RESPONDING TO A MASS CORAL BLEACHING EVENT

CHAPTER 2

2. RESPONDING TO A MASS CORAL BLEACHING EVENT

This chapter outlines five actions managers can take to prepare and respond during bleaching events. Many of these actions aim to help managers develop and communicate reliable information about the impacts of a mass bleaching event. These strategies do not provide a 'cure' to mass coral bleaching. However, managers have found that implementing these actions during and after bleaching events can improve the overall effectiveness of coral reef management. Specifically, managers can gain and maintain critical support from decision-makers and other stakeholders by raising awareness and advancing scientific understanding about the patterns and impacts of coral bleaching and the importance of ecosystem resilience to the future of coral reefs.

2.1 Developing a bleaching response plan

Responding to a mass bleaching event is a demanding task with numerous challenges; managers who have planned in advance for events will have an advantage

Like any contingency plan, developing a 'Coral Bleaching Response Plan' allows managers to respond more effectively during the rapid onset of a mass bleaching event. At its most basic level, the plan should identify the goal of the response, specific steps that will be taken to meet the goal, and resources required to implement the response. Plans can be created to meet the needs of any reef manager, taking into account available resources, staff capacity, management authority, and the characteristics of local coral reef systems. Table 2.1 provides some examples of activities that can be included in bleaching response plans depending on available resources.

The Great Barrier Reef Marine Park Authority (GBRMPA) Bleaching Response Plan provides another example (Appendix). The GBRMPA plan includes procedures for prediction, ecological assessment, and communication of mass bleaching impacts. These procedures consist of routine, responsive, and strategic tasks. Routine tasks occur throughout the summer season, whether or not there is a bleaching event. For example, routine tasks include the monitoring of environmental conditions and frequently updating assessments of bleaching risk.

Responsive tasks are only implemented if a bleaching event occurs. Responsive tasks include rapid assessment of ecological impacts and increased communication activities, which can include briefings for both senior managers and the media. Because it can be difficult to decide exactly when a bleaching event has started, the GBRMPA plan outlines specific thresholds that trigger each type of responsive task. For example, when bleaching thresholds are exceeded at multiple sites, a structured aerial survey is undertaken to determine the spatial extent and severity of bleaching in the region.

Table 2.1 Examples of tasks from four categories of bleaching response actions under three different resource scenarios

Resource Availability		
Low	**Medium**	**High**
Early warning system (Section 2.2)		
• Check NOAA Coral Watch reports • Volunteer network to detect the onset of bleaching	• Check NOAA Coral Watch reports • Check local weather forecasts • Initiate sea temperature monitoring program using in situ loggers • Develop and monitor reef-specific bleaching temperature thresholds	• Check NOAA Coral Watch reports • Work with local weather forecasters to develop forecasts of conditions likely to induce bleaching • Initiate sea temperature monitoring program using in situ loggers • Establish stations for real-time sea temperature measurement • Develop and monitor reef-specific bleaching temperature thresholds
Impact assessment (Section 2.3-2.4)		
• Volunteer network to estimate the severity of bleaching, as well as report coral types affected • Timed swims	• Volunteer network to estimate the severity of bleaching, as well as report coral types affected • Manta tows • LIT/Belt transects	• Volunteer network to estimate the severity of bleaching, as well as report coral types affected • Aerial Surveys • Video Transects • Socioeconomic impact studies
Management interventions (Section 2.5)		
• Take steps to protect herbivore populations and water quality through appropriate actions (eg facilitating community-based protected areas, installing latrines, limiting land-clearing, etc)	• Take steps to protect herbivore populations and water quality through appropriate actions (eg implement fishery regulations, address harmful land-use practices) • Consider restricting potentially stressful impacts from coastal development and recreational use during periods of high water temperature	• Take steps to protect herbivore populations and water quality through appropriate actions (eg implement fishery regulations, address harmful land-use practices) • Consider restricting potentially stressful impacts from coastal development and recreational use during periods of high water temperature
Communication (Section 2.6)		
• Talk to community members and local media about mass bleaching • Brief senior decision-makers • Meet with key stakeholders, local media, and colleagues • Send email updates	• Brief senior decision-makers • Meet with key stakeholders, local media, and colleagues • Send email updates	• Brief senior decision-makers • Meet key stakeholders, local media, and colleagues • Send email updates • Update websites • Make informative publications readily accessible to the public • Offer seminars • Develop and implement an education program for local schools

Strategic tasks may be taken at any time to strengthen a bleaching response or support long-term coral reef resilience (see Chapter 3). Strategic activities can include building capacity, securing funding, raising awareness, developing professional networks to exchange information, establishing policies that support bleaching response, or implementing management initiatives to increase protection for or restore factors that confer resilience to the system.

The remainder of Chapter 2 provides detail of the actions that can be taken as part of a comprehensive response to a mass bleaching event. Managers may wish to take ideas from these sections for their own bleaching response plans.

2.2 Predicting mass coral bleaching

The strong relationship between temperature and the onset of mass bleaching allows managers to estimate the risk of coral bleaching based on forecast and observed climatic conditions and sea temperatures. This ability allows a manager to be the source of timely and credible information about bleaching risk for decision-makers, stakeholders and the media. Additionally, it provides important information needed for impact assessment and management responses. This section describes the key approaches available to predict the probability and severity of a mass coral bleaching event during high risk bleaching periods, when sea temperatures reach their annual maximum (see Figure 2.1).

The strong relationship between temperature and the onset of mass bleaching allows managers to estimate the risk of coral bleaching

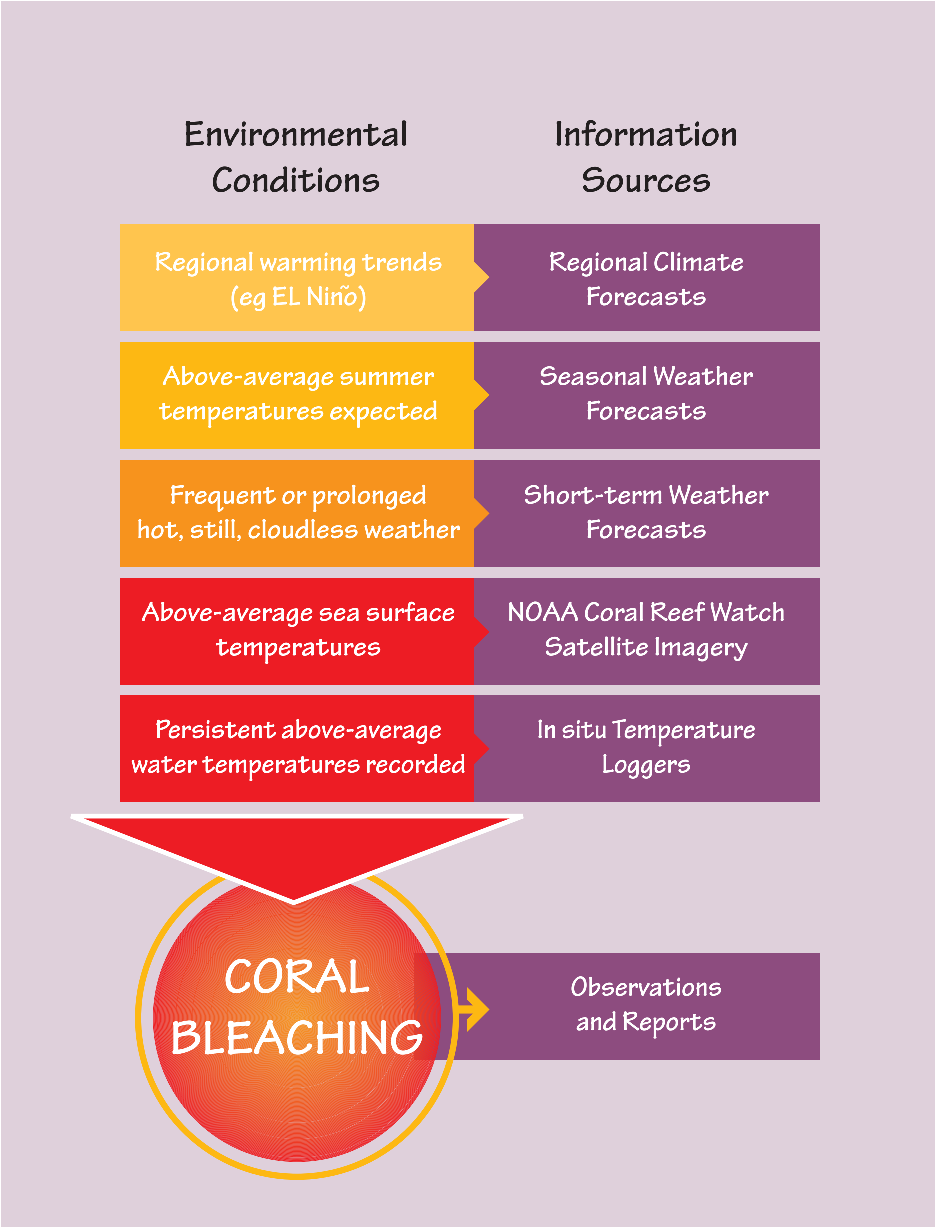

Figure 2.1 Environmental conditions and information sources used to estimate bleaching risk

Mass coral bleaching is preceded by environmental conditions that can be tracked to provide managers with an effective early warning system for bleaching events. In orange and red, these conditions are described hierarchically from general situations that may suggest an increased risk of bleaching to specific circumstances that correspond to a high risk of bleaching. Readily available information sources are listed to the right of each environmental condition and further described in the text.

2.2.1 Climatic conditions

Large-scale climate patterns. Sea temperature is the most reliable predictor of the occurrence and severity of large-scale coral bleaching events[9, 18, 19]. An understanding of the factors that influence sea temperature has the potential to enable managers to predict the probability of occurrence and severity of a bleaching event. In theory, the relationship between climate patterns, seawater heating, and mass bleaching should provide a mechanism for such predictions. In particular, the weather patterns associated with phenomena such as the El Niño Southern Oscillation or the Pacific Decadal Oscillation can be associated with regional and local warming sea temperatures[48]. A dramatic example of the potential influence of large-scale climate patterns is the 1997-98 global mass bleaching event, which was associated with an extreme El Niño event.

Despite the importance of large-scale climate patterns in determining local conditions, precise predictions of bleaching risk remain difficult. Many local and regional factors also affect the rate and duration of sea temperature increases, including regional ocean currents, cloud cover and winds. The interplay of local, regional and global factors make it important that managers do not place too much emphasis on using single variables, such as ENSO, as their only measure of bleaching risk[49]. The extent to which the complex interactions of different oceanic and atmospheric phenomena can be incorporated into predictive models for coral bleaching will vary from place to place depending on climate dynamics and the knowledge and expertise of local forecasting systems.

However, precise predictions are not necessary for many management applications. Reef managers may still get a very useful indication of whether their region is likely to experience increased heating in coming months based on climate predictions. For example, the El Niño Southern Oscillation (ENSO) index is used to indicate the probability of above-average air temperatures, and extent to which the monsoon trough will develop (which affects cloud cover and winds) over the Great Barrier Reef (GBR). These seasonal forecasts are used by the Great Barrier Reef Marine Park Authority to assess the likelihood that conditions conducive to anomalous warming of the waters are going to occur in or around the Great Barrier Reef.

Managers may find it useful to discuss the effects of climatic factors on sea temperatures with local oceanographers, meteorologists and other scientists. For locations where links between climate and sea temperatures are known, reports and information on large-scale climate phenomena can be a useful aid to predicting bleaching risk. An example of a useful source of information is the ENSO Reporting Centre, which provides ENSO forecasts through email updates and a comprehensive website:
www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory

Weather. Weather patterns also provide a useful indication of whether bleaching risk is increasing or decreasing. Longer-term predictions, such as seasonal forecasts, can be used to assess the probability of weather conditions that contribute to increasing sea temperatures occurring over timescales of weeks to months. For example, seasonal outlooks for the hot season that predict above-average air temperatures and decreased storm activity indicate that there is an increased probability of conditions that can lead to stressful sea temperatures.

Shorter-term predictions, such as weekly weather forecasts, indicate whether sea temperatures will increase or decrease in coming days and weeks. The risk of mass bleaching is higher when forecasts are for high air temperatures and extended periods of clear skies, low wind and neap tides[50]. In contrast, forecasts for stormy conditions with cooler air temperatures, high cloud cover and strong winds indicate that sea temperatures may stabilise or decrease over the coming week. Table 2.2 summarises the major climatic variables that are known to influence sea temperatures and thus the risk of a mass bleaching event occurring.

The risk of mass bleaching is higher when weather forecasts are for high air temperatures and extended periods of low wind and low cloud cover

Table 2.2 Climate variables and their influence on bleaching risk

Climate variable	Implications for bleaching risk
ENSO	El Niño conditions increase sea temperatures in the Indian and central to eastern Pacific Oceans, and may increase the chances of stable hot conditions in the atmosphere in some reef regions. La Niña conditions may increase temperatures in the western Pacific.
Air temperature	Hotter air temperatures enhance the warming effect of the sun.
Cloud cover	Low cloud cover increases heating of surface waters. However, middle to high level cloud cover acts as a shade and lessens the heating effects of the sun.
Wind	Low winds increase heating of surface waters. However, strong winds (and waves) have the ability to mix water to great depths, which reduces surface water temperature. A change in wind direction resulting in cooler winds can also dramatically reduce surface water temperatures.
Tidal currents	Strong tidal currents coincident with spring tides increase mixing and reduce temperatures of surface waters.

2.2.2 Sea temperatures

Once atmospheric conditions suggest the development of unusually warm conditions, measurements of sea temperatures provide a more direct indication of the potential for mass coral bleaching. Temperature stress can be monitored using satellite imagery and in-water instruments.

Unusually high seawater temperatures are the most direct indicator of bleaching risk and can be monitored using 'HotSpot' images produced from satellite data by NOAA or by local, in-water temperature loggers

Satellite imagery. Coral Reef Watch, a program of the US National Oceanic and Atmospheric Administration (NOAA), has developed three tools that analyse satellite imagery to assess the likelihood of mass coral bleaching events. These products are freely available over the Internet, and include: HotSpot maps, degree heating week (DHW) maps and Tropical Ocean Coral Bleaching indices.

HotSpot and DHW maps are global to regional images that display the intensity and duration of unusually warm sea surface temperatures (SSTs) using remotely sensed data. Both the intensity and duration of heat stress are important factors in predicting the onset and severity of a mass bleaching event. HotSpot maps show the intensity of temperature anomalies with a colour gradation (Figure 2.2). A temperature anomaly is calculated as the difference between the observed sea temperature and the highest temperature expected for a specific location, based on long-term monthly averages. It provides a useful reference point that shows the extent to which current temperatures vary from those that the corals are accustomed to experiencing that time of year. Because different geographical locations vary in their average water temperature, an anomaly of 2ºC could mean an actual temperature of 28ºC in the Galapagos, but it could mean 34ºC in the Red Sea. Despite the differences in absolute water temperatures, conditions are likely to be equally stressful for corals in both locations because the sea temperature anomaly is the same. Anomalies of only 1-2ºC can cause mass bleaching.

DHW maps combine the intensity of temperature anomalies, found in the HotSpot maps, with the duration of exposure to provide a composite picture of accumulated temperature stress over the last 12 weeks (Figure 2.3). One DHW is equivalent to one week of SSTs 1ºC greater than the expected summertime maximum. Two DHWs are equivalent to two weeks at 1ºC above the expected summertime maximum or one week of 2ºC above the expected summertime maximum. At four DHW, the Coral Reef Watch program issues a Coral Bleaching Alert that a mass bleaching event may occur. Current research on the GBR suggests that other aspects of a thermal regime, particularly the rate of heat stress accumulation, can also be useful indicators of bleaching risk.

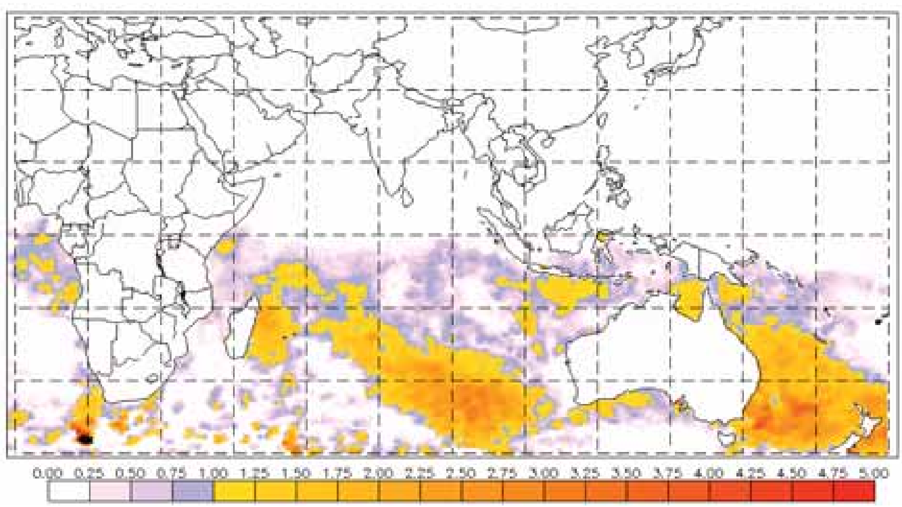

Figure 2.2 NOAA HotSpot map for the eastern hemisphere for 20 February 1998

The colour of the grid cells represents the temperature anomaly in degrees Celsius, as indicated in the legend along the bottom of the map. Temperature anomalies of 1-2ºC extending over a period of days to weeks should alert managers that a medium to high risk of bleaching exists.

DHW maps are updated every 3-5 days, allowing managers to track the development and persistence of temperature anomalies around coral reefs and to estimate bleaching risk. An automated email system sends managers Satellite Bleaching Alerts when stress levels are reached. All products are currently based on SST over a 50 x 50 km grid, and NOAA is improving this product to a grid size of 7 x 7 km. In many cases, the surface temperature measured by satellites can be used as a reliable indicator of the temperature of sub-surface waters (>1 m depth), depending on the extent of mixing. When anomalies are large or persistent, in-water instruments (described below) can complement regional satellite information and provide a more detailed account of local conditions.

The NOAA Coral Reef Watch program also developed a Tropical Ocean Coral Bleaching Indices web page to provide additional near-real-time information for 24 reef locations worldwide. For each reef site, the closest 50 km satellite data is extracted and listed on the indices web page. These data include: current SST, DHW, climatology, links to regional maps (such as ReefBase), SST time-series, satellite surface winds and retrospective data. Visual warnings are provided for each site when conditions reach levels known to trigger bleaching in vulnerable coral species.

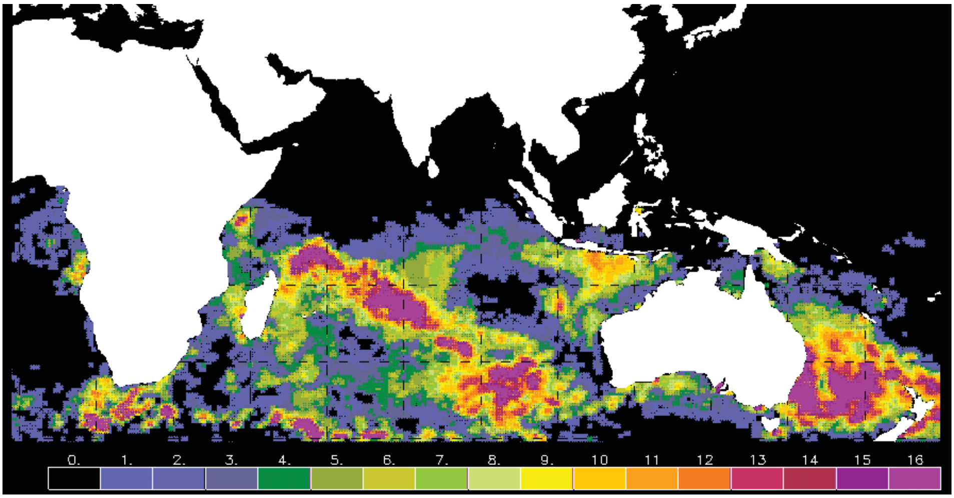

Figure 2.3 NOAA Degree heating weeks (DHW) map for the eastern hemisphere for 31 March 1998

Both the intensity and duration of heat stress are important factors in predicting mass coral bleaching, and the DHW maps combine this information into a composite unit of accumulated temperature stress over the last 12 weeks. One DHW is equivalent to one week of SSTs that are 1°C greater than the expected summertime maximum. At 4 DHW, conditions have become stressful for corals, and bleaching events become likely. Severe stress and possibly mortality is likely to occur at 8 DHW[50]. In this figure, the colours correspond to the number of DHWs indicated in the legend along the bottom of the map.

Direct measurements. Direct measurements of water temperature complement satellite imagery by providing data that are of higher spatial and temporal resolution. These measurements can be used to ground-truth remotely sensed surface temperatures. They can also provide measurements at multiple depths to establish a depth-temperature profile. Particularly for small reef areas with complex oceanography and strong mixing gradients, in situ measurements can help refine bleaching thresholds.

Local sea temperatures can be monitored using in situ instruments that either require manual download or are equipped with remote data transfer features. Simple, stand-alone temperature data loggers are now readily available and affordable. Data from several popular brands can be quickly and easily downloaded in-water by a diver. Where resources are available, weather stations with telemetry systems can be used to provide real-time data on a full range of variables that influence bleaching, such as air and water temperature, wind, current and irradiance.

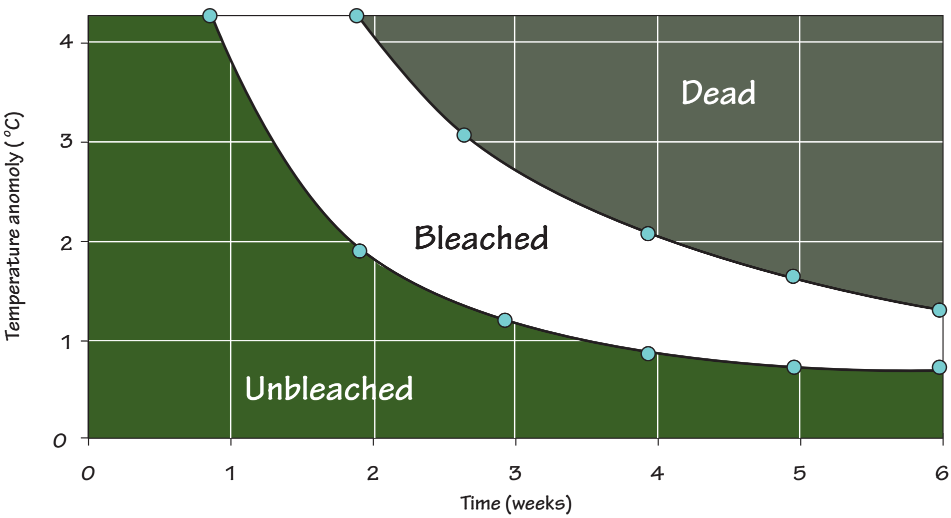

Figure 2.4 The relationship between the intensity and duration of heat stress and the risk and severity of mass bleaching

Directly measuring water temperatures can provide a more detailed account of local conditions to complement regional satellite information about temperature anomalies and bleaching risk. Predicting bleaching risk from in-water measurements requires an understanding of the exposure likely to trigger bleaching in the local area. This graph shows the general relationship between the size of the heat stress (vertical axis), how long it lasts (horizontal axis) and the onset of bleaching. Actual bleaching thresholds will vary by location based on typical ambient conditions and the sensitivity of the dominant coral reef species present.

2.2.3 Coral bleaching thresholds: how warm is too warm?

Interpreting bleaching risk based on direct measurements of sea temperature requires an understanding of the exposure likely to trigger bleaching responses. As introduced in Chapter 2.2.2, the risk and severity of mass bleaching is directly related to both the intensity and duration of exposure to unusually warm sea temperatures. Figure 2.4 illustrates the concept of bleaching thresholds based on temperature and exposure time. This section describes three approaches that can be taken to identify mass bleaching triggers: average high temperatures, past bleaching events and experimental observations. Since the composition of coral communities change, colonies acclimatise and species adapt in response to repeated thermal stress events, triggers can drift over time for particular species or regions; thus, bleaching thresholds should be reviewed regularly and revised as necessary.

Thresholds based on average maximum temperatures. The simplest approach, and the one used to create NOAA's HotSpot and DHW maps, is to compare temperatures against the average maximum temperature in order to calculate a temperature anomaly. Observed temperatures should be compared against average high temperatures for the same month. For example, sea temperature measurements taken in July are compared against the average high temperatures observed in July over the previous ten or more years. Where a long history of local temperature records is not available, managers may be able to derive long-term averages from satellite data sets. These data sets may be available on the Internet, or can often be provided upon request by the coordinators of satellite-derived sea temperature data, such as NOAA, or the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO). Once managers know the long-term average temperatures, it is a relatively simple matter to record current temperatures (using a regularly checked logger or real-time weather station) and compare this with the long-term average. Anomalies should be calculated on a daily or weekly basis and summed to provide a measure of the accumulated exposure to temperatures above the normal maximum. This simple index gives the number of degree heating days or weeks (DHDs or DHWs) for a particular period. NOAA issues a bleaching warning for monitored areas once heat exposure is greater than four DHWs[50]. This indicates that stress levels are high, and managers should consider initiating rapid assessments of reef condition, or at least heightening awareness in a volunteer network used to detect the onset of bleaching (Section 2.3). Anomalies of 1-2°C for days to weeks can induce coral bleaching in many susceptible species, and should alert managers that medium to high risk of bleaching exists.

Thresholds based on past bleaching events. Estimating bleaching thresholds in this way requires reliable records of when coral bleaching did and did not occur in previous years at reefs within the area of interest. Bleaching records are then matched up with temperature records in order to compare the average maximum temperature of bleaching years with that of non-bleaching years. The bleaching threshold falls between the lowest temperature for bleaching years and the highest temperature for non-bleaching years, taking both the intensity and duration of exposure into account. Depending on the resolution of past observations, this analysis may be carried out at either regional or local scales. An example of a detailed estimation of local bleaching thresholds for Kelso Reef in the Great Barrier Reef, Australia[52] is described in Box 2.1. A regional-scale analysis of bleaching thresholds has also been completed for the Indian Ocean region[51].

Box 2.1 Estimating bleaching temperature thresholds for Kelso Reef, GBR, Australia

Experience on the Great Barrier Reef indicates that threshold curves of reefs with similar communities and species vary with latitude and, more precisely, with local ambient temperature regimes. This correlation suggests that reefs have adapted or acclimatised to local conditions and reinforces the need for locally specific bleaching thresholds for use in an early warning system. Such time-temperature bleaching threshold curves are not species-specific, but, if field observations are based on early signs of bleaching, are usefully biased towards the sensitive members of the coral community.

In this example for Kelso Reef (Figure 2.5), cumulative exposure times and temperatures are shown for four consecutive years, one of which coincided with mild bleaching (1998). This graph shows the period when the warmest average daily temperatures were recorded (December to March). Average daily temperatures near the maximum summer range were summed to produce a cumulative frequency distribution of days and temperatures at increments of 0.1°C. The shaded area between the 1998 curve and that for the warmest non-bleaching year (1999) indicates the potential area in time-temperature space in which bleaching could occur. The predicted bleaching curve (bold solid line) was estimated by weighting the mean on a four-point scale according to the intensity of bleaching[52].

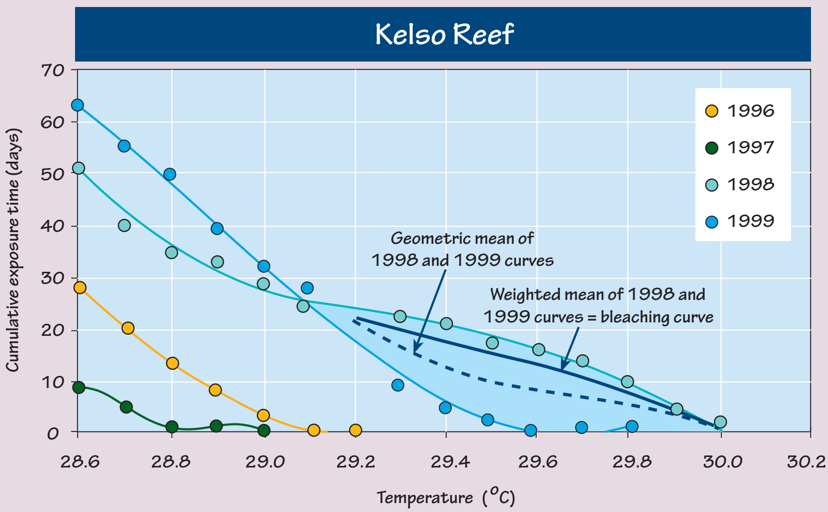

Figure 2.5 Bleaching thresholds for Kelso Reef in the central Great Barrier Reef, Australia

Coral bleaching thresholds can be calculated on the basis of temperature records and observations about the onset and severity of bleaching over several years. The shaded area in this graph shows the predicted bleaching threshold as the cumulative exposure falling between the coolest bleaching year (1998) and the warmest non-bleaching year (1999). From Berkelmans (2002)[52].

Thresholds based on experimental data. This approach is the most resource intensive and will likely require collaboration with scientists to collect detailed experimental observations. The approach, developed by Coles and Jokiel[53] and applied more recently by Berkelmans[52] (See box 2.1), involves exposing corals to different water temperatures in a laboratory situation and recording how many days are required for corals to show visible signs of bleaching at each temperature. Time-temperature bleaching threshold curves derived in this manner can provide the basis for detailed predictions about when bleaching may become evident in select species from particular locations. Care should be taken in applying data obtained from these observations to other species or locations. If the species selected for study are common, relatively sensitive, and from locations that are representative of the wider area, the thresholds can be useful predictors of bleaching within larger jurisdictions.

2.3 Assessing ecological impacts

Managers must rapidly assess the extent and severity of mass bleaching in order to make timely and effective management decisions (Section 2.5) and communicate the situation to others (Section 2.6). Reef users, other stakeholders, the media, and senior government officials will want to know: '*How bad is it? What are the impacts to the reef?*' and '*What will it mean for the local stakeholder community?*'. Thus, we now turn to a discussion of approaches for assessing the ecological (Section 2.3) and socioeconomic (Section 2.4) consequences of mass bleaching events for coral reefs and for the stakeholders who value the ecosystem services those coral reefs provide.

Coral reef monitoring protocols have been developed for a wide range of skill levels, ranging from Reef Check for volunteers to the comprehensive *Survey Manual for Tropical Marine Resources* developed by the Australian Institute of Marine Science (AIMS) and the Global Coral Reef Monitoring Network[54] for reef scientists and managers. Since mass bleaching is transitory in nature, the decision about when to conduct a rapid assessment of bleaching impacts and which protocol to use may have significant implications for the survey results and for any conclusions made from those results.

Experience from around the world during previous bleaching events has led to the development of strategies that can help with such timing concerns and other monitoring-related decisions. The WWF, the WorldFish Centre and the Great Barrier Reef Marine Park Authority (GBRMPA) have compiled these experiences into *A Global Protocol for Assessment and Monitoring of Coral Bleaching*[55]. The protocol can be downloaded from the ReefBase website (www.reefbase.org) by searching the online literature database, or by contacting the authors. The protocol aims to provide detailed guidance for planning and implementing bleaching assessments under a range of resource settings, while ensuring that data are useful and readily integrated into a global database of coral bleaching impacts.

Designing and implementing a coral bleaching monitoring program – Bali Barat National Park

Coral reefs of Bali Barat National Park

Bali Barat National Park contains the most significant area of coral reefs in Bali, and is a focal point for reef conservation in Indonesia. It is a major destination for reef-oriented tourism and contains the only reefs in the region that are under formal protection. Nevertheless, these reefs are at risk from a variety of human activities such as (illegal) destructive fishing, nutrient inputs and anchor damage, and the threat of coral bleaching. The area suffered a crown-of-thorns starfish *(Acanthaster plancii)*, or COTS, outbreak in 1996-97 and was affected by mass coral bleaching in 1997-98.

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Bali Barat Monitoring Team

The role of WWF

The WWF is the lead partner in efforts to study, manage and protect the coral reefs of Bali Barat National Park. The damage observed by the WWF during the 1997-98 coral bleaching event lead to renewed concerns about the sustainability of these reefs under existing management regimes. In particular, the WWF was concerned that the added pressure of climate change would make the reefs particularly vulnerable to existing levels of dynamite fishing, water pollution and poor anchoring practices.

In response to these concerns, the WWF collaborated with experts from the Great Barrier Reef Marine Park Authority (GBRMPA) and the International Centre for Living Aquatic Resources Management (ICLARM) (now WorldFish Centre) to develop a coral bleaching monitoring program for Bali Barat National Park. The resulting program was designed to detect coral bleaching and assess the extent and implications of any bleaching events, yet be implemented with minimal resources. Furthermore, in order to evaluate the importance of various factors in conferring resilience to coral bleaching, the program aimed to monitor the condition of local reefs from 2003 to 2006. The information from this program will be used to assess and improve the effectiveness of management strategies to mitigate bleaching-induced impacts and to protect coral reefs in the area, as well as to raise awareness about coral bleaching and climate change.

The Coral Bleaching Monitoring Program

This WWF Monitoring Program was designed to use existing staff expertise and resources, and to require only modest on-going funding. The WWF uses web-sourced El Niño predictions and NOAA HotSpot maps to assess the risk of bleaching each season. These remote data are backed up with measurements of local temperature obtained using low-cost temperature loggers that are installed at key sites and downloaded regularly (ideally weekly during the bleaching season) by WWF staff or their colleagues in the local tourism industry.

The WWF has also established a network of reef users to provide an early warning system for bleaching or other indications of stress on the reef. This program, called KEYS, 'Keep your Eyes on the Reef', encourages professional and recreational reef users to report any observations of coral bleaching at the sites they frequent.

Reports of possible bleaching received through the KEYS program trigger a field check by the WWF Bali coral reef team. This team consists of staff with appropriate SCUBA diving skills and a mix of scientific training, ranging from Masters Degree to no formal university degree. The team was trained in coral bleaching assessment skills during a four-day workshop run by external experts. The team leader runs regular refresher and calibration sessions to ensure skills are maintained within the team. The WWF team works closely with local tourism and fishing businesses in the area, receiving assistance from local reef guides, and cost-effective access to dive boats and equipment.

If field checks indicate that a bleaching event is occurring, WWF launches a full bleaching assessment survey. This entails a rapid survey of all sites, using timed swims to determine the general severity and extent of bleaching within the Park and surrounding areas. This is followed by detailed monitoring of core sites, using the line intercept technique (LIT), permanent quadrats and a complementary study of tagged colonies. These methods have been chosen because of their widespread use, standardisation and, consequently, ease of comparison of results with other reef regions. Importantly, they can be implemented without the need for expensive equipment or high levels of expertise. Detailed monitoring is done regularly on a semi-annual basis as part of a four-year program designed to provide essential baseline data to document the longer trends in reef condition within the Bali Barat National Park, and to help understand the importance of coral bleaching relative to other threats affecting the area.


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Monitoring on the reef slope at Bali Barat National Park

So far, WWF Bali has completed three baseline monitoring surveys (in February and October 2003, and March 2004). There was no bleaching event recorded during those times. The data indicate a trend that implies coral cover is recovering after the impacts of COTS and coral bleaching during the period 1996-98.

Establishing a network of coral bleaching monitoring programs. Parallel programs are being developed to assess the socio-economic impacts of coral bleaching and mortality, and to identify and promote strategies to mitigate the socio-economic impacts arising from coral bleaching events.

The Bali Barat National Park Coral Bleaching Program is one element of an integrated program being developed by the WWF. The program is designed to understand, document and mitigate climate change impacts on coral reefs worldwide. A network of areas with similar programs is being established and will include Bunaken National Park (Indonesia), American Samoa (USA), Batangas (the Philippines) and Tubataha Marine Park (the Philippines). Linkages with additional areas are also being explored, including with Ujung Kulon National Park (Indonesia), Cendrawasih Marine Park (Indonesia) and the Great Barrier Reef Marine Park (Australia).

For more information about the Bali Barat National Park Coral Bleaching Program, and related regional initiatives, contact:

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CASE STUDY 2

Community participation in monitoring coral bleaching events on the Great Barrier Reef – BleachWatch

The Great Barrier Reef Marine Park has experienced two major coral bleaching events in recent years (1998 and 2002). These have dramatically increased awareness of the threat posed by coral bleaching to the Great Barrier Reef ecosystem. Increasingly, reef users, the general public, the media and senior decision-makers are looking to reef managers to provide timely and credible information about the impacts and implications of coral bleaching.

However, resource limitations in conjunction with the size and remoteness of many reef areas can be a substantial challenge for reef managers wishing to detect the onset of bleaching and monitor bleaching-related impacts. Reef users can play an important role in assisting managers to keep an eye on the reef during periods of high bleaching risk. In the Great Barrier Reef region, a program to facilitate active community involvement in monitoring coral bleaching events has been created. This program, called 'BleachWatch', provides an early warning system for coral bleaching and forms part of the Great Barrier Reef Marine Park Authority's (GBRMPA's) Coral Bleaching Response Plan.

The BleachWatch program acts as an important source of information for managers, and also has an important outreach and communication function. Two different programs, 'BleachWatch-Professional' and 'BleachWatch-Community' have been developed to engage the range of reef users.

BleachWatch participants are provided with a Monitoring Kit. The kit includes a neoprene wrist band to assist with coral identification, a laminated reference sheet, survey form and instructions

The BleachWatch-Professional program is designed for regular reef users, predominantly tourism professionals or marine park rangers who visit a particular reef on a regular schedule. This program is an opportunity for marine tourism professionals to establish an understanding of the coral community at their sites, with the assistance of coral reef ecologists at the GBRMPA. A short monitoring form, which takes about 10 minutes to complete, is provided to participants. Monitoring kits, provided by the GBRMPA, also comprise a waterproof reference key and instructions. The program has been designed with the tourism professional in mind, and allows monitors to go about their everyday work, be it guiding snorkel trails or diving, while taking a mental picture of their 'home reef' with the help of the waterproof reference key. Once back on the vessel, staff members fill in the monitoring form and send it back to the GBRMPA at no postage cost. In return for the monitors' efforts, the GBRMPA analyses the information and provides monthly site reports, collating the data into an informative poster that can be displayed for the education of both staff and tourists.

The BleachWatch-Community program is designed for incidental observations made by reef visitors who make only occasional trips to the reef. Tourists, students and scientists can all contribute to this program by submitting reports via the GBRMPA website. A printer-friendly form is also available to help visitors record observations while they are visiting the reef. Reef visitors are encouraged to submit their data using the online form, and are reminded that a report of no bleaching can be just as important as a report of bleaching.

Information collected through the monitoring form includes:

(a) weather information (wind speed, cloud cover, water temperature)
(b) site information (reef name, type of reef habitat, depth surveyed)
(c) coral cover and community composition (such as dominant coral types)
(d) bleaching information (percentage of coral affected, severity of bleaching, types of growth forms affected).

Participants in both programs are encouraged to report observations prior to and during a coral bleaching event, so that the condition of the reef can be determined and monitored over time. This information provides an important early warning system for managers, indicating where coral bleaching is occurring and how severe it is. The BleachWatch program has been extremely successful in enabling community members to participate in monitoring the Great Barrier Reef and to improve their knowledge about coral bleaching, and reef ecology in general. Reef managers benefit by gaining an early warning of coral bleaching.

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Bleaching impacts may be assessed by way of: (1) volunteer and community-based reports, (2) broad scale assessments and (3) site assessments (Table 2.3). These approaches involve different techniques of data collection by different types of teams with different levels of detail and expertise required. Each approach has advantages and disadvantages in terms of cost, ease of mobilisation, and training required; yet each approach yields information of interest to managers and stakeholders. The choice of assessment approach will depend on the nature of the management questions posed, the nature of the manpower available to do the work, the amount of resources available, and the type of data needed for analysis. A brief overview of the three types of approaches follows. Table 2.3 briefly describes a variety of techniques used in the three approaches and provides a summary for each of the management questions they address, the pros and cons of each technique, and the nature of the data that they provide. An example of how these techniques have been combined into a coral bleaching monitoring program for Bali Barat National Park in Indonesia is described in case study 1. For more in-depth information on how to use these techniques, the reader is directed to *A Global Protocol for Assessment and Monitoring of Coral Bleaching*[55].

2.3.1 Techniques for bleaching assessment

Volunteer and community-based reports. In many cases, stakeholders come into more frequent contact with the reef than do managers. A key goal of a volunteer monitoring program is to take advantage of these 'extra eyes and ears' to rapidly detect the onset of bleaching and support timely management decisions. Another benefit is the opportunity provided by such programs to inform stakeholders about the impacts of mass bleaching and to engage them in coral reef management issues. Often, people feel helpless during mass bleaching events. Volunteer monitoring programs provide a means for community members to help by acting as reef stewards, thereby heightening public awareness of bleaching impacts and of climate change in general. An example of a volunteer bleaching program is the GBRMPA's BleachWatch program, described in case study 2.

Key elements of a community-based bleaching monitoring program are:

- establishing and maintaining a network of reef users to provide casual and regular reports of bleaching status at reef sites.
- developing and distributing an appropriate assessment protocol and datasheets for participating reef users to use to report reef conditions and coral bleaching.
- encouraging regular reporting of both bleaching and non-bleaching observations.
- providing regular and useful feedback to volunteers about their data.

Table 2.3 Management questions and ecological assessment techniques

Technique	Description	Advantages/ disadvantages	Data collected
Volunteer and community-based reports			
• Is bleaching occurring? • Where is it occurring? • What proportion and types of corals are affected, and how badly?			
Monitoring by volunteers	• A network of volunteers is established to report on conditions at their sites and assess whether or not and to what extent bleaching is occurring. Volunteers might include tourism operators, community members, students, NGO staff, scientists or enforcement officers. • The University of Queensland has developed a colour chart system to help volunteers*.	• Cost-effective method for determining if bleaching is occurring and the extent of bleaching, potentially over a large area. • Depending on volunteer training, data may be quite subjective.	• Presence/absence of bleaching at one or multiple sites. • Indication of bleaching progress and severity.
Broad-scale assessments			
• What is the total area (of a large reef ecosystem) affected by bleaching? • How severe is the bleaching?			
Timed swims	• Observers swim in a straight line or 'wandering' path within the depth range selected. Swims are broken into fixed time units, (i.e. 2 minutes). • An example of the use of timed swims to assess bleaching is found in McClanahan et al (2001)[56]. • Table 2.4 provides a simple index for rapidly estimating the proportion of colonies affected.	• Requires expertise to identify corals to at least the genus level. • Capacity to be performed in remote locations. • Does not require access to aircraft or landing strips. • Provides greater resolution of reef characteristics than do aerial surveys. • Useful for selecting representative sites for more detailed surveys • Suitable for detailed coverage of smaller areas or for sparse. sampling of larger areas • More time spent diving and associated costs.	• Percentage of live coral cover. • Dominant coral types. • Percentage of coral bleached. • Average severity of bleaching.

Table 2.3 (cont)

Technique	Description	Advantages/ disadvantages	Data collected
Broad-scale assessments (cont)			
Manta tows	• An observer is towed behind a boat at a slow and constant speed. Tows are broken into fixed time intervals, usually 2 minutes, during which time observations are made. • Most suitable for reef areas between 10-100 km^2. • Detailed guidance is provided in English et al (1997)[54] methods developed for surveying COTS are applicable. • Table 2.4 provides a simple index for rapidly estimating the proportion of colonies affected.	As for timed swims, but: • Allows efficient coverage of larger areas. • Requires boat and manta tow equipment (can be made inexpensively). • Limits opportunities for detailed inspections. • Not suitable for reefs in deep or low-visibility locations.	• Percentage of live coral cover. • Dominant coral types. • Amount of coral bleached. • Average severity of bleaching.
Aerial surveys	• Observers fly in planes over large reef areas to determine if bleaching is occurring and to assess bleaching extent and severity. Data are collected by visual observation or by aerial photography. • To be reliable, conditions must include: 1. Coral cover >10 per cent. 2. Clear shallow water over reefs; low tide is best. 3. Good visibility; no high clouds or rain. 4. Wind <15 knots. • Flying height is determined by data collection method; low altitudes are preferred for visual observations (ie 500 ft) and higher altitudes (2000–10 000 ft) for photography.	• Particularly useful for assessing bleaching over large or remote areas of 100s to 1000s of km. • Require specific conditions of reef cover and visibility. • May substantially underestimate the impacts of bleaching. • Requires funds and availability of suitable aircraft.	• Percentage area bleached or proportion of reef sites bleached. • Estimates of proportion of corals bleached and severity of bleaching.

Table 2.3 (cont)

Technique	Description	Advantages/ disadvantages	Data collected
Site assessments			
• What are the local impacts of a mass bleaching event? • What percentage of corals have survived or died from bleaching? • What kinds of corals were most affected by bleaching? • Has the species composition or diversity of a reef changed due to a bleaching event?			
Line intercept transects (LIT)	• The observer swims along a transect recording the transect distance at every point where the type of organism or substrate changes, and the level of bleaching for each. • Table 2.4 provides a simple index for categorising the severity of bleaching. • Various schemes for classifying reef organisms have been developed for different levels of expertise.	• Widely used for assessing benthic reef communities. • Reliable and efficient. • Allows observers with limited experience to collect useful information, although some training in coral identification required. • Requires little equipment. • Is limited to addressing questions about relative abundance (cannot determine number of organisms or proportion of organisms bleached).	• Relative abundance of organism groups. • Proportion of cover bleached and severity of bleaching.
Belt transects	• Transect tapes are laid as in the LIT method; the observer records the identity and severity of bleaching of every sessile invertebrate within a set distance on both sides of the transect tape. The width of a belt transect is normally 0.5 m or 1 m. • Table 2.4 provides a simple index for categorising the severity of bleaching. • Various classification schemes have been developed for different levels of expertise.	• Reliable. • Does not necessarily require experienced observers, although some training in coral identification required. • Requires little equipment and is relatively simple. • Particularly useful for assessing the proportion of coral colonies that are affected by bleaching. • Less suitable than LIT for collecting data on relative abundance, and more time-consuming.	• Type, abundance and density of individual organisms. • Proportion of corals bleached and severity of bleaching.
Video transects	• A diver swims along the reef above a tape measure, recording on an underwater video camera the reef community. The video footage is analysed back in the laboratory. • The footage analysis should identify all bleached organisms and the severity of the bleaching responses (Table 2.4).	• Provides a permanent visual record of the reef community, and reduces time required in the field. • Requires relatively expensive equipment, trained analysts to collect the data, operate the video-analysis equipment and software, and interpret the footage.	• Percentage cover of organism groups. • Proportion of cover bleached and severity of bleaching. • Recovery rates. • Nature of shifts in species composition.

A variety of coral monitoring methods are presented and statistically evaluated for their effectiveness in reference Brown et al (2004)[57]
* More information on the University of Queensland Colour Charts is available at: www.coralwatch.org

Timed swims, manta tows and aerial surveys are techniques that help managers get a general sense of the extent and severity of a mass bleaching event

Broad-scale assessment. When designing a program to assess a mass coral bleaching event, managers will want to begin with an overall picture of the situation. Timed swims, manta tows, and aerial surveys are techniques that help managers get a general sense of the spatial extent and severity of a mass bleaching event. The most appropriate technique will depend on the size of the area that a manager wishes to survey. In-water techniques are relatively inexpensive and can provide detailed information about conditions on the reef including: assessment of the proportion of live coral cover and bare substrate, proportion of corals affected by bleaching, types of corals bleached, and both the severity of bleaching and amount of recently dead coral. They can also be useful for identifying sites representative of larger areas of reef. These are often the most useful locations for more detailed ecological surveys of coral bleaching impacts.

However, in cases of very large or remote coral reef areas aerial surveys may be the best option for conducting assessments in the relatively short time window available to assess the impacts of a coral bleaching event (typically 1-2 months after peak temperatures). In very large reef areas such as the Great Barrier Reef Marine Park, which spans 350 000 km^2, aerial surveys are the only feasible method for assessing the full spatial extent of bleaching. While aerial surveys have distinct advantages in such circumstances, the observations made should be interpreted with caution.

Aerial surveys of mass coral bleaching events can be the best option for conducting broad scale assessments in very large or remote coral reef areas

Points to consider when using aerial surveys include:

- Aerial surveys will be most effective in locations where reefs have high live coral cover and bleaching is moderate to severe.
- Aerial surveys of bleaching extent will be most accurate for shallow (5-10 m) reef communities on horizontal surfaces.
- Results of aerial surveys should be interpreted with the understanding that they do not distinguish reefs that have low coral cover from reefs on which corals have already suffered major mortality due to bleaching.

One way to address the above issues is to conduct site assessments at key selected locations in order to 'ground-truth' the interpretations that may emerge from aerial survey data. The next section discusses site assessments.

Site assessment. Site assessments help managers understand not just the extent and severity of mass bleaching, but also its impacts on the reef. These more detailed assessments are used to ground-truth broad-scale assessments of bleaching severity, and to provide a more thorough understanding of bleaching response patterns and any observable long-term impacts of the event. Specifically, they enable managers to directly assess the extent to which corals are recovering or dying because of the bleaching event.

Line intercept transects (LIT), belt transects and video transects are common methods for conducting detailed site assessments – these can help managers interpret broad-scale surveys and understand the impacts of bleaching on the reef

Ideally, site assessments are conducted before and after bleaching events so that the results of these surveys can be compared; however, this is not always possible. Whenever site assessments can be repeated 6-8 months after the bleaching event, and in subsequent years, they can provide answers to questions about how the bleaching event has affected the reef ecosystem, such as:

- Did bleaching result in changes to the species composition on the reef?
- Are corals differing in the rate of bleaching or the rate at which they either die or regain their zooxanthellae?
- Overall, how quickly is the reef recovering?

Line intercept transects (LIT), belt transects, and video transects are common methods for conducting detailed site assessments. In all three methods, tape measures are laid out along the reef to provide replicate transects. Deciding where to position transects is important. Survey sites should be partitioned into two or more depth zones (for example the upper reef slope and lower reef slope), and transects laid randomly within the depth ranges specified. Therefore, in many cases transects will be positioned parallel to the reef crest. The length and number of replicate transects should ideally be decided based on pilot studies that assess the level of variation in the reef community in the survey area. Often, however, time and resources do not permit pilot studies. In these cases, a general rule of thumb is to use 20 m long transects, with a minimum of three (ideally five or more) for each depth zone at each site. More patchy or variable reef communities will require longer or more transects. Another way of minimising the effect of high variability in a reef community is to use permanent transects. These are marked out on the seabed with metal stakes or rods, so that the tape measure can be placed in the same location during subsequent surveys. Advances in GPS technology make returning to the sites relatively easy. More detailed guidance on the use of transects to survey coral reef communities can be found in the references[54, 55, 57].


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A diver completes a rapid survey of bleaching in Bali Barat National Park (Indonesia) as part of an ongoing coral bleaching monitoring program described in case study 1

Observers record different information for each of the three techniques. When using LITs, the observer notes changes from one benthic life form (plant or animal growing attached to the seabed) to another along the transect. In contrast, when using belt transects, the observer records every organism within a set distance on either side of the transect, usually 0.5-1.0 m. Though more time intensive, belt transects cover a greater area of the site than LITs can. Therefore, managers choosing to implement this method can better assess the proportion of coral colonies that are affected by bleaching and can evaluate differences in bleaching response that may be linked to colony size.

When using video transects, a diver uses an underwater video camera to film the reef community either along a measuring tape or using a standardized swim time. The video footage is analysed back in a laboratory. This approach can also be achieved using a still camera (digital or film), which can reduce the expense associated with video equipment. Still camera or video footage has the advantage of providing a permanent record of the bleaching event and potentially allowing for more accurate data analysis. However, both still camera and video data are costly, and the results are not available until after laboratory analysis is complete. Because information is needed quickly during a mass bleaching event, it is often useful to complement video footage with observations taken while in the water (for example by rapid in-water surveys[55]). This information becomes the basis for communicating the extent of bleaching impacts on affected reefs until the laboratory analysis is completed.

Data collected by LIT and belt transects can be tailored to the experience level of the observer

Data collection during LIT and belt transects can be tailored to the experience level of the observer. The benthic life forms are normally characterised using a broad taxonomic classification (such as class or family level) or morphological categories (for example branching, massive, etc.), or a combination of both. However, when the expertise of the observer permits, more detailed classification of organisms (to genus or species level) is preferred. Taxonomic detail allows for ease of comparison between reefs and reef regions during far-reaching events when bleaching impacts are being assessed by numerous agencies and researchers.

When applying any of these methods to a mass bleaching assessment, observers will also record the extent to which benthic life forms are bleached. While the focus of such surveys will usually be the hard and soft corals, observers should also record the bleaching category of any organism that appears to be bleached, such as clams, anemones or sponges. For results to be comparable between observers and locations, descriptions of bleaching severity should be based on widely used indices. *A Global Protocol for Assessment and Monitoring of Coral Bleaching*[55] recommends a simple index for categorising the severity of bleaching within reef organisms (Table 2.4), and for estimating the proportion of corals bleached within a survey site (Table 2.5).

Table 2.4 Recording the severity of bleaching of coral colonies

Category	Description
0	No bleaching evident
1	Partially bleached (surface/tips); or pale but not white
2	White
3	Bleached and partly dead
4	Recently dead

Table 2.5 Recording the proportion of corals affected by bleaching

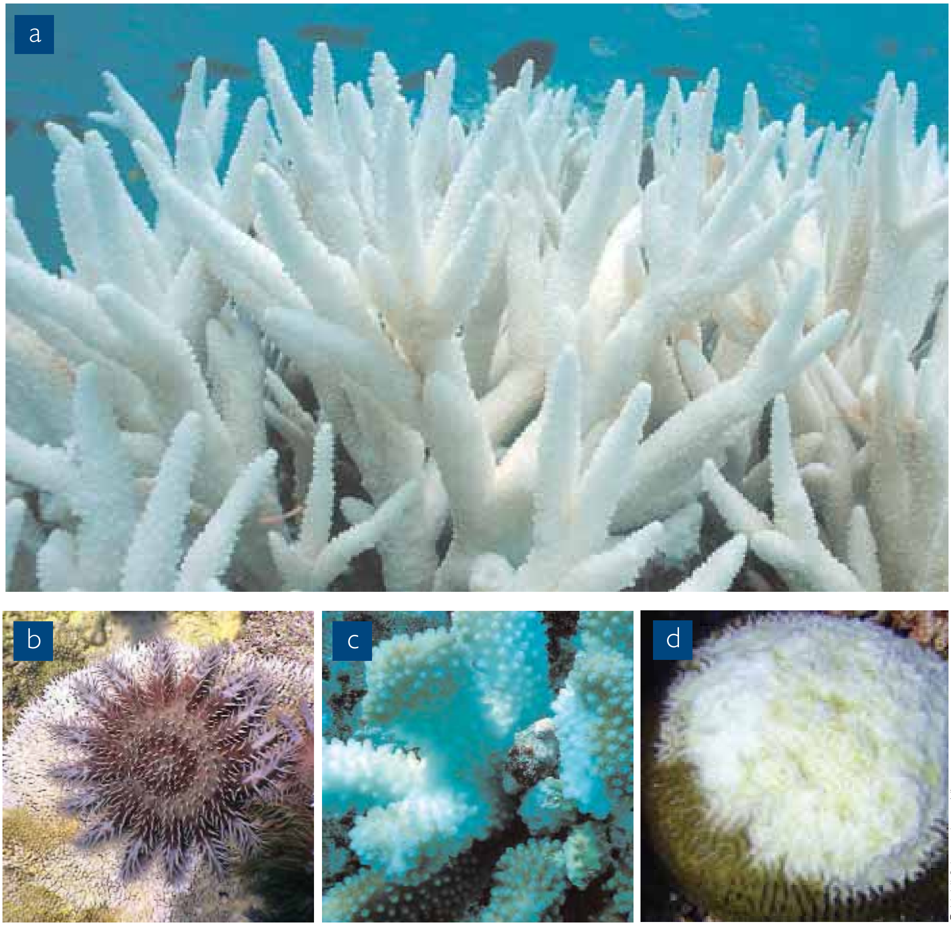
Category	Per cent	Description	Visual assessment
0	<1	No bleaching	No bleaching observed, or only very occasional, scattered bleached colonies (one or two per dive).
1	1–10	Low or mild bleaching	Conspicuous bleached colonies seen occasionally, but vast majority of colonies not bleached.
2	10–50	Moderate bleaching	Bleached colonies frequent but constitute less than half of all colonies.
3	50–90	High bleaching	Bleaching very frequent and conspicuous, most corals bleached.
4	>90	Extreme bleaching	Bleaching dominates the landscape, unbleached colonies not common. The whole reef looks white.

2.3.2 Special considerations for bleaching assessment

There are a number of considerations that a manager should be aware of when assessing mass bleaching events. The manager must be skilled at recognising when a mass bleaching event is occurring, deciding when to survey, and describing the severity of bleaching accurately. The following questions are helpful for providing guidance in these areas:

The proportion of corals affected and their spatial distribution normally distinguishes mass bleaching events from minor bleaching or other disturbances

How do I know whether what I am seeing is mass bleaching? Minor bleaching or paling of corals is a regular occurrence in many reef areas, and bleached colonies can be seen scattered throughout shallow coral communities during the peak of summer. More severe bleaching is sometimes seen within small reef areas due to localised stressors, such as flood plumes. Corals can also appear bleached when they are suffering the effects of coral disease or outbreaks of *Acanthaster plancii*, the crown-of-thorns starfish (COTS). It is important for reef managers to be able to distinguish between these various phenomena and recognise when an actual mass bleaching event is occurring.



© Heidi Schuttenberg (d)

Mass coral bleaching is visually very distinctive, but determining whether bleaching or some other stress is affecting individual corals can sometimes be difficult. (a) Bleaching is usually distinguished by the way it affects entire colonies or large sections of colonies similarly. The effects of coral predators, such as (b) crown-of-thorns starfish and (c) drupella snails can often be recognised by patches of bare skeleton adjoining patches of live, healthy tissue. (d) Coral diseases can also be sometimes mistaken for the early stages of mass coral bleaching. Disease takes many forms, but the effects of disease are often characterised by a strong line separating live and dead parts of a coral, or by rapid erosion of the surface structure of the coral, as shown here.

Reef managers are often asked to distinguish between 'minor' and 'major' bleaching events. The proportion of corals affected and their spatial distribution normally distinguish mass bleaching events from localised bleaching. The early stages of a bleaching event may be limited to the bleaching of more susceptible species of corals and be confined to shallow reef areas. However, at the height of a mass bleaching event, large proportions of the coral community will be visibly affected. Obvious signs of bleaching will extend below the reef flat, to include the reef crest and slope, and will span sites throughout a region. Furthermore, the majority of corals will be at least pale (category 1 in Table 2.4), with many to most completely white (category 2). The proportions of bleached corals might be lower during a mild bleaching event or if the coral communities are dominated by more bleaching-resistant species. In these cases, managers can be confident that a mass bleaching event is occurring if signs of bleaching are being observed at reefs throughout the region. Rarely will the effects of a bleaching event be patchy within an otherwise uniform reef habitat, such as might occur when outbreaks of coral disease or coral predators (such as *COTS* or *Drupella*) move through a reef community.

The distinctions used by the GBRMPA (Table 2.6) to distinguish between minor, moderate and major bleaching events are based on general criteria that can be adapted to local needs and used when providing summary overviews of the severity of a bleaching event.

Table 2.6 Criteria used by the GBRMPA to distinguish between 'minor', 'moderate' and 'major' mass bleaching events

A 'minor' bleaching event shall be declared if there are:

- reliable reports of low coral bleaching (1–10% of colonies completely white) from multiple sites from multiple locations spanning at least two GBR sectors; **or**
- reliable reports of mild bleaching (10–50%) from a few sites only, scattered throughout the GBR or concentrated in only one sector.

A 'moderate' bleaching event shall be declared if there are:

- reliable reports of moderate coral bleaching (10–50% of colonies completely white) from multiple sites from multiple locations spanning at least two GBR sectors; **or**
- reliable reports of severe bleaching (>50%) from a few sites only, scattered throughout the GBR or concentrated in only one sector.

A 'major' bleaching event shall be declared if there are:

- reliable reports of severe to extreme bleaching (>50% of colonies completely white) from multiple sites spanning multiple sectors.

Ideally, bleaching surveys should be done at the peak of bleaching, when the bleaching is at its worst and before corals begin to die or regain their zooxanthallae

When is the best time to survey? Where managers have the resources to do 'pre-bleaching' (baseline) surveys, they should ideally be done just before the time of year when bleaching is most likely to occur. This works to minimise the chance that changes in the reef community due to other disturbances might be mistakenly attributed to a subsequent coral bleaching event.

The timing of 'during-bleaching' surveys is more difficult to determine. Ideally, bleaching surveys should be done at the peak of bleaching, when the bleaching is at its worst and before corals begin to die or regain their zooxanthellae. However, the timing and spatial pattern of mass coral bleaching can be highly variable from year to year. The onset of bleaching is influenced by numerous factors, including the extent and duration of temperature anomalies, variability in local oceanography, and variation in the types, abundance and distribution of corals. The most efficient and reliable means of determining if a bleaching event is actually occurring is via direct reports from people who regularly visit the reef. By monitoring both the levels of heat stress (Section 2.1) and the development of the bleaching event (via regular site visits or reports from reef users), managers should be able to estimate when bleaching is at its peak and implement bleaching surveys accordingly.

'Post-bleaching' surveys are ideally done once bleaching is fully resolved (that is, all corals have either recovered their normal colouration or died). In practice, for most situations, assessments of the level of mortality will be reasonably accurate if they are done between three and six months after the onset of bleaching. Post-bleaching surveys run the risk of underestimating levels of mortality if they are done too soon after bleaching is observed. If done too late, they can overestimate the impact of bleaching by including mortality caused by other sources.

How can I determine whether long-term changes on my reef are due to mass coral bleaching or other causes? Ongoing monitoring is required to document the long-term ecological impacts of coral bleaching and other major disturbances on reef ecosystems. It is necessary to track changes in reef communities over longer time frames (several years to decades) in order to estimate the probability and rate of recovery, increase the ability to determine the cause of changes in reef condition, and evaluate the effectiveness of management strategies. Maintenance of long-term monitoring programs will enable managers to detect gradual changes in coral community structure that may occur because of bleaching and mortality and to maximise their ability to attribute chronic impacts to particular stresses, including coral bleaching. Monitoring on an annual or semi-annual basis should be complemented with additional surveys timed to detect the occurrence and impact of coral bleaching at long-term monitoring sites. The data from such targeted surveys will help managers determine the relative influence of coral bleaching on the long-term dynamics of coral reef ecosystems.

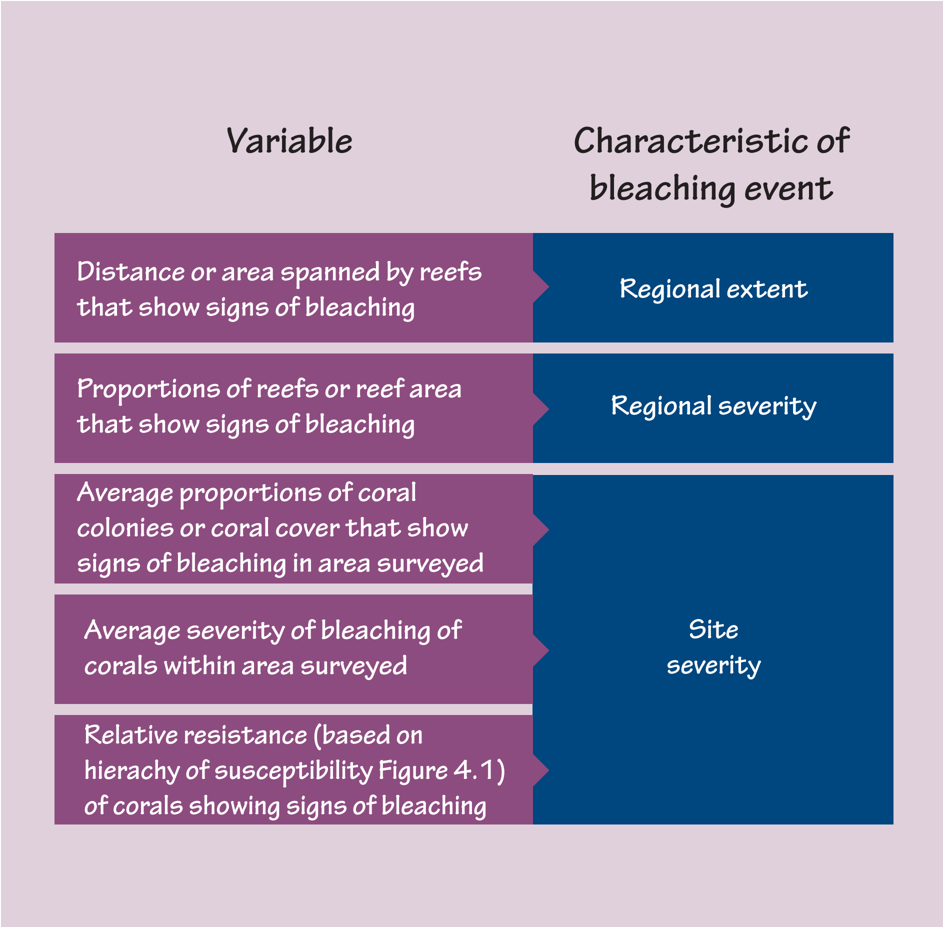


Figure 2.6 Key variables for describing the extent and severity of a bleaching event

These five variables are useful in describing the extent and severity of a mass coral bleaching event and in describing the impacts of bleaching to a particular reef or site. Reporting these variables based on the widely used indices presented in Tables 2.4 and 2.5 is helpful for analysing and comparing different bleaching events.

2.4 Assessing social and economic impacts

The effects of mass bleaching events extend beyond their impacts on coral reef organisms. Coastal communities throughout the world's tropical regions depend on coral reefs for a range of ecosystem goods and services, including fishing, tourism, shoreline protection and recreation[35, 36, 58, 59]. Deterioration in the quality of coral reefs due to disturbances, such as coral bleaching, reduces the reef's ability to provide these commodities and opportunities, resulting in social and economic impacts. Importantly though, social and economic impacts can also arise from management strategies designed to sustain coral reef quality.

Reef managers, policy-makers and communities that understand the relationships people have with the adjacent coral reefs will be able to better identify both the impacts of a mass bleaching event and any impacts associated with management strategies. This knowledge can be used to design management strategies that maximise environmental outcomes while minimising negative impacts on people. Specifically, impact assessments can:

- identify the potential social and economic impacts of mass bleaching
- integrate local knowledge with technical expert knowledge
- evaluate the social and economic costs and benefits of various coral bleaching management strategies
- increase public involvement in the monitoring of bleaching impacts.

2.4.1 Socioeconomic impacts of mass coral bleaching

The nature and magnitude of social and economic impacts resulting from coral bleaching will be influenced by the level of dependency coastal communities have upon coral reefs. Economic impacts may take various forms, including decreased income, reduced business efficiency and decreased business confidence and investment. Social impacts of bleaching might include effects on people's lives (such as how they work, play, and interact), their culture (shared beliefs, customs, values and language) and their community (for example its cohesion, stability, character, facilities and services).

Coral bleaching events can have direct impacts on human uses of reefs by reducing the aesthetic qualities of reef sites that are important for tourism, and by decreasing the abundance or availability of fish stocks (an example of these impacts is described in case study 3). As a result, the major reef uses likely to suffer direct social and economic impacts from coral bleaching are tourism (diving, snorkelling, and charter) and fishing (commercial, recreational, indigenous and subsistence fisheries). An assessment of the economic impacts of mass coral bleaching in the Indian Ocean is described in case study 3.

Tourism impacts. The socioeconomic impacts of mass bleaching on tourism depend on the awareness level of tourists, the severity of coral reef degradation, and coastal community reliance on coral reef condition. Although the ecological impacts of coral bleaching can be both rapid and visual, many of the social and economic impacts can be subtle or gradual. For example, a study of tourists visiting the Philippines found that, generally, visitors had a low awareness of mass coral bleaching; the result being that these businesses did not experience any immediate losses as a result of a bleaching event[60]. Socioeconomic work in Palau found that during a mass bleaching event, the white or pastel colour of the coral improved the aesthetic appeal of dive and snorkelling sites for some tourists[61]. This highlights the fact that many tourists may be currently unaware of the negative ecological implications of bleached corals.

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Coral mortality resulting from bleaching events can have direct impacts on human uses of reefs by reducing the aesthetic qualities of reef sites that are important for tourism and by decreasing the abundance or availability of fish stocks. Degraded reef condition can also have more subtle social impacts on communities by affecting customs and values, and community cohesion or stability

Should coral bleaching lead to mortality, however, the declines in reef quality become very difficult to ignore. As a result, the satisfaction of divers and snorkellers visiting a site that is deteriorated because of coral bleaching is likely to decline, with possible implications for visitation rates, and consequent impacts on tourism businesses. Economic impacts on dive-oriented tourism have now been documented following coral reef damage caused during the 1997-98 bleaching event in Tanzania, the Maldives, Sri Lanka and the Philippines[62].

The socioeconomic impacts of mass bleaching on tourism depend on the awareness level of tourists, the severity of coral reef degradation, and the industry's reliance on coral reef condition. Some studies have shown tourists to be unaware during bleaching events or even to feel that the white or pastel colour of the corals improved the visual appeal of the site. Should bleaching lead to mortality, however, the declines in reef quality become very difficult to ignore and can impact the type and number of divers choosing to visit the site

In the long-term, the extent to which coastal communities depend on coral reef condition will determine whether declines in reef quality due to coral bleaching translate into economic impacts. In some situations, tourism businesses have shown resilience to changing conditions. For example, a combination of issues, including coral bleaching, over-fishing, and tourism-related damage were perceived to have decreased the quality of reefs in the Philippines, causing a decline in occupancy of local hotels by divers from 80 per cent to about 10 per cent over 15 years[60]. The tourism industry recovered partly through a shift from reef-oriented dive tourism to 'honeymooners'. This less reef-oriented market segment now forms over 50 per cent of the resort bookings in the area[60].

CASE STUDY 3

Economic analysis of coral bleaching in the Indian Ocean

The 1997-98 mass coral bleaching event had severe ecological consequences for Kenya, Tanzania, and the Seychelles, with each country estimated to have lost roughly 40-50 per cent coral cover. A two-phase study, undertaken as part of the Coral Reef Degradation in the Indian Ocean (CORDIO) project, estimated economic losses resulting from the mass bleaching event. Results suggest that, five years after the event, economic impacts are most noticeable in the tourism sector[38]. Results describing the economic impacts on fisheries incomes were inconclusive.

The study estimated tourism welfare losses by combining the results of a 'Willingness To Pay' (WTP) survey with estimates for coral recovery. The WTP survey found that tourists were willing to pay US$98.70 extra per holiday in the Seychelles, US$87.70 in Zanzibar and US$59.00 in Kenya in order to experience healthy coral reefs. Applying a conservative estimate that corals should recover at a linear rate over a 20-year period, and assuming that WTP relates linearly to recovery, the study estimated welfare losses in 2001 of US$9.7 million for the Seychelles, US$6.4 million for Mombasa, and US$5.4 million for Zanzibar. Net present values of these annual welfare losses over a 20-year time period with a 10 per cent discount rate shows considerable potential welfare losses: a total of US$71.5 million for the Seychelles, US$47.2 million for Mombasa, and US$39.9 million for Zanzibar.

Related studies showed that tourism losses could vary significantly between locations. A 2000 study by Cesar et al[34] found that, in the Maldives, tourism growth was cut by only one per cent as a result of coral mortality. This is despite significant declines in reef condition (live coral cover decreasing from 50 per cent to less than five per cent). The small loss in tourism is likely to be explained by the successful shift made by operators in the Maldives toward other types of tourism, 'honeymooners' in particular. In addition, with double-digit annual international growth in the number of certified divers, and the relative proximity of the Maldives to the European market, this archipelago is guaranteed a fresh supply of relatively inexperienced divers. New divers are mainly interested in large, charismatic marine creatures (large fish, sharks, turtles, etc.), which are readily visible in the Maldives due to low reef fishing pressure. By comparison, a 2000 study by Westmacott et al[12] found a 19 per cent drop in dive-related tourism to Zanzibar due to severe coral bleaching, corresponding to an estimated 10 per cent reduction in total tourism arrivals. The difference in measurable changes in tourism between the Maldives and Zanzibar is particularly interesting. One possible explanation is that the breadth of the tourism sector in the Maldives enabled a shift in tourism focus (from diving to beach-oriented holidays, for example) that minimised declines in total tourism revenue.

The impact of mass bleaching on fisheries in these nations was far less clear. While fish species' composition changed (in some cases considerably) overall yield and income for fishers did not change significantly. This suggests that fishers are targeting other species to compensate for bleaching-related declines in their normal target species. The influence of coral bleaching on overall fishery trends were difficult to identify because market price and fishing effort were being influenced simultaneously by other factors during the same period. For example, one study[150] found that catch per fisher decreased by around 25 per cent in Kenya in concert with estimated decreases in biomass on fished reefs. However, at around the same time as the bleaching event there was a 16 per cent increase in the number of fishers. Because these impacts coincided it was difficult to identify the reason for the decline in fish catches. Furthermore, despite an increase in the abundance of herbivorous rabbitfish on fished reefs following bleaching, the number of rabbitfish recorded in fishing catches declined due to changes in fishing pressure and target species.

These studies illustrate the difficulty in identifying the impacts of coral bleaching on fisheries. There are complex relationships between habitat quality, fish abundance, community composition and fishing pressure. Coral mortality resulting from bleaching can affect reef communities in two different ways. On one hand, coral mortality increases the opportunity for algae recruitment, which can lead to increases in primary productivity and consequently in the biomass of herbivorous fishes. However, coral mortality also leads to decreased habitat availability for fishes as waves, currents and bio-erosion reduce dead coral skeletons to rubble. This leads to reductions in fish diversity, and, for some species, dramatic declines in abundance[143]. From a fisheries perspective, the impacts of coral mortality associated with coral bleaching are likely to depend on the type of fishery, and the relative importance of increases in algal biomass versus decreases in habitat complexity for the resident fish community. However, fisheries, especially those characterised by small-scale operations, can be highly responsive to changing conditions, and shifts in fishing effort and species targeted can readily confound impacts of changes in abundance of fish populations related to coral bleaching events. More research is required to improve our understanding of the direct and indirect impacts of coral bleaching on fish communities, and on associated fisheries. Such information is essential for the development of management strategies that aim to sustain coral reef ecosystems and dependent fisheries in the face of future coral bleaching events.

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Fishing is an important use of coral reef resources, providing income and food to millions of people worldwide

Fishing impacts. Time lags can be expected between a coral bleaching event and associated social and economic impacts in fishing industries. Studies have documented changes in fish populations as a result of bleaching-related ecological degradation[63, 64]. However, studies have had difficulty demonstrating how changes in fish stocks have translated into changes in fishery yields or fishing income following coral bleaching events. In these cases, the adaptability of many fishers, and the confounding influences of other multiple influences on subsistence and commercial fishing have complicated efforts to understand the impact of bleaching on fisheries. For example, shifts to other target species, changes in net size, and the effects of market prices and other disturbances such as typhoons or upwelling events all serve to mask the possible effects of coral bleaching. However, deterioration in reef quality is likely to have lasting impacts on the sustainability of fishing pressures, even if they are not readily apparent. More comprehensive social and economic monitoring, with adequate baseline data, may be required to properly assess the impacts of coral bleaching events on fishing[38].

Indirect impacts. Coral bleaching may also have indirect effects on local and regional communities through their social and economic links to the fishing and tourism industries. Reduced prosperity of these industries can potentially lead to a multitude of flow-on effects to other elements of the community, ranging from local schools, accommodation providers and food stores, to hardware and fuel suppliers[65]. These subtle but important effects can have ramifications for the stability of regional and coastal communities.

Management strategies designed to protect reefs from coral bleaching may also indirectly affect people and industries by constraining the way people interact and access the reef. While unintended, these restrictions can have significant and lasting social and economic impacts. For example, management initiatives to protect herbivorous fishes from over-exploitation may substantially limit the ability of fishers to pursue their traditional target species. While some fishers in some regions may be in a position to compensate for such restrictions by switching to other species or even to other activities such as tourism, many may not. Understanding these effects will allow management initiatives to be more effective and equitable.

Social and economic resilience. Given the right circumstances, humans are able to adapt to a changing environment. Understanding what factors influence people's capacity to be resilient to change in quality or access to a natural resource is a key focus of current research[66]. Knowledge of a community's capacity to respond to change can strengthen management interventions and assist in predicting the longer-term social and economic impacts of coral bleaching. This adaptive capacity may vary significantly between developing island nations and developed countries with large land areas that vary in their dependency on coral reef ecosystems and in the diversity of their economies.

2.4.2 Measuring socioeconomic impacts from mass bleaching

Managers are likely to have a range of socioeconomic questions related to mass coral bleaching. Some of these are likely to be:

- What are the types of social and economic impacts likely to be experienced due to a bleaching event?
- Who is likely to be affected?
- What are the characteristics of people and industries potentially affected?
- What opportunities exist to minimise the direct effects of a bleaching event?
- How can management responses to bleaching be designed to minimise impacts on reef users?

Answers to these questions may help managers decide if, for example, a contingency fund for tourism operators should be established. Reef managers may wish to work with local communities to identify strategies to promote alternative business opportunities or facilitate access to other resources. Broader-ranging strategies, such as creating subsidies to change land-use practices, or strengthening regulations for land clearing, agriculture, and development may also be considered.

A framework for assessing bleaching impacts. Formal assessment of socioeconomic impacts can help managers to understand, predict and assess the impacts of change on individuals, families, communities and societies. In some instances, social and economic variables may already be monitored on a regular basis to assist with other aspects of reef management, and managers may wish to incorporate a bleaching element into these studies.

The science of measuring and understanding socioeconomic impacts has developed rapidly in recent years, and there are now guidelines for assessment programs. Properly implemented, socioeconomic impact assessments can be valuable tools in a reef manager's approach to minimising the impacts of coral bleaching events. While available resources may limit a manager's ability to complete comprehensive assessments, the impact assessment framework described in Box 2.2 can still provide important guidance for collecting relevant information.

This useful framework for socioeconomic impact assessments comprises six generic steps: scoping, profiling, prediction, evaluation, mitigation and monitoring[67]. Depending on the resources available and the goals of the assessment, not all steps may need to be completed to the same degree. If the main concern of the manager is to identify the main types of impacts, a scoping study may be adequate. In other contexts, it may be highly desirable to quantify all of the community-scale impacts, requiring the manager to complete each step of the assessment framework.

Assessing the character and significance of socioeconomic impacts resulting from mass bleaching can help managers communicate the importance of healthy coral reef ecosystems and develop strategies to minimize impacts on affected people and industries

Box 2.2 A social impact assessment framework

Formal socioeconomic impact assessments generally follow a six-step process. Each of these steps is described below in relation to coral bleaching. Familiarity with these steps can help managers identify realistic goals for social and economic impact assessments, and can provide guidance when developing collaborative assessment projects.

Scoping *involves identifying the goals, issues and methods for the assessment of the potential impacts that might be expected to result from mass bleaching events. The goals of the assessment will determine the social and economic variables that need to be collected. Wherever possible, a well-developed community involvement program should be integrated into the process. A scoping study conducted in consultation with the community may help identify goals important for the whole community with respect to coral bleaching. Community involvement not only provides important information for the development of the assessment, but also provides opportunities for the community to be informed about coral bleaching and involved in the management response. Suitable representatives from the local community, fishing industries (commercial, recreational and subsistence), tourism industries and traditional users should be engaged at this stage. Common methods for scoping include broad-scale workshops, industry-specific workshops, qualitative interviews, key informant surveys and desktop-analyses, or a combination of these.*

Profiling *describes the existing social and economic environment in which impacts are likely to occur. This step should identify the variables and indicators that describe the vulnerability or resilience of people and communities to bleaching events. Profiling provides baseline data about a community and can be carried out any time prior to a bleaching event. Such data provide bases for comparison should managers wish to set up a social and economic monitoring program to quantify the impacts of future bleaching events. Sectors of the community that should be profiled are normally identified in the scoping part of the study. Typically, profiling is achieved using standard survey techniques, although secondary sources such as census data may also be useful. A recent guide, SocMon[68], is an excellent reference to help with profiling surveys. An example of the use of profiling to characterise a commercial fishing industry prior to the implementation of various management actions is provided by a Guide to the Fishers of Queensland[65].*

Predicting *social impacts requires information collected during the profiling exercise to describe potential social and economic impacts. The probabilities, magnitude and distribution of impacts are also described in this section. Indirect impacts can be assessed by identifying and quantifying links between direct and indirect reef users. Prediction can also include quantification of the spatial links between the resource and reef users, and the subsequent economic and social links between users and the rest of the community. This information provides a basis for predicting the social and economic consequences of alternative management actions, such as various locations for 'no fishing zones'. Predictions may also be qualitative, with the results of the profiling exercise being assessed based on broad discussions with the community. Historical records may be important to access during this stage. Any prior change in the quality of the coral reef in the past–and any* *associated social and economic impacts that occurred–may be indicative of how a dependent community may respond to a bleaching event in the future. Historical records may also provide some information on the cumulative nature of social and economic impacts.*

Evaluation *is a process that determines the acceptability of potential impacts. This process should involve considerable public involvement since there are often significant differences between interest groups in how impacts are evaluated. For instance, reef managers may decide to implement a suite of Marine Protected Areas (MPAs) to assist reefs in their recovery from bleaching. The design and placement of the MPAs will have varying social and economic impacts, dependent on their location and size. The evaluation phase allows reef managers to assess the impacts associated with alternative proposals. This phase is initially conducted as a desktop study, but it is crucial to 'ground-truth' the results by querying those people likely to feel the impact. Transparency in evaluations is important if the community is to feel confident that impacts likely to affect them have been considered and understood.*

Mitigation *focuses on minimising impacts. The aim of this section is to develop management strategies that maximise the resilience of reefs, while minimising the social and economic impacts. Again, this step requires extensive community involvement in the design of strategies. Conflicts between user groups in their expectations for management concessions can be minimised with good community engagement.*

Monitoring *can enable reef managers to detect the onset of and changes in social and economic impacts associated with coral bleaching. In addition, a monitoring program will help detect unforeseen impacts, and assess whether mitigation strategies are working as intended. Reef managers may already have survey programs in place to address other goals of marine park management. Where there are existing programs, managers may wish to add components that can determine if the predicted impacts of coral bleaching events are occurring.*

Special considerations. While the structured approaches described here provide a solid framework for assessing bleaching impacts, managers should be aware of issues that impeded the progress of past impact assessments and discuss them with researchers when developing appropriate projects. As noted in the previous section, a key issue is separating the influence of mass bleaching from the effect of other disturbances and from other stressors. For example, studies estimating the economic impacts of the 1997-98 bleaching event on fisheries in the Indian Ocean region found that changes in fisheries effort and gear type made it difficult to isolate bleaching impacts given the data available. Similarly, several studies have found that significant decreases in tourism due to international terrorism attacks complicated attempts to identify changes in tourism associated with the degradation of coral reefs[37, 60, 69]. Challenges also arise when reef degradation results from

A key challenge in assessing the socioeconomic impacts of mass bleaching is separating out the influences of other stressors and changes in resource use – managers should discuss these issues with researchers during project design to focus studies in the most management-relevant directions

multiple sources. Coral reefs in Con Dao, Vietnam, experienced almost 100 per cent mortality in 1998 as a result of a typhoon followed by mass bleaching[15]. Because mortality resulted from the combined influence of both events, it is unclear how much of the subsequent socioeconomic impact should be attributed to the mass bleaching event. By discussing these issues during project design, managers will be able to extend the scope and limitations of research results, as well as fine-tune studies toward the most management-relevant directions.

2.5 Implementing management measures during bleaching events

The current section considers whether any meaningful actions can be taken during mass bleaching events to reduce negative ecological impacts. While above-average sea temperatures are outside the control of reef managers, other factors that influence coral reef resilience to mass bleaching events are amenable to management (also see Section 3.1.2). Ecosystem condition, which influences coral survivorship during mass bleaching events and reef recovery after bleaching-related mortality, can be maintained and improved by effective management of local stressors[40]. However, it is the physical conditions–temperature, light, and mixing–that principally determine whether corals bleach in the first instance. They also play a key role in determining the probability of mortality during bleaching events. While these factors are not amenable to intervention in conventional management approaches, concern about the future of coral reefs is driving new thinking about ways in which bleaching risk might be mitigated. The following strategies for management intervention are based on emerging ideas that mostly have yet to be tested. Some may turn out to be fruitful initiatives, especially those aimed at reducing local stressors; however, most should be considered experimental and undertaken in the spirit of adaptive management.

Bleached corals are in a state of extreme stress and therefore less resilient to local stressors, such as physical damage from recreation, degraded water quality, or pressure from fishing activities

2.5.1 Managing local stressors: recreation, water quality and fishing

Physical damage from snorkelling, diving and boat anchoring. The temperature anomalies that trigger coral bleaching events place substantial stress on coral colonies, even before there are any visible signs of bleaching[70]. Once a coral is bleached, it is in a state of extreme stress, with reduced capacity for feeding and maintenance of essential physiological functions, such as injury repair and resistance to pathogens[18, 23, 27, 71]. Snorkelling, diving, and boat anchoring are all activities that can cause physical injuries to corals if not carefully managed. A coral stressed due to bleaching is likely to be less capable of recovering from physical injuries due to these activities. Repair of even minor tissue damage may be hindered while the colony is in a stressed condition, increasing the risk of infection or overgrowth by competing organisms[71].

Although the principles behind these theories are well established, there have not been any direct studies of the effect of bleaching on a coral's response to physical injury. However, reef managers may wish to explore the costs and benefits of minimising activities that could expose stressed corals to increased risk, especially in high-visitation tourism sites.

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Snorkelling, diving, and boat anchoring (shown here) are all activities that can cause physical injuries to corals if not carefully managed. A coral stressed due to bleaching is less capable of recovering from physical injuries due to these activities

Water quality. Degraded water quality affects various life stages of corals[45, 72], making it likely that it exacerbates the effects of coral bleaching[42]. Acute increases in sediment and pollutants, associated with coastal development or dredging, deliver additional stress to corals that must clear sediment from colony surfaces, wasting precious physiological resources. Corals stressed from mass bleaching are likely to be less effective at defending against invasion by microalgae or at competing with macroalgae[71]. Additionally, nutrient inputs can significantly reduce coral recovery after bleaching-related mortality[45] (Section 4.2.3).

Short-term increases in sediment and pollutants associated with coastal development or dredging cause additional stress to corals that is likely to increase the effects of coral bleaching. Limiting particular coastal activities during bleaching events could reduce damage to coral communities, while also reducing the risk that the developer will be held responsible for any coral mortality that could be due to bleaching

In light of these implications, managers may wish to consider the timing of coastal activities during periods of increased temperature stress. Limiting particular coastal activities during bleaching events could reduce the risk of damage to coral communities that could result from negative interactions between stressors such as turbidity and temperature[41]. Such a strategy could also reduce the risk that developers will be held responsible for any coral mortality that could be due to bleaching.

Fishing activities. Herbivores play a critical role in facilitating recovery of coral reefs after major disturbances (see also Section 4.2.3). In many locations, the grazing activity of herbivores is essential to the maintenance of substrate suitable for coral recruitment[42, 45]. For this reason, should a bleaching event result in substantial coral mortality, a reef manager may wish to consider implementing short to medium term initiatives to protect the herbivore function that is necessary for the reef to recover. This is most relevant in underdeveloped countries where herbivorous fish populations are under threat from fishing pressure. These initiatives are most likely to be effective if they are done in partnership or consultation with relevant stakeholder groups. Ideally, restrictions would be maintained until significant recovery is evident or until there is other evidence that adequate settlement substrate can be maintained despite fishing pressures.

Herbivores play a critical role in facilitating recovery of coral reefs after major bleaching events by maintaining suitable substrate for coral recruitment. Should a bleaching event result in substantial coral mortality, managers may wish to work with local communities to implement short- to medium-term initiatives that protect the herbivore function necessary for the reef to recover

2.5.2 Impeding the causes: light, temperature and mixing

Light. Ultraviolet light is known to be a key factor in coral bleaching[73], and small-scale experiments have shown that reducing intensities of UV light have reduced the incidence or severity of bleaching[24]. These observations suggest that shading moderate sized areas during periods of greatest temperature stress may reduce the amount or severity of bleaching. However, practical considerations involved in implementing a shading strategy, as well as the potential for unwanted side effects, make this proposal particularly challenging. Small to medium-scale experimental tests of this strategy would be best accomplished through close science-management partnerships.

Temperature. Although water temperatures are not amenable to management intervention at large spatial scales, there may be potential for temperatures to be manipulated in some localised circumstances. In situations where high water temperatures are due to the solar heating of shallow or contained water bodies, relatively small volumes of cool water may be adequate to maintain temperatures below critical bleaching thresholds for at least some species. Deep water adjacent to such sites may provide a readily available source of cool water. This strategy may become increasingly appealing at high use tourism sites should coral reefs continue to degrade because of temperature-induced stress. The feasibility of this idea has not been thoroughly investigated to date, and no field tests are known.

Mixing. The amount of water exchange around a coral colony during thermal stress has been hypothesised to influence the severity of bleaching[74]. Increased water flow is thought to increase the flushing of toxins that are the by-products of the cellular processes which lead to coral bleaching. Therefore, it is possible that increased flushing of toxins through greater water circulation around coral colonies may reduce the severity of bleaching or at least delay the onset of bleaching. If greater mixing could be achieved, it is likely that the amount of damage from a thermal stress event could be reduced. The role of water flow in determining the impacts of thermal stress on corals is still being studied, and the practicality of this concept as a strategy for management intervention has not yet been explored or tested.

It seems unlikely that interventions aimed at reducing temperature and light are practicable except at a very small spatial scale, such as at discreet, highly valued tourism sites

2.6 Communicating about mass bleaching

Mass coral bleaching is a visually spectacular phenomenon with potentially severe implications for the health of coral reef ecosystems, the enjoyment of visitors, and the prosperity of individuals and businesses that depend on the reef. For these reasons, bleaching is an issue that attracts strong interest from the public, the media, and policy/decision-makers. In response, managers will want to provide up-to-date and informative answers to important questions about mass bleaching events and related impacts. Preferably, managers will proactively engage their target audiences (Figure 2.7) in discussions about mass bleaching and the actions that are needed to build coral reef resilience.

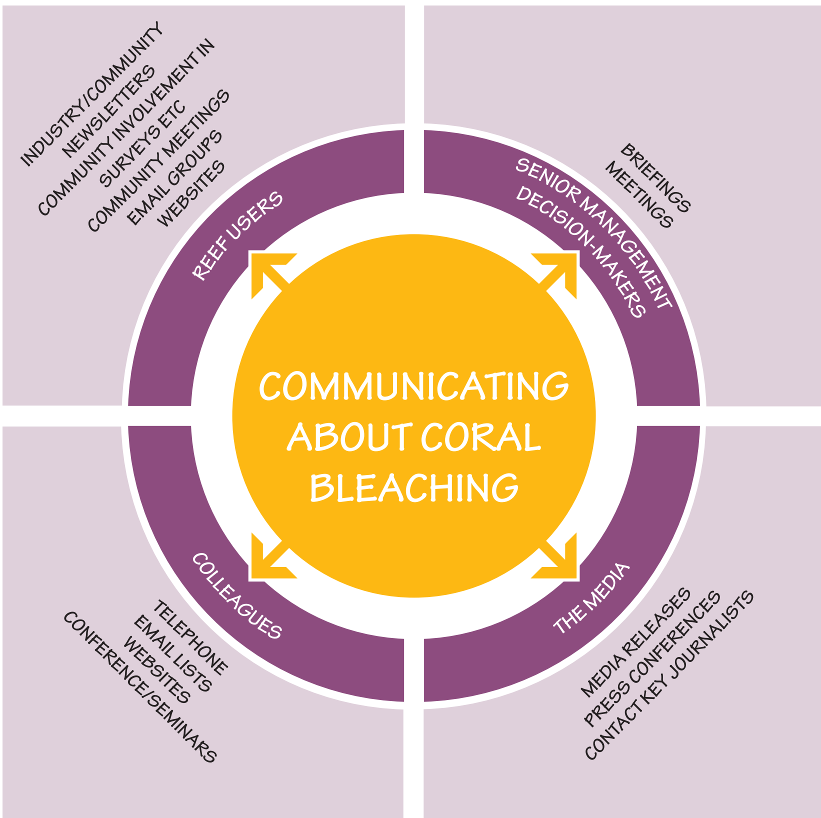

Figure 2.7 Target audiences and strategies for communicating about coral bleaching

Mass bleaching attracts strong interest from the media, reef users, senior decision-makers and management colleagues because it is visually spectacular and has potentially severe implications for the health of reef ecosystems. Effectively communicating with these audiences will increase support for coral reef management responses.

A communication strategy for responding to mass bleaching might have three aims:

(1) Gain support from supervisors and constituencies to respond to mass bleaching in the short and long term
(2) Engage stakeholders in a two-way communication about the extent and severity of bleaching and actions that can be taken to build reef resilience
(3) To work with the media to raise awareness of mass bleaching events and their impacts among the general public.

This section outlines strategies for working with target audiences–senior decision-makers, reef users, the media and colleagues–and provides examples of answers to common questions about mass bleaching events. It also identifies available resources for outreach and education.

2.6.1 Strategies

In working with any audience, managers are advised to take an approach that is clear and well thought out, proactive, solution-oriented, balanced, and respectful of political constraints. In communicating about mass bleaching, it is important that managers maintain the trust of their supervisors and the credibility of their reputation. Managers should be aware of political and social sensitivities and operate within organisational constraints. Managers also need to resist temptations to over-dramatise issues or events in order to meet the expectations of the press. This is of particular importance when bleaching is patchy and tourism operators are wary of the condition of their frequently visited sites becoming highlighted in the media. Lost credibility due to exaggeration of facts or presentation of premature conclusions can be costly and, sometimes, impossible to regain.

In working with any audience, managers are advised to take an approach that is thought-out, proactive, solution-oriented, balanced, and respectful of political constraints

Whether made up of supervisors, stakeholders, or the media, audiences are likely to be more receptive when they feel they are being consulted early and presented with options or useful information. When people feel attacked or helpless to solve a problem, they may become frustrated or angry, disengage in the discussion, or actively try to cover-up the issue. For this reason, over-dramatisation and focus on negative scenarios can be destructive to efforts to address the threat presented by coral bleaching. Instead, managers should enter discussions with a clear, balanced presentation of key issues and solutions, including specific recommendations for how any given audience can help. Specific suggestions are provided below.

Decision-makers. Senior managers, policy-makers and political leaders usually have responsibility for organisational priorities and allocation of funding and staff. Information about mass coral bleaching and its implications for the reef ecosystem, reef users and the wider community should be conveyed to decision-makers. This will ensure that coral bleaching is recognised as a management priority and incorporated into any relevant management decisions and strategies.

When briefing senior decision-makers, managers should strive to provide information early and to suggest actions that can be taken in response to the bleaching event, such as rapid impact assessments

In working with senior decision-makers, managers should strive to provide information early and to clearly articulate actions and solutions that can be implemented in response to mass bleaching events. A coral bleaching response plan is ideal for this purpose. The plan should outline a course of action and identify/estimate the resources required to implement it (see Section 2.1). In addition to immediate response actions, decision-makers should be informed of broader efforts that can be implemented to build coral reef resilience (see Chapter 3).

Formal briefings ensure decision-makers stay well informed and should be delivered in the lead-up to the bleaching-risk season and during major bleaching events. Written briefs should provide timely updates on the pending or current situation, and its environmental, economic, social and political implications. During a bleaching event, briefings are essential to ensure that senior management learn about significant developments prior to any public release of information. This is critical if institutional credibility and political support are to be maintained for the bleaching response as well as for any broader efforts to address mass coral bleaching. Overall, managers should aim to put senior decision-makers in a position where they can say, 'We know what's going on, and we are working hard to address the situation'.

Reef users. Reef users, such as recreational and commercial fishers, divers, and tourism operators, are likely to have a strong interest in the health of the reef and any major disturbances. They are among the groups most likely to be affected by any change in the quality of the reef, and may be key supporters of any efforts to mitigate localised stressors that reduce resilience or exacerbate the impacts of a bleaching event.

In working with reef users, managers should strive to foster a two-way exchange of information. Reef users can often assist the manager in understanding the status of bleaching at their site, and can provide anecdotal information on the sea temperatures, tidal conditions, and cloud cover that preceded the event. This information will allow the reef manager to better communicate the extent and severity of mass bleaching throughout the reef ecosystem, its effects, and its implications. Working together in this way can help raise awareness, build 'grass-roots' support for strategic management goals, and develop a shared understanding of the need for any short-term management actions. This is of particular importance because short-term actions may require restrictions on the types or levels of activities in order to minimise damage to the reef. The experiences of managers working with the diving industry in the Florida Keys National Marine Sanctuary (case study 4) and local fishers in Kenya (case study 5) are examples of using two-way communication during mass bleaching events to build support for broader management measures.

A community-based monitoring program not only provides valuable information about conditions on the reefs (see also Section 2.3.1), but also acts as an important and engaging communication tool. Involvement can convert a sense of helplessness into one of commitment to identifying and implementing practical actions. Reef users who are willing to contribute to community-based reporting programs are often the individuals and organisations who are leaders within the stakeholder community, and are ideal conduits for communication with the larger community. Their commitment to their industry or group,

Building collaborative partnerships with reef users during bleaching events – Florida Keys National Marine Sanctuary

Collaboration between reef users and managers can significantly improve the capacity of managers to respond rapidly to bleaching events. In the Florida Keys National Marine Sanctuary (FKNMS), the periodic occurrence of mass coral bleaching has provided an opportunity for coral reef managers to initiate valuable collaborative partnerships with dive operators.

During coral bleaching events in the 1990s, managers of the FKNMS involved dive operators in the early phases of their management response to coral bleaching. As soon as managers were aware that conditions were developing that could lead to coral bleaching, they communicated their concerns, and the scientific basis for them, to the dive operators. The managers used the HotSpot maps and degree heating keeks maps provided by NOAA to communicate the state of knowledge about the causes and predictability of coral bleaching.

Dive operators are often the first reef users to observe the early stages of coral bleaching. Dive operators and their customers are well placed to assist reef managers to monitor the extent and duration of bleaching, and of any secondary impacts that follow. As well as providing early observations of bleaching, divers and dive guides can assist managers in ground-truthing predictions of conditions known to cause bleaching, derived from remote sensing technology (such as satellite data).

The accuracy of the managers' predictions in the 1990 and 1997-98 mass coral bleaching events improved their scientific credibility with dive operators. The fact that coral reef managers could use remote sensing data from satellites combined with meteorological observations to predict coral bleaching events caught the attention of dive operators. This made it possible for managers to gain a mandate for responsive actions, such as research and monitoring, as well as education and outreach. Dive operators were also able to put in place measures to minimise visitor-related impacts on coral reefs stressed by bleaching. While dive operators routinely caution their customers against coming into contact with corals, the bleaching events provided another opportunity for operators to emphasise the vulnerability of corals to human activities.

In this case, bleaching events provided an opportunity for managers to form collaborative and mutually respectful relationships with a major segment of the tourism industry in the Florida Keys. These relationships have been maintained beyond bleaching events, and they continue to provide benefits in dealing with other management issues in the area.

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as well as to the reef, also makes them valuable partners in collaborative efforts to understand the problem and to devise appropriate solutions.

A community-reporting program can range in complexity from periodic face-to-face meetings and simple phone networks, to specially prepared surveys, with on-line reporting forms and summary reports. It is important that the primary mechanism for information exchange is appropriate to the target group. Active involvement will only occur if managers reach out and demonstrate a genuine interest in the knowledge and concerns of the stakeholders. Ongoing commitment from reef users to a reporting program will depend on their sense of the level of appreciation and utility of the information that they provide. For this reason, feedback is an important ingredient in the success of a community-reporting program. Managers should design active and transparent mechanisms for communicating to reef users how their information is being used. This may include regular dialogue by phone, email, or formal written summaries of conditions at the reporting site.

In addition to community monitoring programs, a number of strategies can be used to share information with reef users about mass bleaching. Managers should select the strategies most appropriate to their stakeholders, which may include speaking at community meetings, using local or industry newsletters, email updates, and the use of appropriate websites.

Good media coverage can significantly advance efforts to increase awareness about coral bleaching and create support for management initiatives

The mass media. A mass coral bleaching event is visually dramatic, attracts strong public interest and therefore, is highly likely to be considered newsworthy. Managers must be prepared to engage with the media in order to respond to questions and inquiries and, ideally, to utilise the media proactively as a communication tool. Good media coverage can significantly advance efforts to increase awareness about coral bleaching and create support for management initiatives. Professional training in media engagements can be extremely valuable in helping managers to maximise the value of media coverage.

Taking an active lead in interactions with the press will allow managers to influence the agenda of discussions and avoid being forced into a defensive position. There is value in meeting with the media before a mass bleaching event to educate, provide contacts, and offer resources. Media statements should be released as soon as new and significant information becomes available and senior decision-makers have been briefed. Managers should consider drafting generic media releases that can be annotated with the current facts and quickly released at key points throughout a bleaching event, such as when:

- conditions develop that indicate a high risk of coral bleaching
- a significant bleaching event occurs (describing spatial extent and general severity)
- the bleaching event has concluded (describing coral mortality and ecological impacts).

Managers should consider making available high-quality images for use by the press. Pictures of mass bleaching are available free of charge from many Internet sites including those listed in Section 2.6.3. High-quality still images of coral bleaching, especially those that have a strong human-interest element (for example a scuba diver or sea turtle in foreground) are often greatly appreciated by the print press. Similarly, television journalists will often be grateful for high quality underwater video footage. The provision of usable images helps foster a good working relationship with journalists, and increases the chance that media reports will highlight the manager's perspective on the issue. Where they exist, managers should work with in-house media experts to ensure that information is packaged appropriately for use by the different branches of the media, while maintaining key messages and factual correctness.

Although a well-prepared manager will usually be able to ensure accurate representation in press articles, there is always the risk that journalists will ask questions about issues that are politically sensitive to the management organisation. This is particularly true when the topic is coral bleaching, as journalists will frequently make links to politically sensitive issues. When a manager is speaking as a representative of an organisation, it is important that he or she has a clear understanding of the organisational protocols for interacting with the media. Working within organisational protocols is important to the manager's professional development and helps ensure access to future media engagements, one of the most powerful tools in the manager's response strategy. It is equally important to the achievement of effective public communication to maintain the trust of the journalist by not appearing evasive. Clearly defining boundaries prior to any media engagements will enable a manager to provide detailed and accurate information about the issue, while ensuring future opportunities to speak as a representative of the organisation. Strategies to deal with pointed questions on sensitive topics should be developed, and may include referring the journalist to a more relevant authority, such as climate scientists, the national meteorology or climatology agency, or a non-government organisation.

To achieve good results with the media, managers can consider meeting with reporters before bleaching starts, developing press releases with key facts, sharing quality images, and developing responses to questions about sensitive topics

Colleagues. Communication should be a collaborative endeavour, and will be most successful when done in close cooperation with colleagues, partner organisations, and other constituencies. Scientists and non-government organisations (NGOs) can be valuable partners in efforts to understand and communicate the effects of coral bleaching events, and to develop, communicate and implement potential mitigation strategies. Colleagues and fellow staff from within the manager's organisation are often overlooked in communication programs. Collegues are an extremely important audience for updates on bleaching conditions, as they will be major conduits to key sectors of the wider community for information about coral bleaching.

Involving fishermen in monitoring of coral reefs affected by bleaching in Kenya

The Kiunga Marine Reserve (KMR), in northern Kenya, is the site of a highly successful participatory monitoring program. The reserve designation allows traditional resource use including fishing, and artisanal fishers have been key participants in the program. The Kenya Wildlife Service (KWS) manages the reserve, while the WWF jointly operates a community-oriented project to raise awareness of the need for management in the area. The Coral Reef Degradation in the Indian Ocean (CORDIO) program gives technical assistance and partial funding for coral reef and fisheries monitoring.

Over its nine years of operation, a mix of fishers, WWF staff, KWS rangers, fisheries officers and researchers from the Kenya Marine and Fisheries Research Institute have participated in the monitoring program. It has been one of the largest annual activities in the KMR area that focuses exclusively on marine issues. This has given the monitoring program a social and communications prominence that has served to raise awareness of environmental issues in general, and particularly of the primary threats to coral reefs in relation to both climate change and fisheries.

The Kiunga Marine Reserve is one of the 'last frontiers' for fishing in Kenya, being protected by its remote location and harsh conditions. However, pressure has steadily increased from fishing communities to the south, repeating the common pattern from other parts of Kenya of invasion by migrant fishers from already depleted areas that use destructive fishing practices. Fishers resident within the reserve area have had a varying understanding of the extent to which these factors threaten their future livelihoods, with some welcoming and working with the newcomers as they bring immediate economic gain, while others have resisted change due to awareness of the longer term threat.

During the El Niño event of 1998, over 90 per cent of corals in the predominantly shallow reefs of the reserve bleached and died. The white corals were clearly observed by fishers, but their significance was not apparent due to the common belief that corals are 'stones' and therefore dead (the local name for coral is 'stone'). The participatory monitoring program offered a direct avenue for explaining the implications of the bleaching event to fishers. The threat posed to the local reefs by coral bleaching (a completely external threat) was used to emphasise the need to manage local threats, primarily recent increases in destructive fishing practices within the reserve.

Fishers were provided with information to help them understand the value of minimising local stressors so as to increase the capacity of reefs to regain their productivity in the face of threats beyond their control (such as climate change). In subsequent years, repeated sampling on the same reefs helped the monitoring team to appreciate the slow rate, and variability of recovery of coral communities.

In 2002 a program of coral transplantation was started, and seized upon eagerly by the fishers who were keen to attempt to rehabilitate reefs that showed little recovery. The fishers were warned that true rehabilitation would not happen with only transplanted corals, but the project provided an opportunity for them to get involved in a direct conservation intervention. The exercise has served to draw parallels between the practises involved in growing and caring for corals with those central to the indigenous farming culture: raising crops and animals, and watching over their slow growth and survival in a harsh environment.

The culmination of the first seven years of coral reef monitoring was a stakeholder workshop in May 2004 to develop the beginnings of a zoning and fisheries management plan for the Kiunga Marine Reserve. Fishers and marine reserve staff that have participated in the coral reef monitoring program have become key resource people in promoting the need for conservation management, and in facilitating the inclusion of their communities in planning stages. The leaders of the monitoring teams played a strong and active role in the workshop. Since the monitoring program was based on traditional fisheries zones and taxon names, presentation of reef health results was based on familiar geographic and ecological concepts to local communities.

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The monitoring team for the Kiunga Marine Reserve includes fishers, WWF staff, Kenya Wildlife Service rangers, fisheries officers and researchers from the Kenya Marine and Fisheries Research Institute, coordinated by David Obura from CORDIO (front right)

Communicating with colleagues can help managers better understand and respond to mass bleaching events – methods for sharing information range from formal websites and email list-servers to informal phone calls or seminar presentations

In working with colleagues, managers should strive to foster a mutual exchange of information and coordinate response and communication efforts. Effective communication channels should be established to share information and facilitate working partnerships. Collaborating on the development of response strategies can set the stage for partnerships of mutual benefit, as well as maximising consistency in methods that can facilitate comparison of results between sites and regions. An analysis of successes and failures can offer valuable learning opportunities, and shared experiences can rapidly accelerate collective improvements in knowledge and in the capacity to respond to bleaching events.

Methods for sharing information range from formal websites and email list-servers to informal phone calls or seminar presentations. Briefings about current conditions and the relevant management activities can be provided before and during bleaching events. Where the technology is readily accessible, email reports or websites are a rapid, cost-effective and far-reaching mechanism for disseminating information about 'current conditions' during bleaching events. Email reports can be sent to pre-existing email discussion groups or new lists can be generated and opened to self-subscription. Websites can be inexpensive to produce and need not require a high level of technical skill. The flexibility of a website enables the manager to present a range of information and photographs through separate, but linked, documents and to provide links to other sites of relevance (such as partner organisations).

Communication between managers and stakeholders is a critical element of an effective response to coral bleaching

2.6.2 Frequently asked questions

While many of the questions that come up when talking to people about mass bleaching are predictable, they can be challenging to answer briefly and without technical jargon. This section provides examples of answers to eight common questions.

Q1: What is coral bleaching?

A1: Coral bleaching occurs when corals become stressed. Under stressful conditions, such as above-average water temperatures, pollutants or other stressors, the important relationship between corals and the microscopic algae that live within their tissue breaks down. These tiny algae, called zooxanthellae, provide corals with most of their energy requirements, as well as giving them their characteristic bright colours. When this relationship breaks down, the algae are expelled from the tissue, which then becomes transparent, allowing the white coral skeleton to be clearly visible. As a result, corals turn noticeably white, giving them the appearance of being 'bleached'.

Q2: Is coral bleaching bad for corals?

A2: Coral bleaching is a serious issue for corals. Mass bleaching events, caused by unusually high water temperatures, can lead to extensive coral mortality if temperatures are high enough (1-2 °C above long term summer maxima) for 4-8 weeks. During the worldwide bleaching event in 1997-98, coral bleaching caused catastrophic mortality at many reefs, including those around the Seychelles, Palau, Maldives and north-western Australia. However, bleached corals do not necessarily die. While many reefs have experienced mortality from coral bleaching, corals on many other reefs that have experienced mass bleaching events have suffered only minor levels of mortality. Providing warm temperatures do not persist for too long, zooxanthellae densities can return to normal. However, even corals that survive bleaching can suffer side effects, such as slower growth, lower rates of reproduction and increased risk of disease.

Q3: What causes mass bleaching?

A3: Many different stresses can cause corals to bleach, but mass coral bleaching occurs when water temperatures become unusually high. When temperatures become too high, the microscopic algae that live within the coral tissue are no longer able to cope with high light levels. As a result, they begin to produce molecules that are toxic to the coral, leading to their expulsion from the tissue.

When large areas of the ocean warm to unusually high temperatures, bleaching can affect corals over hundreds or even thousands of kilometres constituting what is known as a 'mass bleaching event'. High temperatures are projected to occur with greater frequency in many parts of the world over the century, leading to concerns that mass coral bleaching events will become an increasingly frequent and severe threat to coral reef ecosystems.

Q4: What will the impacts be to the affected reefs?

A4: Mass bleaching is a serious threat to coral reefs. While reefs are under pressure from many sources, few stresses have the potential to cause severe damage over such large areas. The unusually warm conditions that trigger mass coral bleaching can affect hundreds or thousands of kilometres. In these situations, extensive areas of coral reef can be severely stressed and potentially damaged. Importantly, the effects are not limited to corals. Damage from bleaching has the potential to affect all of the animals and plants that are part of the coral reef ecosystem, potentially impacting on reef biodiversity and the health of the entire ecosystem.

Q5 Why should people care about mass bleaching?

A5: Reefs that are damaged by coral bleaching are less appealing to tourists, they are less able to support fishing industries, and they may provide less shelter to coastal communities from storms and ocean waves. Recovery of degraded reefs can take decades, and the social and economic impacts can be long lasting. In Australia, for example, one study has estimated that coral bleaching on the Great Barrier Reef could cost the regional economy approximately US$100-300 million over 20 years[28]. In addition, reefs damaged by coral bleaching have lowered biodiversity and, quite simply, are less beautiful.

Q6: What does the future hold? Will mass bleaching events continue to be an issue?

A6: Reefs face a very uncertain future. Many are already under threat from land-based sources of pollution, recreational over-use and destructive or unsustainable fishing. The additional stress of mass bleaching events puts coral reefs at greater risk than ever before. Moreover, the threat of coral bleaching is expected to increase in coming decades. Climate scientists predict that the world's oceans will continue to warm, meaning that the frequency and severity of mass bleaching events is likely to increase. The abundance and vigour of corals is likely to decrease, with a potential shift to a predominance of algae rather than corals. This could have flow-on effects throughout the entire ecosystem, impacting on the full diversity of flora and fauna and the industries and societies that depend on healthy reefs. It is important to recognise that reefs are unlikely to disappear even under extreme climate change scenarios, but they will deteriorate in their ability to provide the ecosystem goods and services upon which human societies have come to depend.

Q7: Can anything be done about mass bleaching?

A7: Mass bleaching events pose a real challenge because there is little a reef manager can do to directly alter the climatic conditions that can cause coral bleaching. However, there are things we can do to help prevent and respond to bleaching. It is clear that reef managers can help build and sustain healthy reefs, and those healthy reefs may be better able to cope with the effects of coral bleaching than degraded reefs. Other stresses reduce a reef's ability to survive bleaching, and can delay or prevent recovery following severe bleaching events. Concentrating our efforts on managing the stresses that we can control, such as water pollution and overfishing, will help support the natural resilience of our reefs, and help maximise their chances of survival in the face of climate change and increasing human pressures.

Q8: What can our listeners/readers do to help?

A8: Listeners/readers can help by becoming more involved in the management and conservation of coral reefs. These precious ecosystems are under unprecedented pressure and need every bit of help they can get. People who visit the reef regularly can help by reporting coral bleaching if they see it. We have a website/information kit/contact person to help members of the public learn about coral bleaching, how to recognise it on the reef, and how to report it.

2.6.3 Resources

There are a number of resources available to help managers to integrate bleaching-specific elements into management and to communicate with stakeholders about mass bleaching. There are many excellent resources available on the broader subject of coral reef management. The list below, includes resources that specifically relate to mass coral bleaching events.

- The Nature Conservancy (TNC) and partners have produced a multimedia CD-ROM toolkit entitled: *Reef Resilience: building resilience into coral reef conservation*. This Reef Resilience (R^2) toolkit (www.reefresilience.org) provides resource managers with cutting-edge strategies and tools to lessen the impacts of coral bleaching and conserve reef fish spawning aggregations. The toolkit is designed to help practitioners begin to build resilience into coral reef conservation programs so that their reefs might better survive mass bleaching events in the future.

- ReefBase (www.reefbase.org) is a global information system for coral reef conservation and management developed by WorldFish Centre, Penang, Malaysia. It provides managers with monitoring data and advice on coral reefs, and stores all records from the Global Coral Reef Monitoring Network (GCRMN) and Reef Check. Worldwide coral bleaching reports, maps, photographs, and literature are available on the website, and bleaching reports can be submitted online for inclusion into the databases.

- The Great Barrier Reef Marine Park Authority (Australia) (www.gbrmpa.gov.au) has developed a volunteer program called 'BleachWatch' to encourage dive operators and other regular users of the reef to monitor for bleaching in areas they frequently visit. Similar programs have also been developed for use in Bali Barat National Park (Indonesia) and the Florida Keys National Marine Sanctuary (USA). BleachWatch kit materials, such as an armband showing degrees of bleaching and reporting forms printed on waterproof paper are designed specifically for these types of reef users so that they can easily note and report any bleaching with minimal inconvenience to their normal operations. The GBRMPA website is also a source of information and images relevant to coral bleaching.

- The Coral Reef Alliance (www.coralreefalliance.org) hosts the International Coral Reef Information Network library online. Bleaching papers, briefing sheets, reports and other information can be accessed online.

- The National Oceanic and Atmospheric Administration (NOAA) Coral Reef Conservation Program (www.coralreef.noaa.gov) provides a number of tools and resources related to coral bleaching events such as Coral Reef Watch (CRW). Coral Reef Watch provides three tools that analyse satellite imagery to assess the likelihood of mass coral bleaching events. These products are freely available over the Internet, and include: HotSpot maps, degree heating week maps, and Tropical Ocean Coral Bleaching Indices. Other tools and information are available through NOAA's Coral Reef Information System (www.coris.noaa.gov).