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Long-Term Monitoring Program Survey Sampling Design

Long-term Monitoring of the Great Barrier Reef
Standard Operating Procedure Number 13 (Edition 1)

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Cover photo:

Current picture 'RV Solander in Western Australia. Image: N. Thake

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1 PREFACE

The Australian Institute of Marine Science's (AIMS) Long-Term Monitoring Program (LTMP) monitors the status and trends of coral reef benthic and fish assemblages, crown-of-thorns starfish populations, and other agents of coral mortality (bleaching, coral diseases, and *Drupella*) across a large swathe of the Great Barrier Reef (GBR).

The purpose of this Standard Operational Procedure (SOP) is to outline the hierarchical sampling design used by the Australian Institute of Marine Science's Long-Term Monitoring Program, to monitor spatial and temporal change in fish and benthic organism community composition and abundance from 1992 until 2021. Details specific to the methods in use to collect data for benthic, fish communities, agents of coral mortality and three-dimensional habitat structure are found in separate SOPs, which have been produced relating to the specific survey type (Emslie and Cheal 2018 for reef fish surveys, Jonker et al. 2020 for benthic surveys, Gonzalez Rivero et al. 2021 for three-dimensional habitat structure on fixed sites, Miller et al 2020 for agents of coral mortality surveys on fixed sites and Miller et al. 2019 for manta tow surveys). (https://www.aims.gov.au/research-topics/monitoring-and-discovery/monitoring-great-barrier-reef/reef-monitoring-sampling-methods#SOPreefmonitoring)

2 INTRODUCTION

Spanning approximately 2300 kilometres along the Queensland coastline and covering an area of 344,000 square kilometres, the GBR is the world's largest coral reef system comprising of approximately 3100 individual reefs supporting a range of users including traditional owners, commercial and recreational fishing, tourism, research, recreation and shipping.

In 1975, the *Great Barrier Reef Marine Park Act 1975* was established by the Federal Government, with the objective to provide for the long-term protection and conservation of the environment, biodiversity, and heritage values of the GBR. Subsequently, the Great Barrier Reef Marine Park Authority (GBRMPA) was created to manage the GBR Marine Park.

From 1985 to 1991, the GBRMPA provided funding for the first large scale monitoring program using manta tow surveys (Moran et al. 1988). These data were used in the reporting and subsequent evaluation of management effectiveness of the GBRMP. In 1991, the Australian Government provided funding to AIMS to conduct in-depth monitoring of the GBR. This led the creation of the Long-Term Monitoring Program (LTMP), which collects and reports on detailed information on the status and trends of coral reef benthic and fish assemblages. The sampling design used by the LTMP from 1991 to 2021 described in this document was developed to provide a balance between geographically small scale, intensive sampling and large scale, less intensive sampling to detect and quantify spatiotemporal change across selected ecological surrogates (Emslie et al 2020).

3 SAMPLING DESIGN

Since 1992, the LTMP has been performing fixed site surveys on SCUBA along permanently marked transects to quantify the abundance, diversity, and assemblage structure of fish and benthic organisms on Australia's Great Barrier Reef (GBR). These intensive fixed site surveys (Jonker et al 2020, Miller et al 2020, Emslie and Cheal 2018 are complemented by manta tow surveys (Miller et al 2019) around the entire perimeter of survey reefs.

3.1 Initial reef monitoring (RM) sampling design (1991-2005)

The Reef Monitoring (RM) component of the LTMP conducted fixed site surveys annually on 46 reefs. Initially the fixed site surveys were conducted within six latitudinal sectors spanning the GBR (Cooktown/Lizard Island, Cairns, Townsville, Whitsunday, Swain and Capricorn Bunker; Figure 1A), and within each of these sectors, where possible, replicate survey reefs were nested within three positions across the continental shelf relative to the coast and shelf edge. These positions were designated; inshore, mid-shelf and outer shelf (Figure 1A) and are intended to represent a cross-shelf gradient of physical, chemical, and environmental conditions. Such gradients are known to be strong drivers of GBR coral reef assemblage structure (Done 1982, Williams and Hatcher 1983, Cheal et al. 2012, Emslie et al. 2010, 2012, 2017).

Three replicate reefs were surveyed in each sector-shelf combination with some exceptions. In the Cairns mid-shelf four reefs were surveyed, five reefs were surveyed in the Swain mid-shelf and two reefs in the Swain outer shelf and four reefs in the Capricorn Bunker outer shelf. No inshore reefs were included from the Swain or Capricorn Bunker sectors and no mid-shelf reefs in the Capricorn-Bunker sector (Table 1, Figure 1A). (Table 1, Figure 1A). From 2005 until 2021, RM surveys by the LTMP were conducted biennially in odd years.

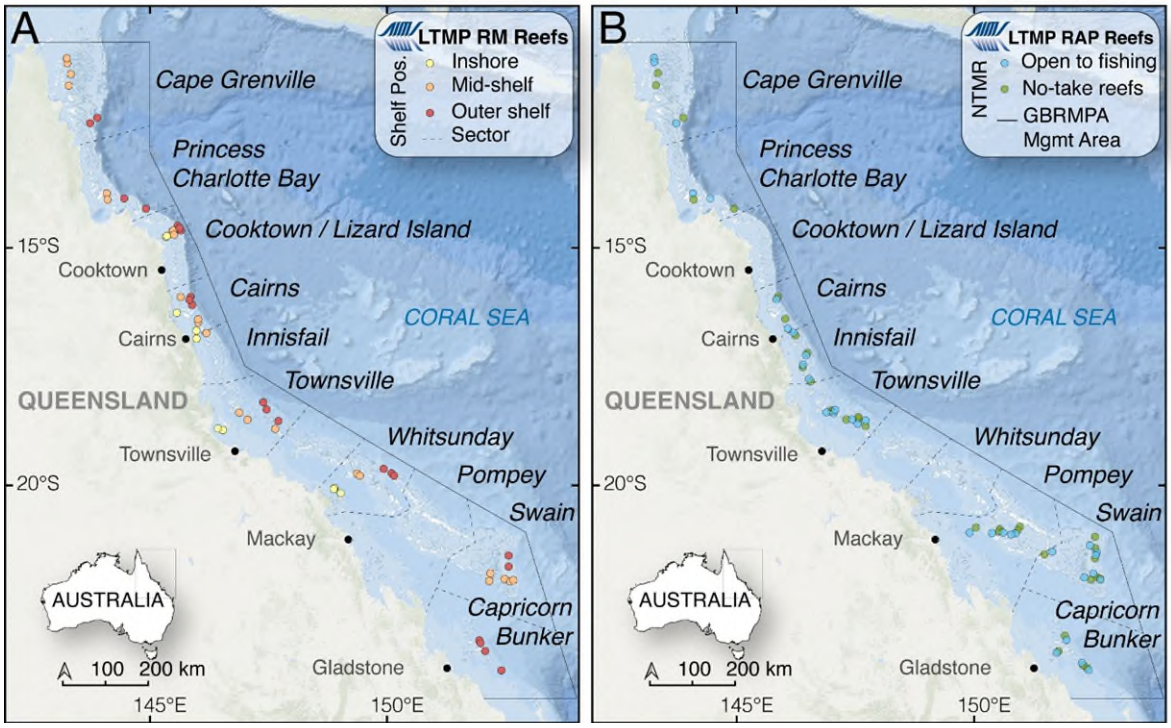

Figure 1. Location of reefs with fixed site surveys in the two LTMP biennially alternating programs. A. the historical Long-term Monitoring Program (RM) with replicate reefs in cross shelf positions (yellow points = inshore, orange points = mid-shelf, red points = outer shelf) in ten latitudinal sectors and B. the RAP monitoring of the 2004 GBRMP rezoning, with replicate pairs of reefs zoned No-Take Marine Reserve (green points) and Open to fishing (blue points) in each sector. There is some overlap of reefs between these two programs (n=10) which are monitored annually. Fixed site surveys in the Cape Grenville and Princess Charlotte Bay sectors commenced in 2019 and were conducted annually.

Table 1. The number of reefs per sector and shelf subregion in the LTMP and RAP fixed site survey design. Six sectors were surveyed every year, however some reefs are surveyed annually, while others are surveyed biennially. * denotes reefs or sectors only surveyed in LTMP RM years, # denotes only surveyed in RAP years, ^ denotes surveyed from 2019.

Sector	Inshore	Mid-Shelf	Outer Shelf
Cape Grenville ^	0	4	2
Princess Charlotte Bay ^	0	2	2
Cooktown/Lizard Island*	2	3	3
Cairns	3 *	5 (*2, #1)	3 (*1)
Innisfail#	0	6	1
Townsville	2 *	11 (*2, #8)	5 (*2, #2)
Whitsunday*	3	3	3
Pompey#	0	12	0
Swain	0	12 (*4, #7)	5 (*2, #3)
Capricorn Bunker	0	0	10 (*2, #6)

3.2 Representative Areas Program (RAP) sampling design (2006-2020)

The LTMP began another sampling program dedicated to assessing the effectiveness of the rezoning of the GBRMP after the area of the GBRMP protected inside No Take Marine Reserves (NTMRs) was increased to 33% in 2004 under the Representative Areas Program ('RAP' - Day et al. 2003, Fernandes et al. 2005). In 2006, the LTMP commenced biennial RAP surveys to examine the effect of expanding the area of NTMRs within the GBRMP. RAP surveys were conducted on 56 reefs, (with 10 reefs surveyed in both the RM and RAP programs), that were paired according to management zone. Each reef pair consisted of a reef located in a No-take Marine Reserve (NTMR) that was closed to fishing after the rezoning in 2004, and another closely located (with similar characteristics including shelf position, exposure, bioregion, geomorphology, and community composition), which remained open to fishing.

3.3 Expanded coverage of RM and RAP sampling design (2019-2021)

Commencing in 2019, both RAP and RM surveys were expanded north to the Cape Grenville and Princess Charlotte Bay sectors of the GBRMP (Figure 1). The additional reefs were chosen as pairs of reefs open and closed to fishing. This meant that both RM and RAP fixed sites were surveyed in 8 latitudinal sectors from 2019-2021, covering 10 latitudinal sectors collectively.

4 SURVEY DESIGN

4.1 Within reef fixed site survey design

Fixed site surveys on RM and RAP reefs are located in a standard reef slope habitat, typically situated on the north-east flank of each reef. This location is described as the first stretch of continuous reef with a slope less than vertical, progressing in a clockwise direction from the back-reef zone towards the front reef (Figure 2). The selection of a common habitat allows valid comparisons to be made among reefs both within and among sectors. At each reef, three sites comprising five permanently marked 50m transects each are surveyed (n = 15 transects $reef^{-1}$ $year^{-1}$). Transect are situated on the reef slope between 6 and 9 metres below Lowest Astronomical Tide and are laid approximately parallel to the reef crest. Each site is separated by at least 250m where possible (Figure 2).

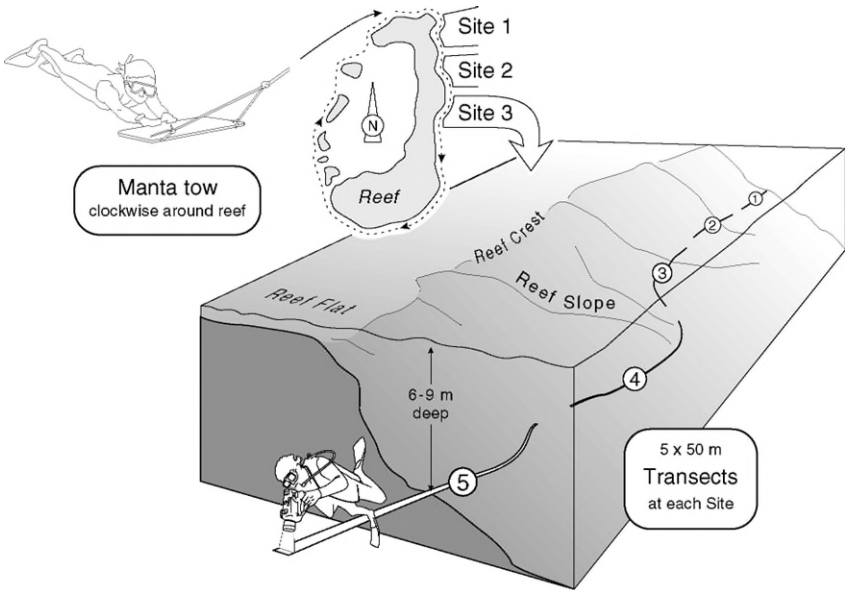

Figure 2. Diagram of the within reef sampling design used by AIMS LTMP

The start of each site is georeferenced with a GPS coordinate and marked by a metal stake with a subsurface buoy attached and a tag identifying it as belonging to AIMS LTMP.

Each transect on an RM fixed survey site is marked with a metal picket at each end and steel rods (10mm diameter) at 10m intervals to guide the transect tape. However, the RAP fixed survey sites are only marked with star pickets at the beginning of each transect. Observers laying the transect tape then follow compass bearings for each 10m segment of transect to ensure year to year consistency in the position of the transects in both programs. There are five different surveys undertaken along each 50m transect, and these are typically conducted concurrently but can be done separately. They are outlined in the Field sampling procedure in Appendix 6.1.

4.2 Manta tow surveys

The manta tow surveys are used to conduct rapid, broadscale assessments of the status of coral reef communities on reef slopes Reefs in all latitudinal sectors are surveyed by towing an observer behind a boat around the entire perimeter of a reef (Figure 2, Figure 3). The observer records selected ecological data including the percent hard and soft coral cover, numbers and size of crown-of-thorns starfish (COTS), as well as numbers of coral trout (*Plectropomus* spp and *Variola* spp) and sharks. These surveys were conducted on all reefs where fixed site surveys occur in both the RM and RAP components but are supplemented by numerous reefs where only manta tow surveys occur. Manta tow only reefs vary in the frequency at which they are surveyed; Key reefs are surveyed annually, Cyclic reefs are surveyed every three years, and Haphazard are surveyed opportunistically. The number of reefs surveyed each year is largely constrained by the weather and has varied from 49 to 127 throughout the LTMP's history. A total of 495 reefs have been surveyed since 1983.

Details of methods used during manta tow surveys are described in depth by Miller et al 2019.

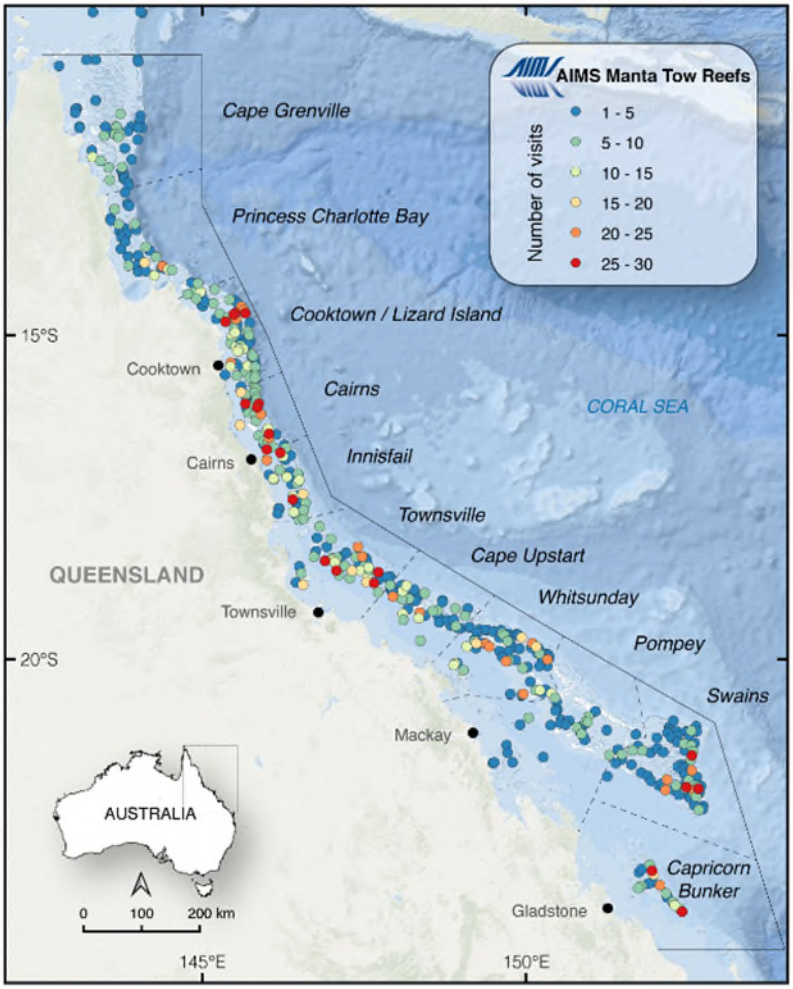

Figure 3. Locations of reefs within the GBRMP where manta tow surveys have been conducted since 1983. Reef surveyed the most frequently are those that also have fixed survey sites.

4.3 Future Directions of the LTMP

In 2015, recognising the social and economic value provided by the GBR, the Australian federal and Queensland state governments released the *Reef 2050 Long-term Sustainability Plan*, hereafter referred to as the Plan, aimed at providing a framework to manage and protect the GBR to build resilience and ameliorate threats.

A key component of the Plan is the *Reef 2050 Integrated Monitoring and Reporting Program* (RIMReP). Based upon the Driver, Pressure, State, Impact, and Response (DPSIR) framework, RIMReP will be a unified system with the vision to combine and integrate data and information from multiple monitoring programs representing a wide range of values of the GBR World Heritage Area to provide reef managers with information to guide management decisions and help them track progress against the Plan.

To meet the RIMReP objectives, the LTMP has modified the sampling design and merged both RM and RAP programs described above into one program, allowing a return to annual sampling. These changes are documented in Edition 2 of this Sampling Design SOP (Osborne et al 2024).

In selecting reefs for the RIMReP program, emphasis will be placed on NTMR/open zone pairings similar to the RAP methodology described earlier as well as continuing surveys on reefs which have been surveyed over a longer period of time.

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6 APPENDICES

6.1 Field sampling procedure

The following section outlines the procedure for undertaking a full survey involving photographing the benthos for 3D habitat reconstructions (Gonzalez Rivero et al 2021), photographing the benthos along the transect, counting juvenile corals (Jonker et al 2020), looking for agents of coral mortality (Miller et al 2020), and censusing large and small fishes (Emslie & Cheal 2018) on a permanent monitoring site. While all survey methods can be conducted concurrently, one or more survey method may be dropped, if required.

1. The site is located from the surface using a handheld GPS and/or past knowledge of the surrounding reef topography. On reaching the general area, a surface marker buoy attached to a 30m rope and drop weight is deployed. A snorkel diver then locates the beginning of the first transect, marked with a star-picket and sub-surface marker buoy. If the surface buoy is not close to the beginning of the first transect, it is redeployed with the aid of the snorkel diver. The boat is then anchored slightly away from the site so that the anchor does not damage the first transect and, if conducting fish censuses, divers entering the water do not swim across transects and disturb fish before the census begins.

2. Four divers enter the water and two diver's attendants remains in the boat. The first diver (fish observer) is equipped with a slate, pencil, data sheets and one fibreglass tape. The second diver acts as a buddy to the fish observer and carries five, 60 m tapes (tape layer). The third diver (benthic observer) is equipped with 3 cameras (2 GoPro cameras and another digital camera) attached to a metal bar and site tags, for identifying the site and transects in the images. The fourth diver (SCUBA searcher) is equipped with three habitat markers, a slate, pencil and data sheet.

3. Beginning at the first star-picket of transect one, the fish observer conducts the 50 m by 5 m fish survey by swimming along the centre line of the transects using the star-pickets and reinforcing rods as guides. The observer counts all large mobiles fishes from a list captured in Standard Operational Procedure No. 3 (Emslie & Cheal 2018) within the area 2.5 m either side of the centre line.

4. The tape layer follows the fish observer, laying a tape measure along the centre line of the transect. The tape is attached to the star-picket at the beginning of the transect, then wrapped once around each reinforcing rod and attached to, or as close as possible to, the star-picket at the end of the transect.

5. The SCUBA searcher then follows behind the tape layer and places three scale bars on the right-hand side of the transect in preparation for the three-dimensional habitat transect (ie. upslope of the tape). The benthic observer films the site tags and swims along right hand side of the transect tape for the first 10m, then slowly turns around and films back down the left hand side of the tape to the start of the transect as per Standard Operational Procedure No. 13 (Gonzalez Rivero et al 2021).

6. The benthic observer then takes a picture of the site tags for the correct site and transect and takes a landscape photograph down the transect, before photographing the benthic transect, as per Standard Operational Procedure No. 10 (Jonker et al 2020).

7. The SCUBA searcher swims with the benthic observer, recording the genus and number of juvenile corals with a diameter less than 5cm occurring within a 34 cm belt on the right side of the transect tape for a distance of 5m. A visual estimate of percentage cover of algae is also recorded for the 34 cm by 5m belt, along with an estimate of the reef slope, the slope for the 5m juvenile transect and the complexity of the substrate, as per Standard Operational Procedure No. 10 (Jonker et al 2020).

8. The benthic observer then follows behind the tape layer to photograph the 50 m transect, ensuring between 50-80 images are taken per transect.

9. The SCUBA searcher then records the presence of COTS, *Drupella* and agents of coral mortality as outlined in Standard Operational Procedure No. 8 (Miller et al 2020) for the transect.

10. The procedure for each method is repeated for the 5 transects.

11. Each pair of divers operate as a buddy pair; therefore, buddy pairs may become separated, but divers of a buddy pair remain within constant visual contact. This distance will depend on water clarity and may have to be adjusted throughout a dive depending on diving conditions.

12. Upon completion of the 5th transect, the two buddy pairs of fish observer and tape layer and benthic observer and SCUBA searcher surface and the divers' attendants collects them. The third buddy pair consisting of the second fish observer and the tape collector then enters the water.

13. Beginning their work at the last star picket on transect 5, the second fish observer and tape collector swim along the same transects (which are now marked with a tape along the centre line) undertaking a census of the Pomacentrid fish and places each species into 2cm bins, in the reverse direction relative to the first fish observer. The tape collector follows the fish observer rolling up the tapes., This buddy pair thus concludes their work, ascends and surfaces together, at the first star picket of transect one. The divers' attendant assists the divers into the boat.