12.15 A Scenario Analysis of Climate Change and Ecosystem Services for the Great Barrier Reef

R Costanza, Portland State University, Portland, OR, USA
E Bohensky, Davies Laboratory, Aitkenvale, QLD, Australia
JRA Butler and I Bohnet, James Cook University, Cairns, QLD, Australia
A Delisle, James Cook University, Townsville, QLD, Australia
K Fabricius, Australian Institute of Marine Science, Townsville MC, QLD, Australia
M Gooch, James Cook University, Townsville, QLD, Australia
I Kubiszewski, Portland State University, Portland, OR, USA
G Lukacs, James Cook University, Townsville, QLD, Australia
P Pert, James Cook University, Cairns, QLD, Australia
E Wolanski, James Cook University, Townsville, QLD, Australia; Australian Institute of Marine Science, Townsville, QLD, Australia

Abstract

The extent to which nations and regions can actively shape the future or must passively respond to global forces is a topic of relevance to current discourses on climate change, ecosystems services, and human well-being. In Australia, climate change has been identified as the greatest threat to the ecological resilience of the Great Barrier Reef and the multiple ecosystem services it provides, but is exacerbated by regional and local pressures. In this chapter, we discuss previous applications of scenario analysis and describe a case study we undertook to explore how two key uncertainties may influence these threats and their impact on the Great Barrier Reef and adjacent catchment's ecosystem services in the future. These two uncertainties were whether (1) global development and (2) Australian development are defined and pursued primarily in terms of economic growth or broader concepts of human well-being and environmental sustainability, and, in turn, how climate change is managed and mitigated. We compared the implications of four scenarios for marine and terrestrial ecosystem services and human well-being. The results suggest that while regional actions can partially offset global inaction on climate change until about mid-century, there are probable threshold levels for marine ecosystems, beyond which the Great Barrier Reef will become a fundamentally different system by 2100 if climate change is not curtailed. Management that can respond to pressures at both global and regional scales will be needed to maintain the full range of ecosystem services. It is possible to maintain human well-being even while some ecosystem services decline, but only if regional management is strong. The future of the region depends largely on whether national and regional decision makers choose to be active future 'makers' or passive future 'takers' in responding to global drivers of change. The chapter concludes by discussing potential avenues for using these scenarios for further discussion and consensus building with the Great Barrier Reef region's stakeholders.

12.15.1 Introduction

Worldwide, alternative discourses surrounding climate adaptation and mitigation are establishing themselves, with much focus on the roles and responsibilities of nations (Doulton and Brown, 2009). In 2007, following a disastrous typhoon, Philippines President Gloria Macapagal-Arroyo remarked that:

> the world is divided into climate makers and climate takers. Climate makers are those responsible for large emissions of greenhouse gases that warm the globe. Climate takers are those who do not emit large amounts of greenhouse gas but nonetheless suffer the consequences of climate change because climate change is global. Climate makers are responsible for mitigating global warming, while climate takers must undertake adaptation measures (Office of the President, 2007).

A divided world of makers and takers was also envisaged nearly a decade earlier by Australian futurist Doug Cocks. His view diverges from Macapagal-Arroyo's, however, and invokes a greater degree of choice: Australia, he argued, could either be a 'future maker' actively engaged in shaping all aspects of the future, or be a 'future taker', passively responding to what comes its way (Cocks, 1999). This choice is implicit in the current debate in Australia about action on climate change (Christoff, 2010) and begs a critical question: To what extent can proactive national, regional, and local responses to climate change and other global drivers shape future outcomes, at least at these subglobal levels, when forces of global change are beyond national, regional, or local control? The significance of scale in understanding and negotiating global environmental change has been emphasized in the literature (Wilbanks and Kates, 1999; Lebel, 2005; and others), yet the challenges presented by these scale dynamics on the ground remain formidable.

In Australia, this question has particular relevance to the Great Barrier Reef (GBR), the world's largest coral reef ecosystem and an international, national, and local icon that is threatened by change at multiple scales. In September 2009, the Great Barrier Reef Marine Park Authority (GBRMPA) identified the following issues in order of priority as threatening the GBR's ecological resilience: climate change, continued declining water quality from catchment runoff, loss of coastal habitats from development, and impacts from commercial and traditional fishing of threatened species (GBRMPA, 2009). Increasing sea-surface temperatures due to global climate change have already led to regional-scale coral bleaching events on the GBR, and coral bleaching, coral mortality, and biodiversity depletion are predicted to continue, possibly with increased frequency in the coming decades (Preston and Jones, 2006; Hoegh-Guldberg et al., 2007). As in other marine ecosystems, these threats are interactive (Hughes et al., 2007). Although the GBRMPA introduced a major rezoning policy in 1998 to address the impact of overharvesting on the ecological resilience of the GBR (Olsson et al., 2008), declining water quality from agricultural runoff may also reduce the resilience of corals to climate change impacts (Wooldridge, 2009; Wooldridge and Done, 2009).

The threats to the GBR outlined above need to be managed through a multiple-scale, cross-agency, and cross-community approach, and the GBR itself needs to be conceptualized as a catchment-to-reef system. Currently, numerous agencies share responsibility for managing the GBR and catchment, but there is no unified institutional management arrangement for the region, an artifact of Australia's historical division of federal and state powers. Arguably, the institutional arrangements for the region have resulted in mismatches between governance and ecosystem processes, exemplified by management that has been largely sectoral, narrowly focused, and short term (Ferrier, 2007). Although there is great concern among GBR institutions about future uncertainty, and recognition of the need for longer term planning (GBRMPA, 1994; Johnson and Marshall, 2007; GBRMPA, 2009), ongoing and integrated strategic planning by these institutions has been limited.

Scenarios – alternative future visions – provide a mechanism for individual and collective consideration and articulation of perceptions and aspirations for the future, and the opportunities and risks that may be associated with particular decisions. Scenarios have been widely used elsewhere to illuminate the enabling conditions for and constraints on current and future management approaches and strategies (MA, 2005; *see* Chapter **12.14**), identify possible adaptations, and, ultimately, assist agencies to move from a position of 'taking' to 'making' desirable future change.

Scenario exercises have been conducted in the GBR region at a range of scales and for various purposes (Roebeling et al., 2005; Bohnet and Smith, 2007; Bohnet, 2008; Bohnet et al., 2008) and have contributed to an understanding of the implications of potential future change by a wide range of local and regional stakeholders. Yet to date, no comprehensive future analysis of the GBR region exists that is based on the downscaling of available global climate change projections and other aspects of global change, to enable exploration of how global change may influence and interact with regional and local responses.

To begin working toward such an exploration of the GBR's future, we conducted a scenario exercise that examined how key drivers of global climate change and its mitigation at the GBR scale might impact on ecosystem services and human well-being. In this chapter, we discuss the process and results of this exercise, implications for management, and potential avenues for using these scenarios further with a range of GBR stakeholders.

12.15.2 Methods

12.15.2.1 Scenario Planning and Analysis

'Scenario' is a term with multiple meanings. Scenario exercises vary in their objectives and hence in their characteristics (Biggs et al., 2007; *see* Chapter **12.14**). In this chapter, we define scenario analysis or scenario planning as a structured process of exploring and evaluating the future. Scenarios are essentially stories that consider how alternative futures, typically related to a particular focal issue (O'Brien, 2000), may unfold from combinations of highly influential and uncertain drivers, and their interactions with more certain driving forces.

Scenario planning differs from forecasting, projections, and predictions, in that it explores plausible rather than probable futures (Peterson et al., 2003). Although aspects of the future worlds depicted by scenarios may come to eventuate, these worlds are often best viewed as caricatures of reality from which we can learn.

Scenarios are best suited to exploring situations of high uncertainty and low controllability (Peterson et al., 2003); for example, climate change and global governance are largely beyond the control of a region such as the GBR. In these situations, scenarios can help to illuminate the consequences of these uncontrollable forces and to formulate robust responses locally. Importantly, scenarios can help to reveal policy and value changes that may be required and key branching points at which such changes can most affect outcomes (Gallopín, 2002).

Scenarios have been developed for a range of applications from global to local scales, including corporate strategy (Wack, 1985), political transition (Kahane, 1992), and community-based natural resource management (Wollenberg et al., 2000; Evans et al., 2006). **Table 1** shows a range of previous scenario planning exercises that have been carried out at the global, national, and, regional scales. In the following, we review some of these exercises, and also several exercises that have been carried out specifically for Australia. The Special Report on Emissions Scenarios (SRESs) and their implications for coastal systems are reviewed in Chapter **12.14**.

An interesting feature of all of these exercises is that their scenarios fall along a spectrum of 'quality of life' or human well-being and we have grouped the scenarios in this way in **Table 1**.

12.15.2.1.1 The great transition initiative

The Great Transition Initiative (GTI) is an ongoing effort with its beginnings in the 1990s (Gallopín et al., 1997). The scenarios have changed name and number over time, but the current set involves four major scenarios: fortress world, market forces, policy reform, and great transition (Raskin et al., 2002).

The fortress world scenario is a variant of a broader class of barbarization scenarios, in the hierarchy of the Global Scenario Group (Gallopín et al., 1997). Barbarization scenarios envision the grim possibility that the social, economic, and moral underpinnings of civilization deteriorate, as emerging problems overwhelm the coping capacity of both markets and policy reforms.

The market forces scenario is a story of a market-driven world in the twenty-first century in which demographic, economic, environmental, and technological trends unfold without major surprise relative to unfolding trends. Continuity, globalization, and convergence are key characteristics of world development – institutions gradually adjust without major ruptures, international economic integration proceeds apace, and the socioeconomic patterns of poor regions converge slowly toward the development model of the rich regions.

The policy reform scenario envisions the emergence of strong political will for taking harmonized and rapid action to ensure a successful transition to a more equitable and environmentally resilient future. It explores the requirements for simultaneously achieving social and environmental sustainability goals under high economic growth conditions similar to those of market forces.

The great transition scenario explores visionary solutions to the sustainability challenge, including new socioeconomic arrangements and fundamental changes in values. This scenario depicts a transition to a society that preserves natural systems, provides high levels of welfare through material sufficiency and equitable distribution, and enjoys a strong sense of local solidarity.

An interactive website allows users to visualize and explore the scenarios. The descriptions of these scenarios in the published books and websites are the most extensive of the scenario studies mentioned here, and probably the most extensive of any existing scenario exercise. The status and trends of over 40 variables are plotted for each scenario, including several variables related to ecosystem services (i.e., CO_2 emissions, water use, and forested area) and an overall quality of development index that is similar in structure to the Genuine Progress Indicator (GPI) and other indices of societal well-being.

Table 1 A selection of previous scenario planning exercises with the scenarios arranged in order of decreasing quality of life

	Overall quality of life of the scenario			
Scenario exercise	*Most desirable (highest quality of life)*	*Intermediate (based on cooperation)*	*Intermediate (based on individuals and markets)*	*Least desirable (lowest quality of life)*
South Africa (Mont Fleur) 1992	Flight of the flamingos	Icarus	Lame duck	Ostrich
Costanza (2000)	Ecotopia	Big government	Star Trek	Mad Max
Special Report on Emissions Scenarios (SRES)	'B2 world' (local stewardship)	'B1 world' (global sustainability)	'A1 world' (world markets)	'A2 world' (national enterprise)
Millennium Assessment	Adapting mosaic	Global orchestration	TechnoGarden	Order from strength
Great transition initiative	Great transition	Policy reform	Market forces	Fortress world
New Zealand	Independent Aotearoa	Living on no. 8 wire	New frontiers	Fruits for a few
Great Barrier Reef	Best of both worlds	Treading water	Free riding	Trashing the commons

12.15.2.1.2 The Millennium Ecosystem Assessment

The Millennium Ecosystem Assessment (MA) scenarios used the two axes of global connectedness (from highly connected to disconnected) and approaches to ecosystem services management (from reactive to proactive) to evaluate the future status of ecosystem services and human well-being (MA, 2005). The two globally connected scenarios were as follows: (1) TechnoGarden, which envisions a globally connected world relying strongly on environmentally sound technology, using highly managed, often engineered, ecosystems to deliver ecosystem services, and taking a proactive approach to the management of ecosystems in an effort to avoid problems before they emerge; and (2) global orchestration, which envisions a globally connected society that focuses on global trade and economic liberalization and takes a reactive approach to ecosystem problems, but that also takes strong steps to reduce poverty and inequality and to invest in public goods such as infrastructure and education. The two regionalized and disconnected scenarios were as follows: (3) order from strength, which envisions a regionalized and fragmented world, concerned with security and protection, emphasizing primarily regional markets, paying little attention to public goods, and taking a reactive approach to ecosystem problems; and (4) adapting mosaic, which envisions that regional watershed-scale ecosystems are the focus of political and economic activity. Local institutions are strengthened, local ecosystem management strategies are common, and societies develop a strongly proactive approach to the management of ecosystems.

All but the order from strength scenarios showed that significant changes in policy can partially mitigate the negative consequences of growing pressures on ecosystems, but that the changes required are large and not currently underway. Some ecosystem services and well-being improve in these three scenarios, but the largest increases across all services are in the adapting mosaic scenario. Climate change is envisioned to affect all of the scenarios, but to varying degrees based on policies to mitigate it.

12.15.2.1.3 Four future scenarios for New Zealand: Work in progress

Researchers in New Zealand and an advisory group created four scenarios along the two axes of resources (depleted or plenty) and identity (individual or cohesion) (Landcare Research Scenarios Working Group, 2007). The two plentiful resource scenarios were titled: (1) fruits for a few, where a focus on individual identity leads to tight resource control, with benefits held in the private sector and costs spread on the wider public; and (2) independent Aotearoa, where a focus on social cohesion leads to a dynamic cohesive society, seeing itself as a global citizen. While outward looking, it remains critical and is confident enough to be distinctly different as a South Pacific nation. The two depleted resource scenarios are as follows: (3) new frontiers, where the focus on individualistic values, defined by visible financial status, rather than by family and cultural traditions, leads to a fragmented society where the losers feel there is unfairness whereas the winners enjoy their freedom as consumers; and (4) living on no. 8 wire, where a focus on social cohesion leads the government to intervene to manage trade offs between economic gain and environmental degradation, to increase trade barriers, and to promote equitable redistribution.

Like the great transition initiative and MA scenarios, the New Zealand scenarios were described in great detail, including their impacts on ecosystem services and quality of life. This exercise included a survey of attitudes toward the scenarios. A group of participants was asked in a game-playing exercise about which scenario they thought New Zealand was presently in, which scenario it was headed toward, and which scenario they would most like to see realized. The results were quite dramatic. Most participants thought that New Zealand was currently in the fruits for a few scenarios and that it was headed toward the new frontiers scenario, but that they overwhelmingly preferred the independent Aotearoa scenario, where quality of life was enhanced by social cohesion and resource management.

12.15.2.1.4 Australian scenarios

Futurist Doug Cocks invoked a fundamental choice for Australia: Would it be a future 'maker' or a future 'taker'? (Cocks, 1999). Cocks developed five big-picture scenarios for the country, three of which he considered positive pathways that could all realistically achieve the goal of high quality of life for most present and future Australians, without abandoning the current democratic, capitalist society with a mixed economy. One way to do this is 'going for growth', whereby very high per capita income will create the money needed to protect the environment and to eliminate poverty. An alternative pathway is 'conservative development', which embraces interventionist industry policies derived from 'new growth' thinking and faith in the capacity of government to contribute strongly to solving the problems of low economic growth, unacceptable levels of life opportunities, and poor environmental quality through a tax-and-spend strategy. 'Post-materialism', by contrast, involves a change in the deep structure of society, via the distribution and use of decision-making power in organizations, institutions, and social groupings. New regional governments would increasingly edge out state governments, and worker ownership and industrial democracy would ensure corporate social responsibility. However, two less desirable pathways could also unfold: 'struggling to cope' describes what happens when a complex, path-dependent society such as Australia encounters multiple crises in a short duration of time. In 'muddling down', quality of life declines slowly at the hands of reactive governments which act only in response to extreme political pressure, or gridlocked governments which are hostages to major interest groups.

In 2005, the Business Council of Australia also developed scenarios that focused on relationships between Australia's diverse populations and with the rest of the world (BCA, 2004). Using the metaphor of the ocean, scenarios were constructed around both endogenous drivers of continued growth and dominance of Sydney and the aging of Australia's population, and exogenous drivers of continued global political dominance of the United States, and the ability of technology to remove some of the constraints arising from the great distance between Australia and its major trading partners. These drivers act together to create three major challenges, or uncertainties in Australia's future, related to social cohesion and shared values between generations and between different cultural, ethnic, and socioeconomic groups, and the stability of the Asia-Pacific region. The 'riding the wave' scenario explores the possibility of a breakdown in trust between Australian people and institutions, 'stormy seas' posits reduced security in the Asia-Pacific region, and 'changing the crew' depicts intergenerational tensions within Australia but increased economic and cultural relatedness between the younger generation and the world outside.

The Energy Futures Forum brought together a wide group of representatives from energy companies, mining companies, environmental groups, banks, and unions to develop qualitative and quantitative scenarios to identify a range of plausible options for Australia's energy sector (Energy Futures Forum, 2006). Among the nine Energy Futures Forum scenario narratives (Delaney, 2006), environmental crisis is most apparent in the 'day after tomorrow' scenario, with the narrative describing water wars in major rivers around the world and conflict over access to fisheries, and in Australia, coastal inundation and coral bleaching in the GBR, with a subsequent loss of tourism expected. In the 'clean green down under' scenario, Australia by 2050 has reduced its greenhouse gas emissions to 80% below 1990 levels in response to several major climate events in the early 2010s that bring about the end of global opposition to addressing climate change. 'Power to the people' reveals as to how new farming practices (i.e., aquaculture and organic crops) develop in Australia in response to ecological change, such as more extreme climate patterns, further outbreaks of diseases, and the need to curtail water consumption. In 'centralized failure', climate change and high adaptation costs bring smaller towns and even Canberra to the point of collapse, requiring the capital to be relocated to a less-drought-prone location.

The Avon River Basin scenario project (O'Connor et al., 2004) in the Western Australia Wheatbelt sought to identify critical issues and drivers of change relevant to community efforts to improve the regional prospects for present and future generations of the basin to 2050. The process, convened by a Wheatbelt resident and landholder, identified 22 critical drivers of change, which included land, infrastructure, alternate fuels, education, plant industries, and demographics. In a ranking exercise, project participants identified access to new markets and whether environmental problems (namely salinity) improve or degrade as the most uncertain and important drivers. In 'grain and drain', salinity damages infrastructure, elevating repair costs, while climate change (of 3–6 °C across the basin) and rising sea levels encourage some Perth residents to settle in the Avon River Basin. In 'saline growth', similar temperature increases are experienced but society responds proactively through social and economic diversification. The 'landcare bounty' and 'harmony with prosperity' scenarios describe slower environmental decline, with temperatures increasing only 1–2 °C, and focus respectively on sustainable land use and developing new markets.

Scenarios conducted for the GBR include the World Wildlife Fund for Nature (WWF) Australia and the Queensland Tourism Industry Council's scenarios based on the SRES of the Intergovernmental Panel for Climate Change (IPCC). The WWF approach to scenarios was to focus on what they considered to be credible eventualities in order to plan responses, rather than to explore uncertainties. They developed successive storylines for Australia, the GBR, reef-based industries (tourism and fisheries), and other industries driving the regional economies, culminating in numerical projections for each scenario for tourism and fisheries and the economic impact on five GBR regions (Hoegh-Guldberg and Hoegh-Guldberg, 2008).

Another scenarios initiative for the GBR was undertaken by Commonwealth Scientific and Industrial Research Organisation (CSIRO) (Bohnet et al., 2008). The scenarios were developed for the catchment-to-reef system based on a literature review and interviews with more than 40 regional leaders from academia, government, nongovernmental organizations, and industry. These scenarios focused on the two key uncertainties that were most frequently mentioned in the interviews: the nature and timing of a climate change event (whether a major climate event, such as a category 5 cyclone, occurs within the next 5 years or is delayed until later) and the nature of regional governance (whether driven mainly by environmental concerns in the region or by the global economy). The plausibility of the scenarios and their implications for research and knowledge, environmental regulation, infrastructure and planning, industry, production systems, and Indigenous livelihoods were explored with key GBR stakeholders, including policymakers, natural resource managers, traditional owners, science advisors, and industry representatives, in a 1-day workshop.

12.15.2.2 GBR Study Site

The GBR (**Figure 1**) spans 2300 km of Australia's northeast coast and covers an area of approximately 348 000 km^2. Supporting a diversity of marine life, it has been protected as a marine park since 1975 and as a world heritage area since 1981. The contribution of the GBR to the Australian economy was estimated to be AUD5.4 billion per annum (p.a.) in 2006–07 (Access Economics, 2008) or 4.7% to Australia's gross domestic product (GDP) in 2007–08 (Oxford Economics, 2009). This consisted mostly of tourism (AUD6 billion p.a.), followed by recreational (AUD623 million p.a.) and commercial fishing (AUD251 million p.a.), which together employ approximately 66 000 people. Shipping activity through the GBR is a vital link in the production chain for many industries and services in regional centers. The GBR has high cultural value for Indigenous Australians, internationally important iconic and scientific value (GBRMPA, 2009), and is part of the Australian national identity (Young and Temperton, 2008).

The adjacent catchment area (426 000 km^2), covering about 22% of the state of Queensland, supports some of the most diverse and treasured landscapes on the Australian continent, including the tropical rainforests of the Wet Tropics World Heritage Area, drier tropical and subtropical savannahs, mountain ranges, and coastal plains. The main land uses include cattle grazing (about 75% of the catchment area), natural forests, production forestry, intensive agriculture, cropping, sugarcane cultivation, horticulture, mining, and urban areas. The current population of the catchments is approximately 1.12 million and is expected to grow to 1.58 million by 2026 (OESR, 2008), fueled largely by mining and industrial activity.

Management and protection of natural resources in the marine park are the responsibility of the federal agency GBRMPA together with the Queensland Government's Department of Environment and Resource Management and Queensland Primary Industry and Fisheries. The GBR catchment is primarily the responsibility of the Queensland Government. Notably, the Australian Government funds seven regional Natural Resource Management (NRM)

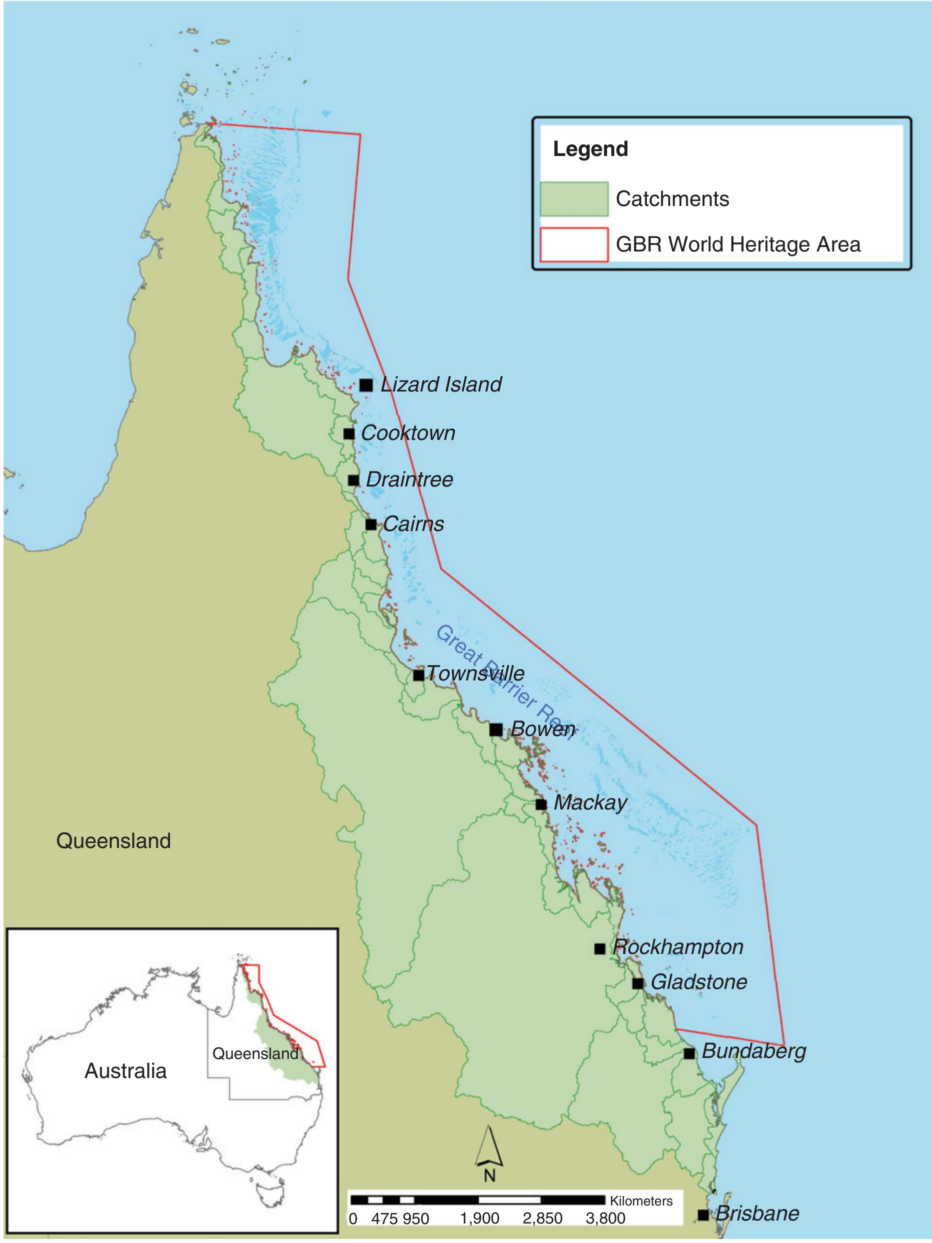

Figure 1 Location of the Great Barrier Reef region.

organizations to support community-based initiatives within the GBR catchment. Response to climate change affecting the marine park is managed by the GBRMPA and broader aspects of climate change by the Australian Department of Climate Change. Since 2003, water quality has been addressed by the Reef Water Quality Protection Plan (Reef Plan) (Australian Government and Queensland Government, 2003) and Reef Rescue (Australian Labour Party, 2007).

12.15.2.3 Development of GBR Scenarios

Scenarios for the GBR region were developed during 3 days of a 2-week workshop in October 2009 attended by scientists and representatives from the GBRMPA and the Queensland Government to discuss an approach for identifying, valuing, and managing ecosystem services in the GBR and adjacent catchments. Scenarios were developed by a team of local and international biophysical and social scientists from research and government institutions (the authors of this chapter) to better understand key uncertainties about the future that may lead to trade offs in the quantity, quality, and flows of ecosystem services, and implications for human well-being (Figure 2). We were interested in the drivers of climate change at the global scale and of mitigation at national, regional, and local scales, which we see as essentially stemming from the same uncertainty: the underlying worldviews and values related to societal development. Thus, scenarios focused on this uncertainty rather than on climate change projections themselves.

We evaluated the scenarios in terms of outcomes for marine and terrestrial ecosystems, as measured by coral cover and land

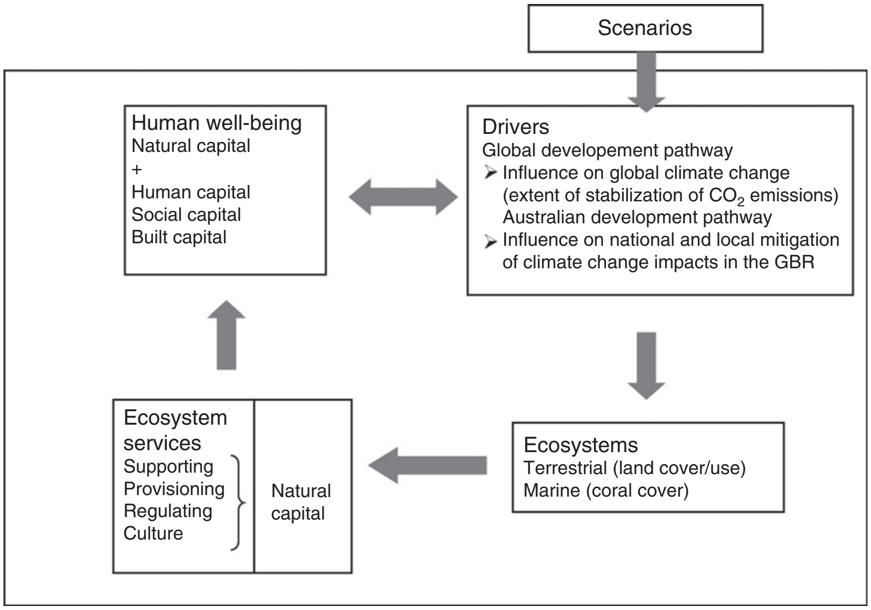

Figure 2 Conceptual framework for analysis. Scenarios were used to explore two key drivers of change: the global development pathway, which influences global climate change, and the Australian development pathway, which influences climate mitigation at the Great Barrier Reef (GBR) scale, and how these might impact on terrestrial and marine ecosystems in the GBR, ecosystem services and human well-being. Natural capital comprises four categories of ecosystem services (MA, 2005), which together with human, social, and built capitals contributes to human well-being.

cover/use, respectively. We then evaluated provisioning, regulating, supporting, and cultural services provided by these ecosystems (MA, 2005) and human well-being. We translated ecosystem services and human well-being into 'capitals', or stocks, with the potential to yield a flow of benefits (Costanza and Daly, 1992; Abel et al., 2006), as we were interested in the potential and adaptive capacity as well as the current states of biophysical and social system components, and because this allows both conceptual and quantitative comparison of components. Hence, we treated ecosystem services as natural capital and human well-being as the sum of natural, human, social, and built capitals.

As discussed above, we first reviewed other global, national, and regional scenario exercises to determine if they could be used or modified. However, none of the existing scenario exercises was completely aligned with our objectives. Hoegh-Guldberg and Hoegh-Guldberg (2008) considered climate change projections for the GBR World Heritage Area and selected industries only, but without developing narratives that explored implications and feedbacks. Bohnet et al. (2008) explored narratives of climate change in combination with governance and focused on the catchment and reef, but these were not adequately specific in their definition of climate events or global economic drivers.

We followed a common scenario-planning approach of developing four scenarios around two axes of uncertainty (Wack, 1985; MA, 2005). We chose the year 2100 as the endpoint for our scenarios to explore societal responses to climate change over a longer period and to retain consistency with the timeline of projections in the IPCC Fourth Assessment Report.

12.15.2.3.1 Axis 1: Empty world/full world – globe

Our first axis depicts two pathways for global development. One, the mainstream model of development, is based on a number of assumptions created during a period when the world was still relatively empty of humans and their built infrastructure. In this 'empty world' context, built capital was the limiting factor, whereas natural, human, and social capitals were often abundant (Costanza, 2008). During this period, environmental and social 'externalities' were assumed to be relatively small and irrelevant, the economy was seen to consist of only marketed goods and services, and it was desirable to increase production and consumption of these. In this context, the use of GDP as a primary measure of human well-being, and one which could be compared across nations, became a logical outcome.

The second pathway is that of the dramatically different 'full world', now dominated by humans and their built capital. An alternative model of development reconceptualizes the nature and purpose of the economy, with its primary goal to sustainably improve human well-being and quality of life. Material consumption is merely means to that end, not ends in themselves. Material consumption in excess of basic needs can actually reduce physical and psychological well-being, while natural, human, and social capital are now the limiting factors to sustainable human well-being in many countries. In this context, the GPI is a more appropriate measure of well-being. GPI accounts for both positive and negative components of marketed economic activity, adding in estimates of the value of nonmarketed goods and services provided by natural, human, and social capitals, and adjusts for income distribution effects. Although it is by no means a complete representation of the well-being of nations, GPI is a much more holistic measure than GDP (Talberth et al., 2007).

These two development pathways yield two options for global climate change. The first option follows the IPCC's SRES A1 scenario storyline (Nakicenovic and Swart, 2000; *see* Chapter 12.14), which describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. In this scenario, CO_2 is projected to reach 850 ppm and mean surface air temperatures to increase by at least 3 °C by 2100 (IPCC, 2007). Although there is uncertainty associated with these projections, they are based on the best-available understanding, and as such are the best present estimates of global climate change impacts on the GBR.

The second option is that an international climate agreement enables CO_2 levels to return to 350 ppm, representing a 50–80% reduction in 1990 levels, and temperatures to not to increase by more than 2 °C, by 2100. This is the widely supported target for CO_2 as the upper limit considered necessary for sustaining a planet "similar to the one on which civilization developed and to which life on earth is adapted" (Hansen et al., 2008), but climate policies to achieve this target have not yet been accounted for in the SRES scenarios (IPCC, 2007).

12.15.2.3.2 Axis 2: Empty world/full world – Australia

Our second axis reflects the degree to which Australia's pathway of development follows the 'empty world' or the 'full world' and influences how regional and local pressures on the GBR are mitigated.

Australia may or may not conform to the given global development pathway. Throughout its history, it has displayed a unique brand of independence due in part to its geographic isolation, now being rapidly overcome by the close links it is forging with a global economy, politics, and culture (James, 2007; Stevenson, 2007). Australia's future very much depends on how it defines, and sustains, itself as a nation in a relatively remote but highly diverse, rapidly changing corner of the world (Gray and Lawrence, 2001; Cork and Delaney, 2005).

Resource management in Australia has been historically dominated by the belief that "economic development is a good thing" (Cocks, 1999), but some longstanding traditions, such as agricultural land use, are dissolving due to changing perceptions as well as global contexts (Dunlop et al., 2002; Christoff, 2010). Australia may continue on its historical trajectory or it can move toward broader concepts of welfare that include ecosystem services and human well-being. Although the idea that alternative measures are needed to evaluate and make regional comparisons of well-being is gaining ground globally (MA, 2003) and in some nations (Landcare Research Scenarios Working Group, 2007), in Australia and the GBR, a paradigm that underpins such measures and their application in management and governance is not clearly evident at present. While such a choice lies mainly in the hands of national government, there is room for regional decision makers to influence this choice on the basis that the GBR is an irreplaceable national as well as global asset.

12.15.2.3.3 Combining two uncertainties

Four scenarios were developed and named as follows (Figure 3):

1. *Trashing the commons*. Both the world and Australia follow an empty world path, and climate emissions reach 850 ppm by 2100.
2. *Treading water*. The world follows an empty world path, and climate emissions reach 850 ppm by 2100, but Australia follows a full world path.
3. *Free riders*. The world follows a full world path, and climate emissions reduce to 350 ppm by 2100, but Australia follows an empty world path.
4. *Best of both worlds*. Both the world and Australia follow a full world path, and climate emissions reduce to 350 ppm by 2100.

12.15.2.4 Evaluation of Implications for Marine and Terrestrial Ecosystems

To assess the outcomes of the scenarios for marine and terrestrial ecosystems, we modeled future coral cover and land cover/use.

12.15.2.4.1 Coral cover

Coral cover was estimated to the year 2100 using the HOME ecohydrology model (Wolanski et al., 2004; Wolanski and

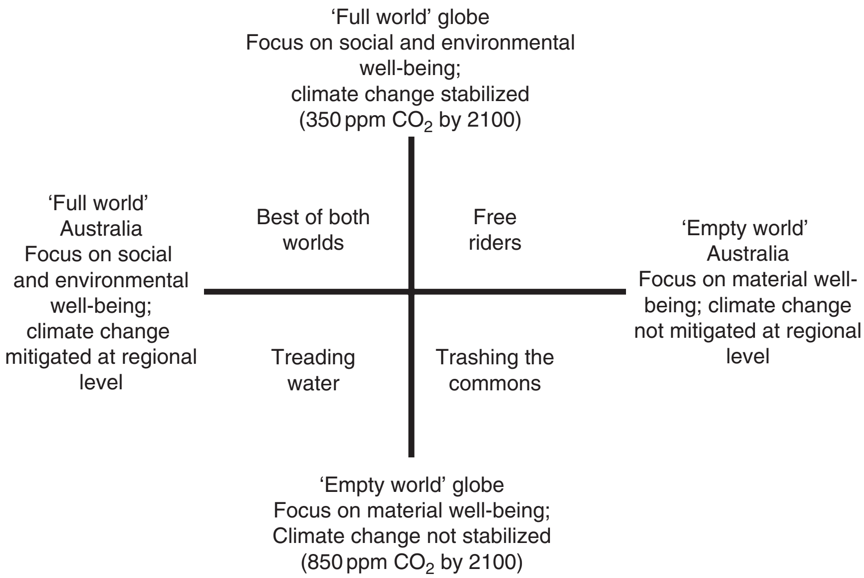

Figure 3 Four scenarios were developed from combinations of alternative development pathways for the world and for Australia.

De'ath, 2005). The model represents the average coral cover of 261 reefs in the GBR between Bowen and Lizard Island, with the ecology determined by herbivorous fish, algae, corals, and crown-of-thorns starfish (COTS) (*Acanthaster planci*), a coral predator which can form very large numbers, leading to outbreaks. The ecosystem is forced by (1) riverine fine sediment, (2) nutrients and turbidity increasing as a result of land use and transient river floods, (3) occasional tropical cyclones, and (4) bleaching events in summer from climate change (warming and ocean acidification).

We note several caveats in interpreting the HOME model which may make these predictions optimistic, namely:

1. The model does not include ocean acidification. Although it has slowed down coral growth (De'ath et al., 2009), ignoring acidification may be justified in scenarios in which CO_2 remains at 350 ppm.
2. It assumes that rainfall and the frequency and intensity of floods and cyclones will in the future remain the same as in the period 1969–2002 (for which data are available). Coral cover could be less than predicted if flood or cyclone frequency and/or intensity increases.
3. It assumes no change in the future in the wind field during coral mass spawning (i.e., the 1969–2002 variability remains unchanged); this controls the connectivity between the reefs and the resilience of coral reefs. Data are unavailable to test this hypothesis.
4. In the model, the coral death rate from bleaching is that experienced in the two GBR coral mass bleaching events during the past 10 years. This mortality was much less than that in other places such as the Seychelles in the 1998 global coral-bleaching event.
5. Each reef is given the same weight when calculating the average.

12.15.2.4.2 Land cover/use

A base map was developed for the GBR catchment from a series of data sets (QEPA, 2005; QDNRW, 2006a, 2006b, Witte et al., 2006). To reduce complexity in the map, related land covers and uses were combined; the resulting base map for the GBR catchment contains 14 categories, which were appended to a map of coral cover (**Figure 4**). Land use and remnant vegetation cover as at 2003 in the GBR catchment was mapped to provide the baseline for developing projections for the GBR catchment in 2100. Local knowledge of the GBR catchment among the scenario development team informed the development of the projections, as an analysis based on time-series data for terrestrial ecosystems was beyond the scope of this exercise. Simple deterministic rules and assumptions for converting natural areas and agricultural land to more intensive uses were developed within the group and through expert opinion. The land cover/use classes were grouped into four categories (cover types) which included natural terrestrial ecosystems, coastal ecosystems, marine ecosystems, and agricultural/urban areas.

12.15.2.5 Indicator Selection

Increasing emphasis is being placed on developing quality-of-life indicators to reflect improvements in the "…quality of human life while living within the carrying capacity of the supporting ecosystems" (Costanza et al., 2009). These have direct relevance to both individuals and societies as they reflect concerns about where to live and how to live (Diener and Suh, 1997). Whether an individual has the capacity to change their personal circumstances depends on the prevailing political, cultural, and social norms relating to resource access, together with an individual's class, gender, ethnicity, age, and religion (Ostrom, 1999). In this exercise, we chose quality-of-life indicators to help make decisions about which scenario would be preferable and why.

In studies that measure well-being, two choices need to be made: one relates to the selection of key indicators while the other considers the relative weights of each (Larson, 2009). During the workshop, expert judgment from participants informed the selection of indicators; however, no attempt was made to assign weights. In most cases, the selection of indicators and their weights is chosen according to expert judgment. In other research, Larson (2009) suggested that stakeholders be invited to weight possible indicators according to their priorities and that these weightings could help in communicating stakeholders' priorities to policymakers (Larson, 2009).

The indicators we selected sit within human, social, built, and natural capitals.

12.15.2.5.1 Natural capital

Natural capital consists of four categories of ecosystem services (MA, 2003) provided by marine and terrestrial ecosystems: (1) provisioning services, or tangible benefits, obtained from ecosystems such as water, food, timber, and minerals; (2) regulating services that regulate ecosystem processes such as climate, water quality, and air; (3) supporting services, which include processes such as soil formation, photosynthesis, and nutrient cycling; and (4) cultural services that provide recreational, aesthetic, or spiritual benefits. Using expert opinion among workshop participants, qualitative changes in the conditions of the services provided by terrestrial and marine ecosystems were projected in the four scenarios.

12.15.2.5.2 Human capital

The human capital indicators considered were health, education, professional skills, job security, and population. Health includes access to clean air and water, sufficient nutritious food, feeling well, access to health-care facilities, work/life balance, and mental health (MA, 2003). We also considered health issues that result from increasing global temperatures, such as mosquito-borne diseases, which could become more widespread in the region (Bryan et al., 1996). However, due to time constraints, we did not consider a whole range of potential health problems associated with climate change including human responses to increased daily temperatures (McMichael et al., 2006).

The education indicator is the quality and interest in general education at all levels. We included professional skills as a separate indicator, using the rationale that in some scenarios, general education would be less valued than professional skills developed in the workplace which would result in higher personal income, and possibly greater job security. Job security implies that workers are shielded from fluctuating labor markets and compensated for geographic mobility, training, and other costs associated with employment (Allard, 2005). Population is another important indicator as population is expected to drive each of the other human capital indicators;

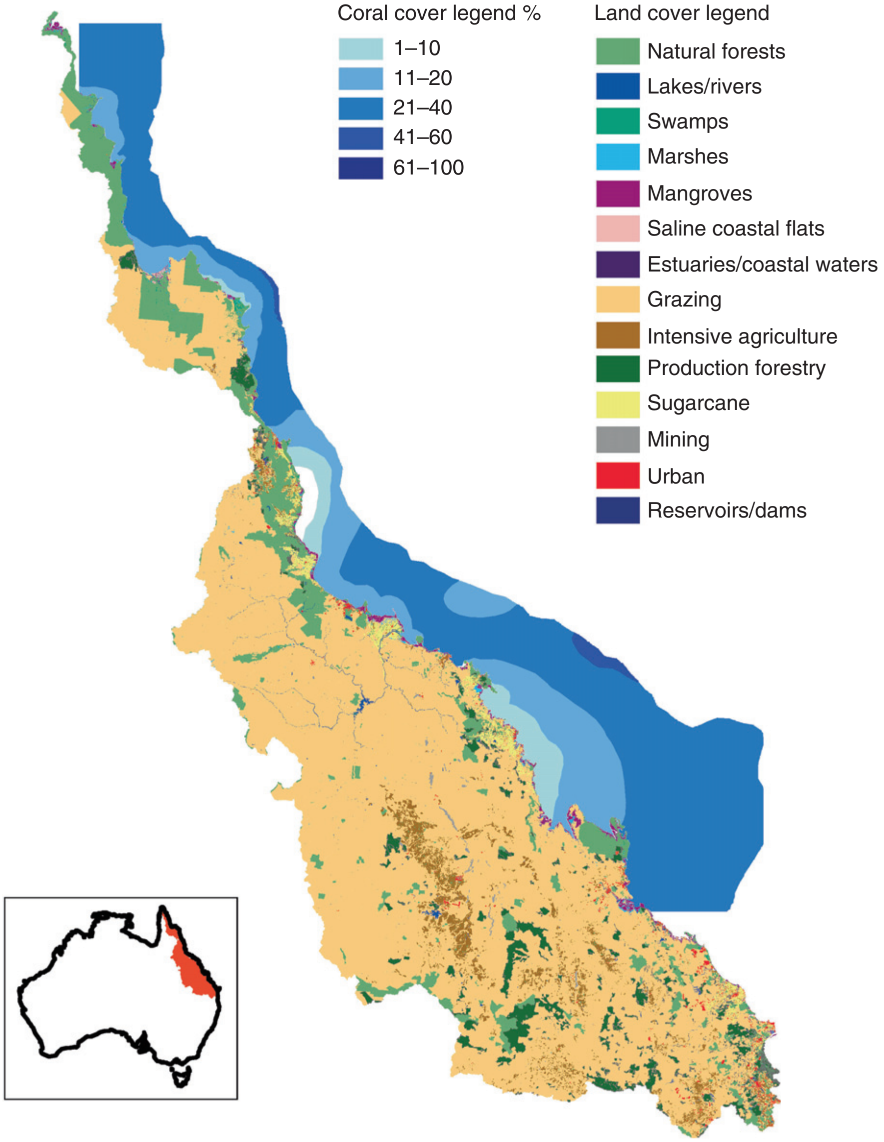

Figure 4 Land cover/use in the GBR catchment and coral cover. Land cover/use data are from QEPA (Queensland Environmental Protection Agency), 2005. Survey and mapping of pre clear and 2003 remnant vegetation communities and regional ecosystems of Queensland, version 5.0 (December 2005). Digital vector data. The State of Queensland, Queensland Herbarium, Environmental Protection Agency, Brisbane; QDNRW (Queensland Department of Natural Resources and Water), 2006a. Land Use (2004) in the Burdekin River Catchment, Queensland. Digital vector data by catchment. The State of Queensland, Department of Natural Resources and Water, Brisbane; QDNRW (Queensland Department of Natural Resources and Water), 2006b. Land Use (2004) in the Johnstone River Catchment, Queensland. Digital vector data by catchment. The State of Queensland, Department of Natural Resources and Water, Brisbane; Witte, C., van den Berg, D., Rowland, T., O'Donnell, T., Denham, R., Pitt, G., Simpson, J., 2006. Mapping land use in Queensland – Technical Report on the 1999 Land Use Map for Queensland, Department of Natural Resources, Mines and Water, Brisbane.

in this analysis, we focused only on numbers, not on structure. Furthermore, population projections for the GBR region are not readily available beyond 2050 (OESR, 2008). The effect of climate change might lead to an influx of climate change refugees (Garnaut, 2008). However, even estimating numbers of refugees only is a complex task, as we need to account for both the capacity of people to move and the legal frameworks of potential host countries (Garnaut, 2008).

12.15.2.5.3 Social capital

For social capital, we identified equity, participatory democracy, social networks, culture, and institutional arrangements as key indicators. Equity, meaning the fair distribution of rewards and resources (Leventhal, 1980), would vary in each scenario, according to prevailing local and global commitments to social justice. We largely equated participation with rates of volunteerism (Putnam, 2000). Networks and social ties are essential components of social capital, generated when individuals cooperate for mutual benefit (Putnam, 1993). Networks would comprise both communities of interest (including online communities) and communities of place. Culture was identified as a key indicator to represent expressions and celebrations of cultural diversity including Indigenous culture. The culture indicator also encapsulates a person's sense of belonging and identity.

Within the social capital domain, security is a key driver for decision making related to climate refugees in the GBR region. This indicator is important on two levels: first, in terms of personal and group tensions among different refugees and locals and, second, the impact of erratic weather patterns on human safety and well-being. Finally, we included institutions to envision the impact of various institutional arrangements for each scenario.

12.15.2.5.4 Built capital

Built capital includes infrastructure, equipment, and technological improvements (Nelson et al., 2007). We divided the built capital domain into quantity and quality measures. Our indicator for quantity included infrastructure and equipment required in each scenario, taking into consideration population pressures due to climate refugees and likely prevailing population policies. The indicator for quality assessed the properties of this built capital in terms of ecological footprint – methods of resource extraction (either extractive or more restorative methods). We also considered the quality of new technology in terms of its ecological footprint.

Each indicator of natural, human, social, and built capitals was given equal weight, as we lacked appropriate information, such as stakeholder rankings, which could allow weights to be assigned.

12.15.3 Results

12.15.3.1 Scenario Narratives

We developed narratives that described how each of the four scenarios would unfold (**Table 1**). Key scenario characteristics are presented in summary form in **Table 2**. Impacts of the key drivers on supporting, provisioning, regulating, and cultural ecosystem services provided by terrestrial and marine ecosystems for the four scenarios are summarized in **Table 3**.

12.15.3.2 Implications for Marine and Terrestrial Ecosystems

12.15.3.2.1 Coral cover projections

The time-series plot of the predicted average coral cover on 261 reefs between Bowen and Lizard Island for the four scenarios is shown in **Figure 5**.

The scenarios depict four options for coral cover in the GBR by 2100:

1. if global climate change is managed and mitigated through regional-scale catchment management, coral cover will be similar in 2100 to what it is now (best of both worlds);
2. if global climate change is not managed, but mitigated at a regional scale, there will be a very minimal level of coral cover (treading water);
3. if global climate change is managed but not mitigated at a regional scale, there will be an intermediate level of coral cover (free riders); and
4. if global climate change is neither managed nor mitigated, there will be no coral cover (trashing the commons).

What we can also observe is a ‘flip’ at about mid-century, where the trajectory of coral cover in the treading water scenario is completely altered and it begins to decline from near-present levels. In interpreting the projections, the following model assumptions need to be borne in mind.

While corals will bleach more often from global warming, the resulting mortality rate is assumed small (i.e., based on GBR historical data). The model further assumes that mortality from bleaching in scenarios with 2 °C warming will not be greater than observed in 1998 and 2002 (+0.7 °C warming), events that resulted in ~5% death of existing corals each time. Thus, the model results rely on the assumption that corals will gradually adapt to warming waters and remain insensitive to ocean acidification. If mortality from coral bleaching remained at 5% every 4 years as the model assumes, a reef may still sustain some coral cover as coral cover can increase by 1–2% per year, if crown-of-thorns outbreaks become infrequent. However, there is presently no evidence for corals adapting to warming waters.

Management of land use will bring some life back to inshore coral reefs; this increases the average coral cover even if coral cover of offshore reefs decreases. Increasing coral cover up until 2050 in the best of both worlds and treading water scenarios assumes that water quality will be greatly improved such that outbreaks of COTS – presently the greatest source of coral mortality – will become rare.

The initial increase in average coral cover in the treading water scenario is due to improvement of inshore reefs until ultimately bleaching decreases cover of all reefs by 2100. This assumes that offshore reefs decline all the time, inshore reefs increase to reach a maximum by 2050, and all reefs are in decline from 2050 to 2100 as they are affected by frequent bleaching from increased temperatures between 2050 and 2100.

Coral cover would also be lower than predicted by the HOME model in the trashing the commons and treading water scenarios if acidification is taken into account, or if the frequency and/or intensity of cyclones and floods in the GBR increase, as some climate models predict.

12.15.3.2.2 Land cover/use

Changes in the extent of terrestrial and marine ecosystems in 2100 relative to the present are summarized for each of the four scenarios (**Table 4**). The main trends are an intensification of current agricultural and urban land use in trashing the commons and free riders, accompanied by a decline in coastal and marine ecosystems, grazing and production forestry. Diversification into a mix of land uses in treading water and best of both worlds allows the extent of some coastal and marine ecosystems to remain at or return to present levels, although a number of ecosystem types continue to decline in treading water.

12.15.3.3 Implications for four capitals

Change in the four capitals (natural, social, human, and built), which collectively comprise human well-being, and in components of these capitals that comprise the economic subset of overall well-being in the four scenarios, is shown in **Table 6**. Change in natural capital was calculated as the average change in the condition of both terrestrial and marine ecosystem services that is outlined in more detail in **Table 5**. Arrows were used to indicate an increase or decrease in the capitals.

A summary well-being indicator was created by summing the arrows for the four scenarios. This indicator showed that overall well-being was lowest within trashing the commons, followed

Table 2 GBR scenario narratives

Trashing the commons	*Free riders*
Australia and the rest of the world continue to pursue the 'empty-world' development pathway, focused on increasing economic growth. By 2100, global warming has exceeded 3.5 °C, sea level has risen by 1 m, cyclones have increased in intensity, marine waters are less alkaline (pH 7.7), and rainfall in GBR catchments has become more erratic. The population of the GBR catchment has reached 3 million, a result of agricultural and mineral industry expansion and intensification, urban growth, and climate refugees from both southern Australia and Asia-Pacific region. Global and national demand for food and minerals remains high, fueling economic growth based on expanded irrigation and extractive industries, and is serviced by increased but poorly designed infrastructure. Corals have largely disappeared, and reefs have become algae dominated. Pollution, overfishing, and a lack of corals for shelter reduce fish biomass and diversity by 80% since 2010. Coasts and islands have receded due to sea-level rise, and swamps and marshlands have been polluted or reclaimed to accommodate the growing population. Terrestrial biodiversity also declines substantially, with biodiversity extinctions in the Wet Tropics, tree loss across the savannah from land clearing and drought, and the proliferation of invasive species. Clearing of native vegetation, including mangroves, though previously prohibited, has resumed. Increasing demand for freshwater has drawn down the groundwater, requiring increased dam building and water transfers, resulting in reduced natural flow regimes. Desalination plants increase. Grazing and production forests suffer from erratic rainfall patterns resulting in more frequent and intense droughts and floods. By 2100, extractive use of ecosystems takes a massive toll on supporting, regulating, and cultural ecosystem services, and the condition of provisioning services also declines, even though quantities produced of food, water supplies, minerals, and farmed fish are at an all-time high. The international tourism industry shifts from biodiversity to beaches, casinos, theme parks, and shopping worlds. High-impact aquaculture becomes the primary marine use. Shipping activity through GBR waters has trebled with new ports, mines, and export markets for eagerly sought Queensland coal. Concern about ecosystem health has reduced as political agendas and media attention target other issues. This, in combination with population pressure, a focus on irrigation for agricultural outputs and erratic rainfall, results in severe decline in the quality and quantity of freshwater and marine water quality. With top-down plutocratic governance and dominance of multinational companies, income disparity has increased and participation in tertiary education has declined. Sea-level rise, storm intensification, and high ambient temperatures in coastal towns have required massive urban and infrastructure redesign and retrofitting at high cost to taxpayers. High costs of living combined with increased health and security risks reduce overall human well-being. Institutions are reactive, as the social consequences of ecological decline, and benefits of reversing it, are not readily perceived. Consequently, the algal-dominated reef ecosystem is unlikely to return to its previous state even if restoration efforts are undertaken.	Global action on carbon emissions and transition to a 'full-world' economic model averts a climate-change catastrophe. After having reached maximum levels of 420 ppm at 2050, atmospheric CO_2 concentrations are stabilized at 350 ppm by 2100. In the GBR region climate-change impacts have intensified up to 2050, but temperatures have stabilized at a <2 °C increase by 2100. Seawater pH, storm intensity, and rainfall patterns do not change drastically, and sea levels do not rise more than 0.3 m. However, Australia's 'empty-world' mindset and *modus operandi* persist and it maintains an isolationist foreign policy and a social paradigm based on irrigated agriculture and extractive, market-based economic growth. Human population in the GBR catchments has increased to 2.5 million, mainly from intrinsic population growth and southern Australian migrants seeking lifestyle changes. Agricultural and some mining expansion have occurred, but are limited by more discerning export markets and international sanctions on environmentally unfriendly Australian products, which drive diversification and development of technology. Supporting and regulating ecosystem services in particular are under pressure. The condition of marine and terrestrial ecosystem services has declined due to centralized and ineffective management of agriculture, fisheries, aquaculture, and urbanization, and terrestrial biodiversity is threatened by expansion and intensification of urban and agricultural areas, as well as invasive species. Terrestrial runoff of nutrients and sediments and overexploitation of fishes are the main impacts on the reef, with coral cover declining to 20% by 2050, and fish biomass declining by 70%. Increasing demand for water and drawdown of groundwater requires construction of dams and desalinization plants. Infrastructure increases but is poorly designed and inefficient. Social inequity is evident and participation in formal education is low as young people leave school to join the workforce in mining and primary industries. Lack of community-based governance, strong business elites, and income disparity combine to reduce overall human well-being. Planning and institutions are reactive and are not well equipped to detect and respond to ecological problems.

Treading water

There is no global action on climate change, and by 2100 global temperatures have warmed by more than 3.5 °C, sea level has risen by 1 m, and seawater reduced to a pH of 7.7. In the GBR region, storm and cyclone intensities have increased, and rainfall has become more erratic. The human population in the GBR catchments exceeds 3 million and is increasingly urban, fueled by immigration in response to expanding opportunities from agricultural expansion and intensification and mineral industry intensification, and climate refugees from southern Australia and the Asia-Pacific region. Through strong, inspired leadership, Australia has made a transition to a 'full-world' economic model based on internalization of externalities and an emphasis on social equity and public participation in political decision making. Impacts and local anthropogenic pressures on ecosystem services in the catchments are partially mitigated by proactive, community-based governance. By 2050, coral cover is less than 20% due to annual bleaching, and reefs become algae dominated, resulting in declining fish biomass and diversity. By 2100, coral cover is approaching 5% due to warming and ocean acidification. The constrained international tourism industry adapts by shifting away from reefs and specializing on more intact areas and species (e.g., whale watching), and tourism generally reduces its ecological footprint.

In terrestrial and marine ecosystems, supporting, regulating, and cultural ecosystem services are hard hit, with biodiversity extinctions in the Wet Tropics, tree death across the savannah and increasing invasive species. Commercial and recreational fisheries decline, but careful management prevents the complete collapse of stocks. Water quality declines with the intensification of grazing and agricultural systems to supply the large human population and more erratic rainfall. This leads to a demand for more irrigation, requiring increased dam building and water transfers, but there is local resistance to loss of native vegetation and impacts on water courses are locally managed. Proactive planning mitigates the impacts of sea-level rise, storm intensification, and high ambient temperatures on coastal towns, but marshlands and many of the coral cays and islands become inundated.

Improved health and education, strong civil society, and more even income distribution increase well-being, but this is tempered by high costs of living and conflict in Asia-Pacific, requiring strong border security. Planning processes and institutions are democratic and adaptive, with emphasis on increased learning about ecosystems and how they are linked to human well-being, but they are better able to respond to local than global pressures.

Best of both worlds

Global action on carbon emissions and global transition to a 'full-world' economic model averts a climate-change catastrophe, with atmospheric CO_2 concentrations returning to 350 ppm by 2100. In the GBR region, climate-change impacts have intensified up to 2050, but temperatures have stabilized at 2 °C above preindustrial levels by 2100. Sea level has risen by only 0.3 m. Australia also succeeds in introducing an economic model based on institutions for the commons, including mechanisms for internalizing externalities, an emphasis on social equity and global fair trade. In the GBR, intrinsic growth and domestic immigration increase the population to 2 million.

The condition of the reef continues to decline until mid-century due to high CO_2 levels and water-quality decline in the early 2000s, before recovering by 2100 to 25% coral cover and higher fish diversity and biomass. The international reef tourism industry declines by mid-century but recovers and remains the primary regional industry, followed by low-impact agriculture and aquaculture and renewable energy aided by technological advances. Land use strives to achieve greater productivity from multiservice landscapes that include increased food production from rain-fed agriculture and the incorporation of biodiversity and agriculture in agro-ecosystems. Terrestrial protected areas increase, and mining and broadacre grazing decline in favor of well-managed, locally confined systems.

Ecosystem services begin to rebound. Commercial fisheries are sustainably managed, and recreational fisheries become strictly regulated to prevent overexploitation by the larger number of people and increased leisure time. Supporting and regulating ecosystem services are restored as nutrient and sediment pollution are controlled, native vegetation is improved, and invasive species are managed. The critical functions that these services provide are protected by novel markets, institutions, and community-based management. Increasing water demand from the larger population growth is mitigated by water use efficiency preventing the construction of additional dams, maintaining catchment ecosystem services.

There is a focus on social justice, democracy, common property rights, and quality of life. Income distribution has become more equitable, education and security improve, resulting in major increases in health and well-being. Built capital is maintained but is redesigned to improve quality, reflecting local aspirations, such as innovative public transport networks. Social capital increases: people look after each other as well as the environment, generating more shared knowledge, awareness and trust, and creating adaptive capacity.

Table 3 Summary of key characteristics of each scenario

Scenario	*Development paradigm*	*Projected CO_2 emissions/ temperature increase by 2100*	*Implications for climate change and its mitigation in GBR*	*GBR 2050 population projections (current population: 1.12 million)*
Trashing the commons	Global empty world; Australia empty world	850 ppm/3.5 °C	- Sea-level rise 1 m - Seawater pH 7.7 - Increased cyclone intensity - Erratic water quantity - Severe nutrient and sediment pollution - Reduced native vegetation extent and condition - Increased invasive species	3.0 Million, due to industrial expansion and intensification, climate refugees from southern Australia and Asia-Pacific
Free riders	Global full world; Australia empty world	350 ppm/<2 °C	- Sea-level rise ≤0.3 m - Seawater pH similar (8.0) - Cyclone intensity similar - Severe nutrient and sediment pollution - Reduced native vegetation extent and condition - Increased invasive species	2.5 Million, some domestic ‘lifestyle’ immigration from southern Australia
Treading water	Global empty world; Australia full world	850 ppm/3.5 °C	- Sea-level rise 1 m - Seawater pH 7.7 - Increased cyclone intensity - Erratic water quantity - Reduced native vegetation extent and condition, and declining water quality, but mitigated by improved land management - Increased invasive species	3.0 Million, due to industrial expansion and intensification, climate refugees from southern Australia and Asia-Pacific
Best of both worlds	Global full world; Australia full world	350 ppm/<2 °C	- Sea-level rise 0.3 m - Seawater pH 8.1 - Cyclone intensity similar - Control of nutrient and sediment pollution at 1990 levels after 20% increase mid-century - Native vegetation extent and condition improved - Invasive species controlled	2.0 Million, limited domestic immigration from southern Australia

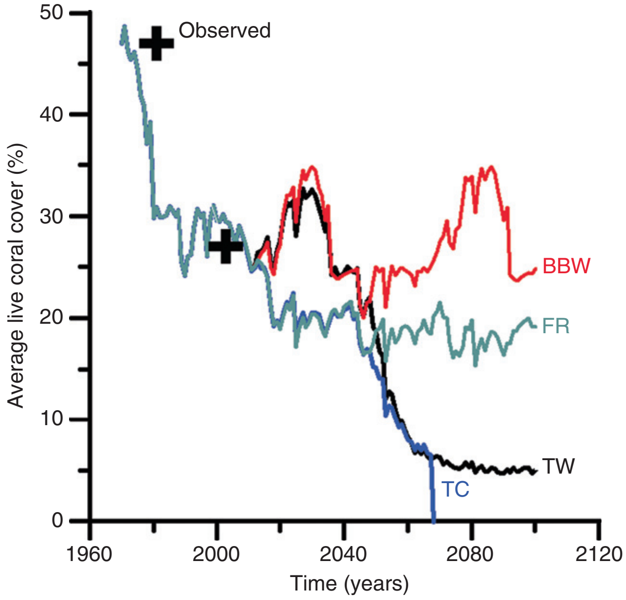

Figure 5 The predicted average coral cover on 261 reefs between Bowen and Lizard Island to 2100 for the four scenarios: TC, trashing the commons; TW, treading water; FR, free riders; BBW, best of both worlds. Observational data are from Bruno, J.F., Selig, E.R., 2007. Regional decline of coral cover in the Indo-Pacific: timing, extent, and subregional comparisons. PLoS One 2 (8), 8.

by free riders, treading water, and the best of both worlds. An economic subset indicator was created by adding the arrows indicating relative change in population and the arrows indicating the relative change in the quantity of built capital.

The graph of these two indicators for the four scenarios depicts an inverse linear relationship ($R^2 = 0.92$) between the summary well-being and the economic subset indicators (Figure 6). We emphasize that the comparative ratios of these measures in the four scenarios are of interest, rather than a comparison of the two types of indicators, given the unequal numbers of indicators contributing to each measure. We further note the need for caution in interpreting this figure given the small number of data points ($n = 4$).

12.15.4 Discussion

12.15.4.1 Analysis of Scenarios

While trashing the commons and best of both worlds represent distinctly different futures for the GBR, the other two scenarios diverge in ways that reveal much about the dynamics that may shape the future of the region. We revisit our conceptual framework to discuss results of the four scenarios, beginning with ecosystems.

For marine ecosystems, the model suggests that until 2050, mitigation of climate change impacts on reefs through regional land management has a good chance of maintaining coral cover. After 2050, the effects of global climate change are likely to outweigh regional mitigation, as evident from the much higher levels of coral cover in free riders than in treading water. Despite this, treading water illustrates that it is possible to maintain a minimal amount of coral reef by the end of the century even in the absence of a change in global climate change policy. However, there are probable threshold levels for coral cover, beyond which the GBR will become a fundamentally different system by 2100 if climate change reaches the upper levels described in the trashing the commons and treading water scenarios.

In terrestrial systems, ecosystem types exhibit unique responses to the four scenarios; natural forest responds negatively to climate change (declines in trashing the commons and treading water) but has great potential to increase where there is effective land management and minimal climate change (best of both worlds). Some ecosystem types appear to be more sensitive to climate change than to intensive or inadequate land management (i.e., natural forest, lakes and rivers, marshes, and wetlands), while for others the opposite is true (i.e., mangroves and swamps). This suggests that management that can respond to pressures at both scales is needed to maintain the full range of terrestrial ecosystem types. Links between marine and terrestrial ecosystems also need to be taken into account, which were not feasible to address in depth in this analysis as we lacked time-series data for terrestrial ecosystems. Increased agriculture and urban land use in the catchment is likely to erode marine and terrestrial ecosystem services, but relationships between catchment activities and water quality in marine systems remain somewhat less tractable (Fabricius and De'ath, 2004; Brodie et al., 2007).

Ecosystems and their services are essential support systems for human well-being, yet the relationships between them are complex (MA, 2003). This is illustrated by the changes in the four capitals in the four scenarios. At best, increases in natural capital (i.e., the four categories of ecosystem services) are moderate, but increases in some of the human and social capital indicators are more substantial (e.g., health and institutions). While conditions of ecosystem services can decline rapidly, recovery is often very slow, if it happens at all (Scheffer et al., 2001). Meanwhile, aspects of social and human capitals can improve rapidly. For example, health improves in treading water even though all ecosystem services decrease. In free riders

Table 4 Summary of impacts on terrestrial and marine ecosystem services in the GBR for each of the four scenarios

		Ecosystem services			
Scenario	*Ecosystem*	*Supporting*	*Provisioning*	*Regulating*	*Cultural*
Trashing the commons	Terrestrial	- Nutrient cycling stressed	- Agriculture intensification and increased cropping area with irrigation due to increasing global population - Increased dams for water supplies due to more erratic water supply - Mining increases due to increasing global demand - Condition of services declining	- Water regulation declining with reduced native vegetation cover - Carbon storage declining - Pollination and disease regulation decline	- Tourism maintained - Recreational fisheries maintained but greatly reduced catches - Biodiversity values decline for non-Indigenous and Indigenous communities - Educational and scientific values decline
	Marine	- Less than 5% coral cover due to acidification and annual coral bleaching, reefs are dominated by algae - Fish biomass and diversity reduced 80% due to overfishing and loss of coral - Nutrient cycling stressed	- Commercial fisheries have severely reduced catch - Aquaculture increases in the coastal zone - Condition of services declining	- Storm protection from reef declines, elevating coastal erosion	- International reef tourism collapses - Recreational fisheries maintained but greatly reduced catches - Biodiversity values decline for non-Indigenous and Indigenous communities - Educational and scientific values decline
Free riders	Terrestrial	- Nutrient cycling stressed but not as much as trashing the commons	- Moderate agricultural intensification and increased cropping area with irrigation - Some increased dams for water supplies	- Water regulation declining with reduced native vegetation cover, but less than in trashing the commons - Carbon storage declining - Pollination and disease regulation decline, but less than in trashing the commons	- Tourism maintained - Recreational fisheries increased but based on reduced biomass - Biodiversity values decline but not as much as in trashing the commons or treading water - Educational and scientific values decline
	Marine	- Coral cover is 34%, declining from 50% mid-century due to poor local management and declining water quality - Fish biomass and diversity reduced 70% due to overfishing - Nutrient cycling stressed but not as much as trashing the commons	- Commercial fisheries have severely reduced catch - Aquaculture increases in the coastal zone	- Storm protection from reef declines, elevating coastal erosion	- International reef tourism collapses but some retained - Recreational fisheries increased but based on lower biomass - Biodiversity values decline but not as much as in trashing the commons or treading water - Educational and scientific values decline

Treading water	Terrestrial	- Nutrient cycling stressed but not as much as trashing the commons	- Mining increases, but alongside renewable energy development - Agriculture intensification and increased cropping area with irrigation, but not as intensive as trashing the commons - Increased dams for water supplies	Water regulation declining with reduced native vegetation cover, but not as much as in trashing the commons - Carbon storage declining - Pollination and disease regulation decline, but not as much as in trashing the commons	- Tourism maintained - Recreational fisheries increased but based on reduced biomass - Biodiversity values decline but not as much as in trashing the commons - Educational and scientific values decline
	Marine	- Coral cover is 20% by 2050, declining to <5% due to coral bleaching and acidification - Fish biomass reduced by 50% - Nutrient cycling stressed	- Commercial fisheries take over tourism as main marine use of GBR, but reduced catch - Aquaculture increases in the coastal zone but impacts mitigated by good management	- Storm protection from reef declines, elevating coastal erosion	- International reef tourism collapses but some retained - Recreational fisheries increased but based on lower biomass - Biodiversity values decline but not as much as in trashing the commons - Educational and scientific values decline
Best of both worlds	Terrestrial	- Nutrient cycling maintained	- Increase in native forestry - Renewable energy promoted - Agriculture maintained with improved management - Water supplies maintained without new dams	- Water regulation maintained with increased native vegetation cover and protected areas - Carbon storage increased - Pollination and disease regulation increases	- Tourism grows with increased protected areas - Recreational fisheries increase based on similar biomass but better managed - Biodiversity improves with restoration - Educational values maintained or improved
	Marine	- Coral cover returned to 25% (1990 levels) - Fish biomass recovering from 80% mid-century - Nutrient cycling maintained	- Commercial fisheries maintained but more sustainable - Low-impact aquaculture developed	- Storm protection from reef maintained	- International reef tourism collapses but some retained - Recreational fisheries increased but based on similar biomass but better managed - Biodiversity values maintained - Educational values maintained or improved

Table 5 Change in extent of terrestrial and marine ecosystems in 2100 relative to the present for each scenario

	Land cover/use	Current area (% of catchment)	Trashing the commons	Free riders	Treading water	Best of both worlds
Upland	Natural forest	12.9	↓	↔	↓	↑↑↑↑↑
	Lakes/rivers	0.4	↓	↔	↓	↔
Coastal	Mangroves	0.9	↓↓	↓	↔	↔
	Marsh/wetland	0.4	↓↓↓↓	↓↓↓	↓↓↓↓	↔
	Swamp	0.1	↓	↓	↔	↔
	Saline coastal flat	0	↓↓	↓	↓	↔
	Estuary/coastal waters	0	↔	↔	↔	↔
Marine	Coral	n/a	↓↓↓↓↓	↓↓	↓↓↓	↔
	Seagrass	n/a	↓	↓	↔	↔
	Shelf	n/a	↔	↔	↔	↔
	Islands	n/a	↓↓	↔	↓↓	↔
Agriculture/urban	Grazing	74.6	↓↓	↓	↑↑↑	↔
	Production forestry	5.1	↓↓↓	↓↓	↓↓↓	↑↑
	Intensive agriculture	3.2	↑↑↑↑↑	↑↑↑↑	↑↑↑	↔
	Sugarcane	1.3	↔	↔	↔	↔
	Mining	0.2	↑↑↑	↑↑	↔	↓↓
	Urban/service/utilities	0.7	↑↑↑↑↑	↑↑↑↑	↑↑↑	↑↑
	Reservoir/dam	0.1	↑↑↑↑	↑↑	↔	↓↓

Upward-pointing arrows indicate an increase in the extent of a type of land cover/use, and downward-pointing arrows indicate a decrease.
The number of arrows (between 1 and 5) indicates the amount of change.
Arrows pointing left and right indicate no change.

and trashing the commons, on the other hand, health declines, which may be linked to declines in ecosystem services. It is worth noting that in trashing the commons, in which all ecosystem services decline the most, indicators of equity, participation, security, education, health, job security, and quality of the built environment are also at their lowest levels. Thus, we see that modest improvements in human well-being are possible even while ecosystem services decline, but only where there is strong regional management. In a departure from this trend, cultural ecosystem services are worse off in treading water than in free riders, as biodiversity values decline as a result of climate change.

Population and built capital (e.g., our economic subset indicators) are the same in free riders and treading water, but outcomes for the GBR in terms of total well-being by 2100 are better in treading water than in free riders, reflecting regional actions to improve ecosystem services and well-being, and higher levels of human and social capital. Trashing the commons and best of both worlds occupy opposite ends of a continuum between total well-being and economic well-being, signifying that one end cannot be achieved without compromising the other.

Impacts on ecosystem services and human well-being in turn have feedbacks on drivers and in essence become drivers for further change. Adaptation, which may mediate global impacts on natural, social, human, or built capital, is likely to be key in these scenarios and can in fact prompt a change in course from one scenario to another. For example, in free riders, in which Australia becomes a pariah state in the eyes of the world, a more limited export market drives innovation and resourcefulness. In trashing the commons, individuals may eventually take action to improve a compromised sense of well-being. Alternatively, a trigger for change may come from ecological crisis (Gunderson et al., 2002). When such action reaches a tipping point, change may begin to occur in policies and management practices. Hence, a seemingly undesirable pathway can become a desirable one if crisis inspires positive change; however, some irreversible damage may happen along the way. A better understanding is needed of such adaptations among individuals and industries in the GBR and, indeed, their adaptive capacity.

12.15.4.2 Implications for Management of GBR

Following the free riders pathway – that is, failing to mitigate climate change at a regional scale although global climate change is being managed in the belief that the reef will be moderately intact by 2100 as long as the rest of the world is doing its part in combating global climate change falls afoul of ‘short-termism’ (Cocks, 1999). There are many uncertainties associated with both ecological and social resilience and adaptation to climate change impacts and their possible interactions across scales. Our scenario analysis may be optimistic (or pessimistic); we simply do not know with any certainty if there is a

Table 6 Change in four capitals in 2100 relative to the present, averaged for terrestrial and marine ecosystems, for each scenario

	Capitals	Trashing the commons	Free riders	Treading water	Best of both worlds
Natural	Supporting	↓↓↓↓	↓↓↓	↓↓↓	↑↑
	Regulating	↓↓↓↓↓	↓↓↓	↓↓↓	↑↑↑
	Provisioning	↓↓	↓	↓	↑↑
	Cultural	↓↓↓↓↓	↓	↓↓↓	↑↑
Social	Equity	↓↓↓↓		↑	↑↑↑
	Participation	↓↓	↑	↑↑	↑↑↑
	Security/safety	↓↓↓	↔	↑↑	↑↑↑
	Democracy	↓↓↓	↓↓↓	↑↑	↑↑↑
	Networks	↑↓	↑↓	↑↓	↑
	Culture	↓	↓	↑	↑↑↑
	Institutions	↑↓	↑↓	↑	↑↑↑↑
Human	Education	↓↓	↓	↑	↑↑↑
	Health	↓↓	↓	↑	↑↑↑↑↑
	Professional skills	↑	↑	↔	↑
	Job security	↓	↔	↑	↑↑
	Population	↑↑↑↑	↑↑↑	↑↑↑	↑↑
Built	Quantity	↑↑↑↑	↑↑↑	↑↑↑	↔
	Quality	↓↓↓↓	↓↓	↑	↑↑
	Well-being Indicator	–29	–10	9	44
	Economic Indicator (Pop. + Built Quality)	8	6	6	2

Upward-pointing arrows signify an increase in the value of an indicator, and downward-pointing arrows signify a decrease.
The number of arrows (between 1 and 5) indicates the amount of change.
Arrows pointing left and right indicate no change.
The summary well-being indicator was calculated by summing upward arrows (each equivalent to +1) and downward arrows (each equivalent to –1) for all indicators.
The economic subset indicator was calculated by summing the arrows for population and quantity of built capital.

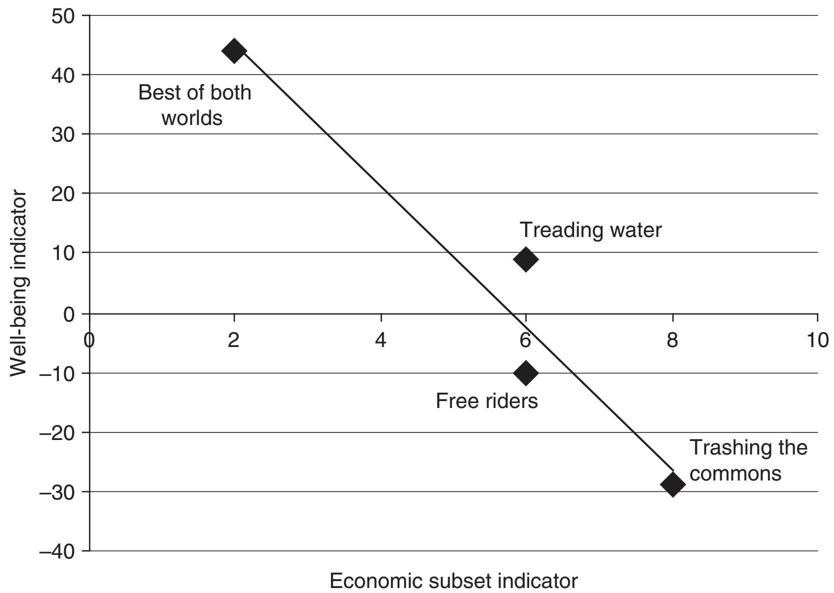

Figure 6 Summary well-being indicator plotted against economic subset indicator for the four scenarios in 2100. Indicators were derived from **Table 5**. $R^2 = 0.92$.

point of no return, beyond which the writing is on the wall with regard to climate change and the GBR.

There are additional arguments for a proactive approach to climate change mitigation: one is based on the benefits for terrestrial ecosystems in the catchment and the many industries that depend on them (Marshall, 2010), and a second on the benefits for health, security, culture, and other components of human well-being. Furthermore, empirical data and models indicate that threats to the GBR clearly need to be addressed in an integrated way, such that the whole social–ecological system is recognized (Olsson et al., 2008).

Global climate change is not easily addressed at regional and local scales, and yet this is where many of the pressures are most profoundly felt (Wilbanks and Kates, 1999). This analysis points to a need to design management responses for the GBR region that account for cross-scale processes even if appropriate global responses (and institutions) do not exist. It also implies that responses of other actors, such as civil society and industry, may need to play a role. Although less frequently stated, there must also be temporal scale matching of institutions and the processes they are intended to address so that they can adequately capture feedback (Wilson, 2006), and so that the current short-term focus of management is superseded by one imbued with vision and foresight.

12.15.5 Conclusion

This approach to scenarios is novel for the GBR in several ways: (1) global climate change projections were downscaled for the region; (2) a combination of qualitative and quantitative scenarios was developed that explored the region as a whole, rather than focusing only on catchments, reef ecosystems, or economic sectors; and (3) the scenarios were framed by the key uncertainties underlying climate change in the GBR – global and Australian development pathways. It is this third aspect in particular that is especially important, as uncertainties related to worldviews are those that often lead to abrupt, surprising outcomes (Janssen, 2002).

Next, we describe some potential avenues for using these scenarios further and in ways that engage with a broad swathe of GBR stakeholders. While some approaches to scenario planning involve participatory processes with stakeholders from the onset, and indeed are even initiated by them (O'Connor et al., 2004), our scenarios were developed in a short duration of time among a small group of scientists and with limited input from government, industry, and other stakeholders. Where the objective of scenarios is primarily to enhance scientific understanding of dynamics that may shape the future, such a scientist-driven approach may be appropriate (Biggs et al., 2007).

We see much value in these scenarios for enhancing, and challenging, our own scientific understanding, and enabling identification of information gaps so that we can prioritize information needs and investment in data collection efforts. Yet they also provide a launching pad for a participatory process of resolving information gaps and developing a shared GBR-wide future vision. Aspects of the scenarios for which scientific knowledge is highly uncertain due to either lack of information or stochasticity may be improved by stakeholder perspectives on future uncertainty. Indeed, the framing of these scenarios reflects a group of scientists' views of major drivers and uncertainties, which may differ from, and be greatly enriched by, those of other stakeholders.

In a participatory process, scenarios can provide a vehicle to discuss, evaluate, and compare future alternatives in ways that are meaningful to participants. A subsequent phase of the process might involve extensive dissemination of these refined scenarios and broad participation in their use and refinement. For example, in New Zealand, a scenarios game has been used as a means of engaging stakeholders in the process of scenario creation (Landcare Research Scenarios Working Group, 2007) and has encouraged discussion and debate around four future visions. The game incorporates a feedback process that allows consensus building around preferred scenarios. Elsewhere, visual representations of different scenarios may be useful in this regard (Bohnet and Smith, 2007; Shaw et al., 2009).

At a policy level, such a participatory process can help GBR decision makers to understand and reexamine society's – and indeed, their own – preferences for the direction of the future and to better develop practices and policies that are most likely to achieve desired scenarios and avoid those which are perceived to be undesirable. A great benefit of scenarios lies in their ability to raise awareness of drivers of change that are not on the day-to-day agenda and are seemingly beyond the control, of many regional decision makers. As Doug Cocks observed,

> Tomorrow's world may be a bugger of a place which we can do little to avoid but, if we try to make it better, it is unlikely to be worse than if we had not tried. We are both future *makers* and future *takers*. We are constantly adapting and reacting to powerful social, political, economic and environmental forces. If, at the end of the present inquiry, we cannot avoid concluding that the future is being determined by powerful irresistible forces we do not like – all take and no make – then such knowledge might at least lessen the pain of living with the consequences (Cocks, 1999).

As Australia and the GBR region engage in climate policy and mitigation processes, this analysis underscores the need to adopt more proactive precautionary attitudes to deal with uncertainty, beginning with the fundamental acknowledgment that it exists. The future is undeniably uncertain; what will matter is whether the region is prepared to accept uncertainty, and if not, what kind of outcomes the region is willing to live with as a consequence.

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References

Abel, N., Cumming, D.H.M., Anderies, J.M., 2006. Collapse and reorganization in social–ecological systems: questions, some ideas, and policy implications. Ecology and Society 11(1), 17.

Access Economics, 2008. Economic Value of the Great Barrier Reef Marine Park 2006–07. Access Economics Party, Canberra.

Allard, G.J., 2005. Measuring job security over time: in search of a historical indicator for EPL (Employment Protection Legislation). Working Paper WP 05–17. Instituto de Empresa Business School, Madrid.

Australian Government and Queensland Government, 2003. Reef Water Quality Protection Plan for Catchments Adjacent to the Great Barrier Reef World Heritage Area. Queensland Department of Premier and Cabinet, Brisbane.

Australian Labour Party, 2007. Labor's Reef Rescue Plan. Australian Labour Party, Canberra.

BCA (Business Council of Australia), 2004. Aspire Australia 2025. Business Council of Australia, Melbourne.

Biggs, R., Raudsepp-Hearne, C., Atkinson-Palombo, C., Bohensky, E., Boyd, E., Cundill, G., Fox, H., Ingram, S., Kok, K., Spehar, S., Tengö, M., Timmer, D., Zurek, M., 2007. Linking futures across scales: a dialog on multiscale scenarios. Ecology and Society 12, 17.

Bohnet, I., 2008. Future visions for the Tully catchment – a participatory planning approach. In: A Future of Extremes, Proceedings of the 11th International Rivers Symposium, Brisbane, pp. 5–6.

Bohnet, I., Bohensky, E., Gambley, C., Waterhouse, J., 2008. Future Scenarios for the Great Barrier Reef Catchment. CSIRO Water for a Healthy Country National Research Flagship, Canberra.

Bohnet, I., Smith, D.M., 2007. Planning future landscapes in the wet tropics of Australia: a social–ecological framework. Landscape and Urban Planning 80, 137–152.

Brodie, J., De'ath G., Devlin, M., Furnas, M., Wright, M., 2007. Spatial and temporal patterns of near-surface chlorophyll *a* in the Great Barrier Reef lagoon. Marine and Freshwater Research 58, 342–353.

Bryan, J.H., Foley, D.H., Sutherst, R.W., 1996. Malaria transmission and climate change in Australia. Medical Journal of Australia 164, 345–347.

Christoff, P., 2010. Touching the void: The Garnaut Review in the chasm between climate science; economics and politics. Global Environmental Change, 20, 214–217. doi:10.1016/j.gloenvcha.2009.10.010.

Cocks, D., 1999. Future Makers, Future Takers: Life in Australia 2050. University of New South Wales Press, Sydney.

Cork, S., Delaney, K., 2005. Thinking about the future of Australia's landscapes. Land and Water Australia and Delaney and Associates, Canberra.

Costanza, R., 2008. Stewardship for a 'full' world. Current History 107, 30–35.

Costanza, R., Daly, H.E., 1992. Natural capital and sustainable development. Conservation Biology 6, 37–46.

Costanza, R., Hart, M., Posner, S., Talberth, J., 2009. Beyond GDP: the need for new measures of progress, The Pardee Papers No. 4. Boston University, Boston.

De'ath, G., Lough, J.M., Fabricius, K.E., 2009. Declining coral calcification on the Great Barrier Reef. Science 323, 116–119.

Delaney, K., 2006. Qualitative scenarios for energy and transport in Australia to 2050. A Report for the Energy Futures Forum. CSIRO Sustainable Ecosystems, Canberra.

Diener, E., Suh, E., 1997. Measuring quality of life: economic, social and subjective indicators. Social Indicators Research 40, 189–216.

Doulton, H., Brown, K., 2009. Ten years to prevent catastrophe? Discourses of climate change and international development in the UK press. Global Environmental Change 19, 191–202.

Dunlop, M., Turner, G., Foran, B., Poldy, F., 2002. Decision points for land and water futures. Resource Futures Program Working Document 2002/08. A Report Prepared for Land and Water Australia. CSIRO Sustainable Ecosystems, Canberra.

Energy Futures Forum, 2006. The Heat is on – the Future of Energy in Australia. CSIRO, Canberra.

Evans, K., Velarde, S.J., Prieto, R., Rao, S.N., Sertzen, S., Dávila, K., Cronkleton, P., de Jong, W., 2006. In: Bennett, E., Zurek, M. (Eds.), Field Guide to the Future: Four Ways for Communities to Think Ahead. Center for International Forestry Research (CIFOR), ASB, World Agroforestry Centre, Nairobi.

Fabricius, K.E., De'ath, A.G., 2004. Identifying ecological change and its causes: a case study on coral reefs. Ecological Applications 14, 1448–1465.

Ferrier, R.C., 2007. Science challenges to support diffuse pollution management in the Great Barrier Reef. CSIRO: Flagship Fellow Report. Water for a Healthy Country National Research Flagship, Canberra. http://www.csiro.au/resources/FerrierReport.html (accessed August 2010).

Gallopín, G.C., 2002. Planning for resilience: scenarios, surprises and branch points. In: Gunderson, L., Holling, C.S. (Eds.), Panarchy: Understanding Transformations in Human and Natural Systems. Island Press, Washington, DC, pp. 361–392.

Gallopín, G., Hammond, A., Raskin, P., Swart, R., 1997. Branch points: global scenarios and human choice. PoleStar Series Report No. 7. Stockholm Environment Institute, Stockholm.

Garnaut, R., 2008. The Garnaut Climate Change Review: Final Report. Cambridge University Press, Cambridge/Melbourne.

GBRMPA (Great Barrier Reef Marine Park Authority), 1994. Twenty-five year strategic plan for the Great Barrier Reef world heritage area. GBRMPA, Townsville. http://www.gbrmpa.gov.au/corp_site/management/the_25_year_strategic_plan (accessed August 2010).

GBRMPA (Great Barrier Reef Marine Park Authority), 2009. Great Barrier Reef Outlook Report 2009. GBRMPA, Townsville. http://www.gbrmpa.gov.au/corp_site/about_us/great_barrier_reef_outlook_report (accessed August 2010).

Gray, I., Lawrence, G., 2001. A Future for Regional Australia: Escaping Global Misfortune. Cambridge University Press, Cambridge.

Gunderson, L.H., Holling, C.S., Peterson, G.D., 2002. Surprises and sustainability: cycles of renewal in the Everglades. In: Gunderson, L., Holling, C.S. (Eds.), Panarchy: Understanding Transformations in Human and Natural Systems. Island Press, Washington, DC, pp. 315–332.

Hansen, J., Sato, M., Kharecha, P., Beerling, D., Masson-Delmotte, V., Pagani, M., Raymo, M., Royer, D.L., Zachos, J.C., 2008. Target atmospheric CO_2: where should humanity aim? Open Atmospheric Science Journal 2, 217–231.

Hoegh-Guldberg, O., Hoegh-Guldberg, H. 2008. The implications of climate change for Australia's Great Barrier Reef: people and industries at risk. WWF Australia, Sydney.

Hoegh-Guldberg, O., Mumby, P.J., Hooten, A.J., Steneck, R.S., Greenfield, P., Gomez, E., Harvell, C.D., Sale, P.F., Edwards, A.J., Caldeira, K., Knowlton, N., Eakin, C.M., Iglesias-Prieto, R., Muthiga, N., Bradbury, R.H., Dubi, A., Hatziolos, M.E., 2007. Coral reefs under rapid climate change and ocean acidification. Science 318 (5857), 1737–1742.

Hughes, T., Rodrigues, M.J., Bellwood, D.R., Ceccarelli, D., Hoegh-Guldberg, O., McCook, L., Moltschaniwskyj, N., Pratchett, M.S., Steneck, R.S., Willis, B., 2007. Phase shifts, herbivory, and the resilience of coral reefs to climate change. Current Biology 17, 360–365.

IPCC (Intergovernmental Panel on Climate Change), 2007. In: Bernstein, L., Lenny, B., Peter, B., Osvaldo, C., Zhenlin, C., Renate, C., Ogunlade, D.,William, H., Saleemul, H., David, K., Vladimir, K., Zbigniew, K., Jian, L., Ulrike, L., Martin, M., Taroh, M., Bettina, M., Bert, M., Monirul, M., Neville, N., Leonard, N., Rajendra, P., Jean, P., Martin, P., Dahe, Q., Nijavalli, R., Andy, R., Jiawen, R., Keywan, R., Cynthia, R., Matilde, R., Stephen, S., Youba, S., Susan, S., Peter, S., Ronald, S., Taishi, S., Rob, S., Dennis, T., Coleen, V., Gary, Y., (Eds.), Climate Change 2007: Synthesis Report to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

James, P., 2007. Reframing the nation–state: rethinking the Australian dream from the local to the global. Futures 39(2–3), 169–184.

Janssen, M.A., 2002. A future of surprises. In: Gunderson, L., Holling, C.S. (Eds.), Panarchy: Understanding Transformations in Human and Natural Systems. Island Press, Washington, DC, pp. 241–260.

Johnson, J.E., Marshall, P.A. (Eds.), 2007. Climate change and the Great Barrier Reef: a vulnerability assessment. Great Barrier Reef Marine Park Authority and Australian Greenhouse Office, Townsville.

Kahane, A., 1992. The Mont Fleur scenarios. Deeper News 7.

Landcare Research Scenarios Working Group, 2007. Four Future Scenarios for New Zealand: Work in Progress, Second ed. Manaaki Whenua Press, Lincoln.

Larson, S., 2009. Communicating stakeholder priorities in the Great Barrier Reef region. Society and Natural Resources 22(7), 650–654.

Lebel, L., 2005. The politics of scale in environmental assessment. In: Reid, W., Berkes, F., Wilbanks, T., Capistrano, D. (Eds.), Bridging Scales and Epistemologies: Linking Local Knowledge and Global Science in Environmental Assessments. Island Press, Washington, DC, pp. 37–57.

Leventhal, G.S., 1980. What should be done with equity theory? No approaches to the study of fairness in social relationships. In: Gergen, K.J., Greenberg, M.S., Wills, R.H. (Eds.), Social Exchange: Advances in Theory and Research. Plenum, New York, NY, pp. 27–55.

MA (Millennium Ecosystem Assessment), 2003. Ecosystems and Human Well-Being: A Framework for Assessment. Island Press, Washington, DC.

MA (Millennium Ecosystem Assessment), 2005. Ecosystems and Human Well-Being: Synthesis. Island Press, Washington, DC.

Marshall, N.A., 2010. Understanding social resilience to climate variability in primary enterprises and industries. Global Environmental Change 20, 36–43.

McMichael, A., Woodruff, R., Hales, S., 2006. Climate change and human health: present and future risks. Lancet 367, 859–869.

Nakicenovic, N., Swart, R. (Eds.), 2000. Special report on emissions scenarios (SRES). A Special Report of Working Group III of the IPCC. Cambridge University Press, Cambridge.
Nelson, R., Brown, P.R., Darbas, T., Kokic, P., Cody, K., 2007. The potential to map the adaptive capacity of Australian land managers for natural resource management policy using Australian BUREAU of Statistics Data. National Land and Water Resource Audit, Canberra.
O'Brien, P., 2000. Scenario planning: a strategic tool. Bureau of Rural Sciences, Canberra.
O'Connor, M.H., McFarlane, M., MacRae, D., Lefroy, E.C., 2004. Avon river basin 2050: four regional scenarios for the next half-century. A Report Prepared for the Partners of the ARB2050 Project. CSIRO Sustainable Ecosystems, Canberra.
OESR (Office of Economic and Statistical Research), 2008. Projected population by statistical division, Queensland 2006 and 2031. http://www.oesr.qld.gov.au/queensland-by-theme/demography/population/tables/pop-proj/proj-pop-sd-qld/index.shtml (accessed August 2010).
Office of the President, 2007. PGMA's Statement after the Regional Disaster Coordinating Council (NDCC) Meeting in Iligan City. http://www.beatingtheodds.ph/op/index.php?option=com_content&task=view&id=1252Itemid=27.
Olsson, P., Folke, C., Hughes, T.P., 2008. Navigating the transition to ecosystem-based management of the Great Barrier Reef, Australia. Proceedings of the National Academy of Sciences of the United States of America 105, 9489–9494.
Ostrom, E., 1999. Coping with tragedies of the commons. Annual Review of Political Science 2, 493–535.
Oxford Economics, 2009. Valuing the effects of Great Barrier Reef bleaching. Great Barrier Reef Foundation, Brisbane.
Peterson, G.D., Cumming, G.S., Carpenter, S.R., 2003. Scenario planning: a tool for conservation in an uncertain world. Conservation Biology 17 (2), 358–366.
Preston, B.L., Jones, R.N., 2006. Climate change impacts on Australia and the benefits of early action to reduce global greenhouse gas emissions. CSIRO Marine and Atmospheric Research, Aspendale. http://www.csiro.au/files/files/p6fy.pdf (accessed August 2010).
Putnam, R., 1993. The prosperous community: social capital and public life. American Prospect 13.
Putnam, R., 2000. Bowling Alone: The Collapse and Revival of American Community. Simon and Schuster, New York.
QDNRW (Queensland Department of Natural Resources and Water), 2006a. Land Use (2004) in the Burdekin River Catchment, Queensland. Digital vector data by catchment. The State of Queensland, Department of Natural Resources and Water, Brisbane.
QDNRW (Queensland Department of Natural Resources and Water), 2006b. Land Use (2004) in the Johnstone River Catchment, Queensland. Digital vector data by catchment. The State of Queensland, Department of Natural Resources and Water, Brisbane.
QEPA (Queensland Environmental Protection Agency), 2005. Survey and mapping of pre-clear and 2003 remnant vegetation communities and regional ecosystems of Queensland, version 5.0 (December 2005). Digital vector data. The State of Queensland, Queensland Herbarium, Environmental Protection Agency, Brisbane.
Raskin, P., Banuri, T., Gallopin, G., Gutman, P., Hammond, A., Kates, R., Swart. R., 2002. Great Transition: The Promise and Lure of the Times Ahead. Stockholm Environment Institute, Stockholm.
Roebeling, P.C., Bohnet, I., Smith, M., Westcott, D., Kroon, F., Hartcher, M., Hodgen, M., Vleeshouwer, J., 2005. Landscapes toolkit for triple-bottom-line assessment of land use scenarios in Great Barrier Reef catchments. In: Zerger, A., Argent, R. (Eds.), MODSIM 05 International Congress on Modelling and Simulation, Melbourne, pp. 711–717.
Scheffer, M., Carpenter, S., Foley, J.A., Folke, C., Walker, B., 2001. Catastrophic shifts in ecosystems. Nature 413, 591–596.
Shaw, A. Sheppard, S., Burch, S., Flanders, D., Wiek, A., Carmichael, J., Robinson, J., Cohen, S., 2009. Making local futures tangible: synthesizing, downscaling, and visualizing climate change scenarios for participatory capacity building. Global Environmental Change 19, 447–463.
Stevenson, T., 2007. Rethinking Oz: more than policy, the underlying mindset. Futures 39 (2–3), 200–214.
Talberth, J., Cobb, C., Slattery, N., 2007. The genuine progress indicator 2006: a tool for sustainable development. Redefining Progress, Oakland.
Wack, P., 1985. Scenarios: uncharted waters ahead. Harvard Business Review 63, 72–89.
Wilbanks, T.J., Kates, R.W., 1999. Global change in local places: how scale matters. Climatic Change 43, 601–628.
Wilson, J.A., 2006. Matching social and ecological systems in complex ocean fisheries. Ecology and Society 11(1), 9.
Witte, C., van den Berg, D., Rowland, T., O'Donnell, T., Denham, R., Pitt, G., Simpson, J., 2006. Mapping land use in Queensland – Technical Report on the 1999 Land Use Map for Queensland, Department of Natural Resources, Mines and Water, Brisbane.
Wolanski, E., De'ath, G., 2005. Predicting the present and future human impact on the Great Barrier Reef. Estuarine, Coastal and Shelf Science 64, 504–508.
Wolanski, E., Richmond, R.H., McCook, L., 2004. A model of the effects of land-based, human activities on the health of coral reefs in the Great Barrier Reef and in Fouha Bay, Guam, Micronesia. Journal of Marine Systems 46, 133–144.
Wollenberg, E., Edmunds, D., Buck, L., 2000. Using scenarios to make decisions about the future: anticipatory learning for the adaptive co-management of community forests. Landscape and Urban Planning 47, 65–77.
Wooldridge, S.A., 2009. Water quality and coral bleaching thresholds: formalising the linkage for the inshore reefs of the Great Barrier Reef, Australia. Marine Pollution Bulletin 58, 745–751.
Wooldridge, S.A., Done, T.J., 2009. Improved water quality can ameliorate effects of climate change on corals. Ecological Applications 19, 1492–1499.
Young, J., Temperton, J., 2008. Measuring Community Attitudes and Awareness Towards the Great Barrier Reef 2007. Research Publication 90. Great Barrier Reef Marine Park Authority, Townsville.

Relevant Websites

http://gtinitiative.org – Great Transition Initiative.
http://www.tellus.org – Tellus Institute; Futures in Motion.