Building Resilience into Coral Reef Management: Key Findings and Recommendations

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Overview

Climate variability and change has emerged as a significant, over-arching threat to coral reefs globally. In this theme we identified ways in which climate change is impacting coral reefs and the people that depend on them, and we explored strategies that coral reef managers can employ to build resilience into coral reef management as a response. The findings and recommendations outlined here were developed during four workshops: "Integrating resilience into marine protected area (MPA) design"; "Management during mass coral bleaching events"; and a two-part session on "Adapting coral reef management in the face of climate change". The recommendations are based on sixteen case studies and the experience of workshop participants—coral reef managers, scientists, and policy specialists—who engaged in debating and synthesizing these challenging issues.

The take-home message of the theme is that climate variability and change are real, are a serious threat to tropical marine ecosystems and require immediate implementation of management strategies at local to global levels in response. An important output of this theme is the production of a statement for decision-makers on "Coral reefs and climate change"[2] that was subsequently adopted by ITMEMS conference participants. The major recommendations from that statement, as well as recommendations for coral reef managers and scientists, are presented here. Together they outline a call to action to:

1. Reduce the rate and severity of climate variability and change
2. Reduce local stressors to increase coral reef resilience to climate variability and change
3. Build constituencies for stronger coral reef management
4. Increase our understanding about how to identify, measure and support the socio-ecological resilience of coral reef ecosystems; and
5. Identify and remove barriers that impede adaptive responses to climate variability and change.

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[2] Available at http://www.itmems.org/final/Statement_coral_reefs_climate_change_FINAL.pdf

10 Key Findings

1. There is no longer any doubt that the earth's climate is changing, causing extensive coral mortality and impacting people that rely on reefs for food and income.

Warming seas are causing increased mass coral bleaching and mortality, with little evidence that corals and their symbionts can evolve fast enough to keep pace. The Global Coral Reef Monitoring Network (GCRMN) estimates that 16% of the world's reefs were destroyed as a result of mass coral bleaching in 1997-98. In 2005, unusually warm sea temperatures in the Caribbean caused mass coral bleaching in over 90% of corals and mortality in over 50% at many coral reefs, according to initial reports. In addition to causing coral mortality, mass bleaching leads to slower growth, reduced reproduction and increased vulnerability to diseases, all of which degrade the future structure and ecological function of coral reef ecosystems.

In addition to the impacts of mass bleaching, climate variability and change will affect tropical ecosystems in other ways. There is now strong evidence that acidifying seas are making it more difficult for corals to build their skeletons and withstand other compounding stressors. Other consequences, such as rapid sea level rise, increased intensity of tropical storms and impacts on other organisms and ecosystems (e.g., sea turtles, seabirds, seagrass beds, etc.), further emphasize the urgent need to limit the rate and extent of climate variability and change. Since coral reefs directly support at least 100 million people and multi-billion dollar industries, like tourism and fisheries, these changes will also have significant social and economic impacts, threatening livelihoods, industries and even food security in developing nations. For example, Moore and Best report that coral reefs support approximately 25% of the fish catch in developing countries. In Asia alone, this catch provides food to approximately one billion people[3] and provides a 'safety net' to vulnerable populations.

2. The future condition of coral reef ecosystems and the services they provide will depend on the rate and severity of climate variability and change.

Existing levels of greenhouse gases in the atmosphere mean that some climate change and degradation of coral reef ecosystems is inevitable. However, the rate and severity of climate change will influence the extent to which coral reefs are degraded and the extent to which coral reef ecosystem services are lost. Therefore, efforts to mitigate climate change will make a critical, and cost effective, difference to the diversity and spatial extent of future coral reef ecosystems.

3. Reef managers can take meaningful actions at a local level to increase coral reef resilience and "buy time" for reefs until actions to mitigate climate change can stabilize the global climate[4].

The ultimate cause of climate change—greenhouse gas emissions—is beyond the control of local coral reef managers. However, managers can respond to climate change by supporting the socio-ecological resilience of coral reef ecosystems. Socio-ecological resilience in this context is the ability of coral reef ecosystems and dependent human communities to cope with changes or stress without losing critical functions. It means, for example, that coral reef ecosystems regain coral dominance after a mass bleaching event, rather than shifting permanently to an algal dominated state. It also means that human communities that currently depend on reefs are able to maintain economic prosperity, social wellbeing and

[3] Report available at http://www.aaas.org/international/africa/coralreefs/ch1.shtml
[4] See also http://assets.panda.org/downloads/6chapter6.pdf

political stability despite changes to coral reef ecosystems resulting from climate change.

4. Managing for socio-ecological resilience represents a paradigm shift. Rather than having a goal to maintain circumstances as they are today, managing for resilience emphasizes protecting the factors that allow recovery after disturbance events.

It aims to support the ability of the environment and dependent human communities to absorb shocks, regenerate and reorganize so as to maintain key functions and processes. Additionally, managing for resilience recognizes that the future may well be determined by unexpected changes, and it values the ability to be responsive to surprises. Both short- and long-term strategies can be implemented to support socio-ecological resilience.

5. Effectively responding to mass coral bleaching events is one way of supporting socio-ecological resilience.

Unusually warm sea temperatures can affect coral reefs on spatial scales of hundreds to thousands of kilometres by causing mass bleaching events. These events are visually dramatic, as temperature-stressed corals appear a bleached white colour. They can also cause substantial coral mortality. Although coral reef managers cannot stop mass bleaching events on large spatial scales, they can respond to these events with strategies that support socio-ecological resilience. By predicting mass bleaching events, involving stakeholders in monitoring and communicating the impacts of mass bleaching, managers can create a constituency for broader coral reef conservation measures. Implementing monitoring programs before and during mass bleaching events—especially those built on partnerships with scientists and community members—generates information that is essential to understanding resilience and communicating the impacts of the event. However, managers are faced with many challenges in responding to mass bleaching events. Often there are not adequate resources (boats, trained observers and budgets) available to implement responsive monitoring programs. Additionally, managers may be under various political pressures to minimise discussion about climate change, mass bleaching or negative impacts on reef areas that are marketed as tourist destinations.

6. Coral reef managers can also identify and protect coral reef areas that are more resilient to climate change as a way of creating refugia that will "re-seed" more vulnerable areas.

Although climate change and mass bleaching affect large spatial areas, their impacts are patchy. Some corals and some coral reef areas are better able to resist heat stress, survive mass bleaching events or recover after climate-related disturbances. Several initiatives are currently developing approaches for identifying the resilience of coral reef and mangrove areas to climate change. These approaches use information about past responses to stressful climatic events and characteristics that are thought to confer ecological resilience. Most approaches are currently experimental and rely on strong monitoring programs, but are likely to lead to important insights to guide future management in the face of climate change.

7. Traditionally, principles of MPA selection, design and management have not specifically considered the threat of climate variability and change.

Integrating additional considerations, identified by The Nature Conservancy and partners[5], into existing or future MPA networks will optimise the role MPAs can play in supporting coral reef ecosystem resilience to climate change. Four key measures need to be incorporated into contemporary reef management in the context of climate change. First, MPA networks can aim to create a network of refugia to re-seed damaged reefs by providing extra protections to areas that resist or tolerate mass bleaching. Second, MPA networks can maximise biological diversity by including representative areas of all habitat types in highly protected zones. Third, incorporating knowledge about connectivity by linking highly-protected areas along prevailing, larvae-carrying currents can increase the probability of recovery at multiple coral reef sites. Fourth, management interventions, such as responding to threats like sedimentation and nutrient run-off, may be able to maintain or restore elements of coral reef condition that confer resilience. Enhanced recovery of reefs provides many benefits for fisheries, tourism and sustainable development.

8. Multiple, synergistic stresses associated with climate change and local activities are now threatening coral reef ecosystems. Reducing or eliminating local to regional, non-climate stressors can increase the system's ability to absorb climate-related stressors and to recover after disturbance events.
High coral cover, high biological diversity, abundant fish populations (particularly herbivores) and good water quality support recovery after high mortality on coral reefs. Additionally, reducing stresses during mass bleaching events, such as those from intensive tourism or coastal development, can help corals survive and recover from these events.

9. Partnerships with reef-dependent stakeholders are essential to supporting socio-ecological resilience.
Coral reef stakeholders will be affected by degradation of coral reef ecosystems and can become powerful actors in efforts to build socio-ecological resilience. Working with stakeholders to understand how climate change is affecting reefs can empower them to become advocates for climate change mitigation and coral reef management interventions. Additionally, it supports the social resilience of reef users by improving their ability to anticipate and plan for climate-related changes. There are now examples of coral reef managers working with stakeholder communities to develop climate change action strategies, such as one developed by marine tourism operators in the Great Barrier Reef, Australia.

10. There are institutional barriers to implementing management for socio-ecological resilience in response to climate change.
Challenges to implementation may stem from resource limitations, mismatches between the scale of the problem and the scale at which management occurs, lack of vertical and horizontal integration within and between relevant organisations, and a lack of belief that management interventions can produce meaningful results. Resource limitations can include lack of funding for activities or lack of available staff time. Existing staff members typically have full work schedules, which limits time and energy available for planning or implementing actions to build resilience into coral reef management.

Many of the challenges that are common in coastal management become more pronounced and problematic in the context of climate change. There are mismatches between the spatial areas that are relevant to ecosystems and political boundaries that separate management jurisdictions. There is a similar disconnect

[5] Available from http://www.reefresilience.org/

between the 1 to 10 year timeframe that drives many government planning cycles and timescales that are meaningful to ecosystem recovery. Aligning or integrating the knowledge, support and technology needed to empower implementation by relevant partners is complicated by differing organisational mandates and priorities. Ecosystem-based management and integrated coastal management offer theoretical paradigms for responding to these barriers; however, practical implementation of mechanisms for overcoming such institutional barriers at local to global scales is still difficult.

Additionally, in many places there remains a lack of awareness about the ability to implement management actions that can provide meaningful benefits to ecosystems that are increasingly stressed by climate change. Unless information about the problems that climate change places on coral reefs is complemented with options for responding, the issue is unlikely to gain political traction. The following sections recommend worthwhile actions that can be implemented by coral reef managers, senior decision-makers and manager-scientist partnerships in response to climate variability and change.

Major Recommendations for Coral Reef Managers

1) **Reduce local stressors to increase the ecosystem's capacity to absorb additional climate change-related stress and recover after damaging events.**
    a) Responding to climate change and managing for resilience means that on-going work to minimise and remove other local to regional stressors to tropical ecosystems becomes even more important.
    b) High coral cover, good water quality, healthy fish populations—particularly herbivores—and biological diversity are all factors that help coral reefs survive and recover from climate-related stress. Implementing management actions that maintain or restore these conditions is essential in resilience-based management.

2) **Develop a coral bleaching response plan and commit to its implementation during mass bleaching events[6]. The plan can include strategies to:**
    a) Predict the on-set of mass coral bleaching events using NOAA Coral Reef Watch satellite products[7] and volunteer observers.
    b) Conduct ecological assessments of mass bleaching using standard assessment methods that are appropriate to the technical capacity of observers[8].
    c) When sea temperatures are unusually warm, report the status of mass coral bleaching to ReefBase[9].
    d) Work with social scientists to conduct socio-economic assessments of the impacts of mass bleaching.
    e) Communicate about mass coral bleaching and associated mortalities to decision-makers, the media, key stakeholder groups, colleagues and the public before, during and after mass bleaching events. Before events, provide basic information and predictions about the likelihood of mass bleaching. During and after events, communicate the ecological and socio-economic impacts. Specific stories and examples of impacts can be effective communication tools.

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[6] *A Reef Manager's Guide to Coral Bleaching* provides an example of a coral bleaching response plan. It can be downloaded from http://www.coris.noaa.gov/activities/reef_managers_guide/welcome.html
[7] Available from http://coralreefwatch.noaa.gov/
[8] See *A Global Protocol for Assessment and Monitoring of Coral Bleaching* available at http://www.reefbase.org/projects_partners/projects.aspx?projectid=8
[9] Submit data at http://www.reefbase.org/contribute/bleachingreport.aspx

f) Minimise local stressors during mass bleaching events, such as snorkelling access to shallow reefs, physical contact with the corals by snorkelers and divers or permitting activities that will increase sedimentation from coastal development.
g) Develop resources needed to implement the bleaching response plan—such as staffing, budgets, boats, etc.—by establishing partnerships, fund-raising and working with decision-makers to create appropriate contingency funds.

3) Incorporate socio-ecological resilience principles into marine protected area design and management.

a) Creating appropriate and adequate buffers for ecosystems to respond to climate change is a key strategy for supporting resilience. Therefore, establishing highly protected areas for representative habitat types is important in resilience-based management. The general wisdom is that at least 30% of each habitat must be represented within highly protected areas for this strategy to be effective.
b) Replicating highly protected areas for representative habitat types in multiple areas provides a further way to spread the risk of climate change. Because the impacts of climate change are also influenced by local conditions, replication increases the chances that some areas will be able to survive climate-related impacts. Reefs within such refugia can 're-seed' areas that experience more severe impacts and, consequently, higher mortality.
c) Areas that might be expected to be more resilient to climate change can also be identified and singled out for additional protections as a way of preserving additional 'seed-banks' to support the recovery of damaged areas.
d) A range of strategies and variables can be used to identify areas that may be more resilient to climate change in general and mass coral bleaching in particular. One approach is to look at how areas have responded to past climatic events. Another is to measure variables that suggest resilience, such as ratio of live to dead coral, range of coral colony size and age distribution, or high species diversity. Refining techniques for identifying resilient areas is a key priority for science-management partnerships.
e) Monitoring programs that include baseline data and measure a suite of factors that can suggest the degree of resilience are valuable for informing MPA design in the context of climate change.
f) The participation of local stakeholders and governments in MPA design is essential to bringing knowledge and political support to the process.

4) Be prepared to manage adaptively.

a) Do not assume that the reef you manage will respond as it has historically. Climate change causes subtle changes that may not be properly recognized if you are not considering your reef under a changing climate. Past recovery does not ensure future recovery.
b) Since the likelihood of surprises is greatly increased, adaptive management becomes more important in the context of climate change . Incorporating institutional mechanisms that allow flexibility and enhance learning and collaboration, such as the creation of stakeholder advisory groups, will facilitate managers' ability to respond to surprises.

5) Engage stakeholders to build constituencies that advocate and support actions to mitigate climate change and reduce non-climate stressors to coral reef ecosystems.

a) Partner with stakeholders (e.g., tourism, fisheries) to raise awareness about the risks from climate change.
b) Include messages about climate change impacts in on-going communication strategies to increase support for personal and government actions in response to climate change.
c) Develop a climate change response plan through a participatory process.
d) Foster and support leadership by stakeholders in efforts to mitigate climate change or enhance resilience.

6) Provide decision-makers with options for responding to the threats that climate change poses to coral reef ecosystems and the people that depend on them.

a) Provide information about resilience-based strategies for responding to climate change impacts and the costs of not responding to climate change impacts on reefs and dependent human communities.
b) Develop science-based recommendations that help government leaders define priorities for MPA networks, fisheries regulations, water quality management and mitigation of climate change.

Major Recommendations for Decision-makers and Funders

1. Limit climate change to ensure that further increases in sea temperature are limited to 2^{o}C above pre-industrial levels and ocean carbonate ion concentrations do not fall below 200 _mol. kg^{-1}.
2. Recognise that mass coral bleaching will have similar social and economic consequences as other environmental disasters such as oil spills and droughts and will require similar responses.
3. Facilitate and finance actions to increase resilience of coral reef social-ecological systems, particularly through marine management area networks comprising adequate areas of coral reefs and associated habitats in non-extraction zones, protection of water quality and herbivore populations, and adaptive governance.
4. Facilitate and finance assessments of risk and vulnerability of coral reefs to climate change.
5. Facilitate and finance the development and implementation of coral bleaching response programs, including contingency funding.
6. Create incentives for development of partnerships for adaptation.
7. Increase investments in targeted messages to accelerate adaptation to climate change.
8. Invest in village-to-global education and communication for climate adaptation that will integrate traditional and scientific knowledge into implementation of adaptation strategies for coral reefs around the world.

Major Recommendations for Science-management Partnerships

1) Monitor changes due to climate change:
   a) Assess the ecological impacts of mass coral bleaching events
   b) Assess the social and economic impacts of mass bleaching events & other climate change issues
   c) Review and analyse existing data to estimate baseline conditions

   d) Take advantage of the knowledge that mass bleaching events are intensifying both spatially and temporally and try to anticipate future events with monitoring and research.

2) Develop methods for measuring and monitoring ecosystem resilience.
3) Identify and prioritize strategies for maintaining or restoring social and ecological resilience.
4) Work with stakeholders to determine options for mitigation and adaptation, such as shading reefs that are highly valued by tourism operators during unusually hot weather.
5) Evaluate the effectiveness of strategies to support resilience in terms of biophysical and socio-economic outcomes as well as operational aspects of management.
6) Develop strategies for raising broader community awareness about the scientific basis for projections of climate change impacts and the benefits of reducing greenhouse gas emissions.

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