Australian Government

Great Barrier Reef Marine Park Authority

Coral Bleaching Response Plan

2010 - 2011

Great Barrier Reef Marine Park Authority

Executive Summary

Climate change poses a multitude of threats to reefs but the increased frequency and severity of coral bleaching events is among the most pressing (Hoegh-Guldberg et al. 2007). To meet the challenge of responding to coral bleaching events, the Climate Change Group at the Great Barrier Reef Marine Park Authority (GBRMPA) developed a Coral Bleaching Response Plan (the Response Plan) in 2002, as part of a response to the bleaching event that occurred in the late summer (February and March) of that year. Since then, the Climate Change Group has coordinated implementation of the Response Plan each summer – December to March – and has reviewed and refined it annually. The Plan outlines a strategic approach for monitoring bleaching risk and responding to coral bleaching events when they occur, and has four components. Within this document, the objectives of each of the four primary components are outlined and described in detail:

1. Early Warning System
2. Incident Response
3. Management Actions
4. Communication Strategy

The Plan includes related routine and responsive tasks. When Early Warning System tools predict bleaching, monitoring network participants ground-truth these predictions and report to managers. Managers and researchers confirm reports of bleaching by conducting site inspections that determine the level of response required under the Incident Response (IR) component of the Plan (based on Australian standard incident response protocols). Thresholds for response levels (1, 2, or 3) in the IR are based on the severity of bleaching impacts as well as the spatial extent of the event. More detailed monitoring during IR enables detailed reporting on reef condition and the severity of bleaching impacts, and works to target management actions. In the months and years that follow the disturbance, resilience-based management actions can: reduce recovery timeframes by mitigating local-scale stress from human-related activities at severely impacted sites, support the natural resilience of habitats in the Marine Park at the whole-of-Reef scale, and increase the resilience of reef users to reef health incidents.

The Response Plan is an operational document implemented throughout the summer season by the GBRMPA Climate Change Group. The Plan is one of a number of response plans that uses the template for incident response found within the GBRMPA's overarching Reef Health Incident Management System (RHIMS). In effect, the Plan, in combination with the RHIMS, guides managers while rendering a transparency and consistency to management decision-making during bleaching events. The Plan also serves to keep representatives from key partner institutions and the public aware of the technologies and protocols used to predict and monitor bleaching, and the criteria that determine how managers communicate the severity of bleaching impacts when events occur.

Contents

Introduction

Of the threats to the resilience of the Great Barrier Reef posed by climate change, expected increases in the frequency and severity of coral bleaching events is among the most pressing. Whilst the Great Barrier Reef has a long history of recovery from major disturbances like the bleaching events of 1998 and 2002 and the cyclones and floods of 2008-09, the recovery capacity of the ecosystem is likely to diminish as disturbance frequencies increase. Consequently, the risk of coral bleaching each summer cannot be viewed in isolation, as the legacy of impacts from previous years may render corals more susceptible to bleaching and disease, which both work as structuring forces shaping future ecosystem condition. Future bleaching events are inevitable and reef managers have a responsibility to monitor, assess and respond to the socio-ecological impacts of coral bleaching.

The Response Plan is an operational document used by members of the Climate Change Group throughout the summer season, and is one of a number of response plans that use the template for incident response detailed within the GBRMPA's Reef Health Incident Management System (RHIMS). The Plan guides managers while rendering a transparent and consistent decision-making framework during bleaching events. The Plan also serves to keep representatives from key partner institutions as well as the public aware of the activities used to predict and monitor bleaching, and the criteria that determine how managers communicate bleaching responses when they occur.

The Plan includes linked routine and responsive tasks (Figure 1, Appendix A). When Early Warning System tools predict bleaching, monitoring network participants ground-truth the predictions and report to managers. Managers and researchers confirm reports of bleaching by conducting site inspections that determine whether the level of bleaching exceeds one of three thresholds defined within the Incident Response (based on Australian standard incident response protocols) section of the Plan. Thresholds for Response Levels 1, 2 and 3 (Figure 1) are defined by the severity and spatial extent of the impacts. More detailed monitoring during the Incident Response enables detailed reporting on reef condition and the severity of bleaching impacts, and works to target management actions. An effective management response to bleaching depends on clear and transparent communication between managers and senior decision-makers, stakeholders and the public. Communication is, therefore, an overarching theme (Figure 1).

Importantly, the Response Plan has been developed in conjunction with *A Global Protocol for Assessment and Monitoring of Coral Bleaching* (prepared by WWF, World Fish Center and the GBRMPA, Oliver et al. 2004) and *A Reef Manager's Guide to Coral Bleaching* (an international collaborative effort led by the GBRMPA, National Oceanic and Atmospheric Administration (NOAA) and the International Union for Conservation of Nature (IUCN), Marshall and Schuttenberg 2006) to maximise comparability and consistency with bleaching responses in other regions.

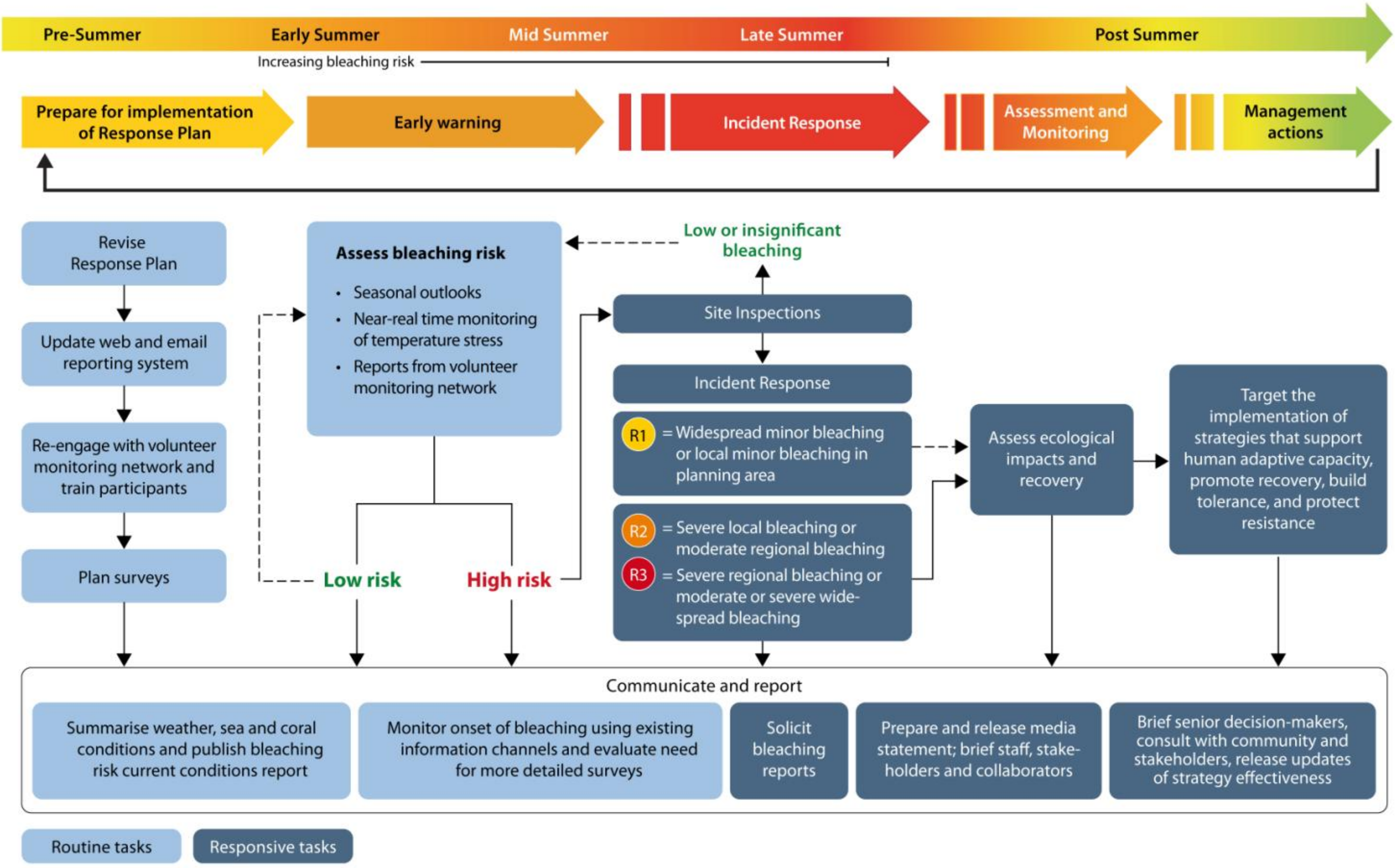


Figure 1. Response Plan schedule of routine and responsive tasks before, during, and after the coral bleaching season (see also Appendix A). Plan components follow on from each other, though responsive tasks are only undertaken if Incident Response is triggered. Response levels 2 and 3 activate efforts to assess and monitor impacts and target the implementation of management actions, both of which are conditionally activated under response level 1 (see also Figures 8 – 10).

Within this document, the objectives of each of the four primary components of the Response Plan are outlined, and the role each component plays in a timely and effective response to coral bleaching events is described in detail.

1. Early Warning System

Mass coral bleaching is preceded by a series of conditions that can be used to assess the probability of an event occurring. The Early Warning System uses: 1) climate forecasts in the months that precede the summer to provide a seasonal outlook of the likelihood bleaching will occur, 2) tools that enable near-real time monitoring of temperature stress during the summer to target monitoring efforts, 3) a monitoring network to detect the early signs of bleaching, and 4) site inspections to ground-truth predictions or reports of bleaching and determine whether and which thresholds requiring Incident Response have been exceeded. All four elements are described briefly below.

Seasonal outlook

A number of factors are known to cause high sea temperatures in the Great Barrier Reef. In particular, delayed or weak development of the monsoonal trough over northern Australia during summer appears to be a strong precursor to the anomalously warm conditions that, if severe or prolonged, can cause coral bleaching. Based on an emerging understanding of the relationship between weather and sea temperatures for the Great Barrier Reef, current and forecast weather conditions can indicate whether conditions conducive to bleaching are likely. Two agencies, the National Oceanic and Atmospheric Administration (NOAA) and the Bureau of Meteorology (BoM) of Australia use climate models to predict bleaching likelihood in the Great Barrier Reef Marine Park in the months that precede summer.

NOAA's Coral Reef Watch group produces a Thermal Stress Outlook[1] based on sea surface temperature (SST) forecasts generated by the Linear Inverse Model from the NOAA Earth System Research Laboratory (Liu et al. 2008). When forecast SST exceeds bleaching thresholds over a long enough period to cause bleaching, the outlook maps display the bleaching potential as 'Watch', 'Warning', 'Alert level 1' and 'Alert level 2' (Figure 2a). The Thermal Stress Outlook is an experimental product and is used as an indicator of potential general patterns rather than a precise predictor of thermal stress at any location – actual conditions vary due to model uncertainty, changes in climatic conditions and localised variability (see Appendix B for key references and further reading).

The probability of above average summer sea temperatures, and hence the likelihood of a mass bleaching event occurring, can also be forecast using the coupled ocean-atmosphere seasonal prediction system, POAMA (Predictive Ocean Atmosphere Model for Australia), developed by the BoM and the Commonwealth Scientific and Industrial Research Organisation (CSIRO). Two operational forecast products are generated in real-time for the Great Barrier Reef region[2]; monthly sea surface temperature anomalies (SSTA), and the mean SSTA in the region, termed the GBR Index (Figure 2b). Experimental probabilistic forecasts of the likelihood of SSTA values exceeding 0.6 degree Celsius in the region (potential coral bleaching conditions) are also produced[3]. All forecasts are for up to six months into the future, with significant skill in predictions up to three months ahead (Spillman and Alves 2009).

Near-real time monitoring of temperature stress

A number of environmental stresses can lead to coral bleaching. It is, however, well established that spatially extensive or mass bleaching events are caused by anomalously high sea temperatures (Hoegh-Guldberg 1999). Excessive and persistent sea temperature anomalies are a good indication that conditions are approaching levels known to be stressful to corals. SST anomalies and other

[1] http://coralreefwatch.noaa.gov/satellite/bleachingoutlook/outlook_messages/bleachingoutlook_20101026_for_2010novfeb.html#summary
[2] http://www.bom.gov.au/oceanography/oceantemp/GBR_SST.shtml
[3] http://poama.bom.gov.au/experimental/poama15/sp_gbr.htm

measures of temperature stress can be monitored in near-real time during the summer via several different tools and information sources.

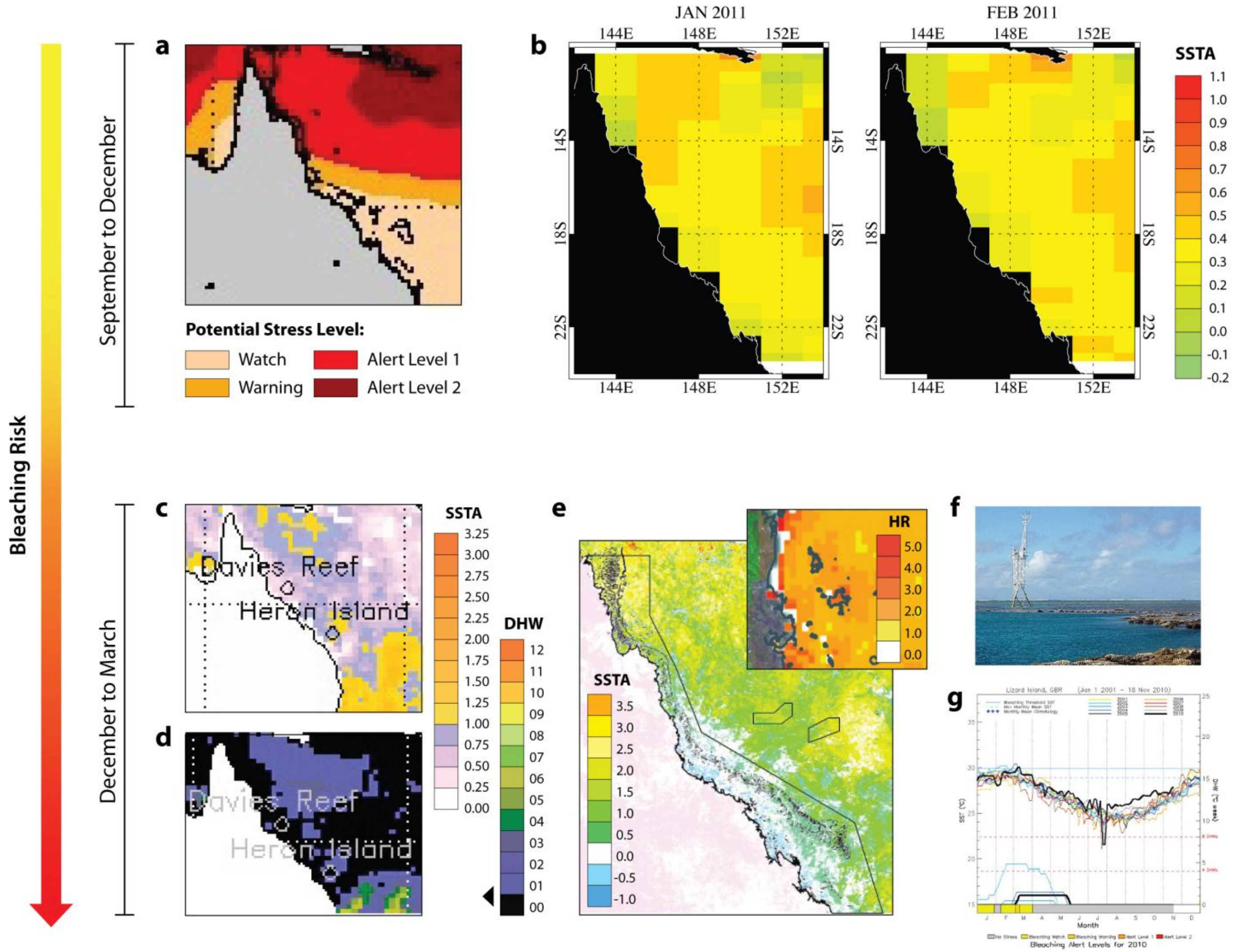
NOAA's Coral Reef Watch (CRW) group produces images at 50-km resolution of the Australian region that show remotely sensed SSTA[4] (referred to as 'Hotspots', Figure 2c) and the accumulation of heat stress, which is measured by Degree Heating Weeks[5] (DHW, Figure 2d) accumulated over the previous 12 weeks. A DHW is equal to 1 degree above the long-term maximum monthly mean, which serves as a useful bleaching threshold. Observations of minor to moderate bleaching are commonly made at sites where temperature stress exceeds 4 DHWs, and severe bleaching is often observed at sites that have experienced >8 DHWs (see Appendix B for key references and further reading). The NOAA CRW group also maintains 15 web-based 'virtual bleaching stations'[6] for the Great Barrier Reef Marine Park. Graphs of temperature for the current and each of the last 10 years are shown with respect to the maximum monthly mean (Figure 2g).

CSIRO Marine and Atmospheric Research, in collaboration with the BoM and the GBRMPA, developed an interactive high-resolution (~1-km) system for monitoring bleaching risk. This suite of tools, called *ReefTemp*[7], produces images that depict remotely sensed SST and three measures of temperature stress: the SST anomaly, the Degree Heating Day, and the heating rate (Maynard et al. 2008) all at the scale of an individual reef (Figure 2e). During the summer season, *ReefTemp* is used to target the efforts of monitoring network participants and/or to target specific site inspections. The colour legends for each temperature stress metric depict bleaching risk as they have been calibrated to in situ observations of bleaching from the 2002 bleaching event in the central Great Barrier Reef (Figure 3). During the 2006 bleaching event in the southern Great Barrier Reef, managers found that the *ReefTemp* system could predict variability in bleaching response severity between islands and reefs separated by as little as 5 km.

In situ measurements of local sea temperatures are available from a network of weather stations installed on the Great Barrier Reef and are maintained through collaboration between the GBRMPA and the Australian Institute of Marine Science (AIMS; Figure 2f)[8]. These weather stations record water temperature at the surface and at 6 m depth providing important information about depth-related variability, and a mechanism to ground truth *ReefTemp* outputs. *ReefTemp* and the weather stations are monitored regularly throughout the summer season. When reefs or reef regions within the Marine Park experience prolonged periods of excessively high temperatures, managers maintain close contact with a network of observers to ensure regular reports of reef condition are submitted and managers are alerted to early signs of bleaching.

---

[4] http://coralreefwatch.noaa.gov/satellite/current/products_hotspot.html
[5] http://coralreefwatch.noaa.gov/satellite/current/products_dhw.html
[6] http://www.coralreefwatch.noaa.gov/satellite/virtual_stations/gbr_virtualstations.html
[7] http://www.cmar.csiro.au/remotesensing/reeftemp/web/ReefTemp.htm
[8] http://data.aims.gov.au/awsqaqc/do/start.do



Applications

- Assesses bleaching risk for upcoming summer
- Helps communicate the need to initiate preparations for the Incident Response *if* conditions *could be* conducive to bleaching

Applications

- Assesses bleaching risk in near-real time
- Targets monitoring effort by participants in volunteer monitoring network and/or site inspections by managers and researchers
- Helps communicate the need to initiate the Incident Response *when* conditions *are* conducive to bleaching

Figure 2. Tools used within the Early Warning System and their applications for management decision-making. NOAA's Bleaching Outlook product (a) and the POAMA SSTA forecasts (b) provide a seasonal outlook of bleaching risk in the months that precede summer. This year, the NOAA product (a) suggests conditions could be conducive to bleaching in the northern Great Barrier Reef, while POAMA forecasts suggest temperatures will be anomalously high in January and February, but not high enough to cause moderate or severe bleaching (see Table 1). GBRMPA staff will continue to monitor bleaching risk during the summer months as temperature stress can be monitored in near-real time using NOAA's Hotspot and DHW products (c, d – examples from February 2010) and at the scale of an individual reef using CSIRO's *ReefTemp* (e, inset example is of the heating rate during the 2006 bleaching in the southern Great Barrier Reef). Data from AIMS/GBRMPA weather stations (f) and NOAA's virtual bleaching stations (g) serve to confirm remotely sensed temperature data.

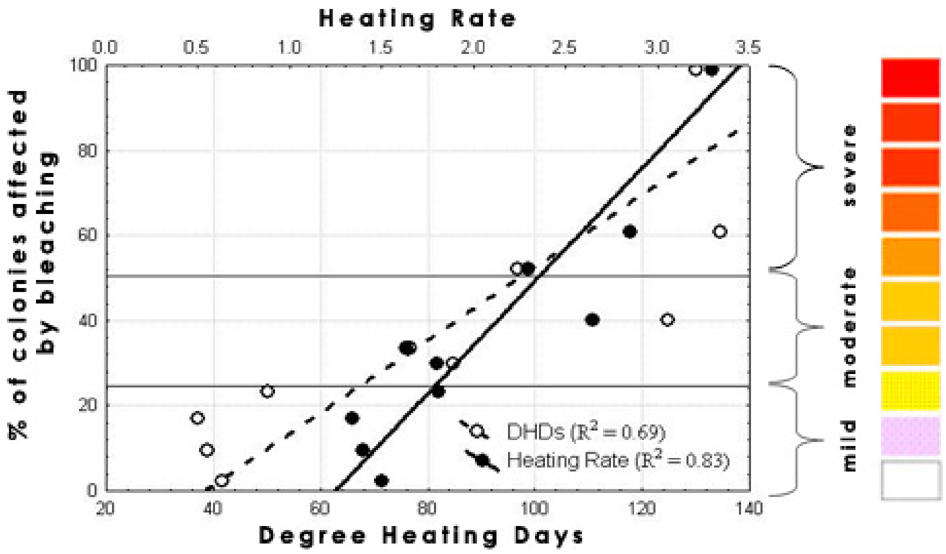


Figure 3. Colour gradations used within *ReefTemp* are based on the approximate number of degree heating days and the value for heating rate that related to mild (<25% colonies affected), moderate (26 - 50% affected), and severe (>50% affected) bleaching responses at sites surveyed in the central GBR in 2002 (from Maynard et al. 2008). <25% colonies affected is considered mild for this Response Plan because some bleaching of susceptible taxa occurs annually, particularly in shallow water areas like reef flats. Therefore, the colour-graded legends used in *ReefTemp* facilitate responses to bleaching events likely to cause some coral mortality.

Monitoring network

Detecting the early signs of a mass bleaching event requires a wide network of observers on the Great Barrier Reef due to its size and because the initial onset of mass coral bleaching can range from gradual and patchy to rapid and uniform. GBRMPA established and maintains a community monitoring network that is built on a network of regular reef users, including professionals, researchers, fishers and other recreational users who voluntarily monitor and report on conditions at reefs that they visit. Participation in the network extends from Port Douglas in the north to Bundaberg in the south. The broad base of participation is supported by the close coordination and linkages between the Eye on the Reef network (based on tourism staff; a partnership of the GBRMPA, GBR tourism community and reef researchers[9]) and the Reef Health and Impact Surveys (RHIS) of Queensland Parks and Wildlife Service.

In 2009 the capacity of the data collected by participants in the monitoring network to inform management decision-making was enhanced through the development of a revised monitoring protocol. The revised protocol (Figure 4) can be completed by snorkelers or divers using a repeated Global Positioning System (GPS) tagged five-metre radius point survey method. This method is used to assess a range of reef health indicators including coral and algal cover and the extent and severity of impacts such as coral bleaching, disease, predation and anchor or storm damage. The revised protocol recognises the limited time that many participants have to complete

[9] http://www.eyeonthereef.com.au/

survey forms. One form will be completed for each point survey thus reducing the time taken to evaluate benthic cover and allowing ample time to accurately evaluate the presence or absence of the range of impacts included in the new form (Appendix C). Ideally, observers will complete at least three point surveys at each site whilst remaining within one habitat type (e.g., reef slope or lagoon). Repeated surveys are conducted to enable statistical analysis of the data; however these surveys do not have to occur on the same day if time is limited.

Reports of severe bleaching from the monitoring networks are verified by the Climate Change Group, in partnership with trained staff from Queensland Parks and Wildlife Service, who undertake detailed site inspections.

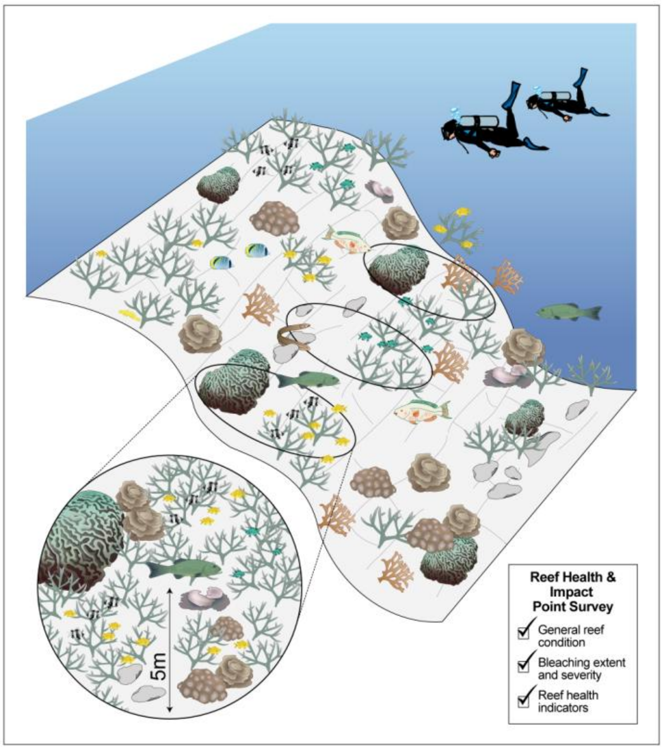


Figure 4. Protocol used in the volunteer monitoring and RHIS network. Observers either diving or snorkelling use this revised protocol to assess reef condition and to detect the early signs of bleaching, as well as other impacts. The same protocol is used by researchers and managers when site inspections are conducted to either ground-truth predictions from the temperature monitoring tools or to further quantify bleaching following a report from a monitoring network participant.

Participants are asked to complete their reports whenever they are out on the Reef and have spare time, and on a weekly or fortnightly basis during summer. These results are reviewed weekly during the summer months (Table 1) to identify where coral bleaching has been sighted. To facilitate reviewing reports, information from reports is collated into a database and loaded into a file managers can view through Google Earth™. This system represents each reef in the Park and uses dots at each reef location to denote the coral cover and severity of impacts via size and colour, respectively (Figure 5). When viewers zoom into a reef location an image comes up containing the information contained within all reports ever received for that location. Developing this system has streamlined linking field observations directly to management decision-making and reporting and helps to target site inspections (see next section, p 11).

Reports submitted by participants in the monitoring network are compiled and synthesised into regional summaries of reef condition between December and March each year. The summaries are sent to participants to update them on reef condition at the sites they visit and as a way of reinforcing the value of the information they collect.

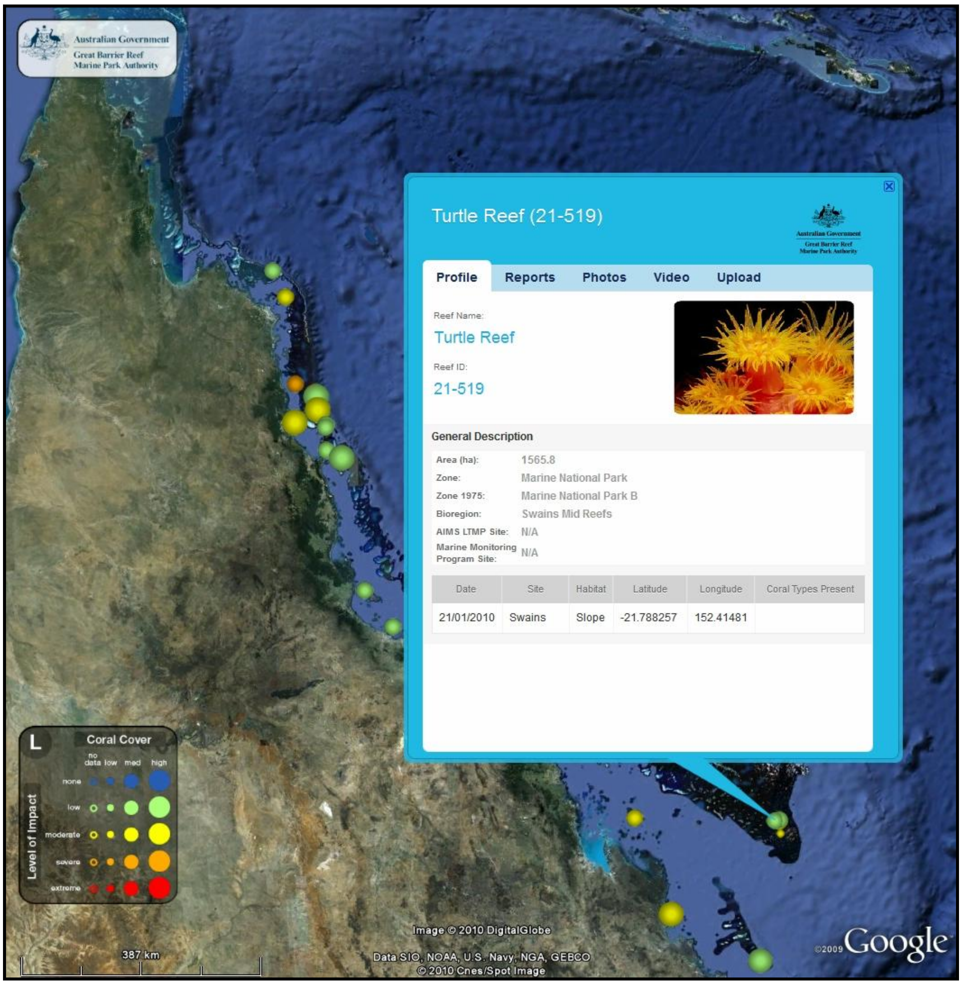


Figure 5. Sample output from the GBRMPA's new system facilitating rapid review and dissemination of reports from participants in monitoring networks. This example shows Turtle Reef and enables access to all reports for that and all other locations for which survey data is available.

Site inspections

Site inspections are conducted on an as-needed basis at sites where: 1) monitoring network participants have reported widespread minor impacts or moderate or severe impacts over any scale (see Table 1), and/or 2) *ReefTemp* outputs indicate bleaching risk is high and participants in the monitoring network are not available to report to managers on reef condition. Site inspections involve the completion of a series of surveys on SCUBA at two depths using the 5 m point survey method used by participants in the monitoring network along with a series of 50 m video transects. When possible, site inspections are completed with the participants who provided the initial bleaching reports.

Table 1. Levels of bleaching severity and extent. Below, reference to morphologies relates to data collected using the RHIS protocol, while reference to coral taxa relates to site inspections that complement the RHIS protocol with 50 m video transects. Hence, both types of monitoring protocols result in data that can be used to determine the severity of bleaching impacts. Examples given within the 'Minor impacts' section of morphologies and taxa that have high, low, and very low sensitivity to bleaching (see also Appendix C) work for both the 'Moderate impacts' and 'Severe impacts' sections. The matrix in Figure 6 of bleaching severity and spatial extent determines the response level triggered in the Incident Response.

Severity	Description
High bleaching risk	POAMA predicts SST anomalies >0.6 °C for > 2 months Degree heating days index >50 at multiple sites Heating rate index >2 at multiple sites Major flooding of coastal catchment imminent Major cyclone passed over reef
Minor impacts	Severe bleaching of many (10-50 per cent) colonies of taxa (*Acropora* and *Pocillopora*), or morphologies (branching, bushy, tabular/plate) usually highly sensitive to bleaching) Severe bleaching of some (<10 per cent) colonies of taxa (*Montipora* and Faviids) or morphologies with low sensitivity to bleaching (encrusting and mushroom) Paling of colonies of taxa (*Porites*) or morphologies (massives) with very low sensitivity to bleaching Severe bleaching of colonies of taxa or morphologies with low or very low sensitivity to bleaching but confined to reef flat
Moderate impacts	***Bleaching extends deeper than reef flat and:*** Severe bleaching of most (>50 per cent) colonies of taxa or morphologies usually highly sensitive to bleaching Severe bleaching of many (10-50 per cent) colonies of taxa or morphologies with low sensitivity to bleaching below reef crest Severe bleaching of some (<10 per cent) colonies of taxa or morphologies with very low sensitivity to bleaching Some mortality of colonies of taxa or morphologies usually highly sensitive to bleaching but confined to reef flat
Severe impacts	***Bleaching extends deeper than upper reef slope and:*** Mortality of many (>50 per cent) colonies of taxa or morphologies usually highly sensitive to bleaching Severe bleaching of most (>50 per cent) colonies of taxa or morphologies with low sensitivity to bleaching Severe bleaching of many (10-50 per cent) colonies of taxa or morphologies with very low sensitivity to bleaching

Extent	Description
Local	Impacts present in less than 10 sites within one region*
Regional	Impacts present in more than 10 sites but confined to one region
Widespread	Impacts present in more than 10 sites in each of multiple regions

* Management regions, see Appendix F.

In summary, the Early Warning System works as a chain of events prior to and during the summer. Forecasting tools heighten alert levels prior to the summer season and tools that enable monitoring of temperature stress in near-real time target the efforts of the monitoring networks. If site inspections confirm moderate to severe localised impacts or widespread minor bleaching (Table 1) then Incident Response is activated, though use of the tools and monitoring networks within the Early Warning System continues until the high risk season has passed.

2. Incident Response

The Incident Response (IR) provides a common organisational structure that identifies the governance, planning, operations, logistics, financial and inter-agency liaison arrangements required to respond in an efficient and effective manner to a reef health incident. The IR is a common structure under the RHIMS that is customised for each of the specific response plans for the various reef health incidents (Figures 8-10).

The IR component of this Plan coordinates the coral bleaching incident response. The level of response required, and management resources invested, is determined via a two-step process. First, a matrix (Figure 6) is used to determine the *potential* response level by relating the severity and spatial extent of the impacts, which are classified using Table 1 and based on data collected by the monitoring network and site inspections. Then, the *actual* response level is determined during a situation analysis (Figure 7). The information presented within the situation analysis is assessed by the governance group (the GBRMPA executive management group, the incident coordinator and the scientific, communication and media liaison, and stakeholder advisory groups) to make a final decision on the required level of response (Figure 7).

The Scientific Advisory Group is made of experts in remote sensing, reef health monitoring, and coral biology and ecology. The Stakeholder Advisory Group is composed of relevant GBRMPA Reef Advisory Committee members. The Communication and Media Liaison Advisory Group includes communication and public relations staff from each government agency involved in the response. Relevant GBRMPA and Queensland Parks and Wildlife Service staff will facilitate advisory group meetings. The purpose of the advisory groups is to provide independent advice to the Incident Coordinator to ensure timely, effective decision-making based upon the best available social, economic and ecological information.

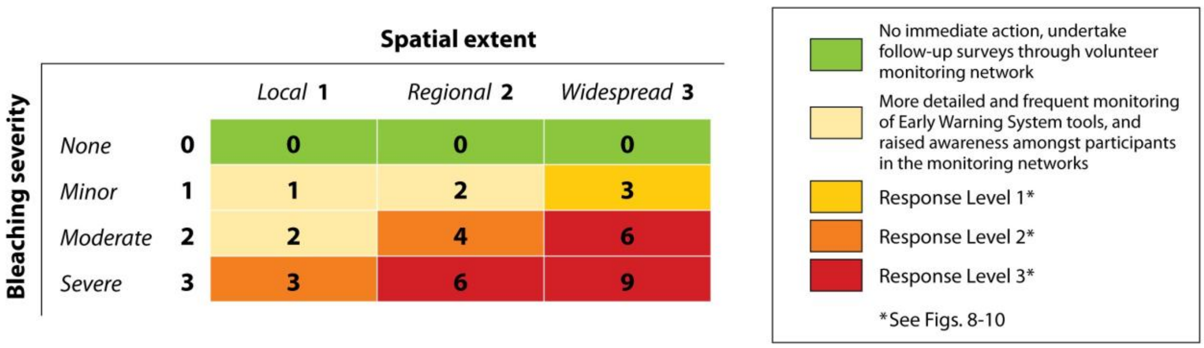


Figure 6. Matrix combining measures of bleaching severity and spatial extent (from Table 1) to inform the situation analysis (Figure 7), which results in the final decision as to whether and which Response Level has been triggered. Specific criteria for the levels of bleaching severity are described in detail in Table 1.

Once the appropriate response level has been determined, the corresponding planning and resource provisions of the IR are activated. The IR is intended to direct and coordinate management actions relating to the incident. The various resilience-building management and recovery activities continue after the incident response is deactivated (Figure 7) and are discussed in the upcoming Management Actions section (p 20).

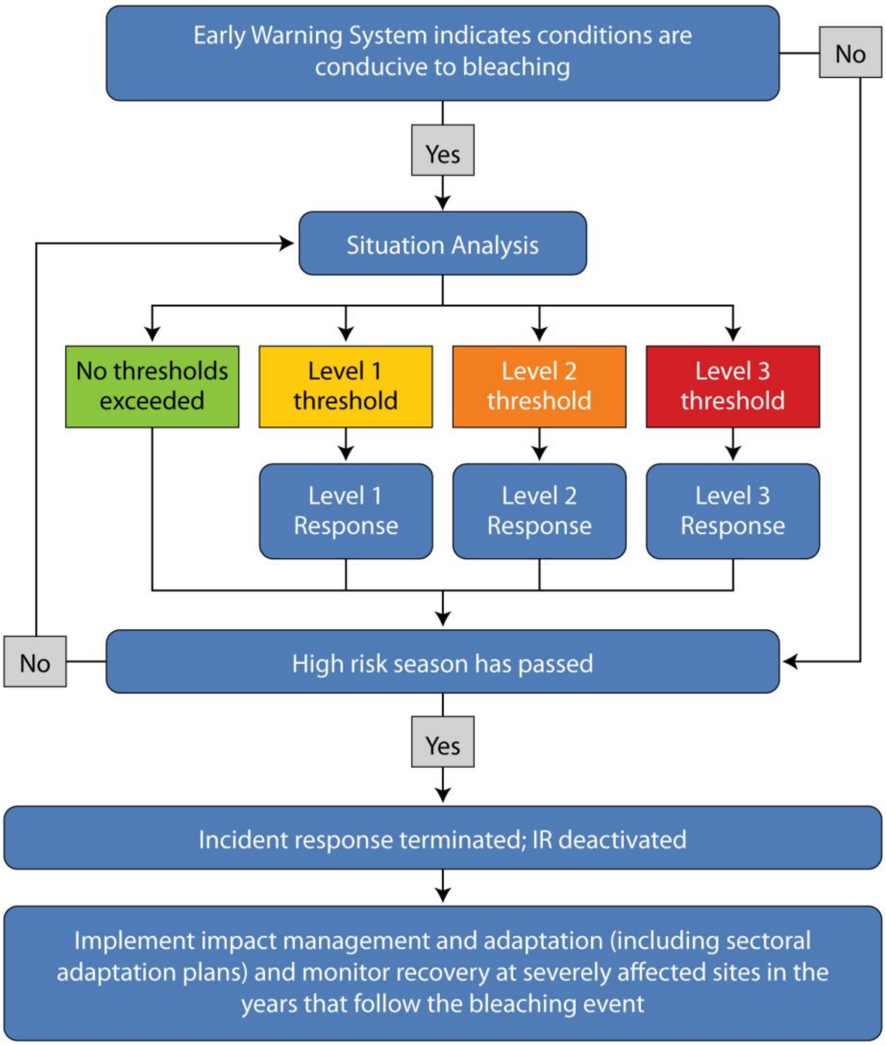


Figure 7. IR chain of events during a bleaching event. The situation analysis is informed by the matrix seen in Figure 6 and is re-visited if the high risk season has not passed.

For all response levels, communications, liaison, and reporting tasks are all activated, while other aspects of the incident response are either activated or conditionally activated based on the level of resource investment and priority warranted at each response level (Figures 8-10). For response level 3 (R3), the entire Incident Response is activated (Figure 10). The next section (p 18) describes the approach and field survey protocols used to assess and monitor bleaching impacts when the situation analysis determines the thresholds for response levels 2 and 3 have been reached.

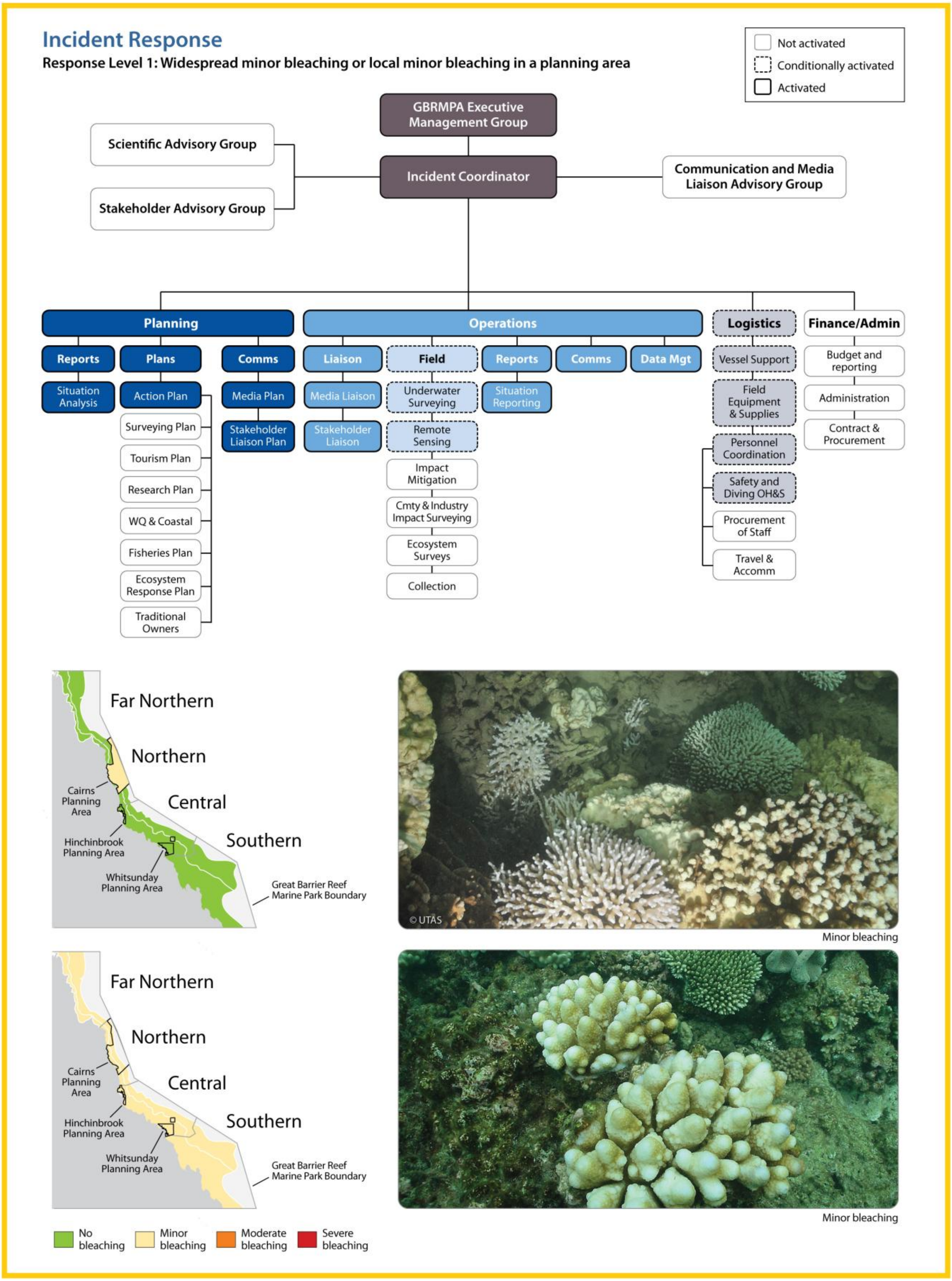


Figure 8. Response level 1 within the Incident Response. Activation and conditional activation of IR components are illustrated by the intensity of colour and border for each box within the diagram above. Scenarios shown in the maps are examples (i.e., local bleaching in a different planning area would result in the same management response).

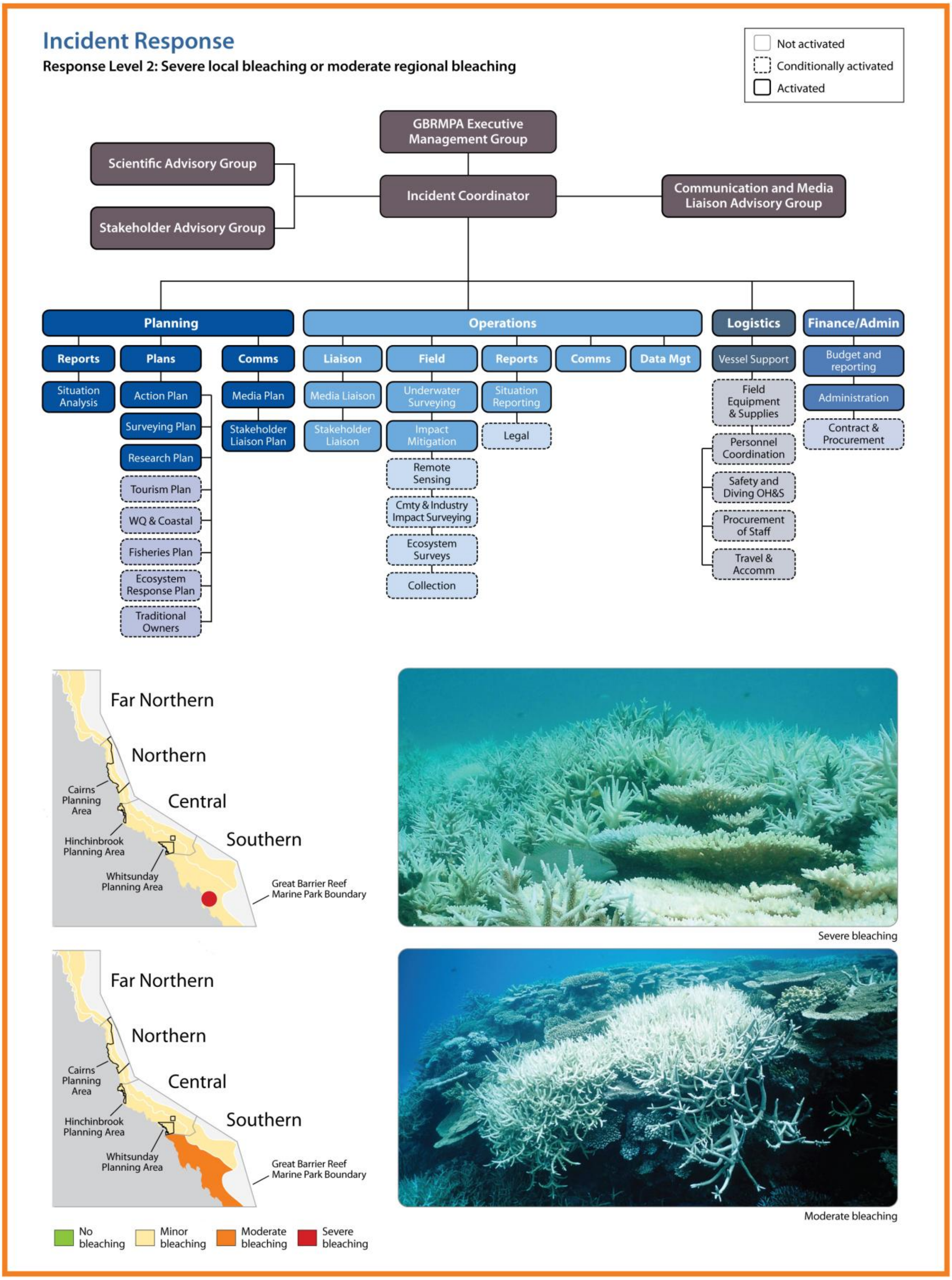


Figure 9. Response level 2 within the Incident Response. Activation and conditional activation of IR components are illustrated by the intensity of colour and border for each box within the diagram above. Scenarios shown in the maps are examples (i.e., local severe bleaching or moderate bleaching in other regions would result in the same management response).

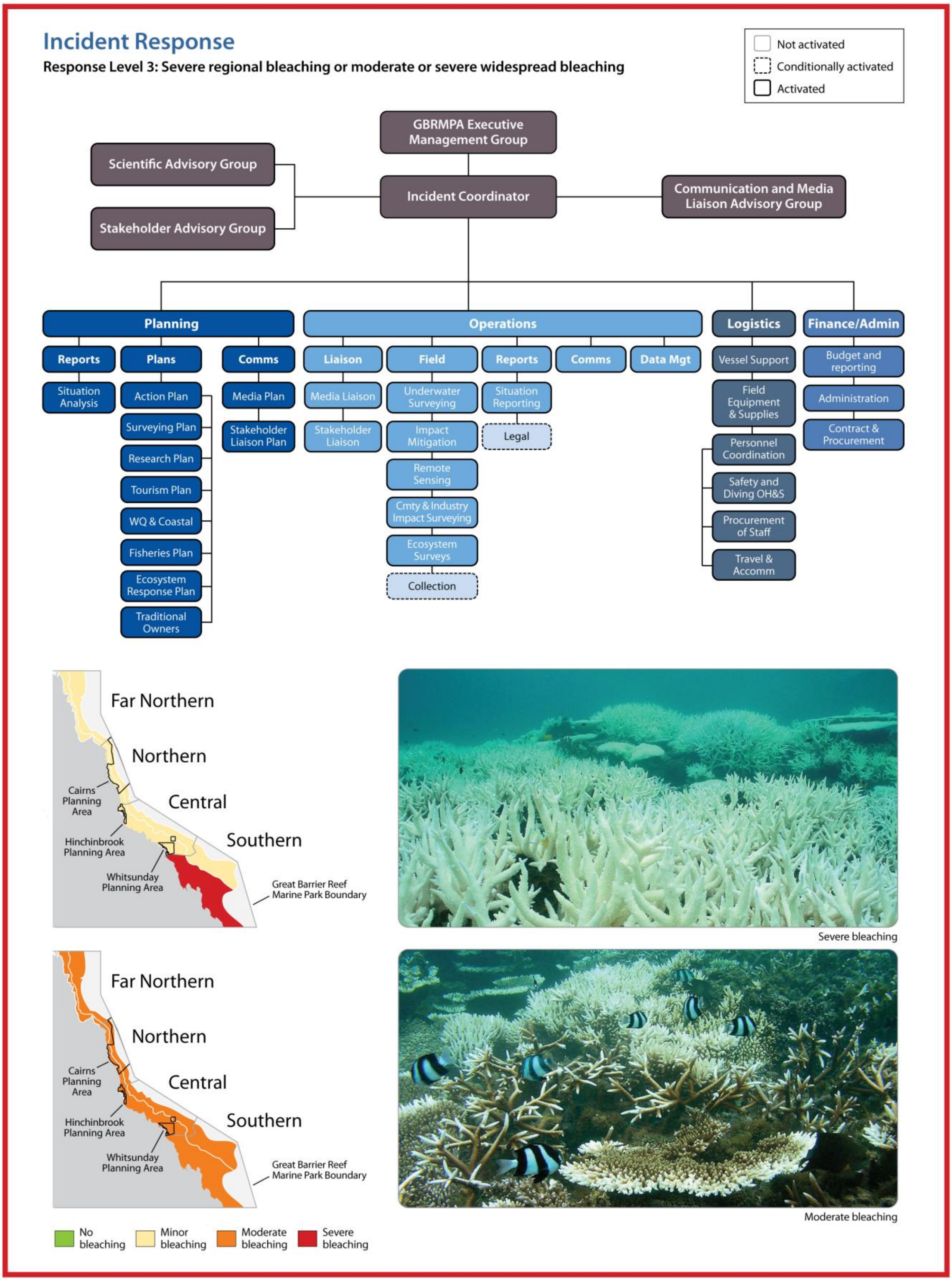


Figure 10. Response level 3 within the Incident Response. Activation and conditional activation of IR components are illustrated by the intensity of colour and border for each box within the diagram above. Scenarios shown below are examples (i.e., severe bleaching in a different region would result in the same management response).

Assessment and Monitoring

To accurately characterise the extent and severity of bleaching, bleaching-induced mortality and the associated longer-term ecological implications requires three temporal surveys are undertaken: baseline, event and survival/mortality. By surveying sites that are also surveyed as part of the AIMS Long Term Monitoring Program, baseline surveys are not required and managers can focus on the surveys during the event to assess the severity of bleaching impacts, and six months and a year after the event to assess the ecological implications of bleaching events. When recovery surveys are undertaken, surveys for disease are conducted concurrently because bleaching can greatly increase the susceptibility of corals to diseases (see Coral Disease Response Plan, GBRMPA 2010). In this sense, the GBRMPA takes the lead on *assessing* impacts and the implications of coral bleaching events in the year that follows the bleaching, while longer-term ecological *monitoring* surveys are coordinated and undertaken by the AIMS LTMP. Assessing reef health and condition during and in the months that follow incidents also informs estimates of reef resilience, which enables testing of the effectiveness of various strategies that support the natural resilience of reefs.

The implications of severe bleaching on reef ecology include but are not limited to coral mortality, shifts in coral community structure, altered habitat composition, and ecosystem flow-on effects. Severe bleaching also has implications for industries that depend on the reef as well as associated human communities since bleaching can reduce the social or economic value of reef sites important to tourism operators, fishers, or recreational users. Monitoring of the social and economic impacts of bleaching events is undertaken in collaboration with AMPTO and researchers.

When the situation analysis (Figure 6) determines thresholds for response levels 2 (Figure 9) or 3 (Figure 10) have been reached, managers implement a two-tiered approach to assessment. Intensive in-water surveys at routine sites (surveyed during each event) and targeted sites (those most affected by bleaching) are conducted, in combination with aerial surveys that give broad reef coverage (Oliver et al. 2004). This approach is a pragmatic yet defensible way to collect data quickly during a bleaching event while creating a long-term record. These surveys are conditionally activated for response level 1 (Figure 7) and may be undertaken depending on the outcome of the situation analysis.

The Response Plan surveys 45 routine sites for intense in-water assessments (Figure 11, coordinates for sites in Appendix D). The sites represent cross-shelf as well as latitudinal gradients along the Great Barrier Reef. The site groupings are located at latitudes centred on Lizard Island, Cairns, Townsville, Whitsunday Islands and the Capricorn Bunker Group (Figure 11). Three inshore, three mid-shelf and three outer shelf reefs are surveyed in each transect.

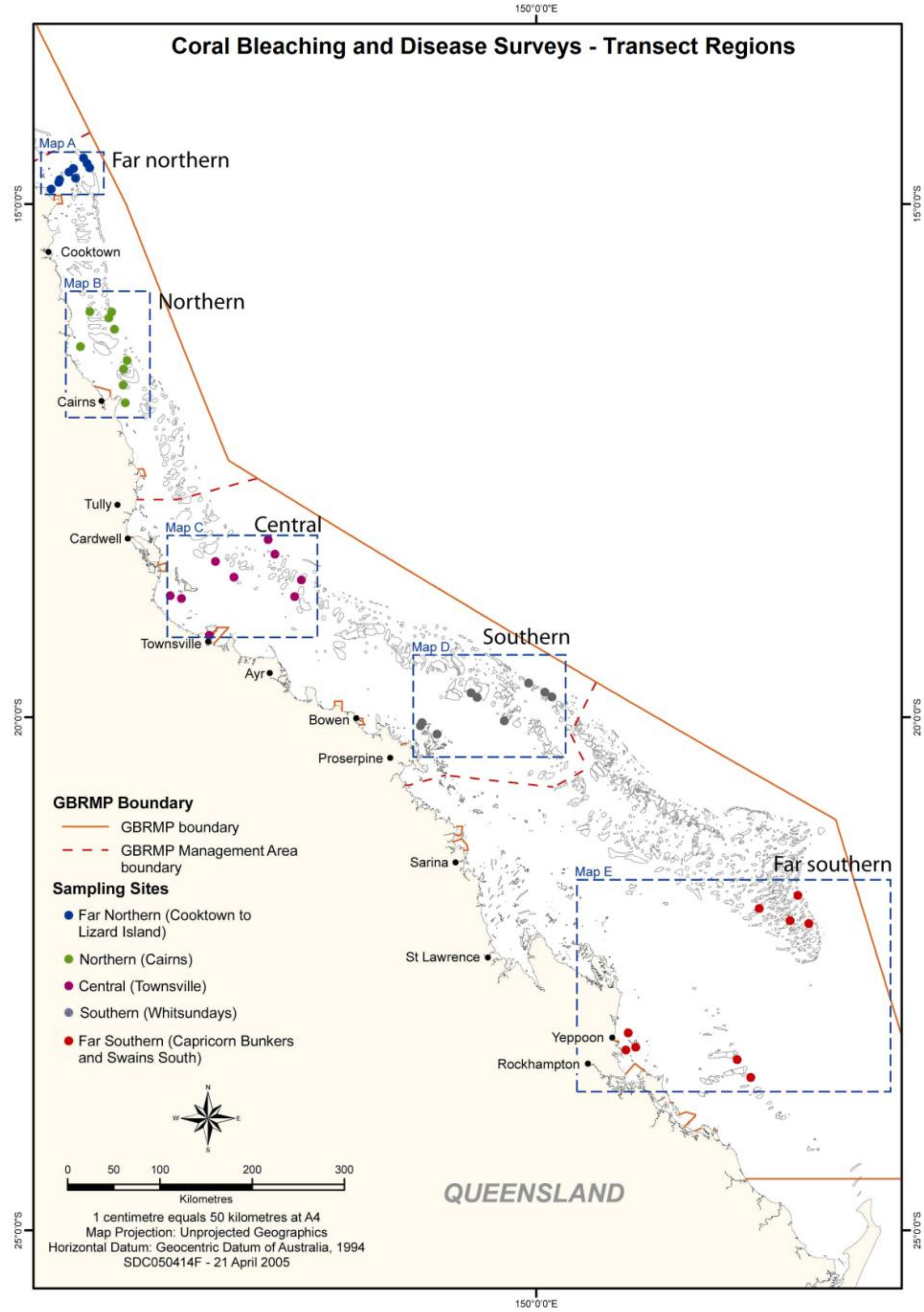


Figure 11. Response Plan monitoring sites routinely surveyed during a mass bleaching event. High-resolution maps of each cross-shelf transect (Maps A – E) can be found at Appendix F.

At each site, three locations are surveyed on the reef crest (1 – 4 m) and lower reef slope (6 – 9 m), by a two-diver team that conduct the RHIS protocol (see Figure 4) and record three 50 m video transects. The videos are later analysed by identifying the substrate, and bleaching severity, at five points within photo frames taken (40 frames/transect, see Hill and Wilkinson 2004). The rapid assessment via the RHIS protocol provides information about the extent and severity of the bleaching event in near real-time, which can be immediately communicated to senior management, government officials and the public (see Marshall and Schuttenberg 2006).

The video transects, whilst requiring a more lengthy analysis, provide a long-term record, more detailed information and increased data resolution, which is useful for understanding the patterns and specificity of bleaching events. In addition, since the video is discontinuous, either photos taken from the video or each transect could be an independent statistical sample, ensuring the data can be used to help answer a variety of research questions. The data from bleaching and recovery surveys is loaded into the same database as the reports collected by participants in the monitoring network (Figure 5). The visual representation of the data facilitated by that system can aid in communicating the need for various management actions.

While there have been recent developments in the use of satellites to measure spatially extensive bleaching events (Elvidge et al. 2004), this approach is still experimental and expensive relative to conducting in-water and aerial surveys. The GBRMPA has received free satellite imagery since 2008 through the Planet Action initiative developed by Spot Image. Currently, the GBRMPA is working in partnership with researchers from CSIRO and the University of Queensland (UQ) to develop techniques for assessing climate change impacts based on the imagery that the Planet Action initiative can provide.

3. Management Actions

The long-term implications of coral bleaching depend on the spatial extent of bleaching impacts and on the amount of coral mortality resulting from bleaching events. Coral mortality rates will strongly influence recovery times as the availability of coral larvae from surviving corals is a key factor in successful recolonisation of a damaged site. Bleaching events are expected to increase in frequency and severity as a result of climate change, making recovery processes increasingly important in the ability of reefs to persist as coral-dominated systems. Significantly, many human activities impose stresses on coral reefs that compound the risks imposed by coral bleaching and can work to lengthen recovery timeframes. Through reducing these compounding stressors, management actions can help reefs cope with or recover from coral bleaching events, which works to build the resilience of reefs to future climate-related disturbances. It is for this reason that managers conduct 'recovery surveys' six and 12 months after a bleaching event. A detailed understanding of coral mortality resulting from the recovery surveys can help target strategies that support the natural resilience of reef systems, which can reduce recovery timeframes.

Specifically, reducing stressors related to human activities can protect resistance to thermal stress, build tolerance to bleaching and promote recovery after a bleaching event, as well as support human adaptive capacity (Figure 12, Table 2). Managers can implement strategies to reduce anthropogenic stress on the local-scale, when the threshold for response level 2 (Figure 9) is reached (i.e., severe local bleaching), or more broadly at the Reef-scale when the threshold for response level 3 (Figure 10) is reached (i.e., moderate widespread bleaching or severe regional or widespread bleaching). Management actions for response level 2 are reactive and implemented at the most severely impacted site where human activities could lengthen recovery timeframes. These local-scale actions include: reactive actions like temporary closures to fishing and no-anchoring areas and longer-term strategic actions like changed water quality targets for nearby river outflows. Reactive actions implemented in the short-term during and immediately following incidents at severely impacted sites will, in some cases, be complemented with an incident recovery plan. Recovery plans lay the foundation for long-term management strategies with the aim of rehabilitating impacted sites.

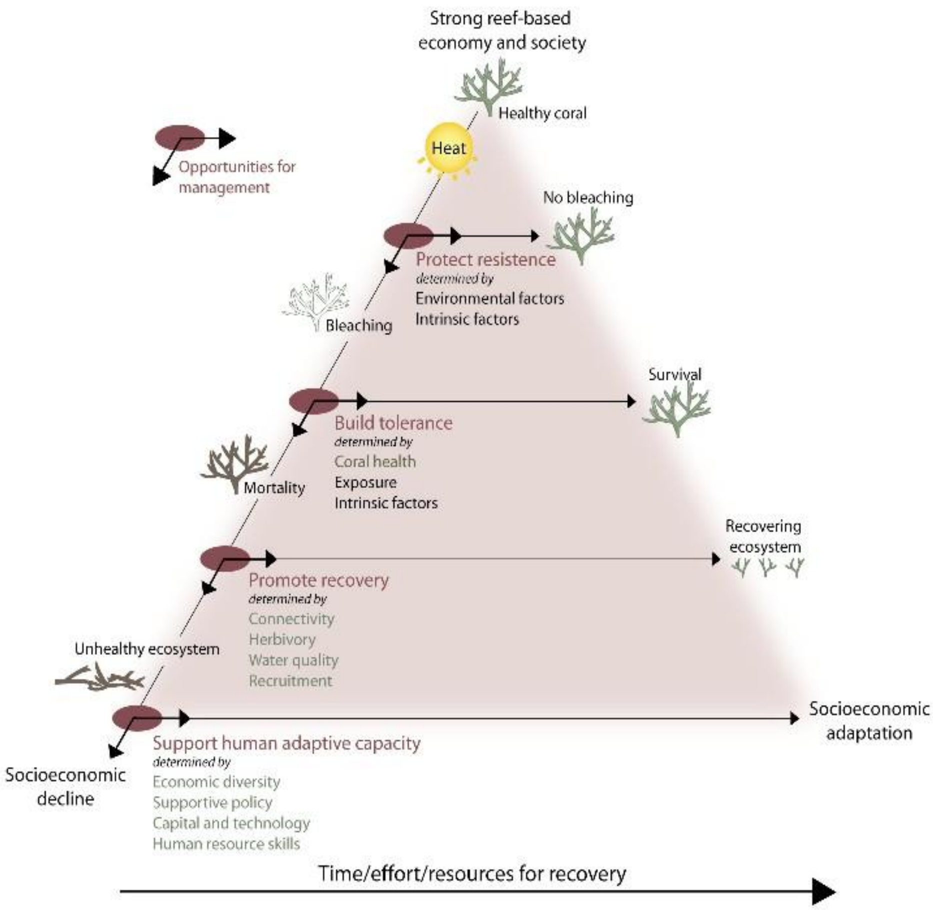


Figure 12. Goals for management actions to reduce the impacts of stressful sea temperatures on coral communities. Specific actions under these goals and the scales over which the actions can be implemented can be found in Table 2 (from Marshall and Schuttenberg 2006).

Because bleaching impacts may be severe and widespread (i.e., Response Level 3), they may also provide the impetus for Reef-scale actions to reduce stress levels. Reef-scale management actions include continuing to improve water quality and utilising community-based social marketing to further encourage responsible use of Park resources. On both the local and Reef-scale, corals exposed to stressors such as pollutants, excessive turbidity, sedimentation, decreased salinity or pathogens (and/or damage by anchors or snorkelers and divers on the local-scale) are likely to have compromised health. Lowered health reduces the survivorship of corals partially bleached and increases susceptibility to disease outbreaks (see Coral Disease Response Plan, GBRMPA 2010) and future bleaching events. Furthermore, chronic stress due to poor water quality can affect the recovery potential of reef communities as reproduction and larval recruitment in corals are particularly sensitive to environmental conditions.

Table 2. Options for management actions that can reduce the severity of bleaching impacts on coral reef ecosystems (from Marshall and Schuttenberg 2006).

Goal	Scale	Management action
Protect resistance	Local to regional	• Identify and protect refugia with resistant populations (e.g., resistant coral species, previous history of bleaching resistance) • Protect areas with environmental factors that facilitate resistance (e.g., high water mixing, upwelling, shading)
Build tolerance	Local and regional	• Minimise pressures associated with human activities that compromise coral health (e.g., physical damage, pollution, resource extraction/fishing pressure and introduced species or disease) • Protect areas with intrinsic and environmental factors that facilitate tolerance (e.g., tolerant species, upwelling, topographic complexity)
Promote recovery	Local and regional	• Minimise pressures associated with human activities that compromise coral recovery, in particular poor water quality (coastal development, catchment uses) • Minimise pressures associated with human activities that compromise recruitment (e.g., damage or removal of 'sources' of coral recruits)
Support adaptive capacity	Local, regional and national	• Flexible planning to allow for targeted protection of reef areas • Supportive policy to allow for immediate and temporary management actions to be implemented • Social and economic diversity to facilitate changes in resource use • Raised awareness of social and economic implications of climate-related disturbances • High level communication with senior decision-makers and stakeholders

Community-based social marketing can encourage stewardship behaviours, (e.g. not anchoring on corals or disposing of fishing tackle on the Reef), as well as raise support for and compliance with management strategies that necessarily limit resource use and/or that result in improvements in water quality. Stewardship building efforts are worthwhile in the face of a changing climate irrespective of whether a bleaching event has just occurred because energy-conscientious decisions around the home reduce the greenhouse gas emissions contributing to climate change.

Following most severe bleaching events it is likely that local actions, like temporary closures, that work to protect extremely unique resources or frequently visited sites, will be complemented with actions that influence the resilience of a greater area of the Reef, like improving water quality. Researchers, in collaboration with managers from the GBRMPA, are also rapidly advancing our understanding of factors that increase the resilience of reefs, as measured by the capacity to resist, tolerate and cope with, and recover from climate-related disturbances. In particular, researchers are poised to increase our understanding of spatial variability in the likelihood that a site will be impacted by climate-related disturbances like bleaching, disease outbreaks, floods and cyclones based on geographic location, community composition and thermal history. Increased knowledge of the spatial variability in factors that confer resilience to reefs may enable the GBRMPA to explicitly include resilience to climate change into management plans. Furthermore, knowledge of spatial variability in resilience factors enables assessments of the effectiveness of strategies implemented to support resilience (Table 2).

The Response Plan, especially through engagement in the monitoring network, provides opportunities for strong involvement by resource users who might be affected by coral bleaching. In addition to measures to build ecosystem resilience, the Response Plan can help build social and economic resilience to coral bleaching events. Resource users who are well-informed of risks are involved in efforts to understand problems and are included in decision-making processes about strategies to address resource issues can be expected to much more resilient to resource impacts (Marshall and Marshall 2007).

These relationships also assist the GBRMPA to identify management actions that might enhance the resilience of reef users and associated industries to bleaching events (e.g., through provision of targeted educational materials, flexible permitting arrangements, etc). Other ongoing efforts to enhance the resilience of reef users to reef health incidents include sectoral-specific contingency plans such as the Provision Reef Stewardship Action Plan[10] and the Coral Stress Response Plan for the Coral and Marine Aquarium Fish Fisheries[11]. The development of new and the refinement of existing contingency plans will occur in coming years as managers, researchers and industries collaboratively determine the socio-economic indicators most important to assess after an incident occurs.

4. Communication Strategy

Responding to coral bleaching events strategically and effectively involves a combination of routine and responsive tasks implemented through an early warning system and, if a bleaching event occurs, assessment and monitoring via the incident response, and the implementation of management actions (see Figure 1). All routine and responsive tasks rely on effective communication, particularly since bleaching events attract significant interest from the public, media and senior decision-makers (see Table 3). The Response Plan ensures timely and credible information on coral bleaching in the Great Barrier Reef Marine Park is available during and in the months and years that follow bleaching events. As a consequence, managers are able to prevent misleading or incorrect information from proliferating through various media sources. This ensures that factually accurate assessments of reef condition are readily accessible by Reef stakeholders, media and the general public during an incident.

[10] http://www.pro-visionreef.org/sites/default/files/Stewardship-Action-Plan_web.pdf
[11] http://www2.dpi.qld.gov.au/extra/pdf/fishweb/Coral-stress-response-plan-for-the-coral-and-marine-aquarium-fish-fisheries.pdf

Table 3. The frequency and timing of tasks associated with collating current bleaching information and effectively communicating during the bleaching season. Tasks that appear in italics are common to both the Bleaching and Disease Response Plans.

Frequency	Timing/Trigger	Task
Weekly	Monday	• *Check CSIRO ReefTemp and NOAA HotSpot and Degree Heating Week maps on web* • *Check sea temperature graphs from AIMS weather stations and the experimental virtual bleaching stations from NOAA* • Review weekly weather summary from the Bureau of Meteorology • *Review reports from the volunteer monitoring network* • *Prepare briefing for internal meetings*
Weekly/ fortnightly	Constant	• Monitor extent of bleaching using existing information and evaluate for trends (i.e., change in bleaching extent) • *Advise GBRMPA senior management and the Minister if worsening of conditions* • *Announce web update and send brief report to senior management*
Event-based	High bleaching risk*	• Actively solicit confirmatory bleaching reports from reliable sources, including: participants in the volunteer monitoring network, Day-to-Day Management field officers, AIMS, and other researchers • *Alert relevant project coordinators and managers* • *Brief relevant GBRMPA staff*
	Response level 1, 2, or 3 (see Figures 8-10) triggered.	• *Brief GBRMPA executive and the Minister* • *Prepare media position, draft statement and consult with GBRMPA media coordinator and executive* • *Brief all GBRMPA staff, stakeholders and collaborators* • *Release media statement* • Actively promote and solicit submissions to online bleaching reports to provide broad spatial coverage

* See also Table 1.

In addition to the task and reporting schedule outlined in Table 3 (see also Appendix A), a briefing schedule for GBRMPA senior management, the Minister, and stakeholders is outlined in Table 4. This schedule ensures these groups are aware when delivery of reports can be expected.

Table 4. Targeted briefing schedule to communicate onset of bleaching season (predetermined dates) and bleaching risk and occurrence throughout the bleaching season (date determined by reaching a trigger). Asterisks denote triggers that will result in determining a media position and the release of a media statement (see also Table 3).

Approx. date	Trigger[1]	Briefings			
		Senior Management	Minister	Stakeholders	Message
1 Dec	Annually	^	^	^	Summer approaching; bleaching risk period; Response Plan being implemented

20 Dec	Annually	^			Temperature trends for December; plans for Christmas break
	*High bleaching risk**	^	^		Temperatures unusually high; coral bleaching event probable
	*Response level 1 (see Figure 8)**	^	^	^	High temperatures recorded; widespread minor bleaching observed; and the areas most affected
	*Response levels 2 and 3 (see Figures 9 and 10) **	^	^	^	Very high temperatures recorded; moderate or severe bleaching observed at regional scale or widespread; areas worst affected and mortality likely
15 Feb[3]	Annually	^			Temperature trends for first half of summer; summary of any observed coral bleaching
31 March	*No bleaching*	^	^	^	Summer concluding; bleaching risk period over; no significant bleaching observed
	*Response levels 1, 2 and 3 (see Figures 8-10)**	^	^	^	High water temperatures recorded; bleaching observed; preliminary assessment of extent and severity; detailed surveys underway (if Response level 2 or 3 triggered)
30 May	*Moderate, major or severe impact (see Table 1)*	^	^	^	Summary of full extent and severity of bleaching; implications for affected regions and Great Barrier Reef

Conclusion

As bleaching events become more frequent and severe, impacts on the reef ecosystem and on reef users will become increasingly acute and apparent. Accordingly, there will be escalating expectations for management actions that can enhance the resilience of the Reef, and the resilience of those who depend on it for cultural connection, recreation and income. This expectation was outlined specifically in the 2009 Outlook Report (GBRMPA 2009) and characterised as the need to assess ecosystem health and manage for resilience. This Response Plan outlines the strategic approach that GBRMPA is employing to tackle the challenge of climate-induced coral bleaching. Specifically, the response plan provides practical tools for monitoring, assessing and reducing bleaching risk and impacts. The four-component structure described here is based on a model proven successful in responding to bleaching events on the GBR and has been adopted by reef managers in Hawaii and Florida.

Coral bleaching is inherently linked to coral disease because bleaching increases the susceptibility of corals to disease outbreaks. This Plan and the Coral Disease Response Plan are united under the overarching Reef Health Incident Response Framework, which assists managers to evaluate and respond to cumulative and simultaneous impacts. The capacity to predict and respond to cumulative and simultaneous impacts will be further developed in the coming years as the capacity to monitor conditions that cause the range of reef health incidents increases. Most importantly, the Plan targets the implementation of strategies that support the resilience of the linked social-ecological systems of the Reef. The Plan also describes protocols for follow-up surveys that can test the effectiveness of various established and emerging resilience-based management strategies. As with the other Response Plans, this Plan and the overarching Reef Health Incident Management System lay the foundations for an informed and adaptive approach to building the Reef's resilience to climate change.

References

Elvidge CD, Dietz JB, Berkelmans R, Andrefouet S, Skirving WJ, Strong AE, and BT Tuttle (2004) Satellite observation of Keppel Islands (Great Barrier Reef) 2002 coral bleaching using IKONOS data. Coral Reefs, 23(1), 123-132.

English S and Wilkinson (eds.) (2004) Survey manual for tropical marine resources, 2 ed., Australian Institute of Marine Science, Townsville.

GBRMPA (2010) Coral Disease Response Plan. Great Barrier Reef Marine Park Authority, Townsville.

Hill J and CR Wilkinson (2004) Methods for Ecological Monitoring of Coral Reefs. Australian Institute of Marine Science, Townsville.

Hoegh-Guldberg O (1999) Climate change, coral bleaching and the future of the world's coral reefs. Marine and Freshwater Research 50:839-866.

Hoegh-Guldberg O, Mumby PJ, Hooten AJ, Steneck RS, Greenfield P, Gomez E, Harvell CD, Sale PF, Edwards AJ, Caldeira K, Knowlton N, Eakin CM, Iglesias-Prieto R, Muthiga N, Bradbury RH, Dubi A, Hatziolos ME (2007) Coral Reefs Under Rapid Climate Change and Ocean Acidification. Science 318: 1737-1742.

Liu G, Matrosova LE, Penland C, Gledhill DK, Eakin CM, Webb RS, Christensen TRL, Heron SF, Morgan JA, Skirving WJ, Strong AE (2008) NOAA Coral Reef Watch Coral Bleaching Outlook System. Proceedings of the 11th International Coral Reef Symposium, Session 20.

Marshall PA and H Schuttenberg (2006) A Reef Managers Guide to Coral Bleaching, *Great Barrier Reef Marine Park Authority*, Townsville.

Marshall NA, Marshall PA. 2007. Conceptualizing and Operationalizing Social resilience with Commercial Fisheries in Northern Australia. Ecology and Society 12(1). http://www.ecologyandsociety.org/vol12/iss1/art1/

Maynard JA, Turner PJ, Anthony KRN, Baird AH, Berkelmans R, Eakin CM, Johnson JE, Marshall PA, Packer GR, Rea A, and BL Willis (2008) *ReefTemp*: an interactive monitoring system for coral bleaching using high-resolution SST and improved stress predictors. Geophysical Research Letters, 35, L05603, doi:10.1029/2007GL032175.

Maynard JA, Johnson JE, Marshall PA, Goby G and Spillman C (2009) A strategic framework for responding to coral bleaching events in a changing climate. Environmental Management 44:1-11.

Oliver, J, Marshall PA, Setiasih N, and L Hansen (2004) A global protocol for assessment and monitoring of coral bleaching. WorldFish Center and WWF Indonesia, Jakarta, Indonesia.

Spillman CM, Alves O (2009) Dynamical seasonal prediction of summer sea surface temperatures in the Great Barrier Reef. Coral Reefs, 28:197-206.

Appendix A - Schedule of Coral Bleaching Response Plan routine and responsive tasks for before, during and after the coral bleaching season.

TIMING/ TRIGGER	TASK	EXPECTED OUTCOME	TICK WHEN COMPLETED
Pre-summer preparations and training			
Sep 2010	Seasonal outlook meeting	• Assessment of coral bleaching risk for the approaching summer • Preparations for coordinated response in the event of coral bleaching	
Oct 2010 – May 2011	Communications processes initiated (see Table 3)	Communications updated regularly on the status of coral bleaching	
Nov 2010	IR planning meeting	Preparations for activation of the Incident Response	
Nov 2010	Eye on the Reef training – Cairns, Port Douglas and Airlie Beach	Training of volunteer network in coral bleaching assessment and reporting	
Nov 2010	GBRMPA internal staff training in the Reef Health Impact Surveys monitoring protocol	Training of GBRMPA Townsville and regional staff in coral bleaching assessment and reporting	
Nov 2010	Refresher training first aid, CPR and oxygen provider training; updates of AS2299 Diver medicals	Field staff suitably qualified and prepared in case response initiated	
Dec 2010	Review of seasonal outlook, meeting convened if high likelihood of coral bleaching	Meeting convened to refine coordinated response if there is a risk of coral bleaching	
Dec 2010	Brief Senior Management, Minister and Stakeholders	Senior management, Minister and stakeholders aware of approaching season bleaching risk	
Dec 2010	Revise Coral Bleaching Response Plan (CBRP)	Revised CBRP published by December	
Dec 2010	In-water rescue refresher training	Staff proficient in in-water rescue and safety	
Jan 2011	Keppels scheduled monitoring	Support for ongoing resilience & monitoring of no anchoring areas	
Jan 2011	Volunteer monitoring network training - southern region - Mackay, Yeppoon and Gladstone	Additional participants for the monitoring network recruited	

Commencement of Early Warning System			
Dec 2010	Commence web based updates for seasonal outlook and coral bleaching risk – current conditions reports	Communication of reef stressors to community through web on a monthly basis	
Dec 2010	Planning for Christmas closure period	• Assignment of duties over Christmas closure period • Senior Management notified of arrangements • Minister advised if coral bleaching risk moderate-high	
Dec 2010 - Apr 2011	Assess bleaching risk weekly	• Check *ReefTemp* and NOAA hotspots on web • Review weekly weather summary reports • Review reports from the volunteer monitoring network and update spatial layers • Review AIMS temperature graphs • Prepare briefings for internal meetings, round table • Advise Senior Management of changes	
Feb 2011	Assess temperature trends and bleaching for first half of summer	• Senior Management update on conditions • Contact made with volunteer monitoring network participants in areas of interest	

Event reported – Incident Response (IR) initiation			
Bleaching reported	Situation analysis conducted	IR situation analysis	
Bleaching reported	Situation analysis reviewed	Level of IR response agreed (this includes nil response)	
IR activated	Appointment of incident controller	Incident coordinator appointed to establish a response team	
IR active	Notification of incident to relevant agencies	Heightened awareness of the incident amongst relevant agencies	
IR active	Action plan developed	• Action plan identifies roles and responsibilities for coral bleaching response • Action plan implemented and all sub plans including communications plan activated	
IR active	Deploy operational teams	• Operational teams to manage incident deployed • Incident managed effectively	

		• Emergency fast track permits authorised	
High risk season passed	Incident response terminated, IR deactivated	Incident debrief convened	

IR terminated and long-term management implemented			
Post event	Progress implementation of long-term impact management actions and adaptation plans	• Sectoral impact management plans implemented • Management actions (e.g. emergency SMAs) implemented	
Post event **April 2011**	Preliminary report on the incident produced	Summary report of responses initiated for internal use	
Post event **May 2011 - June 2011**	Formal incident report produced	Summary report of the extent and severity of the impact	
Post event	IR revision and update	Review IR implementation and incorporate feedback	
Post event	Brief Senior Management, Minister and Stakeholders	Senior management, Minister and stakeholders aware of summer impacts and Reef recovery	
May 2011 - October 2011	End of season updates	• End of season reports posted onto the Web, including nil reports • End of season summary emailed to participants of the volunteer monitoring network	
Post event ongoing	Impact recovery monitoring	Monitoring of recovery from severe coral bleaching impacts	

Appendix B – Early Warning System Tools Key References and Further Reading

Tools that form the early warning system within the Response Plan have been developed by a number of agencies and research institutions, nearly all of which have worked in close collaboration with the GBRMPA. Each of these institutions has scientists who have published peer-reviewed publications on their work in the area of predicting bleaching. Furthermore, each agency maintains their own website, which describes how the models and tools were developed and are meant to be interpreted. The key references and further reading providing technical details (websites) on the products are listed below, and are divided into the same sub-sections seen in the Early Warning System section of the Plan.

Seasonal outlooks of bleaching risk

Eakin CM, Morgan JA, Heron SF, Smith TB, Liu G, et al. (2010) Caribbean Corals in Crisis: Record Thermal Stress, Bleaching, and Mortality in 2005. PLoS ONE 5(11): e13969. doi:10.1371/journal.pone.0013969.

Skirving, W.J., A.E. Strong, G. Liu, F. Arzayus, C. Liu and J. Sapper (2006c). Extreme events and perturbations of coastal ecosystems. In L.L. Richardson & E.F. LeDrew [Eds.], Remote Sensing of Aquatic Coastal Ecosystem Processes. Remote Sensing and Digital Image Processing, Vol. 9, Springer. 11-26 pp.

Spillman CM, Hudson DA, Alves O (2010) Real-time seasonal SST predictions for the Great Barrier Reef during the summer of 2009/2010. CAWCR Research Letters, 4:11-19.

Spillman CM, Alves O, Hudson DA (2010) Seasonal prediction of thermal stress accumulation for coral bleaching in the tropical oceans. Monthly Weather Review, DOI: 10.1175/2010MWR3526.1.

Spillman CM, Alves O (2009) Dynamical seasonal prediction of summer sea surface temperatures in the Great Barrier Reef. Coral Reefs, 28:197-206.

http://coralreefwatch.noaa.gov/satellite/methodology/methodology.html

http://poama.bom.gov.au/experimental/poama15/sp_gbr.htm

Near-real time monitoring of temperature stress

Strong, A.E., F. Arzayus, W. Skirving and S.F. Heron (2006). Identifying Coral Bleaching Remotely via Coral Reef Watch - Improved Integration and Implications for Changing Climate. In J.T. Phinney, et al. [Eds.], Coral Reefs and Climate Change: Science and Management. Coastal and Estuarine Studies, Vol. 61, American Geophysical Union, Washington, DC. 163-180 pp.

Maynard JA, Turner PJ, Anthony KRN, Baird AH, Berkelmans R, Eakin CM, Johnson JE, Marshall PA, Packer GR, Rea A, and BL Willis (2008) *ReefTemp*: an interactive monitoring system for coral bleaching using high-resolution SST and improved stress predictors. *Geophysical Research Letters*, 35, L05603, doi:10.1029/2007GL032175.

Maynard JA, Johnson JE, Marshall PA, Goby G and Spillman C (2009) A strategic framework for responding to coral bleaching events in a changing climate. *Environmental Management* 44:1-11

Berkelmans R (2002) Time-integrated thermal bleaching thresholds of reefs and their variation on the Great Barrier Reef. Marine Ecology Progress Series 229:73-82

http://coralreefwatch.noaa.gov/satellite/methodology/methodology.html

http://www.cmar.csiro.au/remotesensing/*ReefTemp*/web/*ReefTemp*_techinfo.htm

Appendix C – Reef Health and Impact Point Survey reporting form

Note: In the Coral bleaching section reef-framework-building corals have been listed left to right (Branching to Massives) from most to least susceptible to bleaching (see arrow below), followed by the free-living mushroom corals (see also Table 1).

Reef Health and Impact Point Survey

Australian Government – Great Barrier Reef Marine Park Authority | Queensland Government

OBSERVER AND SITE DETAILS

Observer name/s:		Date:
Organisation:	Vessel:	Sheet: ______ of: ______
Email:	Phone:	Snorkel ☐ or Dive ☐

Site information *Centre of survey* / *Check one*

Lat: ____________ S   Decimal Degrees (preferred) ☐   Reef ID: Marine Park Zone:

Long: ____________ E   Degrees Decimal Mins ☐   Reef name:

Degrees Min Sec ☐   Site:

SITE CONDITIONS:

Survey depth: ______ m

Air temp: ______ °C

Water temp (0-3m): ______ °C

(5-10m): ______ °C

Visibility: (*Circle one*) < 5m / 5-10m / >10m

Flood plume: Y/N

Suspended algal bloom: Y/N

Tide at survey time (low/mid/high):

Secchi: ______ m

HABITAT:

Lagoon: A
Crest: B
Slope: C
Bommie field: D
Reef flat: E
*Other: F

* *Please describe:*

BENTHOS:

Macroalgae: ______ %
Live coral: ______ %
Recently dead coral: ______ %
Live coral rock: ______ %
Coral rubble: ______ %
Sand: ______ %
TOTAL: ___100 %

BENTHOS

Macroalgae observations   Present: Y / N   Photos taken: Y / N

MACROALGAE TYPE:	Slime	Entangled / mat-like	Filamentous	Leafy / fleshy	Tree / bush-like	Total
Proportion of the total macroalgae cover ▶	%	%	%	%	%	100 %
Average height (cm)* ▶						

* Macroalgae height: A = 0-3cm B = >3-25cm C = >25cm

Coral observations   Present: Y / N   Photos taken: Y / N

CORAL TYPE:	Soft coral	Branching	Bushy	Plate / table	Vase / foliose	Encrusting	Massive	Mushroom	Total
Proportion of the live coral cover ▶	%	%	%	%	%	%	%	%	100 %

Coral bleaching   Present: Y / N   Photos taken: Y / N

CORAL TYPE:	Soft coral	Branching	Bushy	Plate / table	Vase / foliose	Encrusting	Massive	Mushroom
Proportion of the live corals that are bleached ▶	%	%	%	%	%	%	%	%
Severity of the bleaching* ▶		→					→	

* Bleaching severity: 1 = bleached only on upper surface 2 = pale/fluoro (very light or yellowish) 3 = totally bleached white 4 = recently dead coral lightly covered in algae

IMPACTS

Coral disease   Present: Y / N   Photos taken: Y / N

Proportion of coral cover affected	CORAL TYPE:		Soft coral	Branching	Bushy	Plate / table	Vase / foliose	Encrusting	Massive	Mushroom
%	◀ Black band disease ▶	Number of affected colonies								
%	◀ Brown band disease ▶									
%	◀ White syndromes ▶									
%	◀ Other disease / tumours ▶									

Coral predation   Present: Y / N   Photos taken: Y / N

Proportion of coral cover affected	PREDATOR:	Total # adult	Total # juvenile	Soft coral	Branching	Bushy	Plate / table	Vase / foliose	Encrusting	Massive	Mushroom
				Number of affected colonies							
%	◀ COTS ▶										
%	◀ *Drupella* ▶										

Recent coral damage   Present: Y / N   Photos taken: Y / N

Proportion of coral cover affected	CORAL TYPE:	Soft coral	Branching	Bushy	Plate / table	Vase / foliose	Encrusting	Massive	Mushroom
%	Number of affected colonies ▶								
	Severity of damage* *Insert code* ▶								
	Possible cause** *Insert code* ▶								

* Severity: 1 = Edge / tips 2 = Part / branches 3 = Whole colonies

** Possible cause: A = Anchor D = Divers S = Snorkellers W = Weather / storm V = Vessel C = Animal X = Other U = Unknown

Rubbish   Present: Y / N   Photos taken: Y / N

RUBBISH TYPE:	Fishing line	Plastic	Netting	Rope	Other
Number of pieces of rubbish:					

Additional information *(For example: site conditions, impacts, sightings of protected species and comments on supplied photographs)*

11/2010

Please return to: **Great Barrier Reef Marine Park Authority** | PO Box 1379 Townsville QLD 4810 | Fax: (07) 4772 6093 | Ph: (07) 4750 0700 | reefhealth@gbrmpa.gov.au

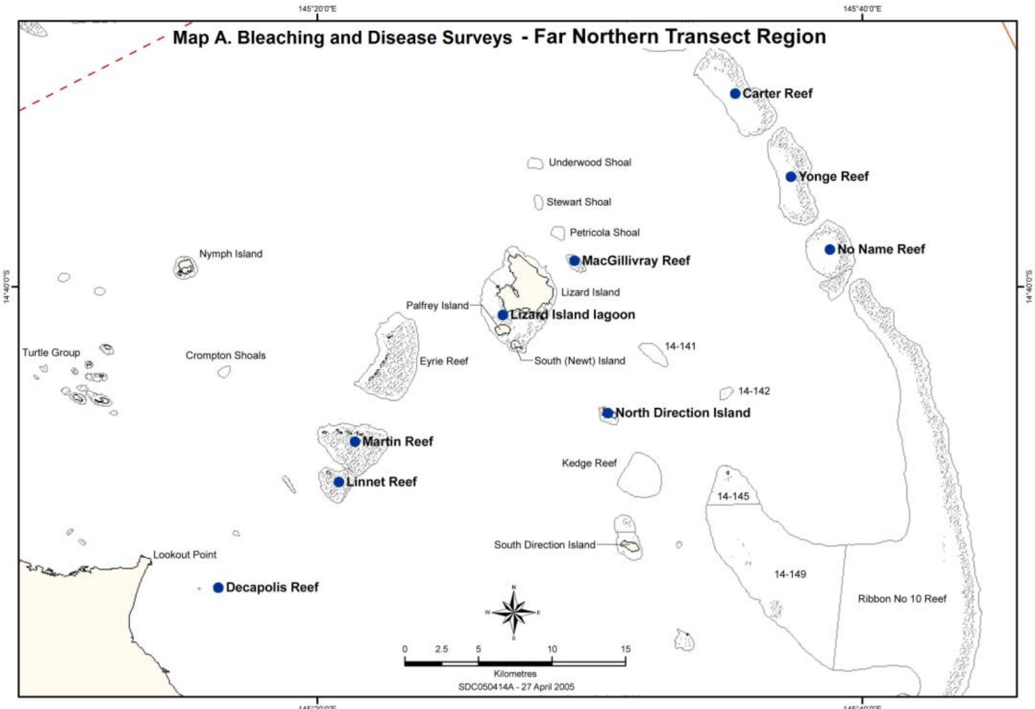
Appendix D —Locations of intensive survey sites

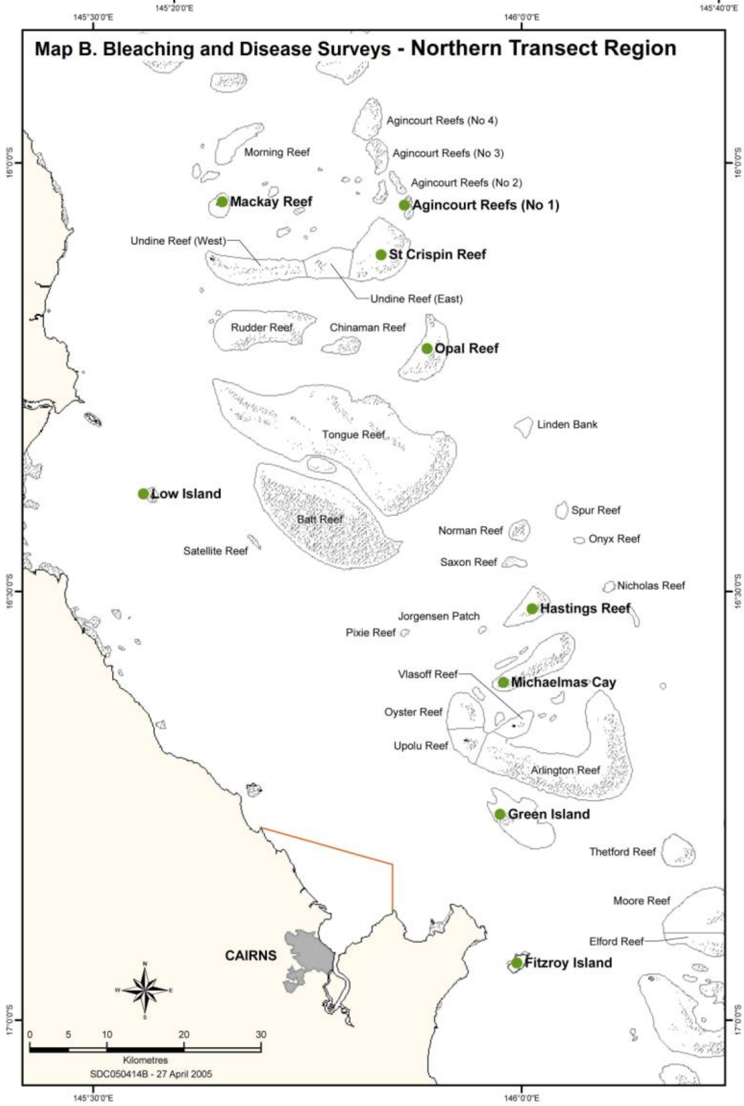
I = Inner-shelf reef, M = Mid-shelf reef, O = Outer-shelf reef

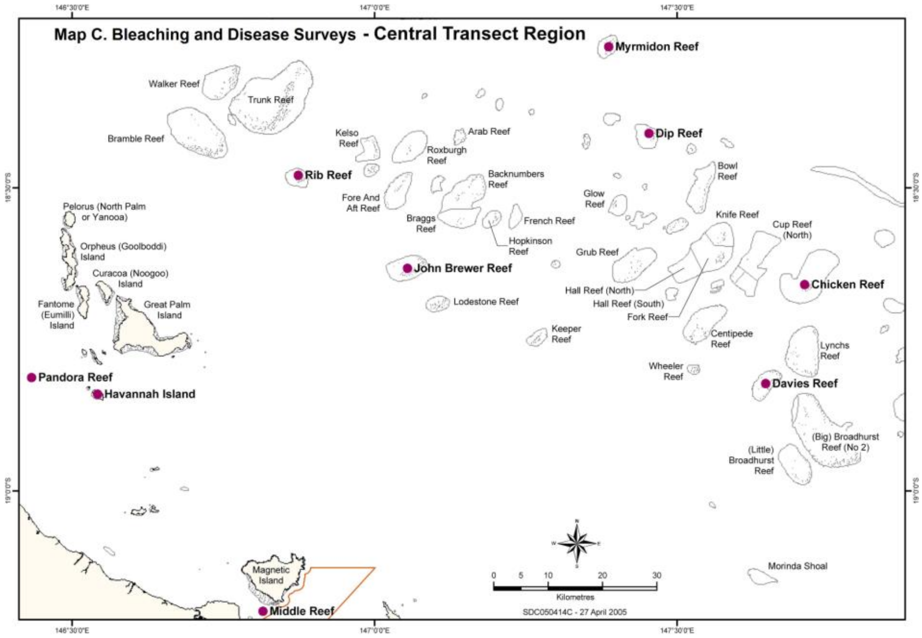
Coordinates

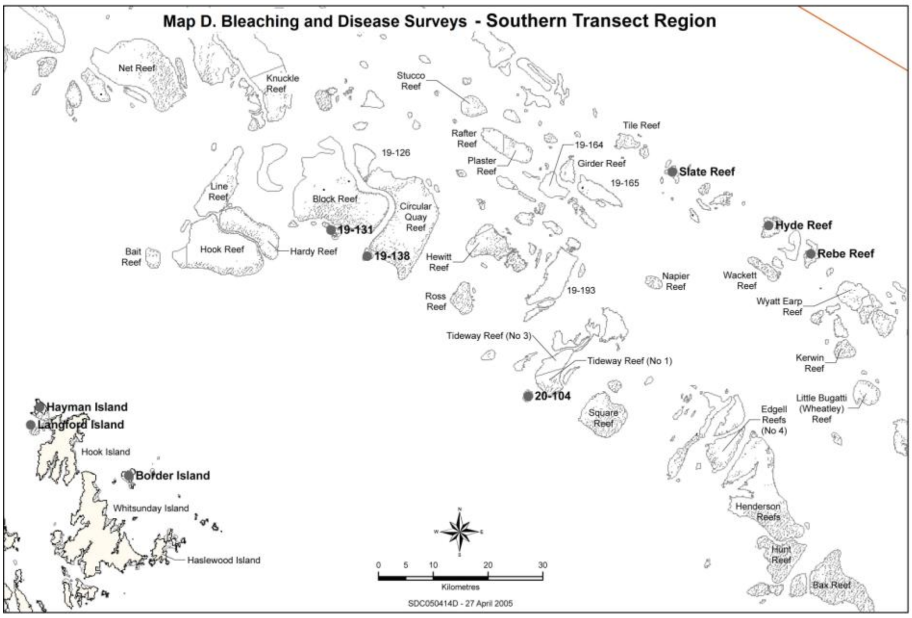
		Site coordinates (deg min)	
Transect and Region	**Reef Name**	**Latitude (S)**	**Longitude**
Far Northern (Cooktown to Lizard Island)	Martin Reef (I)	14 45.566	145 22.586
	Linnet Reef (I)	14 47.33	145 21.21
	Decapolis Reef (I)	14 51.021	145 16.401
	MacGillivray Reef (M)	14 39.02	145 29.65
	Nth Direction Island (M)	14 44.784	145 31.02
	Lizard Island lagoon (M)	14 41.661	145 27.935
	Yonge Reef (O)	14 34.431	145 37.251
	Carter Reef (O)	14 31.584	145 35.1
	No Name Reef (O)	14 37.776	145 38.967
Northern (Cairns)	Green Island (I)	16 46.372	145 58.601
	Low Isles (I)	16 23.189	145 34.356
	Fitzroy Island (I)	16 55.384	145 59.765
	Mackay Reef (M)	16 2.697	145 39.147
	Michaelmas Cay (M)	16 33.09	146 3.241
	Hastings Reef (M)	16 30.182	146 1.594
	St Crispin Reef (O)	16 4.399	145 50.975
	Opal Reef (O)	16 12.451	145 54.452
	Agincourt No.1 Reef (O)	16 2.509	145 52.209
Central (Townsville)	Pandora Reef (I)	18 48.694	146 25.803
	Havannah Island (I)	18 50.04	146 32.482
	Middle Reef (I)	19 11.759	146 48.799
	Davies Reef (M)	18 48.679	147 40.231
	Rib Reef (M)	18 28.495	146 52.863
	John Brewer Reef (M)	18 37.358	147 5.045
	Chicken Reef (O)	18 39.348	147 43.43
	Dip Reef (O)	18 24.227	147 27.32
	Myrmidon Reef (O)	18 15.278	147 23.163
Southern (Whitsundays)	Hayman Island (I)	20 3.58	148 54.099
	Border Island (I)	20 10.517	149 2.098
	Langford & Bird Island (I)	20 4.78	148 52.614
	Reef 19131S (M)	19 46.162	149 22.719
	Reef 19138S (M)	19 48.5	149 25.58
	Reef 20104S (M)	20 2.007	149 41.686
	Slate Reef 19159 (O)	19 39.837	149 55.061
	Hyde Reef (O)	19 44.488	150 5.187
	Rebe Reef (O)	19 47.829	150 9.775
Far Southern (Capricorn Bunkers and Swains South)	Nth Keppel Island (I)	23 5.187	150 54.311
	Middle Island (I)	23 9.896	150 55.42
	Halfway Island (I)	23 12.193	150 58.187
	Gannet Cay (M)	21 58.743	152 28.955
	Chinaman Reef (M)	22 0.116	152 40.119
	Reef 21529S (M)	21 52.02	152 11.183
	Turner Cay (O)	21 42.204	152 33.807
	Wreck Island (O)	23 19.149	151 58.785
	One Tree Island (O)	23 29.261	152 5.554

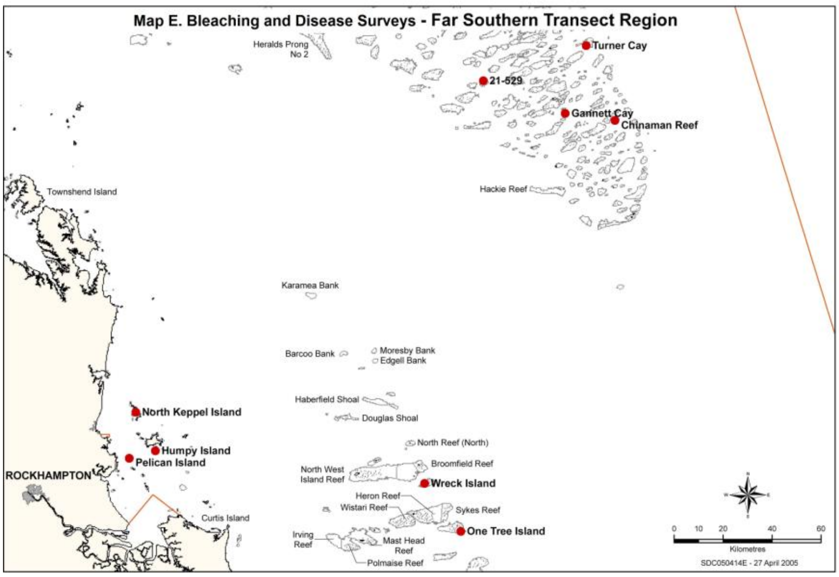
Appendix E – Detailed maps of survey site locations in each cross-shelf transect






Map C. Bleaching and Disease Surveys - Central Transect Region
146°30'0"E
147°0'0"E
147°30'0"E
18°30'0"S
19°0'0"S
Myrmidon Reef
Walker Reef
Trunk Reef
Bramble Reef
Kelso Reef
Arab Reef
Dip Reef
Roxburgh Reef
Rib Reef
Backnumbers Reef
Bowl Reef
Fore And Aft Reef
Glow Reef
Pelorus (North Palm or Yanooa)
Braggs Reef
French Reef
Knife Reef
Cup Reef (North)
Hopkinson Reef
Grub Reef
Orpheus (Goolboddi) Island
Curacoa (Noogoo) Island
John Brewer Reef
Chicken Reef
Hall Reef (North)
Fantome (Eumilli) Island
Great Palm Island
Lodestone Reef
Hall Reef (South)
Fork Reef
Keeper Reef
Centipede Reef
Lynchs Reef
Wheeler Reef
Pandora Reef
Davies Reef
Havannah Island
(Big) Broadhurst Reef (No 2)
(Little) Broadhurst Reef
Magnetic Island
Middle Reef
Morinda Shoal
0 5 10 20 30
Kilometres
SDC050414C - 27 April 2005


Map D. Bleaching and Disease Surveys - Southern Transect Region
Net Reef
Knuckle Reef
Stucco Reef
Tile Reef
Rafter Reef
19-164
19-126
Plaster Reef
Girder Reef
Slate Reef
19-165
Line Reef
Block Reef
Circular Quay Reef
Hyde Reef
19-131
Bait Reef
Hook Reef
Hardy Reef
19-138
Hewitt Reef
Rebe Reef
Napier Reef
Wackett Reef
19-193
Ross Reef
Wyatt Earp Reef
Tideway Reef (No 3)
Tideway Reef (No 1)
Kerwin Reef
20-104
Little Bugatti (Wheatley) Reef
Hayman Island
Square Reef
Edgell Reefs (No 4)
Langford Island
Hook Island
Border Island
Whitsunday Island
Henderson Reefs
Haslewood Island
Hunt Reef
Bax Reef
0 5 10 20 30
Kilometres
SDC050414D - 27 April 2005


Map E. Bleaching and Disease Surveys - Far Southern Transect Region
Heralds Prong No 2
Turner Cay
21-529
Gannett Cay
Chinaman Reef
Townshend Island
Hackie Reef
Karamea Bank
Barcoo Bank
Moresby Bank
Edgell Bank
Haberfield Shoal
Douglas Shoal
North Keppel Island
North Reef (North)
Humpy Island
Pelican Island
North West Island Reef
Broomfield Reef
ROCKHAMPTON
Wreck Island
Heron Reef
Wistari Reef
Sykes Reef
Curtis Island
Irving Reef
One Tree Island
Mast Head Reef
Polmaise Reef
0 10 20 40 60
Kilometres
SDC050414E - 27 April 2005

Appendix F – Great Barrier Reef Marine Park Planning Areas