# Case Study for Great Barrier Reef Cumulative Impact Guidance: Whitsundays Plan of Management

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**Project E1 – Guidelines for analysis of cumulative impacts and risks to the Great Barrier Reef**

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*Milestone 11 (RPV6 2020)*

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Staff from the Great Barrier Reef Marine Park Authority provided significant assistance advising on the scope, providing data and advising on zoning implementation.

## Important Disclaimer

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# 1. EXECUTIVE SUMMARY

- A case study was developed for the Whitsundays Plan of Management as an example of a cumulative impact assessment for coral reef ecosystems in the GBR. The area of assessment included reefs surrounding Hayman, Arkhurst, Langford, Black, Bird and Hook Isles.

- Assessed pressures impacting coral reefs included coral bleaching, cyclonic storms and COTS outbreaks. Pressures emanating from different levels of recreational use of the reef were assessed with respect to impacts from boat anchor damage, recreational fishing and fin damage from snorkelling and scuba diving.

- An ecosystem model was developed to represent general ecological dynamics and the direct effects of pressures on coral reef ecosystems. The model was validated against observed responses of reef biota within the area of assessment following Severe Tropical Cyclone Debbie in 2017.

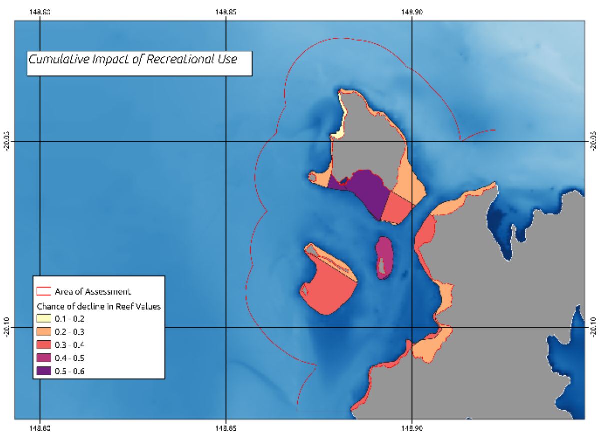
- Model predictions were used to assess the cumulative impacts on values associated with coral reef ecosystem through a set of perturbation scenarios for recreational use only and another set that included climate change and COTS outbreaks.

- Cumulative impacts from recreational use alone were found to range from relatively low levels of likelihood, where use and activity levels are most restricted, to relatively high levels where use and activities levels were at their greatest, with a majority of reefs having a low to moderate level of likelihood for a decrease in reef values.

- The inclusion of climate change and COTS outbreaks dramatically increased the likelihood that reef values could be diminished throughout a majority of the area of assessment.

- Estimate of impacts could be improved through monitoring, better quantification of dose response relationships and formal expert elicitation.

Recreational use only




Recreational use, climate change and COTS

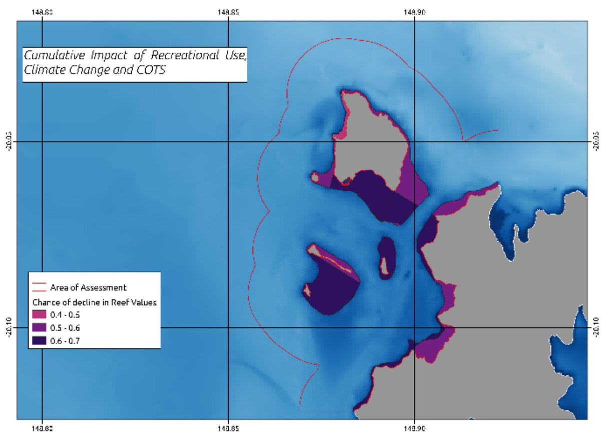



Figure 1: Cumulative impact of recreational use of the reef, climate change and COTS outbreak

# 2. INTRODUCTION

The Great Barrier Reef (GBR) is an ecosystem under significant threat from a number of pressures including climate change and anthropogenic use[1]. The reef had experienced widespread stress in the last decades[2], and pressures continue to reduce the resilience of the reef. Climate change remains the most significant pressure on the GBR. Other pressures such as pollutant loads from coastal runoff, coastal development and direct use all contribute to the declining status of the GBR system.

However, the way these pressures cumulatively contribute to the decline is difficult to establish. When pressures overlap in space and time, they can combine together to cumulatively impact natural values significantly more than any one pressure singly. Cumulative impacts can result from a single activity repeatedly producing a single pressure, a single activity producing multiple pressures, multiple activities producing a single pressure, or multiple activities producing multiple pressures. Cumulative impacts from a wide range of causes have been identified for many of the values in the GBR region, including corals, seabirds and dolphins. The Outlook Report identifies many examples of where cumulative impacts from pressures are expected but poorly understood, such as coastal development, pollutants, fisheries, cyclones and climate change.

The GBR Cumulative Impact Management Policy[3] (CIMP) was developed under the Reef 2050 plan and identifying pathways for implementation of the policy is an action under the Reefs 2050 Long Term Sustainability Plan[4]. A stated goal of the plan is to "Provide a clear and target-driven framework to support planning and assessment of development proposals through the Cumulative Impact and Net Benefit policies to ensure cumulative impacts are managed below threshold levels and ensure protection and transmission of the Reef's Outstanding Universal Values". Identifying pathways for implementation of this policy remains a priority, and this case study aims to provide a practical application of cumulative impact assessment within a management context. This case study implements the steps described in the National Environmental Science Program (NESP) Marine Biodiversity Hub report "Technical Report describing Guidelines for analysis of cumulative impacts and risks to the Great Barrier Reef (Part 1)" for an area of assessment within the Whitsundays Plan of Management area. The case study describes the data and analysis for each of the steps within the Guidelines (1) Understanding Pressures, (2) Understanding Values, (3) Conceptual Models of Key Habitats, (4) Zone of Influence, and (5) Risk and Uncertainty.

## 2.1 Area of Assessment

Assessment of the cumulative impacts within the Whitsundays Plan of Management area is a priority for the Great Barrier Reef Marine Park Authority (GBRMPA). Plans of Management (POM) are based on understanding how the impacts of tourism can interact with the other activities and pressures that occur within the plan of management area. This understanding allows GBRMPA to ensure that the current levels of activities are sustainable and will

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[1] Great Barrier Reef Marine Park Authority 2019, Great Barrier Reef Outlook Report 2019, GBRMPA, Townsville.

[2] Great Barrier Reef Marine Park Authority. Great Barrier Reef outlook report 2009

[3] Great Barrier Reef Marine Park Authority 2018, Cumulative impact management policy, GBRMPA, Townsville.

[4] Reef 2050 Long-Term Sustainability Plan—July 2018, Commonwealth of Australia 2018.

improve the current outlook for the reef and high priority areas within the Reef. Four adjoining areas within the Whitsundays POM area were chosen, in consultation with staff from GBRMPA to provide a case study on how the CIMP could be implemented, focusing on an area of assessment encompassing Blue Pearl Bay near Hayman Island and Stonehaven Bay near Hook Island (Figure 1). The POM setting areas covered in this assessment include reefs adjoining Hayman Island and Hayman Island Resort, and Arkhurst, Langford, Black, Bird and NW Hook Isles (Figure 2). Excluding land area of islands, there is a total of 4,686 ha in the area of assessment of which 761 ha is designated as coral reef.

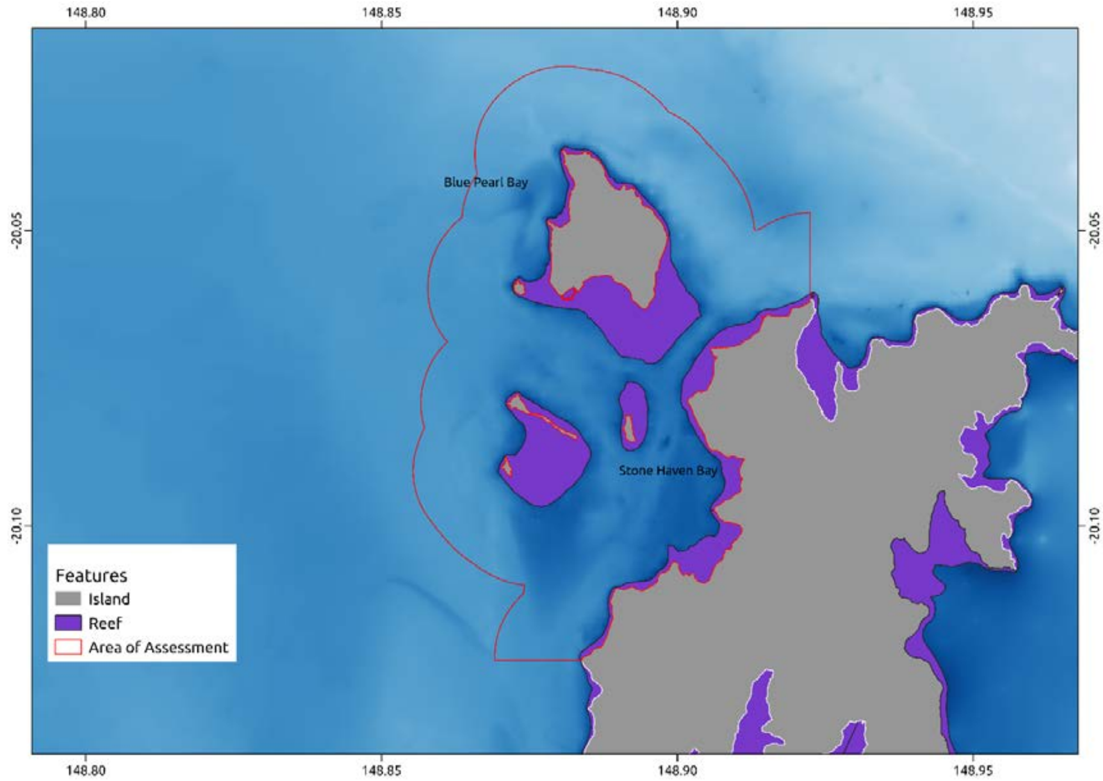



Figure 2: Area of assessment with general habitat features; the total area is 4,686 ha in which 761 ha is designated as coral reef.

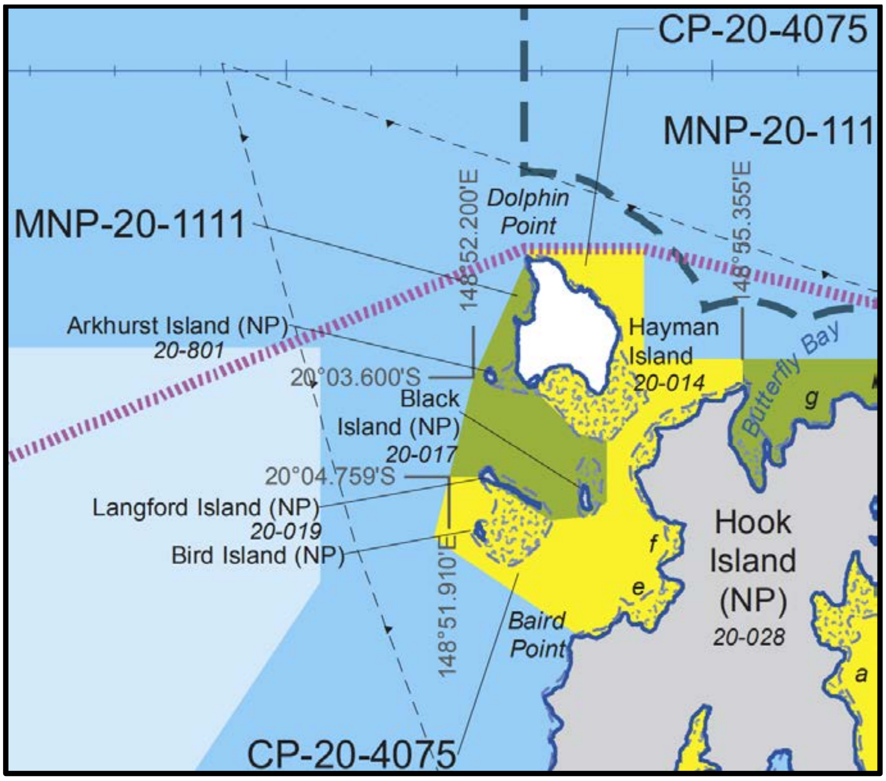



Figure 3: Marine Park zones for area of assessment (Figure 1); blue zones denote Habitat Protection, yellow zones Conservation Park and green zones Marine National Park. Adapted from Whitsunday, Great Barrier Reef Marine Parks Zoning Map10 - Whitsunday

# 3. UNDERSTANDING PRESSURES

The area of assessment is periodically subjected to a number of pressures that negatively impact ecological values, including the effects from climate change, outbreaks of crown-of-thorn starfish (COTS), but also effects associated with tourism and sport fishing activities across the entire area of assessment.

The Whitsundays region is prone to a high frequency of cyclones, with wind velocities that generate destructive wave energy (Figure 3). On 28 March 2017 Severe Tropical Cyclone Debbie passed directly over the area of assessment as a Category Four cyclone that generated very destructive winds (Figure 4).

The threat of coral bleaching from high sea surface temperatures is relatively high in the area of assessment, with moderate to high temperatures and a large magnitude of impact to corals occurring in past Reef-wide bleaching events (Figure 5). Reports from reef monitoring programs indicate significant levels of bleaching were observed in the area of assessment in recent years (i.e., AIMS & GBRMPA monitoring of Hayman Island and Langford and Bird Isles).

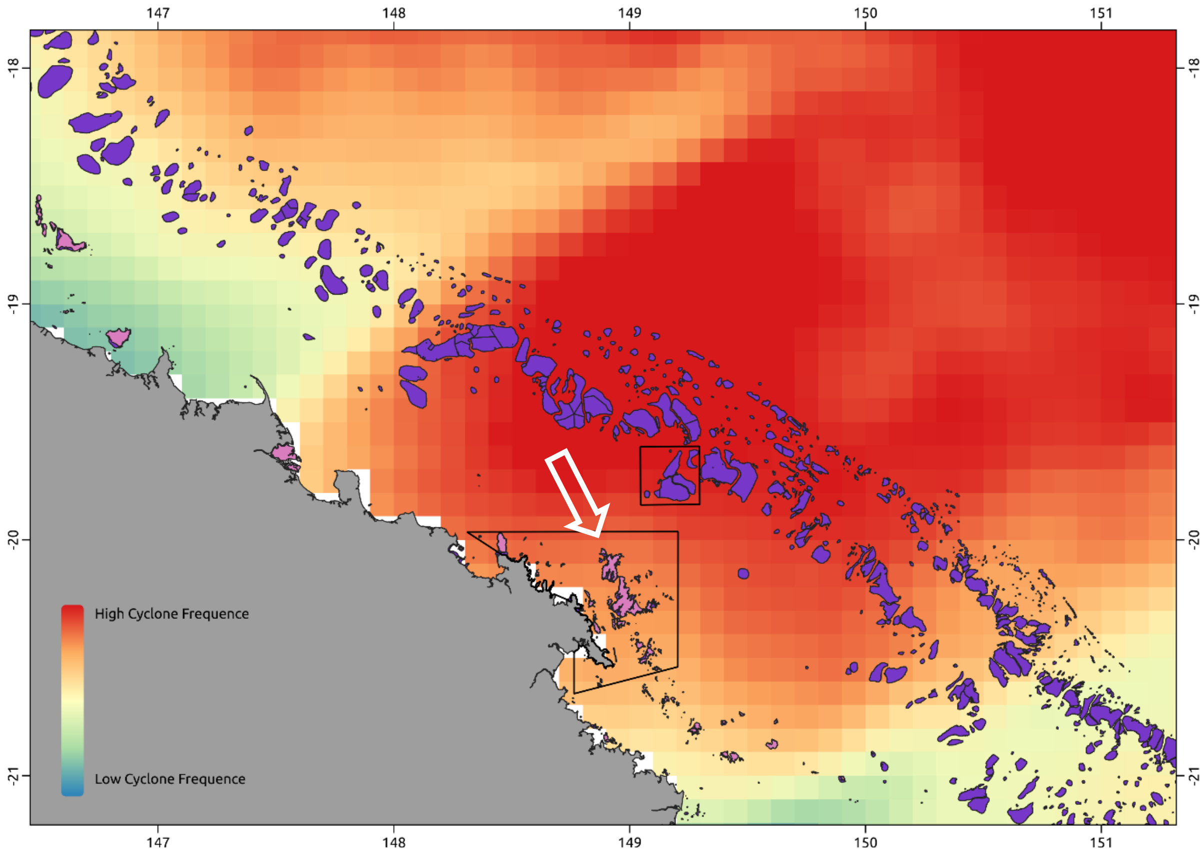



Figure 4: The relative frequency of cyclones that generate damaging wave energy in the Whitsundays Plan of Management Area; white arrow indicates location of area of assessment.

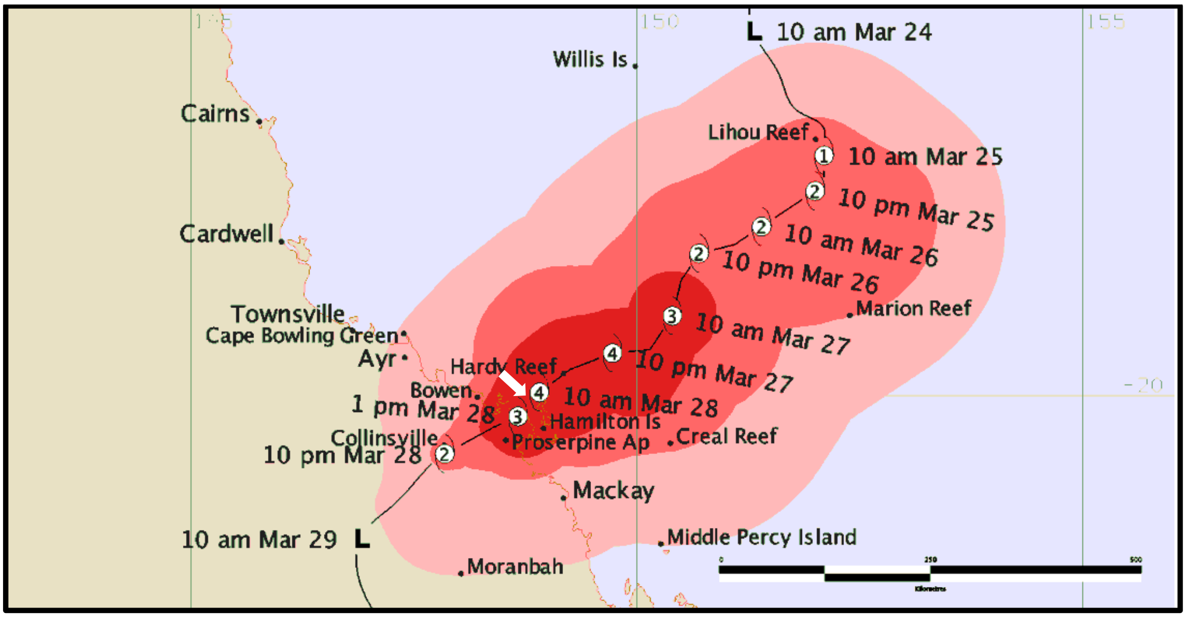



Figure 5: Post event track of Severe Tropical Cyclone Debbie showing areas affected by very destructive (red), destructive (dark pink) and damaging (light pink) winds. Numbers in white circles denote category of cyclone intensity, white arrow indicates area of an assessment location where Debbie passed over at a Category Four level on 28 March 2017; adapted from BOM (2017).

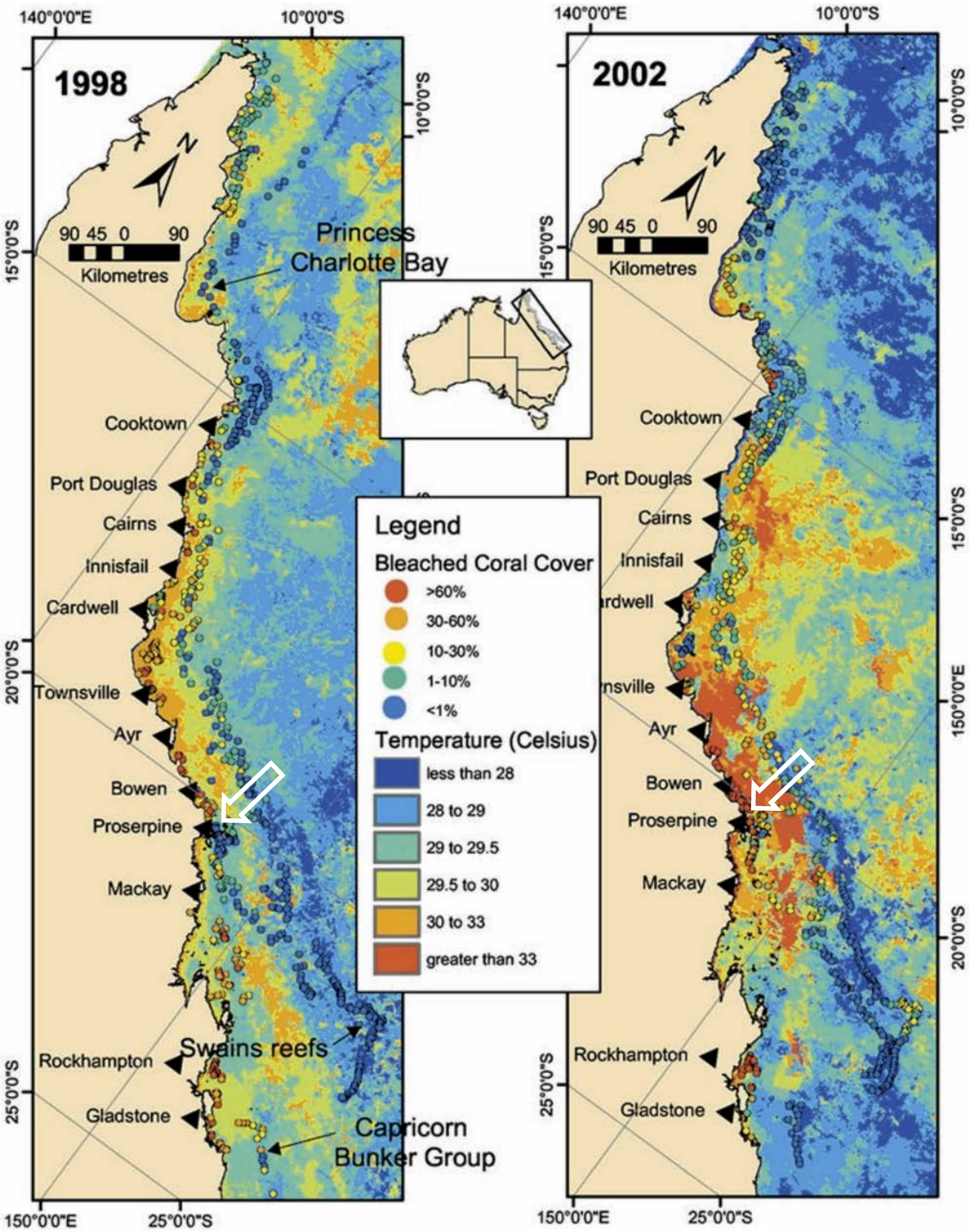



Figure 6: Prevalence and relative intensity of coral bleaching in the Great Barrier Reef in 1998 and 2002 overlaid on maximum summer sea surface temperature. White arrow indicates location of area of assessment; adapted from Berkelmans et al. (2004) [5]

The threat from outbreaks of COTS is of concern in the area of assessment. In general, at this latitude of the GBR there has previously been only a low to moderate probability of a COTS outbreak (Figure 6d), however, COTS appear to have an increasing variability in population abundance at this latitude since 2008 (Figure 6b). While the most recent surveys indicate COTS populations have been relatively low in the area of assessment, there was an incipient outbreak recorded in 2013 that was concurrent with a GBR-wide spike in abundance (Figure 6c). This incipient outbreak appeared to have left observable damage to coral cover in reefs of Langford and Bird Isles.

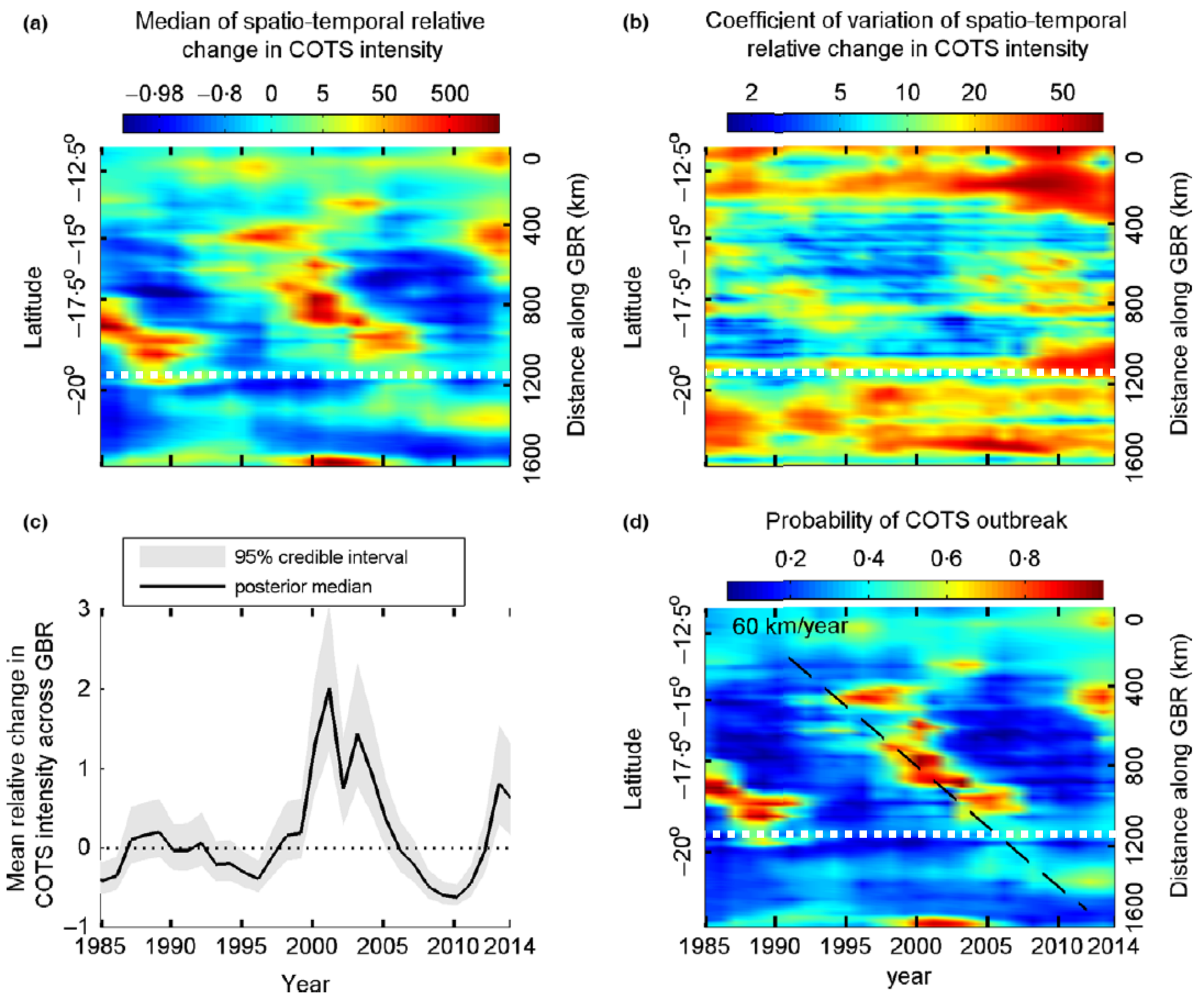



Figure 7: Relative intensity and spatio-temporal variation of COTS across the GBR, based on AIMS 1985-2014 monitoring. The latitude of the area of assessment is referenced by white-dotted line; adapted from Vanhatalo et al. 2017[6].

[5] Berkelmans, R., De'ath, G., Kininmonth, S. and Skirving, W.J., 2004. A comparison of the 1998 and 2002 coral bleaching events on the Great Barrier Reef: spatial correlation, patterns, and predictions. *Coral reefs*, *23*(1), pp.74-83.

[6] Vanhatalo, J., Hosack, G.R. and Sweatman, H., 2017. Spatiotemporal modelling of crown-of-thorns starfish outbreaks on the Great Barrier Reef to inform control strategies. *Journal of Applied Ecology*, *54*(1), pp.188-197.

## 3.1 Marine Park Zones and Levels of Use

The Whitsundays Plan of Management regulates the intensity of human use and activities to minimize impacts to both natural and cultural values, and to avoid conflicts between existing users of the Reef. Five categories are defined that include protected, low, moderate, high and intensive levels of use (Table 1). The area of assessment includes four of these categories, with the absence of protected areas (Figure 7). Additionally, the POM controls specific activities through such means as no-anchor areas, public moorings, designated anchor areas, water sports zones and aircraft landing areas (Figure 8).

Table 1: Levels of use permitted in different setting areas of the Great Barrier Reef Marine Park; adapted from Whitsundays POM

| Setting | Description | Maximum group size (including crew) | Overall length of vessel (metres) |
|---|---|---|---|
| Setting 1 (Intensive) | Areas in this setting are immediately adjacent to urban areas and resorts. They are the access points to the Planning Area and a focus for intensive tourism and recreation. The areas are heavily used by a wide range of craft, and contain permanent facilities (for example, marinas, jetties and boat ramps). | No limit | Less than 70 |
| Setting 2 (High use) | This is a natural setting that may have high levels of visitation. The areas in this setting are easily accessed, and appropriate facilities (for example, pontoons, moorings, markers) may be required to manage impacts and assist in visitor appreciation of the area. The areas are regularly visited by larger vessels and aircraft. | No limit | 35 or less |
| Setting 3 (Moderate use) | This is a natural setting that may have moderate levels of visitation, with appropriate moorings and management facilities to manage impacts. The areas in this setting are occasionally visited by larger vessels and aircraft. | 40 people | 35 or less |
| Setting 4 (Low use) | This is a natural setting that has low levels of visitation. The areas in this setting are generally free from facilities, larger vessels and aircraft. | 15 people | 35 or less |
| Setting 5 (Protected) | This is a protected natural setting that has areas of outstanding or unique conservation value and areas of special management concern. Operations conducted in these areas are limited and managed according to individual site plans. | 15 people | 20 or less |

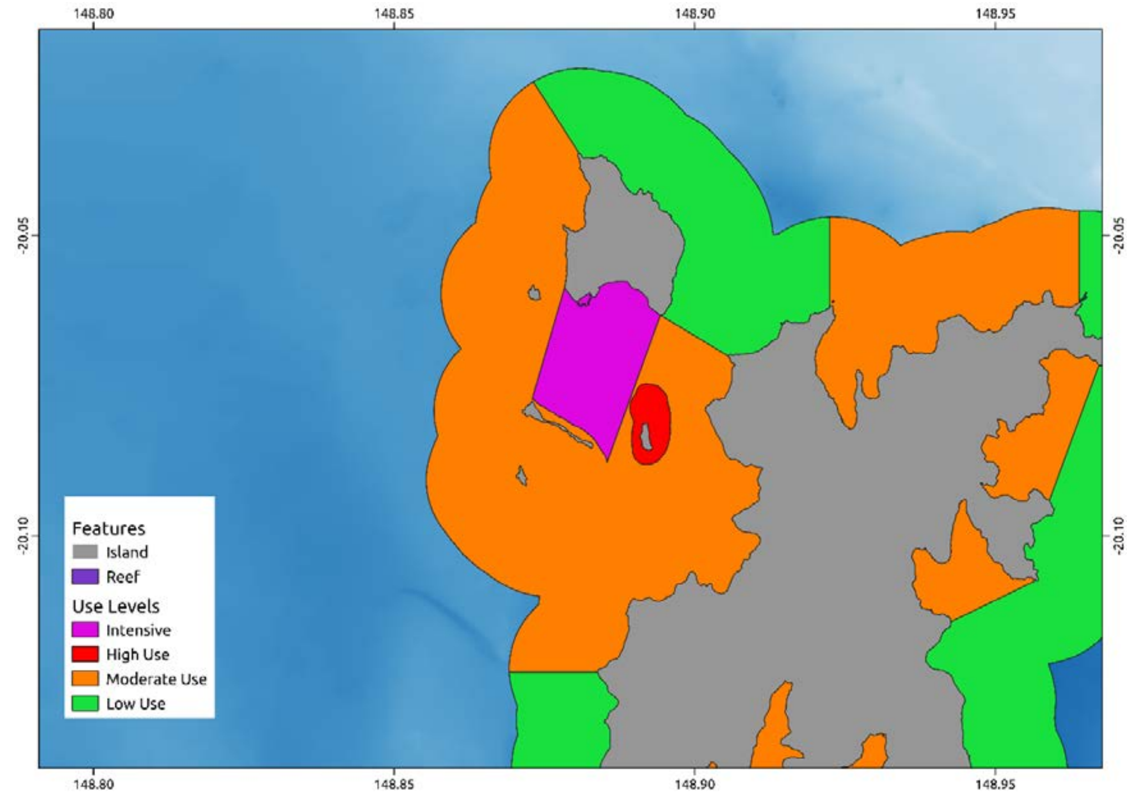



Figure 8: Use level settings for the area of assessment

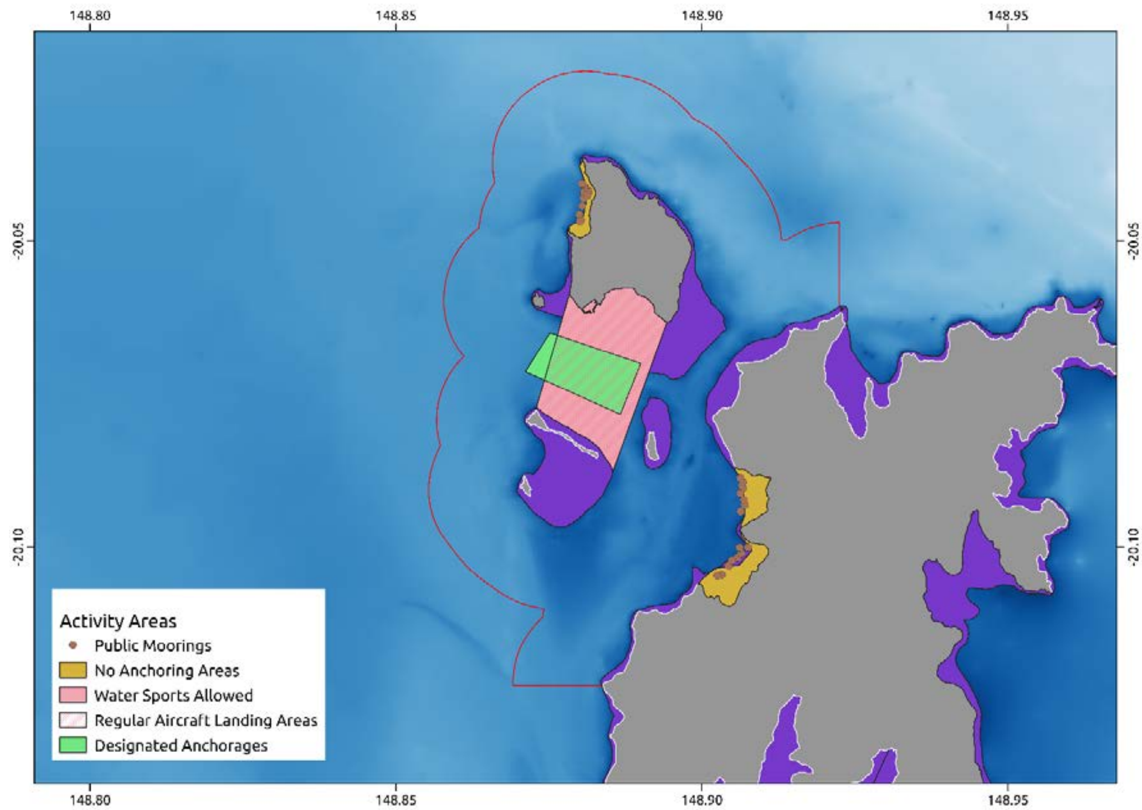


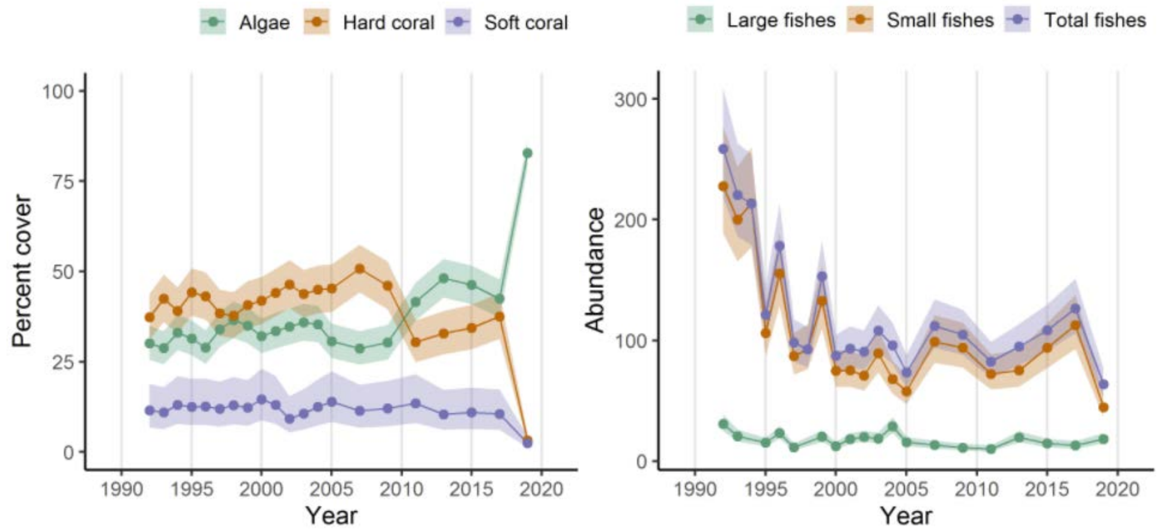

Figure 9: Locations of public moorings and areas identified for specific activities within the area of assessment.

# 4. UNDERSTANDING VALUES

The key values identified in this assessment are coral reefs and associated tourism. The distribution of coral reefs in Figure 1 is based on the known distribution of coral within the Plan of Management area. The distribution of tourism is not known at fine scale, but for the purposes of this report will simply be associated with the distribution of coral reef ecosystems. Natural values recognized by the GBRMPA for coral reef ecosystems include corals and associated reef fishes and invertebrates. These same values are important to various human use activities in the area of assessment including recreational fishing, snorkelling and scuba diving.

The status and trend of natural values for coral reefs of Hayman Island and Langford and Bird Isles are monitored by the AIMS Long-term Monitoring Program and the GBRMPA Marine Monitoring Program (Figure 9). Hard coral cover has varied between 10%-30% over the last 10 yrs at Hayman Island, and between 5%-20% at Langford and Bird Isles. The abundance of fishes was more variable over this time period, but both corals and fishes show a sharp drop in abundance in the most recent survey of 2019.

a. Hayman Island reefs




b. Langford and Bird Isles reefs

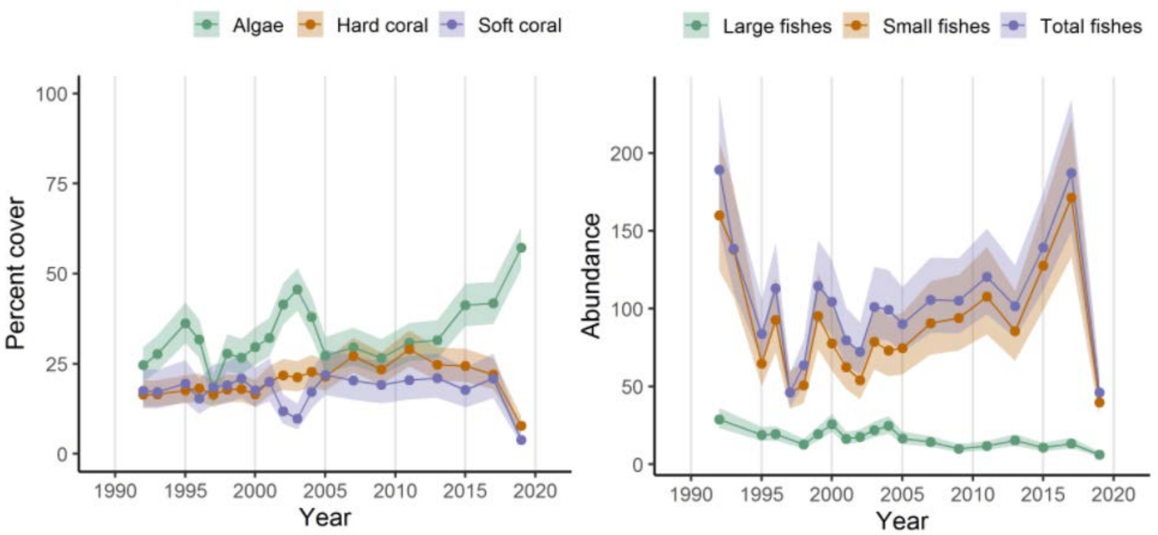



Figure 10: Benthic cover and fish abundance from fixed site surveys of coral reef ecosystems of a) Hayman Island and b) Langford and Bird Isles reefs; adapted from AIMS Long-term Monitoring Program and GBRMPA Marine Monitoring Program.

# 5. CONCEPTUAL MODELS OF KEY HABITATS

## 5.1 Qualitative Mathematical Model

A qualitative mathematical model of coral reef ecosystems (Figure 10) was adapted from Anthony et al. (2013)[7]. The model includes variables representing the dynamics between three functional groups of hard corals (laminar and foliose corals, acropora corals and massive corals), macro algae, herbivorous fishes and other reef fishes and invertebrates. Mediating effects from herbivorous fishes are propagated through turf algae and crustose coralline algae to determine the success of coral recruitment.

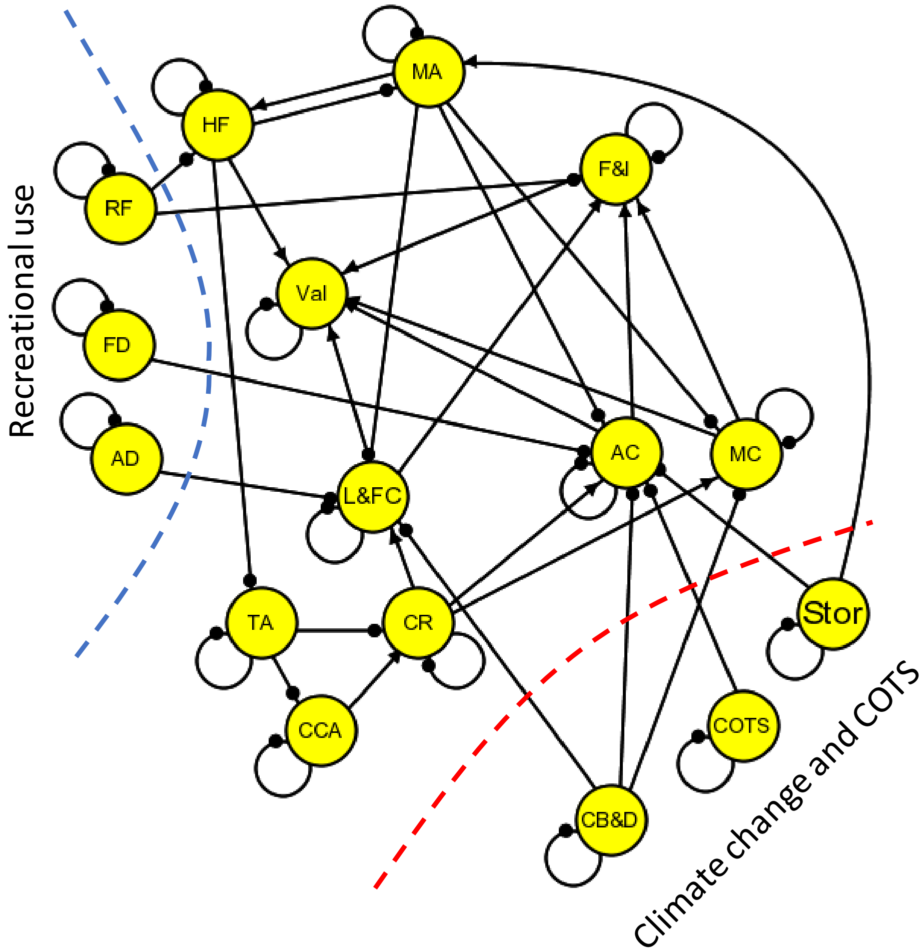



Figure 11: Signed digraph model of coral reef ecosystem, including sources of perturbations from recreational use, climate change and COTS; model variables are AC: acropora corals, AD: anchor damage, CB&D: coral bleaching and disease, CCA: crustose coralline algae, COTS: crown-of-thorns starfish, CR: coral recruitment, FD: fin damage, F&I: fish and invertebrates, HF: herbivorous fishes, L&FC: laminar and foliose corals, MA: macroalgae, MC: massive corals, RF: recreational fishing, Stor: storms, TA: turf algae, Val: values. Graph links

[7] Anthony, K.R., Dambacher, J.M., Walshe, T. and Beeden, R., 2013. A framework for understanding cumulative impacts, supporting environmental decisions and informing resilience-based management of the Great Barrier Reef World Heritage Area: Final Report to the Great Barrier Reef Marine Park Authority and Department of the Environment.

ending in an arrow indicate a positive direct effect and links ending in a filled circle indicate a negative direct effect.

Direct effects from exogenous pressures include recreational use, climate change and COTS. Damage from fins of snorkelling and scuba diving are shown to have a negative effect on acropora corals, and anchor damage from boats negatively impact laminar and foliose corals. Recreational fishing is depicted as having a negative effect on herbivorous fishes and other reef fishes and invertebrates. Coral bleaching and disease negatively impact all functional groups of hard corals, while storms are depicted as having the greatest impact on acropora corals, while favouring the growth of macroalgae. COTS are depicted as having a negative impact on acropora corals. A single response variable "values" was added to the model to provide a cumulative response of variables that directly represent known natural values in the coral reef ecosystem, including herbivorous fishes, other fishes and invertebrates, laminar and foliose corals and massive corals.

## 5.2 Model Validation

The qualitative model of Figure 10 was converted into a Bayes net according to the methods of Hosack *et al.* (2008)[8]. In this configuration the Bayes net nodes represent the qualitative dynamics of the signed digraph model by assigning levels of likelihood or probability to model tests, predictions or diagnoses based on assertions regarding inputs or perturbations to the system or observations of how the system responds to perturbations.

To test how well the qualitative model represents known dynamics of coral reef ecosystems within the area of assessment, we drew upon the observed changes in the coral reefs of Hayman Island following the impact of Severe Tropical Cyclone Debbie (Figure 4). In the below Bayes net example (Figure 11) an input to storms was selected with 100% likelihood, while the remaining five other sources of input or perturbation were designated as 100% unchanged. Based on post-cyclone changes in relative abundance from AIMS and GBRMPA monitoring of Hayman Island reefs[9], observations were entered for increases in macro algae, herbivorous fishes, crustose coralline algae and turf algae. Decreases in abundance were entered for acropora coral, and fish and invertebrates, with no change entered for COTS or coral bleaching and disease. The resulting test of the qualitative model indicates that it is highly consistent (*i.e.*, likelihood 99%), with the observed dynamics that occurred in the reefs of Hayman Island following Cyclone Debbie.

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[8] Hosack, G.R., Hayes, K.R. and Dambacher, J.M., 2008. Assessing model structure uncertainty through an analysis of system feedback and Bayesian networks. *Ecological Applications*, *18*(4), pp.1070-1082.

[9] https://apps.aims.gov.au/reef-monitoring/reef/20014S

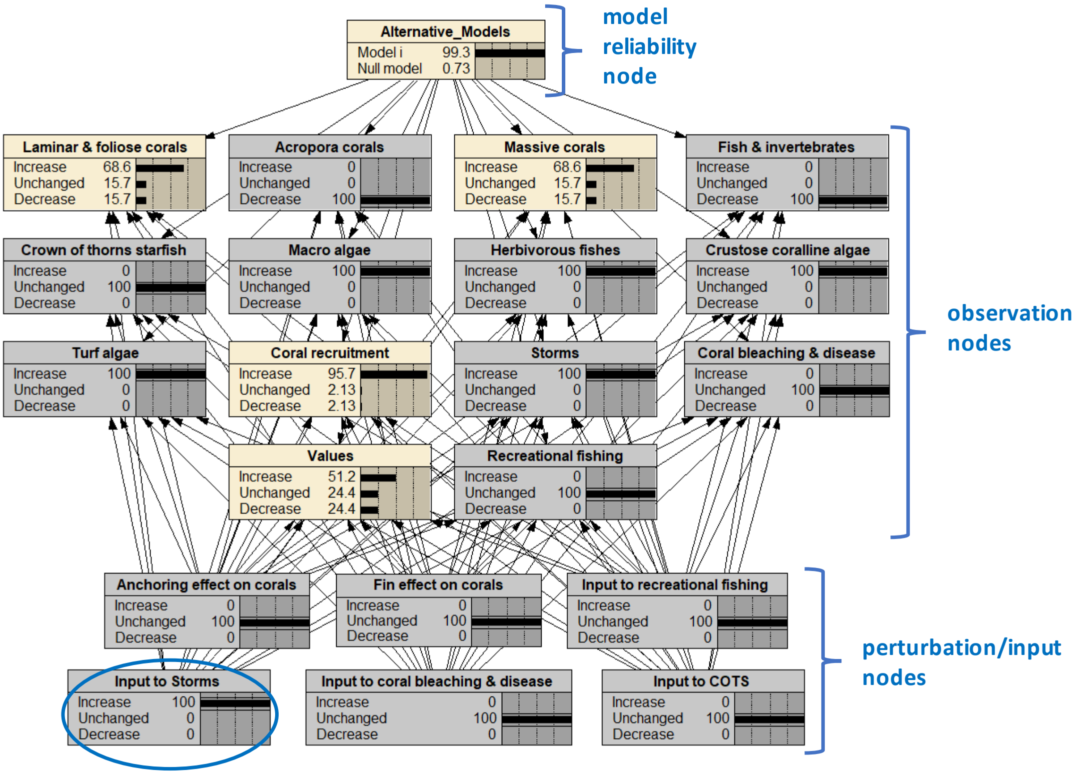


Figure 12: Bayes net test of signed digraph model of coral reef ecosystem (Figure 10) based on observations made of Hayman Island reefs following Cyclone Debbie (Figure 4) in 2017

# 6. ZONE OF INFLUENCE

To evaluate the cumulative impact of multiple pressures on coral reefs within the area of assessment each level of use was spatially partitioned against different permitted activities. This led to nine different combinations across the area of assessment (Table 2), the greatest proportion of which (39% of total reef area assessed) was in a moderate use level that permitted both boat anchoring and fishing. Table 3 shows how these combinations are distributed across each reef in the area of assessment including Marine Park zones. Each combination of use level and permitted activity provides the basis to consider discrete zones of influence to assess cumulative impacts to coral reefs within the area of assessment.

Table 2: Combinations of use levels and permitted activities across 761 ha of coral reefs within the area of assessment.

| Use level | Anchoring permitted | Fishing permitted | ha | % |
|---|---|---|---|---|
| Low | yes | yes | 138 | 18% |
| Moderate | yes | no | 61 | 8% |
| Moderate | yes | yes | 295 | 39% |
| Moderate | no | no | 15 | 2% |
| Moderate | no | yes | 85 | 11% |
| High | yes | no | 45 | 6% |
| High | yes | yes | 1 | 0.1% |
| Intensive | yes | no | 14 | 2% |
| Intensive | yes | yes | 105 | 14% |

Table 3: Marine Park zones and use levels to evaluate cumulative impacts across each of the coral reefs in the area of assessment; Marine Park zone one abbreviations: CP Conservation Park, HP Habitat Protection, and MNP Marine National Park; recreational fishing is not permitted within MNP zones.

| Reef name | Marine Park zone | Use level | Anchoring permitted | Percent reef area[a] |
|---|---|---|---|---|
| Black Island Reef | CP | High | yes | 0.1% |
| Hayman Island Reef | CP | Intensive | yes | 14% |
| Hayman Island Reef | CP | Moderate | yes | 7% |
| Hayman Island Reef | CP | Low | yes | 13% |
| Hook Island Reef (No 5) | CP | Moderate | no | 7% |
| Hook Island Reef (No 5) | CP | Moderate | yes | 3% |
| Hook Island Reef (No 6) | CP | Moderate | no | 4% |
| Hook Island Reef (No 6) | CP | Moderate | yes | 6% |
| Hook Island Reef (No 6) | CP | Low | yes | 6% |
| Langford-Bird Reef | CP | Moderate | yes | 21% |
| Hayman Island Reef | HP | Moderate | yes | 0.04% |
| Hook Island Reef (No 5) | HP | Moderate | yes | 2% |
| Black Island Reef | MNP | High | yes | 6% |
| Hayman Island Reef | MNP | Intensive | yes | 2% |
| Hayman Island Reef | MNP | Moderate | no | 2% |
| Hayman Island Reef | MNP | Moderate | yes | 3% |
| Langford-Bird Reef | MNP | Moderate | yes | 5% |

[a]: out of a total of 761 ha of reef in area assessed.

# 7. RISK AND UNCERTAINTY

## 7.1 Cumulative impact likelihood

The calculation of risk and uncertainty in this assessment is presented within a qualitative mathematical modelling framework, which provides an assessment or prediction for the likely direction (*i.e.*, increase or decrease) of change in a natural value rather than the magnitude of that change (*e.g.*, percentage change of coral cover or fish population abundance). This approach provides a comparative analysis of possible cumulative impacts of pressures from both natural and anthropogenic sources within the area of assessment.

For the pressures considered as a potential source of input to the Bayes net model an array of likelihood values were developed to match the relative intensity of use levels throughout the area of assessment (Table 4). These likelihood values, when entered into the input or perturbation node of the Bayes net model, represent how likely is it that the associated pressure will have an observable impact on the coral reef ecosystems within the area of assessment and within a given time horizon relevant to the Plan of Management. This time horizon was taken to be on the order of one to two decades.

For the low use level, which has the least number of visitors allowed and smallest allowable size for boats (Table 1), the likelihood for a negative effect occurring from anchor damage and fin damage from snorkelling and scuba diving was set at 0.05 (Table 4). The likelihood values for anchor and fin damage were both increased to 0.25 in high use areas. In intensive use areas however, the value for anchor damage was set at 0.35, but the value for fin damage was not increased above the previous use level as the intensive level of boating activity was considered a deterrent to higher numbers of snorkelling and scuba diving. The likelihood for an impact to the coral reef ecosystem from recreational fishing was uniformly set at 0.15 across all use levels. In areas were anchoring was prohibited (*e.g.*, Hook Island Reef No 5, Table 3), the likelihood for anchor damage was set to zero. Similarly, where fishing was not permitted (*i.e.*, Marine National Park zone, Table 3) the likelihood for impacts from recreational fishing was set to zero.

Perturbations to the Bayes net model that included climate change and COTS were developed based on a scenario where each event (*i.e.*, cyclone storm, coral bleaching and COTS outbreak) were to occur simultaneously. Here the likelihood for these three events to occur simultaneously over the planning horizon was set at 0.25. In perturbation scenarios that omitted these three pressures the likelihood for each of these inputs was set to zero, noting that the selection of likelihood values (Table 3) were designed to represent the scope of the modelling technique and are for illustrative purposes only.

Table 4: Likelihood values used in perturbation scenarios to assess cumulative impacts to coral reef ecosystems from recreational use, climate change and outbreaks of crown-of-thorns starfish (COTS).

| | Recreational boating, snorkelling, scuba diving and fishing | | | Climate change and COTS | | |
|---|---|---|---|---|---|---|
| Use level | Anchor damage[a] | Fin damage | Recreational fishing[b] | Storm damage[c] | Coral bleaching[c] | COTS outbreak[c] |
| Low | 0.05 | 0.05 | 0.15 | 0.25 | 0.25 | 0.25 |
| Moderate | 0.15 | 0.15 | 0.15 | 0.25 | 0.25 | 0.25 |
| High | 0.25 | 0.25 | 0.15 | 0.25 | 0.25 | 0.25 |
| Intensive | 0.35 | 0.25 | 0.15 | 0.25 | 0.25 | 0.25 |

[a]: Zero likelihood applied for anchor damage where anchoring is not permitted.

[b]: Zero likelihood applied for recreational fishing in Marine National Park zones.

[c]: Zero likelihood applied for scenarios without climate change and COTS.

The likelihood values in Table 4 were used to develop perturbation scenarios that match the various combinations of use levels and permitted activities for each reef in the area of assessment (Table 4). Two sets of perturbation scenarios were developed, one to assess impacts only from human uses and activities (*i.e.*, anchor damage, fin damage and recreational fishing) and a second to additionally consider climate change and COTS. In total there was an assessment of the cumulative impact to coral reef ecosystems for 18 different perturbation scenarios. Figure 12 provides an example of a perturbation scenario for a moderate use level where fishing and anchoring of boats is prohibited and with no impact from climate change or COTS. In this and all other perturbation scenarios, a likelihood level of 1.0 was selected for Model i in the alternative model node, which thereby provides a set of prediction based on the signed digraph model of Figure 8. The likelihood for an impact from fin damage was set at 0.15 with all other sources of input set to zero. Here the Bayes net provides a prediction for each variable in the coral reef ecosystem model of Figure 8. In this scenario there is a predicted decrease in both acropora corals and fish and invertebrate with a likelihood of 0.16, with the predicted decrease in the values node also at 0.16.

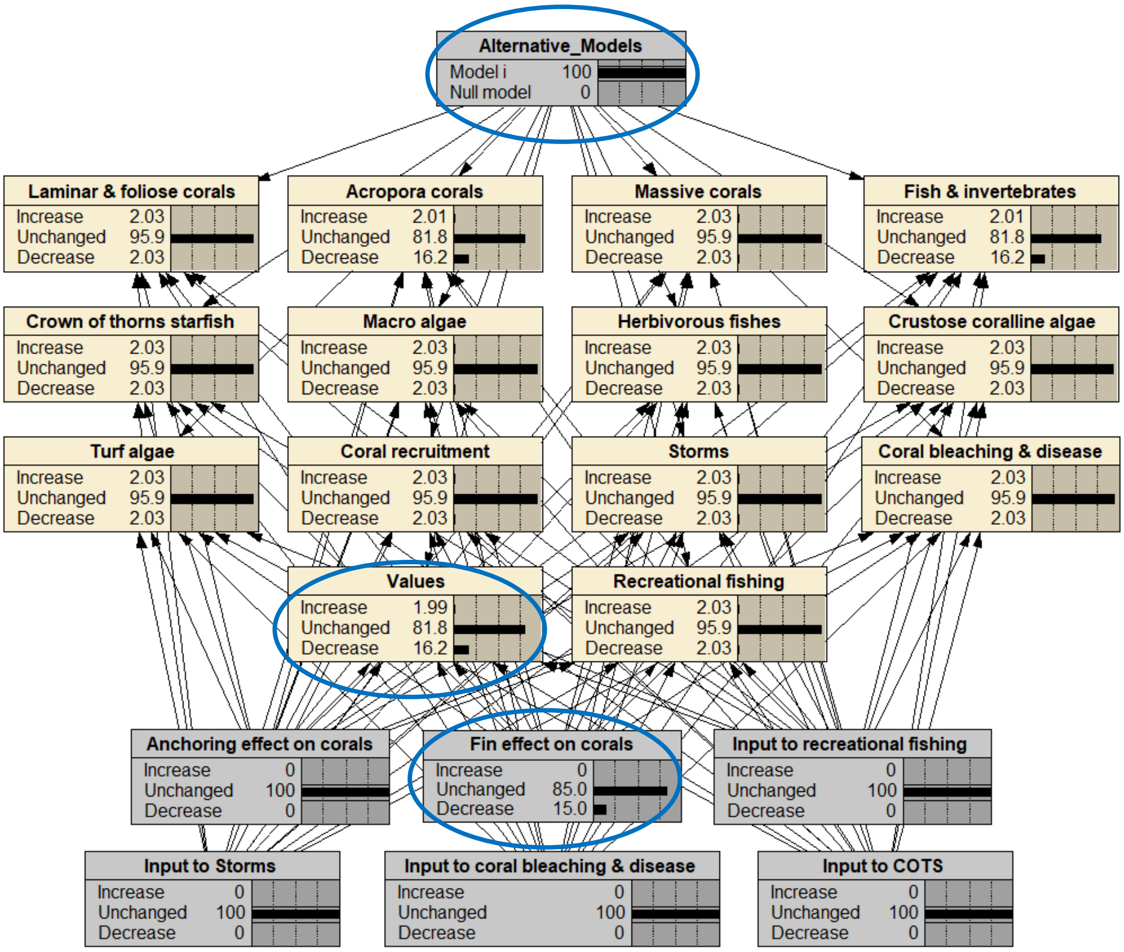


Figure 13: Bayes net prediction for coral reef ecosystem model (Figure 8) with a likelihood of 0.15 for fin damage in coral reefs in areas of moderate use where fishing and anchoring of boats is prohibited and with no impacts from climate change or COTS.

For each of the 18 perturbation scenarios the predicted change to coral reef values was tabulated and referenced back to each of the reefs designated in Table 3. A cumulative distribution of percent reef area and likelihood levels for decrease in coral reef values shows the impact from recreation uses of the reef to range between 0.16 and 0.58 (Figure 11). A moderate use level that does not permit anchoring or fishing had the smallest likelihood for a decline in reef values, while the largest likelihood was associated with intensive use levels that permitted both fishing and boat anchoring. Adding the cumulative impact of climate change and COTS on top of the pressures from recreational use elevated this distribution to a range of 0.49 to 0.70, with the rank order of the different use levels and activities remaining unchanged.

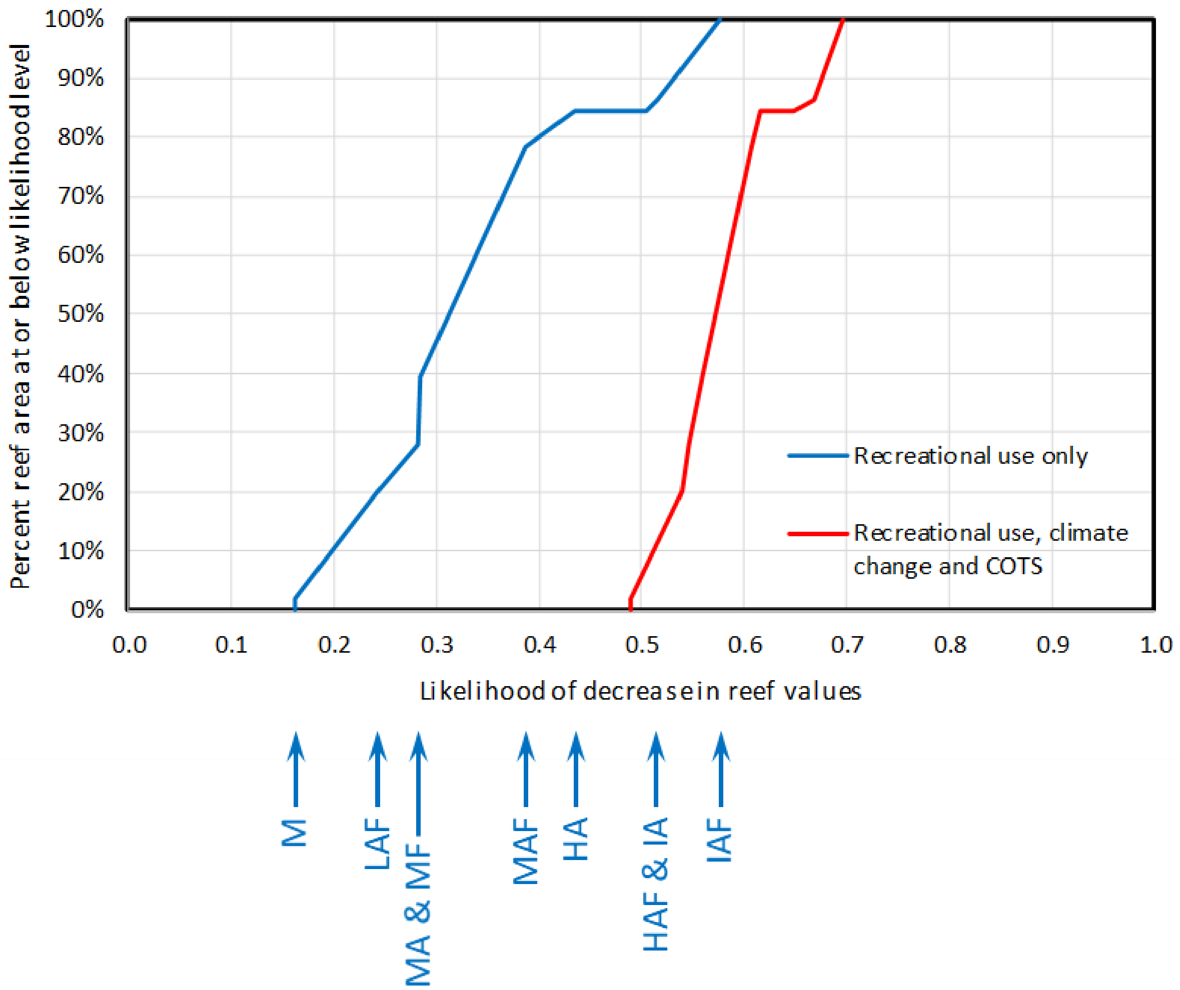


Figure 14: Cumulative distribution of percent reef area at or below levels of likelihood for a decrease in coral reef values from perturbation scenarios including only recreation use or those additionally including impacts from climate change and COTS. Blue text permitted activities; A: anchoring permitted, F: fishing permitted, H: high use, I: intensive, L: low use, M: moderate use.

Figure 14 shows the cumulative impact on coral reefs from recreational use within the area of assessment. Here the highest likelihood levels for a decrease in reef values is restricted to the reefs with an intensive use level in the southern quarter of Hayman Island. Adding the cumulative impact of climate change and COTS distributes the highest likelihood level to a majority of the reefs within the area of assessment (Figure 15).

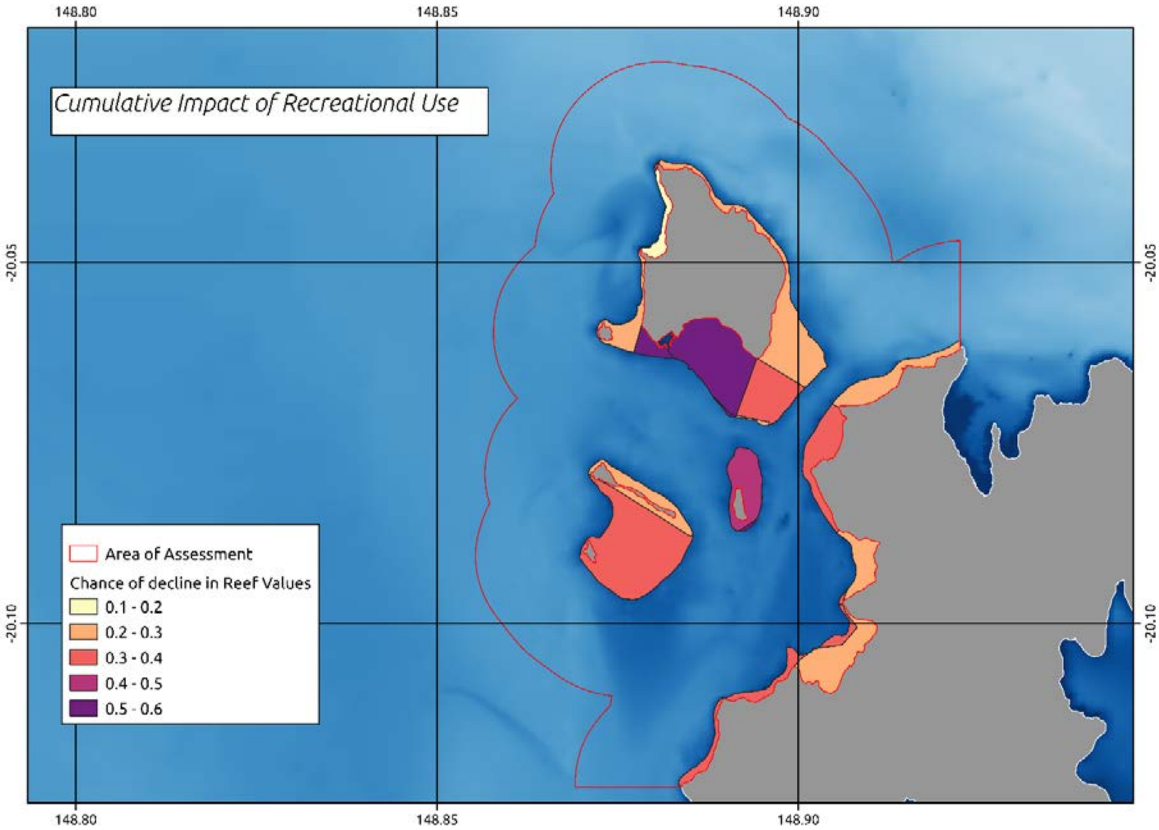


Figure 15: Cumulative impact to coral reef values from recreational use.

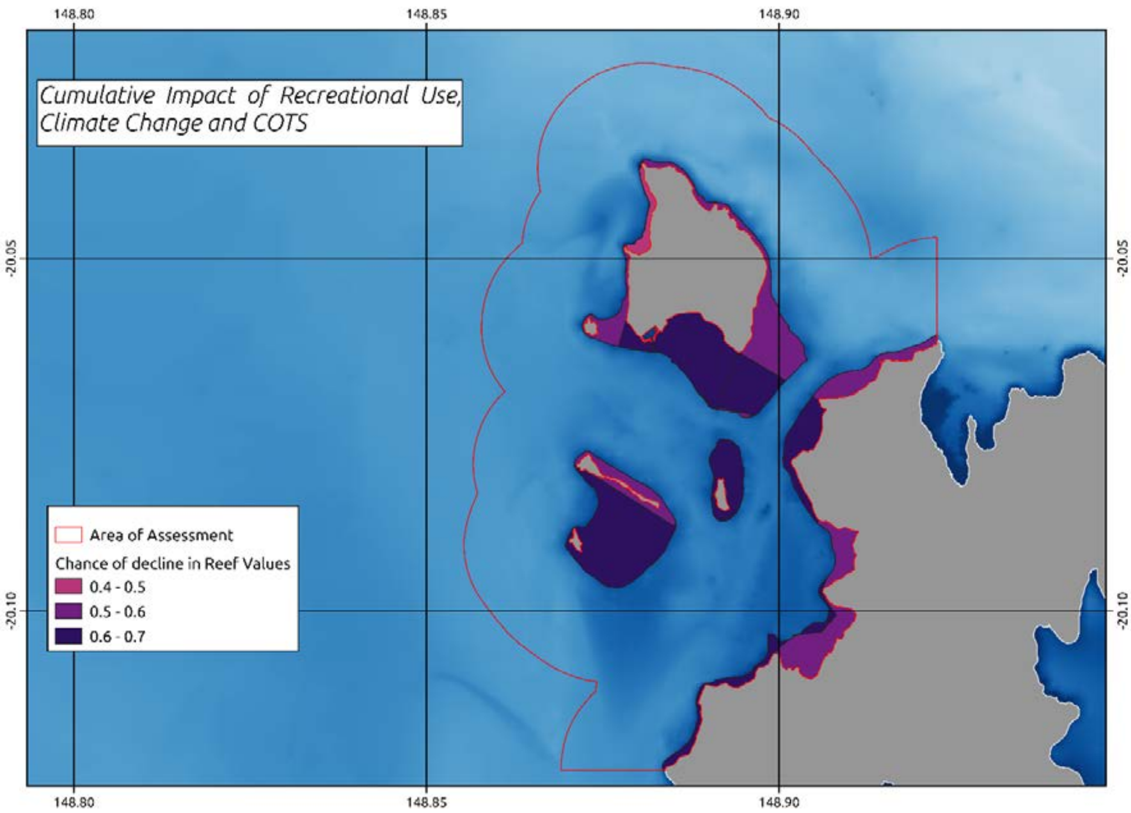


Figure 16: Cumulative impact to coral reef values from recreational use, climate change and COTS.

# 8. CONCLUSION

This case study demonstrates the application of the cumulative impact guidelines to the assessment of impacts from climate and anthropogenic use within the Whitsunday Plan of Management. The case study used the data that was currently available to estimate the likely impacts across an area where human use is varied, but where climate is having a known impact which cannot be managed. It shows how the cumulative impacts of a set of diverse uses can be integrated to estimate the total impact on the system and the overall contribution of climate change on the system. While the current case study was limited to an area within the Whitsundays POM, with sufficient data it could be applied at POM or regional scale, and the approach integrated into existing models. This rapid approach can be used to guide an understanding of how the different pressures occurring within a POM can be managed and where the most significant impacts are likely to occur, allowing prioritisation of mitigation where appropriate.

# 9. RECOMMENDATIONS

The key assumptions of this model are the likelihood values given in Table 4. These are estimates that were derived in consultation with GBRMPA and were set only for illustrative purposes. More accurate and robust estimates of these values would allow more accurate predictions of the outcomes of different perturbations caused by each pressure and could be used to modify the use limits currently imposed by the POM on the area to increase resilience and long term sustainability. Better estimates could be obtained through the collection of monitoring data and specific experimental studies to estimate the response relationships between pressures and values. Ideally, monitoring data would be fed back into the models, providing increasingly accurate risk assessments and allowing zoning to be modified to ensure that the system stays in the desired state. While this data is being collected, formal expert elicitation could be used to provide bounds of environmental response (Hosack *et al.* 2008)[8]. Overall, increasing the data available at each step of the guidelines will increase the overall robustness of the assessment and the checklist attached can be used to identify where additional effort should be applied.

# 10. ANNEX

## 10.1 Annex I: Check list for the assessment of Pressures

| **Specific Questions** | **Caveats** |
|---|---|
| *Data Availability* | |
| Is there sufficient data available on pressures for the area of interest? | Yes |
| Are available data on different pressures at comparable spatial and temporal scales? | Yes |
| Is there data on the historical distribution and intensity of the pressures? | Partial, there is information on historical cyclones, sea surface temperature, bleaching events and COTS outbreaks, but impacts from tourism are not well identified. |
| Do the available pressure data have comparable resolutions for all pressures considered? | Yes |
| Are empirical data available or are the data inferred, modelled, or based on expert option? | Empirical |

## 10.2 Annex II: Checklist for the assessment of Values

| Specific Questions | Caveats |
|---|---|
| *Data Availability* | |
| Is there sufficient data available on values for the area of interest? | Yes, although fine scale information on tourism is absent |
| Are data on values available on comparable spatial and temporal scales to the pressures? | Yes |
| Are baseline data available? | Yes |
| Do available data on values have comparable resolutions for all values? | Yes |
| Are empirical data available or are the data inferred, modelled, or expert option? | Empirical |

## 10.3 Annex III: Checklist for Conceptual Models of Key Habitats

| **Specific Questions** | **Caveats** |
|---|---|
| *Is the context of the conceptual model clearly defined?* | |
| Does the conceptual model of the system capture the same temporal and spatial scales as desired for the assessment/of interest? | Yes |
| Are the spatial and temporal limits of the system clearly identified? | Yes |
| Does the conceptual model include ecosystem components that adequately represent key species, habitats and processes (*i.e.*, resource flows, ecological relationships, and disturbance regimes)? | Yes |
| *Can you measure the outputs of the system, identify indicators and monitor the outcomes* | |
| Does the conceptual model describe how the pressures, values and ecosystem components relate to each other and interact? | Yes |
| Are the assessment endpoints (the ecosystem components that will be monitored) represented in the conceptual model? | Yes |
| Are there alternative ways that pressures could impact values or alternatives for how the ecosystem might be structured? | No, there only one model assessed, however, there are other alternative models available beyond the case study. |

## 10.4 Annex IV: Checklist for Zone of Influence

| Specific Questions | Caveats |
|---|---|
| *Are Pressures links to ecosystem components?* | |
| Is the response variable of the dose-response relationship clearly represented in the ecosystem's conceptual model? | Yes |
| Is the zone of influence based on a well-defined dose-response type relationship (demonstrated and measured clear impact) relevant to the valued components of the ecosystem? | Yes, however, aspects of tourism (*i.e.*, fin and anchor damage, fishing levels) are not clearly articulated |
| Are threshold values sufficiently detailed to address the biology of the response variable (*e.g.*, do they address breakpoints in effects on key variables such as seagrass growth increasing or decreasing at relatively low or high levels of nutrients)? | No, these relationships remain to be rigorously defined, thus caution should accompany interpretation of results |
| Do threshold values address a range of effects that are relevant to management concerns and desired future conditions of associated values? | Yes, the POM is focused on relative differences between allowed levels of use. |
| *Is uncertainty in the dose-response relationship adequately assessed and documented?* | |
| If based on empirical data, does the dose-response relationship included error bounds? | No, uncertainty about the threshold for a response should be considered |
| If based on modelling studies is there documentation of variation in modelling results? | NA |
| If based on expert opinion is there documentation of the elicitation process and attendant level of uncertainty? | NA |

| | |
|---|---|
| *Does the zone of influence adequately address or document different sources of pressures relevant to the assessment?* | |
| Is the granularity of the pressure data sufficient to address the pattern of distribution in the response variable of the dose-response relationship and the distribution pattern of valued components of the system? | Yes |
| Are concentrations or intensities of existing pressures adequately differentiated from pressures associated with proposed projects and plans of management? | Yes |
| Are anthropogenic sources of pressures adequately differentiated from natural or otherwise background levels of pressures (*i.e.*, turbidity from a catchment includes natural sources from sediment transport but also from runoff associated with land use practices)? | Yes |

## 10.5 Annex V: Checklist for cumulative risk assessment

| Specific Questions | Caveats |
| --- | --- |
| Can the method predict the spatial distribution of cumulative impacts? | Yes, the spatial predictions are done by assigning different impacts to different reefs within the respective zones of influence |
| Can the method identify alterations to ecosystem components and processes such as nutrient cycling, predation, habitat modification, sedimentation, light penetration? | Yes |
| Does the method imply the link between multiple pressures and values or is this explicitly described in the approach? | Explicitly described |
| Can the proposed methods assess the indirect effects caused by the pressures on values? | Yes |
| Can the method assess facilitative effects of multiple pressures on values be detected? | Yes |
| Can the method distinguish between masking, antagonistic, additive and synergistic links between multiple pressures and values? | No, the full magnitude of impact of pressures is not estimated. |
| Are non-linear links between pressures and ecosystem components possible? | Partially, will precise inflection points and transitions in impact are not precisely estimated, they are addressed within the signed digraph model structure. |
| Can the method distinguish between the impacts of a single pressure acting sequentially? | No, assessment may not capture the transitory impacts of pressures acting through time. |
| Can the method distinguish between the impacts of multiple pressures acting simultaneously or sequentially? | Yes |
| Can the method include future impacts in the predictions? | Yes |

| Specific Questions | Caveats |
|---|---|
| Can the method produce an estimate of uncertainty in the predictions in likelihood and consequence? | No, the qualitative assessment does not produce estimates of error around a mean, but only direction of response. Additional caution is necessary as the estimate of impact and risk is not precisely assessed. |
| Can the method incorporate temporal variation and time lags? | Not explicitly, the assessment may not capture the full impact of pressures acting through time. |

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