptation outcomes participants valued and whether or not these would be achievable under the different scenarios. Through facilitated discussion we focused first on broad reflections on the scenarios, then on desirable adaptation outcomes, and finally we systematically considered five broad categories of adaptation strategies in turn. These emerged in the literature review and scientific elicitation as important potential adaptation strategies, and include Business planning; Diversification; Effort management; Mobility and migration; and Stewardship. Participants identified and discussed specific adaptation actions within these broad classifications. In general, our approach was exploratory; we did not expect participants to strictly differentiate between each of the four scenarios when sharing their views on adaptation. Instead, the scenarios provided a broad future vulnerability context (different from the current status of the reef) that participants could draw on to explain or frame their perceptions. We digitally recorded and transcribed data, which were coded by three project investigators using QSR Nvivo v9.

Our results present the original scenarios as developed through the expert elicitation and literature review: we did not change the scenarios based on participant stakeholders’ perceptions. We then highlight areas of convergence and divergence among the scenarios and stakeholders’ views on climate change, not to compare scientific and lay knowledge but to investigate what understandings and motivations underlie stakeholders’ views on adaptation. We believe this offers unique insight into how coastal stakeholders frame adaptation choices within the context of future ‘realities.’

A final workshop was held in Brisbane on 12th August 2011 ($n=7$) to disseminate research findings to policy makers and managers. In total, over 60 people representing industry, government, and the scientific community participated in this study either inputting or responding to the scenarios.

Results

From the systematic literature review and scientific elicitation we outline, below, the scientific evidence for the alternative scenarios² (Fig. 2).

² The scenarios for the GBR and its fishing and tourism industries are available in full at http://dl.dropboxusercontent.com/u/9744348/Limits_to_CCA_in_the_GBR.pdf.

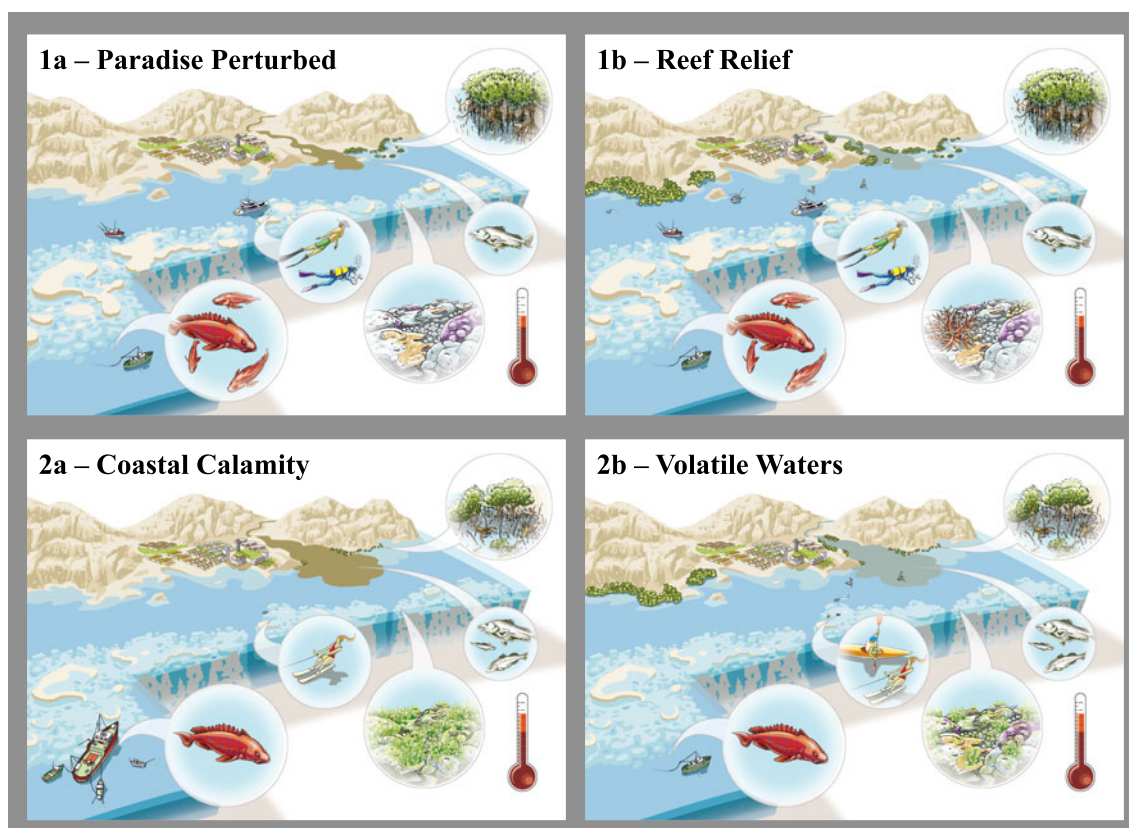


Fig. 2 Four alternative future scenarios for the Great Barrier Reef to 2050 under moderate (1a and 1b) and extreme (2a and 2b) climate change, and limited (1a and 2a) and ideal (1b and 2b) adaptation. The scenarios reflect key differences in run-off from the catchment and

water quality, coral cover and composition, mangrove erosion and distributional change, fish abundance (illustrated by coral trout and barramundi) and social adaptation in the fishing and tourism industries. Artwork by Pinillos, 2011

Climate Change Impacts by 2050

The impacts of moderate (best-case) and more extreme (worst-case) climate change trends are summarised in Table 1. Current exposure to climate variability; extreme events such as the 1998 and 2002 temperature anomalies and bleaching; and Tropical Cyclones Hamish and Yasi illustrate the potential consequences of *moderate climate change* impacts on the region's coastal ecosystems (see [Supplementary material](#) for references on impacts from distinct drivers on corals, fish and mangroves). For *more extreme impacts*, exposure to extreme climatic events, laboratory experiments on the responses of marine organisms to environmental stress including increased temperature and acidification (e.g., Munday *et al.* 2009; Nilsson *et al.* 2012), and models of environmental change driven by future climates (e.g., Hoegh-Guldberg *et al.* 2007; Bohensky *et al.* 2011; Fulton 2011) can inform projections of potential ecological effects.

Research suggests that even under a moderate, best-case climate scenario, combinations of warmer ocean temperatures, acidification, and increased disturbance events will alter coral reef and coastal habitats. In particular, we will see changes in coral cover, species composition, fish distribution and possibly

abundance, with subsequent implications for productivity and diversity (e.g., Hoegh-Guldberg *et al.* 2007; Gilman *et al.* 2008; Munday *et al.* 2008; Anthony *et al.* 2012). Reef-dependent and reef-associated fish species will likely be most negatively affected by climate-induced changes. Productivity of other fisheries may increase, or fluctuate with weather patterns (e.g., rainfall dependent species) although on the whole, declines in primary productivity or prey availability may negate benefits from growth (Robins *et al.* 2005; Hobday *et al.* 2008; Munday *et al.* 2008; Gillson 2011).

Under more extreme climate change trends, studies suggest that the rapid rates of change and the increased incidence of disturbance events would significantly reduce the resilience of coral reefs and increase the prospect of phase shifts from coral to algal dominance (even with high herbivory and low nutrient inputs) (Anthony *et al.* 2012; Thomas *et al.* 2012). With potentially widespread phase shifts to algal dominance, reef-dependent fish species would decline significantly or be lost, reef-associated marine organisms would be heavily impacted (Munday *et al.* 2008), and the aesthetics of the reef would be substantially altered. Pandolfi *et al.* (2011) argue that research into historical responses of coral reefs to climate change suggests that effects over the next few

Table 1 Climate change trends affecting the Great Barrier Reef under different scenarios by 2050

Moderate climate change trends	Extreme climate change trends
<p>Impacts on coral reef ecosystems include:</p> <ul style="list-style-type: none"> • increased incidence of temperature anomalies • increased exposure of coral reefs to freshwater run-off in wet seasons • moderate increases in cyclone damage • more frequent outbreaks of pests and diseases on corals • mild ocean acidification effects <p>Impacts on other coastal ecosystems include:</p> <ul style="list-style-type: none"> • increased erosion from both sea-level rise and more intense cyclones. <p>Direct impacts on fish relate to:</p> <ul style="list-style-type: none"> • warming sea temperatures. <p>Impacts are projected to be localized, i.e., felt in different places at different times.</p>	<p>Impacts on coral reef ecosystems include:</p> <ul style="list-style-type: none"> • markedly increased incidence of temperature anomalies • increased exposure of coral reefs to freshwater run-off in wet seasons • substantial increases in cyclone damage • more frequent and extensive outbreaks of pests and diseases on corals • moderate ocean acidification effects. <p>Impacts on other coastal ecosystems include:</p> <ul style="list-style-type: none"> • significantly increased erosion from both sea-level rise and more intense cyclones, • increased exposure to more extreme environmental conditions related to flooding and drought events. <p>Direct impacts on fish relate to:</p> <ul style="list-style-type: none"> • warming sea temperatures, • increased exposure to pulses of freshwater. <p>Impacts are projected to be widespread and extend to deeper waters.</p>

decades are likely to be more variable in time and space than most current projections. Nevertheless, many quantitative modelling scenarios indicate that under worst-case climate scenarios drastic changes to coral reef habitats and potential collapse are possible by 2050 (Hoegh-Guldberg *et al.* 2007; Baskett *et al.* 2009; Bohensky *et al.* 2011; Thomas *et al.* 2012). Other than habitat alteration, more rapid and extreme climate change would mean more severe sub-lethal and lethal effects on fish and other marine organisms, particularly on more vulnerable early life-stages (Munday *et al.* 2008). There are also greater implications for distributional shifts of marine organisms.

Ecological Adaptation and Outcomes

The potential for ecological adaptation of coastal ecosystems and marine organisms remains highly uncertain; dependent on the magnitude and rate of climate change, the resilience of the reef environment, and species-specific traits (Pandolfi *et al.* 2011). Some argue that the rates of change under both moderate and extreme scenarios exceed historic rates of change and, therefore, are likely to overwhelm the capacity for ecological adaptation or acclimation in most marine organisms. This is particularly so with heat-resistant corals (Hoegh-Guldberg 1999; Hoegh-Guldberg *et al.* 2007). Others suggest that under certain conditions, adaptation of corals and fish may be possible with moderate climate change trends (Munday *et al.* 2008; Baskett *et al.* 2009; Miller *et al.* 2012). Fish species with geographical ranges that span large temperature gradients or with relatively short

re-generation times are more likely to adapt fast enough to moderate climate change impacts. However, adaptation of marine organisms to habitat degradation is unlikely (Munday *et al.* 2008). Finally, some fish species and habitat types may adapt through distributional range shifts (Perry *et al.* 2005; Hobday *et al.* 2006; Gilman *et al.* 2008; Hobday 2011; Traill *et al.* 2011). It is unlikely, however, that coral reef fishes will be found at higher latitudes than current distributions (Munday *et al.* 2008) or that corals and reef-associated fish would shift significantly (Hoegh-Guldberg *et al.* 2007).

Considering both moderate and extreme climate change trends, and optimistic versus limited scope for ecological adaptation, our alternative future scenarios suggest four trajectories of ecological change (Table 2).

Social Adaptation and Outcomes

Local to regional management of coastal ecosystems can potentially minimise the environmental impacts of climate change (Bohensky *et al.* 2011). Similarly, social adaptation can mediate the direct and indirect impacts of climate change on society (Adger *et al.* 2005). People's experiences of managing and adapting to long-term environmental change (e.g., declining fish stocks), climate fluctuations (e.g., seasonal and inter-annual variability in resource availability), climatic extremes (floods, droughts, cyclones), and other extreme events (e.g., tsunamis, conflict, economic crises) can illustrate the potential of particular strategies to reduce vulnerability or risk and to capture new opportunities. In the scenarios we posit that under moderate climate change (scenarios 1a and 1b) the changes to coastal

Table 2 Four alternative future scenarios on ecological change in the Great Barrier Reef by 2050

	Limited adaptation	Ideal adaptation
Moderate climate change trends (best-case)	<p>1a) Paradise Perturbed</p> <p><i>Reefs remain in a coral-dominated state:</i></p> <ul style="list-style-type: none"> • Coral cover declines and composition shifts to more heat-resistant massive and encrusting species (e.g., <i>Porites</i> spp). • As impacts are localised, refuges of heat-sensitive staghorn, branching and table corals allow some recovery. • Mild ocean acidification effects on coral growth hinder recovery. <p><i>Ecological adaptation of coastal habitat is constrained:</i></p> <ul style="list-style-type: none"> • Coastal habitats, like mangroves, cannot easily shift shoreward, upstream and southward. • Coastal habitats experience a slight decline in cover. <p><i>Habitat changes affect dependent species, including reef fish, turtles and sea-birds:</i></p> <ul style="list-style-type: none"> • Reef function is maintained although marine biodiversity declines. <p><i>Direct climate change impacts on fish are moderate:</i></p> <ul style="list-style-type: none"> • Some species (e.g., coral trout) to shift their distribution southward and into deeper waters. 	<p>1b) Reef Relief</p> <p><i>Reefs remain in a coral-dominated state:</i></p> <ul style="list-style-type: none"> • Coral cover is high and is comprised of heat-sensitive and more heat-resistant species • Coral mortality in heat-sensitive corals is lower than expected due to ecological adaptation. • Refuges of heat sensitive corals and improved water quality foster recovery of reefs. • Mild ocean acidification effects on coral growth hinder recovery. <p><i>Ecological adaptation of coastal habitat is facilitated:</i></p> <ul style="list-style-type: none"> • Coastal habitats, like mangroves and beaches shift shoreward, upstream and southward. • Overall cover is maintained. <p><i>Marine animals adapt to these moderate changes in reef and coastal habitat:</i></p> <ul style="list-style-type: none"> • Reef function and overall biodiversity are maintained. • Composition and distribution of marine environments are altered. <p><i>Direct climate change impacts on fish are moderate:</i></p> <ul style="list-style-type: none"> • Some species to shift their distribution southward and into deeper waters.
Extreme climate change trends (worst-case)	<p>2a) Coastal Calamity</p> <p><i>Reefs shift from coral to algal-dominance:</i></p> <ul style="list-style-type: none"> • Coral mortality is non-selective. • Reef recovery is hindered by more frequent and intense disturbance events and a scarcity of coral refuges. • Moderate ocean acidification slows coral growth and undermines reef structure. <p><i>Ecological adaptation of coastal habitat is constrained:</i></p> <ul style="list-style-type: none"> • Coastal habitats cannot shift shoreward, upstream and southward. • Cover and quality of coastal habitats is significantly reduced. • Shoreline erosion is exacerbated. <p><i>Habitat changes affect dependent species, including reef fish, turtles and sea-birds:</i></p> <ul style="list-style-type: none"> • Many of the essential functions of the reef are lost. <p><i>Direct climate change impacts on fish are significant:</i></p> <ul style="list-style-type: none"> • Warmer temperatures cause some species (e.g., coral trout) to shift their distribution southward and into deeper waters. 	<p>2b) Volatile Waters</p> <p><i>Reefs tend towards a state of flux, shifting between coral and algal-dominance:</i></p> <ul style="list-style-type: none"> • Coral mortality is lower than expected in more heat-resistant corals (e.g., <i>Porites</i> spp). • A few refuges of primarily massive and encrusting corals remain on mid-shelf and outer reefs. • Large-scale recovery is undermined by the frequency and intensity of disturbance events. • Moderate ocean acidification slows coral growth and undermines reef structure. <p><i>Ecological adaptation of coastal habitats is facilitated:</i></p> <ul style="list-style-type: none"> • Coastal habitats shift shoreward, upstream and southward. • Chronic erosion and more variable water availability reduce overall habitat cover. <p><i>Some marine species adjust to compositional and distributional changes in reef and coastal habitat:</i></p> <ul style="list-style-type: none"> • Yet, many organisms dependent on these habitats (e.g., damselfish) decline significantly. • The essential functions of the reef are maintained periodically and in patches. • Overall marine biodiversity declines significantly. <p><i>Direct climate change impacts on fish are significant:</i></p> <ul style="list-style-type: none"> • Negatively impact the growth and productivity of many species, though some pelagic species benefit.

Table 2 (continued)

Limited adaptation	Ideal adaptation
<ul style="list-style-type: none"> • Warming also negatively impacts the growth and productivity of many species, though some pelagic species (e.g., trevally) benefit. • Bigger fluctuations in rainfall cause numbers and distributions of rainfall-dependent species (e.g., barramundi) to vary considerably. 	<ul style="list-style-type: none"> • Bigger fluctuations in rainfall also cause numbers and distributions of rainfall-dependent species to vary considerably.

ecosystems and marine organisms reflect the variability experienced by reef-based industries from other drivers of change, including market fluctuations or regulatory change. Whereas under more extreme climate change (scenarios 2a and 2b) the changes to coastal ecosystems and marine organisms present greater and longer lasting risks to reef-industries than other drivers of change. In the latter case previous experience of risk and adaptation may be limited in illustrating future outcomes (Adger and Barnett 2009). We draw on relevant regional research on varied adaptation strategies and the expert elicitation to deliberately counterpose ‘limited’ and ‘ideal’ adaptation strategies (Table 3). As such, our scenarios are speculative and do not reflect the current state of management and adaptation in the GBR.

In complex social-ecological systems, the ecological and social domains cannot be uncoupled. Thus, it is important to first account for how management and social adaptation can hinder or foster ecological adaptation, thereby influencing the nature of environmental change that the fishing and reef-based tourism industries would adapt to. Limited social adaptation under both moderate and extreme climate change trends (scenarios 1a and 2a) exacerbate the detrimental impacts of climate change impacts (Table 2). For instance, reactive adaptation measures such as shading and coral transplantation, help only a few individual reefs (Hoegh-Guldberg *et al.* 2007), heavy fortification of coastlines prevents new coastal habitat from establishing (Gilman *et al.* 2008), and failure to change land use practices in the reef catchments means continued decline in water quality on the reef (McCulloch *et al.* 2003; Eberhard *et al.* 2009; Thomas *et al.* 2012). In the scenario *Coastal Calamity* nutrient loads in run-off reinforce the algal-dominated state of the reef (De’ath and Fabricius 2010). In contrast, with ideal adaptation, whether under moderate or extreme climate change (scenarios 1b and 2b), the outlook for the reef is improved by integrated management of the catchment, reef and its fisheries (Hughes *et al.* 2010; Wooldridge *et al.* 2012), and rapid responses to bleaching events, cyclones, and predation outbreaks, combined with the use of technical solutions to protect vital coral refuges. Planned retreat of communities from

the coast and effective habitat restoration also foster ecological adaptation of coastal habitats (Gilman *et al.* 2008).

Under the limited adaptation scenarios (1a and 2a), we suggest that climate change does not trigger major reorganisation within the fishing and tourism industries. Fishers respond to changes in availability of target fish species by increasing fishing effort, travelling further south and offshore, and using less selective fishing methods to diversify the catch (McClanahan and Cinner 2012). The tourism industry also responds by increasing effort, for instance, by fish-feeding and coral farming, concentrating effort on remaining coral refuges, travelling further south and offshore, and diversifying into other water-based activities. Flooded coastal infrastructure is abandoned and replaced elsewhere. Under more extreme climate change conditions (scenario 2a) the commercial fishing industry is increasingly absorbed into large international corporations, which organise around off-shore ports and motherships to reduce travel time at sea while increasing effort. Similarly, under the guise of efficiency the tourism industry amalgamates into large corporations.

By contrast, where adaptation is effective the scenarios (1b and 2b) suggest that stakeholders anticipate climate change and pursue planned, strategic adaptation. Adaptation in both the fishing and tourism industries includes: improving marine stewardship; improving business planning and forecasting; reducing effort (technology, time and capacity); migrating to different areas to relieve stress on vulnerable species or impacted sites; diversifying products, incomes and activities; and developing comprehensive emergency planning (GBRMPA 2009b; Gunn *et al.* 2010; Turton *et al.* 2010; Tobin *et al.* 2010; Cinner *et al.* 2012). Fisheries and tourism infrastructure are gradually retrofitted or relocated in response to sea-level rise (COAG 2009; DERM 2012). Under more extreme climate change conditions (*Volatile Waters*), the commercial fishing and tourism industries organise around co-operatives and the recreational fishers create linkages to these co-operatives. While ecological adaptation is largely overwhelmed by the rate and scale of change in *Volatile Waters*, management and social adaptation mediate, to the extent possible, the risks and opportunities created by climate change.

Table 3 Possible climate change adaptation options for managers and users of coral reef and coastal ecosystems based on empirical observations of adaptation to environmental change, climate variability, and extreme events

Social adaptation	Potential effectiveness	Reference
Geoengineering	<ul style="list-style-type: none"> Limited potential to reduce solar radiation, which does not address ongoing CO₂ emissions Some potential for large-scale geo-engineering to reduce atmospheric CO₂ using oceans Some potential for restoration, though unlikely to be feasible to increase cover and rugosity at scales that match ecosystem degradation. Some new advances in culturing techniques may assist culturing of more resistant species. Enhancement (removing stressors) and restoration (replanting) can improve resilience of mangroves and offset anticipated losses. 	Crabbe, 2009 Hoegh-Guldberg <i>et al.</i> 2007
Coral culture and transplantation	<ul style="list-style-type: none"> Restoration and planned retreat to remove coastal barriers can facilitate distributional shifts. Water quality issues arise from run-off of sediments and pollution from catchment and coastal land-uses 	Gilman <i>et al.</i> , 2008 McCulloch <i>et al.</i> , 2003 Hoegh-Guldberg <i>et al.</i> 2007
Wetland restoration	<ul style="list-style-type: none"> Poor water quality exacerbates stress, bleaching and habitat degradation. Improved water quality can reduce reef stress and confer resilience 	Eberhard <i>et al.</i> , 2009 Munday <i>et al.</i> , 2008
Water quality	<ul style="list-style-type: none"> Does not prevent reef degradation. Can delay coral cover loss from disturbance regimes Can aid recovery of reefs post-disturbance by slowing algal growth and colonization. Effectiveness depends on timing of herbivory in recovery processes and numbers of herbivores relative to varieties and cover of turf and macro algae. 	De'ath and Fabricius 2010 Thomas <i>et al.</i> , 2012 Woodrudge <i>et al.</i> , 2012 Hughes <i>et al.</i> , 2003 Graham <i>et al.</i> , 2008 Munday <i>et al.</i> , 2008 Hughes <i>et al.</i> , 2010
Foster herbivory through fisheries management	<ul style="list-style-type: none"> No-take MPAs can protect functional diversity. Capacity to enhance resilience to climate change impacts is dependent on size and connectivity of protected areas. Protected areas can increase the potential for representation, replication and refugia of mangrove species, thereby creating response diversity. 	Edwards <i>et al.</i> , 2011 Mumby <i>et al.</i> , 2006 Gilman <i>et al.</i> , 2008 Graham <i>et al.</i> , 2008 Munday <i>et al.</i> , 2008 Hughes <i>et al.</i> , 2010
No-take marine protected areas (MPAs)	<ul style="list-style-type: none"> Can build resilience to disturbance by contributing to strategies outlined above. Can provide a marketing and competitive advantage where consumers prioritise green products. Can facilitate trust building between private, public and civil society actors, thereby facilitating co-ordinated adaptation. 	Tobin <i>et al.</i> , 2010 Marshall and Marshall 2012 Cinner <i>et al.</i> , 2012
Stewardship	<ul style="list-style-type: none"> Effective temporary solution to impacts from disturbance events More effective when supported by diversified markets and knowledge of alternative markets. Dependent on response diversity to climate change impacts. If all species/habitats are equally sensitive, opportunities are reduced. 	Graham <i>et al.</i> , 2008 Munday <i>et al.</i> , 2008 Hughes <i>et al.</i> , 2010 GBRMPA, 2009b Turton <i>et al.</i> , 2010
Diversification	<ul style="list-style-type: none"> Alternative <i>Catch/Product</i> Effective temporary solution to impacts from disturbance events More effective when supported by diversified markets and knowledge of alternative markets. Dependent on response diversity to climate change impacts. If all species/habitats are equally sensitive, opportunities are reduced. 	Tobin <i>et al.</i> , 2010 Marshall and Marshall 2012 Cinner <i>et al.</i> , 2012

Table 3 (continued)

Social adaptation	Potential effectiveness	Reference
Effort	<p data-bbox="248 1171 272 1451"><i>Diversified Income/Livelihoods</i></p> <ul data-bbox="284 478 360 1440" style="list-style-type: none"> • People with multiple income sources appear to cope better with cyclone effects on their livelihood, though this is not consistent across individuals. • More effective where alternative income sources are not climate-sensitive <p data-bbox="371 1192 395 1451"><i>Increasing effort or capacity</i></p> <ul data-bbox="406 604 496 1440" style="list-style-type: none"> • Could be an effective solution in under-utilised fisheries. • Can buffer impacts in the short-term. • Can be mal-adaptive in the medium to long-term in fully utilized or over-exploited fisheries. 	McClanahan and Cinner, 2012 Gunn <i>et al.</i> , 2010
Mobility and Migration	<p data-bbox="507 1192 531 1451"><i>Decreasing effort or capacity</i></p> <ul data-bbox="542 489 775 1440" style="list-style-type: none"> • Effective in fully utilized fisheries at improving catches and profits for other fishers, as well as protecting impacted fish stocks and ecosystems. • Does incur costs in the short-term for those who reduce effort or exit a fishery. • Can be effective as a temporary measure. • Tends to be constrained by current ecological knowledge (fishers revert back to places they know) and existing market locations. • Can lead to concentration of effort, over-exploitation, and conflict among resource users. • High levels of migration can lead to social disruption to immigrant and host populations. 	Tobin <i>et al.</i> , 2010 Lédée <i>et al.</i> , 2012
Emergency response and Insurance	<ul data-bbox="783 531 960 1440" style="list-style-type: none"> • Disaster relief funding available to agricultural industries in GBR catchment but not necessarily to reef-industries. • Effective as a temporary adaptation response. • State pay-outs likely to be unsustainable as a response to long-term impacts of climate change. • Potential for private insurance mechanisms linked to adaptation best-practice (e.g., high stewardship, high building standards) 	Tobin <i>et al.</i> , 2010

Building on the four ecological change storylines (Table 2), our scenarios posit a range of social outcomes from limited and effective management and social adaptation in the GBR (Table 4).

Stakeholders' Perspectives on Adaptation

This section highlights areas of convergence and divergence between the scenarios and stakeholder representatives' views of climate change impacts, social adaptation options and desirability of outcomes. These data emerged from the workshops and interviews.

Participants emphasised two overarching messages in reaction to the scenarios. First, the need to couch climate change adaptation research and planning in terms of opportunities in order to move forward and find solutions; participants highlighted that while changes to climate are not necessarily disputed, the rate of change, the capacity of individuals to mitigate and adapt to it, and the consequences for the reef and its industries remain contested. And some voiced concern over what they perceive as

a general trend among the scientific and management community to represent climate change as *overly* negative. Second, participants noted that climate change is one of many challenges facing reef managers and industries, some of which are more immediate. They often shared experiences and examples that were related to other disturbances, such as the global financial crisis, fluctuations in the cost of energy, extreme weather events and other natural disasters, and regional security. Participants wanted the current spotlight on climate change to enhance rather than detract from attention to other issues in the GBR region.

Views on Ecological Impacts and Environmental Governance

Overall, participants associated a high level of uncertainty with the ecological impacts of climate change on the GBR. Tourism and commercial fishing representatives saw climate change as a key driver of change in the region but tended to align more closely with the moderate climate change scenarios (1a and 1b). For instance, they focused on variable or localised

Table 4 Four alternative future scenarios on social change in the Great Barrier Reef by 2050

	Limited adaptation	Ideal adaptation
Moderate climate change trends (best-case)	<p>1a) Paradise Perturbed</p> <p>Commercial fishing and reef-based tourism sectors can remain profitable for many, though some operators may exit.</p> <p>Recreational fishers can also continue to enjoy the cultural services of the reef.</p> <p>Overall, sustainability of the reef and its fisheries would decline.</p> <p>Conflict between managers, commercial and recreational fishers, and tourism operators would increase slightly.</p> <p>Non-climate drivers of change such as market prices, energy costs, and regulation continue to be of great importance to all sectors.</p>	<p>1b) Reef Relief</p> <p>The new visions and strategies of reef industries effectively offset impacts and improve the outlook for the GBR.</p> <p>Commercial fishing and reef-based tourism sectors can remain profitable.</p> <p>Recreational fishers can also continue to enjoy the cultural services of the reef.</p> <p>Sustainability of the reef is improved.</p> <p>Conflict between stakeholders is reduced.</p> <p>Adapting to climate change furnishes reef sectors with capacity to adapt to other non-climate drivers of change, which continue to be significant.</p>
Extreme climate change trends (worst-case)	<p>2a) Coastal Calamity</p> <p>Reef-based industries would no longer be profitable and many independent operators would be forced to exit these industries.</p> <p>Some recreational fishers might continue to fish but would likely receive far less enjoyment from the cultural services of the reef; many would choose to fish elsewhere.</p> <p>Sustainability of the reef's fisheries would also decline.</p> <p>Conflict between managers, commercial fishers, and recreational fishers would increase dramatically.</p> <p>With limited adaptation, many lifestyle values associated with reef-based industries are lost.</p>	<p>2b) Volatile Waters</p> <p>Even with ideal adaptation extreme climate change will mean that reef-based industries are less profitable.</p> <p>Anticipating this, many operators exit reef industries voluntarily. Given this, the industries can be viable for the few who remain and adapt.</p> <p>Recreational fishers might continue to fish but would likely combine fishing with other leisure activities in order to maintain enjoyment from the varied cultural services of the reef.</p> <p>Sustainability of the GBR would be an ongoing challenge.</p> <p>Collaboration between stakeholders could be strengthened by the common problem.</p>

impacts across the vast and diverse geography of the +2900 reefs of the GBR stretching from north to south, they discussed compositional shifts in corals rather than phase shifts to algal reefs, and they challenged the notion of significant losses of coastal habitat, such as mangroves from climate change as opposed to coastal development. A tourism industry representative countered the scenarios under more extreme climate change (in particular 2a):

I'm buoyed by the fact that the reef isn't going to disappear, it's going to change. (March 2011)

Representatives of the recreational fishing sector suggested that recreational fishers do not generally perceive a problem adapting to the direct impacts of climate change, only to the adaptation actions of other stakeholders, including managers:

We can adapt to climate change but it's going to be increasingly difficult for us to adapt to some of the other changes that are forced on us.

(Recreational fishing representative, April 2011)

In terms of environmental governance, participants identified coastal development and catchment land-use practices as the primary threats to reef resilience and both ecological and social adaptive capacity. The current political focus on climate change was seen as a key opportunity to reorganise how the GBR catchment and coastline are valued and managed. Participants suggested that really effective management and adaptation in the catchment and coastline – including protection and rehabilitation of mangrove habitat around the Trinity Inlet, Hinchinbrook Channel and the Fitzroy River, for example – could substantially improve the outlook for GBR ecosystems and industries despite climate change (as reflected under 'ideal' adaptation in 1b). However, it was recognised that this opportunity could require significant changes in other industries, including sugar cane farming, cattle production, and property development. For participants, government subsidies to agricultural industries and current demographic trends in the region indicate that transformation of catchment industries and coastal development trajectories is extremely unlikely.

With regards to more conventional reef management, participants argued for a more dynamic approach to spatial management that could respond to environmental change triggered by climate change, such as species and habitat distribution shifts, and to the changing vulnerabilities of the GBR industries. Participants discussed positive examples of situations where fishing or tourism operators were permitted to access alternative sites, temporarily, when their usual grounds were impacted by flooding or cyclone events. Of particular note was the shift from spatial to stock entitlements in the Marine Aquarium Fishery that enabled fishers to relocate fishing grounds but, in return, reduce harvesting pressure on key functional herbivore species in response to bleaching events. Despite some progress, participants emphasised that more

flexibility was needed (rapid adaptation responses to bleaching events, cyclones, and predation outbreaks are posited under ideal adaptation in 1b and 2b).

Perspectives on Adaptation in the Fishing Industry

The GBR fishing industry is comprised of a range of commercial fisheries, including the East-Coast Otter Trawl Fishery, Coral Reef Finfish ('Reef Line') Fishery, East Coast Inshore Finfish ('Inshore Net') Fishery, and others, as well as a charter and a recreational line fishery. Participants discussed the potential of a range of adaptation strategies, most importantly business planning (e.g., financial management, networking, and marketing) and environmental stewardship (e.g., adopting, monitoring, and communicating sustainable activities), to deliver desirable outcomes, which they identified as: economic viability; environmental sustainability; and enjoyment (associated with recreational activities and the lifestyle values of commercial reef-based industries). Participants argued that those in the commercial fishing sector most adept at business planning³ were more profitable, less vulnerable, and more able to adapt to change than those who identify more closely with being a fisher than a business owner. However, participants stressed that the viability of the fishing sectors as a whole relied on adaptation among the entire cross-section of operators. As a result, current fisheries management and adaptation planning aim to furnish all operators with enhanced business skills and information in contexts of change. Similarly, government agencies and industry representative organisations provide information, technical assistance, and financial support to enable operators to improve their stewardship credentials and associated market share, a key example of which is the Reef Guardian Fishers programme (<http://www.gbrmpa.gov.au/our-partners/reef-guardians/reef-guardian-fishers>). Participants acknowledged the considerable progress made in terms of stewardship and sustainability and the continued opportunity to leverage a market advantage through green, organic, and buy-local marketing strategies considered essential to counter declining profitability as prices stagnate or decline through globalisation, market integration and competition, and as costs increase, particularly energy costs.

Other adaptation strategies were also viewed as processes that do or should occur at the industry level. Both the organisational structure and capacity of particular sectors were certainly factors beyond the influence of individual operators. In response to the scenarios, participants identified some key areas of convergence and also concern. For example, participants noted that fishing sectors on the east coast of Queensland were not currently amalgamating into international conglomerates (2a – *Coastal Calamity*) but that a few northern Australian fisheries were beginning to, driven by high value seafood rather than climate change. Participants suggested that while this could

³ Entrepreneurs were not necessarily associated with larger businesses.

improve efficiency in times of stability, it reduced the adaptive capacity of individual participating owner operators. These conglomerates were also perceived to possess fewer stewardship values than independent owner operators. Alternatively, organisation into co-operative structures, industry associations, and networks (2b – *Volatile Waters*) was perceived to facilitate spread of innovation and effective adaptation. However, it was noted that sectors and individuals varied and that a range of organisational and business models was needed to accommodate changing circumstances, preferences, and capabilities.

The management of effort within fishing sectors suggested in the scenarios was also an area of contention, in particular the permanent removal of effort and capacity from commercial sectors (2b – *Volatile Waters*). Fisheries buy-backs of quota or effort units and, in some cases, vessels and infrastructure have been undertaken in a number of Australian fisheries since the late 1990s (e.g., ECTF 2004). Participants identified three models of fishery buy-back schemes: full government funding; government loans to industry and industry co-operative funding. They also noted that buy-back schemes typically occurred under a sustainability banner, but were needed to address declining profitability. In general, buy-back processes have had mixed results with some failing to effectively minimise environmental impact and the social costs to operators exiting the industry. Generally, participants consider buy-back schemes as more or less appropriate depending on: i) the concentration of effort within individual fisheries – the more concentrated the effort, the higher the likelihood of effective effort reduction; ii) the value of the seafood commodity targeted – the higher the value the more potential for increased profits with fewer operators, and; iii) the nature of resource allocation in the fishery – in some sectors catch is not necessarily constrained by competition with other operators for limited resources. Legitimacy in buy-back schemes was improved when industry associations could manage the funds allocated.

Participants noted that organisation into representative associations and networks, co-ordinated management of capacity, and demonstrated stewardship of the reef could also benefit the recreational fishing sector by enhancing its legitimacy and thereby its participation in, and influence of, mainstream management and adaptation planning processes. However, to date, the sector struggles with membership, representation and co-ordination of a large number of recreational fishers. As a result, representatives argue that they are not yet sufficiently consulted in policy and management decision-making, although this is improving.

Perspectives on Adaptation in the Reef-based Tourism Industry

Our data suggest that the tourism industry shares many commonalities with the fishing industry. First, they are both

exposed to a range of climatic and non-climatic perturbations from which insight can be drawn about management and adaptation to climate change. Second, management of both sectors accounts for many types of disturbance; climate change is not considered separate. Third, representative stakeholders valued business planning and stewardship as key adaptation strategies, and considered networking and linking through representative organisations as beneficial for adaptive capacity (1b – *Reef Relief* and 2b – *Volatile Waters*).

In contrast to the fishing industry, participants did not consider permanent removal of effort/capacity nor migration/mobility as viable strategies for the reef-based tourism industry (contradicting 1b and 2b). Existing reef-based tourism hubs stretching along the GBR from north to south, including Cairns, Port Douglas, and the Whitsundays will likely remain the core centres for marine tourism regardless of the impacts of climate change. Therefore, financial management, diversification, and marketing to create resilient businesses and communities that benefit from but do not overly depend on reef-based tourism are critical.

Participants identified marketing and communication campaigns as central to effective adaptation (not explicitly reflected in the scenarios) first, to ensure that customer expectations shift alongside changes to marine and coastal ecosystems, and; second to ensure that the comparative advantage of the GBR relative to other regions and reefs around the world is recognised. These campaigns relate to the long-term and short-term reputation of the reef. For instance, since 2006 representative organisations have promoted the reef as “the best managed reef in the world.” In partnership with reef management agencies and scientists, they also disseminate up-to-date information packs globally, following surprise events such as cyclones and floods:

Every time something physically blows up here we just send it [the statistics] all back to our American and British staff to say: ‘Yes there was a cyclone. Yes this part of the reef has been severely damaged. But, it’s actually 1/20th of the entire reef size and we don’t go there anyway’ ... We work really closely with [the management agency] to make sure we’ve got that sort of messaging.

(Industry representative, March 2011)

This proactive marketing underpins other adaptation strategies including business planning and diversification at individual operator and industry level (scenarios 1b and 2b). At the industry level examples include diversifying into inter- and intra-state tourism and developing new tourist attractions like the ‘Great Eight’ to parallel the ‘Big Five’ in terrestrial wildlife tourism. At the individual operator level, perceived opportunities to diversify were often linked to stewardship practices, for instance eco-tourism, accreditation, and uptake

of green technologies. Reflecting the fishing industry discussion, participants perceived that tourism entrepreneurs and innovators – as those most likely to take risks and adapt through green technology and other strategies – were also most likely to remain profitable. However, the high turn-over of businesses in tourism and the challenge of achieving return on investment in an insecure global context mean that the level of capital investment needed to diversify is often prohibitive. Participants suggested that only a relatively small number of innovators could manage this risk and successfully leverage financial and technical support through their networks with government and representative industry associations.

Overall, recent experiences of composite perturbation suggest that while temporary, unexpected threats can be easily buffered and adapted to by individual operators, prolonged exposure to economic and climate risk are highly problematic for the industry.

Discussion: Responding to Scenarios in Adaptation Research

We developed scenarios to elicit diverse perspectives on climate change adaptation under a range of possible ecological and social impacts. Below, we discuss three key insights that influenced how stakeholders responded to the scenarios, and thus, their utility as a research tool. First, climate change impacts are still contested, so influencing how participants engage with representations of potential futures. Second, climate change impacts are perceived as relative, so scenarios for the GBR are not considered in isolation. Third, overall outcomes for people and industries are a culmination of vulnerabilities to climate change and other drivers. In some cases a climate change lens can strengthen and in other instances detract from wider debates on regional and national environment and development policy.

Our scenarios assume that anthropogenic climate change is happening but explore both a best-case and worst-case situation to accommodate for diverging perspectives on rates and impacts of change. Most stakeholder representatives accepted that change is happening and that adaptation is needed, regardless of attribution. But they differed in their emphasis on climate change as risk or opportunity, and some criticised the scenarios as being ‘overly’ negative. The scenarios posit that climate change introduces more risk than opportunity but that how this risk is managed is the key to creating opportunities. So opportunities are more likely to emerge from adaptation action than directly from climate change impacts. Research increasingly recognises that adaptation outcomes are a significant influence on people’s well-being (Eriksen and Brown 2011; Marino and Ribot 2012) and are often more important than direct impacts (Eide and

Heen 2002). Such opportunities are reflected in the contrast between the *Reef Relief* (1b) and *Paradise Perturbed* (1a) scenarios. In the former – supported by participants – effective adaptation can improve on current trends in environmental change. In the latter, adaptation limited by ecological, institutional and economic factors fails to mediate change in quality, composition, and distribution of reef and coastal habitat or decline in habitat-associated species and biodiversity. This latter scenario does not make judgements about the social acceptability of such change nor does it intend to reflect the status quo in GBR management. Instead, the contrast of limited and ideal adaptation aims to highlight the opportunity cost of not pursuing more ‘transformative’ adaptation policy (Park *et al.* 2012), acknowledging that it will create winners and losers within and outside of reef industries (Marino and Ribot 2012).

The alternative scenarios aimed to represent a reasonable amount of complexity by accounting for drivers external to the reef and its industries, such as run-off impacts. However, the storylines did focus solely on the GBR meaning that the primary point of reference to qualitatively evaluate the scenarios is the current state of the reef. Consequently, participants were somewhat uncomfortable considering limited adaptation scenarios because they purposefully reflected a worst-case situation as opposed to current practice. Scenario planning methods often emphasise a set of quality criteria for scenarios, for instance, whether they are relevant, plausible, clear, and challenging (Kahane 2012). To elicit a broader range of stakeholder perspectives on ecological and social change, our scenarios purposefully contrasted extreme situations in terms of climate change trends and potential adaptation. As a result, while *challenging*, the *relevance* of these scenarios for GBR stakeholders (as opposed to scientists) was sometimes questioned.

Discussion also revealed that the outcomes for reef industries were not only dependent on responses in the GBR region but also management and adaptation elsewhere, particularly in competing markets. The clearest illustration of this came when we asked participants about the World Heritage status of the GBR under the more extreme climate change scenarios. Even under more extreme climate change with limited adaptation (scenario 2a), participants argued that other regions would suffer more impacts than the GBR, which was buffered by its history of effective management, and would not lose its World Heritage status. Indeed, many of the opportunities identified by participants related to the GBR’s resilience and appeal relative to other destinations. For example, fisheries with reduced productivity might still increase in market share as other global fisheries collapsed. Similarly, tourism numbers could be maintained as other destinations suffered more extreme climate change impacts. This is supported by research suggesting that tourism is closely linked to perceptions of risk and impacts rather than real levels of risk or

the actual state of the environment (McClanahan and Cinner 2012). While other regions may fare worse, opportunities for GBR stakeholders can nevertheless be maximised by effective adaptation of the fishing and tourism industries through the strategies discussed above, such as business planning, marketing, and diversification.

Participants emphasised that climate change adaptation is viewed as an integral part of overall enterprise and ecosystem management not as a separate agenda. There is some concern among stakeholders that the political interest in climate change and the financing attached to it could detract from the fundamentals of coastal and marine resilience, described as biodiversity, sustainability, water quality, and coastal development. To this end, participants argued that climate change should be incorporated into these policy arenas, rather than representing the overarching policy issue. Many of the insights shared by participants related to experiences of adaptation to other drivers of change. Maintaining a broad agenda can ensure inclusion of stakeholders who remain uncertain about the risks of climate change but who want to engage in broader processes of building adaptive capacity. At the same time, our findings suggest that climate change research further strengthens arguments to pursue sustainability and deal with coastal development and catchment land-use.

Overall, participants were more able to relate to the best-case climate change scenarios than the more extreme scenarios. This is concerning considering the current emissions trajectories (Global Carbon Project 2010) but understandable given the uncertainty and differing perspectives around what society can achieve in the next 40 years. Regardless, both incremental (doing things better) and transformative (doing things differently) adaptation strategies were considered favourably. For instance, within the context of current fishing and reef-based tourism practices, participants discussed having the flexibility to move between heavily and lightly impacted sites following disturbance events, such as cyclones or bleaching. Participants also discussed strategies that move away from fishing and traditional reef-based tourism practices, such as skills training for fishers exiting the fishery, and even considered transformation of regional agricultural and coastal development policy.

Conclusion

Much of the literature on scenarios focuses on developing scenarios as the end point. Many studies conclude that involving stakeholders in the scenario development process can facilitate buy-in to complex environmental management and adaptation planning (Wollenberg *et al.* 2000; Tompkins *et al.* 2008; Cobb and Thompson 2012; Haward *et al.* 2012; Kahane 2012). Here, we developed comprehensive scenarios

as a research tool to elicit data on adaptation experiences and expectations rather than an end product (see Fenton and Beedon 2006 and Daw *et al.* 2012 for use of more simple scenarios to frame research data collection). The scenarios developed in conjunction with scientists conveyed the range and complexity of possible change to the GBR and its fishing and tourism industries under a best-case and worst-case climate change future. They elicited a diversity of responses from multiple stakeholders in the region that contributed new and interesting insights into how adaptation is perceived. Stakeholders emphasised the inseparability of climate and other drivers of change, the importance of relative impacts, experiences, and outcomes, and the opportunities available from strategies such as business planning and stewardship, which are not typically considered in adaptation research.

We endeavoured to develop qualitative scenarios that reflected the complexity of interactions that constitute environmental and social change in the GBR region under a changing climate. For instance, we incorporated the impacts of catchment land-use and coastal development on water quality and ecological adaptation of coastal habitats. However, in practical terms, it was difficult to communicate the full extent of these scenarios to stakeholders in a workshop and interview setting (see Turton *et al.* 2010). Further, the complexity of the scenarios and/or the difficulty of situating responses in a future ‘reality’ considerably different from the present, limited the relevance (Kahane 2012) of the scenarios for GBR stakeholders and, therefore, the extent to which participants were able/willing to discuss adaptation to extreme climate change. Many of the responses were couched in localised, compositional change to the reef where climate change impacts were commensurate with other economic and regulatory drivers of change. Other research suggests that decision-support tools, and by extension research tools, may be more effective where they minimise ‘cognitive complexity’ for the decision-maker (see Tompkins *et al.* 2008). However, this negates to some extent the power and appeal of scenarios, which allow scientists, stakeholders, decision-makers, and others to explore complex combinations of drivers, choices and outcomes. From our experience, finding novel ways to communicate scenarios as part of a research or management process, through visual and audio tools, would overcome this tension and enhance the potential of scenarios to deliver important and insightful research and management outcomes.

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