

Towards an integrated monitoring program: Identifying indicators and existing monitoring programs to effectively evaluate the Long Term Sustainability Plan

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Australian Institute of Marine Science



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ACRONYMS

AIMS	Australian Institute of Marine Science
AMSA	Australian Maritime Safety Authority
BCCA	Burnett Catchment Care Association
BHP	BHP Billiton
BIEEC	Boyne Island Environmental Education Centre
BoM	Bureau of Meteorology
CQU	Central Queensland University
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CVA	Conservation Volunteers Australia
DAF	Queensland Department of Agriculture and Fisheries
DERM	Queensland Department of Environment and Resource Management
DNRM	Queensland Department of Natural Resources and Mines
DOE	Department of the Environment
DSITI	Queensland Department of Science, Information Technology and Innovation
EHP	Queensland Department of Environment and Heritage Protection
Entox	The National Research Centre for Environmental Toxicology (Entox)
FBA	Fitzroy Basin Association Inc.
FMP	Field Management Program (GBRMPA and QPWS)
GBR	Great Barrier Reef
GBRMPA	Great Barrier Reef Marine Park Authority
GBRWHA	Great Barrier Reef World Heritage Area
GHHP	Gladstone Healthy Harbour Partnership
GPC	Gladstone Ports Corporation (multiple stakeholders)
IMOS	Integrated Marine Observing System
JCU	James Cook University
LTSP	Long-Term Sustainability Plan
NAILSMA	North Australian Indigenous Land and Sea Management Alliance
NESP	National Environmental Science Programme
NOAA	National Oceanic and Atmospheric Administration
NQBP	North Queensland Bulk Ports Corporation
OCR	Ocean and Coast Research
PCIMP	Port Curtis Integrated Monitoring Program consortium
PN	Ports North
PoT	Port of Townsville Limited
QG	Queensland Government
RC & PCL	Reef Catchments and Pioneer Catchment Landcare
RIMREP	Reef Integrated Monitoring and Reporting Program
RLS	Reef Life Survey Foundation
RRRC	Reef and Rainforest Research Centre Limited
SCU	Southern Cross University
SELTMP	Social and Economic Long Term Monitoring Program
STF	Sea Turtle Foundation
TBF	Tangaroa Blue Foundation
TCC	Townsville City Council
TWQ	Tropical Water Quality
UNSW	University of New South Wales
UQ	University of Queensland
WWF	World Wide Fund for Nature

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EXECUTIVE SUMMARY

The Reef 2050 Long-Term Sustainability Plan (LTSP) uses an outcomes-based approach to align its vision, long-term objectives, short-term targets and actions. Targets are specified for 2020 and represent stepping-stones to the achievement of objectives in 2035 and outcomes by 2050. The implicit claim of the LTSP is that success in implementing actions will lead to success in the achievement of associated targets, objectives and outcomes.

The specification of targets, objectives and outcomes in the LTSP elevates the importance of monitoring. The LTSP calls for an integrated monitoring and reporting program that will provide a comprehensive and up-to-date understanding of the Great Barrier Reef, its values, the processes that support it and the pressures that affect it. Further, the establishment of an effective integrated performance monitoring program is a fundamental precursor to enable adaptive management to protect and restore the Reef. The evidence of success (or failure) of meeting the targets, objectives and outcomes of the LTSP will be derived largely from the signal provided by an integrated monitoring program. This program will provide a comprehensive and up-to-date understanding of the Great Barrier Reef, its values, the processes that support it and the pressures that affect it.

This report summarises the results of a desktop study that completed a series of critical steps towards the development of an integrated monitoring and reporting program for the LTSP:

1. Breakdown of the LTSP targets and objectives to assist in the identification and/or development of appropriate and effective indicators to identify the environmental and socio-economic values and attributes that could be monitored to assess progress towards the LTSP targets and objectives.
2. Collation of an inventory of existing monitoring programs, and assessment of the relevance of the marine monitoring programs to measure the environmental and socio-economic values and attributes of the LTSP.
3. Assessment of the statistical power of two selected monitoring programs to assess their capacity to detect changes at scales relevant to the LTSP.

The GBRWHA is a busy space for environmental monitoring, with 80 monitoring programs associated with the marine environment. Among these, few have a demonstrated capability to detect and measure change in key attributes of the GBRWHA, such as important habitats (e.g. coral reefs and seagrasses), species of conservation concern (megafauna) and important environmental drivers, particularly water quality. These programs should form the foundation on which a broader integrated monitoring program can be built. The majority of existing monitoring programs either have been established for independent purposes (e.g. university research, education/awareness raising/stewardship), operate at small geographic or temporal scales, are not government funded, or are conducted to ensure compliance with development conditions. Access to data collected by these programs, and our ability to influence or change them to incorporate them into an integrated monitoring program is limited.

There are also gaps in current monitoring. None of the 80 programs have as their primary purpose the monitoring of deeper (>30 m) coral reefs, the lagoon floor, shoals, *Halimeda*

banks, the continental slope, benthic microalgae, plankton and microbes, or sea snakes. The most striking gap in socio-economic monitoring is the absence of dedicated and co-ordinated monitoring pertaining to Traditional Owner use, dependency and well-being. Therefore, an integrated monitoring program must also include a funded process to develop, test and incorporate over time new indicators, new technologies and guidelines that are able to inform the evaluation of the effectiveness of the Reef 2050 Plan and ensure data comparability and continuation of long-term data series.

Power analyses provide a platform to explore the capacity of monitoring to detect declines (or improvements) in attributes that are considered important for the LTSP. Assessment of the capacity to detect changes relevant to LTSP targets and objectives is recommended to be a key decision criterion when establishing an integrated monitoring and reporting program. However, monitoring the full breadth of targets and objectives in the LTSP with sufficient power to clearly differentiate success and failure will carry a high price tag. Stakeholders will need to make difficult decisions about trade-offs between the breadth of attributes monitored, the reliability with which they are monitored, and costs. The content of this report provides a suitable basis to inform these trade-offs and negotiations.

1.0 INTRODUCTION

The Reef 2050 Long-Term Sustainability Plan (LTSP) was released early in 2015 with a vision that by *“2050 the Great Barrier Reef continues to demonstrate the Outstanding Universal Value for which it was listed as a World Heritage Area and supports a wide range of sustainable economic, social, cultural and traditional activities”* (Commonwealth of Australia 2015).

The LTSP uses an outcomes-based approach to align its' vision, long-term objectives, short-term targets and actions under seven themes: ecosystem health, biodiversity, heritage, water quality, economic benefits, community benefits, and governance. Targets are specified for 2020 and represent stepping-stones to the achievement of objectives in 2035 and outcomes by 2050. The implicit claim of the LTSP is that success in implementing actions will lead to success in the achievement of associated targets, objectives and outcomes.

The specification of targets, objectives and outcomes in the LTSP elevates the importance of monitoring. The LTSP calls for an integrated monitoring and reporting program that will provide a “comprehensive and up-to-date understanding of the Great Barrier Reef, its values, the processes that support it and the pressures that affect it is fundamental to protecting and restoring the Reef and making informed decisions”. The evidence of success (or failure) of meeting the targets, objectives and outcomes of the LTSP will be derived largely from the signal provided by an integrated monitoring program.

The integrated monitoring program will draw heavily on the many existing monitoring programs in the Great Barrier Reef World Heritage Area (GBRWHA). Subject to the availability of additional resources, the integrated monitoring program will also require the establishment of new monitoring programs to fill gaps in the coverage of existing monitoring programs to ensure that a comprehensive evaluation of the LTSP targets and objectives is possible.

The components of this project were identified through the monitoring and reporting actions of the LTSP that must be undertaken over the next five years. This project was led by AIMS, with ongoing consultation with members of the Reef Integrated Monitoring and Reporting Program (RIMREP) Program Design working group and other key stakeholders from academic institutions and government agencies involved in monitoring, research and management of the GBRWHA (listed in Appendix 1).

1.1 Project Aims

This project addresses a series of critical initial steps required to develop an integrated monitoring and reporting program for the LTSP. There were three stages to this project:

- (1) Breakdown of the LTSP targets and objectives to assist in the development of appropriate and effective indicators:
Aim: To identify the environmental and socio-economic values (e.g., a habitat or group of species) and attributes (e.g., specific characteristics of values, e.g., the current condition of a habitat) that could be monitored to assess progress towards the LTSP targets and objectives.

(2) Monitoring program inventory:

Aim: To assess the efficacy of existing marine monitoring programs against the environmental and socio-economic values and attributes of the LTSP.

(3) Assessment of the power of the AIMS Long Term and Marine Monitoring Programs (LTMP and MMP) to detect important changes for the LTSP:

Aim: To assess the power of the LTMP and MMP in addressing the LTSP targets, in order to illustrate how power analysis could be undertaken for other monitoring programs in the future.

2.0 METHODOLOGY

2.1 Breakdown of the LTSP targets and objectives to assist in indicator development

A content analysis of the LTSP objectives and targets was undertaken to identify the elements and attributes that could be monitored through an integrated monitoring and reporting program. This involved searching for values (e.g., “coral reefs”) and attributes (e.g., “current condition”) in Chapter 4 of the LTSP.

Flow charts were then developed to illustrate the range of elements and attributes that would need to be monitored to comprehensively assess progress towards the LTSP targets and objectives. Note that this work does not involve identifying indicators for values and attributes. Rather the flow charts will inform future work by the RIMREP Program Design working group in the development of specific indicators that will best capture the state and trend of key indicators and underlying processes that align directly to the LTSP targets and objectives.

2.2 Monitoring program inventory

Environmental monitoring programs

We conducted an inventory of monitoring programs in the GBRWHA to identify the variables that are currently monitored and that can help address the LTSP values and attributes, and in turn the targets and objectives in future evaluations of the LTSP. This inventory built on the most recent assessment of GBR monitoring programs by Hugh Sweatman in 2013 (Hedge *et al.* 2013), and was conducted alongside the review of terrestrial, freshwater and estuarine monitoring programs by the department of Environment Heritage and Protection (led by Claire Andersen). Thus, while we also collated information on terrestrial, freshwater and estuarine monitoring programs in the GBRWHA catchments, we do not summarise these monitoring programs in this report. We only summarise the marine monitoring programs, as agreed with EHP who are providing summaries of terrestrial, freshwater and estuarine monitoring programs to the RIMREP Program Design working group.

For the purpose of this inventory, we define environmental monitoring as the repeated and systematic collection of data through time (Lindenmayer & Likens 2010; Mascia *et al.* 2014). To be included in this inventory, environmental monitoring programs also had to meet the following criteria:

- Location: Monitoring occurs in the GBRWHA or neighbouring catchments.
- Current: At least one monitoring event has occurred in the last 5 years, with some indication that the monitoring will continue in the future (dependent on funding).
- Relevant to the LTSP: The values monitored address at least one of the LTSP environmental or socio-economic values and attributes (e.g., coral reef condition), or one of the threats identified through the LTSP.
- Publicly available: Monitoring results are publicly accessible through scientific publications (e.g., published reports or peer-reviewed papers), government/

institutional reports (standard operating procedures, report cards), online databases (e.g., AODN, IMOS, e-Atlas), or are available upon request from data custodians.

For inclusivity we also include programs that are based on sightings, where observations are made repeatedly through the GBRWHA, but sites are not necessarily re-visited.

Programs not included in the inventory:

- Ports and other regulatory (“near field”) monitoring programs: These are very difficult to discover through online searches, as often there are no data or reports that are publicly available. This would require a thorough investigation of monitoring programs associated with environmental approvals within the GBRWHA using searches within state and federal regulatory agencies – something that was beyond the scope of this project.
- Research programs: We did not include experimental studies (e.g., seagrass transplant/restoration experiments), or surveys undertaken to support research (e.g., coral cores to investigate historic events in the GBR).
- Monitoring inputs or processes: We did not include monitoring programs of inputs or processes (e.g., assessing whether management actions were done – e.g., the number of farms using best practice management systems).

We used the web-based resources Google, Google Scholar, DuckDuckGo, and Thomson Reuters Web of Science to identify existing monitoring programs that met our selection criteria. We used a series of search terms in the following combinations: (Great Barrier Reef OR Queensland OR Queensland Coast) AND (monitoring OR survey OR health).

Once the first round of the monitoring inventory was completed, we double checked the monitoring programs against online databases (e.g., eAtlas, AODN, and Coastal Research) to identify additional monitoring programs. The RIMREP Program Design group and key project stakeholders (Appendix 1) were also given the opportunity to comment on any missing monitoring programs when they were sent the draft inventory from 27 October – 6 November 2015.

A key output from this section of work is a spreadsheet that can be interrogated in a range of ways, which has been provided directly to the RIMREP Program Design working group. In this report we present a summary of this interrogation of the marine monitoring programs against the newly developed LTSP targets and objectives and threatening processes. However the spreadsheet is likely to be much more useful for the Program Design working group to update their database of monitoring programs and continue to develop an integrated monitoring and reporting program.

Socio-economic monitoring

Dedicated comprehensive monitoring of the human dimension of the GBRWHA is in its infancy. Although extensive time series exist for some elements as part of national or statewide programs (e.g. the ABS National Census of Population and Housing) there is a dearth of long term records for many of the social and economic objectives and targets of the LTSP. The Social and Economic Long Term Monitoring Program (SELTMP; Marshall et al. 2013) is by far the most substantial attempt to capture and collate information at a resolution

and scale of immediate relevance. While the aspiration is for SELTMP to be funded and implemented on an ongoing basis, its focus to date has been the characterisation of the state of social and economic conditions at a single point in time, c. 2013. This report identifies the sub-set of LTSP targets and objectives for which information captured and collated in the 2013 SELTMP snapshot could be utilised in longer term monitoring. It also identifies objectives and targets for which no data are readily available currently.

2.3 Assessment of the power of monitoring programs: AIMS' Long Term and Marine Monitoring Programs as examples

Data from a monitoring program can provide insight into patterns of change in an ecosystem, assemblage or a population. With the aid of statistical models it is possible to explore those patterns and make inferences about status and trend. Statistical interpretation of monitoring data can range from plotting means with 95% confidence intervals to explore temporal and spatial patterns, through to developing more complex models such as logistic regression models that attribute variation in the data to different influencing factors allowing for potentially clearer exploration of temporal and spatial patterns (De'ath *et al.* 2012).

When interpreting monitoring data with statistical models it is critical to note that the monitoring data collected will only ever provide an **estimation** of what is happening within an ecosystem, assemblage or a population. There is always a chance that the estimate from a monitoring program will be **wrong**.

There are two ways that incorrect inferences can be made from monitoring data:

- (1) You conclude that there is a substantive change in a monitored variable (e.g., hard coral cover) when in fact no change occurred in the true population (e.g., coral reefs in the GBRWHA). This is the Type I error rate (α), which by convention is commonly set at 0.05 (Fairweather 1991). For a statistical test that sets $\alpha = 0.05$, this means that 5% of the time that you conclude that there is a substantive change in a monitored variable there actually has been no change in the true population.
- (2) You conclude that there is no substantive change in a monitored variable, when in fact there has been a change in the true population. This is the Type II error rate (β), which is often ignored when undertaking statistical analyses (Mapstone 1995). A Type II error rate relates to the power of a monitoring program ($1 - \beta$). If power is not estimated for a monitoring program, then there is an unknown chance that you will be concluding that there is no change in a monitored variable when in fact there has been a true substantive change in the true population.

Type I and II errors have very different consequences in environmental management (Fairweather 1991; Underwood & Chapman 2003):

- (1) The cost of a Type I error will be to the environmental agency that implements an adaptive management response to the perceived decline in the monitored variable when it was not required (i.e. the monetary value of an unnecessary management intervention).
- (2) The cost of a Type II error will be to the environment, which is the cost of an undesirable environmental change (e.g. a loss of biodiversity) that goes undetected and unmanaged. A Type II error can thus be much more serious in protected area management.

As environmental decisions are sensitive to Type II errors and Type I errors, it is crucial that both errors are considered when developing or integrating monitoring programs for new applications. This is the case for the LTSP. If existing monitoring programs are to be used to provide data to help evaluate whether LTSP targets and objectives are being achieved, the Type I and II error rates associated with those monitoring programs (and the statistical models used to interpret the data) should be calculated prior to their use in an integrated monitoring and reporting program.

Consideration of Type I errors compared to Type II errors is comparatively easy, as a Type I error rate can be set for any statistical model by the decision maker (and there is no need to adhere to the convention of $\alpha = 0.05$).

The Type II error rate of an existing monitoring program can be explored by calculating the power of the monitoring program. Power is the probability of detecting an effect, given that the effect is really there. The power of a monitoring program to detect a significant effect in a statistical test depends on the variation in the dataset (standard error), the replication in the monitoring program (sample size), the chosen Type I error rate (e.g. 0.05) and the magnitude of difference to be detected (the effect size) (Fairweather 1991; Quinn & Keough 2002). Power can be assessed by characterising existing monitoring data (e.g., the mean, standard error, and trend in a monitored variable) and then simulating new sets of monitoring data. Different levels of variation and effect sizes can be created in the simulated datasets to see how often a statistical model will detect important shifts in a monitored variable. By simulating many new sets of monitoring data and testing how often important shifts in a monitored variable can actually be detected, the power of that monitoring program can be calculated.

Conceptually, and for the purpose of designing a cost-effective monitoring program, exploring combinations of sampling effort and effect size (while setting alpha to 0.05) that achieve a minimal acceptable power of say 80% can inform decisions around how much to invest in monitoring effort (**Figure 1**). Importantly, investing in less sampling where the power curve starts its steep ascent means that power potential (ability to detect true effect) given modest investment is unrealised. Conversely, increased sampling effort where the power curve is flat implies poor cost effectiveness.

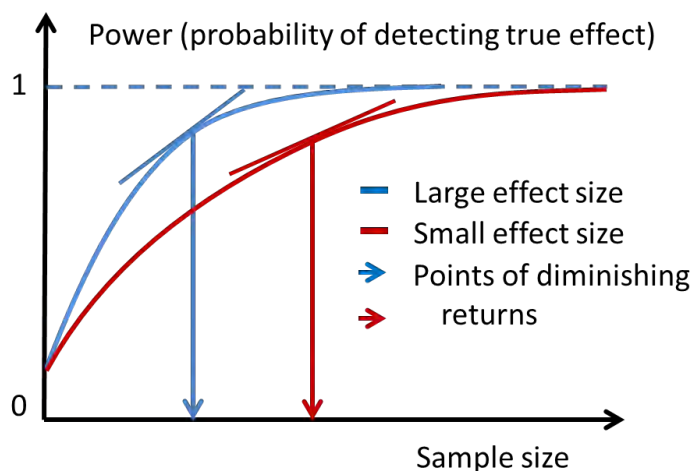


Figure 1: Conceptual representation of how statistical power varies with sample size and effect size, assuming constant Type 1 error rate (alpha).

Using the AIMS Long Term Monitoring Program (LTMP) and Marine Monitoring Program (MMP) as examples, we demonstrate how to assess power of monitoring programs prior to their application to the integrated monitoring and reporting program for the LTSP. This work builds on the analysis and recommendations made to the Department of the Environment around integrated monitoring, modelling and management in the Mackay Whitsunday region by Walshe *et al.* (2014).

Specifically, we conducted power analyses for two indicators, reef fish species richness and percent hard coral cover. We illustrate how assessments of the power of other monitoring programs could be undertaken in the future. This desktop assessment evaluates the programs' ability to detect different declines away from current condition (effect sizes), which may be included as quantitative targets under the LTSP.

Power analysis of reef fish richness and coral cover

To estimate the power of the LTMP to detect changes in fish species richness we built a basic hierarchical model to estimate average variability within and among the spatial units of the GBR sampling scheme. As our objective was to estimate average variability, we de-trended the data by including annual random effects as nuisance parameters. We also accounted for cross-shelf differences (inner, mid, and outer shelf positions) that have been shown to influence biodiversity patterns across the GBR (Williams & Hatcher 1983).

The approach taken follows the advice of Gelman and Hill (2006), who develop a coherent approach to power analysis for multilevel (hierarchical) models using simulated data. We adopt this approach because the spatial structure of management and a majority of ecological processes on coral reefs is inherently hierarchical (MacNeil & Connolly 2015), making hierarchical models a critical step for understanding many coral reef patterns and processes (MacNeil *et al.* 2009).

The analysis proceeds by first modelling the data and estimating the intrinsic variability of the data at the scale of observation. These estimates are then used to simulate hundreds of new data sets that include a specified (known) trend, estimating an effect size for that trend at each spatial scale for each data set. The proportion of simulated data estimates for which a trend is detected - i.e. the 95% uncertainty interval does not span zero (Type I error rate is set at $\alpha = 0.05$) - is the power to detect a given trend at a given scale.

More precisely, the full Bayesian model for estimating variability in reef fish richness (r_{irst}) was:

$$\begin{aligned}
 r_{itrs} &\sim N(\mu, \tau_{obs}) \\
 \mu &= \delta_{trs} + \delta_y \\
 \delta_{trs} &\sim N(\beta_{rs}, \tau_{rs}) \\
 \beta_{rs} &\sim N(\mu_{sc}, \tau_{sc}) \\
 \mu_{sc} &= \eta_s + \eta_c \\
 \eta_s &\sim N(\gamma_0, \tau_s) \\
 \delta_y, \eta_c, \gamma_0 &\sim N(0.0, 0.001) \\
 \tau_{obs}, \tau_r, \tau_s &= \sigma_{obs}^{-2}, \sigma_r^{-2}, \sigma_s^{-2} \\
 \sigma_{obs}^{-2}, \sigma_r^{-2}, \sigma_s^{-2} &\sim U(0, 1000).
 \end{aligned}$$

While more sophisticated models for fish species richness have been developed (Cheal *et al.* 2013), the normal model used was sufficient to characterize average variability in richness and the power to detect inter-annual trends.

At each replicate ($n=100$) we used the posterior transect level means (δ_{trs}) and observation-scale variances (τ_{obs}) to generate initial transect-scale richness values (s_{1trs}). We then scaled the s_{1trs} values by a given percent decline (1, 5, 10, 25, & 50% - a range of effect sizes likely to be important to detect for the LTSP) and simulated a second set of diminished observations (s_{2trs}) for a following year (y_2), again using the observation-scale variance.

Next we estimated the power to detect a given trend, using a Bayesian hierarchical model similar to the one above that also included a hierarchical trend effect at each scale:

$$\begin{aligned}
 s_{itrts} & \sim N(\mu, \tau_{obs}) \\
 \mu & = \delta_{0trs} + \delta_{1trs}y_2 \\
 \delta_{0trs} & \sim N(\beta_{0rs}, \tau_{0r}) \\
 \delta_{1trs} & \sim N(\beta_{1rs}, \tau_{1r}) \\
 \beta_{0rs} & \sim N(\eta_{0s}, \tau_{0s}) \\
 \beta_{1rs} & \sim N(\eta_{1s}, \tau_{1s}) \\
 \eta_{0rs} & \sim N(\gamma_0, \tau_0) \\
 \eta_{1rs} & \sim N(\gamma_1, \tau_1) \\
 \gamma_0, \gamma_1 & \sim N(0.0, 0.001) \\
 \tau_{obs}, \tau_{0r}, \tau_{1r}, \tau_{0s}, \tau_{1s}, \tau_0, \tau_1 & = \sigma_x^{-2} \\
 \sigma_x^{-2} & \sim U(0, 1000).
 \end{aligned}$$

This allowed us to record whether the 95% uncertainty intervals (UI) for trend effects spanned zero for each iteration, at each of four spatial scales. Power was then taken to be the proportion of iterations for which a trend effect was definitively observed (i.e. trend effect 95% UI did not span zero).

Algorithmically for a given percent decline (PD) at each iteration this process was:

1. Simulate $s_{1trs} \sim N(\delta_{trs}, \tau_{obs})$
2. Simulate $s_{2trs} \sim N(s_{1trs}(1 - PD), \tau_{obs})$
3. Estimate $\delta_{1trs}, \beta_{1rs}, \eta_{1s}, \gamma_1$
4. Record if 95% UI's for estimates do not span zero

This process was repeated to estimate the power to detect declines in the percentage of coral cover within the combined LTMP and MMP surveys, using a binomial distribution in place of the normal distribution assumed for fish richness. Analyses were carried out in [Python](#), using the [PyMC 2](#) package for Bayesian estimation. The initial model and subsequent power estimation models were run for 100,000 iterations, with the final 10,000 iterations retained for inference. Multiple chains were run on the initial model and Geweke R-hat statistics calculated to infer model convergence.

3.0 RESULTS

3.1 Breakdown of the LTSP targets and objectives to assist with indicator development

Environmental objectives and targets

We developed flow diagrams of each LTSP outcome that refer to environmental objectives and targets (Figures 2 – 4). These flow diagrams are intended to illustrate the natural values (key marine ecosystems and species) that are referred to (or implied) in Chapter 4 of the LTSP, and the attributes of the natural values that would need to be monitored/measured in order to evaluate the LTSP targets and objectives in the future.

The natural values mentioned specifically in Chapter 4 of the LTSP are far fewer than those used in the Strategic Assessment and Outlook Reports. We assumed that natural values assessed through the Strategic Assessment and Outlook Reports would be the same for the LTSP (particularly those listed in Table 4.8 of the Strategic Assessment), based on discussions with GBRMPA staff. However, this was not confirmed before the completion of this project, and is something that should be clarified by the RMREP working groups.

The attributes mentioned in Chapter 4 of the LTSP reflect those attributes of natural values already referred to and assessed in the Strategic Assessment and Outlook Reports (for the marine environment). For Ecosystem Health the attributes include: current condition and trend; connectivity; resilience; and extent (**Figure 2**). For Biodiversity the attributes include: current condition and trend; diversity; habitat availability and condition for species of conservation concern; incidental bycatch of species of conservation concern; and, population size of species of conservation concern (**Figure 3**). For Water Quality the attributes relating to the marine environment are not well articulated, but are assumed from Reef Plan to be: Reef water quality parameters: Chlorophyll a; total suspended sediment; pesticides; and nutrients (**Figure 4**).

We note that the Ecosystem Health targets and objectives do not mention any of the process attributes that are included in the Outlook report (e.g.: physical processes, chemical processes, ecological processes). Rather the Ecosystem Health attributes in the LTSP reflect the attributes of “Habitats to support species” that appear under the Biodiversity section of the Outlook report.

The purpose of this section is not to list all of the possible indicators for every combination of attribute by natural value. Below we provide examples of the types of indicators that could be used to assess the LTSP attributes (and thus objectives and targets):

Current condition and trend (and population size of species of conservation concern): Indicators for Ecosystem Health and Biodiversity:

- Abundance of species/genus/family or functional/morphological groups (current, and change over time);
- Species diversity (current, and change over time);

- Extent of habitat forming species (e.g., coral reefs, seagrass beds, and mangroves); and,
- Change in extent over time.

Connectivity:

Possible indicators for Ecosystem Health

- Area of available habitat;
- Quality (condition) of available habitat;
- Spatial arrangement/connectedness of habitat for larval dispersal; and
- Spatial arrangement/connectedness of habitat that is protected by green zones.

Resilience:

Possible indicators for Ecosystem Health and Biodiversity

- The rate of recovery of a system after disturbance (e.g., the rate of increase in cover of hard corals following a cyclone);
- Abundance of juveniles corals (evidence of recruitment and potential for population replenishment);
- Species diversity and functional redundancy; and,
- Presence of key functional species.

Extent:

Possible indicators for Ecosystem Health and Water Quality:

- Extent of habitat forming species (e.g., coral reefs, seagrass beds, and mangroves), and change in extent over time (while accounting for the ephemeral nature of some species, e.g., seagrasses).

Habitat availability and condition for species of conservation concern:

Possible indicators for Biodiversity:

- Extent of available habitat;
- Spatial configuration of available habitat (e.g. for migrating species); and,
- Quality (condition) of available habitat.

Incidental bycatch of species of conservation concern:

Possible indicators for Biodiversity:

- Bycatch of species of conservation concern (from commercial fishing records).

Water Quality environmental attributes: These are all assumed to mirror those water quality attributes (and therefore indicators) and already developed indicators for the Reef Plan report card.

These attributes were used as a guide to assess the monitoring programs against the LTSP objectives and targets (Section 3.2). We provide details of the variables that are currently monitored in Section 3.2, which could inform indicator selection. We finish with advice about indicator selection in the final recommendations (Section 4).

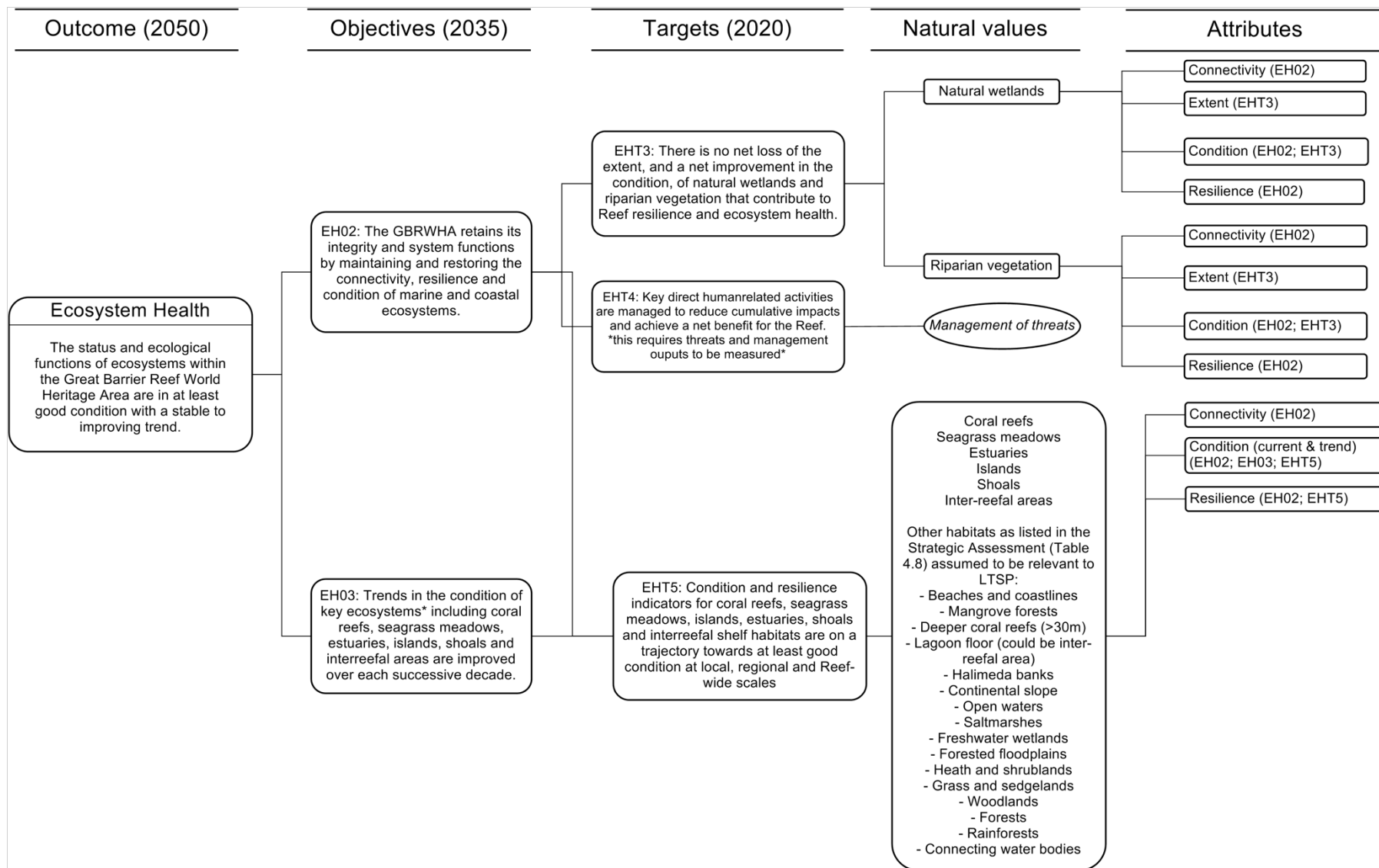


Figure 2: Ecosystem Health breakdown of natural values and attributes.

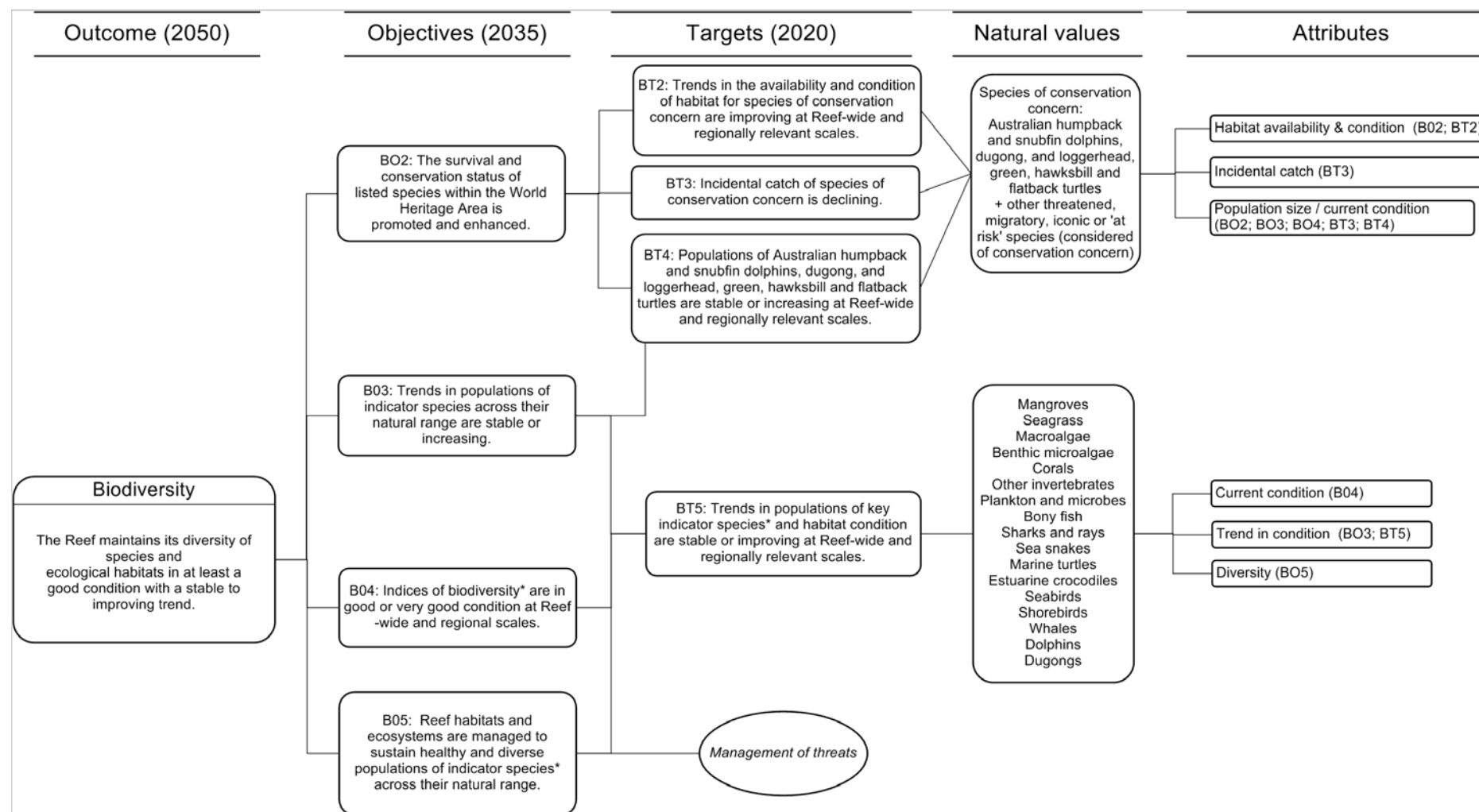


Figure 3: Biodiversity breakdown of natural values and attributes.

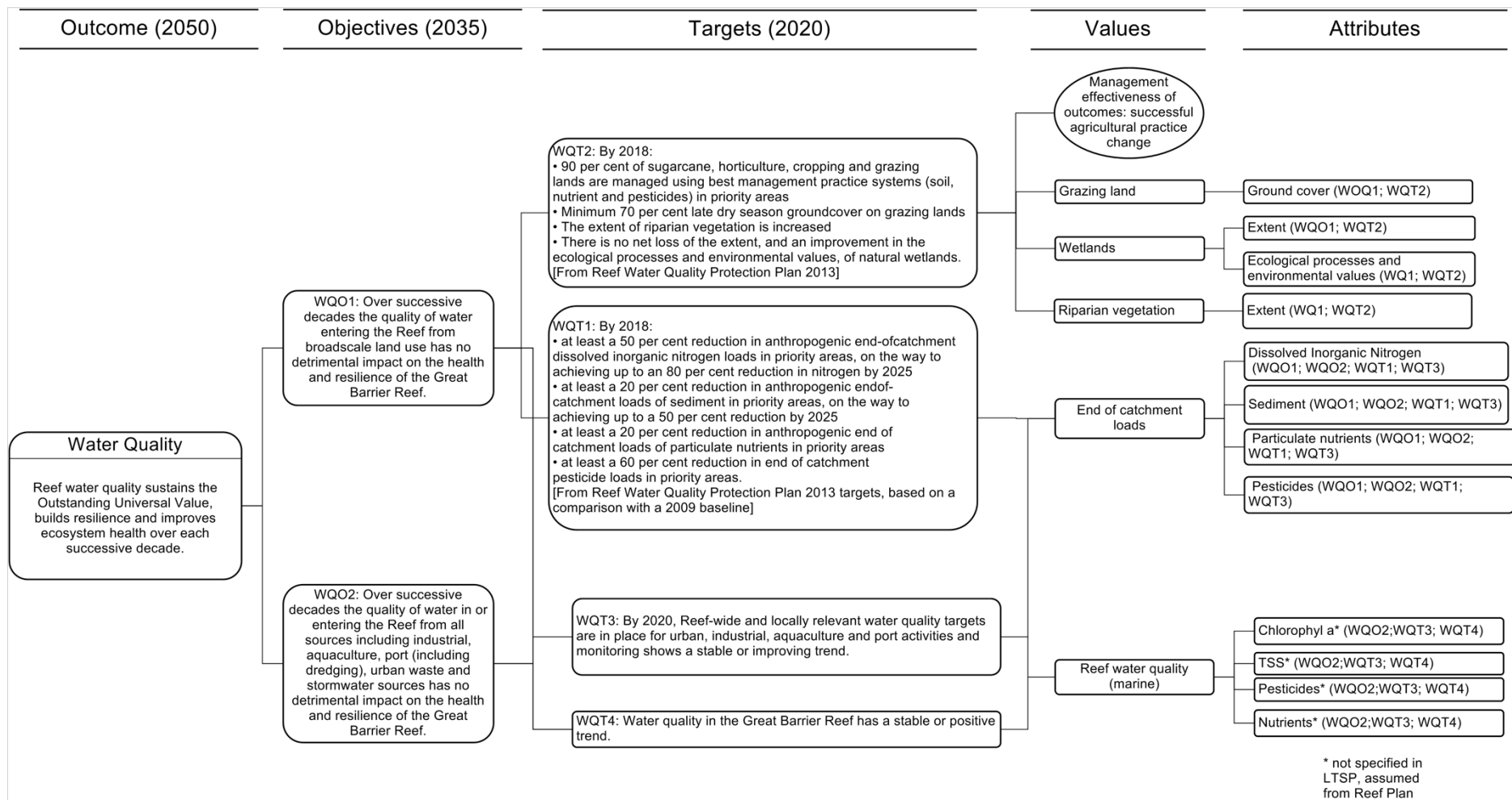


Figure 4: Water Quality breakdown of natural values and attributes.

Socio-economic objectives and targets

We also conducted a breakdown of the socio-economic objectives and targets of the LTSP (Figures 5 - 8). Using the concepts underpinning the DPSIR framework and the Millennium Ecosystem Assessment (Assessment 2005) SELTMP seeks to characterise the human dimension of the GBR socio-ecological system using four components:

- Use and Dependency
- Human Wellbeing
- Indirect Drivers (capacity and context)
- Direct Drivers (use and development)

Targets and objectives specified by the LTSP focus on use and dependency and human wellbeing. The LTSP has a notable emphasis on outcomes for Traditional Owners.

Use and dependency encompasses market and non-market values associated with the GBR. Alongside traditional economic outcomes such as employment, harvest and price, the values associated with use and dependency include recreation, beauty and sense of place.

Characterisation of *human wellbeing* is not straightforward. Here we adopt the same approach as SELTMP, which recognises three elements to wellbeing (Scherl and Emerton 2008):

- Opportunities: the perceived range of options to access and enjoy the Great Barrier Reef.
- Empowerment: the extent that people's needs are acknowledged and have been taken into account and the extent that people are able to contribute to decision-making processes.
- Security: perceptions of social stability, environmental sustainability and environmental quality.

In the LTSP, an example of opportunity is:

- Reef-associated industries are planned and managed in such a way as to protect the Reef's Outstanding Universal Value and are sustainable, productive and profitable.

Numerous LTSP objectives and targets are motivated by empowerment, including:

- Traditional Owners are engaged and participate in and manage the conservation and ecologically sustainable use of cultural keystone species and biocultural resources.
- Indigenous and non-Indigenous heritage values are identified, documented and protected in decision-making and planning processes.

Examples of security include:

- A healthy Reef that supports sustainable lifestyles and livelihoods, and provides coastal communities with protection from extreme weather events.
- Protecting the Reef's Outstanding Universal Value is embedded within decision making with impacts first avoided, then mitigated and then, as a final consideration, any residual impacts are offset to achieve a net environmental benefit.

We coarsely classified LTSP objectives and targets under four values:

Traditional Owners - Use and dependency

- EBO1: Traditional Owners derive economic benefits from conservation and sustainable use of biological resources.
- EBT1: There is an increase in the number of Traditional Owner service providers and viable businesses.
- EBT2: The number of employment opportunities for Traditional Owners in sea country management and Reef-based industries is increased.

Community benefits - Use and dependency

- CBO3: Community benefits provided by the Reef, including its superlative natural beauty and the sense of place, are maintained for current and future generations.
- CBT4: Community benefit values for Great Barrier Reef coastal ecosystems are being monitored and show a positive trend.
- EBO3*: Reef-associated industries are planned and managed in such a way as to protect the Reef's Outstanding Universal Value and are sustainable, productive and profitable.
- EBO4: Reef-dependent industries are productive and profitable based on a healthy Reef and are ecologically sustainable.
- EBT6: Economic indicators are included in the Integrated Monitoring and Reporting Program

Traditional Owners - Wellbeing

- BO1: Traditional Owners are engaged and participate in and manage the conservation and ecologically sustainable use of cultural keystone species and biocultural resources.
- BT1: Customary use of biological resources, in accordance with traditional cultural practices that are compatible with conservation or cultural use requirements, are formally recognised and adopted in management arrangements.
- CBO1: The rights of Traditional Owners to derive benefits from the conservation and cultural use of biological resources are recognised.
- CBT1: The number of benefit sharing initiatives and agreements with Traditional Owners is increased.
- EHO1: The knowledge, innovations and practices of Traditional Owners relevant for conservation and cultural use of biocultural diversity are preserved and maintained.
- EHT1: Traditional Owners have developed Indigenous Ecological Knowledge Management Systems for collecting, handling and sharing culturally sensitive information, and its integration in decision making
- EHT2: The number of agreements with Traditional Owners addressing management of ecosystems within their traditional estates is increased.
- HO1: Traditional Owners' cultural heritage rights and responsibilities are incorporated in all facets of management.

Community Benefits - Wellbeing

- CBO2: A healthy Reef that supports sustainable lifestyles and livelihoods, and provides coastal communities with protection from extreme weather events.
- CBO4: Local, regional and Reefwide community benefits are understood and the community is actively engaged in managing Reef activities.
- CBT2: Community benefit values have been identified and are considered in decision making.
- CBT3: Community participation in stewardship actions to improve Reef health and resilience continues to grow.
- EBO2: Protecting the Reef's Outstanding Universal Value is embedded within decision making with impacts first avoided, then mitigated and then, as a final consideration, any residual impacts are offset to achieve a net environmental benefit.
- EBO3*: Reef-associated industries are planned and managed in such a way as to protect the Reef's Outstanding Universal Value and are sustainable, productive and profitable.
- EBT3: Cumulative impacts on the Reef from human activities are understood and measures to ensure a net environmental benefit approach for the Reef are in place.
- EBT4: Shipping within the Reef is safe, risks are minimised, and incidents are reduced to as close to zero as possible.
- EBT5: The relationship between Reef health and the viability of Reef-dependent industries (e.g., tourism and fishing) is understood and considered in planning and development decisions.
- HO2: Indigenous and non-Indigenous heritage including natural, aesthetic, historic, scientific, and social values are identified, conserved and managed in partnership with the community.
- HT1: New and effective cooperative management practices are developed for protection and conservation of Great Barrier Reef Indigenous and non-Indigenous heritage.
- HT2: Indigenous and non-Indigenous heritage values are identified, documented and protected in decision-making and planning processes.
- HT3: Partnerships between Traditional Owners and all stakeholders are increased to ensure key Reef heritage values are identified, documented, and monitored.
- WQT5: Traditional Owners, industry and community are engaged in onground water quality improvement and monitoring.

*note that EBO3 is included in both coastal community *use and dependency* and *wellbeing*.

When considering the socio-economic values and attributes derived from Chapter 4 of the LTSP, there is coarse alignment with the socio-economic values and attributes listed in the Outlook Report and Strategic Assessment (**Table 1 – Table 3**). We note that emphases in the LTSP on (a) outcomes for Traditional Owners, and (b) empowerment as a core underpinning of wellbeing, are less prominent in the Outlook Report and Strategic Assessment.

Table 1: Outlook 2014 Heritage values (referred to as Assessment Criteria) and attributes (referred to as values; source Sections 4.8.1 – 4.8.5).

Assessment criteria	Values
Indigenous heritage values	Cultural practices, observances, customs and lore Sacred sites, sites of particular significance, and places important for cultural tradition Stories, songlines, totems and languages Indigenous structures, technology, tools and archaeology
Historic heritage values	Historic voyages and shipwrecks Historic lightstations World War II features and sites Other places of historic significance
Other heritage values	Social heritage values Aesthetic heritage values Scientific heritage values
World heritage values and national heritage values	Natural beauty and natural phenomena Major stages of the Earth's evolutionary history Ecological and biological processes Habitats for conservation of biodiversity Integrity
Commonwealth heritage values	Processes Rarity Research Characteristic values Aesthetic characteristics Technical achievement Indigenous tradition

Table 2: Outlook 2014 Commercial and non-commercial use values (referred to as Assessment Criteria) and attributes (referred to as values; source: 5.10.1 & 5.10.2).

Assessment criteria	Values
Economic and social benefits of use	Commercial marine tourism Defence activities Fishing Ports Recreation (not including fishing) Research and educational activities Shipping Traditional use of marine resources
Impact of use	Commercial marine tourism Defence activities Fishing Ports Recreation (not including fishing) Research and educational activities Shipping Traditional use of marine resources

Table 3: Strategic Assessment 2014 community benefits (values; source: Table 4.8).

<i>Community benefit values</i>
Income
Employment
Understanding and appreciation
Enjoyment
Access to Reef resources
Personal connection
Health benefits
Aesthetics

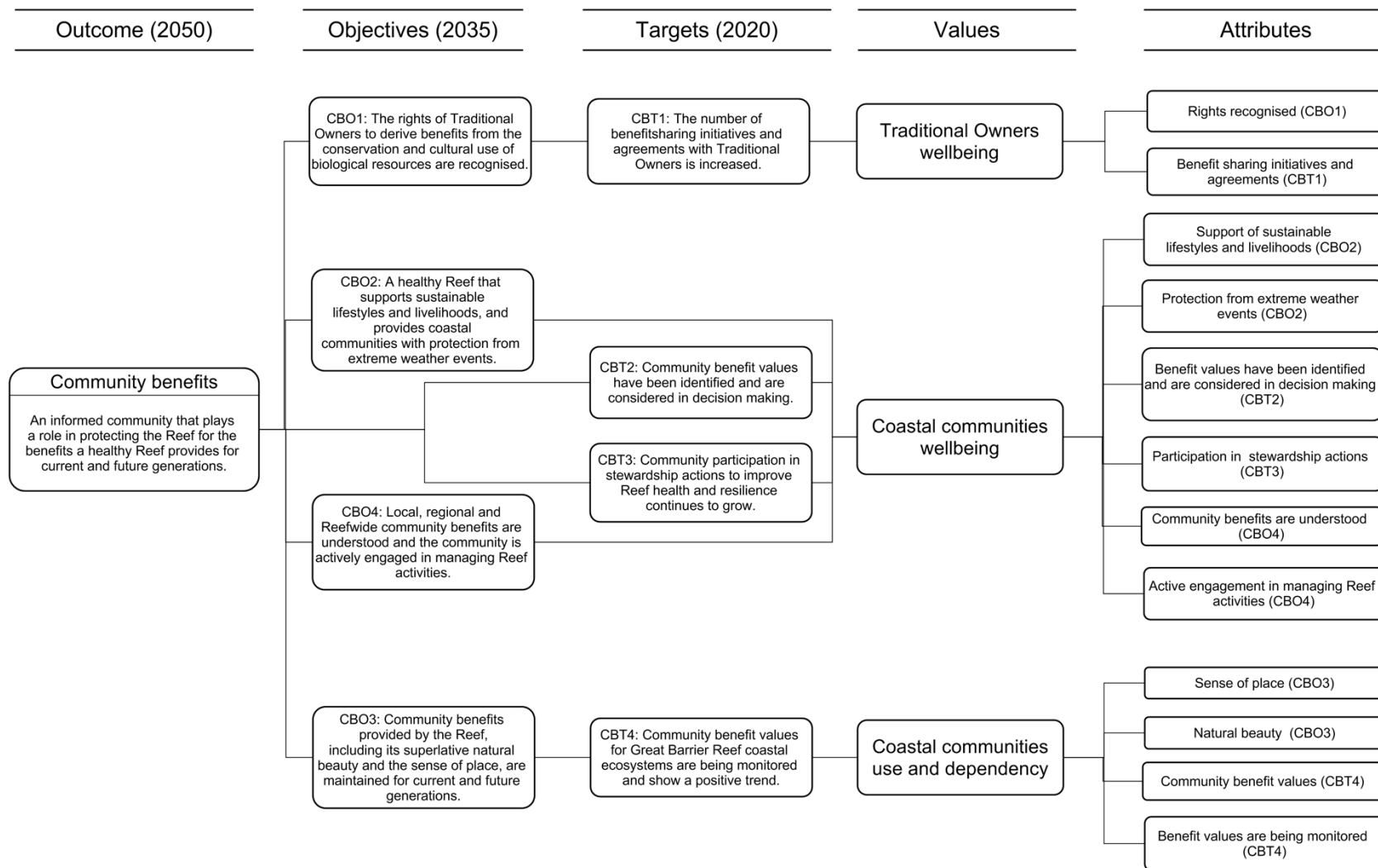


Figure 5: Community Benefits breakdown of socio-economic values and attributes.

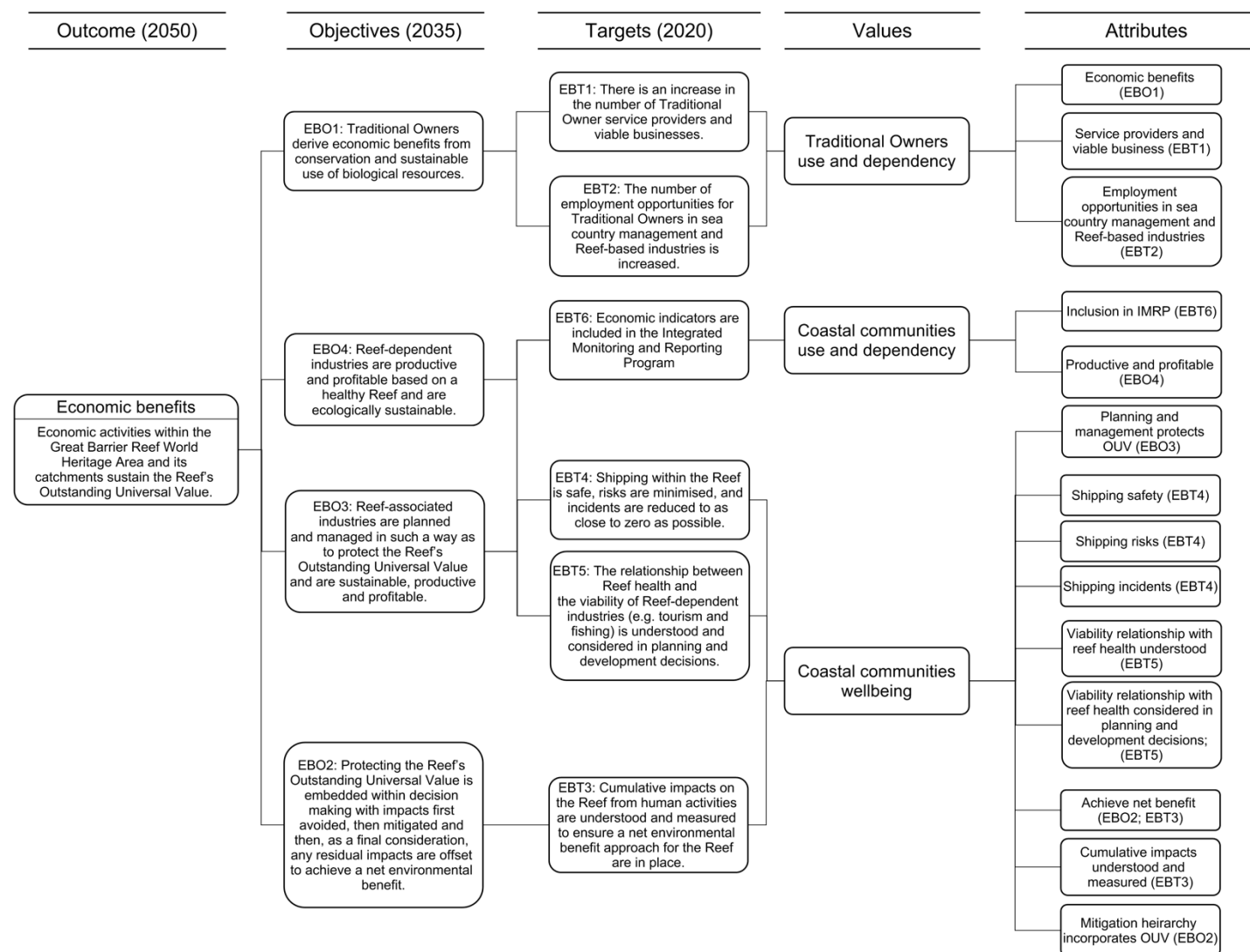


Figure 6: Economic Benefits breakdown of socio-economic values and attributes.

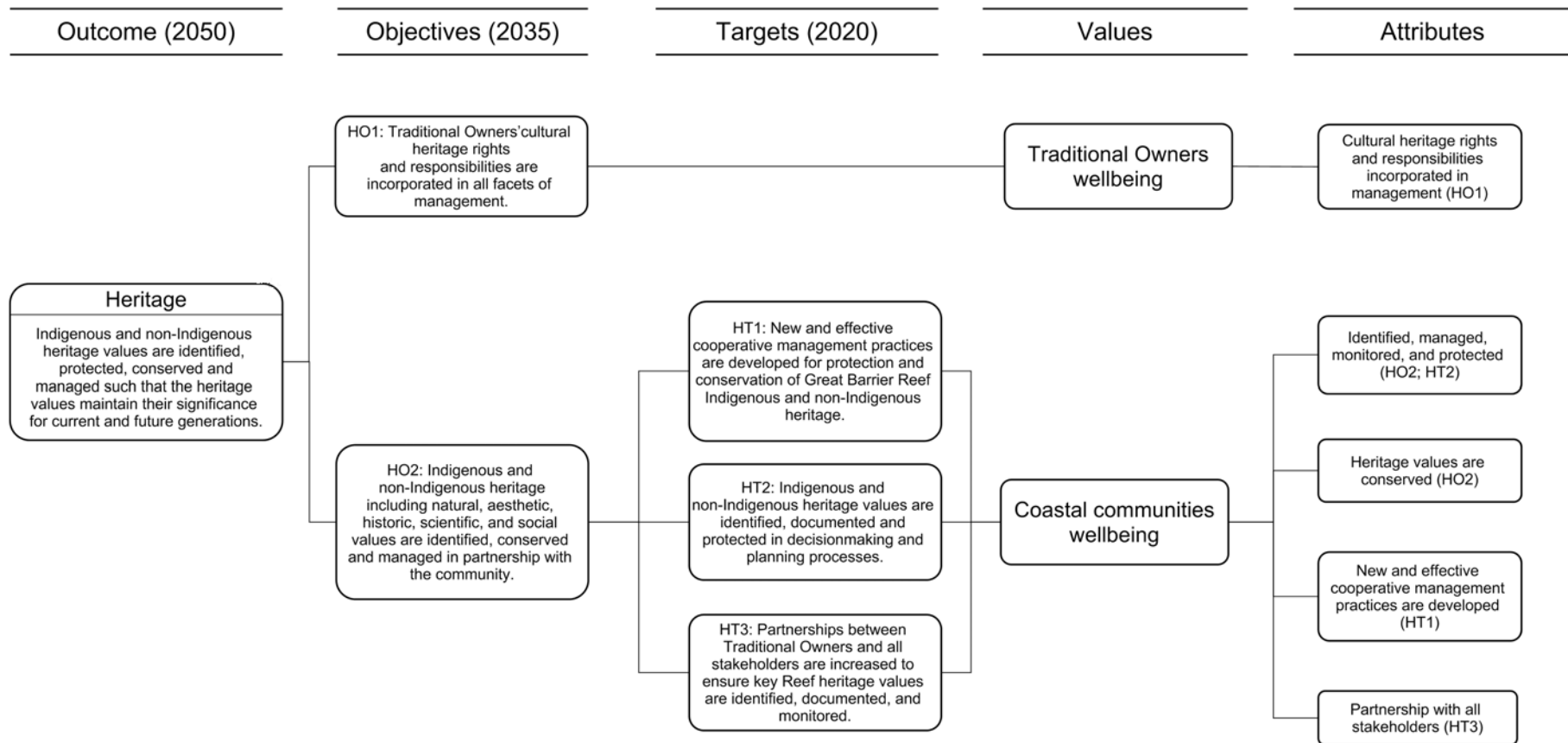


Figure 7: Heritage breakdown of socio-economic values and attributes.

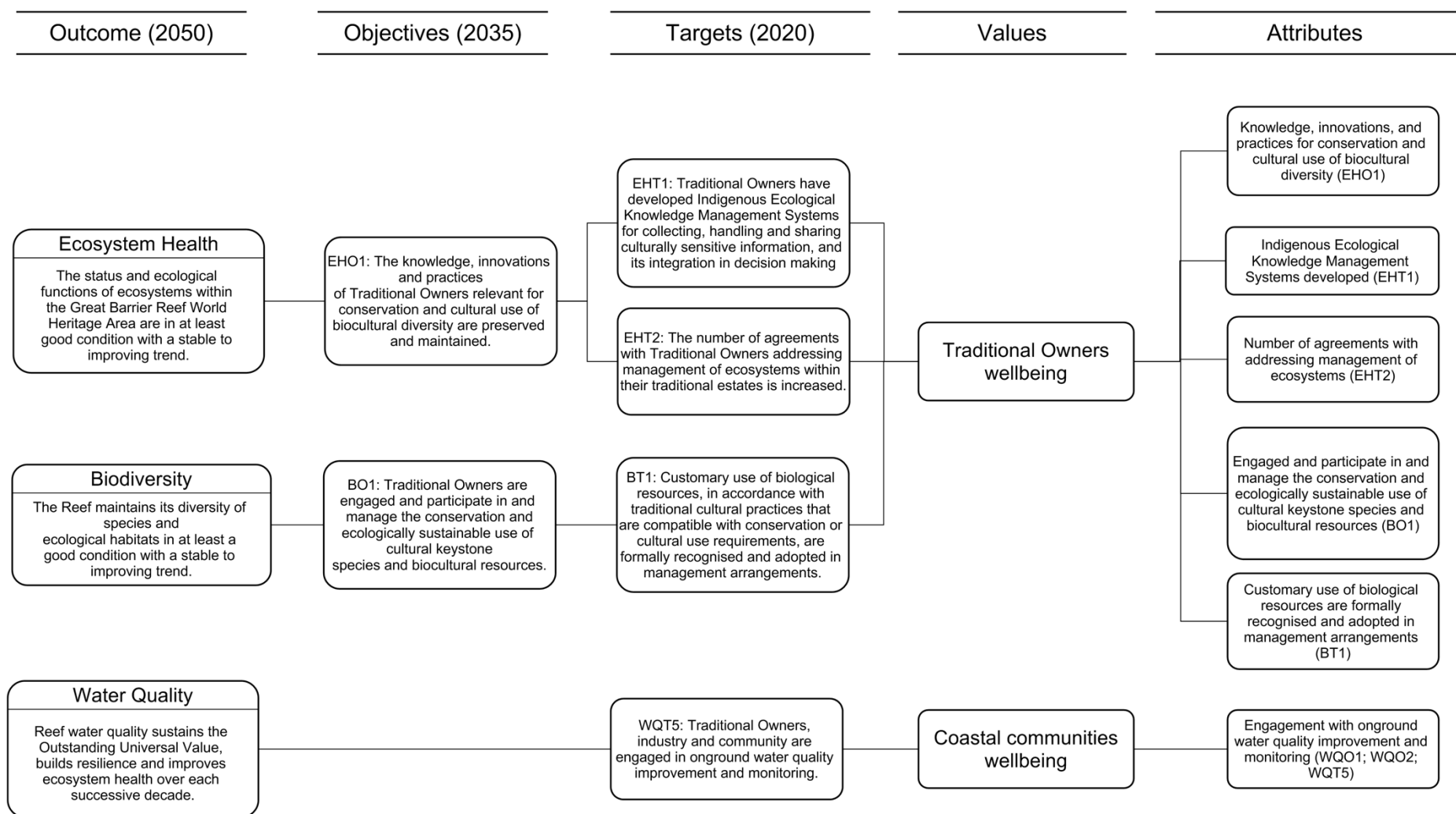


Figure 8: Ecosystem Health, Biodiversity and Water Quality breakdown of socio-economic values and attributes.

LTSP threats

We also assessed all threats mentioned in the LTSP, and crossed checked these against the Outlook Report and Strategic Assessment. We outline all threats mentioned across all three reports and assessments in **Table 4**.

Threats that are mentioned in either the Outlook Report or Strategic Assessment, but are not mentioned in the LTSP are (and may want to be considered for inclusion into the LTSP): Altered ocean currents, Altered weather patterns, Atmospheric pollution, Coastal reclamation, Cyclone activity, Extraction — death of discarded species, Increased freshwater inflow, Ocean acidification, Outbreak of disease, Sea level rise, Sea temperature increase, and Vessel waste discharge.

Table 4: Threats listed in the LTSP, and additional threats (indicated with an asterisk) from Outlook and Strategic Assessment (high and very high threat; source Table 6.11 Strategic Assessment; Figure 9.3 Outlook report) not included in LTSP.

Threats	Source			Where threat is mentioned in LTSP				Description
	LTSP	Outlook 2014	Strategic Assmnt	Theme	Target	Action	Report text only	
Acid sulphate soils	•	•	•	Water quality				Exposure of acid sulphate soils (Outlook 2014, Appendix 5)
Altered ocean currents*		•	•					Climate change induced altered ocean currents (Outlook 2014, Appendix 5)
Altered weather patterns*		•						Climate change effects on weather patterns (e.g., cyclones, wind, rainfall,, air temperature) (Outlook 2014, Appendix 5)
Artificial light	•	•	•	Biodiversity				Artificial lighting including from resorts, industrial infrastructure, mainland beaches and coastlines, vessels and ships (Outlook 2014, Appendix 5)
Atmospheric pollution		•	•					Pollution of the atmosphere related to domestic, industrial and business activities in both the Region and adjacent areas. The contribution of gases such as carbon dioxide to climate change is not included as this is encompassed under threats such as sea temperature increase and ocean acidification (Outlook 2014, Appendix 5)
Barriers to flow	•	•	•	Ecosystem health				Artificial barriers to riverine and estuarine flow (e.g., dams, weirs, breakwalls and gates) (Outlook 2014, Appendix 5)
Broadscale land use	•					WQA5		Not defined in Outlook or Strategic Assessment
Climate change	•					EHA19; CBA9	p 10 - Long-term, system-wide threat	Not defined in Outlook or Strategic Assessment
Coastal reclamation*			•					Coastal land reclamation, including for ports and groynes (Strategic Assessment Table 6.1)
Cyclone activity*			•					Cyclone activity (Strategic Assessment Table 6.1)
Damage to reef structure	•	•		Ecosystem health				Physical damage to reef benthos (reef structure) through actions such as snorkelling, diving, anchoring and fishing, but not vessel grounding (Outlook 2014, Appendix 5)

Threats	Source			Where threat is mentioned in LTSP				Description
	LTSP	Outlook 2014	Strategic Assmnt	Theme	Target	Action	Report text only	
Damage to sea floor*		•	•					Physical damage to non-reef benthos (seafloor) through actions such as trawling and anchoring (Outlook 2014, Appendix 5). Assuming this is "Physical damage" listed in the Strategic Assessment.
Discarded catch	•	•				BA6; BA23	p 11 - Immediate, local/regional "direct use" threat	Immediate or post-release effects (such as death, injury, reduced reproductive success) on discarded species as a result of interactions with fishing gear. Does not include species of conservation concern (defined in Outlook as "Discarded catch")
Disposal of dredge material	•	•	•	Water quality		WQA18		Disposal and resuspension of dredge material (Outlook 2014, Appendix 5)
Dredging	•	•	•	Water quality		WQA14-20		Dredging of the seafloor (Outlook 2014, Appendix 5)
Extraction from spawning aggregations	•	•	•	Biodiversity				Retained take (extraction) of fish from unidentified or unprotected spawning aggregations (Outlook 2014, Appendix 5)
Extraction of particle feeders	•	•	•	Biodiversity				Retained take (extraction) of particle feeders (filter feeders, detritivores) through commercial and non-commercial uses (Outlook 2014, Appendix 5)
Extraction of predators	•	•	•	Biodiversity			p 11 - Immediate, local/regional "direct use" threat	Retained take (extraction) of predators (e.g., sharks, fish) through commercial and non-commercial uses (Outlook 2014, Appendix 5)
Extraction of herbivores	•	•	•	Biodiversity				Retained take (extraction) of herbivores (e.g., some fishes, molluscs, dugongs, green turtles) through commercial and non-commercial uses (Outlook 2014, Appendix 5)
Extraction — death of discarded species*			•					Death of non-retained species from fishing, collecting, hunting, scientific sampling and Queensland's Shark Control Program (Strategic Assessment Table 6.1)
Grounding vessel (large)	•	•		Ecosystem health				Grounding of large vessels (>50m) including physical damage and the dislodging of antifoulants (Outlook 2014, Appendix 5)
Grounding vessel (small)	•	•		Ecosystem health				Grounding of small vessels (<50m) including physical damage and the dislodging of antifoulants (Outlook 2014, Appendix 5)

Threats	Source			Where threat is mentioned in LTSP				Description
	LTSP	Outlook 2014	Strategic Assmnt	Theme	Target	Action	Report text only	
Illegal activities	•	•		Ecosystem health				Illegal activities — other: Illegal activities such as entering a protected or restricted area, illegal release of industrial discharge, shipping outside of designated shipping areas (Outlook 2014, Appendix 5)
Illegal fishing and poaching	•	•	•	Biodiversity		BA6; BA23	p 11 - Immediate, local/regional "direct use" threat	Illegal fishing, collecting and poaching (defined in Outlook as "Illegal fishing and poaching"; Outlook 2014, Appendix 5)
Incidental catch of species of conservation concern	•	•			BT3	BA6; BA23	p 11 - Immediate, local/regional "direct use" threat	Immediate or post-release effects (such as death, injury, reduced reproductive success) of interactions of species of conservation concern with fishing gear (defined in Outlook as "Incidental catch of species of conservation concern"; Outlook 2014, Appendix 5)
Incompatible activities by different user groups	•	•					p 11 - Immediate, local/regional "direct use" threat	Activities undertaken within the Region that disturb or exclude other users, such as recreational use in areas important for cultural activities (Outlook 2014, Appendix 5)
<i>Increased freshwater inflow*</i>			•					Increased freshwater inflow from prolonged or heavy rainfall including flood events, and from changes to catchment ecosystems; resulting in reduced salinity (Strategic Assessment Table 6.1)
Increasing regional populations and economic development	•						p 11 - Immediate, local/regional "direct use" threat	Not defined in Outlook or Strategic Assessment
Key direct human related activities that contribute to cumulative impacts	•			Ecosystem health	EHT4			Not defined in Outlook or Strategic Assessment
Marine debris	•	•	•	Ecosystem health		EHA27	p 11 - Immediate, local/regional "direct use" threat	Manufactured material discarded, disposed of or abandoned in the marine and coastal environment (including discarded fishing gear and plastics) (Outlook 2014, Appendix 5)

Threats	Source			Where threat is mentioned in LTSP				Description
	LTSP	Outlook 2014	Strategic Assmnt	Theme	Target	Action	Report text only	
Mining			•					Whilst mining of the Great Barrier Reef was halted 50 years ago and subsequent coral growth has obliterated most impacts, mining on high and low islands for guano based phosphate rock has a continuing impact. In addition, many of the significantly important beach ridge sequences are seen as a source of building materials by developers (Strategic Assessment Table 6.1)
Modifying coastal habitats	•	•	•	Ecosystem health; Biodiversity			p 11 - Immediate, local/regional threat	Clearing or modifying wetlands, mangroves and other coastal habitats (Outlook 2014, Appendix 5)
Noise pollution	•	•	•	Biodiversity	BA25			Noise from human activities, both below and above water (Outlook 2014, Appendix 5)
Nutrient run-off	•	•	•	Ecosystem health; Water quality			p 10 - Immediate, system-wide threat	Nutrients from diffuse land-based run-off (Outlook 2014, Appendix 5)
<i>Ocean acidification*</i>		•	•					Decreasing pH of the Region's waters (Outlook 2014, Appendix 5)
Outbreak of COTS	•	•	•	Ecosystem health; Water quality		EHA12		Outbreak of crown-of-thorns starfish (Outlook 2014, Appendix 5)
<i>Outbreak of disease*</i>		•	•					Outbreak of disease, both naturally occurring and introduced (Outlook 2014, Appendix 5)
Outbreak of other species	•	•	•	Ecosystem health				Outbreak or bloom of naturally occurring species other than crown-of-thorns starfish (Outlook 2014, Appendix 5)
Pesticide run-off	•	•	•	Ecosystem health; Water quality			p 10 - Immediate, system-wide threat	Pesticides (including herbicides, insecticides, fungicides) from diffuse land-based run-off (Outlook 2014, Appendix 5)
Port activities	•						p 11 - Immediate, local/regional "direct use" threat	Not defined in Outlook or Strategic Assessment
Port sediments	•					WQA17		Not defined in Outlook or Strategic Assessment
<i>Sea level rise*</i>		•	•					Rising sea level (Outlook 2014, Appendix 5)

Threats	Source			Where threat is mentioned in LTSP				Description
	LTSP	Outlook 2014	Strategic Assmnt	Theme	Target	Action	Report text only	
Sea temperature increase*		•	•					Increasing sea temperature (Outlook 2014, Appendix 5)
Sediment run-off	•	•	•	Ecosystem health; Water quality			p 10 - Immediate, system-wide threat	Sediments from diffuse land-based run-off (Outlook 2014, Appendix 5)
Shipping incidents	•			Ecosystem health		EHA26		Not defined in Outlook or Strategic Assessment
Spill — large chemical (LTSP: Chemical spill (large))	•	•	•	Ecosystem health				Chemical spill that triggers a national or regional response or is more than 10 tonnes (Outlook 2014, Appendix 5)
Spill — large oil (LTSP: Oil spill (large))	•	•	•	Ecosystem health				Oil spill that triggers a national or regional response or is more than 10 tonnes (Outlook 2014, Appendix 5)
Spill - small	•	•	•	Ecosystem health				Chemical or oil spill that does not trigger a national or regional response and is less than 10 tonnes (Outlook 2014, Appendix 5)
Terrestrial discharge	•	•	•	Water quality		WQA10, 12		Terrestrial point-source discharge including polluted water, sewage, wastewater and stormwater (Outlook 2014, Appendix 5)
Urban, industrial and port activities	•					WQA5		Not defined in Outlook or Strategic Assessment
Vessel strike	•	•	•	Biodiversity		BA7; BA14		Death or injury to wildlife as a result of being struck by a vessel of any type or size (Outlook 2014, Appendix 5)
Vessel waste discharge*		•	•					Waste discharge from a vessel (including sewage) (Outlook 2014, Appendix 5)
Wildlife disturbance	•	•	•	Biodiversity		BA7; BA8; BA14; BA15; BA25		Disturbance to wildlife including from snorkelling, diving, fish feeding, walking on islands and beaches, and the presence of boats; not including noise pollution (Outlook 2014, Appendix 5)

3.2 Monitoring program inventory

The inventory of environmental monitoring programs revealed a total of 109 monitoring programs that are currently being undertaken in the GBRWHA marine environment and neighbouring catchments (see Appendix 2 for a full list of monitoring program names and responsible organisations). The full inventory (a spreadsheet and supporting references) has been provided to the RIMREP Program Design working group to continue to use in the development of an integrated monitoring and reporting program. Here we provide an overview the monitoring programs compiled in the inventory, with a focus on an assessment of the **marine monitoring programs** against LTSP objectives, targets and threats (as EHP will be providing an in depth assessment of the freshwater, estuarine and terrestrial monitoring programs associated with the GBRWHA catchments).

Environmental monitoring program overview

Of the 109 monitoring programs, 80 of these monitoring programs are associated with the marine environment¹. Most (48) of the marine monitoring programs have the primary purpose of monitoring biological variables (Figure 9; e.g., monitor species or ecosystems), with fewer (23) programs having a primary purpose of monitoring physico-chemical variables (e.g., water quality parameters) or threatening processes (9; e.g., marine debris). Of the 71 programs that have the primary purpose of monitoring biological or physico-chemical variables, 47 also monitor at least one threatening process at the same time (e.g., water turbidity or presence of marine debris).

¹ Here marine monitoring including coastal monitoring of mangroves, seabirds and shorebirds

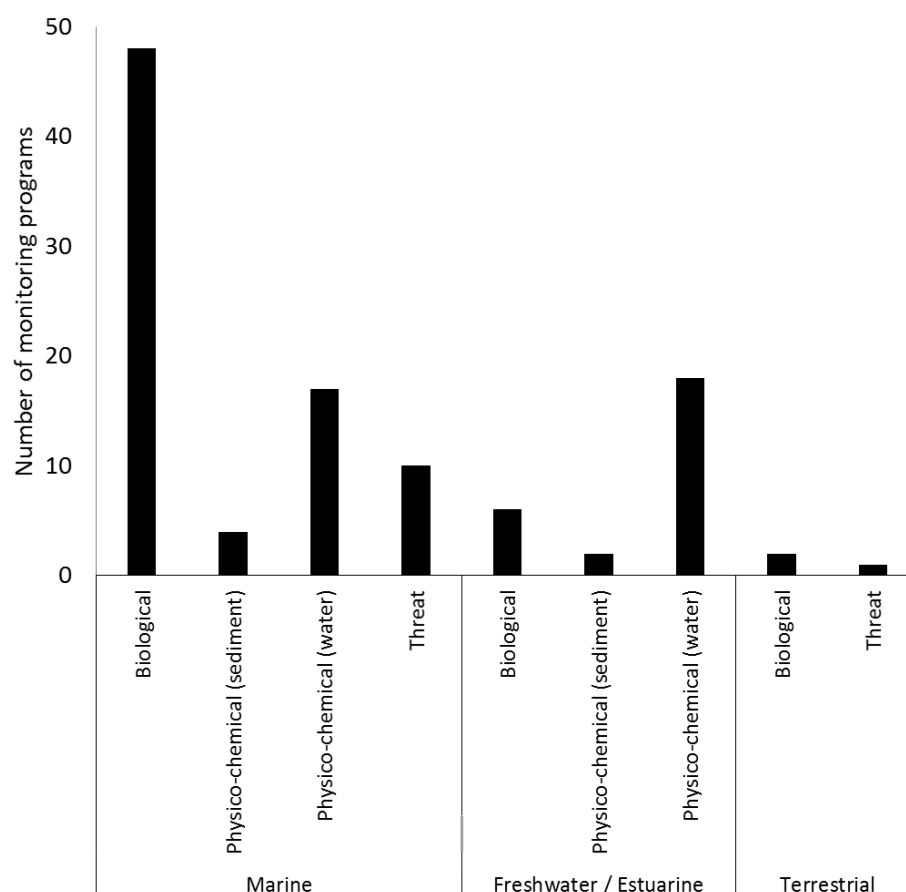


Figure 9: Type of monitoring undertaken in the GBRWHA and catchments.

The spatial extent of the marine monitoring programs range from only occurring in the GBRWHA or neighbouring catchments (50 programs; e.g., the AIMS long term monitoring program (AIMS ID #23)), state-wide (13 programs; e.g., EHP's Queensland Turtle Conservation Project (AIMS ID #12)), national (8 programs; e.g., the ReefTemp monitoring program (AIMS ID #3; led by CSIRO, GBRMPA and BoM)), to international (9 programs; e.g., Reef Life Survey (AIMS ID #66)). A full breakdown of the spatial extent of all monitoring programs is shown in Figure 10, and details of the spatial extent of each individual monitoring program can be found in the full inventory provided to the RIMREP Program Design working group.

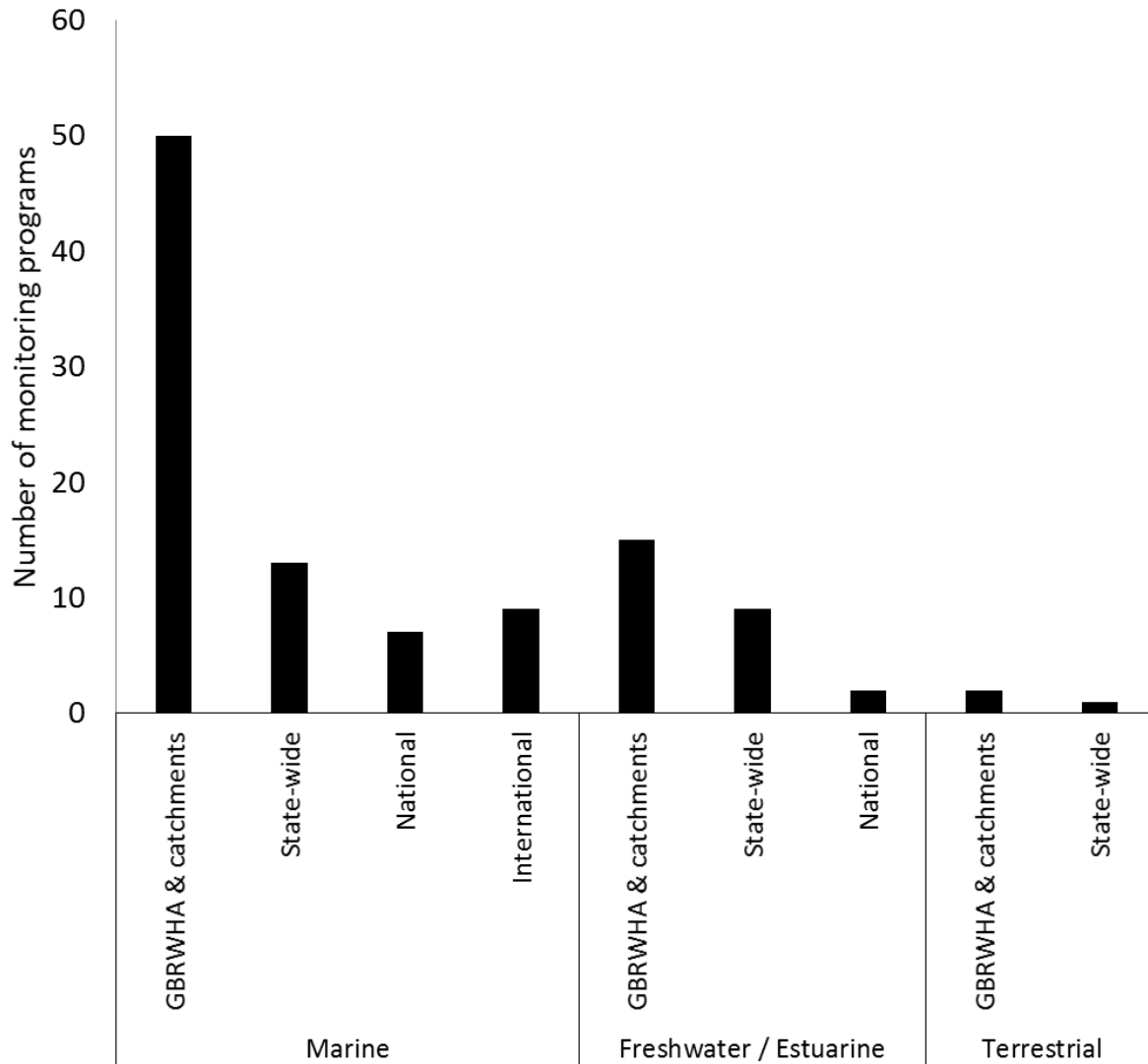


Figure 10: The spatial extent of monitoring programs.

When comparing the age classes (**Table 5**) of the marine monitoring programs, it is clear that they vary substantially in age² (Figure 11). Some are very new programs that have only been conducted once within the last two years (10 marine monitoring programs; e.g., WWF's Rivers to Reefs to Turtles programs (AIMS ID #81) which commenced in 2014) all the way through to programs which have been running for over 20 years (23 marine monitoring programs; e.g., Seagrass Watch (AIMS ID #34) which commenced in 1999).

² Note for monitoring programs where the start date has varied (e.g., between sites, or monitoring has evolved from when it commenced), we used the earliest start date to represent the age of the monitoring program. Full details of the monitoring program age can be found in the full inventory provided to the RIMREP Program Design working group.

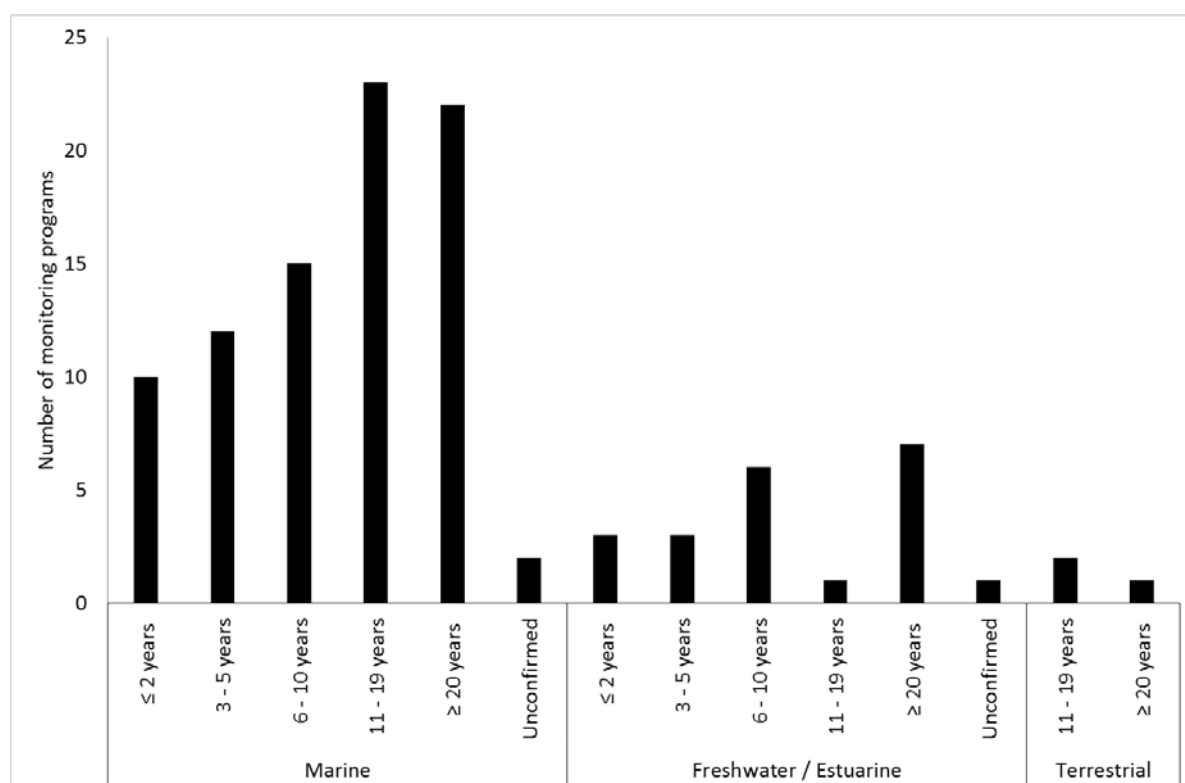


Figure 11: The age of monitoring programs in the GBRWHA.

Table 5: Age classes used to categorise the marine monitoring programs.

<i>Age class</i>	<i>Year monitoring commenced</i>
≤ 2 years	2013, 2014, 2015
3 - 5 years	2010, 2011, 2012
6 - 10 years	2005, 2006, 2007, 2008, 2009
11 - 19 years	1996 – 2004
≥ 20 years	Earlier than 1995

The marine monitoring programs in the GBRWHA are undertaken by many different organisations and groups (Figure 12, Table 6). These range from trained scientists in academic institutions or government agencies (45 marine monitoring programs; e.g., JCU's Dugong Monitoring Program (AIMS ID# 10)), to citizen scientists (8 marine monitoring programs; e.g., GBRMPA's Eye on the Reef sightings network (AIMS ID# 26)), and the tourism industry (3 marine monitoring programs; e.g., the monitoring component of the Crown-of-thorns Starfish Outbreak Management Program (RRRC & GBRMPA; AIMS ID #86).

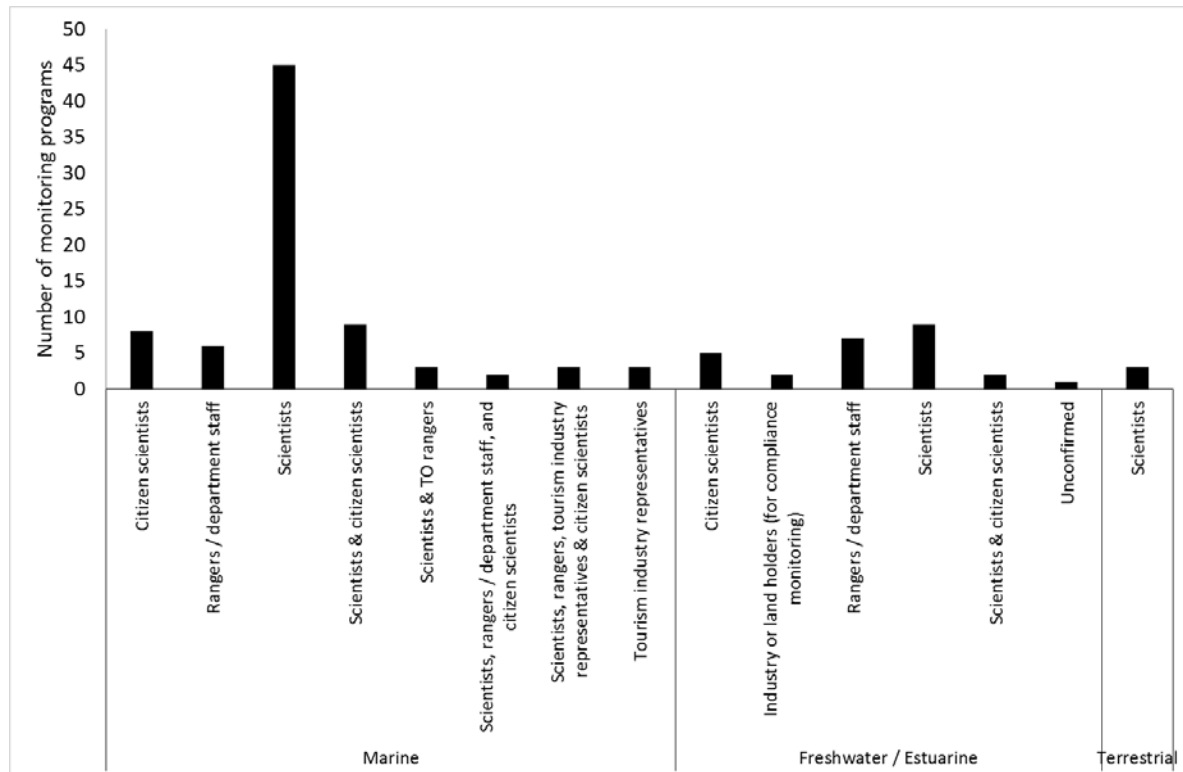


Figure 12: Those who undertake monitoring.

Table 6: Definitions of those who conduct monitoring.

Who conducts monitoring	Definitions
Scientists	Those with scientific training from academic or government institutions whose jobs include monitoring.
Citizen scientists	Members of the community with varying levels of monitoring training (from highly trained scientists doing surveys in their spare time (e.g., Reef Life Survey (AIMS ID #66) through to untrained school groups (e.g., Port Curtis Harbour Watch (AIMS ID #101)) who participate in monitoring programs on a volunteer basis.
Rangers / department staff	Rangers or staff who have received monitoring training from state/federal government agencies or Traditional Owner groups whose jobs include monitoring.
Tourism industry representatives	Tourism operators or members of the Association of Marine Park Tourism Operators (AMPTO) who have received monitoring training and whose jobs include monitoring.
Industry or land holders (for compliance or contracted monitoring)	Industry (e.g., sewage treatment plant operators) or landholders of farms who are either required to do monitoring (compliance) or have been contracted to do monitoring.

Assessment of marine environmental monitoring programs against the LTSP natural values and attributes (derived from LTSP objectives and targets) and threats

Here we present an assessment of the marine monitoring programs against the newly developed LTSP targets and objectives and threatening processes. In order to do this we first aligned the monitoring programs with the LTSP natural values (presented in the flow charts in Section 3.1). We then assessed which marine monitoring programs could be used to assess which attributes of the natural values (derived from LTSP objectives and targets).

Table 8 - Table 38 illustrate how the marine environmental monitoring programs address the LTSP natural values and attributes, and objectives and targets. In our assessment, we summarise whether monitoring programs address certain attributes using the following criteria:

Ecosystem Health

- Connectivity: monitoring must occur across > 2 regions (note that this is a very simplistic criterion, and much more work is required to establish what monitoring programs will be able to provide data for meaningful indicators of connectivity in the future).
- Condition: abundance or % cover of species or groups of species must be monitored.
- Resilience: monitoring must occur for > 10 yrs (note that this is a very simplistic criterion, and much more work is required to establish what monitoring programs will be able to provide data for meaningful indicators of resilience in the future).
- Extent: the area of habitat must be monitored.

Biodiversity

- Current and trend in condition: abundance or % cover of species or groups of species (accommodating for different programs that vary greatly in the taxonomic breadth and resolution that they record) in a location must be monitored through time.
- Diversity: multiple species (or genus, family or functional groups) of the same natural value (e.g., multiple species of reef fish) must be monitored.
- Species of conservation concern³ (habitat availability and condition): The condition of habitat used by species of conservation concern must be monitored.
- Species of conservation concern (incidental bycatch): Bycatch of species of conservation concern must be monitored.
- Species of conservation concern (population size): Abundance of species of conservation concern must be monitored.

Water Quality

- Wetland extent: the area of wetlands must be monitored.
- Wetlands ecological processes and environmental values: ecological processes and values of wetlands must be monitored.
- Chlorophyll a: Chlorophyll a must be monitored.
- TSS: TSS must be monitored.
- Pesticides: Pesticides must be monitored
- Nutrients: Nutrients must be monitored

³ Species of conservation concern include: dugongs, whales, dolphins, seabirds, marine turtles, sharks and rays, threatened species, migratory and iconic species (GBRMPA 2014).

These criteria are a first cut at assessing which monitoring programs will help evaluate the LTSP objectives and targets. We also summarise the monitoring programs' temporal coverage (in relation to the age of the monitoring programs, and the frequency of monitoring), and the spatial coverage (the NRM regions where monitoring occurs). However we stress that further assessment of the adequacy of monitoring programs should be undertaken **once indicators have been developed**. The adequacy of monitoring program data to inform specific indicators could be very different to our first cut assessment of monitoring programs, as the type of data collected by some monitoring programs will not be suited to all indicators. Much more detailed information on each program can be found in the full inventory provided to the RIMREP Program Design working group – which can be used to inform whether monitoring programs will inform indicators once they have been developed.

Maps have been produced to illustrate the spatial coverage of current monitoring programs for most natural values, where spatial data could be obtained from program contacts: coral reefs (**Figure 13** and **Figure 14**), seagrass (**Figure 15**), mangroves (**Figure 16**), bony fishes (**Figure 17**), dolphins and dugong (**Figure 18**), marine turtles (**Figure 19**), sharks and rays (**Figure 20**), and shorebirds and seabirds (**Figure 21**).

We note clear gaps in existing monitoring relating to the following key values of matters of national environmental significance:

- Deeper (>30 m) coral reefs
- Lagoon floor
- Shoals
- *Halimeda* banks
- Continental slope
- Benthic microalgae
- Plankton and microbes
- Sea snakes⁴

We also aligned the environmental monitoring programs with the LTSP threats outlined in **Table 4**. As this was not a core part of this project, we have not done an in depth assessment of the coverage of these monitoring programs in addressing the threats (as we have with the natural values), rather we have listed the monitoring programs against the threats (**Table 39**) and summarised the variables that are monitored through these programs that can be used to assess the threats (**Table 40**). Further assessment of adequacy can be undertaken by viewing the “Threats monitored” worksheet of the full inventory provided to the RIMREP Program Design working group.

⁴ Some coral reef and dugong/dolphin monitoring programs record sea snakes, but there are no programs dedicated to sea snake monitoring.

Coral reefs (Habitat/Species) (corals, other invertebrates, macroalgae)**Table 7:** Assessment of environmental monitoring programs against the LTSP natural values and attributes (derived from LTSP objectives and targets): Coral reefs

AIMS ID	Program and organisation	Ecosystem health				Biodiversity					
		Connectivity (EHO2)	Condition (EHO2; EHO3; EHT5)	Resilience (EHO2; EHT5)	Wetland extent (EHT3)	Current condition (BO4)	Trend in condition (BO3; BT5)	Diversity (BO5)	Species of conservation concern: habitat availability and condition (BO2; BT2)	Species of conservation concern: incidental bycatch (BT3)	Species of conservation concern: population size (BO2; BO3; BO4; BT4)
13	Effects of management zoning on inshore reefs of the Great Barrier Reef Marine Park: benthic condition & fish (JCU)	•	•	•		•	•	•			
14	Effects of management zoning on inshore reefs of the Great Barrier Reef Marine Park: Derelict fishing line on fringing reefs (JCU)	•	•	•		•	•	•			
23	AIMS Long-term Monitoring Program (AIMS)	•	•	•		•	•	•			
24	Effects of rezoning on offshore coral reef systems (AIMS)	•	•	•		•	•	•			
25	Eye on the Reef - Rapid Monitoring Survey (GBRMPA)	•	•			•	•	•			
27	Eye on the Reef - Reef Health and Impact Survey (GBRMPA)	•	•			•	•	•			
28	Eye on the Reef - Tourism Weekly Monitoring Surveys (GBRMPA & Tourism Industry)	•	•			•	•	•			
29	Reef Check (Coral Reef Health Monitoring) (Reef Check Australia)	•	•	•		•	•	•			
36	Marine Monitoring Program - Inshore Coral (AIMS)	•	•	○ ⁵		•	•	•			
48	AIMS coral monitoring Gladstone Harbour (AIMS)		•	○ ⁴		•	•	•			
56	North Queensland Bulk Ports Corporation – Coral Monitoring (NQBP)		•			•	•	•			

⁵ The AIMS MMP coral and Gladstone Harbour coral monitoring programs are both 10 years old, so just miss our criteria for addressing the resilience attribute (>10 years), however both have developed resilience indicators for coral cover, coral juvenile density and macroalgae cover.

AIMS ID	Program and organisation	Ecosystem health				Biodiversity					
		Connectivity (EHO2)	Condition (EHO2; EHO3; EHT5)	Resilience (EHO2; EHT5)	Wetland extent (EHT3)	Current condition (BO4)	Trend in condition (BO3; BT5)	Diversity (BO5)	Species of conservation concern: habitat availability and condition (BO2; BT2)	Species of conservation concern: incidental bycatch (BT3)	Species of conservation concern: population size (BO2; BO3; BO4; BT4)
66	Reef Life Survey (RLS)	•	•			•	•	•			
77	Coral Watch (UQ)		•	•		•	•				
86	Crown-of-thorns Starfish Outbreak Management Program (RRRC & GBRMPA)		•			•	•	•			
88	Catlin Seaview Survey (UQ)	•	•			•	•	•			
95	Recovery of the Great Barrier Reef (Earthwatch & AIMS)		•			•	•	•			

Table 8: Monitoring duration, frequency and spatial extent: Coral reefs

AIMS ID	Program and organisation	Monitoring program duration ⁶	Monitoring program frequency ⁷	Region where monitoring occurs ⁸					
				CY	WT	B	MW	F	BM
13	Effects of management zoning on inshore reefs of the Great Barrier Reef Marine Park: benthic condition & fish (JCU)	11 - 19 years	Annual			•	•	•	
14	Effects of management zoning on inshore reefs of the Great Barrier Reef Marine Park: Derelict fishing line on fringing reefs (JCU)	6 - 10 years	Annual			•	•	•	

⁶ Note for monitoring programs where the start date has varied (e.g., between sites, or monitoring has evolved from when it commenced), we used the earliest start date to represent the age of the monitoring program. Full details of the monitoring program age can be found in the full inventory provided to the RIMREP Program Design working group.

⁷ Note for monitoring programs where the temporal frequency varies as the monitoring program has evolved, we use the current frequency or lowest frequency (e.g., for a monitoring program conducted monthly at some sites and annually at others, we count this as monthly). All monitoring frequencies were coded into the following categories: < hourly (i.e. continuous); Daily; Weekly; Monthly; Quarterly; Annual; Once every 2 years (i.e., biennial); Once every 3 or more years. Full details of the monitoring program frequency can be found in the full inventory provided to the RIMREP Program Design working group.

⁸ NRM regions: CY – Cape York, WT – Wet Tropics, B – Burdekin, MW – Mackay Whitsunday, F – Fitzroy, BM – Burnett Mary.

AIMS ID	Program and organisation	Monitoring program duration ⁶	Monitoring program frequency ⁷	Region where monitoring occurs ⁸					
				CY	WT	B	MW	F	BM
23	AIMS Long-term Monitoring Program (AIMS)	≥ 20 years	Once every 2 years	•	•	•	•	•	•
24	Effects of rezoning on offshore coral reef systems (AIMS)	6 - 10 years	Once every 2 years		•	•	•	•	•
25	Eye on the Reef - Rapid Monitoring Survey (GBRMPA)	6 - 10 years	Opportunistic	•	•	•	•	•	•
27	Eye on the Reef - Reef Health and Impact Survey (GBRMPA)	6 - 10 years	Opportunistic	•	•	•	•	•	•
28	Eye on the Reef - Tourism Weekly Monitoring Surveys (GBRMPA & Tourism Industry)	11 - 19 years	Almost weekly (40 times each year)		•		•		•
29	Reef Check (Coral Reef Health Monitoring) (Reef Check Australia)	11 - 19 years	Opportunistic	•	•	•	•	•	•
36	Marine Monitoring Program - Inshore Coral (AIMS)	6 - 10 years	Once every 2 years		•	•	•	•	
48	AIMS coral monitoring Gladstone Harbour (AIMS)	≤ 2 years	Annual					•	
56	North Queensland Bulk Ports Corporation – Coral Monitoring (NQBP)	6 - 10 years	Biannual			•	•		
66	Reef Life Survey (RLS)	6 - 10 years	Opportunistic	•	•	•	•	•	•
77	Coral Watch (UQ)	11 - 19 years	Variable	•	•	•	•	•	•
86	Crown-of-thorns Starfish Outbreak Management Program (RRRC & GBRMPA)	3 - 5 years	Unconfirmed	•	•				
88	Catlin Seaview Survey (UQ)	3 - 5 years	Variable	•	•	•		•	•
95	Recovery of the Great Barrier Reef (Earthwatch & AIMS)	3 - 5 years	Biannual			•			

Variables monitored: Coral: % cover of hard & soft corals, coral size classes, larval settlement, species composition, counts of juvenile corals, coral disease and damage estimated from underwater visual census or still images. Macroalgae: % cover of macroalgae (different taxonomic resolution or morphological groupings) estimated from underwater visual census or still images. Other invertebrates: abundance of common/focal mobile invertebrates and sessile invertebrates estimated from underwater visual census, still images, or commercial catch data. NB there is great variation in the variables monitored among these programs – more details can be seen in the full inventory provided to the RIMREP Program Design working group.

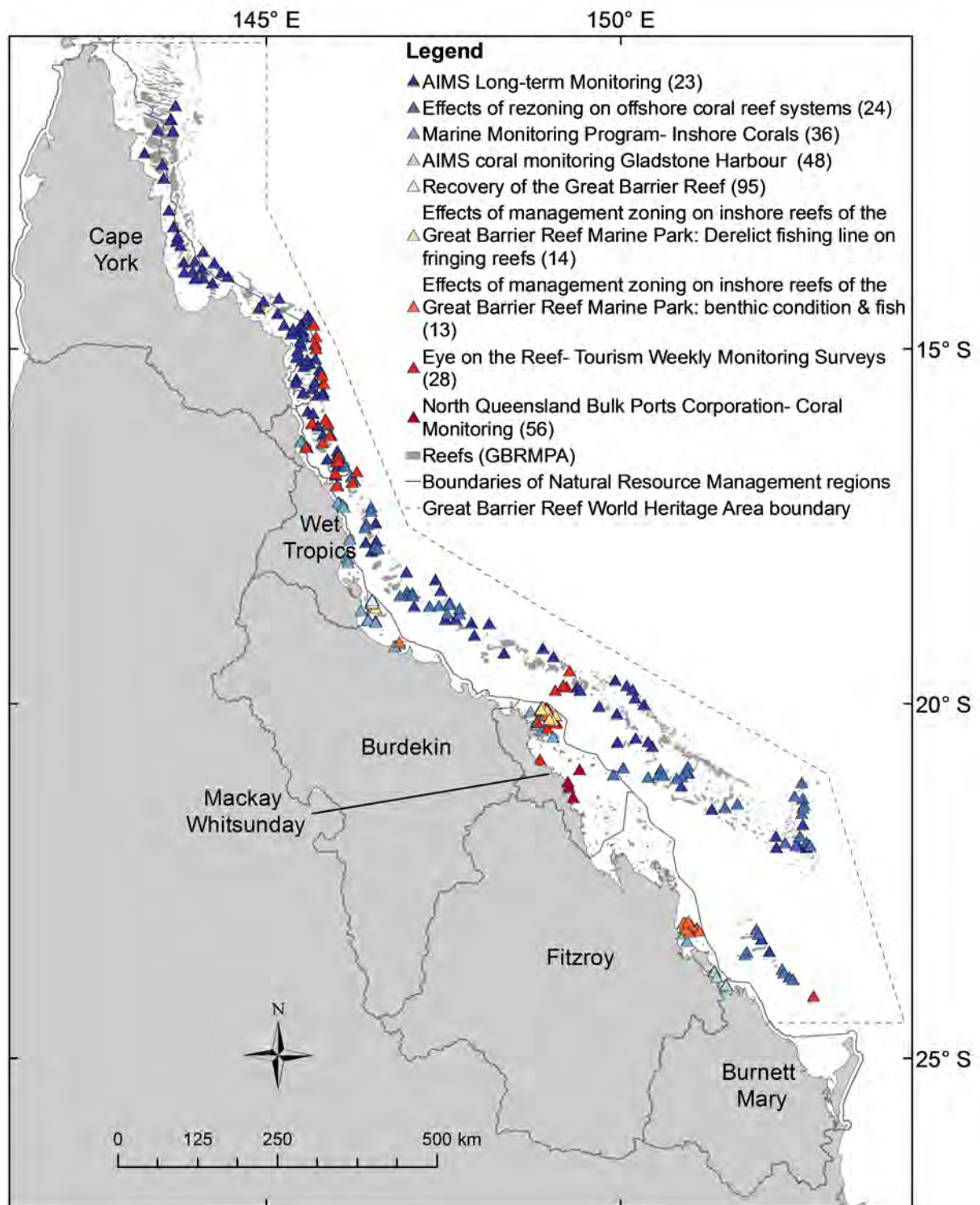


Figure 13: Current monitoring locations: Coral reefs (corals, other invertebrates, macroalgae) Part 1. Displaying programs with *fixed monitoring locations* associated with coral reefs, where corals, other invertebrates and macroalgae are monitored (except for program 14, as spatial data were not available). Points represent single survey locations, where replicate observations are commonly made. All monitoring locations displayed are considered current, where monitoring has been undertaken within the last five years (2010 – 2015). Boundaries for the GBRWHA and the six NRM regions (catchments into the marine environment) are also shown.

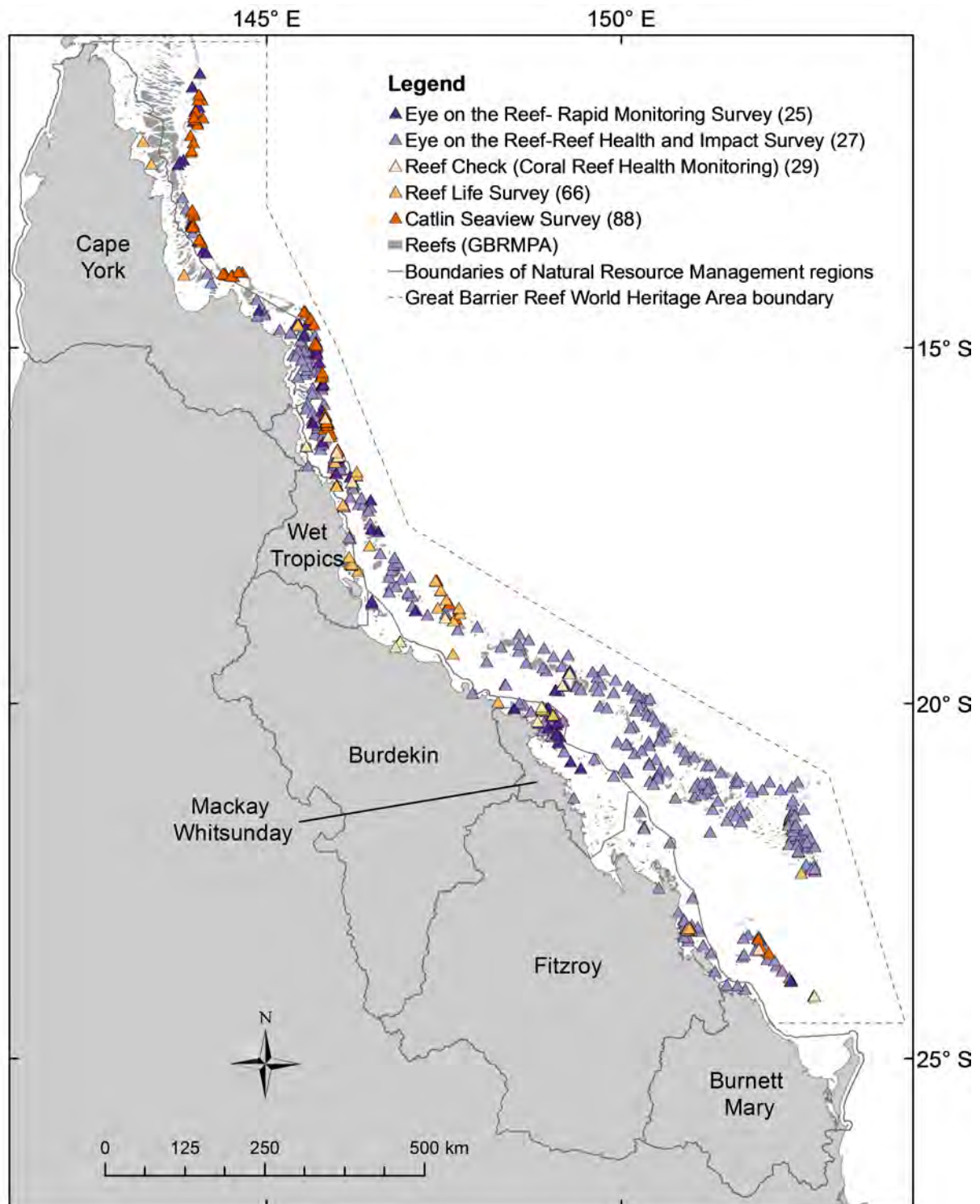


Figure 14: Current monitoring locations: Coral reefs (corals, other invertebrates, macroalgae) Part 2. Displaying programs that undertake opportunistic or variable frequency surveys of different sites over the last five years. Programs are associated with coral reefs, where corals, other invertebrates and macroalgae are monitored (except for programs 77 and 86, as spatial data were not available). Points represent single surveys or observations have been made within the last five years (2010 – 2015). Boundaries for the GBRWHA and the six NRM regions (catchments into the marine environment) are also shown.

Summary: 16 programs monitor coral reef habitat, corals, macroalgae and other invertebrates. The most extensive of these monitoring programs is the AIMS Long-term Monitoring Program (manta tow surveys since 1982, and intensive under water visual census since 1992). The temporal frequency of these monitoring programs varies considerably: ranging from opportunistic surveys (e.g., Reef Check), to surveys occurring once every two years, all the way through to surveys that are undertaken almost weekly (e.g., Eye on the Reef Tourism Weekly Monitoring Surveys). There is good spatial coverage of inshore coral reefs in the central GBR (Wet Tropics, Burdekin, and Mackay Whitsunday), however less monitoring occurs in Cape York and Burnett Mary. The GBRWHA includes extensive coral shoals in deeper water, which are not currently monitored.

Seagrass (Habitat and species)**Table 9:** Assessment of environmental monitoring programs against the LTSP natural values and attributes: Seagrass

AIMS ID	Program and organisation	Ecosystem health				Biodiversity				
		Connectivity (EHO2)	Condition (EHO2; EHO3; EHT5)	Resilience (EHO2; EHT5)	Wetland extent (EHT3)	Current condition (BO4)	Trend in condition (BO3; BT5)	Diversity (BO5)	Species of conservation concern: habitat availability and condition (BO2; BT2)	Species of conservation concern: incidental bycatch (BT3)
34	Seagrass Watch (separate to surveys under MMP) (Seagrass-Watch HQ)	•	•	•		•	•	•	•	
35	Marine Monitoring Program – Inshore Seagrass (Seagrass-Watch HQ)	•	•	O ⁹		•	•	•	•	
44	Queensland Ports Seagrass Monitoring (JCU)	•	•	•		•	•	•	•	

Table 10: Monitoring duration, frequency and spatial extent: Seagrass

AIMS ID	Program and organisation	Monitoring program duration	Monitoring program frequency	Region where monitoring occurs					
				CY	WT	B	MW	F	BM
Seagrass (Habitat and species)									
34	Seagrass Watch (separate from surveys under MMP) (Seagrass-Watch HQ)	≥ 20 years	Quarterly	•	•	•	•	•	•
35	Marine Monitoring Program – Inshore Seagrass (Seagrass-Watch HQ)	6 - 10 years	Once every 2 years	•	•	•	•	•	•
44	Queensland Ports Seagrass Monitoring (JCU)	≥ 20 years	Monthly	•	•	•	•	•	•

Variables monitored: Seagrass % cover, bed extent, species composition, epiphyte cover, sediment composition, canopy height, reproductive structures, tissue samples, nutrient status (carbon, nitrogen and phosphorus) leaf isotopic signatures (carbon and nitrogen), rhizosphere sediment herbicides, in-situ canopy light and temperature, dugong feeding trails estimated from intertidal surveys and aerial surveys.

⁹ The MMP seagrass monitoring program is 10 years old, so just misses our criteria for addressing the resilience attribute(>10 years). However this program does have indicators that could be used to infer the resilience of seagrass.

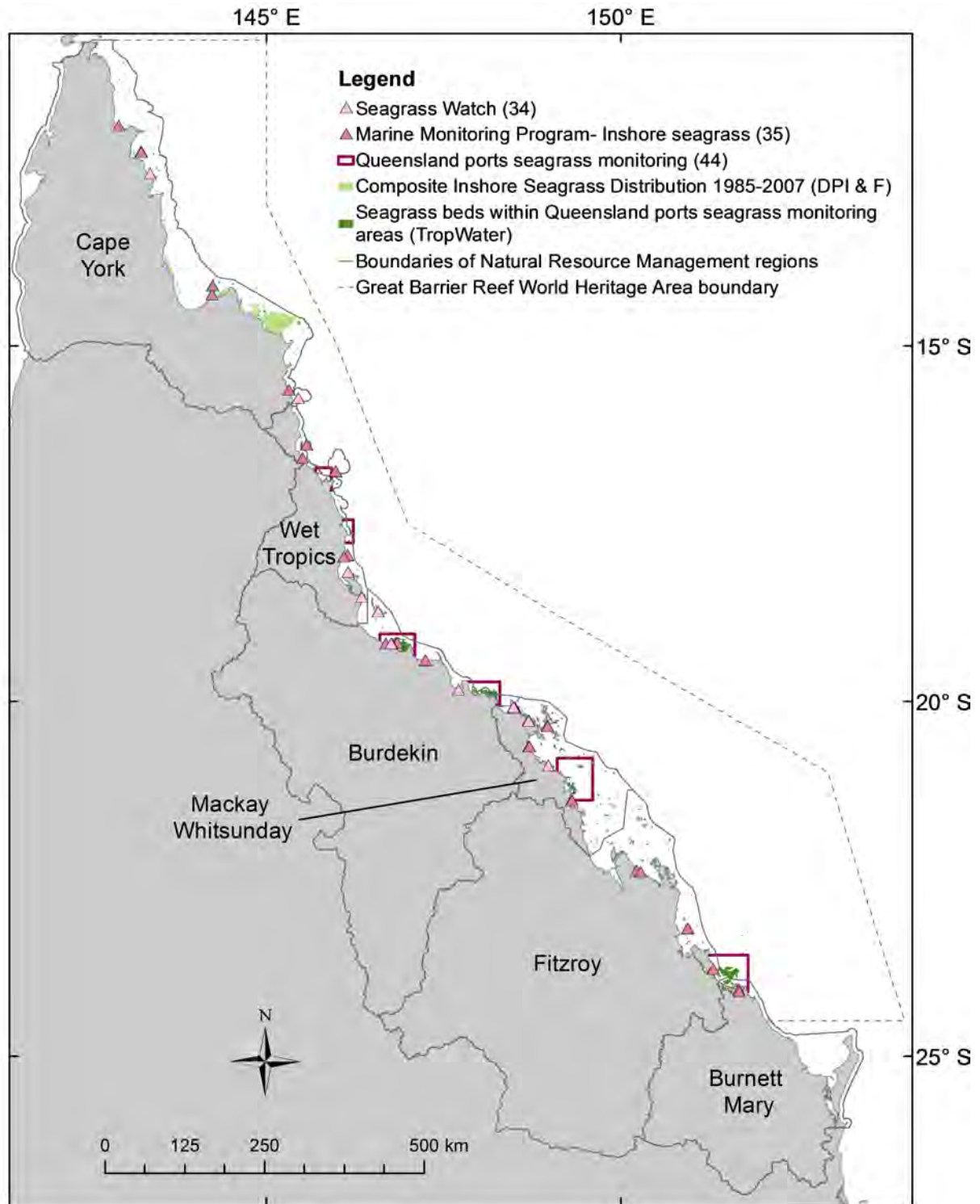


Figure 15: Current monitoring locations: Seagrass (habitat and species). Displaying programs where seagrass meadows are monitored. Points represent survey locations, where replicate observations are commonly made. Polygons represent entire areas where large-scale surveys occur (for the Queensland Ports Seagrass Monitoring, AIMS ID #44). All monitoring locations displayed are considered current, where monitoring has been undertaken within the last five years (2010 – 2015). Composite inshore seagrass distribution (1985 – 2007; eAtlas 2007) and offshore seagrass distribution (2003 – 2006; eAtlas 2015a) in the GBRWHA is shown. Boundaries for the GBRWHA and the six NRM regions (catchments into the marine environment) are also shown.

Summary: Three programs monitor seagrass beds (habitat) and species. Two of these programs have been running for more than twenty years (e.g., Seagrass Watch and Queensland ports seagrass monitoring began monitoring some sites in the mid to late 1990's). The frequency of monitoring is variable between and within programs. For example there can be a high frequency of monitoring for both the Seagrass Watch and Queensland Ports Seagrass Monitoring, but this is dependent on funding and/or contractual arrangements, so can vary through time and from site to site (e.g., Queensland Ports Seagrass Monitoring varies from monthly to annual for different port survey locations). The spatial extent of monitoring undertaken varies between the monitoring programs, with Seagrass Watch and the MMP seagrass monitoring focussing on small-scale evaluation of replicate transects within survey locations, whereas the Queensland Ports Seagrass Monitoring assesses large areas using a combination of on-ground and remote survey techniques. Whilst all three monitoring programs survey sites in each NRM region, these monitoring sites are predominantly located in shallow coastal sites along the urban coast, including the main ports of the GBRWHA. There is limited monitoring coverage in Cape York and there is no ongoing monitoring of the extensive areas of seagrass in deeper water (to 30m).

Mangroves (Habitat/species)**Table 11:** Assessment of environmental monitoring programs against the LTSP natural values and attributes: Mangroves

AIMS ID	Program and organisation	Ecosystem health				Biodiversity					
		Connectivity (EHO2)	Condition (EHO2; EHO3; EHT5)	Resilience (EHO2; EHT5)	Wetland extent (EHT3)	Current condition (BO4)	Trend in condition (BO3; BT5)	Diversity (BO5)	Species of conservation concern: habitat availability and condition (BO2; BT2)	Species of conservation concern: incidental bycatch (BT3)	Species of conservation concern: population size (BO2; BO3; BO4; BT4)
42	Coastal Habitat Archiving and Monitoring Program (JCU & MangroveWatch)	●	●	●		●	●	●			

Table 12: Monitoring duration, frequency and spatial extent: Mangroves

AIMS ID	Program and organisation	Monitoring program duration	Monitoring program frequency	Region where monitoring occurs					
				CY	WT	B	MW	F	BM
42	Coastal Habitat Archiving and Monitoring Program (JCU & MangroveWatch)	≥ 20 years	Annual	•	•			•	•

Variables monitored: Mangrove extent, change in extent, species composition, biomass, vegetative structure, drivers of change estimated from boat and aerial surveys.

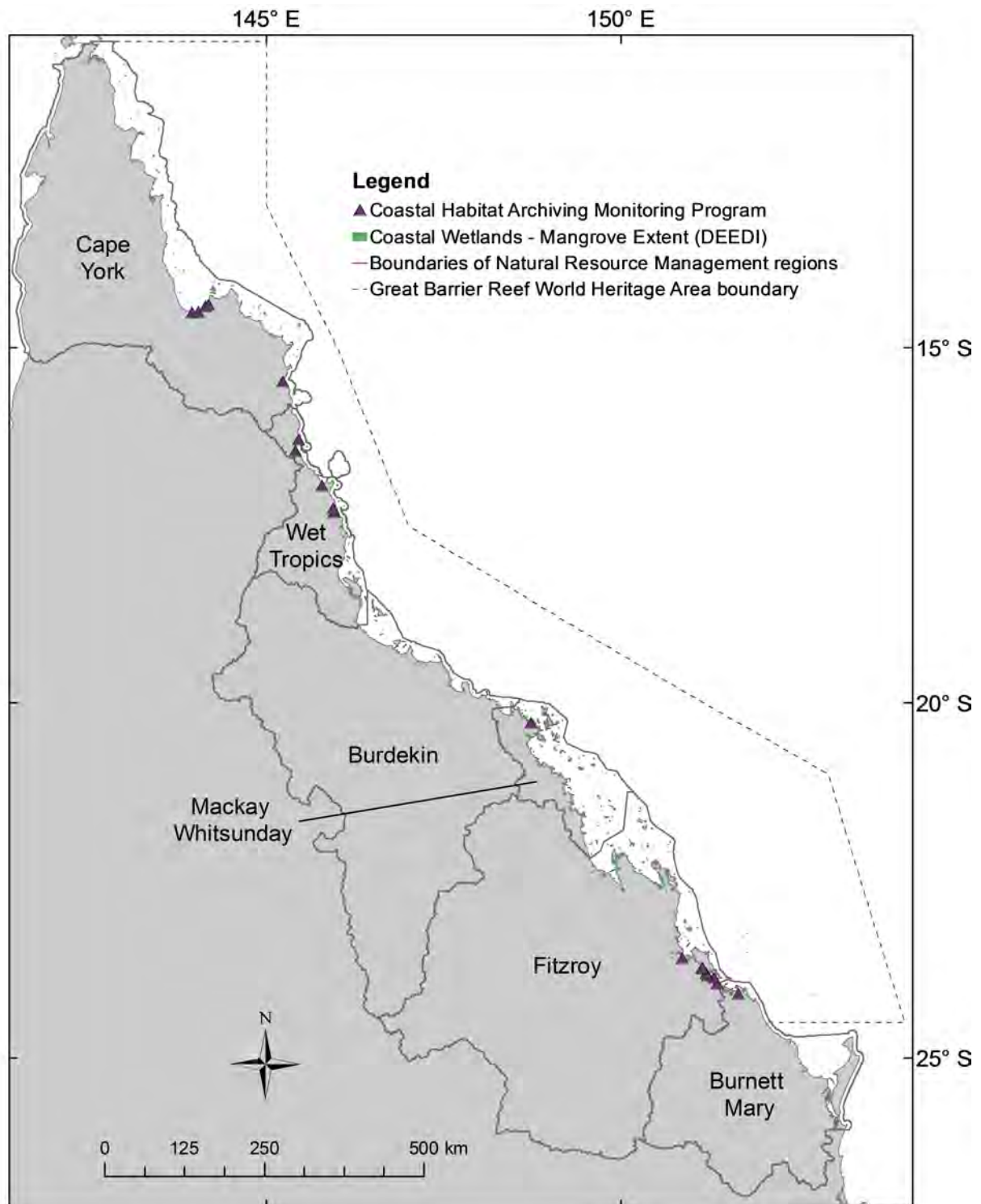


Figure 16: Current monitoring locations: Mangroves (habitat and species). Displaying the one program which monitors mangroves. Points represent single survey locations, where replicate observations (large tracks along river systems or shorelines) are commonly made. All monitoring locations displayed are considered current, where monitoring has been undertaken within the last five years (2010 – 2015). Mangrove extent within the GBRWHA is displayed (1987 – 1997; eAtlas 2015b). Boundaries for the GBRWHA and the six NRM regions (catchments into the marine environment) are also shown.

Summary: Just one program monitors mangrove habitats and species. This is the Coastal Habitat Archiving and Monitoring Program (CHAMP), which is conducted by scientists, citizen scientists and Traditional Owner group rangers. Whilst this program has been going for more than twenty years (e.g., MangroveWatch Daintree River commenced in 1986) it is entirely dependent on external funding which means that some monitoring sites in the three NRM regions are currently inactive (like MangroveWatch Daintree River). Currently CHAMP monitoring is undertaken in Port Curtis and Port Alma 2015 (frequency: annual to every two years) and Princess Charlotte Bay 2013 (frequency: annual).

Wetlands (Habitat)**Table 13:** Assessment of environmental monitoring programs against the LTSP natural values and attributes: Wetlands

AIMS ID	Program and organisation	Ecosystem health				Water Quality	
		Connectivity (EHO2)	Condition (EHO2; EHO3; EHT5)	Resilience (EHO2; EHT5)	Wetland extent (EHT3)	Wetland extent (WQO1; WQT2)	Wetlands ecological processes and environmental values (WQO1; WQT2)
41	Queensland wetland extent change mapping (Queensland Herbarium & DSITI)				•	•	

Table 14: Monitoring duration, frequency and spatial extent: Wetlands

AIMS ID	Program and organisation	Monitoring program duration	Monitoring program frequency	Region where monitoring occurs					
				CY	WT	B	MW	F	BM
41	Queensland wetland extent change mapping (Queensland Herbarium, DSITI)	6 - 10 years	Once every 3 or more years	•	•	•	•	•	•

Variables monitored: Wetland type, extent and change in extent estimated from aerial surveys.

Summary: Only one program collects data on wetland extent across all NRM regions associated with the GBRWHA. The Queensland wetland extent change mapping program measures extent only, and not ecological processes or environmental values of wetlands (other attributes mentioned in the LTSP WQO1 & WQT2). In 2015 DSITI have trialled a new monitoring program for wetland values and functions (not yet reported on, and no funding has been committed beyond the first sampling event).

Bony fishes**Table 15:** Assessment of environmental monitoring programs against the LTSP natural values and attributes: Bony fishes

AIMS ID	Program and organisation	Biodiversity ¹⁰					
		Current condition (BO4)	Trend in condition (BO3; BT5)	Diversity (BO5)	Species of conservation concern: habitat availability and condition (BO2; BT2)	Species of conservation concern: incidental bycatch (BT3)	Species of conservation concern: population size (BO2; BO3; BO4; BT4)
13	Effects of management zoning on inshore reefs of the Great Barrier Reef Marine Park: benthic condition & fish (JCU)	•	•	•			
15	Fish Spawning Aggregation Monitoring (GBRMPA with support from Qld Fisheries and Science and Conservation of Fish Aggregations society)	•	•	•			
20	Queensland fishery independent surveys of specific species (DAF)	•	•				
21	Queensland biological fishery dependent data collection (commercial and recreational) (DAF)	•	•				
22	Queensland commercial fisheries monitoring (DAF)	•	•				
23	AIMS Long-term Monitoring Program (AIMS)	•	•	•	•		
24	Effects of rezoning on offshore coral reef systems (AIMS)	•	•	•			
25	Eye on the Reef - Rapid Monitoring Survey (GBRMPA)	•	•	•			
28	Eye on the Reef - Tourism Weekly Monitoring Surveys (GBRMPA & Tourism Industry)	•	•	•			
29	Reef Check (Coral Reef Health Monitoring) (Reef Check Australia)	•	•	•			
66	Reef Life Survey (RLS)	•	•	•			

¹⁰ Some fishes will be considered a "species of conservation concern", so could also be counted as contributing to "species of conservation concern" attributes.

Table 16: Monitoring duration, frequency and spatial extent: Bony fishes

AIMS ID	Program and organisation	Monitoring program duration	Monitoring program frequency	Region where monitoring occurs					
				CY	WT	B	MW	F	BM
13	Effects of management zoning on inshore reefs of the Great Barrier Reef Marine Park: benthic condition & fish (JCU)	11 - 19 years	Annual		•	•	•	•	
15	Fish Spawning Aggregation Monitoring (GBRMPA with support from Qld Fisheries and Science and Conservation of Fish Aggregations society)	≥ 20 years	Annual			•			
20	Queensland fishery independent surveys of specific species (DAF)	11 - 19 years	Annual					•	•
21	Queensland biological fishery dependent data collection (commercial and recreational) (DAF)	11 - 19 years	Daily	•	•	•	•	•	•
22	Queensland commercial fisheries monitoring (DAF)	11 - 19 years	Daily	•	•	•	•	•	•
23	AIMS Long-term Monitoring Program (AIMS)	≥ 20 years	Once every 2 years	•	•	•	•	•	•
24	Effects of rezoning on offshore coral reef systems (AIMS)	6 - 10 years	Once every 2 years		•	•	•	•	•
25	Eye on the Reef - Rapid Monitoring Survey (GBRMPA)	6 - 10 years	Opportunistic	•	•	•	•	•	•
28	Eye on the Reef - Tourism Weekly Monitoring Surveys (GBRMPA & Tourism Industry)	11 - 19 years	Weekly		•		•		•
29	Reef Check (Coral Reef Health Monitoring) (Reef Check Australia)	11 - 19 years	Opportunistic	•	•	•	•	•	•
66	Reef Life Survey (RLS)	6 - 10 years	Opportunistic	•	•	•	•	•	•

Variables monitored: Fish abundance (species & higher taxonomic level), size, sex and age (commercial + coral reef fish species) estimated from underwater visual census, commercial catch data and surveys of recreational fishers.

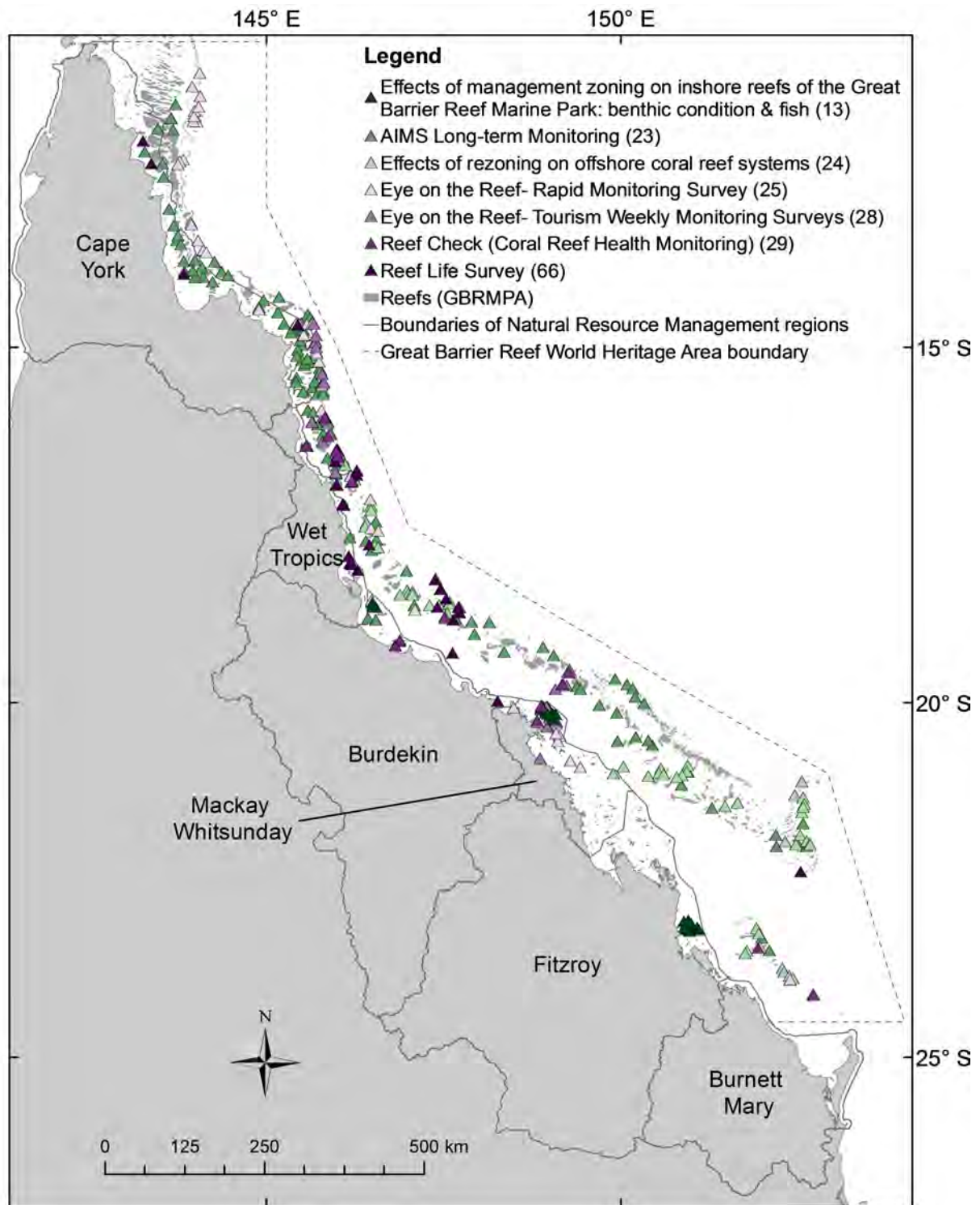


Figure 17: Current monitoring locations: Bony fishes. Displaying programs associated with coral reefs where bony fishes are monitored (note that spatial data were unavailable for programs 15, 20, 21 and 22). Points represent single survey locations, where replicate observations are commonly made. All monitoring locations displayed are considered current, where monitoring has been undertaken within the last five years (2010 – 2015). Boundaries for the GBRWHA and the six NRM regions (catchments into the marine environment) are also shown.

Summary: There are 11 programs that monitor bony fishes, three of which are associated with commercial fisheries and the remaining eight programs are associated with coral reefs (). The most extensive monitoring of bony fishes in coral reefs through the AIMS Long-term Monitoring Program (intensive under water visual census since 1992). The temporal frequency of these monitoring programs varies considerably: ranging from opportunistic surveys (e.g., Reef Life Survey), to surveys occurring once every two years, all the way through to surveys that are undertaken daily (e.g., Queensland commercial fisheries monitoring). There is good spatial coverage of inshore coral reefs in the central GBR (Wet Tropics, Burdekin, and Mackay Whitsunday), however less monitoring occurs in Cape York and Burnett Mary. The GBRWHA includes extensive coral shoals in deeper water, which are not currently monitored. Bony fish associated with habitats other than coral reefs (e.g., seagrass meadows and mangroves) are also not monitored.

Dolphins**Table 17:** Assessment of environmental monitoring programs against the LTSP natural values and attributes: Dolphins

AIMS ID	Program and organisation	Biodiversity ¹¹					
		Current condition (BO4)	Trend in condition (BO3; BT5)	Diversity (BO5)	Species of conservation concern: habitat availability and condition (BO2; BT2)	Species of conservation concern: incidental bycatch (BT3)	Species of conservation concern: population size (BO2; BO3; BO4; BT4)
10	Dugong Population Monitoring (JCU)						•
26	Eye on the Reef - Sightings Network (GBRMPA)						•
31	Marine Wildlife Stranding and Mortality (EHP)					•	
47	Capricorn cetaceans project (SCU)				•		•
97	Dolphin and dugong monitoring, Girringun Sea Country (JCU & Girringun Aboriginal Corporation)						•
98	Dolphin and dugong monitoring, Lama Lama Sea Country (JCU & Lama Lama Aboriginal Corporation)						•
99	Dolphin and dugong monitoring, Mandubarra Sea Country (JCU & Mandubarra Land and Sea Inc.)						•

Table 18: Monitoring duration, frequency and spatial extent: Dolphins

AIMS ID	Program and organisation	Monitoring program duration	Monitoring program frequency	Region where monitoring occurs					
				CY	WT	B	MW	F	BM
10	Dugong Population Monitoring (JCU)	≥ 20 years	Once every 3 or more years	•	•	•	•	•	•

¹¹ Dolphins are considered a “species of conservation concern”, hence not counted as contributing to “current condition” or “trend in condition” of biodiversity.

AIMS ID	Program and organisation	Monitoring program duration	Monitoring program frequency	Region where monitoring occurs					
				CY	WT	B	MW	F	BM
26	Eye on the Reef - Sightings Network (GBRMPA)	6 - 10 years	Opportunistic	•	•	•	•	•	•
31	Marine Wildlife Stranding and Mortality (EHP)	≥ 20 years	Opportunistic		•	•	•	•	•
47	Capricorn cetaceans project (SCU)	6 - 10 years	Monthly					•	
97	Dolphin and dugong monitoring, Girringun Sea Country (JCU & Girringun Aboriginal Corporation)	≤ 2 years	Annual		•				
98	Dolphin and dugong monitoring, Lama Lama Sea Country (JCU & Lama Lama Aboriginal Corporation)	≤ 2 years	Annual	•					
99	Dolphin and dugong monitoring, Mandubarra Sea Country (JCU & Mandubarra Land and Sea Inc.)	≤ 2 years	Annual		•				

Variables monitored: Dolphin population estimates, genetics, and habitat use estimated from boat and aerial surveys.

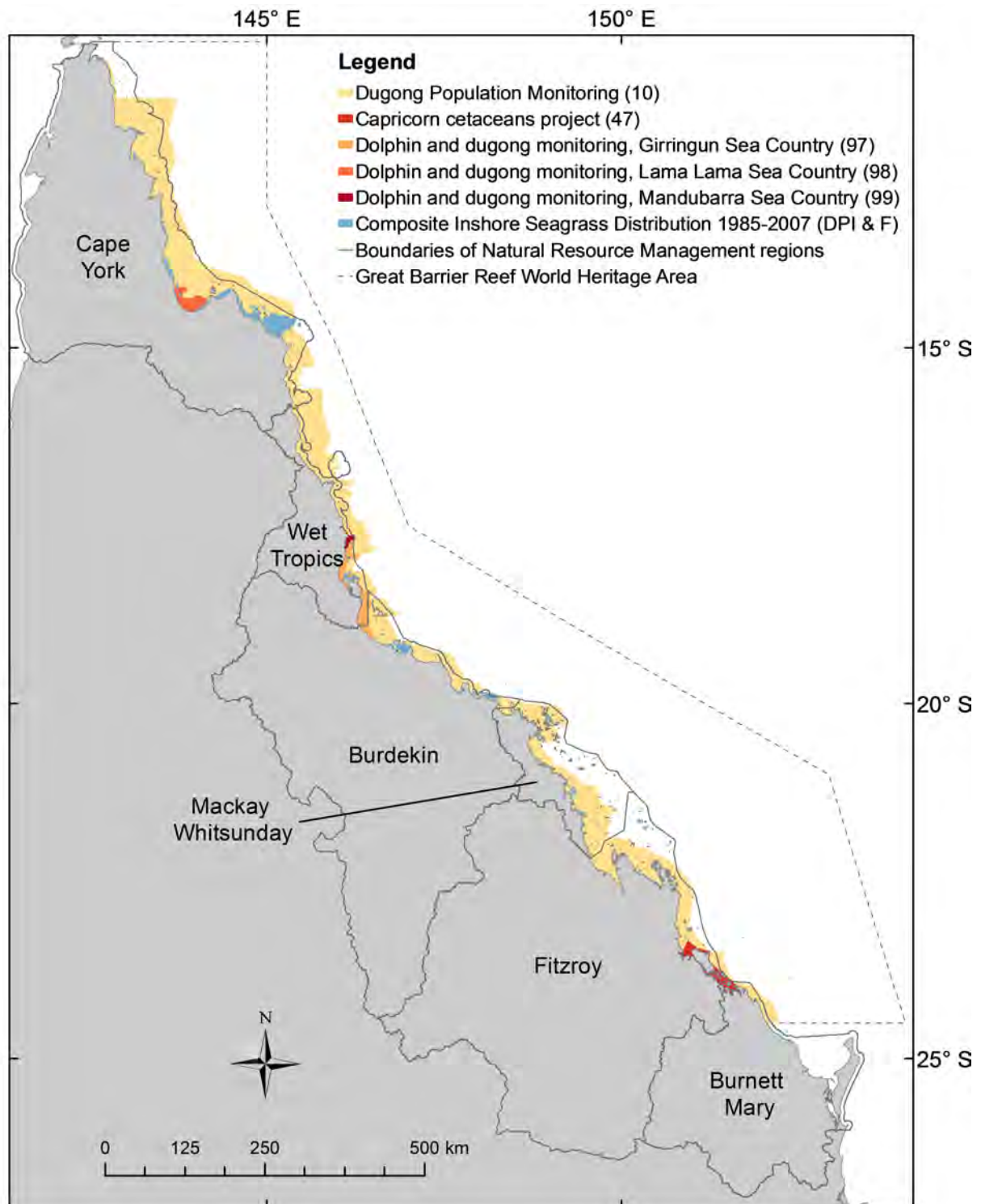


Figure 18: Current monitoring locations: Dugong and Dolphins. Displaying programs that monitor dolphins and dugong (except for programs 26 and 31, which do not have fixed survey locations). Areas plotted represent entire survey locations. All monitoring locations displayed are considered current, where monitoring has been undertaken within the last five years (2010 – 2015).). Composite inshore seagrass distribution (1985 – 2007; eAtlas 2007) in the GBRWHA is shown. Boundaries for the GBRWHA and the six NRM regions (catchments into the marine environment) are also shown.

Summary: There are seven programs that monitor dolphins in the GBRWHA. Most of these programs are relatively new (< 10 years), except for the Marine Wildlife Stranding and Mortality program (which records incidents of dolphin stranding and mortality) and the JCU Dugong Population Monitoring where dolphins are also recorded during dugong surveys. Both of these programs have the most extensive coverage of the GBRWHA regions. More recent localised dolphin monitoring programs have been established with Gladstone Ports Corporation (Capricorn cetaceans project, AIMS ID #47) and with Traditional Owner groups (led by JCU with Giringun Aboriginal Corporation, Lama Lama Aboriginal Corporation, and Mandubarra Land and Sea Inc). The frequency of monitoring ranges from opportunistic surveys, to annual surveys, through to surveys once every 3 or more years.

Dugong**Table 19:** Assessment of environmental monitoring programs against the LTSP natural values and attributes: Dugong

AIMS ID	Program and organisation	Biodiversity ¹²					
		Current condition (BO4)	Trend in condition (BO3; BT5)	Diversity (BO5)	Species of conservation concern: habitat availability and condition (BO2; BT2)	Species of conservation concern: incidental bycatch (BT3)	Species of conservation concern: population size (BO2; BO3; BO4; BT4)
10	Dugong Population Monitoring (JCU)						•
26	Eye on the Reef - Sightings Network (GBRMPA)						•
31	Marine Wildlife Stranding and Mortality (EHP)					•	
46.3	Port Curtis and Port Alma Environmental Research and Monitoring Program - Dugongs (GPC)				•		•
97	Dolphin and dugong monitoring, Girringun Sea Country (JCU & Girringun Aboriginal Corporation)						•
98	Dolphin and dugong monitoring, Lama Lama Sea Country (JCU & Lama Lama Aboriginal Corporation)						•
99	Dolphin and dugong monitoring, Mandubarra Sea Country (JCU & Mandubarra Land and Sea Inc.)						•

Table 20: Monitoring duration, frequency and spatial extent: Dugong

AIMS ID	Program and organisation	Monitoring program duration	Monitoring program frequency	Region where monitoring occurs					
				CY	WT	B	MW	F	BM
10	Dugong Population Monitoring (JCU)	≥ 20 years	Once every 3 or more years	•	•	•	•	•	•
26	Eye on the Reef - Sightings Network (GBRMPA)	6 - 10 years	Opportunistic	•	•	•	•	•	•

¹² Dugong are considered a “species of conservation concern”, hence not counted as contributing to “current condition” or “trend in condition” of biodiversity.

AIMS ID	Program and organisation	Monitoring program duration	Monitoring program frequency	Region where monitoring occurs					
				CY	WT	B	MW	F	BM
31	Marine Wildlife Stranding and Mortality (EHP)	≥ 20 years	Opportunistic		•	•	•	•	•
46.3	Port Curtis and Port Alma Environmental Research and Monitoring Program - Dugongs (GPC)	3 - 5 years	Opportunistic					•	
97	Dolphin and dugong monitoring, Girringun Sea Country (JCU & Girringun Aboriginal Corporation)	≤ 2 years	Annual		•				
98	Dolphin and dugong monitoring, Lama Lama Sea Country (JCU & Lama Lama Aboriginal Corporation)	≤ 2 years	Annual	•					
99	Dolphin and dugong monitoring, Mandubarra Sea Country (JCU & Mandubarra Land and Sea Inc.)	≤ 2 years	Annual		•				

Variables monitored: Dugong population estimates, genetics, and habitat use estimated from boat and aerial surveys and satellite tracking

Summary: There are seven programs that monitor dugong in the GBRWHA. Most of these programs are relatively new (< 10 years), except for the Marine Wildlife Stranding and Mortality program (which records incidents of dugong stranding and mortality) and the JCU Dugong Population Monitoring. Both of these programs have the most extensive coverage of the GBRWHA regions. More recent localised dugong monitoring programs have been established with Gladstone Ports Corporation (Capricorn cetaceans project, AIMS ID # 47) and with Traditional Owner groups (led by JCU with Girringun Aboriginal Corporation, Lama Lama Aboriginal Corporation, and Mandubarra Land and Sea Inc). The frequency of monitoring ranges from opportunistic surveys, to annual surveys, through to surveys once every 3 or more years.

Marine turtles**Table 21:** Assessment of environmental monitoring programs against the LTSP natural values and attributes: Marine turtles

AIMS ID	Program and organisation	Biodiversity ¹³					
		Current condition (BO4)	Trend in condition (BO3; BT5)	Diversity (BO5)	Species of conservation concern: habitat availability and condition (BO2; BT2)	Species of conservation concern: incidental bycatch (BT3)	Species of conservation concern: population size (BO2; BO3; BO4; BT4)
10	Dugong Population Monitoring (JCU)			•			•
12	Queensland Turtle Conservation (QTC) Project – marine turtle monitoring (EHP)			•			•
25	Eye on the Reef - Rapid Monitoring Survey (GBRMPA)			•			•
26	Eye on the Reef - Sightings Network (GBRMPA)			•			•
28	Eye on the Reef - Tourism Weekly Monitoring Surveys (GBRMPA & Tourism Industry)			•			•
31	Marine Wildlife Stranding and Mortality (EHP)					•	
46.4	Port Curtis and Port Alma Environmental Research and Monitoring Program - Marine turtle light impacts on hatchlings (GPC)						•
67	Raine Island Green Turtle Recovery Project (EHP & BHP)						•
81	Rivers to Reefs to Turtles (WWF)						•
97	Dolphin and dugong monitoring, Girringun Sea Country (JCU & Girringun Aboriginal Corporation)						•
98	Dolphin and dugong monitoring, Lama Lama Sea Country (JCU & Lama Lama Aboriginal Corporation)						•
99	Dolphin and dugong monitoring, Mandubarra Sea Country (JCU & Mandubarra Land and Sea Inc.)						•
103	Flatback turtle's whereabouts project (WWF, EHP & JCU)						•
104	Loggerhead watch (UQ, WWF, The Wreck Rock Turtle Research Team, the BMRG & Queensland						•

¹³ Marine turtles are considered a “species of conservation concern”, hence not counted as contributing to “current condition” or “trend in condition” of biodiversity.

AIMS ID	Program and organisation	Biodiversity¹³					
		Current condition (BO4)	Trend in condition (BO3; BT5)	Diversity (BO5)	Species of conservation concern: habitat availability and condition (BO2; BT2)	Species of conservation concern: incidental bycatch (BT3)	Species of conservation size concern: population size (BO2; BO3; BO4; BT4)
	Government)						

Table 22: Monitoring duration, frequency and spatial extent: Marine turtles

AIMS ID	Program and organisation	Monitoring program duration	Monitoring program frequency	Region where monitoring occurs					
				CY	WT	B	MW	F	BM
10	Dugong Population Monitoring (JCU)	≥ 20 years	Once every 3 or more years	•	•	•	•	•	•
12	Queensland Turtle Conservation (QTC) Project – marine turtle monitoring (EHP)	≥ 20 years	Annual	•	•	•	•	•	•
25	Eye on the Reef - Rapid Monitoring Survey (GBRMPA)	6 - 10 years	Opportunistic	•	•	•	•	•	•
26	Eye on the Reef - Sightings Network (GBRMPA)	6 - 10 years	Opportunistic	•	•	•	•	•	•
28	Eye on the Reef - Tourism Weekly Monitoring Surveys (GBRMPA & Tourism Industry)	11 - 19 years	Weekly		•		•		•
31	Marine Wildlife Stranding and Mortality (EHP)	≥ 20 years	Opportunistic		•	•	•	•	•
46.4	Port Curtis and Port Alma Environmental Research and Monitoring Program - Marine turtle light impacts on hatchlings (GPC)	≤ 2 years	Annual					•	
67	Raine Island Green Turtle Recovery Project (EHP & BHP)	≤ 2 years	Variable	•					
81	Rivers to Reefs to Turtles (WWF)	≤ 2 years	Biannual	•		•			
97	Dolphin and dugong monitoring, Girringun Sea Country (JCU & Girringun Aboriginal Corporation)	≤ 2 years	Annual		•				

98	Dolphin and dugong monitoring, Lama Lama Sea Country (JCU & Lama Lama Aboriginal Corporation)	≤ 2 years	Annual	•					
99	Dolphin and dugong monitoring, Mandubarra Sea Country (JCU & Mandubarra Land and Sea Inc.)	≤ 2 years	Annual		•				
103	Flatback turtle's whereabouts project (WWF, EHP & JCU)	≤ 2 years	Variable	•		•	•		
104	Loggerhead watch (UQ, WWF, The Wreck Rock Turtle Research Team, the BMRG & Queensland Government)	≤ 2 years	Annual						•

Variables monitored: Turtle nesting population estimates (nesting adults, hatchlings, eggs), light impacts on hatchlings, and foraging population estimates (tracking adults, growth rate, toxicology) and turtle sightings throughout the GBRWHA. Estimated from nesting beach surveys, boat surveys, mark-recapture, satellite tracking, sightings from citizen scientist and counts in underwater visual census.

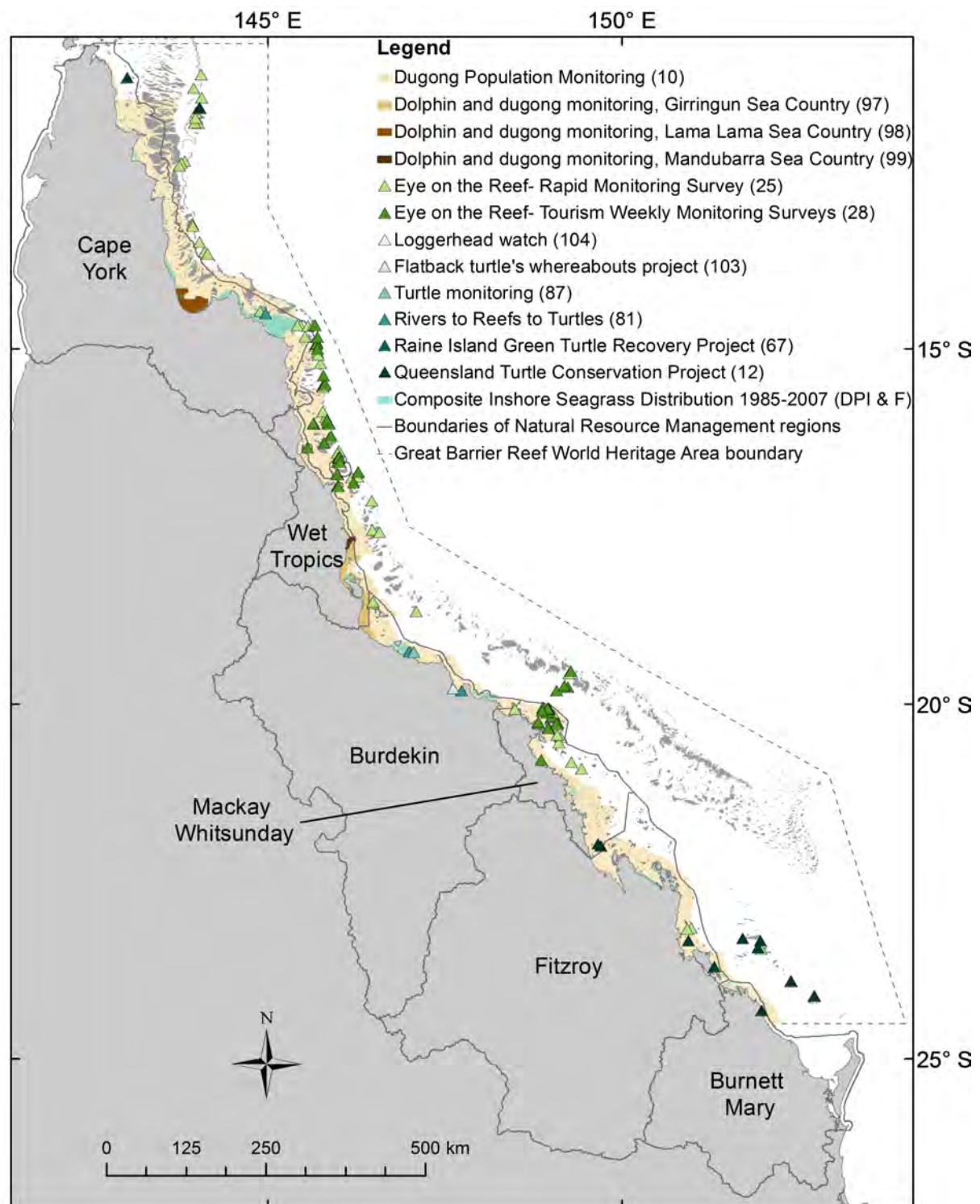


Figure 19: Current monitoring locations: Marine turtles. Displaying programs that monitor marine turtles (except for programs 26 and 31, which do not have fixed survey locations; also program 46.4 is not shown as spatial data could not be obtained). Areas plotted represent entire survey locations. All monitoring locations displayed are considered current, where monitoring has been undertaken within the last five years (2010 – 2015). Composite inshore seagrass distribution (1985 – 2007; eAtlas 2007) in the GBRWHA is shown. Boundaries for the GBRWHA and the six NRM regions (catchments into the marine environment) are also shown.

Summary: There are 14 programs that monitor marine turtles in the GBRWHA. Most of these programs are relatively new (< 10 years), except for the Queensland Turtle Conservation (QTC) project undertaken by EHP, the Marine Wildlife Stranding and Mortality program and the JCU Dugong Population Monitoring which also monitors marine turtles sighted during dugong surveys. These programs have the most extensive coverage of the GBRWHA regions. More recent localised marine turtle monitoring programs have been established with Gladstone Ports Corporation (that fund additional surveys through the QTC project and the program investigating light impacts on marine turtle hatchlings), and by the WWF (with various partner organisations). The frequency of monitoring ranges from opportunistic sightings, to annual surveys, through to surveys once every three or more years.

Other Invertebrates**Table 23:** Assessment of environmental monitoring programs against the LTSP natural values and attributes: Other invertebrates (non-coral reef)

AIMS ID	Program and organisation	Biodiversity					
		Current condition (BO4)	Trend in condition (BO3; BT5)	Diversity (BO5)	Species of conservation concern: habitat availability and condition (BO2; BT2)	Species of conservation concern: incidental bycatch (BT3)	Species of conservation concern: population size (BO2; BO3; BO4; BT4)
20	Queensland fishery independent surveys of specific species (DAF)	•	•				
63	Ports North - Benthic infauna (PN)	•	•	•			

Table 24: Monitoring duration, frequency and spatial extent: Other invertebrates (non-coral reef)

AIMS ID	Program and organisation	Monitoring program duration	Monitoring program frequency	Region where monitoring occurs					
				CY	WT	B	MW	F	BM
Other Invertebrates									
20	Queensland fishery independent surveys of specific species (DAF)	11 - 19 years	Annual					•	•
63	Ports North - Benthic infauna (PN)	11 - 19 years	Once every 3 or more years		•				

Variables monitored: Other invertebrates (non-coral reef): abundance of common/focal mobile invertebrates and benthic invertebrates estimated from underwater visual census or commercial catch data.

Summary: There are only two programs that monitor invertebrates (other than corals) that are not associated with coral reef habitats. Both are localised programs (occurring in the Wet Tropics, Fitzroy and Burnett Mary region). The fishery independent surveys blue swimmer crab, spanner crab, brown tiger and eastern king prawn (size, sex and population estimates), and the other program undertaken by Ports North assesses benthic infauna associated with soft sediment habitats in Cairns Port. There is very limited monitoring of invertebrates that are not associated with coral reefs.

Sharks & rays**Table 25:** Assessment of environmental monitoring programs against the LTSP natural values and attributes: Sharks & Rays

AIMS ID	Program and organisation	Biodiversity¹⁴					
		Current condition (BO4)	Trend in condition (BO3; BT5)	Diversity (BO5)	Species of conservation concern: habitat availability and condition (BO2; BT2)	Species of conservation concern: incidental bycatch (BT3)	Species of conservation concern: population size (BO2; BO3; BO4; BT4)
10	Dugong Population Monitoring (JCU)			•			•
23	AIMS Long-term Monitoring Program (AIMS)			•			•
25	Eye on the Reef - Rapid Monitoring Survey (GBRMPA)			•			•
26	Eye on the Reef - Sightings Network (GBRMPA)						•
28	Eye on the Reef - Tourism Weekly Monitoring Surveys (GBRMPA & Tourism Industry)			•			•
31	Marine Wildlife Stranding and Mortality (EHP)					•	
52	Queensland Shark Control Program (DAF)			•			•
82	Long-term shark tagging program (OCR)						•
102	Project Manta (UQ)						•

¹⁴ Sharks and rays are considered a “species of conservation concern”, hence not counted as contributing to “current condition” or “trend in condition” of biodiversity.

Table 26: Monitoring duration, frequency and spatial extent: Sharks & rays

AIMS ID	Program and organisation	Monitoring program duration	Monitoring program frequency	Region where monitoring occurs					
				CY	WT	B	MW	F	BM
10	Dugong Population Monitoring (JCU)	≥ 20 years	Once every 3 or more years	•	•	•	•	•	•
23	AIMS Long-term Monitoring Program (AIMS)	≥ 20 years	Once every 2 years	•	•	•	•	•	•
25	Eye on the Reef - Rapid Monitoring Survey (GBRMPA)	6 - 10 years	Opportunistic	•	•	•	•	•	•
26	Eye on the Reef - Sightings Network (GBRMPA)	6 - 10 years	Opportunistic	•	•	•	•	•	•
28	Eye on the Reef - Tourism Weekly Monitoring Surveys (GBRMPA & Tourism Industry)	11 - 19 years	Weekly		•		•		•
31	Marine Wildlife Stranding and Mortality (EHP)	≥ 20 years	Opportunistic		•	•	•	•	•
52	Queensland Shark Control Program (DAF)	≥ 20 years	Opportunistic		•	•	•	•	•
82	Long-term shark tagging program (OCR)	3 - 5 years	Continuous tracking		•	•	•	•	•
102	Project Manta (UQ)	6 - 10 years	Variable	•	•	•	•	•	•

Variables monitored: Shark and ray abundance, large shark movement, sharks caught on drumlines (to estimate population size); manta ray abundance, movement, genetics and habitat use. Estimated from underwater visual census, manta tows, tagging and shark control (drumlines)

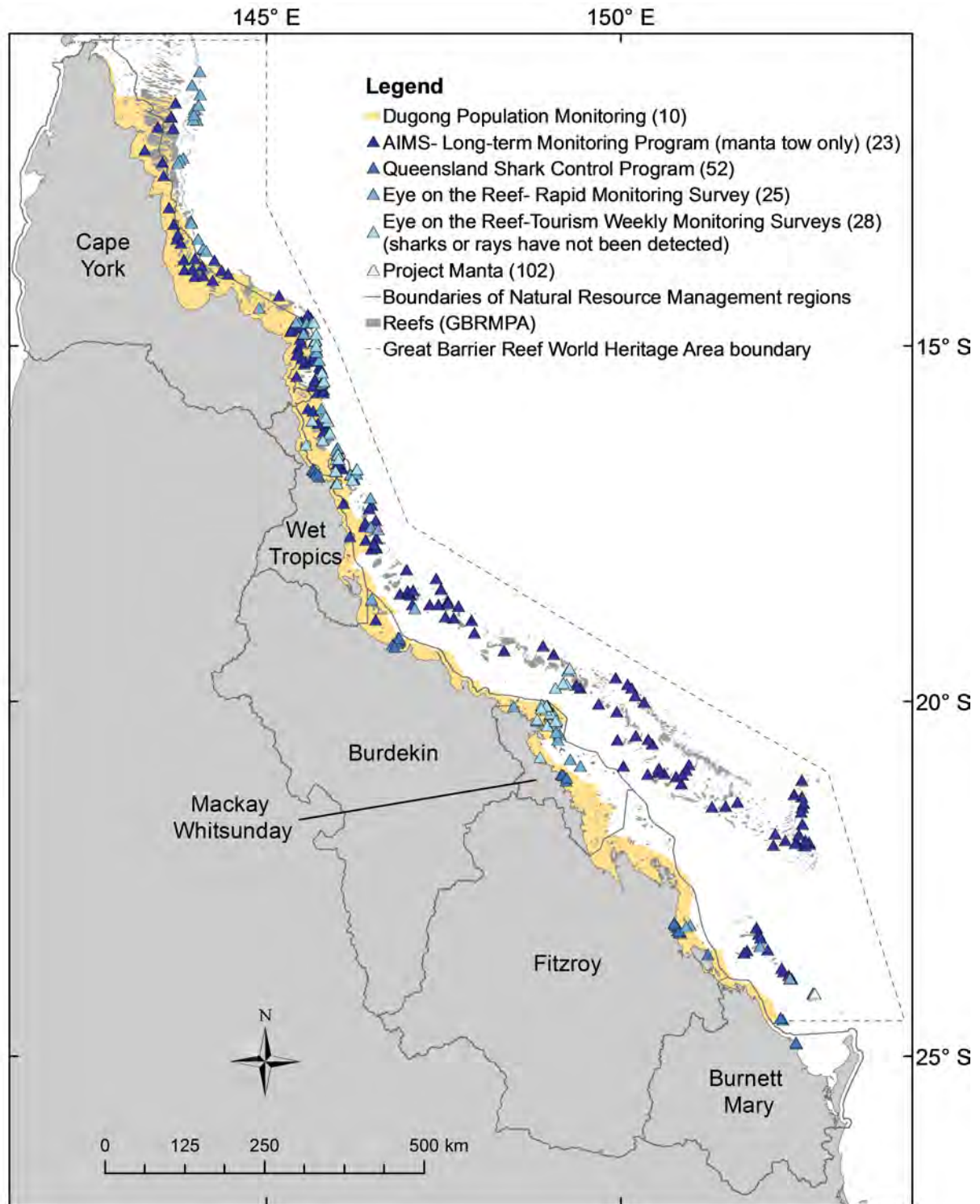


Figure 20: Current monitoring locations: Sharks and rays. Displaying programs that monitor sharks and rays (except for programs 26 and 31, which do not have fixed survey locations; also program 82 as this is a shark tagging project). Points represent single survey locations, where replicate observations are commonly made. All monitoring locations displayed are considered current, where monitoring has been undertaken within the last five years (2010 – 2015). Boundaries for the GBRWHA and the six NRM regions (catchments into the marine environment) are also shown.

Summary: There are nine programs that monitor sharks and/or rays. Half of these programs are associated with coral reefs, one program (Dugong monitoring program) monitors sharks and rays beyond coral reefs (e.g., seagrass and soft sediment habitats), and the remaining programs involve either tagging, culling records or standing/mortality sightings. Many of these programs involve opportunistic surveys (e.g., the Eye on the Reef - Sightings Network). Long-term shark tagging program gathers continuous data on shark movements, as does Project Manta for manta rays along with other methods to estimate manta ray population size. These programs appear to have good spatial coverage across the NRM regions, however since most programs involve opportunistic surveys or tracking of a limited number of individuals, the information about sharks and rays within each region is likely to be limited.

Shorebirds and seabirds

Table 27: Assessment of environmental monitoring programs against the LTSP natural values and attributes: Shorebirds & seabirds

AIMS ID	Program and organisation	Biodiversity¹⁵					
		<i>Current condition (BO4)</i>	<i>Trend in condition (BO3; BT5)</i>	<i>Diversity (BO5)</i>	<i>Species of conservation concern: habitat availability and condition (BO2; BT2)</i>	<i>Species of conservation concern: incidental bycatch (BT3)</i>	<i>Species of conservation concern: population size (BO2; BO3; BO4; BT4)</i>
17	Coastal Bird Monitoring (Joint Field Management Program, QPWS & GBRMPA)	•	•	•			
18	Shorebird monitoring (Queensland Wader Study Group)	•	•	•			
19	Eastern Australian Waterbird Survey (UNSW)	•	•	•			
46.5	Port Curtis and Port Alma Environmental Research and Monitoring Program - Migratory shorebirds (GPC)	•	•	•			

¹⁵ Some shorebirds and seabirds will be “species of conservation concern”, so some monitoring programs could also contribute to the “species of conservation concern” biodiversity attributes.

Table 28: Monitoring duration, frequency and spatial extent: Shorebirds & seabirds

AIMS ID	Program and organisation	Monitoring program duration	Monitoring program frequency	Region where monitoring occurs					
				CY	WT	B	MW	F	BM
17	Coastal Bird Monitoring (Joint Field Management Program, QPWS & GBRMPA)	11 - 19 years	Quarterly	•	•	•	•	•	•
18	Shorebird monitoring (Queensland Wader Study Group)	≥ 20 years	Monthly		•	•	•	•	•
19	Eastern Australian Waterbird Survey (UNSW)	≥ 20 years	Annual			•			
46.5	Port Curtis and Port Alma Environmental Research and Monitoring Program - Migratory shorebirds (GPC)	3 - 5 years	Annual					•	

Variables monitored: Shorebird and seabird census at nesting sites and feeding grounds (nests, chicks and adult abundance estimates) estimated from visual surveys.

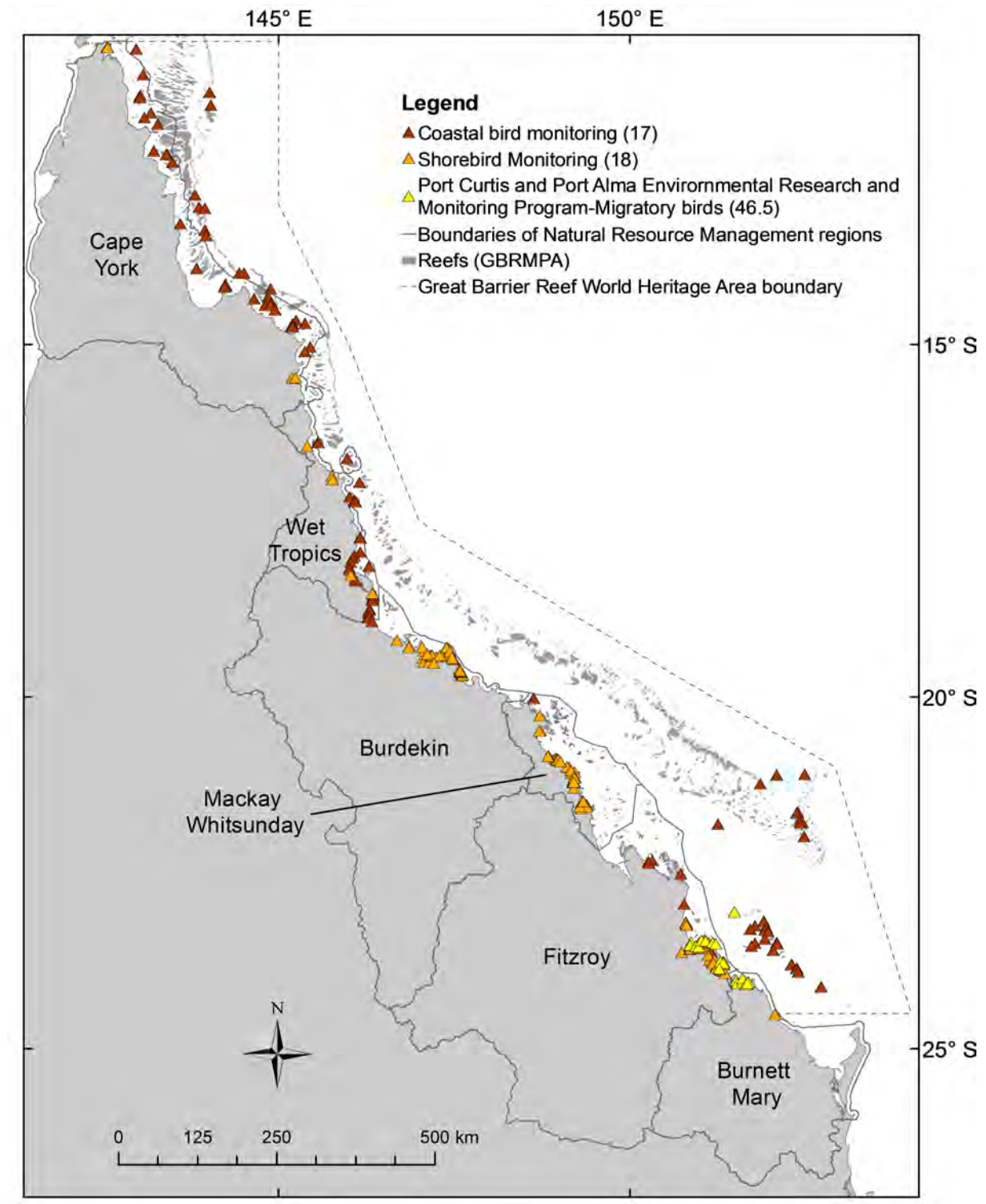


Figure 21: Current monitoring locations: Shorebirds and seabirds. Displaying programs that monitor shorebirds and seabirds (except for program 19, which monitors inland). Points represent single survey locations, where replicate observations are commonly made. All monitoring locations displayed are considered current, where monitoring has been undertaken within the last five years (2010 – 2015). Boundaries for the GBRWHA and the six NRM regions (catchments into the marine environment) are also shown.

Summary: Four programs monitor shorebirds and seabirds in the GBRWHA. Most of these programs have been going for over 10 years (e.g., the Coastal Bird Monitoring began in the early 2000's), and can involve fairly high monitoring frequency (monthly – annual). The Coastal Bird Monitoring and Shorebird Monitoring programs have good spatial coverage across the NRM regions, however the other two programs are much more localised in their extent.

Whales**Table 29:** Assessment of environmental monitoring programs against the LTSP natural values and attributes: Whales

AIMS ID	Program and organisation	Biodiversity¹⁶					
		Current condition (BO4)	Trend in condition (BO3; BT5)	Diversity (BO5)	Species of conservation concern: habitat availability and condition (BO2; BT2)	Species of conservation concern: incidental bycatch (BT3)	Species of conservation concern: population size (BO2; BO3; BO4; BT4)
11	Humpback Whale Population Monitoring (UQ)						•
26	Eye on the Reef - Sightings Network (GBRMPA)						•
31	Marine Wildlife Stranding and Mortality (EHP)					•	
83	Minke whale project (JCU)						•

Table 30: Monitoring duration, frequency and spatial extent: Whales

AIMS ID	Program and organisation	Monitoring program duration	Monitoring program frequency	Region where monitoring occurs					
				CY	WT	B	MW	F	BM
11	Humpback Whale Population Monitoring (UQ)	≥ 20 years	Once every 3 or more years						
26	Eye on the Reef - Sightings Network (GBRMPA)	6 - 10 years	Opportunistic	•	•	•	•	•	•
31	Marine Wildlife Stranding and Mortality (EHP)	≥ 20 years	Opportunistic		•	•	•	•	•
83	Minke whale project (JCU)	11 - 19 years	Annual	•	•				

¹⁶ Whales are considered a “species of conservation concern”, hence not counted as contributing to “current condition” or “trend in condition” of biodiversity.

Variables monitored: Humpback and Minke Whale abundance estimated from land, boat-based and aerial surveys, and from citizen science sightings

Summary: There are four programs that monitor whales, three of which take place in the GBRWHA, and one where monitoring takes place south of the GBRWHA (Humpback Whale Population Monitoring) but provides population estimates for the region. The most frequent monitoring program is the Minke whale project where minke whales are monitored on an annual basis throughout their GBR season (March to October). The extent of whale monitoring is limited within each region due to the main opportunistic style of monitoring.

Crocodile**Table 31:** Assessment of environmental monitoring programs against the LTSP natural values and attributes: Crocodile

AIMS ID	Program and organisation	Biodiversity					
		Current condition (BO4)	Trend in condition (BO3; BT5)	Diversity (BO5)	Species of conservation concern: habitat availability and condition (BO2; BT2)	Species of conservation concern: incidental bycatch (BT3)	Species of conservation concern: population size (BO2; BO3; BO4; BT4)
84	CrocWatch (EHP)	•	•				
98	Dolphin and dugong monitoring, Lama Lama Sea Country (JCU & Lama Lama Aboriginal Corporation)	•	•				

Table 32: Monitoring duration, frequency and spatial extent: Crocodile

AIMS ID	Program and organisation	Monitoring program duration	Monitoring program frequency	Region where monitoring occurs					
				CY	WT	B	MW	F	BM
84	CrocWatch (EHP)	3 - 5 years	Opportunistic	•	•	•	•	•	•
98	Dolphin and dugong monitoring, Lama Lama Sea Country (JCU & Lama Lama Aboriginal Corporation)	≤ 2 years	Annual	•					

Variables monitored: Crocodile sightings

Summary: There are 2 programs that monitor crocodiles. The first is CrocWatch, which involves opportunistic sightings of crocs made by the general public (all regions). The recent dolphin and dugong monitoring in Lama Lama Sea Country also monitors crocodiles during dolphin and dugong monitoring (a localised program within Cape York). Both programs are relatively new (< 5 years).

Marine water quality**Table 33:** Assessment of environmental monitoring programs against the LTSP values and attributes: Marine water quality

AIMS ID (2015)	Program and organisation	Marine water quality LTSP objectives and targets			
		Reef Water Quality: Chlorophyll a (WQO2; WQT3; WQT4)	Reef Water Quality: TSS (WQO2; WQT3; WQT4)	Reef Water Quality: Pesticides (WQO2; WQT3; WQT4)	Reef Water Quality: Nutrients (WQO2; WQT3; WQT4)
2	Great Barrier Reef Ocean Observing System (IMOS)	•	•		
37	Marine Monitoring Program - Ambient Water Quality Monitoring (AIMS & JCU)	•	•	•	•
38	Marine Monitoring Program - Inshore (Ambient Pesticide) Water Quality (UQ & Entox)			•	
40	Marine Monitoring Program - Water Quality Remote Sensing (BoM)	•	•		
45.3	Port Curtis Integrated Monitoring Program (PCIMP) - Water quality (PCIMP)	•	•		•
46.2	Port Curtis and Port Alma Environmental Research and Monitoring Program - Water quality (GPC)	•	•		•
49	Port of Townsville – Marine Water Quality Monitoring (PoT)	•	•	•	•
55	North Queensland Bulk Ports Corporation – Marine Water Quality Monitoring (NQBP)	•	•	•	•
61	Ports North - Water Quality Monitoring (PN)	•	•		

Table 34: Monitoring duration, frequency and spatial extent: Marine water quality

AIMS ID	Program and organisation	Monitoring program duration	Monitoring program frequency	Region where monitoring occurs					
				CY	WT	B	MW	F	BM
2	Great Barrier Reef Ocean Observing System (IMOS)	6 - 10 years	< hourly (i.e. continuous)	•		•		•	•
37	Marine Monitoring Program - Ambient Water Quality Monitoring (AIMS & JCU)	≥ 20 years	Monthly		•	•	•		
38	Marine Monitoring Program - Inshore (Ambient Pesticide) Water Quality (UQ & Entox)	6 - 10 years	Monthly		•	•	•	•	
40	Marine Monitoring Program - Water Quality Remote Sensing (BoM)	11 - 19 years	Daily	•	•	•	•	•	•
45.3	Port Curtis Integrated Monitoring Program (PCIMP) - Water quality (PCIMP)	11 - 19 years	Quarterly					•	
46.2	Port Curtis and Port Alma Environmental Research and Monitoring Program - Water quality (GPC)	3 - 5 years	Monthly					•	
49	Port of Townsville – Marine Water Quality Monitoring (PoT)	11 - 19 years	< hourly (i.e. continuous)			•			
55	North Queensland Bulk Ports Corporation – Marine Water Quality Monitoring (NQBPP)	3 - 5 years	< hourly (i.e. continuous)			•	•		
61	Ports North - Water Quality Monitoring (PN)	≥ 20 years	Quarterly		•				

Variables monitored: Temperature, pH, nutrients, pesticides, turbidity, light, Chlorophyll a, suspended solids, coloured dissolved organic matter estimated from water samples and remote sensing.

Summary: Nine programs monitor marine water quality attributes specified in the LTSP. Three of these programs are for the Reef Plan Report Card (Marine Monitoring Programs), five are localised programs associated with ports, and the final program is the Great Barrier Reef Ocean Observing System. Most of these programs have been collecting water quality data for over 10 years, and do so on a regular basis (e.g., hourly, monthly or quarterly). A lot of these monitoring program are localised within distinct regions, except for the Marine Monitoring Program - Water Quality Remote Sensing, which uses remote sensing to estimate TSS and Chlorophyll a.

Other habitats where LTSP objectives/targets are not well articulated: Beaches, coastlines and islands

Table 35: Other habitats that are monitored (specific attributes not articulated as well for these in the LTSP objectives or targets): Beaches, coastlines and islands

AIMS ID	Monitoring program and organisation
12	Queensland Turtle Conservation (QTC) Project – marine turtle monitoring (EHP)
17	Coastal Bird Monitoring (Joint Field Management Program, QPWS & GBRMPA)
18	Shorebird monitoring (Queensland Wader Study Group)
19	Eastern Australian Waterbird Survey (UNSW)
42	Coastal Habitat Archiving and Monitoring Program (JCU & MangroveWatch)
46.4	Port Curtis and Port Alma Environmental Research and Monitoring Program - Marine turtle light impacts on hatchlings (GPC)
46.5	Port Curtis and Port Alma Environmental Research and Monitoring Program - Migratory shorebirds (GPC)
64	Australian Marine Debris Initiative (TBF)
100	Gladstone Healthy Harbour Marine Debris (CQU)
103	Flatback turtle's whereabouts project (WWF, EHP & JCU)
104	Loggerhead watch (UQ, WWF, The Wreck Rock Turtle Research Team, the BMRG & Queensland Government)
114	Eco Barge Marine Debris Cleanup and Monitoring (Eco Barge)

Table 36: Monitoring duration, frequency and spatial extent: Beaches, coastlines and islands

AIMS ID	Monitoring program and organisation	Monitoring program duration	Monitoring program frequency	Region where monitoring occurs					
				CY	WT	B	MW	F	BM
12	Queensland Turtle Conservation (QTC) Project – marine turtle monitoring (EHP)	11 - 19 years	Opportunistic	•	•	•	•	•	•
17	Coastal Bird Monitoring (Joint Field Management Program, QPWS & GBRMPA)	Unconfirmed	Unconfirmed						
18	Shorebird monitoring (Queensland Wader Study Group)	≤ 2 years	Once every two weeks					•	
19	Eastern Australian Waterbird Survey (UNSW)	≤ 2 years	Annual		•				
42	Coastal Habitat Archiving and Monitoring Program (JCU & MangroveWatch)	3 - 5 years	Quarterly					•	
46.4	Port Curtis and Port Alma Environmental Research and Monitoring Program - Marine turtle light impacts on hatchlings (GPC)	≤ 2 years	Variable	•		•	•		
46.5	Port Curtis and Port Alma Environmental Research and Monitoring Program - Migratory shorebirds (GPC)	≤ 2 years	Annual						•
64	Australian Marine Debris Initiative (TBF)	Unconfirmed	Unconfirmed		•				
100	Gladstone Healthy Harbour Marine Debris (CQU)	6 - 10 years	Annual				•		
103	Flatback turtle's whereabouts project (WWF, EHP & JCU)	≥ 20 years	Annual	•	•	•	•	•	•
104	Loggerhead watch (UQ, WWF, The Wreck Rock Turtle Research Team, the BMRG & Queensland Government)	≥ 20 years	Annual	•				•	•
114	Eco Barge Marine Debris Cleanup and Monitoring (Eco Barge)	≥ 20 years	Annual			•			

Variables monitored: Nesting habitat condition (for turtles and seabirds), mangrove extent and condition, and presence of marine debris on beaches.

Summary: The 12 programs associated with beaches, coastlines and islands, involve monitoring biological variables (e.g., turtles and seabirds) or threats (e.g., marine debris) in these habitats, but do not monitor the condition of these habitats directly. The temporal coverage of these programs varies substantially, and most have a limited spatial extent (within individual regions).

Other habitats where LTSP objectives/targets are not well articulated: Open water**Table 37:** Other habitats that are monitored (specific attributes not articulated as well for these in the LTSP objectives or targets): Open water

AIMS ID	Monitoring program and organisation
1	Coral Reef Watch Satellite SST Monitoring (NOAA)
2	Great Barrier Reef Ocean Observing System (IMOS)
3	ReefTemp (CSIRO, GBRMPA, BoM)
4	Sea Temperature Monitoring Program (AIMS & GBRMPA)
5	AIMS Weather Observing System (AIMS)
6	Australian Baseline Sea Level Monitoring Program (BoM)
8	Wave Monitoring (DSIT)
9	Storm Tide Monitoring (EHP)
37	Marine Monitoring Program - Ambient Water Quality Monitoring (AIMS & JCU)
38	Marine Monitoring Program - Inshore (Ambient Pesticide) Water Quality (UQ & Entox)
40	Marine Monitoring Program - Water Quality Remote Sensing (BoM)
45.3	Port Curtis Integrated Monitoring Program (PCIMP) - Water quality (PCIMP)
46.2	Port Curtis and Port Alma Environmental Research and Monitoring Program - Water quality (GPC)
49	Port of Townsville – Marine Water Quality Monitoring (PoT)
55	North Queensland Bulk Ports Corporation – Marine Water Quality Monitoring (NQBP)
61	Ports North - Water Quality Monitoring (PN)
101	Port Curtis Harbour Watch (BIEEC)

Table 38: Monitoring duration, frequency and spatial extent: Open water

AIMS ID	Monitoring program and organisation	Monitoring program duration	Monitoring program frequency	Region where monitoring occurs					
				CY	WT	B	MW	F	BM
1	Coral Reef Watch Satellite SST Monitoring (NOAA)	11 - 19 years	Daily	•	•	•	•	•	•
2	Great Barrier Reef Ocean Observing System (IMOS)	6 - 10 years	< hourly (i.e. continuous)	•		•		•	•
3	ReefTemp (CSIRO, GBRMPA, BoM)	11 - 19 years	Daily	•	•	•	•	•	•
4	Sea Temperature Monitoring Program (AIMS & GBRMPA)	≥ 20 years	< hourly (i.e. continuous)	•	•	•	•	•	•
5	AIMS Weather Observing System (AIMS)	≥ 20 years	< hourly (i.e. continuous)	•	•	•	•	•	•

AIMS ID	Monitoring program and organisation	Monitoring program duration	Monitoring program frequency	Region where monitoring occurs					
				CY	WT	B	MW	F	BM
6	Australian Baseline Sea Level Monitoring Program (BoM)	≥ 20 years	< hourly (i.e. continuous)			•			
8	Wave Monitoring (DSITI)	≥ 20 years	< hourly (i.e. continuous)		•		•	•	
9	Storm Tide Monitoring (EHP)	≥ 20 years	< hourly (i.e. continuous)	•	•	•	•	•	•
37	Marine Monitoring Program - Ambient Water Quality Monitoring (AIMS & JCU)	≥ 20 years	Monthly		•	•	•		
38	Marine Monitoring Program - Inshore (Ambient Pesticide) Water Quality (UQ & Entox)	6 - 10 years	Monthly		•	•	•	•	
40	Marine Monitoring Program - Water Quality Remote Sensing (BoM)	11 - 19 years	Daily	•	•	•	•	•	•
45.3	Port Curtis Integrated Monitoring Program (PCIMP) - Water quality (PCIMP)	11 - 19 years	Quarterly					•	
46.2	Port Curtis and Port Alma Environmental Research and Monitoring Program - Water quality (GPC)	3 - 5 years	Monthly					•	
49	Port of Townsville – Marine Water Quality Monitoring (PoT)	11 - 19 years	< hourly (i.e. continuous)			•			
55	North Queensland Bulk Ports Corporation – Marine Water Quality Monitoring (NQBP)	3 - 5 years	< hourly (i.e. continuous)			•	•		
61	Ports North - Water Quality Monitoring (PN)	≥ 20 years	Quarterly		•				
101	Port Curtis Harbour Watch (BIEEC)	≤ 2 years	Monthly					•	

Variables monitored: Temperature, salinity, sea level, currents, waves (height, direction, period), turbidity, light, dissolved oxygen, phytoplankton, nutrients, pesticides, chlorophyll, and suspended solids. Estimated from water samples or remote sensing.

Summary: The 17 programs associated with open water, involve monitoring physico-chemical variables (e.g., ocean currents and water quality) of open water. Most programs have been going for more than 10 years, and include frequent surveys (hourly, daily, monthly). The programs include some GBRWHA wide programs (e.g., Storm Tide Monitoring) through to localised programs (e.g., ports monitoring).

Outline of LTSP threats**Table 39:** Monitoring programs that assess LTSP threats

AIMS ID	Monitoring program and organisation
Sediment run-off (20 programs)	
2	Great Barrier Reef Ocean Observing System (IMOS)
37	Marine Monitoring Program - Ambient Water Quality Monitoring (AIMS & JCU)
40	Marine Monitoring Program - Water Quality Remote Sensing (BoM)
46.2	Port Curtis and Port Alma Environmental Research and Monitoring Program - Water quality (GPC)
49	Port of Townsville – Marine Water Quality Monitoring (PoT)
55	North Queensland Bulk Ports Corporation – Marine Water Quality Monitoring (NQBP)
57	Paddock to Reef - Catchment loads monitoring (DSITI)
61	Ports North - Water Quality Monitoring (PN)
68	Central Queensland Ambient Estuary Program (DERM & EHP)
69	Monitoring and tracking of water releases (compliance monitoring) (DSITI)
70	Environmental Flows Assessment Program (DNRM)
74	Wetland Walkabout Monitoring (RC & PCL)
75	Creek Watch Townsville (originally recorded as Creek to Coral Community Monitoring) (TCC & CVA)
76	Fitzroy Priority Neighbourhood Catchments Water Quality Monitoring Program (FBA)
80	Estuarine monitoring (Mackay Whitsundays) (DSITI)
93	Following the Flood: Identifying sources of environment contaminants in the North Burnett subcatchments post Cyclone Oswald (BCCA)
101	Port Curtis Harbour Watch (BIEEC)
106	Paddock to Reef - Paddock Monitoring and Rainfall Simulation (DNRM)
107	Streambank erosion baseline establishment project (DNRM)
108	Soil Acidification and Soil Organic Matter baseline establishment for the Burnett and Mary River Catchments 2012 (DNRM)
Urban, industrial and port activities (19 programs)	
42	Coastal Habitat Archiving and Monitoring Program (JCU & MangroveWatch)
45.1	Port Curtis Integrated Monitoring Program (PCIMP) - Bioaccumulation in oysters (PCIMP)
45.2	Port Curtis Integrated Monitoring Program (PCIMP) - Sediment quality (PCIMP)

AIMS ID Monitoring program and organisation

45.3	Port Curtis Integrated Monitoring Program (PCIMP) - Water quality (PCIMP)
46.1	Port Curtis and Port Alma Environmental Research and Monitoring Program - dredging activities (GPC)
46.2	Port Curtis and Port Alma Environmental Research and Monitoring Program - Water quality (GPC)
46.3	Port Curtis and Port Alma Environmental Research and Monitoring Program - Dugongs (GPC)
46.4	Port Curtis and Port Alma Environmental Research and Monitoring Program - Marine turtle light impacts on hatchlings (GPC)
46.5	Port Curtis and Port Alma Environmental Research and Monitoring Program - Migratory shorebirds (GPC)
47	Capricorn cetaceans project (SCU)
49	Port of Townsville – Marine Water Quality Monitoring (PoT)
50	Port of Townsville – Sediment Quality Monitoring (PoT)
53	North Queensland Bulk Ports Corporation – Marine Sediments Monitoring (NQBP)
55	North Queensland Bulk Ports Corporation – Marine Water Quality Monitoring (NQBP)
56	North Queensland Bulk Ports Corporation – Coral Monitoring (NQBP)
60	Ports North - Sediment Quality Monitoring (PN)
61	Ports North - Water Quality Monitoring (PN)
62	Ports North - Marine Pest Monitoring (PN)

Nutrient run-off (16 programs)

2	Great Barrier Reef Ocean Observing System (IMOS)
37	Marine Monitoring Program - Ambient Water Quality Monitoring (AIMS & JCU)
40	Marine Monitoring Program - Water Quality Remote Sensing (BoM)
46.2	Port Curtis and Port Alma Environmental Research and Monitoring Program - Water quality (GPC)
49	Port of Townsville – Marine Water Quality Monitoring (PoT)
55	North Queensland Bulk Ports Corporation – Marine Water Quality Monitoring (NQBP)
57	Paddock to Reef - Catchment loads monitoring (DSITI)
61	Ports North - Water Quality Monitoring (PN)
68	Central Queensland Ambient Estuary Program (DERM & EHP)
69	Monitoring and tracking of water releases (compliance monitoring) (DSITI)
70	Environmental Flows Assessment Program (DNRM)
75	Creek Watch Townsville (originally recorded as Creek to Coral Community Monitoring) (TCC & CVA)

AIMS ID Monitoring program and organisation

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- 76 Fitzroy Priority Neighbourhood Catchments Water Quality Monitoring Program (FBA)
 - 80 Estuarine monitoring (Mackay Whitsundays) (DSITI)
 - 101 Port Curtis Harbour Watch (BIEEC)
 - 106 Paddock to Reef - Paddock Monitoring and Rainfall Simulation (DNRM)

Outbreak of COTS (13 programs)

- 23 AIMS Long-term Monitoring Program (AIMS)
- 24 Effects of rezoning on offshore coral reef systems (AIMS)
- 25 Eye on the Reef - Rapid Monitoring Survey (GBRMPA)
- 26 Eye on the Reef - Sightings Network (GBRMPA)
- 27 Eye on the Reef - Reef Health and Impact Survey (GBRMPA)
- 28 Eye on the Reef - Tourism Weekly Monitoring Surveys (GBRMPA & Tourism Industry)
- 29 Reef Check (Coral Reef Health Monitoring) (Reef Check Australia)
- 36 Marine Monitoring Program - Inshore Coral (AIMS)
- 48 AIMS coral monitoring Gladstone Harbour (AIMS)
- 54 North Queensland Bulk Ports Corporation – Invasive Marine Pests Monitoring (NQBP)
- 62 Ports North - Marine Pest Monitoring (PN)
- 85 COTS surveillance (FMP)
- 86 Crown-of-thorns Starfish Outbreak Management Program (RRRC & GBRMPA)

Marine debris (10 programs)

- 14 Effects of management zoning on inshore reefs of the Great Barrier Reef Marine Park: Derelict fishing line on fringing reefs (JCU)
 - 25 Eye on the Reef - Rapid Monitoring Survey (GBRMPA)
 - 26 Eye on the Reef - Sightings Network (GBRMPA)
 - 27 Eye on the Reef - Reef Health and Impact Survey (GBRMPA)
 - 28 Eye on the Reef - Tourism Weekly Monitoring Surveys (GBRMPA & Tourism Industry)
 - 29 Reef Check (Coral Reef Health Monitoring) (Reef Check Australia)
 - 64 Australian Marine Debris Initiative (TBF)
 - 66 Reef Life Survey (RLS)
 - 100 Gladstone Healthy Harbour Marine Debris (CQU)
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AIMS ID Monitoring program and organisation

114 Eco Barge Marine Debris Cleanup and Monitoring (Eco Barge)

Outbreak of disease (10 programs)

23 AIMS Long-term Monitoring Program (AIMS)

24 Effects of rezoning on offshore coral reef systems (AIMS)

25 Eye on the Reef - Rapid Monitoring Survey (GBRMPA)

26 Eye on the Reef - Sightings Network (GBRMPA)

27 Eye on the Reef - Reef Health and Impact Survey (GBRMPA)

28 Eye on the Reef - Tourism Weekly Monitoring Surveys (GBRMPA & Tourism Industry)

29 Reef Check (Coral Reef Health Monitoring) (Reef Check Australia)

36 Marine Monitoring Program - Inshore Coral (AIMS)

48 AIMS coral monitoring Gladstone Harbour (AIMS)

95 Recovery of the Great Barrier Reef (Earthwatch& AIMS)

Climate change (9 programs)

1 Coral Reef Watch Satellite SST Monitoring (NOAA)

2 Great Barrier Reef Ocean Observing System (IMOS)

3 ReefTemp (CSIRO, GBRMPA, BoM)

4 Sea Temperature Monitoring Program (AIMS & GBRMPA)

5 AIMS Weather Observing System (AIMS)

6 Australian Baseline Sea Level Monitoring Program (BoM)

8 Wave Monitoring (DSITI)

9 Storm Tide Monitoring (EHP)

77 Coral Watch (UQ)

Outbreak of other species (9 programs)

23 AIMS Long-term Monitoring Program (AIMS)

24 Effects of rezoning on offshore coral reef systems (AIMS)

27 Eye on the Reef - Reef Health and Impact Survey (GBRMPA)

28 Eye on the Reef - Tourism Weekly Monitoring Surveys (GBRMPA & Tourism Industry)

29 Reef Check (Coral Reef Health Monitoring) (Reef Check Australia)

AIMS ID Monitoring program and organisation

36	Marine Monitoring Program - Inshore Coral (AIMS)
48	AIMS coral monitoring Gladstone Harbour (AIMS)
54	North Queensland Bulk Ports Corporation – Invasive Marine Pests Monitoring (NQBP)
62	Ports North - Marine Pest Monitoring (PN)
Port sediments (7 programs)	
1	Coral Reef Watch Satellite SST Monitoring (NOAA)
45.2	Port Curtis Integrated Monitoring Program (PCIMP) - Sediment quality (PCIMP)
46.2	Port Curtis and Port Alma Environmental Research and Monitoring Program - Water quality (GPC)
50	Port of Townsville – Sediment Quality Monitoring (PoT)
53	North Queensland Bulk Ports Corporation – Marine Sediments Monitoring (NQBP)
56	North Queensland Bulk Ports Corporation – Coral Monitoring (NQBP)
60	Ports North - Sediment Quality Monitoring (PN)
Sea temperature increase (9 programs)	
1	Coral Reef Watch Satellite SST Monitoring (NOAA)
2	Great Barrier Reef Ocean Observing System (IMOS)
3	ReefTemp (CSIRO, GBRMPA, BoM)
4	Sea Temperature Monitoring Program (AIMS & GBRMPA)
5	AIMS Weather Observing System (AIMS)
6	Australian Baseline Sea Level Monitoring Program (BoM)
45.3	Port Curtis Integrated Monitoring Program (PCIMP) - Water quality (PCIMP)
77	Coral Watch (UQ)
91	Ships of Opportunity on Tropical Research Vessels (IMOS)
Pesticide run-off (8 programs)	
37	Marine Monitoring Program - Ambient Water Quality Monitoring (AIMS & JCU)
38	Marine Monitoring Program - Inshore (Ambient Pesticide) Water Quality (UQ & Entox)
57	Paddock to Reef - Catchment loads monitoring (DSITI)
68	Central Queensland Ambient Estuary Program (DERM & EHP)
69	Monitoring and tracking of water releases (compliance monitoring) (DSITI)

AIMS ID Monitoring program and organisation

70	Environmental Flows Assessment Program (DNRM)
80	Estuarine monitoring (Mackay Whitsundays) (DSITI)
106	Paddock to Reef - Paddock Monitoring and Rainfall Simulation (DNRM)
Wildlife disturbance (5 programs)	
31	Marine Wildlife Stranding and Mortality (EHP)
46.3	Port Curtis and Port Alma Environmental Research and Monitoring Program - Dugongs (GPC)
46.4	Port Curtis and Port Alma Environmental Research and Monitoring Program - Marine turtle light impacts on hatchlings (GPC)
46.5	Port Curtis and Port Alma Environmental Research and Monitoring Program - Migratory shorebirds (GPC)
47	Capricorn cetaceans project (SCU)
Altered ocean currents (5 programs)	
2	Great Barrier Reef Ocean Observing System (IMOS)
5	AIMS Weather Observing System (AIMS)
6	Australian Baseline Sea Level Monitoring Program (BoM)
8	Wave Monitoring (DSITI)
9	Storm Tide Monitoring (EHP)
Cyclone activity (5 programs)	
2	Great Barrier Reef Ocean Observing System (IMOS)
5	AIMS Weather Observing System (AIMS)
6	Australian Baseline Sea Level Monitoring Program (BoM)
8	Wave Monitoring (DSITI)
9	Storm Tide Monitoring (EHP)
Extraction of particle feeders, herbivores & predators (3 programs)	
20	Queensland fishery independent surveys of specific species (DAF)
21	Queensland biological fishery dependent data collection (commercial and recreational). (DAF)
22	Queensland commercial fisheries monitoring (DAF)
Grounding vessel (large & small) (2 programs)	
89	Great Barrier Reef and Torres Strait Vessel Traffic Service (REEFVTS) (Aus & QLD govt)
90	The Modernised Australian Ship Tracking and Reporting System (MASTREP) (AMSA)

AIMS ID Monitoring program and organisation

Ocean acidification (3 programs)

- 2 Great Barrier Reef Ocean Observing System (IMOS)
- 77 Coral Watch (UQ)
- 91 Ships of Opportunity on Tropical Research Vessels (IMOS)

Sea level rise (3 programs)

- 2 Great Barrier Reef Ocean Observing System (IMOS)
- 6 Australian Baseline Sea Level Monitoring Program (BoM)
- 9 Storm Tide Monitoring (EHP)

Modifying coastal habitats (2 programs)

- 42 Coastal Habitat Archiving and Monitoring Program (JCU & MangroveWatch)
- 46.1 Port Curtis and Port Alma Environmental Research and Monitoring Program - dredging activities (GPC)

Spill — large chemical, large oil, or small (2 programs)

- 89 Great Barrier Reef and Torres Strait Vessel Traffic Service (REEFVTS) (Aus & QLD govt)
- 90 The Modernised Australian Ship Tracking and Reporting System (MASTREP) (AMSA)

Artificial light (1 programs)

- 46.4 Port Curtis and Port Alma Environmental Research and Monitoring Program - Marine turtle light impacts on hatchlings (GPC)

Coastal reclamation (2 programs)

- 42 Coastal Habitat Archiving and Monitoring Program (JCU & MangroveWatch)

Artificial light (1 programs)

- 46.4 Port Curtis and Port Alma Environmental Research and Monitoring Program - Marine turtle light impacts on hatchlings (GPC)

Extraction from spawning aggregations (1 program)

- 15 Fish Spawning Aggregation Monitoring (GBRMPA with support from Qld Fisheries and Science and Conservation of Fish Aggregations society)

Shipping incidents (2 programs)

- 89 Great Barrier Reef and Torres Strait Vessel Traffic Service (REEFVTS) (Aus & QLD govt)
- 90 The Modernised Australian Ship Tracking and Reporting System (MASTREP) (AMSA)

Altered weather patterns (1 program)

- 2 Great Barrier Reef Ocean Observing System (IMOS)

Dredging

AIMS ID Monitoring program and organisation

46.1 Port Curtis and Port Alma Environmental Research and Monitoring Program - dredging activities (GPC)

Illegal activities / Illegal fishing and poaching

111 Compliance surveillance (FMP)

Noise pollution

46.1 Port Curtis and Port Alma Environmental Research and Monitoring Program - dredging activities (GPC)

Table 40: Variables monitored for LTSP threats

Threats	What variables are monitored
Altered ocean currents	Currents, sea level, wave height/direction/period, and wind speed/direction
Altered weather patterns	Wave height/direction/period, and wind speed/direction
Artificial light	Light impacts on turtle hatchlings
Climate change	Sea surface temperature, sea level, pH, dissolved CO ₂ concentrations, coral bleaching
Coastal reclamation	Mangrove change in extent and drivers of change
Cyclone activity	Wind speed/direction and wave height/direction/period
Dredging	Dredging activity, Sedimentation, Light, Turbidity
Extraction from spawning aggregations	Fish abundance in spawning grounds, and commercial fisheries records
Extraction of particle feeders, herbivores & predators	Bycatch records from commercial fisheries
Grounding vessel	Ship movements and incidents
Illegal activities / Illegal fishing and poaching	Incident and offence type and numbers (e.g. illegal recreational fishing, tourism permit offences, recreational offences on islands (dogs and camping), hunting of threatened spp); Compliance rates amongst users identified during patrols; Enforcement actions taken
Marine debris	Weight and type of marine debris collected
Modifying coastal habitats	Mangrove change in extent and drivers of change
Noise pollution	Underwater noise from dredging activities
Nutrient run-off	Particulate and dissolved nutrients (N & P), Chlorophyll a, Phytoplankton
Ocean acidification	pH, dissolved CO ₂ concentrations
Outbreak of COTS	COTS densities on coral reefs, number of eradicated COTS, COTS feeding scars on hard coral
Outbreak of disease	Incidence of coral disease on coral reefs
Outbreak of other species	Introduced pests in ports
Pesticide run-off	Pesticide concentrations—ambient and in flood waters
Port sediments	Heavy metal content in sediments, sedimentation on corals, and particle size distribution
Sea level rise	Sea level
Sea temperature increase	Sea surface temperature
Sediment run-off	Suspended sediment (freshwater, estuarine and marine) and light attenuation.
Shipping incidents	Ship movements and incidents
Spill — large chemical, large oil, or small	Ship movements and incidents

<i>Threats</i>	<i>What variables are monitored</i>
Urban, industrial and port activities	Mangrove change in extent and drivers of change; Bioaccumulation of metals, metalloids and fluoride in oysters; Sediment quality (metal, metalloid and nutrients and particle size distribution); Water quality (pH, dissolved oxygen, turbidity, conductivity, salinity, temperature, light, nutrients, pesticides and metals); Dredging and shipping activity; dugong population estimates; light impacts on marine turtles; Migratory shorebird population estimates (near ports); Dolphin population estimates and heavy metal content (near ports); Seagrass cover, extent and condition (near ports); Benthic infauna; Coral sediment loadings (near ports); and Invasive species (near ports).
Wildlife disturbance	Wildlife strandings, light impacts on turtle hatchlings, port activity impacts on dolphins and dugongs

Summary: There are 8 programs that have the primary purpose of monitoring threatening processes (e.g., Australian Marine Debris Initiative), and another 47 programs that have the primary purpose of monitoring biological or physico-chemical variables but also monitor at least one threatening process at the same time. As the assessment of monitoring programs against threats was not a core part of this project, we point to the “Threats monitored” worksheet of the full inventory provided to the RIMREP Program Design working group for future assessment of the temporal and spatial adequacy of these programs in addressing LTSP threats.

Online databases where environmental monitoring program data or metadata are stored

Environmental monitoring program metadata and data are housed in a range of online databases (**Table 41**). eAtlas is one of 32 different online databases where metadata or raw data can be sourced for the monitoring programs in the GBRWHA. eAtlas contains monitoring metadata for 14 of the environmental monitoring programs (see Appendix 2 for names of monitoring programs). Thus, there are many monitoring programs could be added to eAtlas.

Table 41: Online databases (including hyperlinks) where monitoring metadata or data are contained.

Online databases where marine monitoring data is stored	Data type that is publicly available	Monitoring programs (AIMS ID)
AIMS Data Catalogue	Metadata ¹⁷	4,5, 23, 24, 36, 37, 48
Atlas of Living Australia	Species records ¹⁸	42
Australian Marine Debris Database	Raw data ¹⁹	64, 114
Bureau of Meteorology Australian Baseline Sea Level Monitoring Array Monthly Data Report	Summary data ²⁰	6
Coral Watch	Raw and summary data	77
Crystal Bowl (InfoFish)	Summary data	78, 79
CSIRO Coastal Research	Metadata	42
Digital Information Management System (DIMS) available after 2015	Metadata + summary data	41, 42, 44, 45, 46, 48
eAtlas	Metadata	10, 13, 14, 23, 24, 29, 35, 36, 37, 38, 39, 40, 86, 97
Eye on the Reef network database	Metadata	25, 26, 27, 28
Fitzroy Basin Report Card	Summary data	76, 92
Global Reef Record	Summary data	88
Integrated Marine Observing System, Australian Ocean Data Network (AODN) Portal	Raw data and/or metadata	2, 4, 5, 23, 91
National Oceanic and Atmospheric Administration Satellite Coral Bleaching Monitoring Datasets	Summary data	1
National Pollution Inventory	Summary data	105
PCIMP and AIMS database	Metadata and summary data	45
QFish Data Portal	Summary data	20, 21, 22
Qld Shark Catch data webpage	Raw data	52
Qspatial	Metadata and all data	41, 43, 65

¹⁷ Metadata: Summary information about the data collected (variables, sites, sampling times)

¹⁸ Species records: Species identification and location

¹⁹ Raw data: The format that the data was collected in the field

²⁰ Summary data: e.g., averages or totals grouped through time or space (i.e. not raw data), can also include maps or images

Online databases where marine monitoring data is stored	Data type that is publicly available	Monitoring programs (AIMS ID)
Queensland Coastal Data System – Near real time storm tide data	Summary data	9
Queensland EHP CrocWatch	Raw data	84
Queensland FishNet	Raw data	22
Queensland Government Data	Raw data	8
Queensland StrandNet	Raw data	12, 31
Queensland Water Monitoring Data Portal	Summary data	43, 71, 72, 73
Reef Check, Reef Health Database	Summary data	29
Reef Life Survey Data Portal	All data	66
Reef Temp	Summary data	3
Spatial and Scientific Information Management for Reef (SSIMR) (Qld Govt), DARTS (Data Recording Tool for Science)	Metadata	58 (53-57 - NQBP currently investigating getting their data onto SSIMR), 106
Waterbird Population Estimates online database	Summary data	18
WetlandInfo	Metadata	17, 18, 19, 41, 43, 68, 70, 71, 72, 73, 74, 75, 76

Socio-economic monitoring

SELTMP represents the most comprehensive attempt to date to capture and collate information on the human dimension of the socio-ecological system of the whole of the GBR. Primary data captured by SELTMP in 2013 comprise a face-to-face survey of 2877 tourists and 3181 coastal residents, a telephone survey of 119 tourism operators and 210 fishers, and an online national survey of 2002 residents. The face-to-face telephone surveys include respondents across 14 main population centres along the Great Barrier Reef. Secondary data includes a raft of sources ranging from national-scale programs (e.g. those conducted by the Australian Bureau of Statistics and Tourism Australia) to local programs co-ordinated by regionally based organisations (e.g. records held by GBRMPA and port authorities).

Here we present an assessment of the relevance of the content of SELTMP against the newly developed LTSP social and economic targets and objectives. In order to do this we qualitatively identified monitoring elements that aligned with the implied LTSP values, objectives, targets and attributes. **Table 42 - Table 45** shows the outcomes of our assessment. For each of the four socio-economic values, the tables describe the type of monitoring required (administrative *processes* or physical *outcomes*) and an indication of the availability of relevant information through SELTMP's primary social survey and/or secondary sources collated by SELTMP.

It is important to qualify our use of the judgment $\times$ = *no data of immediate relevance* in **Table 42 - Table 45**. The LTSP's emphasis on human wellbeing is evident in classification of objectives and targets according to our four overarching values (**Figure 22**). Consistent with this emphasis, many of the LTSP targets and objectives pertain to *processes*, requiring monitoring of the adequacy of administrative arrangements that provide (or fail to provide) empowerment via participation in decision-making, or other mechanisms. For example, we characterised as a process, *CBT2: Community benefit values have been identified and are considered in decision making*. In general, SELTMP does not include monitoring of administrative mechanisms associated with processes²¹. Objectives and targets deemed to require process monitoring were denoted $\times$ = *no data of immediate relevance*.

Many aspects of wellbeing are indirectly described by physical outcomes. More proximal descriptors of status and trend are associated with *perceptions*, and the extent to which administrative *processes* underpinning the way decisions are made empower individuals and communities. SELTMP's social survey includes many aspects of perceptions. However the monitoring of processes is underdeveloped. RIMREP will need to develop guidance to encourage consistent and unambiguous collation of data associated with objectives and targets identified as requiring process monitoring in the tables below. We note that SELTMP's primary survey includes perceptions of the extent to which stakeholder's needs are recognised, the effectiveness of governance, and opportunities to contribute to decision-making. These data can complement monitoring of administrative processes to provide a more detailed understanding of the perceived imperative to engage with stakeholders and communities.

²¹ Arrangements for monitoring administrative arrangements may be addressed in ongoing work undertaken as part of NESP project 3.11 *Monitoring and adaptively reducing system-wide governance risks facing the GBR*.

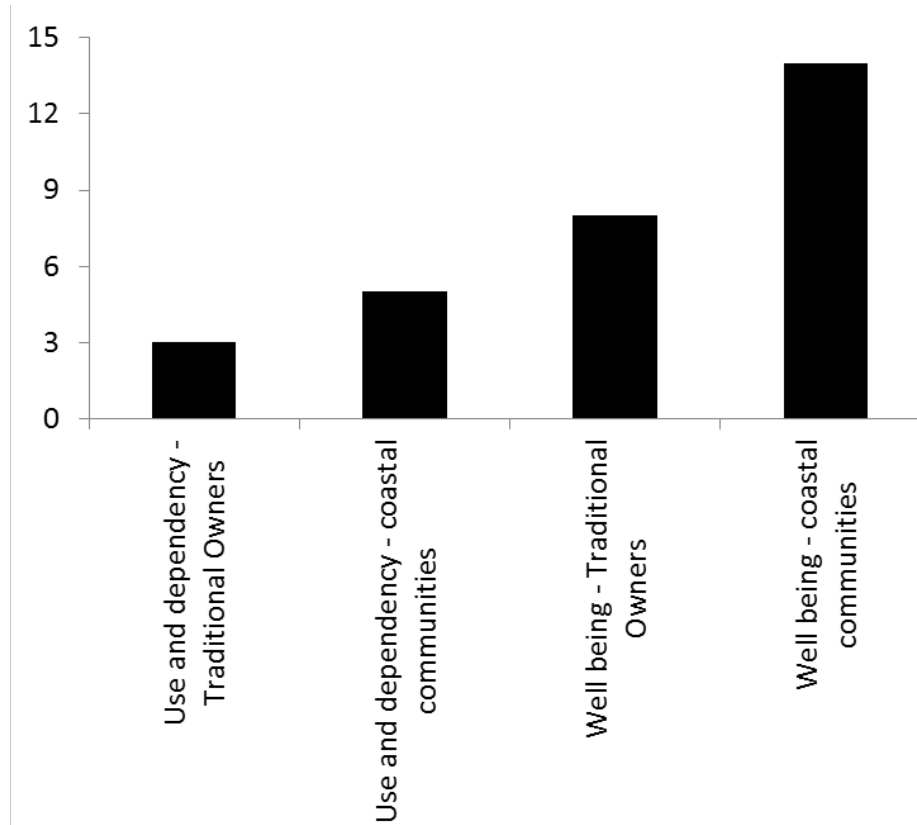


Figure 22: The number of objectives/targets associated with each of four socio-economic values in the LTSP.

We also note that some targets and objectives are too ambiguous or cumbersome to readily identify appropriate attributes for monitoring. These too were denoted $\times$ = *no data of immediate relevance*. For example, *EBO2: Protecting the Reef's Outstanding Universal Value is embedded within decision making with impacts first avoided, then mitigated and then, as a final consideration, any residual impacts are offset to achieve a net environmental benefit*. What might constitute 'net environmental benefit' is a difficult question, and one that may require identification and aggregation of salient environmental indicators. In truth, data are available or could be captured, but a critical task remains in clarifying the meaning and intent of the objective or target before monitoring can be made operational. Other elements for which *no data of immediate relevance* was identified include those for which the resolution of available data was considered inadequate. For example, although aspects of the ABS Census of Population and Housing inform *EBO1: Traditional Owners derive economic benefits from conservation and sustainable use of biological resources*, there is insufficient resolution in the survey instrument to identify the source of any decline or improvement in economic benefits.

The most striking outcome of our assessment is the dearth of readily available data pertaining to the many objectives and targets associated with Traditional Owner use, dependency and wellbeing. As a starting point, the disparate data elements held by GBRMPA, NAILSMA and other Indigenous organisations will need to be collated to inform a gap analysis and to develop protocols for consistent capture, storage and reporting.

Table 42: Assessment of SELTMP against the LTSP socio-economic values and attributes: Use and dependency – Traditional Owners. Key to ‘relevant data captured by SELTMP’, × = no data of immediate relevance, ● = primary data captured by social surveys, ○ = secondary data.

Objective or target	Attribute	Type of monitoring	Relevant data captured by SELTMP	Examples
EBO1: Traditional Owners derive economic benefits from conservation and sustainable use of biological resources.	economic benefits	Outcome	×	nil
EBT1: There is an increase in the number of Traditional Owner service providers and viable businesses.	service providers and viable businesses	Outcome	×	nil
EBT2: The number of employment opportunities for Traditional Owners in sea country management and Reef-based industries is increased.	employment opportunities in sea country management and Reef-based industries	Outcome	×	nil

Table 43: Assessment of SELTMP against the LTSP socio-economic values and attributes: Use and dependency – coastal communities. Key to ‘relevant data captured by SELTMP’, × = no data of immediate relevance, ● = primary data captured by social surveys, ○ = secondary data.

Objective or target	Attribute	Type of monitoring	Relevant data captured by SELTMP	Examples
CBO3: Community benefits provided by the Reef, including its superlative natural beauty and the sense of place, are maintained for current and future generations.	sense of place	Outcome	●	Perceptions of cultural identity and place attachment (e.g. Level of agreement with the statement, ‘ <i>There are not many other places that are better than the Reef for the tourism activities / recreation activities/ commercial fishing that I do</i> ’).
CBO3: Community benefits provided by the Reef, including its superlative natural beauty and the sense of place, are maintained for current and future generations.	natural beauty	Outcome	●	Perceptions of amenity and aesthetics (e.g. Level of agreement with the statement, ‘ <i>The aesthetic beauty of the Reef is outstanding</i> ’).
CBT4: Community benefit values for Great Barrier Reef coastal ecosystems are being monitored and show a positive trend.	community benefit values	Outcome and process	●○	Many descriptors of patterns of resource use and resource dependency. See Bohensky et al. 2014 for details.
EBO3: Reef-associated industries are planned and managed in such a way as to protect the Reef’s Outstanding Universal Value and are sustainable, productive and profitable.	productive and profitable	Outcome	●○	Primary data capture includes responses to the question, ‘ <i>To what extent does the Reef contribute to your household income?</i> ’ Secondary data includes descriptors of investments and employment at a coarse resolution.
EBO4: Reef-dependent industries are productive and profitable based on a healthy Reef and are ecologically sustainable.	productive and profitable	Outcome	●○	As for EB03
EBT6: Economic indicators are included in the Integrated Monitoring and Reporting Program	inclusion in IMRP	Process	×	nil

Table 44: Assessment of SELTMP against the LTSP socio-economic values and attributes: Wellbeing – Traditional Owners. Key to 'relevant data captured by SELTMP', × = no data of immediate relevance, ● = primary data captured by social surveys, ○ = secondary data.

Objective or target	Attribute	Type of monitoring	Relevant data captured by SELTMP	Examples
BO1: Traditional Owners are engaged and participate in and manage the conservation and ecologically sustainable use of cultural keystone species and biocultural resources.	engaged and participate in and manage the conservation and ecologically sustainable use of cultural keystone species and biocultural resources	Process	×	nil
BT1: Customary use of biological resources, in accordance with traditional cultural practices that are compatible with conservation or cultural use requirements, are formally recognised and adopted in management arrangements.	customary use of biological resources are formally recognised and adopted in management arrangements	Process	×	nil
CBO1: The rights of Traditional Owners to derive benefits from the conservation and cultural use of biological resources are recognised.	rights recognised	Process	×	nil
CBT1: The number of benefit sharing initiatives and agreements with Traditional Owners is increased.	benefit sharing initiatives and agreements	Process	×	nil
EHO1: The knowledge, innovations and practices of Traditional Owners relevant for conservation and cultural use of biocultural diversity are preserved and maintained.	knowledge, innovations and practices for conservation and cultural use of biocultural diversity	Outcome	×	nil
EHT1: Traditional Owners have developed Indigenous Ecological Knowledge Management Systems for collecting, handling and sharing culturally sensitive information, and its integration in decision making	Indigenous Ecological Knowledge Management Systems developed	Process	×	nil
EHT2: The number of agreements with Traditional Owners addressing management of ecosystems within their traditional estates is increased.	number of agreements addressing management of ecosystems	Process	×	nil
HO1: Traditional Owners' cultural heritage rights and responsibilities are incorporated in all facets of management.	cultural heritage rights and responsibilities are incorporated in management	Process	×	nil

Table 45: Assessment of SELTMP against the LTSP socio-economic values and attributes: Wellbeing – Coastal communities. Key to 'relevant data captured by SELTMP', × = no data of immediate relevance, ● = primary data captured by social surveys, ○ = secondary data.

Objective or target	Attribute	Type of monitoring	Relevant data captured by SELTMP	Examples
CBO2: A healthy Reef that supports sustainable lifestyles and livelihoods, and provides coastal communities with protection from extreme weather events.	support sustainable lifestyles and livelihoods	Outcome	●○	Many descriptors of patterns of resource use and resource dependency. See Bohensky et al. 2014 for details.
CBO2: A healthy Reef that supports sustainable lifestyles and livelihoods, and provides coastal communities with protection from extreme weather events.	protection from extreme weather events	Outcome	●	Perceptions of security (e.g. Level of agreement with the statement, <i>'I am uncertain how to plan for changes in the Reef that may affect me, such as floods, cyclones or financial crises'</i>).
CBO4: Local, regional and Reefwide community benefits are understood and the community is actively engaged in managing Reef activities.	community benefits are understood	Outcome	●	Many aspects of perceived benefits captured in SELTMP surveys. See Bohensky et al. 2014 for details.
CBO4: Local, regional and Reefwide community benefits are understood and the community is actively engaged in managing Reef activities.	active engagement in managing Reef activities	Process	●	Perceptions of security (e.g. Level of agreement with the statement, <i>'I am uncertain how to plan for changes in the Reef that may affect me, such as floods, cyclones or financial crises'</i>).
CBT2: Community benefit values have been identified and are considered in decision making.	benefit values have been identified and are considered in decision making	Process	×	nil

Objective or target	Attribute	Type of monitoring	Relevant data captured by SELTMP	Examples
CBT3: Community participation in stewardship actions to improve Reef health and resilience continues to grow.	participation in stewardship actions	Process	●	Perceptions of stewardship (e.g. Level of agreement with the statements, ' <i>I would like to do more to help protect the GBR</i> ' and ' <i>I regularly get involved in research and/or management activities for the GBR</i> ').
EBO2: Protecting the Reef's Outstanding Universal Value is embedded within decision making with impacts first avoided, then mitigated and then, as a final consideration, any residual impacts are offset to achieve a net environmental benefit.	achieve net benefits	Outcome	×	nil
EBO2: Protecting the Reef's Outstanding Universal Value is embedded within decision making with impacts first avoided, then mitigated and then, as a final consideration, any residual impacts are offset to achieve a net environmental benefit.	mitigation hierarchy incorporates OUV	Process	×	nil
EBO3: Reef-associated industries are planned and managed in such a way as to protect the Reef's Outstanding Universal Value and are sustainable, productive and profitable.	planning and management protects OUV	Process	●	Perceptions of governance and management (e.g. Level of agreement with the statements ' <i>I feel confident that the GBR is well managed</i> ' and ' <i>I support the current rules and regulations that affect access and use of the GBR</i> ').
EBT3: Cumulative impacts on the Reef from human activities are understood and measures to ensure a net environmental benefit approach for the Reef are in place.	achieve net benefits	Outcome	×	nil
EBT3: Cumulative impacts on the Reef from human activities are understood and measures to ensure a net environmental benefit approach for the Reef are in place.	cumulative impacts understood and measured	Outcome	×	nil

Objective or target	Attribute	Type of monitoring	Relevant data captured by SELTMP	Examples
EBT4: Shipping within the Reef is safe, risks are minimised, and incidents are reduced to as close to zero as possible.	shipping safety and incidents	Outcome	○	Groundings and collisions collated by Curnock et al. 2014.
EBT4: Shipping within the Reef is safe, risks are minimised, and incidents are reduced to as close to zero as possible.	shipping risks	Process	○	Risk management systems summarised by Curnock et al. 2014.
EBT5: The relationship between Reef health and the viability of Reef-dependent industries (e.g., tourism and fishing) is understood and considered in planning and development decisions.	viability relationship with Reef health understood	Outcome	●	Perceptions of reef quality and sustainability (e.g. Level of agreement with the statement ' <i>I would not be personally affected if the health of the Reef declined</i> ').
EBT5: The relationship between Reef health and the viability of Reef-dependent industries (e.g., tourism and fishing) is understood and considered in planning and development decisions.	viability relationship with Reef health considered in planning and development decisions	Process	×	nil
HO2: Indigenous and non-Indigenous heritage including natural, aesthetic, historic, scientific, and social values are identified, conserved and managed in partnership with the community.	identified, managed, monitored and protected	Process	×	nil
HO2: Indigenous and non-Indigenous heritage including natural, aesthetic, historic, scientific, and social values are identified, conserved and managed in partnership with the community.	heritage values are conserved	Process	×	nil
HT1: New and effective cooperative management practices are developed for protection and conservation of Great Barrier Reef Indigenous and non-Indigenous heritage.	new and effective cooperative management practices are developed	Process	×	nil

Objective or target	Attribute	Type of monitoring	Relevant data captured by SELTMP		Examples
HT2: Indigenous and non-Indigenous heritage values are identified, documented and protected in decision-making and planning processes.	identified, managed, monitored and protected	Process	×	nil	
HT3: Partnerships between Traditional Owners and all stakeholders are increased to ensure key Reef heritage values are identified, documented, and monitored.	partnerships with all stakeholders	Process	×	nil	
WQT5: Traditional Owners, industry and community are engaged in onground water quality improvement and monitoring.	engagement in onground water quality improvement and monitoring.	Process	●		Stewardship (e.g. Level of agreement with the statement, ' <i>I regularly get involved in research and/or management activities for the GBR</i> ').

3.3 Assessment of the power of monitoring programs: AIMS' Long Term and Marine Monitoring Programs

If existing monitoring programs are to be used to provide data to help evaluate whether LTSP targets and objectives are being achieved, the power of these monitoring programs (and the statistical models used to interpret the data) should be calculated prior to their use in an integrated monitoring and reporting program.

We conducted a power analysis of two indicators from the AIMS Long Term Monitoring Program (LTMP) and Marine Monitoring Program (MMP), reef fish species richness and per cent hard coral cover, to illustrate how assessments of the power of other monitoring programs could be undertaken in the future. The power analysis focussed on the ability of the LTMP and MMP programs to detect declines in indicators (reef fish species richness and hard coral cover) that we believe may be important declines to detect for the LTSP. These population declines were 1, 5, 10, 25, and 50% between current condition (estimated from monitoring data) and a simulated second set of diminished observations.

Reef fish richness

Bayesian power analysis revealed relatively low overall power (0.22) of the LTMP to detect small (<10%) declines in reef fish species richness between subsequent sampling occasions (**Figure 23**). However this power to detect trends varied substantially between sectors, with the highest (0.32) and lowest (0.12) power occurring within the Cairns (CA) and Capricorn-Bunker (CB) sampling sectors, respectively. At the scale of individual reefs, power was notably higher, averaging 0.25 for 1% declines, and 0.30 for 10% declines.

In contrast to the smaller changes, larger (>25%) declines in fish richness, that would represent more serious ecosystem losses, were much more likely to be detected between subsequent years (**Figure 23**). Here overall power (at the whole GBR scale) was high (0.86) and roughly equivalent among sectors (range 0.76 to 0.84), indicating the replication present in the LTMP is sufficient to discern substantial losses of fish biodiversity. In contrast to small declines, reef-scale average power (displayed by the individual dots in **Figure 23**) was lower on average for declines of 25% (0.67) and 50% (0.80), revealing a potentially important trade-off between sampling variability and power among scales.

Where declines are small it appears that sampling variability dominates, leading to higher uncertainty in trend effect sizes at progressively larger scales. The result is that there is low power (< 0.12) to detect small declines (e.g., 1, 5 and 10%) from current condition. However as decline magnitudes increase, the trends themselves begin to dominate sampling variability, with larger-scale effect sizes becoming more discernibly negative, even as sampling variability continues to impact lower-scale observations. This result implies that, despite potential interannual heterogeneity in diversity among individual reefs, large-scale declines in fish richness will be detected by the LTMP program as a whole. Note that these results are for system-wide trends (i.e. all reefs declining by the same amount at the same time) which is unlikely in practice.

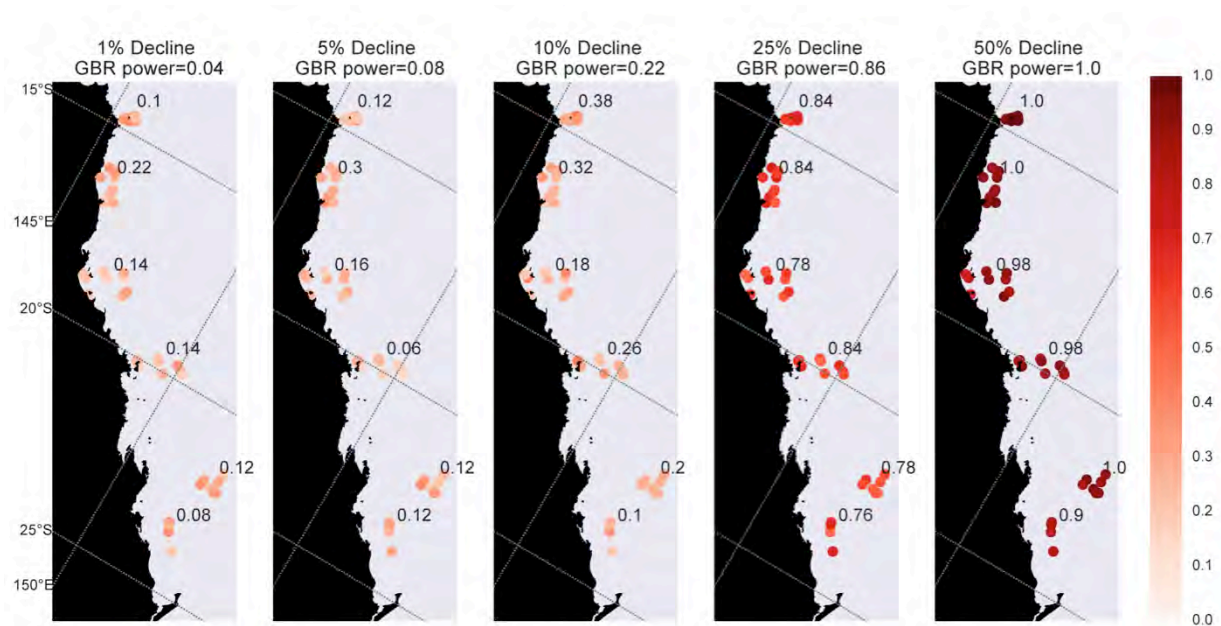


Figure 23: Bayesian power analysis of the LTMP to detect different levels of fish richness decline (1, 5, 10, 25, and 50% between current condition (estimated from monitoring data) and a simulated second set of diminished observations, shown at different spatial scales. Spatial scales displayed: i) the GBR wide scale (power noted at the top of each map), ii) the average reef-scale (average power noted for each of the 6 regions), iii) individual reef-scale (individual reef power plotted, with colour variation indicating power).

Percent cover of hard coral

In contrast to fish richness, Bayesian power analysis showed that the combined LTMP and MMP monitoring programs were likely to capture (power = 0.58) relatively small changes (10% decline) in system wide hard coral cover (**Figure 24**). The generally higher power to detect smaller trends in hard coral cover reflects the lower sampling variability of sessile corals relative to mobile fishes. At the highest levels of decline (25 and 50%), system-wide power to detect hard coral cover changes remained high (0.79 and 0.91 respectively).

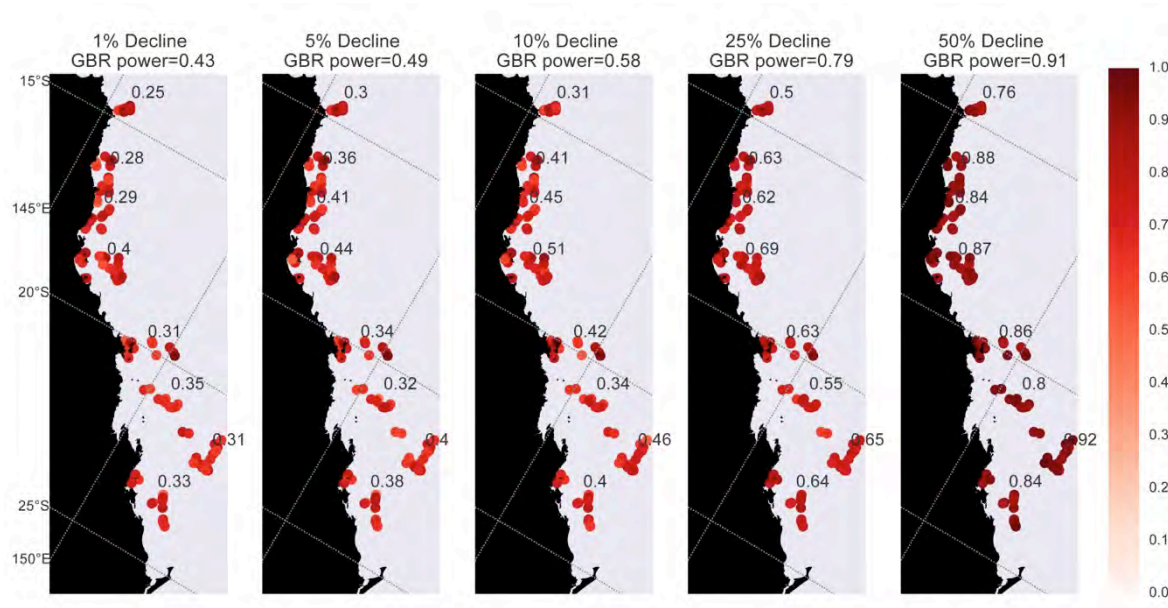


Figure 24: Bayesian power analysis of the LTMP and MMP to detect different levels of hard coral decline (1, 5, 10, 25, and 50% between current condition (estimated from monitoring data) and a simulated second set of diminished observations, shown at different spatial scales. Spatial scales displayed: i) the GBR wide scale (power noted at the top of each map), ii) the average reef-scale (average power noted for each of the 6 regions), iii) individual reef-scale (individual reef power plotted, with colour variation indicating power).

Implications of power analysis

Our assessment of reef fish richness and hard coral cover data from the LTMP and MMP shows that these monitoring programs have reasonably high power (>0.50) at the GBR-wide and NRM region scales to discern substantial losses (declines of $\geq 25\%$) of fish biodiversity and hard coral cover. This analysis suggests that despite potential interannual variability among monitoring locations (reefs), large-scale declines in fish richness or hard cover will be readily detected by the LTMP program (for fish) and the combined LTMP/MMP program as a whole. Thus LTSP stakeholders can be confident that the LTMP will detect declines of $\geq 25\%$ in reef fish richness, which would result in failure to meet Biodiversity Objective 5 for bony fishes and trigger an adaptive management response. Similarly, LTSP stakeholders should be confident that declines $\geq 25\%$ in coral cover will be detected, resulting in a failure to meet Biodiversity Objective 4 that would trigger an adaptive management response.

If stakeholders would like to detect smaller declines (e.g. 10 – 20%) in hard coral cover or reef fish richness, then the same power analysis can be repeated to explore whether increasing the number of monitoring locations or sites within locations (transects) could help materially improve the power of the LTMP and MMP. If statistical power does not improve with increased replication in a monitoring program, this would indicate that the current monitoring program is sampling within a very heterogeneous environment, and the monitoring design (e.g., temporal frequency and spatial stratification) should be reviewed and modified as necessary (see in depth discussion of this in Quinn & Keough 2002).

4.0 RECOMMENDATIONS: TOWARDS AN INTEGRATED MONITORING AND REPORTING PROGRAM

The LTSP (Commonwealth of Australia 2015) has the vision that

“By 2050 the Great Barrier Reef continues to demonstrate the Outstanding Universal Value for which it was listed as a World Heritage Area and supports a wide range of sustainable economic, social, cultural and traditional activities”.

The specification of targets, objectives and outcomes in the LTSP elevates the importance of monitoring to provide a clear understanding of the GBRWHA, its values, the processes that support it and the pressures that affect it. Further, the establishment of an effective integrated monitoring program is a fundamental precursor to enable adaptive management to protect and restore the Reef.

Recognising that an integrated monitoring program must be established in time to deliver data for the next GBRMPA Outlook Report in 2019, and that long-term data series and situational awareness of the condition of the GBR must be maintained, a pragmatic, adaptive, approach to the design and implementation of the integrated monitoring program must be adopted. The approach must include the formulation and agreement on the indicators, objectives and targets/benchmarks of the monitoring program, evaluate the adequacy of existing monitoring programs, and, where appropriate, build on these existing programs to establish a ‘first generation’ integrated monitoring program. We must also recognise that there are gaps in our current monitoring. Therefore, an integrated monitoring program must also have the capacity to evolve over time, and subject to the availability of additional resources, incorporate monitoring of new indicators, new technologies and guidelines that are able to inform the evaluation of the effectiveness of the Reef 2050 Plan and ensure data comparability and continuation of long-term data series.

Based on the findings of our research, we provide some recommendations on indicator selection and the development of an integrated monitoring and reporting program.

4.1 Indicator selection

We have illustrated that there are a very large number of environmental, ecological and socio-economic values, attributes and threatening processes that could be monitored to help assess progress towards the LTSP objectives and targets (Section 3.1). Overlaps and ambiguities in some objectives and targets implies that if an integrated monitoring program was to collect data on all of these elements, there would be significant double counting of similar patterns. This would be a very costly, inefficient and confusing use of monitoring data, and this approach would certainly not represent an “integrated” monitoring and reporting program.

A substantial amount of work will be required to refine any list of indicators that will provide clear signals to help evaluate whether the LTSP objectives and targets are being achieved. There are a range of decision-making tools and frameworks that can help with the challenging task ahead of indicator development, prioritisation and selection (Hedge *et al.* 2013; Walshe *et al.* 2014; Maxwell *et al.* 2014).

The development of some types of indicators will require dedicated scientific research. New indicators can be incorporated into the monitoring program over time once they have been tested. This is particularly the case for developing indicators of connectivity and resilience, which to date have proved to be conceptual and hard to quantify. The conceptual properties of connectivity (*“The extent to which a species or population can move among landscape elements in a mosaic of habitat types”*; LTSP; Commonwealth of Australia 2015) and resilience (*“The capacity of an ecosystem to recover from disturbance or withstand ongoing pressures”*; Strategic Assessment; GBRMPA 2014b) are not easy to measure in any direct way in practice. The indicators of resilience that have been identified by scientists (e.g., Maynard *et al.* 2010; McClanahan *et al.* 2012) have been based primarily on expert opinion and remain unverified. It is unlikely that there will be clear-cut linear relationships between an indicator and the condition or process it is meant to measure. A linear increase or decrease in an indicator may in fact reflect a curvilinear change in the property of interest. Therefore the development of and justification for indicators of resilience and connectivity will be a significant research task, requiring predictive models to help understand ecosystem processes.

Once a suite of indicators has been identified or developed to help measure the various values, attributes and threatening processes of the LTSP, further work will be required to prioritise and select a final suite of indicators. We point to the Driver/Pressure/State/Impact/Response (DPSIR) framework to assist with clarifying thinking around how ecosystems work and identifying key threats and natural values (e.g., Berg *et al.* 2015; Rees *et al.* 2008).

The use of criteria to prioritise indicators can be a crude approach, however will likely be necessary to sort through the long list of candidate indicators implied in an exhaustive interpretation of the natural values, attributes and threats of the LTSP (e.g., Jennings 2005; Rice & Rochet 2005). Finally, more advanced approaches like using qualitative loop models or influence diagrams could help with indicator prioritisation and selection, by exploring strengths of interactions and indicators that could help understand multiple objectives and/or threats at the same time (e.g., Failing & Gregory 2003; Hayes *et al.* 2015).

4.2 Development of an integrated monitoring program

The development of an integrated monitoring and reporting program should be a concurrent task alongside indicator selection, as both tasks will influence each other.

The GBRWHA is a busy space for environmental monitoring, with 80 monitoring programs associated with the marine environment (Section 3.2). There are varying amounts of monitoring dedicated to the natural values and threats identified in the LTSP (e.g., coral reefs and associated species currently receive the most monitoring attention). With respect to environmental monitoring, we have identified that there are no monitoring programs with the primary purpose of monitoring: Deeper (>30 m) coral reefs, Lagoon floor, Shoals, *Halimeda* banks, Continental slope, Benthic microalgae, Plankton and microbes, and Sea snakes. The most striking gap in socio-economic monitoring is the absence of dedicated and co-ordinated monitoring pertaining to Traditional Owner use, dependency and well-being. We also note that the capacity to report on the use, dependency and well-being of coastal communities rests critically on future support for SELTMP, or some variant of its current form.

Large sections of the GBRWHA are remote, thus are difficult and expensive to access to undertake routine and systematic monitoring. While marine monitoring programs undertake surveys across all NRM regions, the extent of sampling within NRM regions varies greatly among programs (as is highlighted in the maps, **Figure 13 - Figure 21**). This is most evident in the far northern GBR, where monitoring activity is very limited. The lack of monitoring is also apparent in most offshore areas and even inshore areas that are away from major townships, tourism sites, and island research stations.

The existing monitoring programs have been developed for a range of purposes and are undertaken by a range of organisations and individuals with differing levels of scientific training. As a result, data are collected at different taxonomic resolutions (e.g., species level identification through to broad morphological categories) and data resolutions (e.g., continuous vs categorical data), and are subject to varying amounts of quality control.

A substantial amount of work will be required to assess the merit of each monitoring program in relation to specific LTSP *indicators*. Beyond this, an integrated monitoring and reporting program that uses the data from these existing monitoring programs will require the development and implementation of standardised protocols for data collection, analyses, sharing, collation and aggregation, and methods for evaluation of the success, or otherwise, of the LTSP.

We have illustrated an approach to assess the statistical power of existing monitoring programs to determine their adequacy in assisting future evaluations of the LTSP (Section 3.3). We strongly recommend all existing monitoring programs that are being considered for integration into the monitoring and reporting program be evaluated for statistical power in a similar way.

The power analysis provides a platform to explore changes considered important to detect through the LTSP in order to trigger an adaptive management response. If monitoring programs lack the power to adequately address the LTSP, then the same analysis can be repeated to explore whether increasing monitoring replication could help improve the power of a monitoring program.

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APPENDIX 1: KEY PROJECT STAKEHOLDERS

The RIMREP Program Design working group and other key stakeholders consulted during NESP Project 3.8.

Name	Organisation
David Souter	Australian Institute of Marine Science
Jeffrey Dambacher	CSIRO
Beth Fulton	CSIRO
Kate O'Callaghan	Department of the Environment – Reef 2050 Plan
Giles West	Department of the Environment – Reef Delivery and the Reef Trust
Eva Alba	Great Barrier Reef Foundation and University of Queensland
Fergus Molloy	Great Barrier Reef Marine Park Authority
Josh Gibson	Great Barrier Reef Marine Park Authority
David Wachenfeld	Great Barrier Reef Marine Park Authority
Damien Burrows	James Cook University
Allan Dale	James Cook University
Natalie Stoeckl	James Cook University
Peter Doyle	North Queensland Bulk Ports Corporation
Amanda Parr	Parks Australia (Commonwealth Marine Reserves)
Ross Quinn	Qld Department of Agriculture and Fisheries
Claire Andersen	Qld Department of Environment and Heritage Protection
Nyssa Henry	Qld Department of Environment and Heritage Protection
Ian Gordon	Queensland Department of Natural Resources and Mines
Sheridan Morris	RRRC
Peter Mumby	University of Queensland

APPENDIX 2: FULL LIST OF ENVIRONMENTAL MONITORING PROGRAMS

AIMS ID	Program and organisation
1	Coral Reef Watch Satellite SST Monitoring (NOAA)
2	Great Barrier Reef Ocean Observing System (IMOS)
3	ReefTemp (CSIRO, GBRMPA, BoM)
4	Sea Temperature Monitoring Program (AIMS & GBRMPA)
5	AIMS Weather Observing System (AIMS)
6	Australian Baseline Sea Level Monitoring Program (BoM)
8	Wave Monitoring (DSITI)
9	Storm Tide Monitoring (EHP)
10	Dugong Population Monitoring (JCU)
11	Humpback Whale Population Monitoring (UQ)
12	Queensland Turtle Conservation (QTC) Project – marine turtle monitoring (EHP)
13	Effects of management zoning on inshore reefs of the Great Barrier Reef Marine Park: benthic condition & fish (JCU)
14	Effects of management zoning on inshore reefs of the Great Barrier Reef Marine Park: Derelict fishing line on fringing reefs (JCU)
15	Fish Spawning Aggregation Monitoring (GBRMPA with support from Qld Fisheries and Science and Conservation of Fish Aggregations society)
17	Coastal Bird Monitoring (Joint Field Management Program, QPWS & GBRMPA)
18	Shorebird monitoring (Queensland Wader Study Group)
19	Eastern Australian Waterbird Survey (UNSW)
20	Queensland fishery independent surveys of specific species (DAF)
21	Queensland biological fishery dependent data collection (commercial and recreational) (DAF)
22	Queensland commercial fisheries monitoring (DAF)
23	AIMS Long-term Monitoring Program (AIMS)
24	Effects of rezoning on offshore coral reef systems (AIMS)
25	Eye on the Reef - Rapid Monitoring Survey (GBRMPA)
26	Eye on the Reef - Sightings Network (GBRMPA)
27	Eye on the Reef - Reef Health and Impact Survey (GBRMPA)
28	Eye on the Reef - Tourism Weekly Monitoring Surveys (GBRMPA & Tourism Industry)
29	Reef Check (Coral Reef Health Monitoring) (Reef Check Australia)
31	Marine Wildlife Stranding and Mortality (EHP)

AIMS ID	Program and organisation
34	Seagrass Watch (Seagrass-Watch HQ)
35	Marine Monitoring Program – Inshore Seagrass (Seagrass-Watch HQ)
36	Marine Monitoring Program - Inshore Coral (AIMS)
37	Marine Monitoring Program - Ambient Water Quality Monitoring (AIMS & JCU)
38	Marine Monitoring Program - Inshore (Ambient Pesticide) Water Quality (UQ & Entox)
40	Marine Monitoring Program - Water Quality Remote Sensing (BoM)
41	Queensland wetland extent change mapping (Queensland Herbarium, DSITI)
42	Coastal Habitat Archiving and Monitoring Program (JCU & MangroveWatch)
43	Surface Water Ambient Network (SWAN) (DNRM)
44	Queensland ports seagrass monitoring (JCU)
45.1	Port Curtis Integrated Monitoring Program (PCIMP) - Bioaccumulation in oysters (PCIMP)
45.2	Port Curtis Integrated Monitoring Program (PCIMP) - Sediment quality (PCIMP)
45.3	Port Curtis Integrated Monitoring Program (PCIMP) - Water quality (PCIMP)
46.1	Port Curtis and Port Alma Environmental Research and Monitoring Program - dredging activities (GPC)
46.2	Port Curtis and Port Alma Environmental Research and Monitoring Program - Water quality (GPC)
46.3	Port Curtis and Port Alma Environmental Research and Monitoring Program - Dugongs (GPC)
46.4	Port Curtis and Port Alma Environmental Research and Monitoring Program - Marine turtle light impacts on hatchlings (GPC)
46.5	Port Curtis and Port Alma Environmental Research and Monitoring Program - Migratory shorebirds (GPC)
47	Capricorn cetaceans project (SCU)
48	AIMS coral monitoring Gladstone Harbour (AIMS)
49	Port of Townsville – Marine Water Quality Monitoring (PoT)
50	Port of Townsville – Sediment Quality Monitoring (PoT)
52	Queensland Shark Control Program (DAF)
53	North Queensland Bulk Ports Corporation – Marine Sediments Monitoring (NQBP)
54	North Queensland Bulk Ports Corporation – Invasive Marine Pests Monitoring (NQBP)
55	North Queensland Bulk Ports Corporation – Marine Water Quality Monitoring (NQBP)
56	North Queensland Bulk Ports Corporation – Coral Monitoring (NQBP)
57	Paddock to Reef - Catchment loads monitoring (DSITI)
58	Paddock to Reef - Ground cover monitoring (QG)
59	Paddock to Reef - Riparian vegetation monitoring (QG)
60	Ports North - Sediment Quality Monitoring (PN)

AIMS ID	Program and organisation
61	Ports North - Water Quality Monitoring (PN)
62	Ports North - Marine Pest Monitoring (PN)
63	Ports North - Benthic infauna (PN)
64	Australian Marine Debris Initiative (TBF)
65	Queensland Land Use Monitoring Program (DSITI & DNRM)
66	Reef Life Survey (RLS)
67	Raine Island Green Turtle Recovery Project (QPWS)
68	Central Queensland Ambient Estuary Program (DERM & EHP)
69	Monitoring and tracking of water releases (compliance monitoring) (DSITI)
70	Environmental Flows Assessment Program (DNRM)
71	Surface Water Monitoring Network (DNRM)
72	Groundwater Ambient Network (GWAN) – Water quality (DNRM)
73	Groundwater Water Level Network (DNRM)
74	Wetland Walkabout Monitoring (RC & PCL)
75	Creek Watch Townsville (originally recorded as Creek to Coral Community Monitoring) (TCC & CVA)
76	Fitzroy Priority Neighbourhood Catchments Water Quality Monitoring Program (FBA)
77	Coral Watch (UQ)
78	Gladfish (InfoFish)
79	Fitzroy River Estuarine Fish Monitoring (Rocky Barra Bounty is a part of this) (InfoFish)
80	Estuarine monitoring (Mackay Whitsundays) (DSITI)
81	Rivers to Reefs to Turtles (WWF)
82	Long-term shark tagging program (OCR)
83	Minke whale project (JCU)
84	CrocWatch (EHP)
85	COTS surveillance (FMP)
86	Crown-of-thorns Starfish Outbreak Management Program (RRRC & GBRMPA)
88	Catlin Seaview Survey (UQ)
89	Great Barrier Reef and Torres Strait Vessel Traffic Service (REEFVTS) (Aus & QLD govt)
90	The Modernised Australian Ship Tracking and Reporting System (MASTREP) (AMSA)
91	Ships of Opportunity on Tropical Research Vessels (IMOS)
92	Enhanced Environmental Monitoring Program (Fitzroy Basin) (DNRM)

AIMS ID	Program and organisation
93	Following the Flood: Identifying sources of environment contaminants in the North Burnett subcatchments post Cyclone Oswald (BCCA)
94	Gladstone Creek Watch (CVA & GHHP)
95	Recovery of the Great Barrier Reef (Earthwatch& AIMS)
96	The Lakes Environmental and Ecosystem Health Monitoring Program (TCC)
97	Dolphin and dugong monitoring, Girringun Sea Country (JCU & Girringun Aboriginal Corporation)
98	Dolphin and dugong monitoring, Lama Sea Country (JCU & Lama Aboriginal Corporation)
99	Dolphin and dugong monitoring, Mandubarra Sea Country (JCU & Mandubarra Land and Sea Inc.)
100	Gladstone Healthy Harbour Marine Debris (CQU)
101	Port Curtis Harbour Watch (BIEEC)
102	Project Manta (UQ)
103	Flatback turtle's whereabouts project (WWF, EHP & JCU)
104	Loggerhead watch (UQ, WWF, The Wreck Rock Turtle Research Team, the BMRG & Queensland Government)
105	National Pollution Inventory - water pollutants (DOE)
106	Paddock to Reef - Paddock Monitoring and Rainfall Simulation (DNRM)
107	Streambank erosion baseline establishment project (DNRM)
108	Soil Acidification and Soil Organic Matter baseline establishment for the Burnett and Mary River Catchments 2012 (DNRM)
109	Tully Basin Water Quality Monitoring (unclear if ongoing) (Girringun Aboriginal Corporation)
110	Eco Barge Marine Debris Cleanup and Monitoring (Eco Barge)
111	Compliance surveillance (FMP)

