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Great Barrier Reef
Marine Park Authority

Tropical Cyclone Risk and Impact Assessment Plan
2011

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Published by the Great Barrier Reef Marine Park Authority

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ISSN 2200-2049 (pdf)

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Executive Summary

Tropical cyclones can cause major physical damage to coral reef ecosystems. Although cyclones are natural meteorological events, severe cyclones are predicted to increase in frequency as oceans warm under a changing climate (Nott & Hayne, 2001). This Cyclone Risk and Impact Assessment Plan (the Plan) was developed by the Great Barrier Reef Marine Park Authority (GBRMPA) in April 2011 after TC Yasi (one of the largest category 5 cyclones in Australia's recorded history) crossed the Great Barrier Reef near Mission Beach in North Queensland. This Plan is part of the GBRMPA reef health incident management system that provides a structured framework for the management of impacts on the health of the Great Barrier Reef. The GBRMPA implements this Plan each year during the cyclone season – November to April.

The Plan outlines a strategic approach for how we compile and monitor cyclone risks, and how responses are coordinated and implemented, before, during and following cyclone impacts. The Plan has three components whose objectives are outlined and described in detail:

1. Early Warning System
2. Incident Response
3. Communication Strategy

The Plan is designed so that risk assessments for cyclone damage include seasonal forecasts, near real-time monitoring and impact response tasks. When the Early Warning System tools predict a high risk of cyclone impacts, team members compile a *map of potential impacts* (MPI) and generate daily synoptic reports. After the storm has passed, the MPI is used to determine the response required under the Incident Response System component of the Plan (based on the Australasian Inter-service Incident Management System[1] framework). Thresholds for the response levels (1, 2, or 3) in the Incident Response (IR) component are based on the severity of cyclone impacts, their spatial distribution and the extent of the Marine Park that is affected. The result is a *map of actual impacts* (MAI) that contributes to an up-to-date dynamic understanding of the vulnerability of the Marine Park.

The Plan is a dynamic operational document that is updated each year to incorporate major advances in cyclone forecasting and impact assessment techniques. The Plan is one of a number of risk and impact assessment plans that use the three-component template (as above) for incident response described within our overarching Reef Health Incident Response System. As a component of our reef health incident management system, this plan is implemented along with other plans e.g. for coral bleaching and coral disease when simultaneous incidents occur. This Plan also serves to keep representatives from key partner institutions and the public aware of the nature and extent of cyclone impacts that affect the Great Barrier Reef.

[1] Australasian Fire Authority Council, 2004, www.afac.com.au

Contents

Introduction

Tropical storms are the most destructive form of mechanical damage to coral reefs. They are natural meteorological phenomena that have impacted coral reefs for millennia. However, the frequency of severe storms has increased in the past 3-4 decades as ocean surface waters have warmed, fuelling increases in the power storms generate. The natural forces of tropical storms are expected to be enhanced as the climate changes, resulting in an increased frequency of severe cyclones. Like bleaching events and disease outbreaks, cyclones reduce the resilience of reef ecosystems (Anthony *et al.*, 2011). The 2009 Outlook Report (GBRMPA 2009) identifies the need for managers to continually assess the ecosystem health of the Great Barrier Reef Marine Park and manage it for resilience. Assessing impacts ensures managers have an up-to-date understanding of the vulnerability of the Great Barrier Reef. Managers can therefore distinguish between the effects of acute and chronic stressors (e.g., cyclones and water quality, respectively) and target resilience-building management strategies and awareness raising communications efforts.

Tropical cyclones that represent a risk to the Great Barrier Reef (the Reef) are formed during summer (November – April) over pools of warm (>26.5˚C) water in the Coral Sea and south-western Pacific. Once formed, tropical cyclones follow tracks within the latitudinal belt of 10 – 30˚S, spanning most of the expanse of the Great Barrier Reef. Based on historical data, however, most cyclones impacting the Great Barrier Reef have occurred within the 13˚S to 20˚S latitude band (see Figure 1).

On average, around 5 cyclones threaten the Queensland coast every year, depending on the El Niño-Southern Oscillation phenomenon. More cyclones have occurred in the past during La Niña than during El Niño years. The Great Barrier Reef has a long history of recovery from tropical cyclones. However, reef damage from recent cyclones - Larry in 2006, Hamish in 2009 and Yasi in 2011 (see Figure 2) - was so severe that the time needed for full ecosystem recovery may well exceed the return times of subsequent storms, leading to lowered resilience and increased vulnerability.

We use the Tropical Cyclone Risk and Impact Assessment Plan as an operational document throughout the cyclone season. This is one of a number of plans that use the template for incident response detailed within our Reef Health Incident Response System (RHIRS). The RHIRS guides us and is a transparent and consistent decision-making framework during reef health incidents. The Cyclone Risk and Impact Assessment Plan serves to keep representatives from key partner institutions as well as the public aware of the technologies and protocols used to predict and assess cyclone impacts. In addition, the Plan also describes the criteria that determine how we communicate about cyclone impacts upon the Great Barrier Reef when they occur.

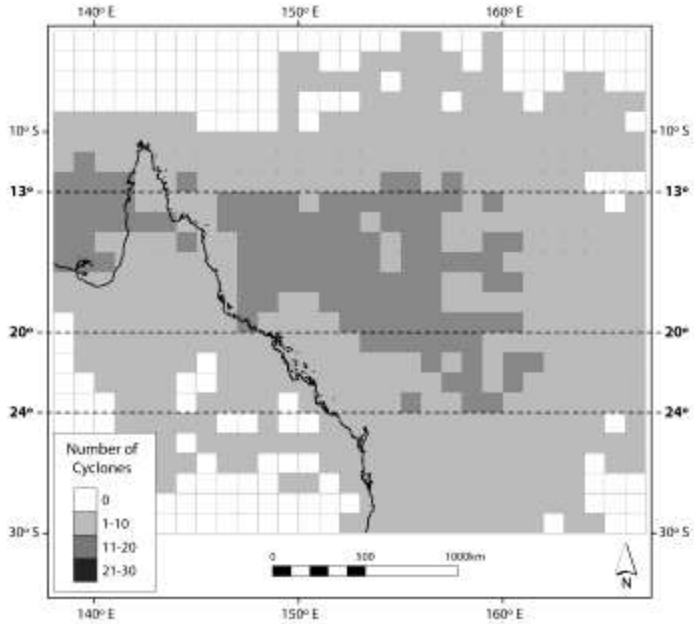


Figure 1. Distribution of the number of named tropical cyclones in Queensland waters between 1970 and 2006 – most named cyclones occurred between 13 and 20 deg. S. Data are based on observations within 1-degree latitude by longitude cells. (Adapted from Puotinen, 2007).

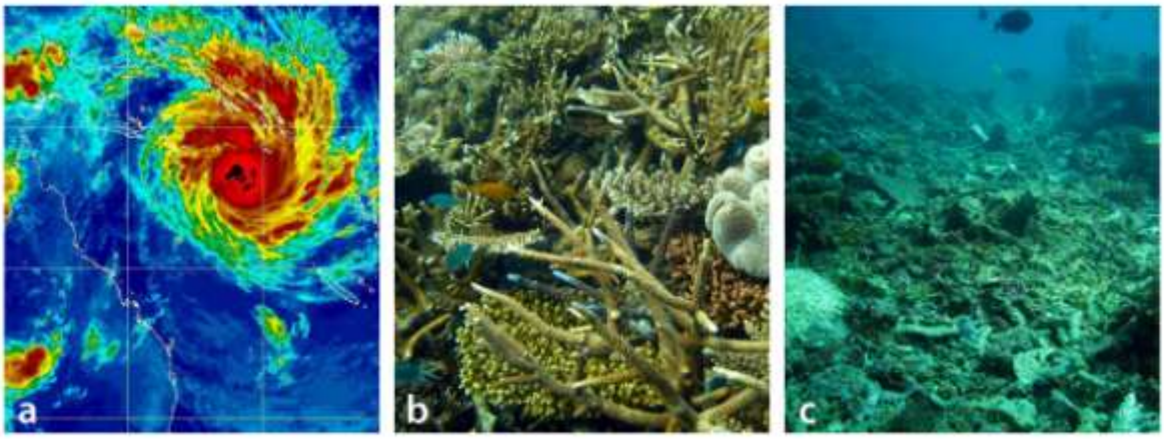


Figure 2. Examples of damage incurred by TC Yasi on mid-shelf reef communities in the central section of the Great Barrier Reef (off Tully and Mission Beach) (a) in March 2011. Images (b) and (c) show sections of Bramble reef – (b) shows a protected section that was left unscathed while (c) shows a section of the same reef that was severely damaged.

The Risk and Impact Assessment Plan has three primary components: 1) Early Warning System, 2) Incident Response, and a 3) Communication Strategy (Figure 1).

The Plan includes linked routine and responsive tasks (Figure 3). When the Cyclone Early Warning System predicts *damaging*, *destructive* or *very destructive* winds in an area of the Marine Park, the team generates a *map of potential impacts* (MPI). After the storm has been downgraded to a tropical low, we determine the appropriate response level. Response levels are defined by the severity and spatial extent of the potential impacts and are described in detail in the Incident Response section of the Plan (based on the Australasian

Inter-service Incident Management System[2] framework) (see p. 10). Based on the survey results, we produce a map of actual impacts (MAI), which is then used for reporting.

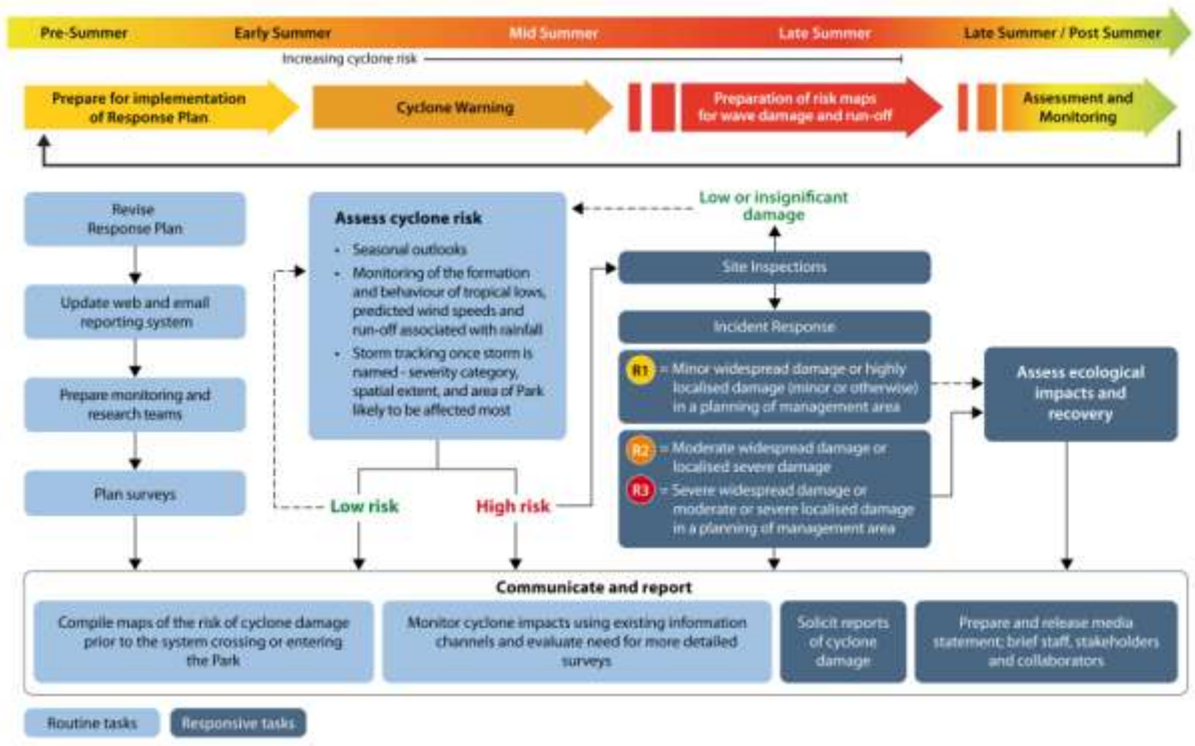


Figure 3. Plan schedule of routine and responsive tasks before, during, and after the cyclone season (see also Appendix A).Components of the plan follow on from each other, but responsive tasks are only undertaken if an Incident Response is triggered. Response levels 2 and 3 activate efforts to assess and monitor impacts, which is only conditionally activated under response level 1 (see also Figures 9 - 11).

Within this document, the objectives of each of the three primary components of the Risk and Impact Assessment Plan are outlined and the role each component plays in a timely and effective response to cyclones is described in detail.

[2] Australasian Fire Authority Council, 2004, www.afac.com.au

1. Early Warning System

The Early Warning System uses a combination of indicators and tools. Firstly, the Australian Bureau of Meteorology (BoM) provides an ENSO based seasonal outlook of cyclone activity during the high risk summer season. On average, almost twice as many cyclones are formed in La Niña (wet cold phase) as opposed to El Niño (dry warm phase) years. Secondly, sets of tools are combined to enable the short-term risk forecasting and near-real time monitoring of tropical lows and cyclones once formed. These include mapping of points of origin (cyclogenesis), observed and predicted eye pressure (a proxy for maximum wind speeds), and storm path, size and speed of movement (a proxy for residence time over individual reefs). The tools and products used for the seasonal outlook and near-real time monitoring are described below.

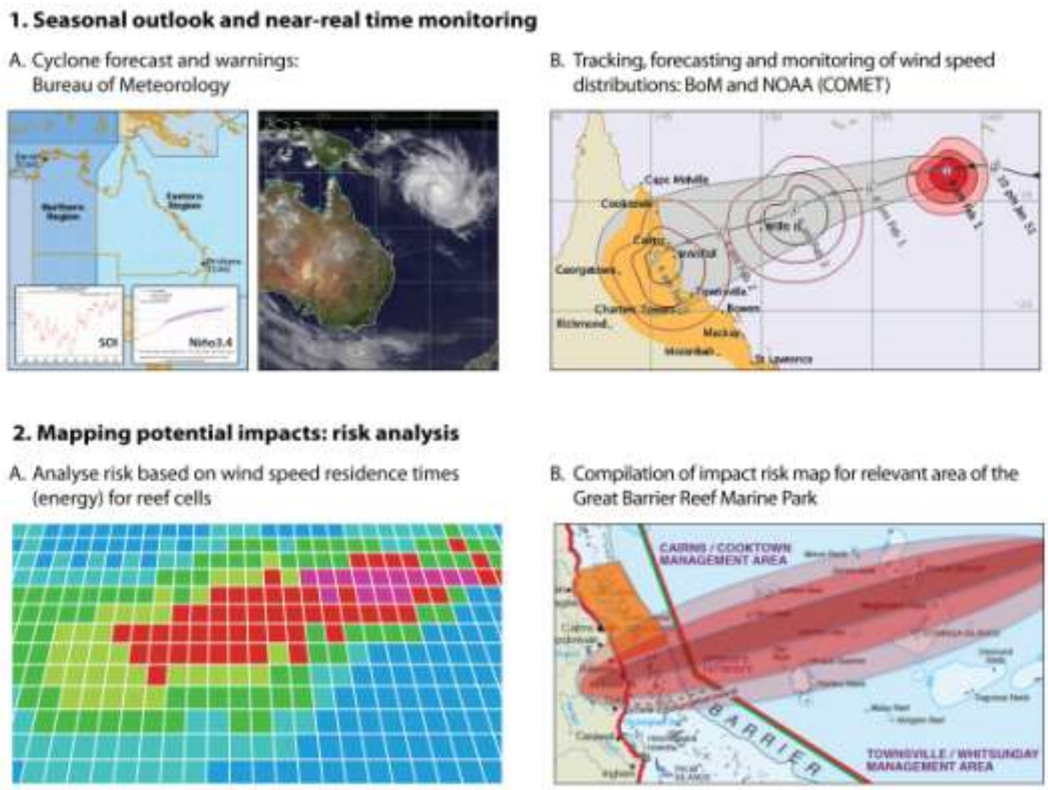


Figure 4. Summary of the two elements of the Early Warming System for tropical cyclones used to inform the risk of a cyclone and the degree of required Incident Response. [Track map shown in B is of TC Yasi and is courtesy of the Australian Bureau of Meteorology.]

Seasonal and short-term outlooks

The seasonal outlook for tropical cyclones is driven largely by a combination of the El Niño-Southern Oscillation (ENSO) and the projected sea surface temperatures for the western Pacific and Coral Sea region. The Australian Bureau of Meteorology (BoM) uses climate models to determine whether relatively few (e.g. < 4) or many (e.g. > 4) cyclones will develop and threaten the Queensland coast and reef systems during a given season. The BoM publishes a Tropical Cyclone Seasonal Outlook[3] in October or November each year, which includes statements of the projected frequency and spatial patterns of tropical cyclones in the coming season. The Outlook includes a measure of the reliability (or uncertainty) of the forecasts.

Within a season, the probability of a tropical cyclone forming in the southwest Pacific has historically been highest during the period late December to end of March, with risks peaking in January and February (Figure 5). For La Niña years, the risk analyses and real-time monitoring products need to be diligently monitored in January and February.

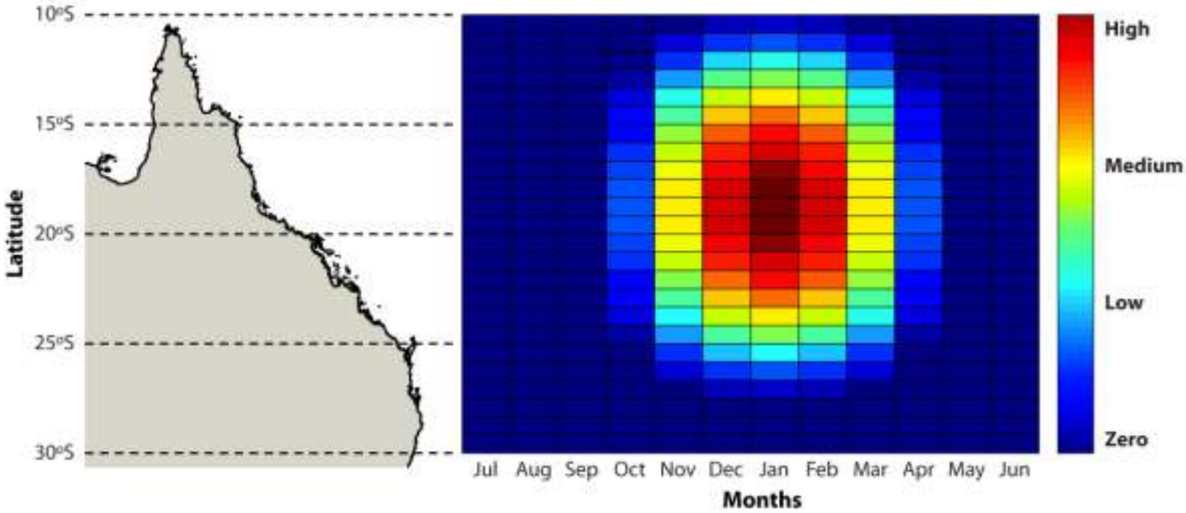


Figure 5. Risk distribution for cyclone occurrence in the Coral Sea and Great Barrier Reef area as a function of time of year and latitude. The distribution is derived based on data from McDonnell and Holbrook (2004) for the seasonal trend and from data by Puotinen et al. (2007) for the latitudinal trend. Specifically, risk is approximated based the accumulated number of named tropical cyclones formed in the Australian–southwest Pacific Ocean region (6˚–20˚S, 105˚–170˚E) during 1960-1993 (season) and 1969-2003 (latitudes). The highest risk zone corresponds to 10-15% probability for a given year.

Within a shorter, sub-weekly, timeframe, the Bureau of Meteorology publishes a 3-day outlook daily for tropical cyclone development in the Coral Sea[4]. The outlook provides a semi-quantitative assessment of the likelihood that a tropical low is formed during each day in the forecast period. The following chance categories are used for likelihood estimates for each day.

- Very low: less than 5% chance
- Low: 15% - 20% chance
- Moderate: 20% - 50% chance
- High: greater than 50% chance

[3] http://www.bom.gov.au/cyclone/about/warnings/seasonal.shtml
[4] http://www.bom.gov.au/qld/forecasts/cyclone.shtml

Once a tropical low system is developed in the Coral Sea, and is expected to produce gale force winds (>62 km/h) over land in Australia within 48 hours, the BoM issues *Tropical Cyclone Advice*[5] every six hours, increasing to every 3 hours (or hourly) when *Tropical Cyclone Warnings* are issued. Information included in the BoM tropical cyclone advice service relevant to the Great Barrier Reef includes:

- Intensity category of the cyclone
- Latest observed location of the cyclone centre (eye-wall)
- Central pressure of the cyclone (for warnings only)
- Expected or recent movement of the storm system
- Range of destructive winds

Near real-time monitoring of tropical cyclone behaviour and risk to the Great Barrier Reef Marine Park

The synoptic information included in BoM's tropical cyclone advice and warnings (in combination with satellite images of storm system movements and projected paths) provide an excellent spatial and temporal framework for the development of maps of potential cyclone impacts. The ***risk*** associated with an event is a compound metric composed of ***impact likelihood*** (cyclone will occur and cross the coast) multiplied by consequence (i.e., ***impact severity*** – likely severity of damage to reefs and/or offshore infrastructure). Table 2 describes an approach used to produce a map of potential impacts, which informs incident response.

The ***impact likelihood*** for an individual reef area within the Marine Park is a function of the projected storm ***track*** (trajectory) and storm ***size*** (diameter). Both track and size can be estimated directly from BoM's *Tropical Cyclone Forecast Track Maps* - a graphical product that provides near real-time cyclone tracks in conjunction with cyclone warnings. The product indicates recent movement of the active system(s) as well as projected movement of the cyclone over a period of 48 hours. This information is useful for planning and communications purposes but only on timeframes that range from a few days to 2 weeks. Once it is clear a cyclone will enter the Marine Park, the likely severity of the impacts is used to produce the map of potential impacts to inform the incident response.

The likely ***impact severity*** is a function of cyclone category intensity (max wind speeds) and cyclone size (determines residence time of damaging winds over a reef location). Cyclone category intensities range from 1 to 5, based on maximum wind speeds as measured by the Beaufort scale (see Table 1).

[5] http://www.bom.gov.au/cyclone/about/warnings/advice.shtml

Table 1. Cyclone intensity categories used by the Australian Bureau of Meteorology.

Category	Max wind speeds (km/h)	Beaufort scale
1	Gales: 90 – 125	8-9
2	Destructive: 125 – 165	10-11
3	Very destructive: 165 - 225	12
4	Very destructive: 225 - 280	12
5	Very destructive: > 280	12

Provided that the track of the cyclone is well forecast, the predicted ***risk*** to reef communities within and on either side of the track are mapped based on the amount of time the communities are exposed to a given wind speed (residence time, see '2A' in Figure 4). Large, slow-moving systems represent a greater risk than small, fast-moving systems (Fig. 7), even if both storms are the same category. For severe cyclones (3+, table 1), the residence times of gale force, and potentially destructive, winds in a given area increases with storm size, and inversely with the speed at which the system moves along its path.

In addition to the framework outlined above, three other key factors affect estimates of potential impacts:

- The cyclone category intensity, track and size relative to the location of priority planning areas (reefs off Cairns and the Whitsundays)
- Variation in wave energy due to wave protections by the reef framework itself (Puotinen, 2007), and
- The susceptibility of the coral reef communities and reef structures to physical damage. For example, offshore reefs may face the brunt of the cyclonic waves, but have developed under high wave exposure whereas areas protected from wave action under non-cyclonic conditions may be damaged more easily in cyclonic conditions (Fabricius *et al.*, 2008).

Table 2. Levels of cyclone severity and extent. The matrix in Figure 8 of cyclone severity and spatial extent determines the response level triggered in the Incident Response and adds whether the cyclone crossed a Planning of Management Area as a consideration.

Element	Severity	Description
POTENTIAL IMPACTS	**Minor**	Cyclone category of either 1 or 2 moving either fast (>20 km/hr) or slow (<20 km/hr)
	Moderate	Cyclone category of 3 or 4 moving fast
	Severe	Cyclone category of 3 or 4 moving slow or 5 moving either fast or slow
SPATIAL EXTENT	**Localised**	Impact area limited to a narrow track with destructive and gale force winds not extending more than 75km on either side of the track
	Extensive	Very wide path with destructive and gale force winds extending more than 75 km on either side of the track

In summary, the Early Warning System provides a risk and impact assessment framework. The seasonal cyclone outlook helps managers prepare for the prospect of cyclones, while near-real time monitoring can be used to assess where impacts are likely to be most severe. All cyclone types can trigger an incident response, which is discussed next.

2. Incident Response

The Incident Response (IR) component uses the internationally recognized incident management framework described in the Australasian Inter-agency Incident Management System (AIIMS)[6]. Once activated, the IR component generates the scalable, common organisational structure required to respond in an efficient and effective manner to a reef health incident. Specifically, the IR component identifies the governance, planning, operations, logistics, financial and inter-agency liaison arrangements for a cyclone response. The level of response required, and management resources invested, is determined via a two-step process. First, a matrix (Figure 5) is used to determine the *potential* response level by combining the likely severity of impacts with the spatial extent of the cyclone path, both of which are classified using Table 2. Potential socio-economic impacts of the cyclone, for example whether the storm crossed a high use Plan of Management Area are also considered. The *actual* response level is determined based upon the situation analysis (Figure 6). The information presented within the situation analysis is assessed by the governance group to make a final decision on the required level of response.

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 6). Once the appropriate response level has been determined the corresponding conditional planning and resource provisions of the IR component are activated.

We enlist the support of expert advisory groups to assist with incident responses (see IR chart in Figure 9). The advisory groups provide independent advice to the Incident Coordinator to ensure timely, effective decision-making based upon the best available social, economic and ecological information. The Scientific Advisory Group includes experts in 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 facilitate the advisory group meetings.

[6] http://knowledgeweb.afac.com.au/training/aiims

		Spatial extent	
Scenario	*Impact*	*Localised 1*	*Extensive 2*
A	*Outside Planning of Management Area*		
	Minor 1	1	2
	Moderate 2	2	4
	Severe 3	3	6
B	*Inside Planning of Management Area*		
	Minor 2	2	4
	Moderate 3	3	6
	Severe 4	4	8

Based on wind maps, any cyclone impacts here are considered negligible

Response Level 1

Response Level 2

Response Level 3

Figure 6. Combinations of cyclone impact categories to reef areas and their spatial extent (from Table 2) inform the situation analysis (Figure 8). The scores (products of the rank numbers for impact severity and spatial extent) are used to assess whether a threshold has been exceeded to determine the required level of response. Specific criteria for likely impact and spatial extent are shown in Table 2. Plans of Management Areas are shown in Figure 7.

Once the appropriate response level has been determined, the corresponding planning and resource provisions of the IR component are activated. The IR component is used to direct and coordinate management actions relating to the incident.

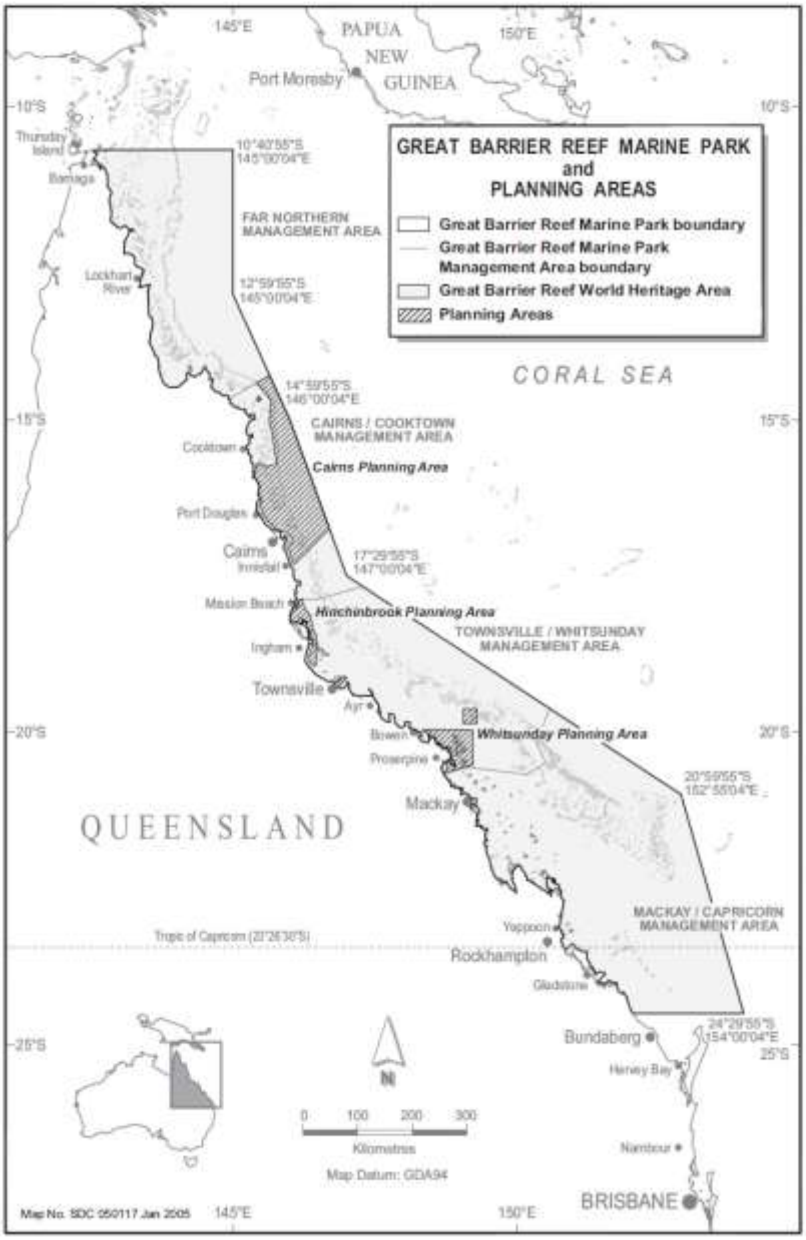


Figure 7. Plans of management (PoM) areas within the Marine Park. Response levels warranted by a cyclone of a given intensity and spatial extent may increase if the storm crosses through one or more of the PoM areas due to their ecological, social or economic significance . There are currently four Plans of Management within the Great Barrier Reef Marine Park.

- Cairns Area Plan of Management
- Hinchinbrook Plan of Management
- Shoalwater Bay (Dugong) Plan of Management
- Whitsundays Plan of Management

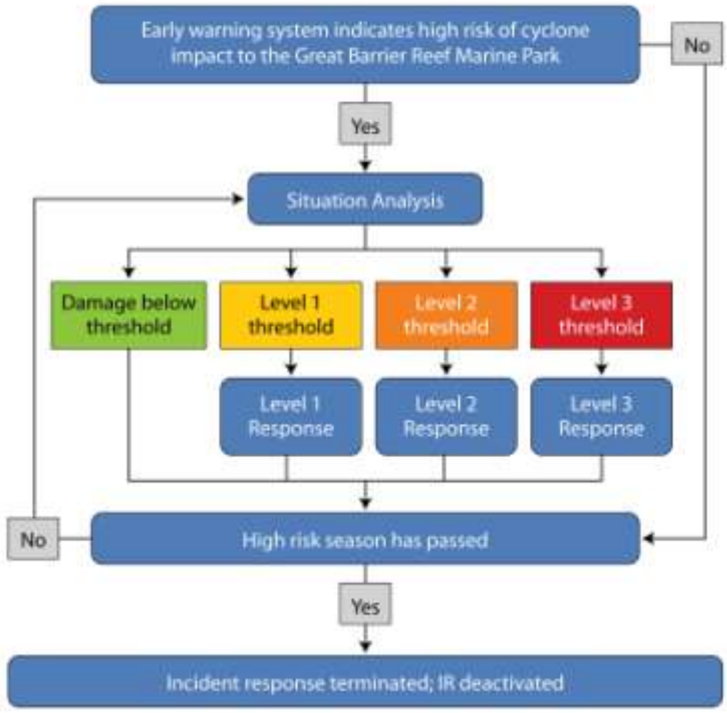


Figure 8. IR chain of events during a cyclone. The situation analysis is informed by the matrix seen in Figure 6 and is re-visited following responses if the high risk season has not passed.

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 9-11). For response level 3 (R3), the entire IR framework is activated (Figure 9).

The next section describes the approach and field survey protocols used to assess and monitor disease impacts when the situation analysis determines triggers for response levels 2 and 3 have been exceeded.

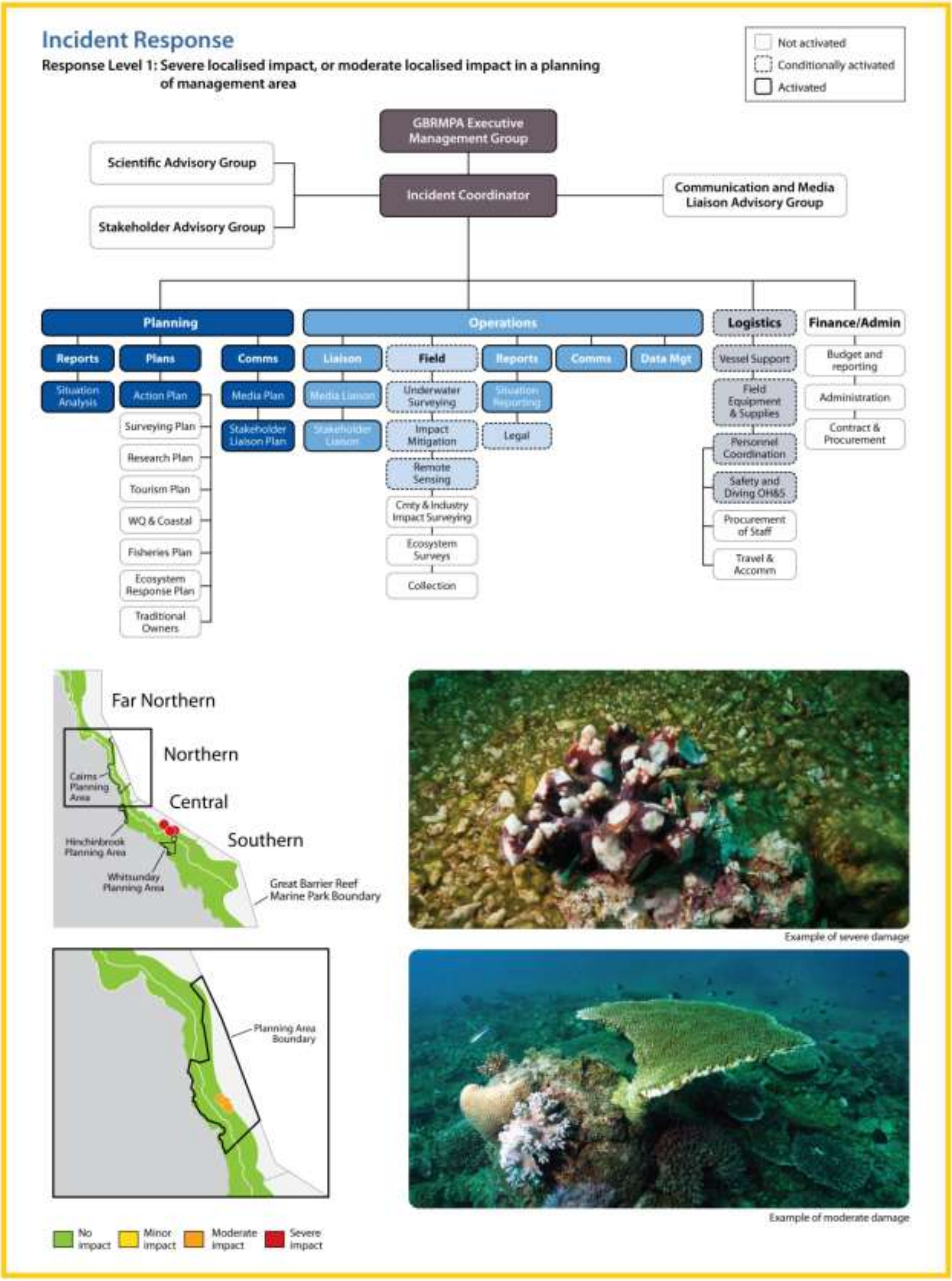


Figure 9. Response level 1 (R1) within the Incident Response. Activation and conditional activation of IR components are illustrated by the intensity of colour and border for each box within the diagram above. Scenarios shown in the maps are examples (i.e., moderate impacts in a different planning area would result in the same management response). For example TC Ingrid (2005) would trigger R1.

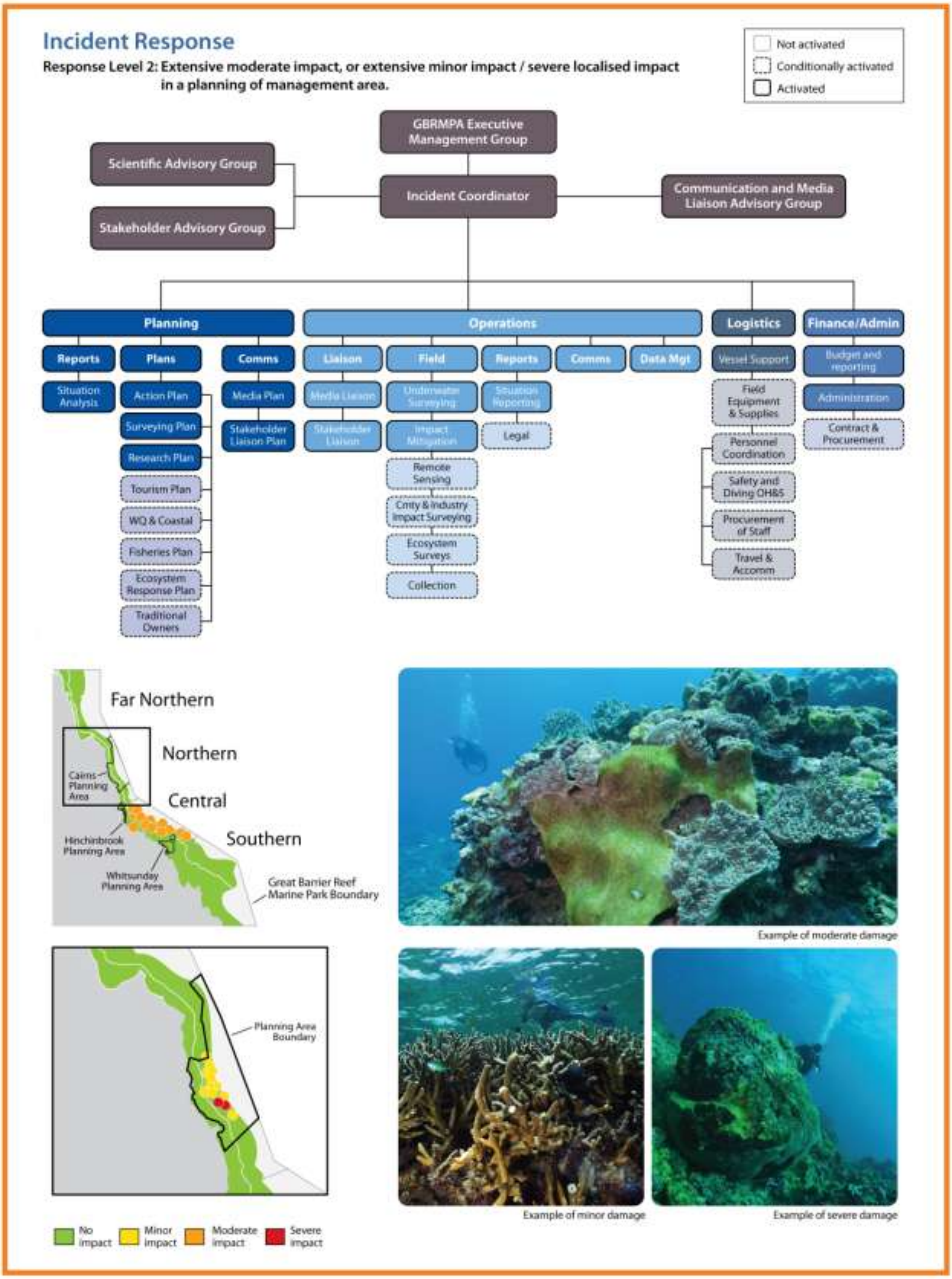


Figure 10. Response level 2 (R2) within the Incident Response. Activation and conditional activation of IR components are illustrated by the intensity of colour and border for each box within the diagram above. Scenarios shown in the maps are examples (i.e., minor, moderate or severe impacts in other regions or other planning areas would result in the same management response). TC Justin in 1997 and TC Larry in 2006 are examples of storms that would trigger R2.

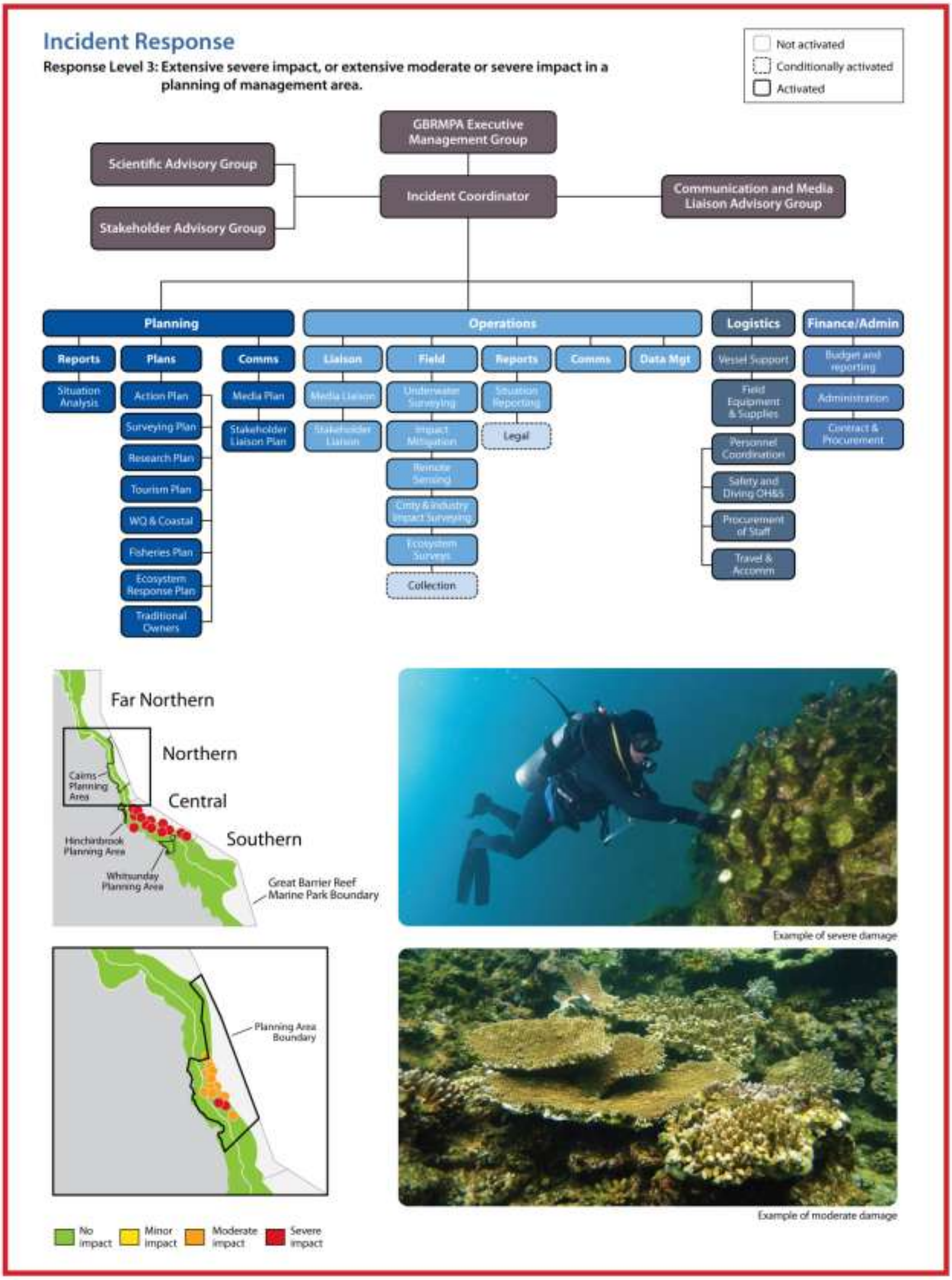
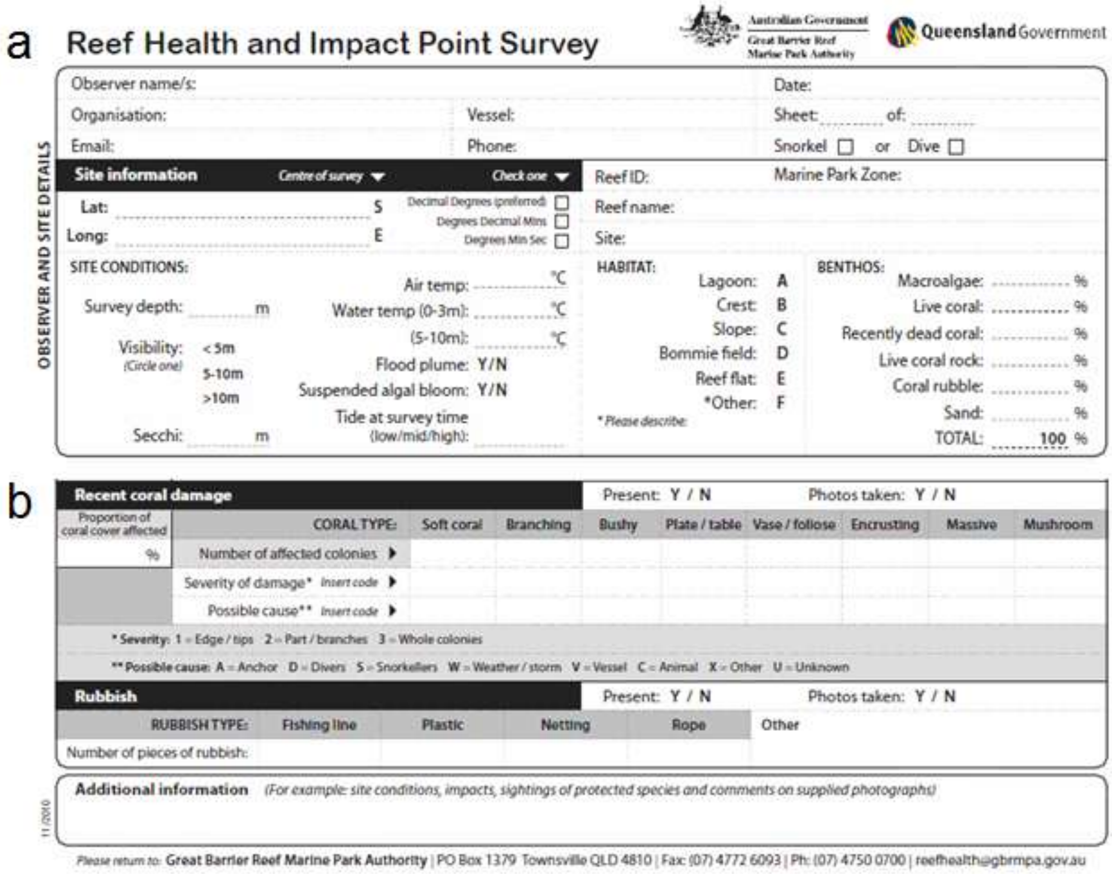


Figure 11. Response level 3 within the Incident Response. Activation and conditional activation of IR components are illustrated by the intensity of colour and border for each box within the diagram above. Scenarios shown below are examples (i.e., severe bleaching in a different region would result in the same management response). TC Hamish in 2009 and TC Yasi in 2011 are examples of storms that would trigger R3.

Assessment and monitoring and reporting on impacts

To accurately document the extent and severity of cyclone impacts and subsequent coral mortality, surveys are undertaken as soon as possible following the cyclone. Conducting surveys at sites that are monitored as part of the Australian Institute of Marine Science (AIMS) Long Term Monitoring Program (LTMP)[7] or sites that have information stored in the integrated Eye on the Reef database negates the need to conduct further baseline surveys. Thus, managers can focus post-cyclone Reef Health and Impact Surveys (RHIS) on documenting the severity of the impacts (Figure 12), and surveys six months to a year after the event can focus on assessing the ecological implications of cyclone impacts.


a 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 ▼ | Reef ID: | Marine Park Zone:
Lat: .... S — Decimal Degrees (preferred) ☐ | Reef name:
Long: .... E — Degrees Decimal Mins ☐ — Degrees Min Sec ☐ | Site:

SITE CONDITIONS:
Survey depth: ...... m
Visibility: (Circle one) < 5m / 5-10m / >10m
Secchi: ...... m
Air temp: ...... °C
Water temp (0-3m): ...... °C
(5-10m): ...... °C
Flood plume: Y/N
Suspended algal bloom: Y/N
Tide at survey time (low/mid/high):

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 %

b

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

Figure 12. Relevant sections of the RHIS survey form used for cyclone impact assessment. Cyclone impact severity is documented using general estimates of coral rubble and recently killed coral (a). More detailed descriptions of cyclone impact are made by counting the total number and types of coral colonies affected and by documenting the severity of damage (b). Damage severity is based upon three impact categories: 1) Damage to edges or tips of coral colonies, 2) Damage to larger parts of colonies or entire branches of coral, and 3) Damage to entire colonies. RHIS data is entered into the integrated Eye on the Reef database and is analysed via a damage matrix to provide detailed information about geographic extent and severity of cyclone damage (Figure 13).

If the situation analysis (Figure 8) determines thresholds for response levels 2 (Figure 10) or 3 (Figure 11) have been reached, managers implement intensive in-water RHIS and video surveys at routine sites (surveyed by long term monitoring programs) and targeted sites (those anticipated to be most affected by the cyclone). This approach is a pragmatic yet defensible way to collect comprehensive data quickly immediately

[7] Sweatman, H.P.A., Cheal, A.J., Coleman, G.J., Emslie, M.J., Johns, K., Jonker, M., Miller, I.R. and Osborne, K. 2008, *Long-term Monitoring of the Great Barrier reef, Status Report,* Australian Institute of Marine Science.

after a cyclone event, while also creating a long-term record. These surveys are conditionally activated for response level 1 (Figure 9) and may be undertaken depending on the outcome of the situation analysis and the location of the cyclone (i.e., inside or outside a Planning of Management Area (see Figure 7)).

Where conditions permit, the windward and leeward aspects of each reef are surveyed to assess the extent, severity and patchiness of cyclone damage. Most assessments are completed on snorkel, and cover on the upper reef slope. Surveys of sites that are part of the AIMS LTMP are **Error! Reference source not found.**done on SCUBA to enable damage to be assessed for both the upper and lower slope, and thus enable comparison with long-term data from these sites. Survey teams complete a minimum of three RHIS for at least three sites around each reef (Figure 12, Appendix B). RHIS impact assessment teams recorded cyclone damage over a series of randomly selected five metre radius circle plots (78.5 m^2) at each site (Appendix C). Surveyors categorise both the extent and severity of the coral damage within each RHIS area. The extent of the damage is recorded as the proportion of coral cover affected within the survey area, whilst severity is evaluated using categories. The damage severity categories describe the most common characteristic of the hard coral colony damage in the RHIS area: Category 1 = colony tips / edges; Category 2 = colony parts / branches; Category 3 = whole colonies (Figure 12, Appendix B).

Recovery surveys also include assessments of bleaching and disease as cyclones may increase the susceptibility of corals to these impacts (see Coral Disease Response Plan, GBRMPA 2010). In this sense, we take the lead on *assessing* impacts and the implications of cyclone events in the first year following the cyclone, 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.

Damage Matrix	Damage Extent						
Damage Severity Description	SCORE	0%	1 - 10%	11 - 30%	31 - 50%	51 - 75%	76 - 100%
None	0	0	0	0	0	0	0
Tips / Edges	1	0	10	30	50	75	100
Branches / Parts	2	0	20	60	100	150	200
Colonies	4	0	40	120	200	300	400

Damage Levels	
0	No Damage
1	Minor Coral Damage
2	Moderate Coral Damage
3	High Coral Damage / Minor Reef Damage
4	Severe Coral Damage / Moderate Reef Damage
5	Extreme Coral Damage / High Reef Damage

Figure 13. Cyclone damage matrix. Coral damage extent and severity scores in light blue represent the survey area that was damaged (Damage Extent) and the predominant type of colony damage observed in the survey area (Damage Severity Description). Damage Levels represent ecological impact groupings and encapsulate both colony and reef damage. For example, Damage Level 3 applies to either Minor Reef Damage (e.g. 11-30% of colonies damaged) or High Coral Damage (31-50% branches or >75% tips). Coral Damage Levels 1 and 2 indicate partial colony mortality. Reef Damage Levels 3, 4 and 5 indicate the increasing extent of complete colony mortality and reef framework damage (Figure 14).

The implications of severe cyclones on reef ecology include but are not limited to coral mortality, shifts in coral community structure, altered habitat composition, and ecosystem flow-on effects. Of particular concern is the physical damage to individual coral colonies and, with severe cyclones, direct physical damage to the reef structural framework (figure 14). Severe cyclones also have implications for industries and users that depend on the Reef as well as for associated human communities because cyclones 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 cyclone events is undertaken in collaboration with industry bodies such as the Association of Marine Park Tourism Operators (AMPTO) and the Queensland Seafood Industry Association (QSIA) and researchers from universities and the Commonwealth Scientific and Industrial Research Organisation (CSIRO).

Damage Level 0 (No damage): Healthy reef.

Damage Level 1 (Minor damage): Some (1-30%) corals partially damaged; primarily broken tips and some branches or plate edges.

Damage Level 2 (Moderate damage): Many (31-75%) corals partially damaged; most fragile colonies have tips or edges broken, some branches missing or as large rubble fragments.

Damage Level 3 (High damage): Up to 30% of colonies removed, some scarring by debris, soft corals torn, coral rubble fragments from fragile and robust coral lifeforms.

Damage Level 4 (Severe damage): Many (31-50%) colonies dead or removed, extensive scarring by debris, rubble fields littered with small live coral fragments, soft corals severely damaged or removed and some large coral colonie

Damage Level 5 (Extreme damage): Most (51-100%) corals broken or removed, soft corals removed and many large coral colonies dislodged.

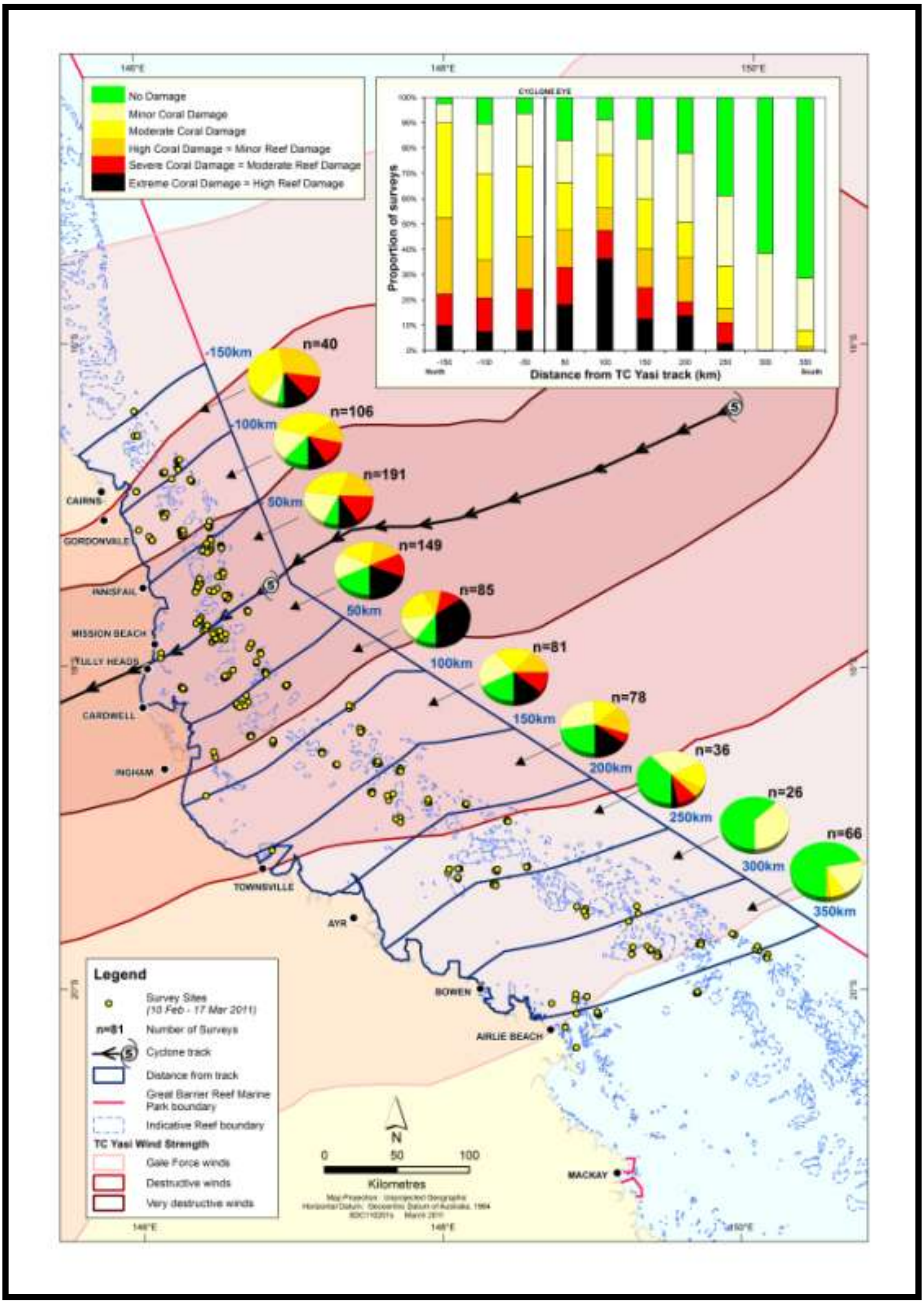
Figure 14: The six damage levels used in the Yasi assessment and analysis. The damage levels were used to evaluate the damage caused by TC Yasi and are comparable to previous studies of cyclone damage on the Reef.

Reporting cyclone impacts

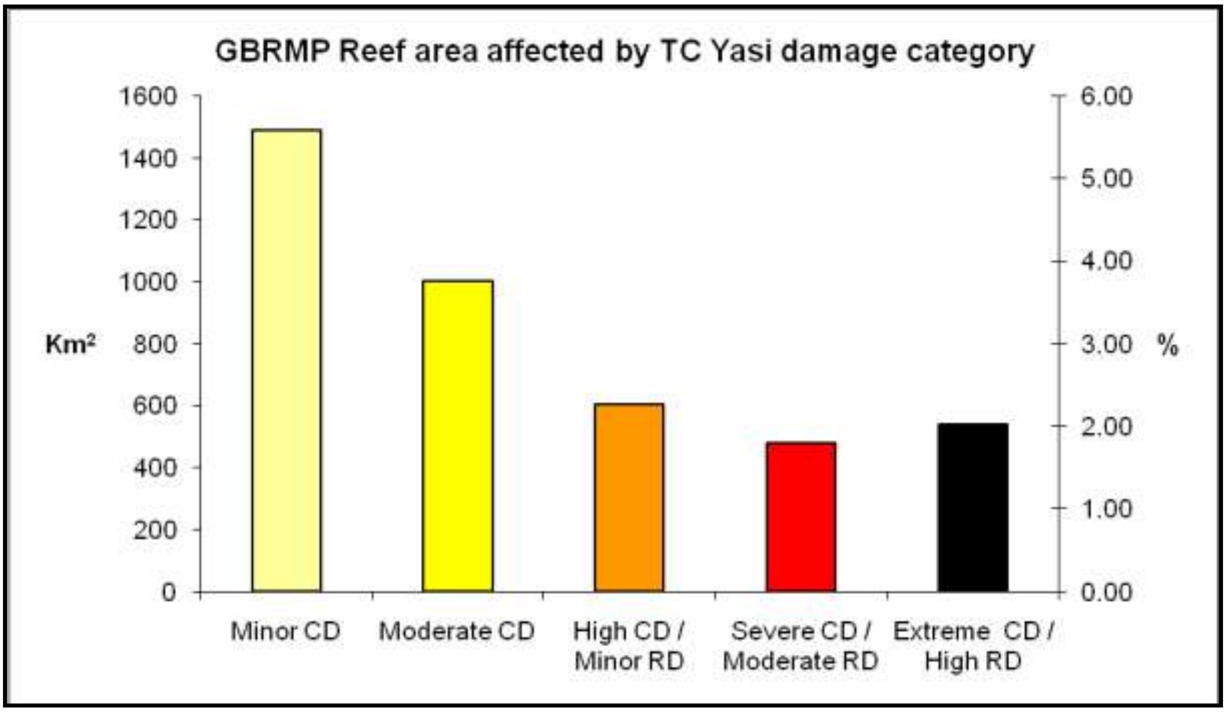
The rapid assessment via the RHIS protocol provides information about the extent and severity of the cyclone event in near real-time, which can be immediately communicated to senior management, government officials and the public. The data collected during post-cyclone rapid assessments must be analysed and presented quickly, while also providing a level of detail and accuracy that enables reporting. Below are four examples of the types of analysis outputs from the impact assessment of Severe Tropical Cyclone Yasi in February 2011.

1. *Intra-reef variability*: Contrasting benthic photographs of one reef area (taken within 100 m of each other) to document the range of impacts provide an easily understood means of displaying the patchiness of cyclone impacts.

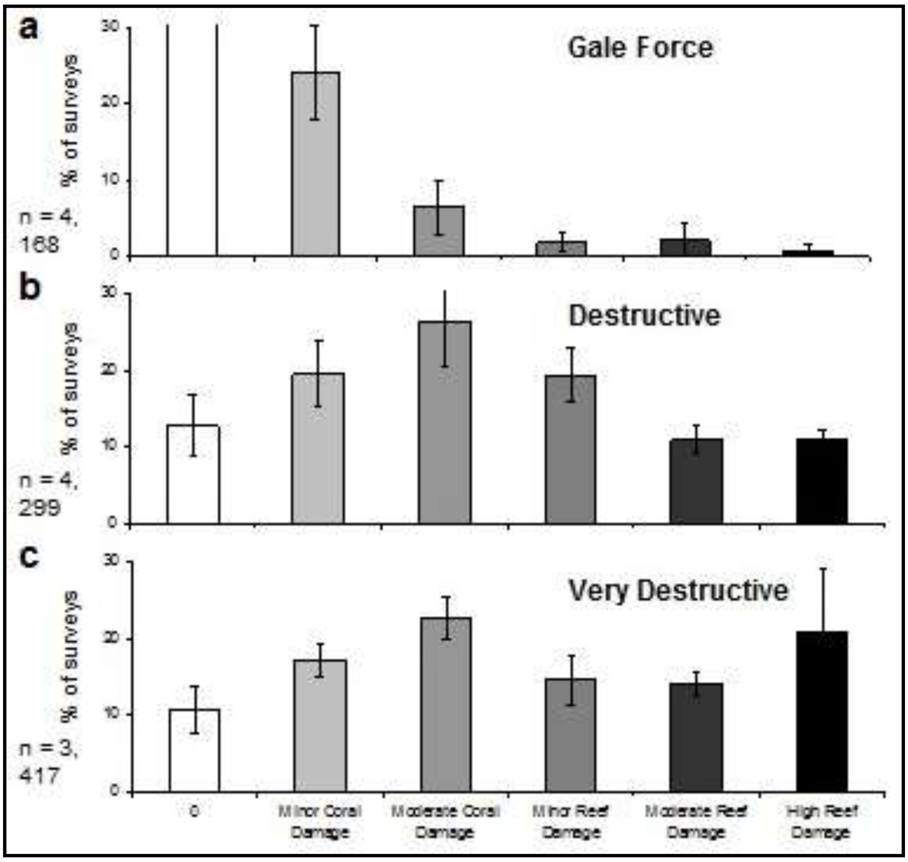
2. *Percentage of surveys in each severity category within each wind zone boundary:* Pie charts display the results of the damage matrix (Figure 13) both by geographic area (as overlayed on a map of Queensland) and wind boundary zone (as shown by very destructive, destructive and gale force winds). The histogram in the top right shows the same data included in the pie charts, but more effectively displays the contrast in impacts by distance from cyclone eye.



3. *Reef area affected by damage matrix category.* This simple histogram displays the matrix damage categories (adapted from Figure 13) by both affected reef area affected and the proportion of reef area in the Marine Park.



4. *Variability between wind zones*. Wind speed is a major determining factor for predicting cyclone impacts on coral reefs. Separating the proportion of RHIS surveys completed by damage matrix category clearly shows the impacts by wind zone.



3. Communication Strategy

Responding to tropical cyclones strategically and effectively involves a combination of routine and responsive tasks implemented via the early warning system and, if a cyclone occurs, assessment and monitoring via the incident response (see Figure 3). Since cyclones attract attention from the public, media and senior decision-makers, all routine and responsive tasks rely on effective communication. The Tropical Cyclone Risk and Impact Assessment Plan ensures that timely and reliable information on cyclone risks in the Great Barrier Reef Marine Park is available throughout the season.

Table 3. The frequency and timing of tasks associated with collating and effectively communicating current cyclone and bleaching risk and impact information each summer. Tasks that appear in italics are common to both the Cyclone and Bleaching Risk and Impact Assessment Plans.

Frequency	Timing/Trigger	Task
Weekly	Monday	• *Check BoM cyclone advice and NOAA cyclone monitoring sites* • *Monitor tropical lows that can potentially turn into cyclones* • Review weekly weather summary from the Bureau of Meteorology • *Prepare briefing for internal meetings*
Weekly/ fortnightly	Constant	• Monitor and review synoptic cyclone situation, and compile against recent cyclones • *Advise GBRMPA senior management and the Minister if worsening of conditions* • *Announce web update and send brief report to senior management*
Event-based	High cyclone risk*	• Start preparing maps of potential impacts using tools from BoM and NOAA (COMET), prepare Incident Response • *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*

* 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 cyclone risk and impacts during the high risk summer season (November to April). Asterisks denote triggers that will result in the development of a media position and the release of a media statement (see also Table 3).

Approx. date	Trigger[1]	Briefings			
		Senior Management	Minister	Stakeholders	Message
1Nov	Annually	^	^	^	Cyclone season approaching; Risk and Impact Assessment Plan implemented
20 Dec	Annually	^			Seasonal outlook and summary of cyclone advice from BoM; plans for Christmas break
	Cyclone warnings	^	^		Category 4 cyclone developed in the Coral Sea, small storm heading for far north Queensland
	*Response level 1 (see Figure 8)**	^	^	^	Cyclone predicted to cross the Great Barrier Reef near Cairns; predicted widespread damage to reefs in both planning and non-planning areas.
	*Response levels 2 and 3 (see Figures 9 and 10)**	^	^	^	Surveys observe extensive impacts across a 200 km wide belt, with severe structural damage to planning areas.
15 Feb[3]	Annually	^			Cyclone summary for first half of summer; outlook for remaining part of the season
31 March		^	^	^	Cyclone period concluded
30 May		^	^	^	Summary of full extent and severity of cyclone impacts; implications for affected regions and the Great Barrier Reef

Importance of management actions

The severity of tropical cyclones is expected to increase a result of climate change, making recovery processes increasingly important if reefs are 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. For example, 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. Through reducing compounding stressors, management actions help reefs to cope with or recover from coral bleaching events, which works to build the resilience of reefs to future climate-related disturbances.

By working in collaboration with researchers, we are also rapidly advancing our understanding of factors that increase the resilience of reefs, as measured by the capacity to resist, tolerate, 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 us to explicitly incorporate 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.

In addition to measures to build ecosystem resilience, the Plan can help build social and economic resilience to coral bleaching events. Resource users who are well-informed of risks and are included in decision-making processes about strategies to address resource issues can be expected to be much more resilient to resource impacts (Marshall and Marshall 2007). Similarly, community-based social marketing can encourage stewardship behaviours, (e.g. not anchoring on corals or disposing of rubbish on the Reef). Such communications efforts may be undertaken following reef health incidents like cyclones in the future.

Conclusion

As severe cyclones become more frequent, impacts on the reef ecosystem and on reef users will become increasingly acute and apparent. This Risk and Impact Assessment Plan outlines the strategic approach that we employ to assess the risk posed by cyclones and to assess impacts. The three-component structure described here is based on a model proven successful in responding to bleaching events on the Great Barrier Reef and has been adopted by reef managers in Florida and Hawaii.

Cyclones are inherently linked to coral bleaching and disease - they occur during the hotter summer season when the risk of bleaching is greatest, and corals on cyclone-damaged reefs are likely to be more susceptible to bleaching and disease. This Plan and the Coral Disease and Coral Bleaching Risk and Impact Assessment Plans are united under the overarching Reef Health Incident Response System, which enables managers to evaluate and effectively respond to simultaneous and cumulative impacts. The capacity to predict and respond to simultaneous and cumulative impacts will be further developed in the coming years as the capacity to monitor conditions that cause reef health incidents increases. As with the other Risk and Impact Assessment Plans and the overarching Reef Health Incident Response System, this Plan helps lay the foundations for an informed and adaptive approach to building the resilience of the Great Barrier Reef under a changing climate.

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Appendix A- Schedule of Cyclone Risk and Impact Assessment 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 Reef health incident risks (cyclones, flooding, coral bleaching, disease) for the approaching summer • Preparations for coordinated response to high risk incidents.	
Oct 2010 – May 2011	Communications processes initiated (see Table 3)	Communications updated regularly on Reef health status	
Nov 2010	IR planning meeting	Preparations for activation of the Incident Response Framework	
Nov 2010	Eye on the Reef training – Cairns, Port Douglas and Airlie Beach	Training of volunteer network in Reef health impact 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 RHIS 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 Reef Health Incident(s)	Meeting convened to refine coordinated response if there is a high risk of one or more reef health incidents	
Dec 2010	Brief Senior Management, Minister and Stakeholders	Senior management, Minister and stakeholders aware of approaching risk season	
Dec 2010	Revise Risk and Impact Assessment Plans; Coral Bleaching, Coral Disease, Cyclones.	Risk and Impact Assessment Plans revised and published	
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 reef health incident 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 Reef health incident risk is moderate-high	
Dec 2010 - Apr 2011	Assess incident risk weekly	• Check AIMS, CSIRO (*ReefTemp*), BoM and NOAA risk tools • Review weekly weather summary reports • Review reports from the monitoring network • Prepare briefings for internal meetings, round table • Advise Senior Management of any changes to risk assessment	
Feb 2011	Assess temperature, rainfall and cyclone patterns and monitoring network reports for first half of summer	• Senior Management update • Contact volunteer monitoring network participants	

Event reported – Incident Response(IR) initiation			
Reef Health Incident reported	Situation analysis conducted	IR situation analysis	
Reef Health Incident 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 across relevant agencies	
IR active	Incident Response plan developed	• IR plans identify roles and responsibilities for response • IR plans 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 • End of season summary emailed to participants of the monitoring network	
Post event ongoing	Impact recovery monitoring	Monitoring of recovery from severe reef health impacts	

Appendix B –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: Time:
Organisation:	Vessel:	Sheet: ____ of: ____
Email:	Phone:	Snorkel ☐ or Dive ☐

Site information — Centre of survey / Check one

Lat: ______________ S — Decimal Degrees (preferred) ☐
Long: ______________ E — Degrees Decimal Mins ☐ — Degrees Min Sec ☐

Reef ID: — Marine Park Zone:
Reef name:
Site:

SITE CONDITIONS:

Survey depth: ______ m
Visibility: (Circle one) < 5m / 5-10m / >10m
Secchi: ______ m
Air temp: ______ °C
Water temp (0-3m): ______ °C
(5-10m): ______ °C
Flood plume: Y / N
Suspended algal bloom: Y / N
Tide at survey time (low/mid/high): ______

ASPECT: (Select one option) NW NE SW SE ▶ ☐

HABITAT: (Select one option) Lagoon [A] Reef flat [B] Crest [C] Slope [D] ▶ ☐

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	Mushroom	Massive	Total
Proportion of coral cover (live and recently dead) ▶	%	%	%	%	%	%	%	%	100 %
Proportion of the above that is recently dead ▶	%	%	%	%	%	%	%	%	

IMPACTS

Coral bleaching — Present: Y / N — Likely cause: Temp. ☐ Salinity ☐ Both ☐ Unknown ☐ — Photos taken: Y / N

CORAL TYPE:	Soft coral	Branching	Bushy	Plate / table	Vase / foliose	Encrusting	Mushroom	Massive
Proportion of the corals that are bleached ▶	%	%	%	%	%	%	%	%
Most common level of bleaching severity* ▶								

* 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

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

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

Coral predation — Present: Y / N — Algae: 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	Mushroom	Massive
				Number of affected colonies							
%	◀ COTS ▶										
%	◀ *Drupella* ▶										

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

Proportion of coral cover affected	CORAL TYPE:	Soft coral	Branching	Bushy	Plate / table	Vase / foliose	Encrusting	Mushroom	Massive
%	Number of affected colonies ▶								
	Most common level of severity* *Insert code* ▶								
	Possible cause** *Insert code (one only)* ▶								

* Severity: 1 = Edge / tips 2 = Part / branches 3 = Whole colonies 4 = Reef structure

** 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)*

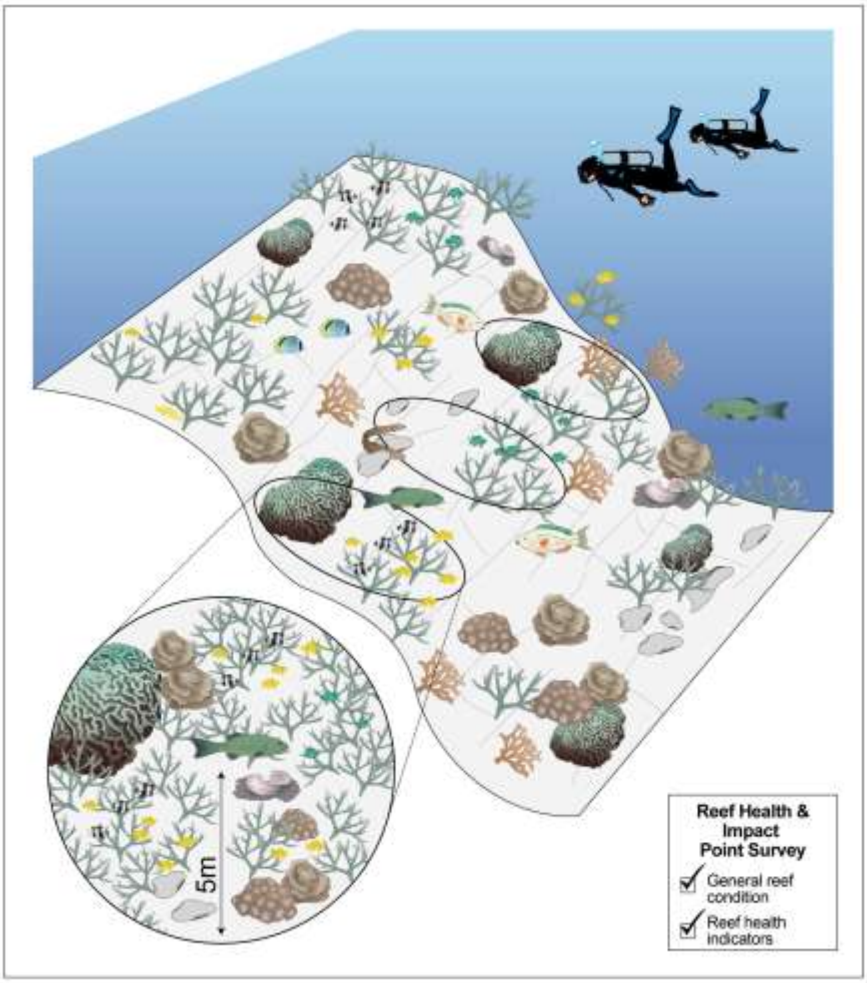
08/2011

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

25 cm 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0

Appendix C – Survey protocol used in monitoring network

The protocol used by the monitoring network during site inspections can be completed by snorkelers or divers. It involves using a repeated Global Positioning System (GPS) tagged five metre radius point survey method (see image below). 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, rubbish, predation and anchor or storm damage (Appendix B). The protocol recognises the limited time that many participants have available to complete 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 form. 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.



Protocol used by the monitoring network for site inspections. Observers use this protocol to assess reef condition and to detect and document impacts.