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AUSTRALIAN INSTITUTE
OF MARINE SCIENCE

Crown-of-thorns starfish and coral surveys using the manta tow technique

Long-term Monitoring of the Great Barrier Reef
Standard Operational Procedure Number 9

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AIMS: Australia's tropical marine research agency
SOP 9 - Edition 4 (2019)

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This report should be cited as:

Miller IR, Jonker MJ, Coleman G (2018) Crown-of-thorns starfish and coral surveys using the manta tow technique. Australian Institute of Marine Science, Townsville, Australia.

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Revision History:		Name	Date	Comments
1	Prepared by:	Ian Miller	1/07/2019	
	Approved by:	Nicole Webster	1/07/2019	A comprehensive guide for manta based surveys of COTS and corals.
2				

Cover photo:

Observer conducting manta tow surveys. Photo: Ian Miller

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1 PREFACE

The Australian Institute of Marine Science's Long-term Monitoring Program (LTMP) monitors benthic and reef fish assemblages, crown-of-thorns starfish populations and other agents of coral mortality (bleaching, coral diseases, and *Drupella*) on a biennial basis. In alternate years when LTMP surveys are not conducted, there is a monitoring program to assess the effectiveness of management within the Great Barrier Reef Marine Park (GBRMP) under the Representative Areas Program (RAP). In both survey programs, reef fish and benthic communities are monitored along permanently marked transects in a standard reef slope habitat on selected reefs.

This Standard Operational Procedure is Volume 7 in a series of 9, produced by the Long-term Monitoring Program at the Australian Institute of Marine Science. It details the standard procedure used to gather broadscale data on the distribution and abundance of crown-of-thorns starfish collected using a plotless method called "manta tow". Details on data management, training, and quality control are also provided.

2 INTRODUCTION

This document describes the manta tow technique that is used by the Long-term Monitoring Program to survey crown-of-thorns starfish (COTS) and coral cover.

The manta tow technique was first described by Moran and others (1989) and later used in the Survey Manual for Tropical Marine Resources (English et al. 1994). The method is used to provide a general description of large areas of reef and to gauge broad changes in abundance and distribution of organisms on coral reefs. The advantage of manta tow over other survey techniques is that it enables large areas of reefs to be surveyed quickly and with minimal equipment. The manta tow technique was originally developed in 1969 to assess crown-of-thorns starfish densities on reefs in Micronesia (Chesher 1969). Similar studies were done in the Red Sea (Roads & Ormond 1971), Micronesia (Goreau et al. 1972) and on the Great Barrier Reef (Edean & Stablum 1973). Since the 1970s, the manta tow technique has been used extensively on the Great Barrier Reef for broadscale surveys (at the scale of entire or large parts of reefs). A definitive study by Moran et al. (1988) to assess the distribution and abundance of crown-of-thorns starfish (COTS) and corals on the Great Barrier Reef led to a standardization of the technique at AIMS (English et al. 1994). Studies by Fernandes (1989, 1990), Fernandes et al. (1990), Moran and De'ath (1992) and Miller and Müller (1999) have shown the manta tow technique to be a relatively accurate and cost-effective way of determining the abundance of non-cryptic COTS and corals over large areas, in clear water. Moran & De'ath (1992) found that the counts of COTS from manta tow surveys could be calibrated to predict estimates obtained from more intensive searches using SCUBA.

A number of changes to the manta tow procedure have been made in recent years to improve data collection, data entry and incorporate new technologies. More recently the method for providing descriptions of reef habitat has been changed. This method is also described in detail.

3 SAMPLING DESIGN

Selected reefs along the length of the Great Barrier Reef (GBR) (Figure 1) are surveyed annually for crown-of-thorns starfish using the manta tow technique according to designated survey design. Generally, manta tow survey reefs were chosen from the reefs within each region of the GBR according to the goals of the project taking in consideration of logistics as well as the history of surveys. Because of the non-biological nature of the selection criteria, the survey reefs are deemed likely to be representative of the reefs in each of the regions. Often reefs are sampled hierarchically within and between sectors to satisfy research objectives (sampling design) with reefs given priority for survey depending on weather and limited ship time.

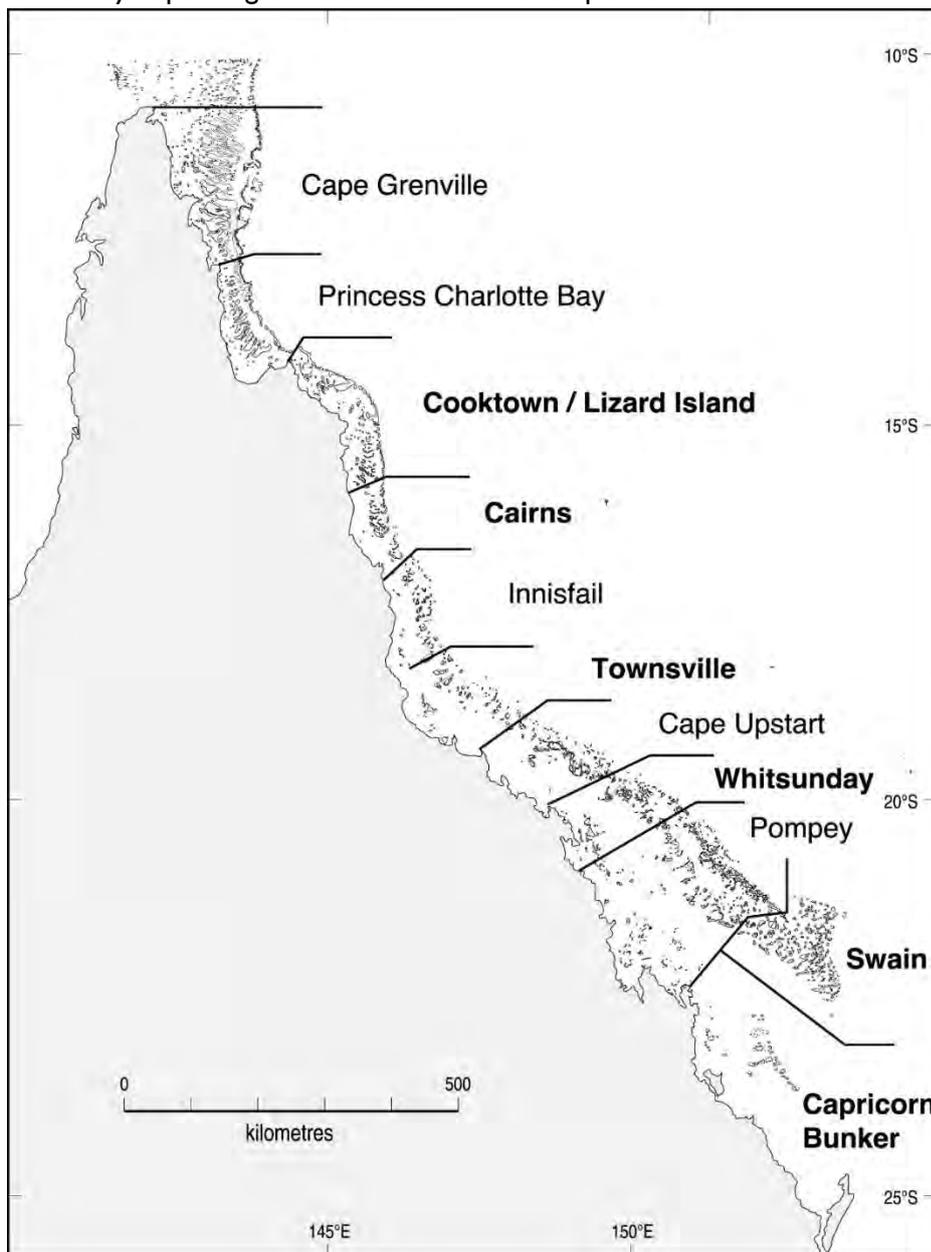


Figure 1. Sectors of the Great Barrier Reef surveyed as part of the LTMP.



Figure 2. Observer being towed along the reef edge using the manta tow technique.

4 DATA COLLECTION

4.1 Equipment

The equipment used to conduct manta tow surveys is listed below. The field gear is required in each boat while the extra gear remains on the ship. A small (~4-5m) boat (preferably a rigid-hulled inflatable) with 15-25 HP outboard motor and necessary safety gear are required to complete surveys.

4.1.1 Field gear

1. Waterproof VHF hand-held radio.
2. Rope harness that attaches to the boat's transom (Figure 3).
3. Manta board with a fitted harness and attached pencil (Figure 3).
4. 17 metres, 10mm towing rope with quick release clips on either end (Two small white floats are attached to the rope at 6 metre intervals from the manta board (Figure 13)).
5. A4 size manta tow pro forma data sheet printed on underwater paper (Appendix I) (This is held in the recess on the manta board by a fixed clamp (Figure 3)).
6. Container with spare 2B pencils, twine, and rubber bands.
7. Photocopy of an aerial photograph of the reef, attached to a slate by screw-down clamps and rubber bands (The photocopy is made on waterproof drawing film). This photograph is marked with the areas that constitute the front, back, and flanks of the reef (see 4.4.4. Data recording).

8. Snorkeling gear (mask, fins, snorkel, and wetsuit or stinger suit) for each person.
9. Large buoy(s), anchor rope (at least 10 m) and a dump weight.
10. Waterproof smart phone with inbuilt GPS and manta tow software (otherwise waterproof hand held GPS) and a watch with countdown function.
11. Waterproof digital camera.

4.1.2 Extra gear on the mother ship

1. Field logbook.
2. One reef pro forma and at least two, manta tow data sheets for each reef to be surveyed (plus extra data sheets for both manta tow and scuba search).
3. Laptop computer complete with data entry software, Image processing software (i.e. proprietary software for downloading JPG images from the digital camera(s), sorting and filing photographs, etc.).
4. Marine Park zoning maps of the Great Barrier Reef.
5. Maps of manta tow paths of previously surveyed reefs.
6. Spare stationery items.
7. Tide Tables.
8. Basic toolbox and spare snorkeling gear.
9. Spare batteries for a digital camera(s) and chargers for androids.
10. Plug-in battery re-charger.
11. Waterproof hard carry case for transporting camera equipment.
12. Camera maintenance equipment (i.e. O-ring (silicon) grease, spare o-rings for underwater camera housing, blower brush, lens cleaning fluid, lens cleaning cloth, lens polishing spray, cotton buds).

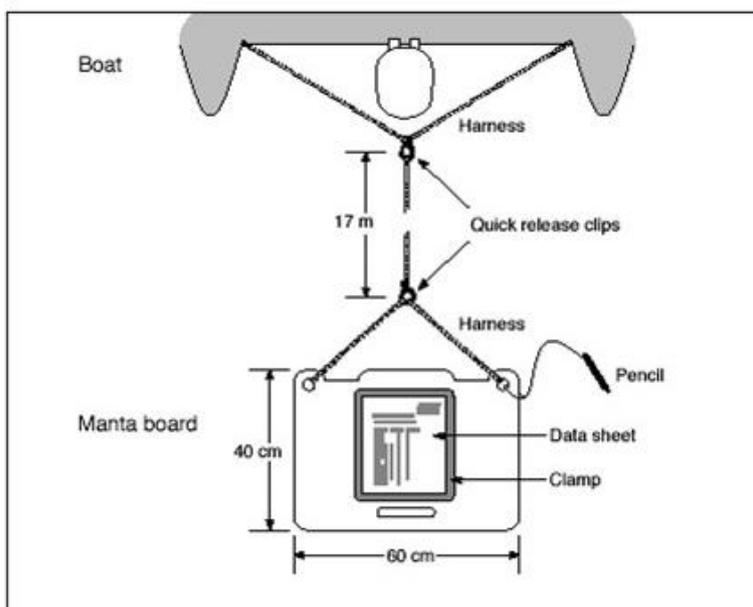


Figure 3. Manta board and attachments (from Moran et al. 1989).

4.2 Personnel

The manta tow technique involves towing a snorkel diver (observer) at a constant speed behind a boat (Figure 2). The observer holds on to a 'manta board' (Figure 2) attached to a small boat by a 17-metre length of rope. This person makes a visual assessment of specific variables during each manta tow (2 minutes duration) and records these data on a data sheet attached to the manta board when the boat stops.

A minimum of six people is required to conduct the surveys efficiently. One nominated person is responsible for planning the trip and ensuring that the surveys follow a standardized and safe procedure.

The surveys are conducted using two boats. Each boat has a driver, a spotter, and an observer. These roles are generally rotated during the survey of the reef. The driver is responsible for navigating the boat along the reef edge. The spotter is responsible for watching the observer on manta tow and logging the track of the survey. The observer is responsible for recording data. Each person should have good knowledge of their roles, the coral reef environment, its fauna, and be competent in the identification of benthic lifeforms (i.e. differentiating hard and soft corals and growth forms). They should also be an experienced snorkeler and possess a recreational shipmaster's license and a Marine Radio Operators Certificate of Proficiency.

4.3 Sampling procedure

On arrival at a reef, the following procedure should be adopted.

1. The two teams discuss the location of the starting point, manta towpath, location(s) for reef photography and weather conditions before commencing the survey. The cruise leader must ensure that everyone is aware of tides, currents, weather conditions and daylight hours remaining. Note. If the weather is expected to change for the worse, the teams should agree on a strategy before leaving the ship. Radio contact with the ship and between boats should always be maintained. This is particularly important on large reefs where it is easy to lose sight of the other boat conducting manta tow surveys.
2. Begin the survey at the predetermined starting point (usually at the northern end of the reef) unless conditions are unsuitable. Note: factors such as wind, the direction of current, and angle of the sun may alter the starting point. The driver should avoid towing into the sun continuously, where possible. Mark the starting point as '0' on the aerial photograph. (The two boats start together but proceed in opposite directions around the perimeter of the reef, meeting up at the other end Figure 4).
3. Clip the towrope to the transom and attach the other end to the manta board with the quick release clip. The observer should then record the ambient variables, such as weather conditions on the top of the data sheet (Appendix I), don snorkeling gear, and enter the water with the manta board.
4. The observer signals the spotter and driver to commence the manta tow when he/she is ready. As the driver commences the tow the spotter begins recording the log track for that particular

tow. The observer and driver use hand signals to communicate information about the towpath and the towing speed. The driver tows the observer, holding the manta board, behind the boat at a constant speed of about 4 km/hr. To keep the observer at constant speed requires the driver to accelerate through sharp corners when navigating around the reef. Despite the best efforts of the driver in many instances, the actual speed may vary, depending on wind and current. This is usually not a problem unless sea/weather conditions make towing impractical (e.g. the observer cannot make headway against a strong current). Note: observations are generally made from the surface, however, when closer inspection is required, the observer can maneuver the manta board below the surface in compliance with AIMS dive procedures (i.e. Repetitive Factor has returned to 1.0 – see AIMS Dive Procedures 2018 Section 9.4). To dive down, tilt the leading edge of the board down, and tilt up-wards to ascend.

5. The towpath should be parallel to the reef crest, and close enough so the observer can clearly see as much of the reef slope as possible. The search area will vary depending on; towpath, the speed of the boat, visibility, reef gradient, and distance from substrate, distribution, and density of organisms being counted (Moran & De'ath 1992). The variability of reef slope and conditions make it impossible to define a search area, but where possible the observer should try and scan a ten-metre band. Ideally, this band should take in the reef slope from just below the reef crest.
6. The spotter times the tow period and after two minutes signals the driver who then pauses the boat by idling the motor. At this time the observer records the data for that tow (i.e. COTS number and size, percentage cover of live and dead hard coral, soft coral and presence of feeding scars). The motor should be kept in gear during this time to prevent the towrope fouling the propeller. To help with navigation the driver should keep a record of the number of tows continuously monitor the boat's position on the aerial photograph (Figure 4). When the observer signals that they are ready to proceed (i.e. data recording is complete), the driver recommences towing, stopping again after two minutes.
7. The observer, spotter and driver change roles, where safe to do so, after an agreed number of tows (usually after no more than fifteen tows to avoid fatigue). During the changeover time, it is important to discuss observations about the reef and sea conditions.
8. The changeover can also be used as an opportunity to take representative reef photos for the reef pro forma. Otherwise, photography for the reef pro forma is taken by the observer at the agreed point(s) on the reef in between tows
9. This procedure is repeated until the entire perimeter of the reef is surveyed. Thus, a completed survey consists of a series of consecutive two-minute tows.

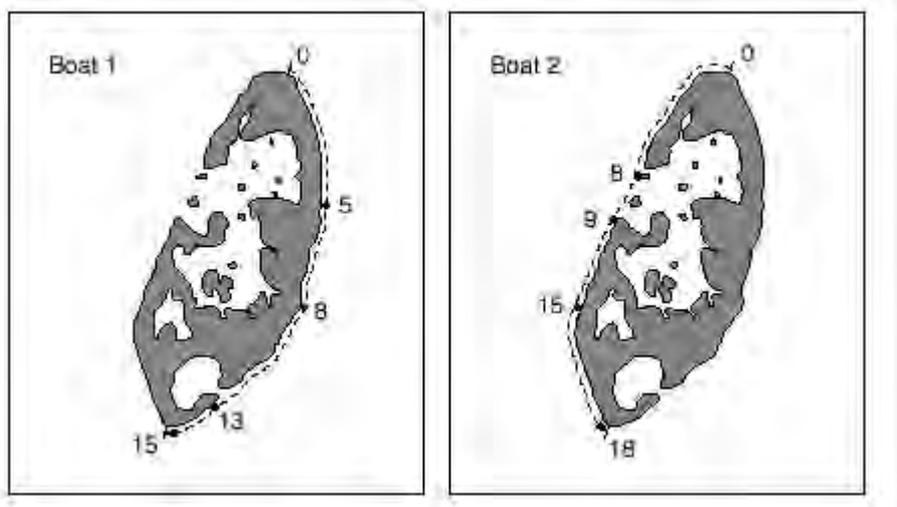


Figure 4. Reef aerial maps showing numbered towpaths for each boat.

4.3.1 Potential problems

At any time, if the observer or driver believes conditions are unsuitable for towing they should give primary consideration to personal safety. Listed below are some of the common problems that make towing conditions difficult and can increase personal risk.

1. **Rough seas:** Rough sea conditions can make it too difficult and dangerous to manta tow. Generally, the reef front receives the roughest seas on the southeast edge. As a guideline, if the swells are greater than 2 metres with breaking crests, or break in a confused manner then it may be unsafe to manta tow. Washing machine conditions where strong currents run counter to swells to create confused seas and whirlpools should also be avoided. Note: this is only a guide and each person should use his or her discretion. If at any point one team decides to stop towing, then they must notify the other team by radio, and both teams cease towing. The point at which the tow ceases should be marked (i.e. with a surface float or on the aerial) so that towing can recommence when conditions improve. If a break in the towpath is made to avoid a limited area of rough seas, it should be clearly marked on the aerial. In some cases, it may be easier to simply abandon the tow and start again when conditions improve.
2. **Strong winds:** rough seas are usually the result of strong winds. Unless exceptional circumstances prevail it is not prudent to conduct manta tows when the wind gusts exceed 25kn due to safety considerations. Also, it is strongly recommended that manta tow surveys be not conducted during official strong wind warning periods (conditions may deteriorate while separated from mother ship) or while there are strong winds and rain squalls about. When working on exposed reef faces (e.g. front reef) the driver, at the end of each two-minute manta tow, should point the boat into the wind at a safe distance from the reef edge, to avoid being pushed onto the reef crest by prevailing winds.
3. **Currents:** When there is a strong current flowing along the reef edge, towing speed and/or direction should be modified accordingly. If the current is going in the same direction as the boat, the driver should slow down to compensate for the speed of the water flow. If the current is against the boat, the driver should increase the speed of towing. However, if the observer finds towing difficult, the tow should be discontinued. If the area of strong current is localised then skip that area and recommence tows on the other side of the current line.

4. **Low tide:** At low tide, the water may recede from the reef periodically, or completely, exposing the crest. In these conditions, the boat driver should keep a safe distance from the reef crest to prevent the boat or the observer being caught in the surge and deposited upon the reef. The driver should point the boat into the wind at the end of each two-minute manta tow at low tide to avoid being pushed onto the reef crest.
5. **Low visibility:** Generally if the visibility is less than 6 metres, (i.e. the nearest float on the tow rope is not visible) then surveys should not be conducted. However, if there is only a patch of low visibility, then the observer should continue to record data if possible, and record the visibility change on the data sheet (see visibility section in data recording).
6. **Channels:** Where the reef perimeter is broken by a channel that is deep and wider than about 25 metres, the tow should end at one side of the channel and begin again at the other side. This break in the towpath should be marked on the aerial photograph and the GPS log track paused while navigating the gap.
7. **Sandy back areas:** Some back reefs may consist of mainly sand with no hard edge, making it difficult to determine a towpath. In these circumstances, the driver, keeping the orientation of the reef in mind, must choose a direct towpath across the back reef to include as much hard reefal substrate by taking the most parsimonious route.

4.4 Data recording

4.4.1 Manta tow data sheet

All data is recorded on a pro forma data sheet (Appendix I) that is located on the manta board.

4.4.1.1 Ambient variables

The ambient variables recorded include information about the survey (reef name, time, date, data collectors) and the weather conditions (Appendix I). The weather conditions are recorded as wind strength, cloud cover, sea-state and tide, and are described as follows.

Wind

Wind strength is recorded as a category as described in Table I.

Table I. Wind strength categories

Category	Wind strength
1	0-5 knots
2	6-10 knots
3	11-15 knots
4	16-20 knots
5	21-25 knots

Cloud

Cloud cover is quantified in terms of eighths of the sky area covered by cloud. The unit is the okta. One okta means one-eighth of the sky. If the sky is completely covered in cloud, the cloud cover is given as 8 oktas, or 8/8. If the sky is half covered, the cloud cover is given as 4 oktas, or 4/8.

Sea State

A modified Beaufort scale (Table 2) describes the sea state.

Table 2. Sea state description

Sea state	Description
Calm	Mirror-like to small ripples
Slight	Small waves, <1 m, some whitecaps
Moderate	Medium waves, 1-2 m, many whitecaps
Rough	Large waves, 2-3 m, whitecaps everywhere, some spray

Tide

Tide is recorded as low, high, falling or rising, determined from a Tide Table. The tide-state is entered as one of the categories shown in Table 3. Low and high tide periods extend one and a half hours either side of mean high water and mean low water.

Table 3. Tide states

State	Description
Low	One hour and a half either side of Low water
High	One hour and a half either side of High water
Falling	The period between High and Low water
Rising	The period between Low and High water

4.4.1.2 Manta tow variables

For each two-minute manta tow, the number and size of COTS, percentage cover of live coral, dead coral and soft coral, the presence of COTS feeding scars, visibility and any observations of note are recorded (Appendix I). These are recorded in rows (i.e. one row for each two-minute tow) of columns on the data sheet. The columns are defined as follows:

COTS numbers

The count of COTS observed during a two-minute manta tow is recorded.

COTS size

The size of COTS is recorded as a number of size-classes (Table 4 and see Figure 5, 6, 7 and 8). These have been changed from the previous SOP because, in practice, COTS less than 15cm are rarely seen on manta tow surveys (they are small and relatively cryptic). By including an extra COTS size from 15-25cm provides more information on size distribution that is currently the case. If no COTS are seen, then this column is left blank. When several size categories are seen, only the category with the most numerous counts is recorded in this column, and a note is made of the other size categories in the 'other' column.

Table 4. Size of COTS categories

Size	Age estimate	Category
<= 5 cm	Up to one year.	J (Early juvenile)
6 - 15 cm	One to two years.	A (Juvenile)
15-25 cm	Two to three years.	B (Sub-Adult)
>25cm	Three plus year.	C (Adult)



Figure 5. Early juvenile crown-of-thorns starfish are less than one-year-old.



Figure 6. Juvenile crown-of-thorns starfish, one to two years old.



Figure 7. Sub-adult crown-of-thorns starfish, two to three years old.



Figure 8. Adult crown-of-thorns starfish greater than three years old.

Live coral cover

Live coral includes all living colonies belonging to hexacorallia (anthozoans where each of the polyps bears six, or multiples of six, tentacles without pinnules) that have an aragonite skeleton. Observers record the cover of live corals as one of six categories that are split by the addition of a plus or minus to each (except for 0). The observer makes a decision as to whether their benthic cover estimate falls in the upper (+), or lower (-), part of a given category (Table 5). This provides a reduction in measurement error at the lower end of the category scale (Miller 1994). Note: percentage cover estimates are made from the total area of reef observed during each two-minute manta tow.

Dead coral cover

This category is difficult to define but designed to capture coral that has recently died (previous six months). Dead coral is defined as a whole or part coral colony that is not covered by living tissue but still has a distinguishable corallum structure. A 'newly' dead coral is easily recognized by its brilliant white colour. The white skeleton is subsequently colonized by a succession of algal types. Initially, turf algae give the dead coral a dull, greenish/brown/black colour. Eventually, coralline algae take over and give the skeleton a smooth pink appearance. By the time the detailed structure of the coral skeleton is lost (grazing and weathering) the coral is considered part of the substratum (not dead coral), or if fragmented, becomes rubble. The percentage cover estimate of dead coral is recorded as one of 6 categories (Table 5) as is the case for live coral cover. Note: percentage cover estimates are made from the total area of reef observed during each two-minute manta tow. Once a coral skeleton has become encrusted by coralline algae or is heavily overgrown by turfing algae, it is generally considered to be substratum and not dead coral.

Table 5. Percentage cover estimates

Category	Cover estimate
0	0%
1-	>0-5%
1+	>5-10%
2-	>10-20%
2+	>20-30%
3-	>30-40%
3+	>40-50%
4-	>50-62.5%
4+	>62.5-75%
5-	>75-87.5%
5+	>87.5-100%

Soft coral cover

Soft coral includes all members belonging to the subclass Octocorallia (i.e. anthozoans where each of the polyps bears eight hollow tentacles which are fringed on both sides by one or several rows of pinnules) that lack a massive carbonate skeleton. The percentage cover estimates are the same as for live coral is recorded as one of six categories (Table 5). Note: percentage cover estimates are made from the total area of reef observed during each two-minute manta tow.

COTS Scars

Feeding scars are patches of recently dead coral easily recognized by their white colour (Figure 9). Such scarring is often indicative of feeding activity by COTS and is useful in locating cryptic populations. However, COTS are not the only organisms that cause coral scarring. The gastropod *Drupella* spp. leave less discrete scars that are often blurred (by the growth of turfing algae) around the edges of all but the most recent areas of feeding activity (*Drupella* spp. rarely move across live coral before feeding Figure 10). White-syndrome (Figure 11) or even coral bleaching (Figure 12) can produce scars similar to those of COTS, however, COTS scars can be distinguished by their large, usually round, size and stark white colour. Feeding scars of COTS are recorded as absent (A), present (P) or common (C) (Table 6).

Table 6. Feeding scar categories

Category	No. of scars/2 min
Absent	0
Present	1-10
Common	>10

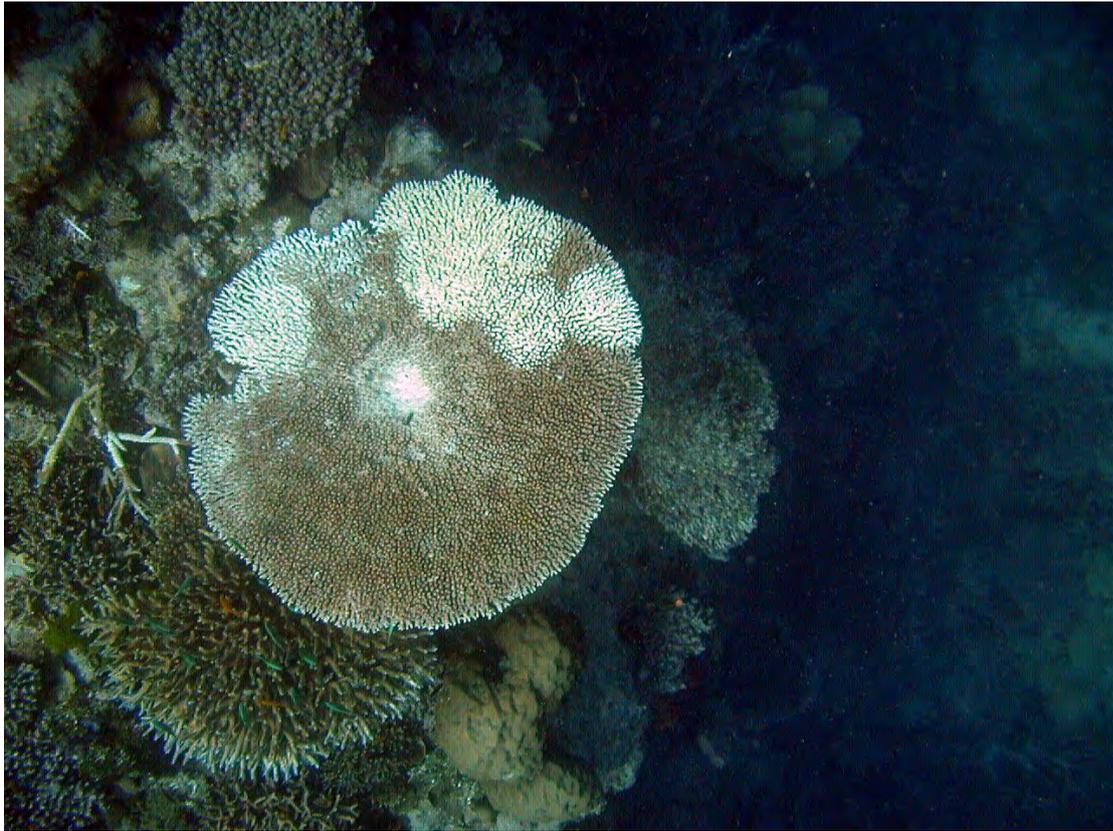


Figure 9. Tabulate *Acropora* sp. coral with distinctive COTS feeding scars. Note the circular shape of the scars formed by the extrusion of the stomach beneath the oral disc.



Figure 10. Branching *Acropora* sp. coral with *Drupella* sp. and associated feeding scars.



Figure 11. Tabulate *Acropora* sp. coral with white syndrome. Unlike COTS white syndrome rarely leaves a discrete circular scar (i.e. in some respects similar in appearance to scars left by *Drupella* sp.). The scar or lesion is bordered on one side by dead coral covered in turf algae.

Visibility

Water visibility estimates are recorded during the first manta tow and subsequently whenever the visibility changes. Visibility is estimated by diving below the surface and looking at the two floats that are attached along the towrope at six-metre intervals. The visibility is recorded as one of four categories (Table 7). If the observer can see the boat motor and beyond, then the visibility is scored as category 4 and if the nearest float cannot be seen, then the visibility is scored as category 1 (Figure 13). Manta tows are not conducted where visibility is less than 6m.

Table 7. Categories for estimating visibility

Category	Distance
1	< 6 m
2	6 - 12 m
3	13 - 18 m
4	> 18 m



Figure 12. Bleached digitate *Acropora* sp. coral. Unlike recently dead coral, polyps remain alive and intact. Areas of coral on the same colony will often remain unbleached with a gradation in colour from the unbleached to the bleached part of the colony.

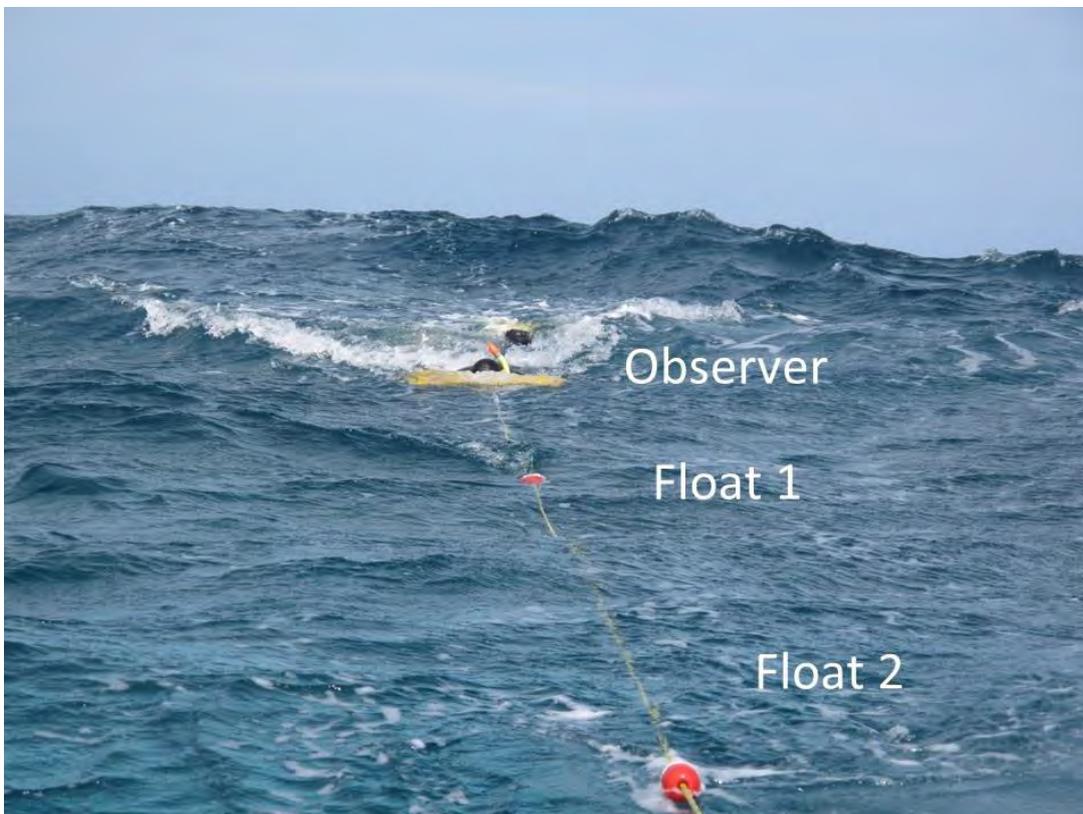


Figure 13. During manta tow surveys visibility is estimated using two floats that are placed at 6m intervals along the tow rope. The first float is 5m from the front of the manta board.

Blank column

The blank column is a free column for recording target organisms of particular interest. In the case of the LTMP, this column is used to record counts of the popularly commercial coral trout (*Plectropomus* spp., *Gracila* sp. and *Variola* spp.). Coral trout are counted for each tow and only recorded when the observer feels it will not interfere with COTS counts. If trout are not counted, then a note should be made in the other column to say 'no data'.

Remarks

The other column is for any observations such as the reef slope, dominant coral growth forms, diversity, fish abundance, coral mortality, bleaching or any information required for the reef pro forma sheet (Appendix IIa). This column is also used to record shark counts that are collected as for coral trout. The number of sharks and the type (species/common name) of shark is recorded.

4.5 Reef description pro forma

The reef description pro forma data sheet is designed to provide descriptive and semi-quantitative information about the reefs that are surveyed using manta tows. The data are obtained from the collective manta towers' observations. The result is a description that provides a qualitative impression of different parts of the reef by describing its physical environment, topography and major lifeforms. Obtaining photos enhance the information and including these in the reef description provides a useful visual tool for interpreting the results derived from the pro forma. The photos are particularly important as they are ultimately presented on the reef pages.

4.5.1 Procedure

When recording the manta tow data the observer writes descriptive notes in the 'remarks' column of the manta tow data-sheet. These can be used to describe the reef slope, conspicuous organisms, and important points of interest as well as areas of change in the reef habitat. At the completion of a manta tow survey; these notes are used in conjunction with those taken by the other observers to form an impression of the reef. To record the information a series of attributes used to describe the reef. One or more categories are assigned for each attribute from the description sheet (Appendix III) and recorded on the reef pro forma data sheet (Appendix IV).

4.5.2 Data recording

Each reef to be surveyed by manta tow is divided into four zones. Zones are marked on the aerial photograph used by the boat driver to navigate around the reef and are: the back (leeward) reef, front (windward) reef, 1st flank (area between the back and front reef in a clockwise direction from the back) and the second flank (area between the front reef and the back reef moving in a clockwise direction from the front). The driver marks the number of the tow closest to the corresponding point on the reef aerial marking the beginning of a zone. For each zone, attributes are assigned to describe the area. The attributes are listed in a "key" (Appendix III). The corresponding number or letter from the key is then placed in the appropriate box on the pro forma (Appendix IV). Where more than one attribute can be scored there are multiple boxes.

4.5.2.1 Position and reef topography

Start tow

Firstly the aerial is renumbered to reflect the sequential tows and their relative position on the reef in a clockwise direction from the starting point “0” (see data management). The number of the first tow for each of the zones is then placed in the appropriate box. Note: the last tow of the last reef section is written on the reef aerial, the next tow will be the first tow for that reef section.

Exposure

Exposure describes the physical environment and prevailing sea conditions of the reef zone in question. This description should be based on the observer’s impressions of prevailing conditions of the area rather than the conditions encountered at the time. Choose one variable only and place in the corresponding box on the data-sheet.

1. **Sheltered:** areas of reef that are in the lee of prevailing wind and waves (typically from the southeast on the GBR); these are usually back-reef areas.
2. **Partly exposed:** areas of the reef that have some protection from prevailing waves and winds but are exposed on regular occasions; these are usually the flanks.
3. **Exposed:** areas of reef that are exposed to prevailing wind and seas on an almost constant basis; these are usually the front-reef areas.

General area surveyed

This simply describes the part of the reef slope that the towpath encountered the most. Choose one variable only and place in the corresponding box on the data-sheet.

1. **Reef crest:** sharp break in the slope on the seaward margin of the algal ridge or edge of the reef flat.
2. **Reef slope:** the portion of main reef framework seaward and adjacent to the reef crest
3. **Reef flat:** the summit of a reef, a flat, tidal, often stony expanse of pavement, coral fragments, and sand that can be dry at low tide.
4. **Deep no edge:** the area dominated by deep water (>10m) with no reef crest or slope in the immediate vicinity.
5. **Shallow no edge:** the area dominated by shallow water (<10m) with no reef crest or slope in the immediate vicinity. These areas are often seen on sandy back reefs.

Reef slope

Describes the overall average reef slope on the zone (section of the reef) surveyed. Choose one variable only and place in the corresponding box on the data sheet.

1. **Shallow:** (0-20°)
2. **Moderate:** (21-45°)
3. **Steep:** (46-75°)
4. **Vertical:** (75-90°)
5. **Broken:** no continuous coherent reef edge. A broken reef slope typically consists of a series of embayments and bommies.
6. **No edge:** no reef slope or crest in the immediate vicinity, most often seen in sandy back reef areas. On back reefs, the observed is usually towed over large areas of sand at the base of the reef slope.

Depth to bottom of the slope

Defined as the average depth (in metres) to the bottom of the hard reef framework that comprises the reef slope to where the reef base begins. The reef base is recognised as a sharp break in the reef slope on the seaward margin of the reef often where the framework meets the sand. Choose one variable only and place in the corresponding box on the data sheet. The option “no bottom” is used when there is no apparent break in the reef slope.

1. **5m**
2. **10m**
3. **15m**
4. **20m**
5. **No bottom**
6. **Varied**
7. **>20m**

Slope at reef base

Describes the average angle of the slope at the reef base regardless of whether the edge can be seen (for instance sandy areas on the back reef may be considered the reef base in the absence of a clear reef edge). Choose one variable only and place in the corresponding box on the data sheet.

1. **Shallow:** (0-20°)
2. **Moderate:** (21-45°)
3. **Steep:** (46-75°)
4. **Variable:** no consistent slope

Substratum at reef base

Describes the habitat found at the bottom of the reef slope on the reef base. More than one response can be entered into the appropriate box.

1. **Sand:** abiotic granular particles usually white and composed of carbonate on coral reefs.
2. **Rubble:** unconsolidated dead coral fragments usually <5cm in size.
3. **Consolidated rubble:** rubble fragments that have been bound together by coralline algae to form a solid substratum.
4. **Reef framework:** underlying biogenous carbonate structure of the reef. Reef-building (hermatypic) corals contribute to the reef framework as they produce their calcium carbonate skeletons.
5. **Live hard coral:** reef-building (hermatypic) corals
6. **Soft coral:** living colonies of soft-bodied corals belonging to the Order Alcyonacea (i.e. this does not include Gorgonians, Blue Coral or red Organ Pipe Corals).

General reef features

Describes the topology of the reef slope and its physical attributes; more than one response can be entered into the appropriate box.

1. **Spur and groove:** mainly found in high-energy areas that regularly encounter strong wave action. The spurs are ridges composed of reef framework that rise above the intervening

grooves that can be filled with white carbonate sand and scattered larger coral fragments. The spurs often have areas of hard corals or can be colonized by soft corals and algae.

2. **Gullies:** grooves or gaps in the reef that are typically not formed by wave action
3. **Caves:** holes in the reef with one obvious entrance large enough for a diver to penetrate.
4. **Overhangs:** a projection of the reef crest or upper slope beyond the wall or slope of the lower part of the reef.
5. **Swim throughs:** caves that have an entrance at both ends and large enough to accommodate a diver.
6. **Bommies:** isolated discrete outcrops consisting of coral(s) and or reef framework usually 3m or more in diameter and extending vertically (at least 3m) from the underlying substratum towards the surface.
7. **Pavement:** a consistent featureless area of the reef slope that has a shallow angle and forms an expanse (>0.2 ha) of the flat substratum. Usually restricted to high-energy front reef areas.
8. **Continuous wall:** reef slope is characterised by few features and a generally vertical drop off into deeper water. This includes continuous wall at scales from tens of metres to hundreds of metres.

4.5.2.2 Community description

Dominant benthic group

Describes the major components of the benthic community; numbers corresponding to lifeforms should be entered into the box in order from the most dominant (in terms of spatial coverage) to the least dominant. More than one type of sessile benthos may be entered but all do not have to be entered.

1. **Hard coral:** all hermatypic scleractinian corals.
2. **Soft coral:** octocorals from the Order Alcyonacea not including Gorgonians, Blue Coral or red Organ Pipe Corals.
3. **Macroalgae:** fleshy algae with clearly defined structures such as a thallus, stem, and holdfast.
4. **Coralline/turf algae:** filamentous (usually blue-green but can include red and green algae) turf algae growing on hard substratum and coralline algae. Often the two are found growing together hence the combined category.
5. **Sponge:** all sponges.
6. **Gorgonian:** all erect branching soft corals from the Order Gorgonacea.
7. **Millepora:** all calcified hydrozoans belonging to the genus *Millepora* including all growth forms.
8. **Sand:** abiotic granular particles usually white and composed of carbonate on coral reefs.
9. **Rubble:** unconsolidated coral fragments

Dominant hard coral genus

Describes the dominant hard coral for the zone surveyed in terms of coverage. One of the four options is to be entered into the box. Where a non-*Acropora* genus is chosen the type of hard coral genus should be written into the separate box provided.

- A. **Acropora genus:** corals belonging to the family Acroporidae including coral from the family Isoporidae.
- P. **Porites genus:** all coral belonging to the family Poritidae
- C. **Non-Acropora genus:** if another group of hard coral dominates a zone on the reef the name of the group should be noted in the appropriate box.

- N. **No one coral genus dominant:** on some reefs, it is too hard to tell if one group of corals dominates the other. Where this is the case then this value (N) should be entered.

Dominant coral life form.

The box is filled in no matter what the level of coral cover on the reef is. More than one response can be entered into the box. The responses should be ranked from the most dominant to the least dominant. All lifeforms do not have to be entered.

- B. **Branching:** *Acropora* and non-*Acropora* corals consisting of arborescent colonies with an open primary and secondary branching where branches are generally longer than they are wide. Typified by staghorn corals, such as *Acropora grandis*. Other branching species include *Porites cylindrica* and *Seriatopora hystrix*. Figure 14.
- T. **Tabulate:** *Acropora* spp. hard corals consisting of horizontal plates with a small area of basal attachment where the colony is at least twice as wide as it is high, e.g., *A. hyacinthus* and *A. clathrata*. Figure 15.
- D. **Digitate:** *Acropora* spp. hard corals consisting of short, protruding, vertically orientated digit like branches arising from an encrusting base, e.g., *A. humilis* and *A. gemmifera*. Figure 16.
- E. **Encrusting:** *Acropora* and non-*Acropora* corals consisting of colonies with a prostrate, spreading growth form, that adheres to the substratum e.g., *Pavona varians*, *Porites heronensis*, and many *Montipora* species. Figure 17.
- S. **Submassive:** *Acropora* and non-*Acropora* corals consisting of knobs, protrusions or columnar structures, sometimes rounded, with more than 50% of the colony raised indiscreetly from the underlying substratum, e.g., *Acropora cuneata*, *Stylophora pistillata*, *Pocillopora damicornis*, and *Scaphophyllia cylindrica*. Figure 18.
- M. **Massive:** Non-*Acropora* corals consisting of colonies with generally solid construction and the same shape in all directions (hemispherical in shape) and may form very large colonies, e.g., *Favia lizardensis*, *Diploastrea heliopora*, and many *Porites* spp. Figure 19.
- X. **Bottlebrush Acropora:** *Acropora* spp. hard corals consisting of colonies with small branchlets with both primary and secondary branching arising from main arborescent branches, e.g. *Acropora echinata*. Figure 20.
- F. **Foliose:** Non-*Acropora* corals consisting of colonies with a leaf-like appearance or composed of flattened sheets that may be fused or convoluted to form whorls e.g., *Turbinaria mesentaria* and *Echinopora lamellosa*. Figure 21.
- U. **Mushroom:** Unattached, free-living easily moved Fungiid corals, e.g. *Fungia* spp. Figure 22.



Figure 14. Branching coral (*Acropora* sp.)



Figure 15. Tabulate *Acropora* spp. hard corals jostle for position on the reef slope.



Figure 16. Digitate *Acropora* sp. hard coral.



Figure 17. Encrusting *Isopora* sp. hard coral.



Figure 18. Large submassive *Pocillopora* sp. hard coral.



Figure 19. A number of massive hard corals belonging to a variety of different genera.



Figure 20. Bottlebrush *Acropora* spp. hard corals on the reef slope.



Figure 21. Foliose *Turbinaria* sp. hard coral.



Figure 22. Mushroom corals, *Fungia* sp. (the round ones) and *Ctenactis* sp. (the elongate ones) on the reef slope.

4.5.2.3 Other Details

Level of coral bleaching

Indicates the level of hard coral bleaching; only one response in the appropriate box is selected. This category is defined as the percentage of the total hard coral cover bleached white, partly or near white or has a lurid appearance. For instance, if all hard corals in a zone were bleached then a '5' (75-100%) would be placed in the box, even though hard corals may occupy less than half of the total reef benthic environment. The categories are similar to those used for cover estimates during manta tows. However, in this case, "0" and "1" are the only two categories that have been split into two. Corals that are partially bleached (i.e. pale in colour but still retaining much of their pigment) are not included. However, if these are common relevant notes should be placed in comments. If no bleaching is recorded then this must be expressed as a "0" in the box.

Table 8. Coral bleaching categories

Category	Cover estimate
0	0%
0+	Individual colonies (>1% total hard coral cover)
1-	1-5%
1+	5-10%
2	10-30%
3	30-50%
4	50-75%
5	75-100%

Areas of reef affected

Indicates the areas within the reef zone where bleaching was observed. More than one response can be selected. Coral bleaching can look similar to scarring caused by COTS, as the corals appear brilliant white. However, bleaching can often be distinguished from COTS scars because entire colonies are usually bleached white rather than having individual scars. Additionally, colonies that are only partially bleached will have graduation from the white bleached part of the colony to the coloured unbleached part of the colony. A close inspection of bleached coral will reveal that the polyps are still visible, although colourless. Bleaching should be recorded only if it is unambiguous. The area definitions correspond to those given in General Areas Surveyed (1c).

1. **Reef flat**
2. **Reef crest**
3. **Reef slope:** (<10m)
4. **Reef slope:** (>10m)

Black band disease

Provides an indicator of the occurrence of black-band disease on corals in a given reef zone. Black-band disease is characterised by a black band (5-30mm) separating live coral tissue from the recently exposed white coral skeleton. Only one response is placed in the box. If no black-band disease is encountered the box may be left empty.

1. **BBD present:** less than ten individual colonies observed with BBD per tow in a reef zone.
2. **BBD common:** more than ten individual colonies observed with BBD per tow in a reef zone

White syndrome

White syndrome diseases express themselves in a variety of ways and are commonly seen either as a patch of recently dead white coral skeleton within part of the living colony or simply as a white band of recently dead white coral skeleton between fouled old dead coral and the still living part of the colony. There is often a gradation in turf algal cover from the recently white dead parts of the colony to the darkened old dead parts of the colony. Close inspection usually reveals an area of necrotic tissue, often sloughing of the colony, on the border of the white patch/band. Place only one response in the box. If no white disease is encountered the box may be left empty.

1. **WS present:** less than ten individual colonies observed with WS per tow in a reef zone
2. **WS common:** more than ten individual colonies observed with WS per tow in a reef zone

Coral trout count

Simply the total number of coral trout (*Plectropomus* spp., *Gracila* sp. and *Variola* spp.) seen in a given reef zone. The count (number of individuals) is scored in the appropriate box.

Fish abundance

The fish abundance is made as a simple estimate of the total fish abundance within a reef zone compared to other zones seen throughout the Great Barrier Reef. The categories are subjective and rely to a large extent on the experienced observer's perception.

1. **Low**
2. **Moderate**
3. **High**
4. **Very high**

Conspicuous target species

This is designed to provide a picture of the types of fishes in the reef zone that are conspicuous by their abundance. More than one response can be noted and these are placed in the appropriate box in no particular order.

1. **Coral trout:** all *Plectropomus* spp., *Gracila* sp. and *Variola* spp. Figure 23.
2. **Sweetlip:** all individuals of the family Lethrinidae, in particular, *L. nebulosus* and *L. miniatus*. Figure 24.
3. **Parrotfish:** all individuals of the tribe Scarinae family Labridae. Figure 25.
4. **Surgeonfish:** all individuals of the family Acanthuridae. Figure 26.
5. **Pomacentrids:** all individuals of the family Pomacentridae. Figure 27.
6. **Fusiliers:** all individuals of the family Caesionidae. Figure 28.
7. **Baitfish:** all schools of baitfish usually composed of sprat (*Spratelloides* sp.) or hardyheads (*Atherinomorus* sp.). Figure 29.
8. **Pelagic predators:** all roving large pelagic fish, typical examples include mackerel, trevally, barracuda, and tuna. Figure 30.
9. **Snapper:** all individuals belonging to the family Lutjanidae. Figure 31.
- a. **Sharks:** all sharks. Figure 32.
- b. **Butterflyfish:** all individuals belonging to the family Chaetodontidae. Figure 33.



Figure 23. Coral trout, *Plectropomus leopardus*.



Figure 24. Sweetlip (red-throat emperor, *Lethrinus miniatus*).



Figure 25. Parrotfish (Green hump head parrotfish, *Bolbometapon muricatum*).



Figure 26. Surgeonfish (lined bristletooth, *Ctenochaetus striatus*).



Figure 27. Damselfish (Banded humbug, *Dascyllus aruanus*).



Figure 28. Fusilier (school of yellow and blueback fusiliers, *Caesio teres*).



Figure 29. Baitfish (sprat, *Sprattus* sp.).



Figure 30. Pelagic predators (Chevron barracuda, *Sphyraena qenie*).



Figure 31. Snapper (Checkered snapper, *Lutjanus decussatus*).



Figure 32. Shark (Grey reef shark, *Carcharhinus amblyrhincus*).



Figure 33. Butterflyfish (Raccoon butterflyfish, *Chaetodon lunula*).

4.6 Photography for reef pro forma

The aim of taking photos of within each reef zone is to capture the reef community and notable features at that location. The photos are used to provide a visual context to the pro forma content that is summarised in the AIMS website.

4.6.1 Preparation of equipment

How a digital camera is set up for the days' photography is very much dependent upon the type and manufacturer of the camera as well as the type of housing (if any). In general, the default settings (underwater) are used for the camera as this provides the greatest freedom for a variety of people using the camera. Should specialized settings be used then other users should be informed accordingly. Notes for setting up the cameras are supplied by the manufacturer and should be adhered to. Despite this freedom in set-up, there are some basic points that should be considered before the day's activity:

1. All equipment maintenance and assembly should be done in a dedicated dry area free from seawater contamination.
2. Make sure batteries are fully charged and ready the morning before entering the field.
3. Camera memory must be free.
4. Check time and date on the camera is correct.
5. Check the camera for appropriate settings and check the camera function.
6. Check the housing; remove O-ring and grease (where applicable).
7. Assemble unit and check function.
8. Place assembled unit in a hard case for work in the field.

4.6.2 Field procedure

Photographs are taken at a location chosen haphazardly within each reef zone. Photographs should be framed to provide an appropriate impression of the particular reef zone.

Photographs may be taken before the commencement of surveys but are usually taken during surveys so that the observer is able to gain a "feel" for the zone in question. The location is decided by consensus between the boat driver and the observer and is usually near the middle of a reef zone. It is often convenient for photos to be taken at the time the driver and observer swap roles. However, this may not be practical in some cases. During such times towing is paused while the photos are taken.

When the boat stops to take the photo:

1. Consider the ambient conditions. Sometimes it is not prudent to have a diver free from the boat if the wind, waves, tide, and current make sea state too dangerous.
2. Take a picture of the reef aerial marking the spot on the aerial where the photo was taken (this is simply done by pointing to the approximate location).
3. Put on a weight belt, it is important to be neutrally or negatively buoyant when taking photographs; otherwise, it becomes difficult to focus if the diver is moving too much.
4. All photographs are taken on snorkel.
5. Take a number of photos and where possible "bracket" (i.e. a series of continuous graded shots of a particular subject) your shots. Photos should be (where possible) broadly representative of the reef zone in question.
6. Make sure the housing is placed in a protective case after taking the photos.

7. At the end of the day's fieldwork soak and thoroughly wash the housing in freshwater. Dry before opening and removing the camera.

5 DATA MANAGEMENT

To maintain consistency in the database, it is important that data are managed using a set procedure. The following steps will assist in ensuring consistency in the data reaching the database.

5.1 Data sheets

1. When finished recording and upon return to the mother vessel rinse underwater data sheets in fresh water and dry.
2. Re-number the tow numbers on the manta data sheet and the reef aerial from the approved starting point. This is so the numbers are continuous in a clockwise direction around the reef perimeter. The starting point is labeled zero and should be the same point as in previous surveys if known. Tow number one is marked at the end of the first tow (Figure 3). The original tow numbers should not be erased from the data sheets. The end tow for each reef zone should also be marked.
3. Staple manta data sheets and reef aerial maps together.
4. Label each reef data set for the manta tow and reef pro forma data with the same sample identification number. A sample identification number for the LTMP consists of a two-letter code unique to each survey trip, followed by a three-digit number starting at 001, e.g. AB001. The numbering increments up to 099 and then continue again at 600. The SCUBA search data follow on in sequence from the manta tow and reef description data.
5. Complete the reef pro forma data sheet using the manta tow data as a guide.

5.2 Data entry

Data is entered into a laptop computer in the field using software designed for the AIMS LTMP, called Reefmon. For a detailed explanation of the AIMS database structure, refer to Baker and Coleman 2000. The following is a basic guide to using Reefmon.

1. Enter the Reefmon program. Check the database location reads "LOCAL" and enter the cruise code, p-code, year, visit number. Click "Manta tow" to enter manta tow data including log tracks, aesthetics information and photos for the pro forma.
2. The sample-id is entered for that reef and the 'sample data' (i.e. Reef name, location, the type of data, and weather conditions) are entered into a 'sample table'. Note. The data cannot be entered until the sample table is completed. Download files from the android.
3. Use the log track data from the androids (or GPS) to generate tow-paths and tow sequence numbers. The manta tow and reef pro forma data are entered into separate

data tables. Each record in the data table is automatically assigned a sample-id from the sample table. The observers' initials are also entered for each record in the data table. Manta tow data and reef pro forma data share a common sample-id.

4. Back-up the data regularly to an external hard drive.
5. At the completion of a field trip when back in the office and in collaboration with the database manager upload the data to the server.
6. Print the data and check it against the data-sheets. Two people are needed, one to read out the raw figures and one to check these against the printout, to reduce the possibility of errors. Make the appropriate corrections to the database.
7. Keep the checked printout on file as a record of data entry errors.
8. File the data sheets with the checked printouts.

5.3 Processing digital photography

1. Create a trip folder to store photos e.g. ABphotos. The first two letters are the unique cruise code letters for that trip.
2. For each reef create a folder based on the reef name within the trip folder. All photos for that reef to be stored under that reef folder.
3. Copy/move photos from camera to the appropriate folder.
4. Using the photo-editor of your choice, vet the photos and flag at least two of the best photos for each reef zone and any other photos of particular interest or quality. Reduce the size of the window so that it takes up only half the screen.
5. Open Reefmon, click the 'Manta Tow' button, then click the 'Photos' button.
6. Select the sample-id for the reef that the photographs were taken on (i.e. the sample-id will be highlighted in blue).
7. Arrange screens so that Reefmon and the image editor screen can be viewed at the same time.
8. Drag and drop selected photos from the file explorer into the appropriate box (i.e. back photos, flank photos etc.) on the Reefmon database screen (the program will automatically file and rename the photographs for later downloading). Continue this process until all photographs have been placed in appropriate boxes. Photographs of interest that may not necessarily relate to particular aspects of the reef (e.g. fish, people, and objects of interest) are entered in the Other Photos box.
9. Once all photos have been entered click on the "Edit Photos". Captions are then entered for each photograph in the captions column. Keywords can also be entered in the appropriate box.
10. If a photograph in the photo editor box has been inappropriately entered (e.g. accidentally or in the wrong location) it can be removed by clicking on the appropriate file name and depressing the control and delete keys simultaneously.

6 TRAINING AND QUALITY CONTROL

6.1 Training new personnel

The AIMS manta tow technique while being relatively accurate and cost-effective is still subject to a variety of biases. Logistic constraints and the nature of the environment prevent total resolution of bias (Fernandes et al. 1989). However, standardization and the use of trained observers can reduce methodological biases and enhance the precision of estimates (Miller 1994). The use of trained observers is vital to the technique as the observers' perceptions form the basis of any data recorded. Observers should concur in all aspects of the survey and measure implemented to prevent 'drift' (defined as a consistent movement or difference in the direction and magnitude of bias between observers over time). To achieve the levels of competency necessary for manta tow surveys, it is important that a coordinated training program is conducted and that skills are maintained over time.

6.2 Procedure

6.2.1 Introduction to manta towing

The first part of the training exercise is to introduce new personnel to the manta tow technique. To achieve this requires familiarizing new personnel with the historical development of the technique and how it is currently applied (e.g. Moran et al. 1989, Moran & De'ath 1992, and English et al. 1994). In addition, discussion with experienced observers to debate the advantages and disadvantages of manta tow as an ecological sampling technique helps to understand the reasoning behind the method.

The second part involves showing photographs of corals and other benthic organisms to familiarize the new personnel with the different types of benthic cover present on a coral reef. This includes discussion of problems such as the definition of dead coral and how to estimate the appropriate cover categories (i.e. live coral, dead coral, and soft coral).

6.2.2 Field training

Field-based training involves towing the inexperienced observer in line with an experienced observer on a tandem manta board (Miller 1994). The tandem manta tow technique is a simple extension of the AIMS manta tow technique. A second manta board is attached 4m behind the first by two lengths of rope and a bridle (Figure 34). Using this arrangement, the second board tracks behind the first and both boards give a good approximation of conditions normally experienced during manta tow surveys. The number of COTS, feeding scars, categories of live, dead and soft coral is recorded independently at the completion of each two-minute tow. The results are then discussed between the observers. This enables the inexperienced observers to become familiar with estimating coral cover by comparing their estimates with the experienced observer over the same area.



Figure 34. Photograph of observers being towed on the tandem manta board.

Using these methods trainee observers can recognize and compensate for any variations between their COTS counts and benthic cover estimates and those of experienced observers. Thus it is essential that trainees swap around so that they tow with a number of experienced observers. This system also has the advantage of allowing training to occur while surveys are actually being carried out. This is achieved by using the data from the experienced observer as an actual sample. However, consideration should be given to the practical aspects of using the tandem board and towing in this manner should be restricted to calm waters. Once observers are trained, they are incorporated into broadscale surveys. Inexperienced observers are usually considered trained when their results obtained from a section of the reef (8 to 10 manta tows) is consistently within one median category of those obtained by direct comparison with at least three experienced observers.

6.2.3 Quality control

The precision of estimates made by manta tow is expected to vary between observers because estimates are influenced by a large variety of factors (Moran & De'ath 1992). While there are ways to measure the precision of estimates and methods for applying quality controls (Miller and Müller 1997), in practice these are generally time-consuming and can hamper field sampling by reducing the time available for other aspects of surveys during field trips. Research has shown that with training precision of observers increases (Miller 1995). Therefore, from experience, the most parsimonious way to maintain the quality of the data is by standardizing observers before the beginning of each field season or the beginning of a project via a dedicated training period where observers are trained on the tandem manta board as described in the previous section.

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8 APPENDICES

8.1 Appendix I. Manta tow data sheet

MANTA TOW SURVEY

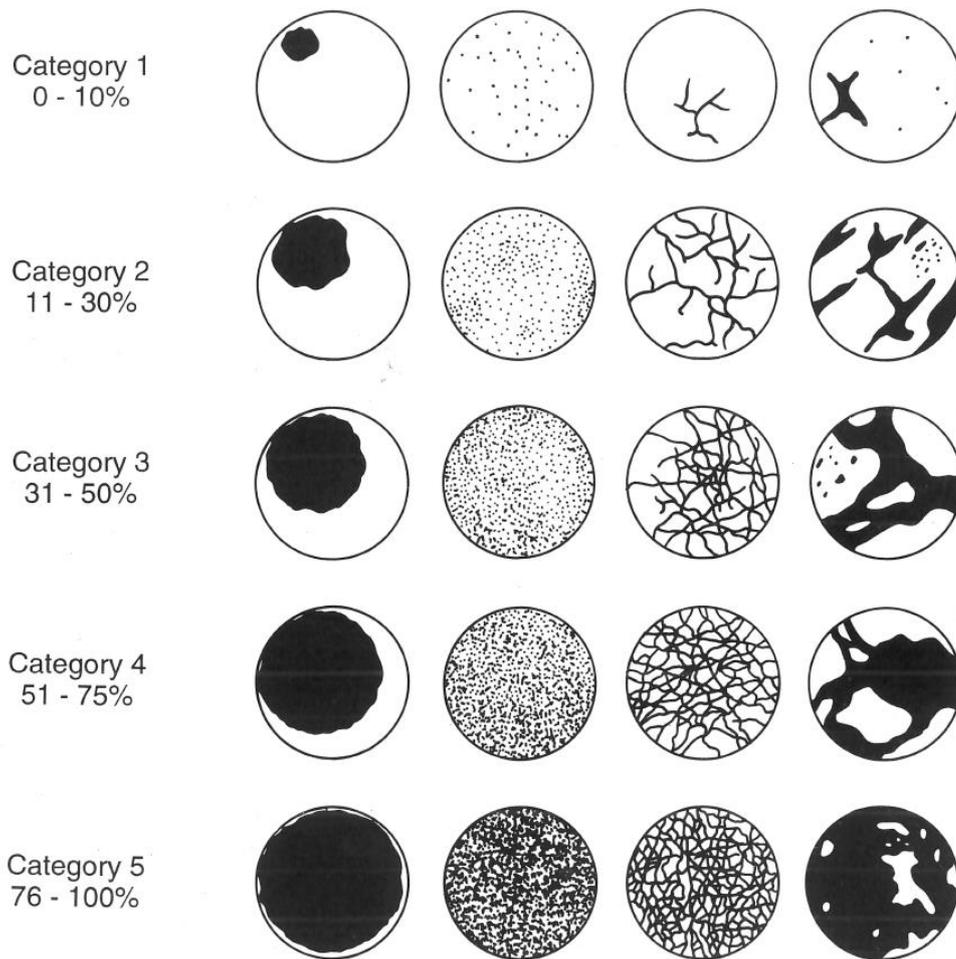


Reef name:..... Sample ID:..... Collector:.....

Time:..... Date:..... Wind:..... Cloud:..... Sea:..... Tide:.....

Tow No.	Coral Cover			Vis.	C O T			Remarks
	Live	Dead	Soft		No.	Size	Scars	
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
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27								

8.2 Appendix II. Visual guide to the manta tow cover categories (from English et al. 1994).



8.3 Appendix III. Key to reef description pro forma

I. POSITION AND REEF TOPOGRAPHY

a. Start tow

1. Sheltered
2. Partly exposed
3. Exposed

b. Exposure

1. Reef crest
2. Reef slope
3. Reef flat

c. General area surveyed

1. Reef crest
2. Reef slope
3. Reef flat
4. Deep no edge
5. Shallow no edge

d. Reef slope

1. Shallow (0-20°)
2. Moderate (20-45°)
3. Steep (45-75°)
4. Vertical (75-90°)
5. Broken
6. No edge

e. Depth to bottom of slope

1. 5m
2. 10m
3. 15m
4. 20m
5. No bottom
6. Varied
7. >20m

f. Slope at reef base

1. Shallow (0-20°)
2. Moderate (20-45°)
3. Steep (45-75°)
4. Variable

g. Substratum at reef base

1. Sand
2. Rubble
3. Consolidated rubble
4. Reef framework
5. Hard coral
6. Soft coral
7. Coralline/turf algae

h. General reef features

1. Spur and groove
2. Gullies
3. Caves
4. Overhangs
5. Swim throughs (i.e. caves with an entrance at both ends)

6. Bommies
7. Pavement
8. Continuous wall

2. COMMUNITY DESCRIPTION

a. Dominant benthic group

1. Hard coral
2. Soft coral
3. Macro-algae
4. Coralline/turf algae
5. Sponge
6. Gorgonian
7. Millepora
8. Sand
9. Rubble

b. Dominant hard coral genus

- A. *Acropora* genus
- P. *Porites* genus
- C. A non-*Acropora* genus
- N. No one coral dominant

c. Dominant coral lifeform

- B. Branching
- T. Tabulate
- D. Digitate
- E. Encrusting
- S. Sub-massive
- M. Massive
- X. Bottle-brush *Acropora* spp.
- U. Mushroom
- F. Foliose

3. OTHER DETAILS

a. Level of coral bleaching

0. 0%
- 0+. Individual colonies
- 1-. 1-5%
- 1+. 5-10%
2. 10-30%
3. 30-50%
4. 50-75%
5. 75-100%

b. Areas of reef affected

1. Reef flat
2. Reef crest
3. Reef slope (<10m)
4. Deep slope (>10m)

c. Black band disease

1. BBD present
2. BBD common

d. White syndrome

1. WS present
2. WS common

e. Coral trout count

f. Fish abundance

1. Low
2. Moderate
3. High
4. Very high

g. Conspicuous target species

1. Coral trout
2. Sweetlip (lethrinids)
3. Parrotfish
4. Surgeonfish
5. Pomacentrids

6. Fusiliers
7. Baitfish (sprat)
8. Pelagic predators
9. Snapper (lutjanids)
- a. Sharks
- b. Butterflyfish

8.4 Appendix IV. Reef description pro-forma.

<p>Reef:</p> <p>Zone 1: Back Reef Observer 1: _____ Observer 2: _____</p>	<p>Sample ID:</p> <p>Zone 2: First Flank Observer 1: _____ Observer 2: _____</p>	<p>Zone 1: Front Reef Observer 1: _____ Observer 2: _____</p>	<p>Zone 1: Second flank Observer 1: _____ Observer 2: _____</p>
<p>1. Position and reef topography</p> <p>a. <input type="checkbox"/> b. <input type="checkbox"/> c. <input type="checkbox"/></p> <p>d. <input type="checkbox"/> e. <input type="checkbox"/> f. <input type="checkbox"/></p> <p>g. <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/></p> <p>h. <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/></p> <p>2. Community description</p> <p>a. <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/></p> <p>b. <input type="checkbox"/> _____</p> <p>c. <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/></p> <p>3. Other details</p> <p>a. <input type="checkbox"/> b. <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/></p> <p>c. <input type="checkbox"/> d. <input type="checkbox"/> e. <input type="checkbox"/> f. <input type="checkbox"/></p> <p>g. <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/></p> <p>Comments</p>	<p>1. Position and reef topography</p> <p>a. <input type="checkbox"/> b. <input type="checkbox"/> c. <input type="checkbox"/></p> <p>d. <input type="checkbox"/> e. <input type="checkbox"/> f. <input type="checkbox"/></p> <p>g. <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/></p> <p>h. <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/></p> <p>2. 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