POLICY PERSPECTIVE

Conservation action in a changing climate

T.R. McClanahan[1], J.E. Cinner[2], J. Maina[3,4], N.A.J. Graham[5], T.M. Daw[6], S.M. Stead[5], A. Wamukota[4], K. Brown[6,7], M. Ateweberhan[4], V. Venus[3], & N.V.C. Polunin[5]

[1] Wildlife Conservation Society, Marine Programs, Bronx, NY, 10460, USA
[2] ARC Center of Excellence for Coral Reef Studies, James Cook University, Townsville, QLD, 4811 Australia
[3] International Institute for Geo-Information Science and Earth Observation, Enschede, The Netherlands
[4] Coral Reef Conservation Project, Mombasa, Kenya
[5] School of Marine Science & Technology, Newcastle University, Newcastle-upon-Tyne, UK
[6] School of Development Studies, University of East Anglia, Norwich, UK
[7] Tyndall Centre for Climate Change Research, University of East Anglia, Norwich, UK

Keywords
Adaptive capacity; social-ecological systems; socioeconomic; marine conservation; climate change; environmental susceptibility; coral bleaching; global change.

Correspondence
T. R. McClanahan, Wildlife Conservation Society, Marine Programs, Bronx, NY 10460, USA. Tel: +254-725-5546822. E-mail: tmcclanahan@wcs.org

Received: 21 February 2008; accepted 22 February 2008

doi: 10.1111/j.1755-263X.2008.00008.x

Abstract

Climate change will pose new challenges to conserving Earth's natural ecosystems, due to incremental changes in temperature and weather patterns, and to increased frequency and intensity of extreme climate events. Addressing these challenges will require pragmatic conservation actions informed by site-specific understanding of susceptibility to climate change and capacity of societies to cope with and adapt to change. Depending on a location's environmental susceptibility and social adaptive capacity, appropriate conservation actions will require some combination of: (1) large-scale protection of ecosystems; (2) actively transforming and adapting social-ecological systems; (3) building the capacity of communities to cope with change; and (4) government assistance focused on de-coupling communities from dependence on natural resources. We apply a novel analytical framework to examine conservation actions in five western Indian Ocean countries, where climate-mediated disturbance has impacted coral reefs and where adaptive capacity differs markedly. We find that current conservation strategies do not reflect adaptive capacity and are, therefore, ill prepared for climate change. We provide a vision for conservation policies that considers social adaptive capacity that copes with complexities of climate change better than the singular emphasis on government control and the creation of no-take areas.

Introduction

Climate change is expected to increase the frequency and intensity of extreme climatic events, and will profoundly influence ecosystems and the communities that depend on them. Examples include droughts and wildfires in forests and bleaching on coral reefs (IPCC 2007). In the light of future climate change, effectively conserving ecosystems and the goods and services they provide will rely on the ability to predict the risk of extreme climatic effects and to harness the capacity of associated human societies to cope or adapt (SEG 2007). Despite the stochastic nature of disturbances at small scales, the probability of extreme climate events in a particular location is predictable over the long term based on historical environmental change (Webster *et al.* 2005; Baettig *et al.* 2007; SEG 2007). To develop appropriate regional conservation strategies that prioritize actions at specific sites, conservation planning should incorporate spatial differences in susceptibility to extreme events, hereafter termed "Environmental Susceptibility" (Clark *et al.* 2001). But conservation planning should also consider the socioeconomic conditions that dictate the range of adaptations and conservation interventions possible in the face of climatic disturbances (Adger *et al.* 2005; SEG 2007). "Adaptive Capacity" indicates society's potential to cope with perturbations and take advantage of new opportunities, whether due to climate impacts (IPCC 2007), conservation interventions, or other changes to the social-ecological system. We present a novel analytical framework that considers the interactions between adaptive capacity and environmental susceptibility to assess a range of conservation strategies. We apply this framework to a quantified example from coastal environments in the Indian Ocean.

A framework for conservation planning

We propose that quantifying and plotting the environmental susceptibility of sites against their social adaptive capacity provides a framework to integrate these two considerations and gives important insights for conservation planning (Figure 1A). This distinguishes four domains where differing policy and conservation activities are required. Biodiverse regions with low environmental susceptibility are refugia and have generally been considered a high priority for conservation using protected area management (Sanderson *et al.* 2002). However, differing socioeconomic conditions in these regions may limit the viability of this management approach. Protected areas may, indeed, be appropriate in sites where adaptive capacity is high because local communities can readily adapt to restrictions and take advantage of new opportunities, such as increased tourism. Conversely, communities with low adaptive capacity are poorly equipped to cope with even short-term restrictions on resource use imposed by no-take areas. Consequently, these communities may be unwilling or unable to comply with protection measures and adding more no-take areas may merely lead to a further proliferation of ineffectual so-called "paper parks" (McClanahan 1999). These low environmental susceptibility and low adaptive capacity regions (Figure 1A) will first require investments in poverty alleviation, infrastructure, social capital, and alternative incomes to develop adaptive capacity. Once local capacity is enhanced, these regions are more likely to be able to take advantage of the opportunities arising from conservation and successfully implement management strategies. Prior to these developments, management options with minimal social costs are required (McClanahan *et al.* 2006).

Regions with high environmental susceptibility should be a lower priority for traditional biodiversity conservation, as efforts to protect nature are likely to be consistently undermined by the impacts of extreme climate events. Again, the adaptive capacity in these regions will influence the necessary and appropriate policy and actions. Where adaptive capacity is high, societal change

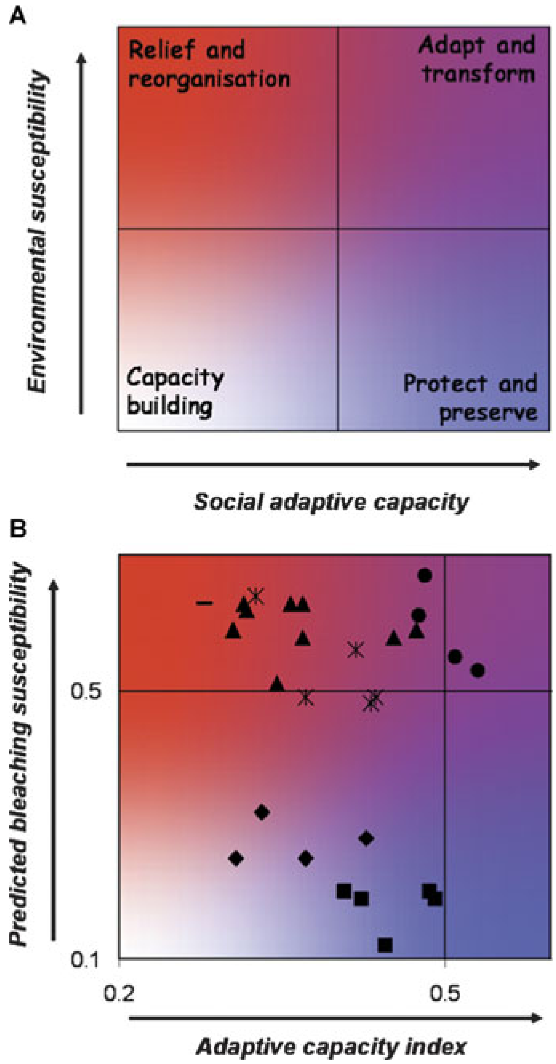

Figure 1 **(A)** Theoretical model indicating gradients of social adaptive capacity against environmental susceptibility to produce four quadrants of differing conservation priorities. **(B)** Case study from the western Indian Ocean spanning five countries: ▲ Kenya, ✳ Tanzania, ● Seychelles, ■ Mauritius, ◆ Northeast Madagascar, and ▬ Northwest Madagascar.

and diversification is more likely and active ecosystem manipulation may be possible through food web restoration, ex situ conservation, genetic engineering, or selective breeding of resistant organisms. As climate change impacts become more widely felt, adaptations developed in these regions may provide innovations ultimately used in the other quadrants of this framework (Figure 1A). Regions in the high environmental susceptibility and low adaptive capacity quadrant do not currently have the resources or ability to adapt to climate change. These regions are a primary concern for human development and require government or donor assistance to ameliorate disaster risk, strengthen social safety nets, diversify sources of livelihoods, and reduce dependence on local natural resources.

Western Indian Ocean case study

We further explore this environmental susceptibility-adaptive capacity framework by applying it to locations with coral reefs and associated fisheries in the Western Indian Ocean (WIO), where climate-mediated coral bleaching has had extensive effects and in combination with local anthropogenic causes of degradation, demands appropriate and effective management interventions. Approximately 30 million people in the WIO depend directly or indirectly on the coastal environment for goods and services. Coral reefs are among the ecosystems with the greatest environmental susceptibility to climate change (Walther *et al.* 2002). During the 1998 El Niño-Southern Oscillation (ENSO) warming event, WIO reefs underwent severe bleaching and suffered 0–95% coral mortality, depending on location (Goreau *et al.* 2000).

We used an oceanographic-environmental model and a socioeconomic survey of coastal households to quantify indices of bleaching environmental susceptibility and adaptive capacity at sites spanning five countries in the region. The oceanographic model used environmental conditions during previous extreme warming events to predict the susceptibility of coral reefs to future bleaching (Maina *et al.* 2008). The model provided an index of predicted environmental susceptibility to bleaching for the entire Indian Ocean that is scaled from 0–1 (Methods).

Our socioeconomic survey provided an adaptive capacity index for 29 communities based on eight quantitative indicators (Methods). Both climate change and the capacity of communities to adapt to it are multiscale issues, with the latter incorporating individual, household, community, and national-level organization. Adaptive capacity can be characterized at each of these scales, but we considered the household and community scales to be most appropriate for our analysis. First, because national and local governments play a relatively minor role in determining capacity at these sites; second, because of the distinctness of rural coastal communities; and third, because practical initiatives to increase adaptive capacity typically focus on the community scale (Smit & Wandel 2006). Thus, our indicators of adaptive capacity mainly focus on the household and community scale, although national-level differences in development and government investment are reflected in the material assets and local infrastructure indicators. Each indicator was normalized then combined as a weighted score to provide a scale of adaptive capacity that also ranged from 0–1 (Methods, Figure 2). We plotted the communities' mean adaptive capacity against the predicted susceptibility of adjacent reefs to bleaching (environmental susceptibility) and examined how differing conservation actions may be appropriate across nations and sites in the WIO (Figure 1B).

Sites in Seychelles and Mauritius all had high adaptive capacity, but the countries differed considerably in their susceptibility to coral bleaching. Mauritian sites fell into the low environmental susceptibility, moderate adaptive capacity quadrant, where our framework suggests that a protectionist conservation policy, for example large marine protected areas, would meet conservation goals that local communities could cope with and potentially support. Conversely, Seychelles sites fell into the high environmental susceptibility, high adaptive capacity quadrant, suggesting a poor prognosis for their reefs, which will likely require active ecosystem management

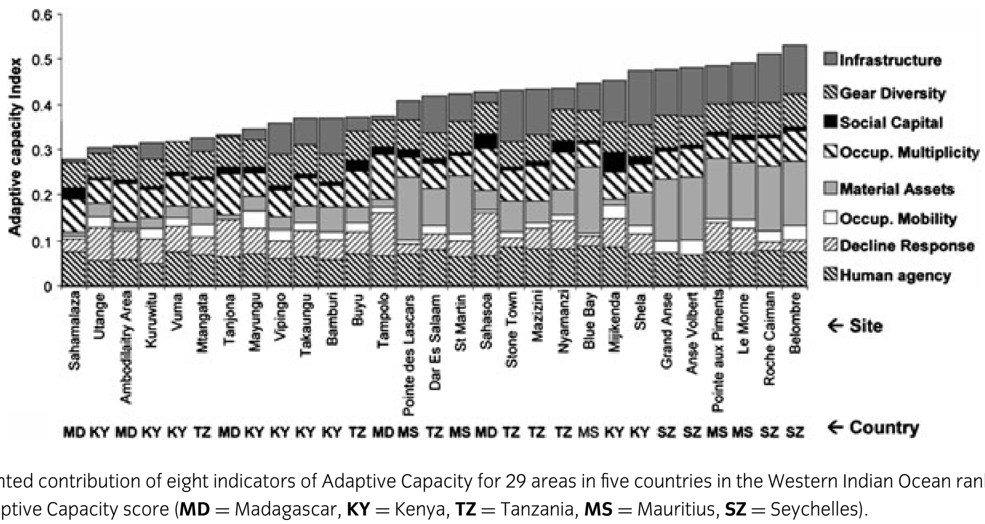

Figure 2 Weighted contribution of eight indicators of Adaptive Capacity for 29 areas in five countries in the Western Indian Ocean ranked according to their overall Adaptive Capacity score (**MD** = Madagascar, **KY** = Kenya, **TZ** = Tanzania, **MS** = Mauritius, **SZ** = Seychelles).

Table 1 Percentage of coral reefs in Kenya, Tanzania, Madagascar, Mauritius, and the Seychelles protected by no-take fishing closures

	Madagascar	Mauritius	Seychelles	Kenya	Tanzania
Area of coral reef (km^2)(Spalding *et al.* 2001)	2,230	870	1,690	630	3,580
No-take area (NTA)(km^2)(Gell & Roberts 2003); (Wells 2006)	10.4	8.5	255.7	54.3	66.0
NTA as % of reef area	0.5%	0.9	15.1	8.6	1.9

programs to recover from past coral bleaching episodes and prepare for future climatic change. These findings suggest strategies at odds with current conservation action in these countries. Mauritius, where reef preservation would provide the greatest long-term benefits, protects only 8.5 km^2, less than 1%, of its reefs, from fishing (the smallest area of any country we studied) (Table 1). The Seychelles, where reefs within and outside of parks have been, and we predict will continue to be, severely affected by climate-induced coral bleaching (Graham *et al.* 2007), has embraced a preservationist approach and protects 255.7 km^2, over 15%, of its reefs from fishing, the highest amount and proportion of the five countries (Table 1). In higher adaptive capacity countries, economic development strategies that lessen dependence on coral reef resources will reduce the vulnerability of their economies and livelihoods to climate change. In Mauritius and Seychelles these strategies include tourism, offshore fisheries, and services based on information technology.

Sites in Madagascar, Tanzania, and Kenya all showed low-to-moderate adaptive capacity, but highly variable environmental susceptibility (Figure 1B). Our framework suggests that development of adaptive capacity is a priority throughout these countries. Conservation strategies at sites with low environmental susceptibility should focus on integrated conservation and development with, for example, investments in income generation and livelihood diversification. In high environmental susceptibility sites it is essential that development strategies do not make local communities or industries more dependent on reef-based resources that are at risk. We find that the current conservation strategies in these countries are not aligned with the approaches suggested by our framework. For example, Kenyan reefs are susceptible to bleaching, suggesting that they are unlikely to sustain a high-quality tourist experience. Yet Kenya has a moderately large marine protected area fisheries closure system (8.6% of its reef area, Table 1) that is highly dependent on tourism. Therefore, the sustainability of this protection strategy under climate change scenarios is questionable. In Tanzania, some sites generally have higher adaptive capacity and lower environmental susceptibility, suggesting that investment in more protection could be effective. However, Tanzania currently lacks an effective system of large fisheries closures, protecting only 66 km^2 (1.9%) of its reefs from fishing. Most sites in Madagascar have low environmental susceptibility and consequently are expected to fare better than reefs in Tanzania and Kenya, yet currently only 10.4 km^2 (0.5%) of their reef area is protected (Table 1). The Madagascar government's commitment to triple the amount of protected areas is critical to regional conservation, but since Madagascar had extremely low overall levels of adaptive capacity, this must be accompanied by investing in community development efforts such that local people can cope and comply with, and benefit from protected areas.

Application of our novel framework to the WIO reveals that current conservation strategies are poorly prepared for climate change. We suggest that this could be improved by a regional approach to coral reef management that integrates development and conservation based on likely long-term outcomes. Our framework provides a basis for understanding the local context and then prioritizing pragmatic actions at the appropriate scale to manage social-ecological systems in the face of environmental change.

Incorporating adaptive capacity and environmental susceptibility into conservation planning will represent a significant shift in how many resource managers and donors approach conservation issues. We predict that the current emphasis on the creation of closures, which are expected to build ecological resilience and minimize climate change impacts through increasing grazing capacity and coral recovery trajectories (Worm *et al.* 2006; Mumby *et al.* 2007), will only work socially and ecologically in a limited region where high adaptive capacity and low environmental susceptibility intersect. Other areas will need to focus on enhancing adaptive capacity, which will require governments and donors to move beyond common measures to involve stakeholders in protected areas (i.e., consultation, participation, compensation), and may involve large investments in economic alternatives to reef-based livelihoods and programs to build social and physical infrastructure. Conservation policies based on integrated analysis of environmental susceptibility and adaptive capacity are more likely to result in actions that enhance the ability of reef ecosystems and local communities who depend on them to cope with both the expected and unexpected impacts of climate change.

Our framework is applicable to a wide range of social-ecological systems and stressors. The intensity of data collection and analysis required for our case study was high because adaptive capacity issues arising at the household and community scales are most relevant for this topic and region. However, metrics of adaptive capacity have been developed at a range of scales, using widely available secondary data (e.g., Yohe & Tol 2002; Tompkins & Adger 2005). Thus, depending on the particular topic under investigation, our framework may be applicable to situations where less-intensive data collection and postprocessing are required. Similarly, map-based environmental susceptibility models are being increasingly developed at a range of scales (e.g., Aragão *et al.* 2007; Baettig *et al.* 2007). Our framework could also be extended to consider additional axes such as local impacts on ecosystems, the strength of governance systems, or the ability of ecosystems to provide goods and services.

Case study methods

Predicting susceptibility to coral bleaching

Six environmental variables (mean and variation of seawater surface temperature [SST], available photoactive radiation [PAR], UV, chlorophyll a concentration, surface currents, and wind velocity) and past coral bleaching data were used to predict environmental susceptibility under climate change scenarios across the western Indian Ocean region (Maina *et al.* 2008). The model used in situ coral bleaching data from 216 sites taken from web archives (www.reefbase.org), field surveys in 2005 (McClanahan *et al.* 2007a), and published relationships between coral bleaching and environmental parameters to calibrate the fuzzy logic part of the model. Environmental parameters were normalized using the GIS fuzzy logic technique (Zadeh 1965). They were then weighted using spatial principal component analysis and the cosine amplitude-AHP method (Maina *et al.* 2008) before they were aggregated using the convex combination technique (Burrough & Mcdonnell 2005) to yield environmental susceptibility maps with continuous values ranging between 0 and 1. The model was evaluated and its predictive ability tested using coral mortality across the 1998 ENSO for 27 reef locations in the western Indian Ocean. The model had good predictive ability ($r^2 = 0.50$, $P = 0.05$) with the exception of northwestern Madagascar and this area will require further investigation to determine the factors that created lower coral mortality than predicted by the model. We used the model's environmental susceptibility predictions for ocean sites closest to the social surveys. Patterns in bleaching susceptibility are mainly explained by gradients of SST variation and PAR (Maina *et al.* 2008). Analysis of long time series in situ SST data indicates that the variable has not changed during the last > 50 years and there were no difference between El Niño-southern oscillation (ENSO) and non-ENSO years (McClanahan *et al.* 2007b). Similarly, there are no indications that PAR has changed.

Quantifying adaptive capacity

We defined adaptive capacity as the ability of households to anticipate and respond to changes in coral reef ecosystems and fisheries, and to minimize, cope with, and recover from the consequences. Based on this definition and previous literature (e.g., Brooks & Adger 2005), we collected data on eight indicators of adaptive capacity in 42 coastal communities (that were later pooled into 29 areas based on proximity and shared fishing grounds) in Kenya, Tanzania, Madagascar, Seychelles, and Mauritius (Table 2).

Communities were purposively sampled based on their use of coral reef resources that were included in ecological surveys. Purposive sampling of communities is an appropriate strategy for exploratory studies such as this (Agrawal 2001), although inferences from the data are constrained by the nonrandom selection of study sites. We used key informant interviews and household surveys to collect information on the eight indicators of adaptive capacity (Table 2). We surveyed a total of 1,564 households. Sampling of households within communities was based on a systematic sampling design (Henry 1990). We conducted between 23 and 143 surveys per site, depending on the population of the communities and the available time per site. Household surveys targeted household heads. In sites with a low density of fishers in the general population, additional systematic surveys were conducted from the population of fishers. Participant observations, oral histories, community transect walks, and secondary information (report, population censuses, etc.) was used to triangulate the results of our surveys.

To aggregate the eight indicators into an interval-level scale of adaptive capacity, we used the Analytic Hierarchy Process (AHP, Saaty 1980) methodology. Ten researchers individually made pairwise comparisons of the importance of the eight indicators, stating which was more important for adaptive capacity given the range of values for each indicator. The difference in importance between each pair of indicators was indicated on a 3-point scale (1 = same, 2 = slightly more important, 3 = much more important) and the resultant matrix was aggregated into a

Table 2 Indicators used to calculate adaptive capacity index

Indicator	Measurement
Recognition of causality and human agency in marine resources (Tompkins 2005)	Whether interviewee suggested factors that affect fish populations and/or interventions to improve fish populations
Capacity to anticipate change and develop response strategies (Brooks & Adger 2005)	Stated response of fishers to a hypothetical 50% decline in catches
Occupational mobility (Allison & Ellis 2001)	Changes of employment within last 5 years, whether forced or voluntary, and whether new occupation preferred.
Wealth (Pollnac & Crawford 2000)	Principal component of presence of 15 material assets: vehicle, electricity, television, gas or electric stove, fan, piped water, refrigerator, radio, video player, and the type of walls, roof, and floors
Occupational multiplicity (Allison & Ellis 2001)	Total number of person-occupations per household (square-root transformed)
Social capital (Pretty & Ward 2001)	Whether the interviewee is a member of community organizations
Technology (IPCC 2007)	Number of different gears used by fishing households (square-root transformed)
Infrastructure (Pollnac 1998)	Principal component of presence of 20 infrastructure items in the community. Infrastructure items adapted from Pollnac (1998) are as follows: hospital, medical clinic, doctor, dentist, primary school, secondary school, piped water, sewer, sewage treatment, septic tanks, electricity service, phone service, food market, pharmacy, hotel, restaurant, petrol station, public transportation, paved road, banking facilities.

weighting for each indicator using AHP. Bray-Curtis similarity indices between the different researchers' weightings ranged from 73% to 92%. An average of the weightings was used to calculate adaptive capacity for each household as the weighted sum of the eight indicators (normalized from 0–1) (Equation 1).

$$\begin{aligned} Adaptive\,capacity = {} & Recognition\,of\,causality \times 0.10 \\ & + Change\,anticipation \times 0.11 \\ & + Occupational\,mobility \times 0.11 \\ & + Occupational\,multiplicity \times 0.19 \\ & + Social\,capital \times 0.10 \\ & + Material\,assets \times 0.15 \\ & + Technology \times 0.13 \\ & + Infrastructure \times 0.12 \end{aligned}$$

Where data were missing at the household level (e.g., fisheries-related questions and nonfishing households), households were allocated mean community scores. The adaptive capacity of each community was then based on the mean of household scores. The resultant score has a theoretical range of 0–1, where a score of 1 would indicate a community where every household had the maximum score for all of the eight indicators. Across the range of sites surveyed here, the weighted contributions of community adaptive capacity indicators summed to a range of 0.28–0.53 (Figure 2).

Acknowledgments

Authors acknowledge the financial support of Western Indian Ocean Marine Science Association, Leverhulme Trust, Fisheries Society of the British Isles, the World Bank Coral Reef Targeted Research Program, EU Erasmus Mundus Programme, and Eppley Foundation; the institutional support of Universities of Mauritius and Dar es Salaam, Institute of Marine Science, International Institute for Geoinformation Science and Earth Observation, Tanga Coastal Zone Management Programme, Seychelles Fisheries Authority, Seychelles Centre for Marine Research and Technology—Marine Parks Authority, and assistance of our field staff. The article was improved through the comments of F. Berkes, T. Hughes, and two anonymous reviewers.

References

Adger, N. & Vincent K. (2005). Uncertainty in adaptive capacity. *Geoscience* **337**, 399–410.

Adger, W.N., Hughes T.P., Folke C., Carpenter S.R., Rockstrom J. (2005) Social-ecological resilience to coastal disasters. *Science* **309**, 1036–1039.

Agrawal, A. (2001) Common property institutions and sustainable governance of resources. *World Devel* **29**, 1649–1672.

Allison, E.H. , Ellis F. (2001) The livelihoods approach and management of small-scale fisheries. *Mar Pol* **25**, 377–388.

Aragão, L.E.O.C., Malhi Y., Roman-Cuesta, Saatchi R.M.S., Anderson L.O., Shimabukuro Y.E. (2007) Spatial patterns and fire response of recent Amazonian droughts. *Geophys Res Lett* **34**, L07701, doi:10.1029/2006GL028946.

Baettig, M.B., Wild M., Imboden D.M. (2007) A climate change index: Where climate change may be most prominent in the 21st century. *Geophys Res Lett* **34**, doi:10.1029/2006GL028159.

Brooks, N., Adger N. (2005) The determinants vulnerability and adaptive capacity at the national level and implications for adaptation. *Glob Environ Chang* **15**, 151–163.

Burrough, P., Mcdonnell R. (2005) *Principles of geographical information systems*. Oxford University Press, New York.

Clark, J.S., Carpenter S.R., Barber M. *et al*. (2001) Ecological forecasts: An emerging imperative. *Science* **293**, 657–660.

Gell, F.R., Roberts C.M. (2003) *The fishery effects of marine reserves and fishery closures*. WWF-US. [WWW document]. Available from URL http://www.californiafish.org/fishery_effects.pdf (accessed 6 Nov. 2007).

Goreau, T., McClanahan T., Hayes R. , Strong A. (2000) Conservation of coral reefs after the 1998 global bleaching event. *Conserv Biol* **14**, 5–15.

Graham, N.A.J., Wilson S.K., Jennings S., Polunin N.V.C., Robinson J., Daw T.M. (2007) Lag effects in the impacts of mass coral bleaching on coral reef fish, fisheries, and ecosystems. *Conserv Biol* **21**, 1291–1300.

Henry, G.T. (1990) *Practical sampling*. Sage Publications, Newbury Park.

IPCC. (2007) Summary for policymakers. Page 23 in M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden, C.E. Hanson, editors. *Climate change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge.

Maina, J., Venus V., McClanahan T.R., Ateweberhan M. (2008) Modeling ecological susceptibility of coral reefs to environmental stress using remote sensing, GIS and in situ observations: a case study in the Western Indian Ocean. *Ecol Mod* **212**, 180–199, doi:10.1016/j.ecolmodel.2007.10.033.

McClanahan, T.R. (1999) Is there a future for coral reef parks in poor tropical countries? *Coral Reefs* **18**, 321–325.

McClanahan, T.R., Marnane M.J., Cinner J.E., Kiene W. (2006) A comparison of marine protected areas and alternative approaches to coral reef management. *Curr Biol* **16**, 1408–1413.

McClanahan, T.R., Ateweberhan M., Graham N.A.J. *et al*. (2007a) Western Indian Ocean coral communities, bleaching responses, and susceptibility to extinction. *Mar Ecol Prog Ser* **337**, 1–13.

McClanahan, T.R., Ateweberhan M., Muhando C., Maina J., Mohammed S.M. (2007b) Climate change and spatio-temporal variation in seawater temperature effects on coral bleaching and mortality. *Ecol Monogr* **77**, 503–525.

Mumby, P.J., Hastings A., Edwards H.J. (2007) Thresholds and the resilience of Caribbean coral reefs. *Nature* **450**, 98–101.

Pollnac, R.B. (1998) *Rapid assessment of management parameters for coral reefs*. University of Rhode Island, Coastal Resources Center, Narragansett, Rhode Island.

Pollnac, R.B., Crawford B. (2000) *Assessing behavioral aspects of coastal resource use*. Coastal Resources Center, University of Rhode Island, Narragansett, Rhode Island.

Pretty, J. & Ward H. (2001) Social Capital and the environment. *World Devel* **29**, 209–277.

Saaty, T.L. (1980) *The analytic hierarchy process*. McGraw-Hill, New York.

Sanderson, E.W., Jaiteh M., Levy M.A., Redford K.H., Wannebo A.V., Woolmer G. (2002) The human footprint and the last of the wild. *Bioscience* **52**, 891–904.

SEG (Scientific Expert Group on Climate Change) (2007) Confronting the climate challenge: avoiding the unmanageable and managing the unavoidable. Page 144. *Report prepared for the United Nations Commission on Sustainable Development*. Sigma Xi, Research Triangle Park, NC, and the United Nations Foundation, Washington, D.C..

Smit, B., Wandel J. (2006) Adaptation, adaptive capacity and vulnerability. *Glob Environ Chang* **16**, 282–292.

Spalding, M.D., Ravilious C., Green E.P. (2001) *World atlas of coral reefs*. UNEP-WCMC/University of California Press, Berkeley, Los Angeles.

Tompkins, E.L. (2005) Planning for climate change in small islands: Insights from national hurricane preparedness in the Cayman Islands. *Glob Environ Chang* **15**, 139–149.

Tompkins, E.L., Adger W.N. (2005). Defining a response capacity for climate change. *Environ Sci Policy* **8**, 562–571.

Walther, G.R., Post E., Convey P. *et al*. (2002) Ecological responses to recent climate change. *Nature* **416**, 389–395.

Webster, P.J., Holland G.J., Curry J.A., Chang H.R. (2005) Changes in tropical cyclone number, duration, and intensity in a warming environment. *Science* **309**, 1844–1846.

Wells, S. (2006) Assessing the effectiveness of marine protected areas as a tool for improving coral reef management. Pages 314–331 inI.M. Côté, J.D. Reynolds, editors. *Coral reef conservation*. Cambridge University Press, Cambridge.

Worm, B., Barbier E.B., Beaumont N. *et al*. (2006) Impacts of biodiversity loss on ocean ecosystem services. *Science* **314**, 787–790.

Yohe, G., Tol R.S.J. (2002) Indicators for social and economic coping capacity: moving toward a working definition of adaptive capacity. *Glob Environ Chang* **12** 25–40.

Zadeh, L.A. (1965) The concept of a linguistic variable and its application to approximate reasoning. *Info Science* **8**, 199–249.

Editor: Dr. Corey Bradshaw