10. Managing for Mass Coral Bleaching: Strategies for Supporting Socio-ecological Resilience

Heidi Schuttenberg and Paul Marshall

Introduction

This volume documents the severe consequences that climate change is predicted to have for coral reefs worldwide. While there are expected to be many impacts on coral reefs from climate change, the most immediate and dramatic are associated with rising sea temperatures and resultant mass coral bleaching events. These events have already been responsible for long-term damage to more than 16% of the world's reefs and with causing serious, although largely unmeasured, hardship for the people who depend on the reefs. As evidence of these socio-ecological impacts grows, so does attention on the associated management question: ***are there any actions that coral reef managers can implement to help reefs in the face of climate change?***

Traditional management approaches that focus on minimizing or eliminating sources of stress can not address the threat of mass coral bleaching. Coral reef managers are unable to directly mitigate the main cause of mass bleaching; above average water temperatures. This makes mass bleaching a uniquely challenging environmental management problem.

In working with colleagues from around the globe to compile the publication, *A Reef Manager's Guide to Coral Bleaching* (see ref. 5), we determined that there is much that managers can do to help reefs cope with climate change. While reef managers cannot directly limit climate change, there is a rapidly growing body of scientific knowledge that provides the basis for a meaningful response to climate-related threats, such as coral bleaching. Central to this response are strategies for supporting the resilience of coral reef ecosystems and the people that depend on them. This chapter presents the key elements of a resilience-based approach to managing coral reefs in the face of climate change, focusing on:

- Defining socio-ecological resilience;
- Describing the process through which unusually high sea temperatures can lead to loss of the ecological services that reefs provide to people;
- Identifying management opportunities that exist at each stage of this process to minimize negative impacts; and,
- Recommending 5 strategies for supporting socio-ecological resilience to mass coral bleaching.

What Does it Mean to Manage for Socio-Ecological Resilience?

Resilience comes from the Latin, 'resilere', which means 'to spring back'. Managing for socio-ecological resilience recognizes that a process of uncertain change is underway, and it aims to support the ability of the environment and dependent human communities to absorb shocks, regenerate, and reorganize to maintain vital functions and processes. Importantly, socio-ecological resilience explicitly considers that social and ecological systems are intrinsically linked and that the resilience of each component of the system is related to its linkages to other components.

For ecosystems, resilience can be characterized as the capacity to maintain the provision of ecosystem goods and services. For coral reefs, this may mean the capacity of the ecosystem to maintain a dominance of hard corals, adequate structural (habitat) complexity, and positive rates of reef growth. A reef system with low resilience would readily lose coral cover, potentially become dominated by algae, provide reduced habitat, and have a net erosion of reef material. The factors that support coral reef ecosystems' resilience to mass bleaching events can be broadly grouped into 4 categories: ecosystem condition; biological diversity; connectivity between areas; and local environmental conditions.

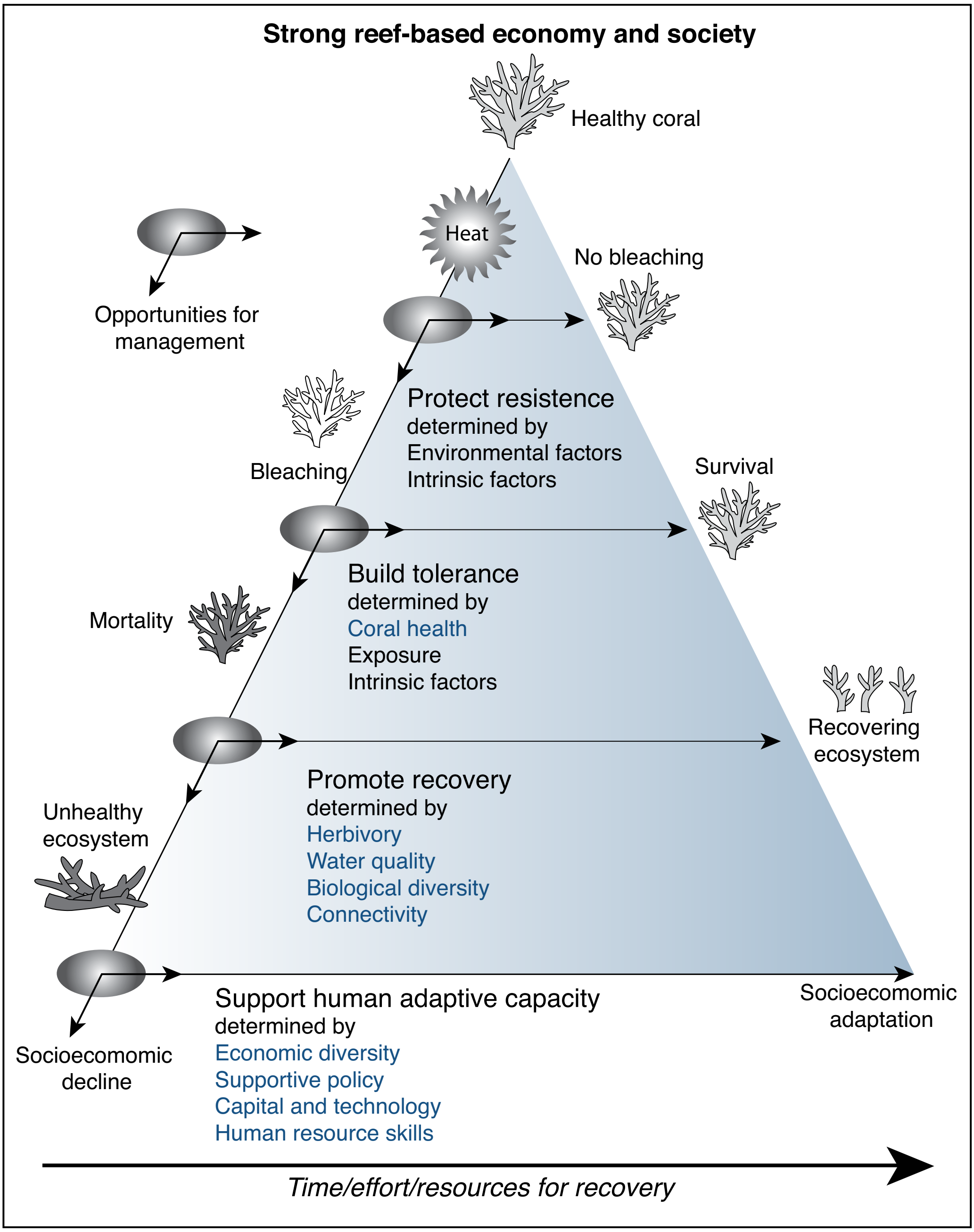
For social systems associated with coral reefs, resilience is determined by the ability to cope with changes in the availability or quality of the goods and services provided by coral reefs. Resilient social systems have the capacity to anticipate, prepare, and adapt to change to minimize the effects on social and economic well-being. The factors that determine the resilience of dependent human communities when coral reefs degrade include people's skills, resources, attitudes, resource dependency, and attributes of their broader socio-ecological context (4).

Managing for resilience differs from traditional coral reef management in 2 ways. Rather than having a goal to maintain circumstances as they are today, managing for resilience emphasizes protecting the factors that allow the socio-ecological system to respond successfully to disturbance events. Managing for resilience also recognizes that the future may well be determined by unexpected changes, and emphasizes the ability to respond to surprises. We explore how resilience principles can be integrated into coral reef management.

Opportunities to Support Socio-Ecological Resilience to Mass Bleaching

Four successive conditions determine the ultimate impacts of mass coral bleaching following a regional heat stress event, and each can be a potential focus for management action; as illustrated in the figure below: 1) 'bleaching resistance' determines how corals within the area of a regional heat stress event are bleached; 2) if corals do bleach, 'coral tolerance' determines how corals either die or regain their zooxanthellae and survive; 3) if there is widespread coral mortality, 'reef recovery' determines how the coral reef ecosystem can recover and maintain the characteristics of a coral-dominated ecosystem; and 4) if the coral reef ecosystem remains degraded, 'human adaptive capacity' determines how human communities will experience negative socioeconomic consequences.

Each condition is influenced by a suite of factors that combine to determine the resilience or vulnerability of the system. Factors vary in how much they can be changed through management interventions, their relative influence, and the scale (coral colony, ecosystem, or human community) at which they are expressed. The following sections discuss these opportunities for management.



This diagram illustrates the possible opportunities for management intervention in coral reefs that are stressed by a coral bleaching event. Four conditions determine the final outcome: bleaching resistance; coral tolerance; reef recovery; and human adaptive capacity. Each is influenced by factors that can determine the resilience or vulnerability of the system. Factors that can be influenced by local management actions are colored blue. Factors that cannot be influenced are colored black, although these should be considered in the design and placement of management actions to enhance ecosystem resilience (adapted from 6).

Take advantage of resistant coral areas

When regional sea temperatures become unusually high, the effects on coral reefs are variable. Although many corals will bleach, some will not. ***What determines the ability of some corals or reef areas to resist bleaching? How can areas that are resistant be used to increase overall resilience of coral reef ecosystems to global climate change?***

A combination of environmental and intrinsic factors determines whether corals eject their zooxanthellae or whether they resist bleaching during a regional heat stress event. Local environmental conditions can support resistance to bleaching by buffering how corals are exposed to unusually high sea temperatures or to sunlight. Three mechanisms can offer protection: shading; cooling; and screening. For example, mountains or cliffs on adjacent land offer shade to some patches of reef, as seen in the high islands of Palau. Some sites may have consistently cooler water as a result of upwelling or proximity to deep water. Sediment and organic matter in turbid waters seems to support coral resistance to bleaching by screening out sunlight; however, unnaturally turbid conditions can also seriously stress corals, thereby undoing any benefits. An additional environmental mechanism providing bleaching resistance is flushing. Strong currents may remove toxins that are the physiological trigger for bleaching, thereby helping corals cope with warmer conditions (7).

Intrinsic factors that influence resistance to bleaching at the colony level include the individual history and genetic composition of the coral and its symbiotic zooxanthellae. This translates to important differences in the bleaching susceptibility of different coral communities. For example, massive, boulder-shaped corals (such as *Porites* and *Favia*) tend to be more resistant to bleaching than branching and plate forming corals (such as *Acropora* and *Pocillopora*). Corals also have some ability to acclimatize to heat and light stress if they are able to survive stressful conditions. Past exposure of coral colonies or communities to stressful conditions can lead to an increased resistance to future bleaching events. The ecological significance of this mechanism is still being examined, because acclimatization of colonies is often short-lived and acclimatization at the community level is often a result of the less resistant corals being lost (3).

Coral reef areas that are naturally resistant to mass bleaching can be incorporated into the design and placement of management initiatives to enhance the overall resilience of the ecosystem. Some consideration has been given to the feasibility of methods for increasing the resistance of other reef areas to bleaching. Such strategies are unlikely to be practicable or cost effective at sufficiently large spatial scales to provide meaningful protection to ecosystems. However, it may be possible to shade, screen, or cool high-value (small) tourism sites to increase their bleaching resistance. These strategies are currently experimental and have the potential for unwanted side effects. They are probably best accomplished through partnerships between industry, scientists, and managers.

Build coral tolerance to mass bleaching

When corals lose their zooxanthellae and bleach, they are not dead. Some bleached corals will survive the heat stress event and regain their zooxanthellae populations; however, corals that bleach but survive the event are in a weakened state. They will probably have lower reproductive capacity, slower growth rates, and greater susceptibility to disease. The ability to survive bleaching events is significant in terms of recovery time. While it may take months or years for corals to recover from the sub-lethal effects of bleaching, it takes years to decades for reefs to recover after high coral mortality. Therefore, promoting coral survival during bleaching events is a particularly efficient focus for management. ***What allows some corals to be tolerant to mass bleaching? Can management actions be taken to build tolerance and minimize the impacts of mass bleaching events?***

Coral health prior to exposure to heat stress may be the most important factor influencing colony survivorship during bleaching events. Most corals rely heavily on the energy provided by their zooxanthellae, and bleaching effectively robs them of their main energy source. As a result, corals in a bleached state are beginning to starve, and their ability to endure this hardship is likely to be important in determining whether they survive. Like many animals, corals store surplus energy as lipids (fats); corals in good condition have relatively high lipid levels, providing a buffer against periods of low energy supply. For this reason, it is thought that the condition of a coral at the time it bleaches may play a crucial role in determining whether it will survive the period of starvation that follows. Conversely, chronic or acute stresses (such as water pollution or anchor damage) that negatively affect coral condition could increase the risk of corals dying of the additional stress from bleaching (1). Therefore, reducing localized stressors is an important strategy to help corals survive bleaching events.

Some corals, especially species adapted to turbid environments, rely heavily on food particles captured from the water column (heterotrophy) to supplement their energy requirements. These corals may be less dependent on the energy provided by their zooxanthellae and thus less prone to starvation during a bleaching event. A better understanding of coral nutrition could help managers identify tolerant coral communities, allowing them to be incorporated into networks of refugia to enhance overall ecosystem resilience.

Coral health and heterotrophy help increase coral tolerance to bleaching when the heat stress causing a bleaching event is moderate. Heat stress above a critical temperature threshold, however, causes direct physiological damage to corals, exceeding any nutritional factors and leading to death. Both environmental and intrinsic factors are important in determining the extent to which this happens. Thus, local environmental factors have an important influence on the amount of heat stress to which a coral is exposed. Similarly, intrinsic factors, such as genetics, influence the threshold temperature at which a coral dies; some species are able to tolerate higher temperatures than others. These factors contribute to patterns of natural tolerance that can be built into management planning.

Promote coral reef recovery
The rates at which corals can adjust to increases in heat stress are widely considered to be too slow to keep pace with even conservative climate change projections (Chap. 2). As a result, it is unlikely that coral reefs will continue to exist in their current condition. Instead, they will increasingly be in a state of recovery. ***What factors encourage successful ecosystem recovery after mass bleaching events or when other stresses associated with climate change cause high levels of coral mortality? What management actions can be taken to restore or maintain these factors?***

Coral reefs will not necessarily recover to become the same types of reefs they were prior to being severely damaged. The goal in managing for resilience is to have a recovery process that maintains vital functions and processes, even if the coral reef itself looks quite different from its pre-disturbance state. Ecosystem condition, biological diversity, and connectivity all contribute to ability of the ecosystem to recover to a coral-dominated system, rather than shifting to an algal-dominated state.

Reefs suffering high coral mortality require a long recovery process of recolonisation by coral larvae and asexual reproduction (such as fragmentation) by surviving corals. Successful recruitment depends on many conditions. These include the presence of 'source' reefs to generate new larvae, good water quality that allows spawning and recruitment to succeed, and both strong herbivore (plant/algae eaters) populations and good water quality to ensure there is suitable clear coral rock available for new coral recruits.

High biological diversity supports ecosystem recovery by increasing the chance that vital functions will still be performed despite some degradation of the system. When a diversity of species fulfill a function (for example, branching corals providing habitat for small fish), the loss of a single species will not lead to loss of the function. This 'functional redundancy' is a major quality of resilient systems. A system is less prone to collapse when crucial functions are performed by multiple species that respond differently to stress or disturbance events (called response diversity).

Connectivity plays a central role in determining the capacity of a system to recover or reorganize following a disturbance, by influencing the likelihood that damaged reefs will be replenished from 'seed' reefs or refugia. Much of the connectivity in reef ecosystems depends on intact and healthy non-reef habitats, such as inter-reef hard bottom communities, mangroves, or seagrass beds. These non-reef habitats are particularly important to maintain and regenerate populations, and they will become increasingly critical as reef systems spend more time in recovery mode.

There is ample evidence that coral ecosystems in good condition will recover from coral mortality more successfully than degraded reefs. Healthy reefs are better able to provide the conditions required for the recruitment, survival, and growth of new corals after established corals have been killed by bleaching. Good water quality, an abundant and diverse community of herbivorous fish, and high coral cover are vital aspects of ecosystem quality that facilitate recovery. Therefore, management of local fisheries, water quality, and tourism strongly influence the rate and success of recovery and future coral reef resilience.

Support human adaptive capacity

In addition to supporting ecosystem resilience, actions can be taken to support the human communities that depend on coral reefs, such as fishers and tourism operators. There may be a question as to whether it is appropriate for coral reef or marine protected area (MPA) managers to engage in supporting human adaptive capacity to the affects of climate change. Yet, it is important to recognize that changes in resource condition are likely to result in changes in the patterns of resource use. Engaging with stakeholders during this reorganization will allow managers to build alliances, and gain knowledge and influence to help in effectively adapting management regimes to the new circumstances. As climate change makes life less predictable for resource users and managers, such cooperative, adaptive approaches will be essential to maintain socioeconomic well-being and achieve responsive, effective natural resource planning and management.

People's ability to adapt to degraded coral reefs will depend on their own skills, resources, attitudes, and how their livelihoods are dependent on good coral reef condition, as well as the broader socioeconomic context in which they live. Resource users who have good skills for planning, learning and reorganizing, good financial and social resources, and confidence in their abilities and prospects are likely to be more resilient. Further, meaningful involvement in decision-making on natural resource management can increase user confidence and, concurrently, social resilience to changes in resource access resulting from the impacts of coral bleaching or through changes in management arrangements (4).

Resource dependency and broader socioeconomic issues will also influence how reef users can successfully diversify their activities when coral reefs become degraded. For example, recent studies suggest that dive businesses in population centers are likely to be more capable of responding to changes in reef quality caused by mass bleaching. These operators can shift from a marketing strategy of providing high quality dive sites for experienced divers to a business that provides instruction for new divers or even to boating experiences for non-divers. In comparison, mass bleaching may significantly affect businesses that take divers to remote locations, renowned for exceptional coral reef quality. Tourists may be unwilling to travel so far when high quality reefs are no longer on offer, and businesses in these remote locations may have limited options for business diversification (2).

As coral reef condition degrades, reef users will probably change their resource-use patterns; these changes will have important implications for coastal environmental quality. For example, dive operators may seek ways of establishing artificial reefs. As coral reef fisheries decline, interest and investment in aquaculture may increase. By engaging with stakeholders during this process, coastal managers will have the best chance of developing and implementing strategies that can meet goals for ecological as well as socioeconomic sustainability.

An Agenda for Action

Global climate change and mass coral bleaching are now considered among the greatest threats to the future condition of coral reefs and the services they provide. Although, it may be difficult to see how coral reef managers can respond to such global threats, a closer look at the discussion above reveals that opportunities for management action are present at each stage of the coral bleaching process. The strategies described below suggest ways to take advantage of these opportunities to support the socio-ecological resilience of coral reefs to global climate change. They also illustrate how managers can influence efforts to limit the rate and severity of global climate change. Mitigating climate change will require action by senior decision-makers working in climate change policy forums; however, coral reef managers have an important role to play in informing decision-makers and the general public about the affects of global climate policy on reefs. By taking action on these 5 strategies, coral reef managers will give reefs the best chance of responding to changes in global climate.

Strategy 1. Support efforts to limit sea temperature increases to 2ºC and maintain ocean carbonate ion concentrations above 200 µmol kg^{-1}.

The rate and extent of warming will determine the window of opportunity for reefs to adjust through acclimatization, adaptation, and other ecological shifts. For example, fewer and less intense sea temperature anomalies will reduce the frequency and severity of bleaching events. Subsequently, this will allow more time for reefs to recover between events that do occur.

These relationships mean that the effectiveness of broader efforts to reduce the rate and extent of global climate change will have significant implications for the effectiveness of local management initiatives. Implementing local management actions, such as those below, will enhance the resilience of coral reefs and 'buy time' to implement actions that will reduce the impacts of global climate change. However, if moderate or pessimistic projections for climate change eventuate, the resulting effects on reefs may overwhelm local management efforts aimed at maintaining coral-dominated systems.

The targets for action at a global level were articulated by coral reef managers and scientists at the 3rd International Tropical Marine Environment Management Symposium (ITMEMS) in October 2006. Conference participants adopted the 'Coral Reefs and Climate Change' statement, which called on senior decision-makers to "limit climate change to ensure that further increases in sea temperature are limited to 2oC above pre-industrial levels and ocean carbonate ion concentrations do not fall below 200 $\mu mol.kg^{-1}$" (http://www.icriforum.org/secretariat/japangm/docs/Coral_Reefs_Climate_Change_Brief.pdf). These recommendations were based on published projections of the temperatures at which severe bleaching events become an annual phenomenon and reef calcification rates become negative (Chap. 2).

Coral reef managers can provide a powerful impetus for policy responses to climate change by generating their own compelling stories about the plight of reefs under their jurisdiction. Reef managers can document and communicate about the ecological and socioeconomic effects of mass coral bleaching, like those in the Caribbean during 2005. Two publications listed in the references that offer technical guidance on evaluating the impacts of mass bleaching are *A Global Protocol for Assessment and Monitoring of Coral Bleaching* (7) and *A Reef Manager's Guide to Coral Bleaching* (5). The latter offers suggestions for communicating about mass coral bleaching with key audiences (e.g. decision-makers, stakeholders, colleagues, and the general public) before, during, and after bleaching events.

Strategy 2. Integrate resilience into Marine Protected Area networks.
MPAs are important tools in coral reef management and can help achieve many of the management goals identified above. Traditionally, the principles of MPA selection, design, and management have not specifically addressed the threat of mass bleaching. Integrating the following considerations into existing or developing MPA networks will optimize the role MPAs can play in supporting coral reef ecosystem resilience to mass bleaching:

- *Refugia* - Sites with natural resistance or tolerance to mass coral bleaching should be considered as sites warranting high protection in MPA networks. These 'lucky' areas can serve as source reefs that provide new coral larvae to more
- *Representation and replication* – To maximize biological diversity, MPA networks should aim to provide high levels of protection to sufficient areas of all habitat types. Rather than only protecting certain kinds of reefs, networks should aim to include representatives of all reef types and associated habitats at replicate sites. This is a risk-spreading approach that helps to account for the uncertainty associated with global climate change.
- *Connectivity* – Incorporating knowledge about connectivity into the selection and arrangement of sites that will receive higher levels of protection can promote recovery after mass bleaching and other disturbances. Linking highly-protected

areas along prevailing, larvae-carrying currents can replenish downstream reefs, increasing the probability of recovery at multiple coral reef sites. Non-reef areas adjacent to highly-protected reefs may also warrant increased protection because they can become staging areas for coral recruits as they move between reefs.

- Good ecosystem condition – High coral cover, abundant fish populations, and good water quality are all elements of coral reef health that support recovery. Maintaining, enhancing, or restoring these valuable characteristics through management interventions are easier to achieve in some areas than others, because of various attributes of site location and use. In developing MPA networks, it is useful to consider whether additional management protection can be effective in maintaining these resilience-supporting qualities of ecosystem condition.

These principles are already being implemented into MPA networks around the world, including: Palau; the British Virgin Islands; Belize; the Seychelles; Yemen; and the Maldives. The Nature Conservancy's Reef Resilience (R2) Toolkit (8) or website (www.reefresilience.org) has a more detailed discussion of how to identify resilient areas and incorporate these areas into MPA design.

Strategy 3. Reduce local stressors to build coral tolerance to bleaching.
Global climate change will add stress to coral reefs; therefore the removal of local stressors can help corals respond to these new, difficult conditions. Removing chronic local stressors caused by intensive tourism use, water pollution, or over-fishing can increase coral reef health and lipid levels. Corals with higher energy reserves are more likely to survive a bleaching event.

Removal of acute stressors to corals during bleaching events is also likely to increase their ability to survive. Bleached corals are extremely stressed and have a reduced capacity for maintenance of essential functions, such as injury repair, resistance to pathogens, and defence against competitors. A stressed coral is less capable of recovering from physical injuries caused by careless snorkeling, diving, and boat anchoring. Repair of even minor tissue damage may be hindered for a stressed coral, thereby increasing the risk of infection or overgrowth by competing organisms. Acute increases in sediments and pollutants from coastal development or dredging will deliver additional stress to corals that must clear sediment from colony surfaces, wasting precious physiological resources. Bleached corals are also less effective at defending against invasion by microalgae or competing with macroalgae. These coral competitors benefit from increases in nutrients or reductions in the herbivorous fish populations that consume them. Therefore, management can promote coral survival during mass bleaching events by limiting damage from recreation, degraded water quality, and fishing pressures.

Strategy 4. Protect, maintain or enhance the conditions that promote ecosystem recovery.
Coral cover, water quality, and herbivorous fish abundance are critical in determining reef recovery through their influence on processes, including: larval supply; availability of substrate for settlement; coral recruitment rates; and survival of juvenile corals. Traditional management strategies may be based on the assumption that reefs are likely to continue in relatively stable condition. As reefs spend more time in recovery mode, management targets may need to become more conservative to achieve satisfactory water quality, fish abundances, and coral cover. For example, water quality standards and fishery management regimes should

be re-evaluated to determine if they are sufficient to maintain the conditions required for coral recruitment, which is the most vulnerable stage in the coral life cycle. Similarly, reef managers may need to re-direct or limit excessive diving pressure at sites where intense recreational use is reducing coral cover.

Although the natural resilience of reef ecosystems will facilitate recolonisation and subsequent recovery of sites that suffer significant coral mortality, full recovery to pre-disturbance coral cover and diversity can take decades. Recovery can be further delayed, and even inhibited, if the natural resilience of the ecosystem has been reduced by other pressures, such as excess nutrients or sediments, habitat damage, or over-harvesting of crucial functional groups. Therefore, reef managers may wish to consider proposals to assist or accelerate natural recovery processes through active restoration. The diversity and scale of experimental restoration approaches used to date vary widely. They cover habitat modification, coral transplantation, species re-introduction, and enhancement of recruitment. The logistics, costs, and effectiveness of restoration activities, as well as any legal considerations, should be carefully examined before deciding on a course of action.

Strategy 5. Engage stakeholders that rely on coral reefs.
Managers can engage with stakeholders to support their ability to cope with the effects of global climate change by identifying potential socioeconomic and ecological vulnerabilities, communicating about potential impacts, and collaborating on response strategies.

Assessments can be implemented to identify potential impacts and vulnerabilities to the coral reef, the people that depend on the reef, or both. A Reef Manager's Guide to Coral Bleaching provides further technical guidance on implementing socioeconomic assessments, which can provide information, such as:

- *What are the types of social and economic effects likely to be experienced as a result of global climate change?*
- *Who is likely to be affected?*
- *What opportunities exist to minimize the direct effects of a bleaching event?*
- *How can management responses be designed to minimize the impacts on reef users?*

Managers can also increase socio-ecological resilience by predicting the start and severity of mass bleaching. These predictions not only allow managers to be the source of timely information about bleaching-risk, but also they increase trust and credibility with stakeholders. Social science research has found that resource users are more resilient and better able to cope with changes in resource management when they trust the decision-making process. NOAA's Coral Reef Watch Program has developed three tools that analyze the likelihood of mass coral bleaching events (http://coralreefwatch.noaa.gov/). The book, *A Manager's Guide…* provides guidance for interpreting the NOAA maps and describes other strategies for predicting mass bleaching.

Effectively communicating with target audiences about the past and future effects of mass bleaching and global climate change will promote awareness among stakeholders and provide information about potential effects to their livelihood. It will also increase support for management responses. This communication can occur passively, through industry newsletters, web sites, or media articles; or it can occur actively, through engagement in volunteer monitoring programs that provide early warnings about mass bleaching.

At the highest level of engagement, managers and resource users can collaboratively develop a climate change action plan. Such a plan could include strategies for: supporting ecological resilience; diversifying economic activities; enhancing human resource skills; making investments in capital and technology; or reworking related government policies. The Box below draws on recent discussions on the Great Barrier Reef, Australia, and is an example of strategies that could be included in an action plan to help a reef-based tourism industry respond to climate change.

A COLLABORATIVE ACTION STRATEGY TO ADDRESS THE IMPACTS OF CLIMATE CHANGE ON REEF-BASED TOURISM

In November 2005, the Great Barrier Reef Marine Park Authority (GBRMPA) hosted a workshop about climate change for leaders of the Great Barrier Reef (GBR) marine tourism industry. Participants heard presentations from leaders in science, industry, and academia about the potential and expected impacts of climate change on the marine ecosystem, insurance costs, and tourist destination choices. Members of the marine tourism industry then assessed their vulnerability to climate change and devised possible responses and adaptation strategies through participatory breakout groups.

Through workshop discussions, the participants concluded that:

- There is now an overwhelming consensus that climate change is occurring as a result of human activity, and that it is one of the biggest threats to coral reefs worldwide.
- The effects and changes to tourism operations as a result of climate change will be significant and are likely to be directly proportional to overall effects on the Great Barrier Reef.
- There are a number of specific actions that the tourism industry can undertake to help it adapt to climate change.
- The challenges presented will be best addressed by working in partnerships, within the tourism industry, with other industries and with government agencies.
- The key areas where actions can be taken are in marketing and communications; product development and business planning; and environmental and site adaptation.

A review of the actions identified by tourism operators at the forum, suggests six strategies that could be implemented through collaborative industry-government-science partnerships as a way of preparing for the impacts of climate change on reef-based tourism:

1. Better understand climate change implications for reef-based tourism:
   - A. Develop regional predictions of future trends
   - B. Assess business risks
   - C. Evaluate potential business adaptation strategies
   - D. Develop environmental management and engineering strategies
2. Integrate climate change into business planning and operations:
   - A. Implement strategies to maintain industry viability
   - B. Plan for extreme weather events
3. Reduce industry contributions to climate change:
   - A. Reduce greenhouse gas emissions
   - B. Offset air travel emissions
4. Support coral reef resilience to climate change:
   - A. Minimize physical impacts to the reef
   - B. Minimize negative impacts to water quality

Conclusions

Although coral reef managers cannot directly mitigate climate change, they can take meaningful actions to support the socio-ecological resilience of coral reef ecosystems to climate change. This chapter offers guidance to reef managers on strategies for implementing resilience-based management as a response to coral bleaching and other threats associated with climate change:

- Identify areas that are naturally resistant or tolerant to bleaching and protect them to act as refugia and as seed-banks to replenish more susceptible sites;
- Reduce local stressors to provide bleached reefs with the best chance to survive mass bleaching;
- Protect, maintain, or restore ecosystem condition, biological diversity, and connectivity to promote recovery at sites that experience high mortality;
- Engage with stakeholders about coming changes to build alliances, knowledge, and influence that can help in maintaining socioeconomic well-being and effectively adapt management regimes to the new circumstances; and finally,
- Inform climate change policy decisions by assessing the socioeconomic and ecological impacts of mass coral bleaching and conveying this information to senior decision-makers, colleagues, stakeholders, and the media.

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Author Contacts

Heidi Schuttenberg, Sustainable Ecosystems, CSIRO and School of Earth & Environmental Sciences, James Cook University, Australia, Heidi.Schuttenberg@jcu.edu.au; Paul Marshall, Climate Change Response Program, Great Barrier Reef Marine Park Authority, Australia, P.Marshall@gbrmpa.gov.au

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