Crown-of-thorns starfish and coral surveys using the manta tow and SCUBA search techniques

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PREFACE

This Standard Operational Procedure was first produced as an internal report in January 1995. This was subsequently followed by a second edition (also in 1995) that was revised to suit a wider audience and also to keep up with changes to the design of the Australian Institute of Marine Science's Long-term Monitoring Program (LTMP). Since this time there have been a number of changes made to the way broad-scale surveys are conducted by the LTMP on the Great Barrier Reef. The third edition has been modified to reflect these changes.

The AIMS LTMP monitors the Great Barrier Reef recording information on benthic reef communities, reef fish abundance, crown-of-thorns starfish populations and other causes of coral mortality on an annual basis. Data on benthic reef communities, reef fish abundance and coral mortality is monitored along permanently marked transects. Broadscale data on the abundance and distribution of crown-of-thorns starfish are collected using a plot less method called "manta tow".

This Standard Operational Procedure remains Volume 1 in a series of five, produced by the Long-term Monitoring Program at the Australian Institute of Marine Science. It details the standard procedure used to manta tow entire reefs in Part one, and site-specific SCUBA searches in Part two. Parts three and four provide details on data management, training and quality control. Further details of the Long-term Monitoring Program are described in Sweatman *et al*. (2005).

INTRODUCTION

This document describes the procedures for surveys of crown-of-thorns starfish (COTS) and corals used by the Australian Institute of Marine Science (AIMS) as part of the Long-term Monitoring Program that commenced in 1992. It also describes the equipment, survey methodology, data recording, data entry and training procedures for each technique. Two basic techniques are used in these surveys: manta tow and SCUBA searches.

Part one detail's the manta tow technique, which was first described by Moran *et al.* (1989) and later in the Survey Manual for Tropical Marine Resources (Eds. English *et. al*.1994). A number of changes to the manta tow procedure have been made in recent years to address problems associated with observer bias and to standardize data collection and recording. More recently the method for providing descriptions of reef habitat has been changed. This method is also described in detail.

Part two describes the SCUBA search technique which has been used in fine scale surveys by AIMS since 1989 to provide additional information on low level populations of COTS, to facilitate the detection of juvenile COTS and to investigate other causes of coral mortality. This method has also undergone a review and a number of subtle changes introduced particularly with regard to recording the incidence of coral disease.

Part three provides details on data management so that it can be entered into the AIMS Long-Term Reef Monitoring database or similarly structured database. Baker et al. (1991) provides a detailed description of the database.

Part four provides details on training personnel for broadscale surveys using the manta tow technique. It also provides a protocol for the ongoing assessment of observers in order to ensure the quality of the data and to identify training needs.

PART ONE: MANTA TOW TECHNIQUE

Sampling design

Reefs are surveyed for crown-of-thorns starfish using the manta tow technique on an annual basis in 11 sectors of the Great Barrier Reef (Cape Grenville, Princess Charlotte Bay, Cooktown/Lizard Island, Cairns, Innisfail, Townsville, Cape Upstart, Whitsunday, Pompey Complex, Swain and Capricorn Bunker sectors Figure 1). Sixty-one “key” reefs have been selected for annual survey. In 6 of the sectors (Cooktown/Lizard island, Cairns, Townsville, Whitsunday, Swain and Capricorn Bunkers) 49 of the key manta tow reefs are designated “core” survey reefs. The core survey reefs are sampled in two stages. Firstly the entire perimeter of each reef is surveyed using manta tows. Secondly visual fish census, benthic photographic surveys and scuba searches are conducted at three sites in a habitat that is standardised across reefs (for details see Sweatman et. al. 2005). Where possible, three or more reefs in each sector have been selected in each of three positions across the continental shelf: inshore, mid-shelf and outer shelf. There are no inshore or mid-shelf reefs in the Capricorn-Bunker sector. Also, the innermost reefs in the Swains are more than 100 km from the mainland and so are not subject to coastal influences. These innermost Swains reefs are grouped with mid-shelf reefs.

The key manta tow survey reefs were chosen from the reefs within each region for logistical and historical reasons. 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. An additional 117 reefs from the 8 sectors (excluding the Whitsunday, Swain and Capricorn-Bunker sectors) are scheduled for survey every third year (cycle reefs). The cycle manta tow reefs take second priority if surveys are unable to be completed because of bad weather and limited ship time.

COTS and coral surveys

The manta tow technique 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 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

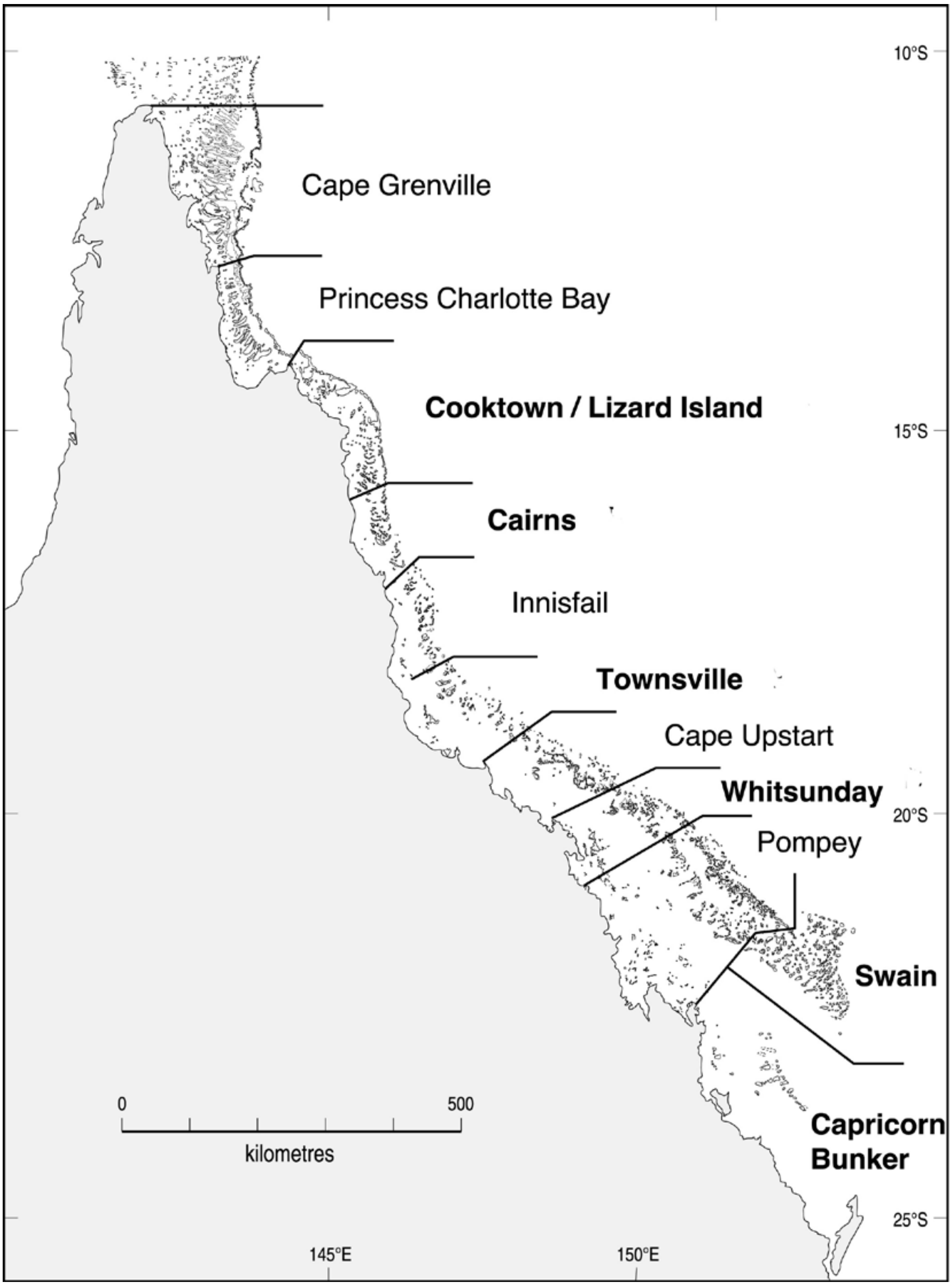

Figure 1. Sectors of the Great Barrier Reef surveyed as part of the LTMP**.**

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.

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 (Endean & Stablum 1973). Since the 1970's, 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 more recent 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 (Eds. English *et al*. 1994). Studies by Fernandes (1989, 1990), Fernandes *et al*. (1990), and Moran and De'ath (1992) 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.

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

Personnel

A minimum of four people are 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 and an observer and these roles are rotated during the survey of the reef. Each person should have a good knowledge of the coral reef environment, its fauna, and be competent in the identification of benthic lifeforms. They should also be an experienced snorkeller and possess a recreational shipmaster's license and a Marine Radio Operators Certificate of Proficiency.

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.

Field gear

1. A small (~4-5m) boat (preferably a rigid hulled inflatable) with 15-25 HP outboard motor and necessary safety gear.
2. Waterproof VHF hand-held radio.
3. Rope harness that attaches to the boat's transom (Figure 2).
4. Manta board with fitted harness and attached pencil (Figure 2).
5. 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 2)*).
6. 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)*).
7. Container with spare 2B pencils, twine and rubber bands.
8. 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).
9. Snorkeling gear (mask, fins, snorkel and wetsuit or stinger suit) for each person.
10. Large buoy(s), anchor rope (at least 10 m) and a dump weight.
11. Waterproof, digital watch with countdown function (for each person).
12. Digital camera in underwater housing.
13. Waterproof hard carry case for transporting digital camera.

Extra gear on mother ship

1. Field logbook.
2. One reef pro-forma and at least two, manta tow data sheets for each reef (plus extra data sheets for both manta tow and SCUBA search).
3. Laptop computer complete with: Reefmon data entry software, Image processing software (i.e. proprietary software for downloading JPG images from the digital camera(s), sorting and filing photographs e.g. Thumbs© software, and camera memory card reader).
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 digital camera(s).
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).

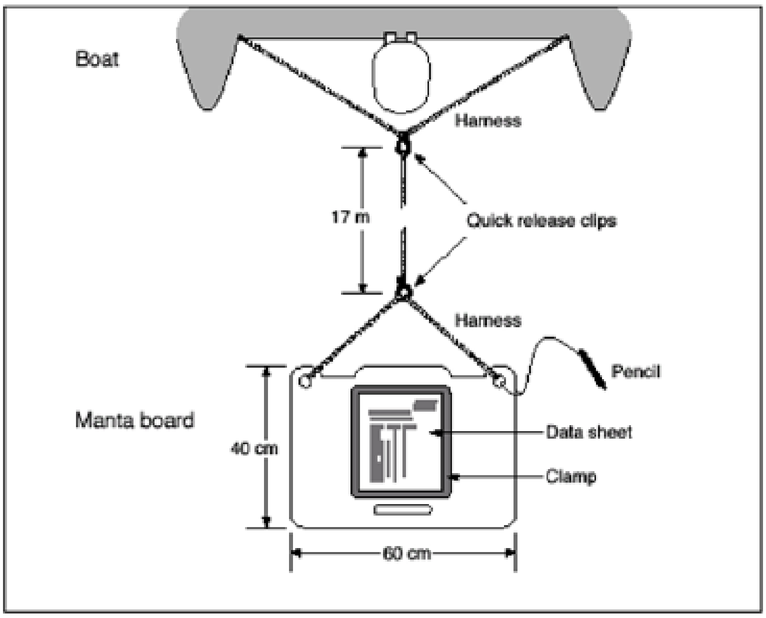

Figure 3. The manta board and attachments (from Moran *et al*. 1989).

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 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, direction of current, and angle of 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 harnesses so that it can move freely, 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 snorkelling gear, and enter the water with the manta board.

4. The observer signals the driver to commence the manta tow when he/she is ready. 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 round 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. To dive down, tilt the leading edge of the board down, and tilt upwards 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, speed of the boat, visibility, reef gradient, 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 driver times the tow period and pauses after two minutes by idling the motor. The motor should be kept in gear to prevent the towrope fouling the propeller. Tension on the towrope will be reduced allowing the observer to record the data for that tow (i.e. COTS number and size, percentage cover of live and dead coral, sand/rubble and presence of feeding scars). The driver should keep a record of the number of tows and where possible, mark the tow number and 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.

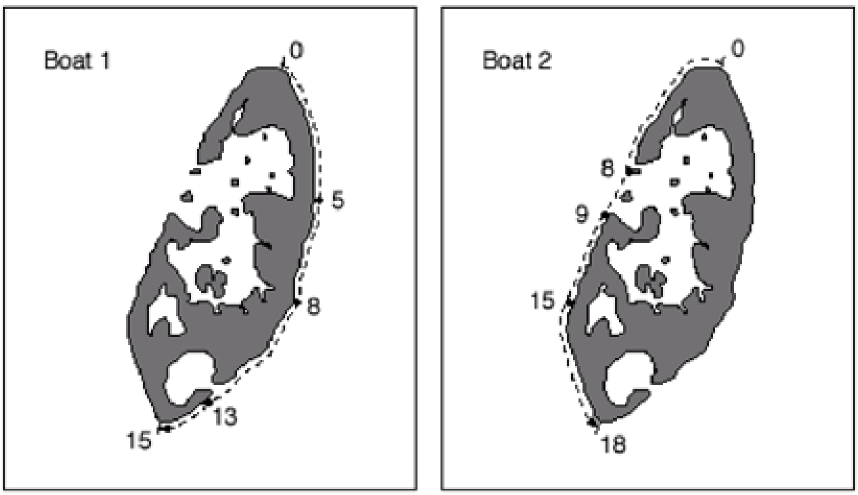

Figure 4. Reef aerial maps showing numbered towpaths for each boat.

7. The observer and driver change roles 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. 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.

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. *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.

2. Strong winds: rough seas are usually the result of strong winds. Unless exceptional circumstances prevail it is usually 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) . 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 end there and continue further around the reef perimeter where the current is less. Where towing ceased should be marked with a buoy so that area of reef can be surveyed when conditions are more suitable.

4. Low tide: At low tide, the water may recede from the reef completely, or periodically, 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 water, 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: On occasions the reef perimeter can be broken by a channel that may be quite deep (>9 m) and have a strong current running through it. If the channel is deep and wider than about 25 metres, then 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.

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 as possible.

Manta tow data pro-forma

Data recording

All data is recorded on the manta tow pro-forma data sheet (Appendix I) that is located on the manta board during surveys.

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:

Wind

Wind strength is recorded as a category as described in Table 1.

Table 1. 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 of measure 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 sea state.

Table 2. Sea state description.

Sea state	*Description*
Calm	Mirror-like to small ripples
Slight	Small waves, some whitecaps
Moderate	Moderate waves, 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

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, 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	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 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.

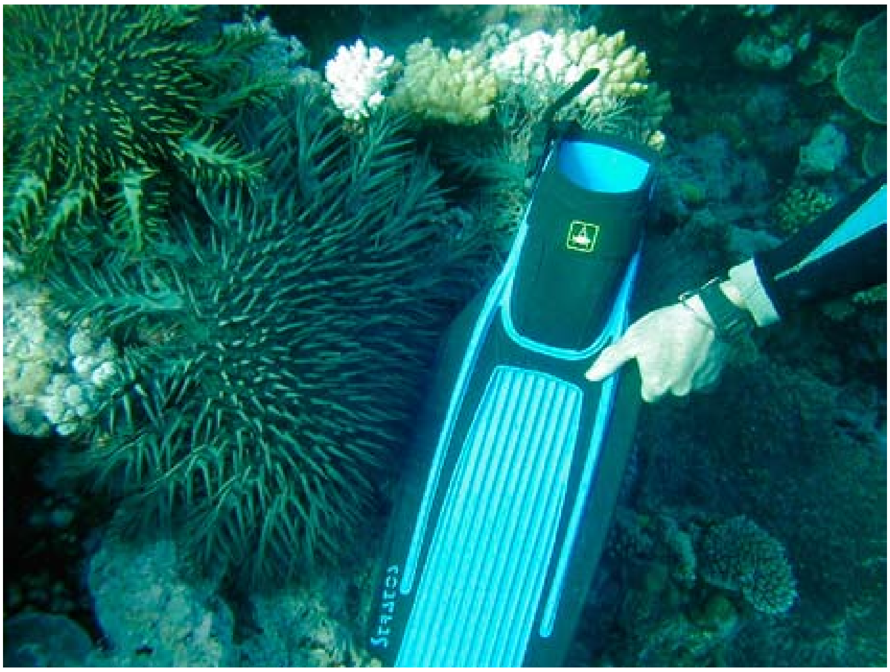

Figure 8. Adult crown-of-thorns starfish greater than three years old.

Live coral cover

Live coral is coloured by the presence of living tissue and can be easily recognized by its colour and the detailed structure of the corallites. Live coral includes all members belonging to hexacorallia (anthozoans where each of the polyps bear six, or multiples of six, tentacles without pinnules) that have a massive aragonite skeleton. Observers record the cover of live corals as one of six categories (Table 5). The categories are based on those recommended for use as the international standard (see English *et. al*.1994). At AIMS however, each of the standard categories is split by the addition of a plus or minus to each. The observer makes a decision as to whether they feel their benthic cover estimate falls in the upper (+), or lower (-), part of a given category. 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.*

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%

Dead coral cover

This category is designed to classify 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 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 this time, the detailed structure of the coral skeleton is lost, due to the algal colonizers and weathering, and the coral is now 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.*

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 are 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 mins*
Absent	0
Present	1-10
Common	>10

Figure 9. Tabulate ***Acropora*** 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*** coral with ***Drupella*** sp. and associated feeding scars.

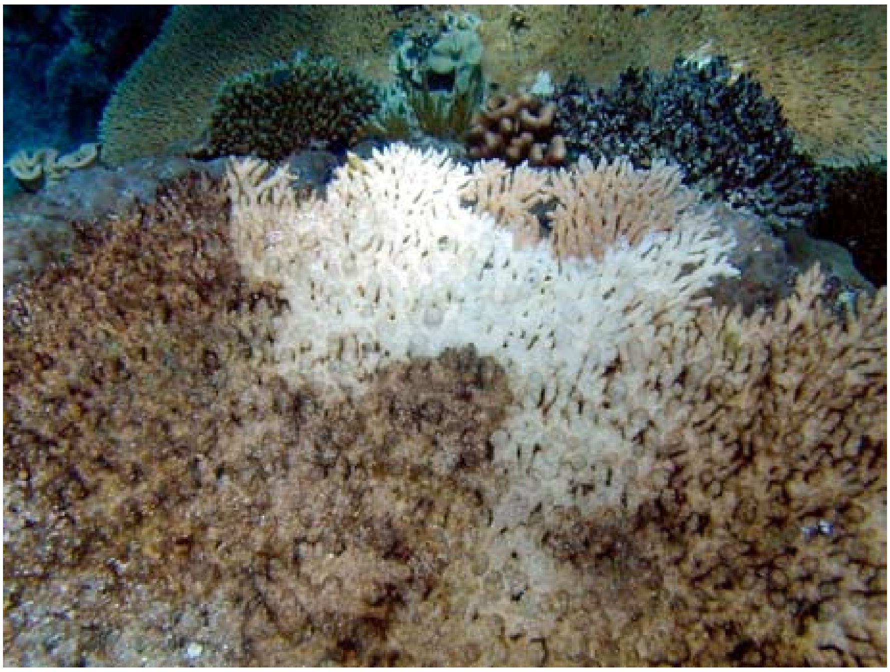

Figure 11. Tabulate ***Acropora*** coral with white syndrome. Unlike COTS white syndrome rarely leaves a discrete circular scar (i.e. in some respects similar in appearance to scars left by ***Drupella*** sp.). Recently dead white coral is bordered on one side by dead coral covered with turf algae and live coral on the other. Often a line of necrotic tissue demarcates the live coral from the recently dead coral.

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 (as can be seen at the base of the digits of the coral in this photo) with a gradation in colour from the unbleached to the bleached parts of the colony.

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 attached along the towrope at six metre intervals. Depending on how far the observer can see along the towrope, the visibility is recorded as one of four categories (Table 7). For example, if the observer can see the boat motor and beyond, then the visibilityis scored as category 4 and if the nearest float cannot be seen, then the visibility is scored as category 1 (Figure 13).

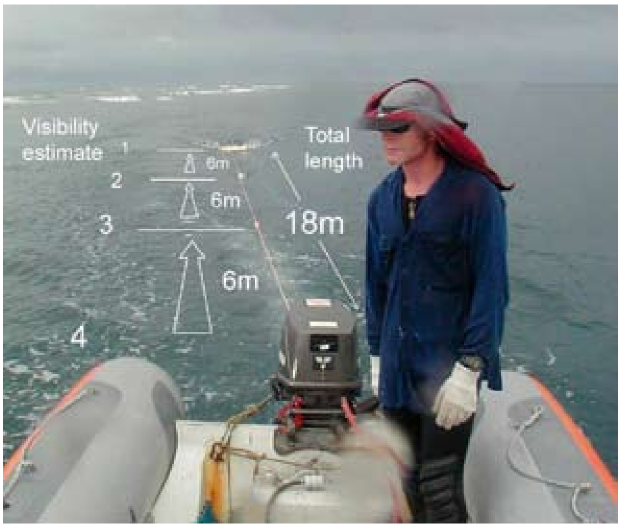

Figure 13. Visibility category estimates for manta tow surveys. Floats are placed at 6m intervals along the towrope.

Table 7. Categories for estimating visibility.

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

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.). 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 structure, slope, diversity, fish abundance, coral mortality, bleaching or any information required for the reef pro-forma sheet (Appendix IIa).

Reef description pro-forma

Introduction

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 (Appendix II). Obtaining photos enhances 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 World Wide Web.

Procedure

When recording the manta tow data the observer writes descriptive notes in the 'remarks' column on the manta tow data sheet 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 observers to form an impression of the reef. To help form this impression, a series of attributes have been devised to describe the reef. One or more categories is assigned for each attribute from the description sheet (Appendix IIc) and recorded on the reef pro-forma data sheet.

Data recording

Each reef to be surveyed by manta tow is divided into four zones. These zones are marked on the aerial photograph used by the boat driver to navigate around the reef. The zones are the back (leeward) reef, front (windward) reef, 1^{st} 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 derived from a “key” (Appendix IIb). The corresponding number or letter from the key is then placed in the appropriate box on the pro-forma (Appendix IIa). Where more than one attribute can be scored the box on the pro-forma is a rectangular shape.

1. Position and reef topography

a. 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.*

b. 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.

c. 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 – portion of reef 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 – area dominated by deep water (>10m) with no reef crest or slope in the immediate vicinity.

5. Shallow no edge – 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.

d. Reef slope

Describes the overall average reef slope on the zone (section of 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.

e. Depth to bottom of slope

Is the average depth (in metres) to the bottom of the hard reef framework that comprises the reef slope to where the reef base starts. The reef base is defined as a sharp break in the reef slope on the seaward margin of the reef. 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 reef slope (i.e. "no edge" is chosen for the reef slope option).

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

f. Slope at reef base

Describes the average angle of the slope at the reef base regardless of whether the edge can be seen. Choose one variable only and place in the corresponding box on the data sheet. Often on the back reef this area consists of a large expanse of shallow sloping sand.

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

g. 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 from 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).

h. 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 on the front of reefs. 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 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 wall at all scales from a metre to tens of metres.

2. Community description

a. 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 – includes all hermatypic scleractinian corals.
2. Soft coral – includes all octocorals from the Order Alcyonacea (i.e. this does not include Gorgonians, Blue Coral or red Organ Pipe Corals).
3. Macro algae – 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 Gorgonaceae.
7. Millepora – all calcified hydrozoans including all known growth forms.
8. Sand – abiotic granular particles usually white and composed of carbonate on coral reefs.
9. Rubble – unconsolidated coral fragments

b. Dominant hard coral genus

Describes the dominant hard coral for the zone surveyed in terms of area covered compared to other coral types present. 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 – all coral belonging to the family Acroporidae including coral from the family Isoporidae.
P. *Porites* genus – all coral belonging to the family Poritidae
C. A 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.

c. *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 open primary and secondary branching where branches are generally narrower 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 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 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 a 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* species. Figure 19.

X. *Bottlebrush Acropora* – Acropora 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 easily moved Fungiid corals, e.g. *Fungia spp*. Figure 22.

3. Other Details

a. 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 have a lurid appearance. Corals that are partially bleached (i.e. pale in colour but still retaining much of there pigment) are not included. However if these are common relevant notes should be placed in comments. 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.

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%

b. 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 a gradation 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)

c. Coral disease I

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 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 in a reef zone.
2. BBD common – more than ten individual colonies observed with BBD in a reef zone

d. Coral disease II

Provides an indicator of the occurrence of white syndrome type disease on corals in a given reef zone. White syndrome diseases express themselves in a variety of ways on a living coral. Due to the variable presentation and the limited understanding of the etiology of this disease(s) on the GBR, they are grouped together as "white-syndromes". White syndrome is 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. This is often expressed as 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 on the border of the white patch/band that is often sloughing off the colony. 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 BBD in a reef zone
2. WS common – more than ten individual colonies observed with BBD in a reef zone

e. Coral trout count

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

f. Fish abundance

Is 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

g. 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.*
2. Sweetlip – all individuals of the genus Lethrinus, in particular *L. nebulosus* and *L. miniatus*
3. Parrot fish – all individuals of the family Scaridae
4. Surgeon fish – all individuals of the family Acanthuridae
5. Pomacentrids – all individuals of the family Pomacentridae
6. Fusiliers – all individuals of the family Caesionidae
7. Baitfish – all schools of baitfish usually composed of sprat (*Spratelloides sp.*) or Hardyheads.
8. Pelagic predators – all roving large pelagic fish, typical examples include mackerel, trevally, barracuda and tuna
9. Snapper – all individuals belonging to the family Lutjanidae
    a. Sharks – all sharks
    b. Butterfly fish – all individuals belonging to the family Chaetodontidae

Figure 14. Branching coral.

Figure 15. Tabulate ***Acropora.***

Figure 16. Digitate coral.

Figure 17. Encrusting coral.

Figure 18. Submassive coral.

Figure 19. Massive coral.

Figure 20. Bottlebrush ***Acropora.***

Figure 21. Foliose coral.

Figure 22. Mushroom coral.

Photography

Preparation of equipment

How a digital camera is set up for the days' photography is very much dependent upon the type and manufacture of the camera as well as the type of housing. In general the default settings (automatic) 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 camera for appropriate settings and check camera function.
6. Check housing; remove o-ring and grease (where applicable).
7. Assemble unit and check function.
8. Place assembled unit in hard case for work in the field.

Field procedure

Photographs are taken haphazardly at a location 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. Be mindful of conditions. Sometimes it is not prudent to have a diver free from the boat if the wind, waves, tide and current make sea conditions 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" (ie. a series of continuous graded shots of a particular subjects) your shots. Photos should be (where possible) broadly representative of the reef zone in question.
6. Make sure the housing is placed in 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.

PART 2 - SCUBA SEARCH TECHNIQUE

Introduction

Historically SCUBA searches have been used in conjunction with manta tow surveys to provide quantitative measures of abundance of COTS (Endean 1974, Kenchington & Morton 1976, Roads & Ormond 1971). SCUBA searches have also been employed to investigate possible biases in manta tow surveys (Fernandes, 1990, Fernandes *et al*. 1990). More recently SCUBA searches have been used by the LTMP to provide information on sources of coral mortality, particularly disease of hard corals, to assist in interpreting trends in benthic cover on permanent sites. SCUBA searches are able examine the reef in greater detail than is possible with the manta tow technique. This has many important implications for COTS surveys as well as detailed benthic surveys:

SCUBA searches enable the detection of low-level populations of COTS. At low densities they are cryptic and more difficult to detect by manta towing.

SCUBA searches provide a method for the detection of juvenile COTS, which because of their small size and cryptic behaviour, are not easily seen by a manta tow observer.

SCUBA searches enable the diver to detect other factors that may be causing coral mortality such as *Drupella*, bleaching or disease (e.g., white syndromes and black band disease).

Historically there have been few reports of high-density populations of juvenile COTS on the GBR and these have involved only small areas of reef and very few COTS (Pearson and Endean, 1969; Fisk et. al. 1988; Doherty and Davidson, 1988). It is only recently with the third series of outbreaks on the central GBR that high-density populations of juveniles were found (Engelhardt et. al. 2001). The detection of juvenile starfish provides a basis for understanding recruitment events and forecasting population increases. More recently there was a growing body of evidence that the prevalence and effects of marine diseases in general and coral epizootics, particularly in the Caribbean, has increased over the last twenty years. Thus the objective of SCUBA searches in the Long-term Monitoring Program has shifted from detecting COTS and other coral predators to a greater emphasis on defining other sources of coral mortality, particularly disease or disease-like syndromes that may not be visible by manta tow. Two methods of SCUBA searching are described, fixed and timed. The vast majority of surveys are conducted using fixed transects.

Fixed transect searches

Sampling design

Fixed transect SCUBA searches are carried out on the standard transects used by the LTMP to survey fishes and benthic organisms. On each "key" reef, three sites are located in the first stretch of continuous reef to be encountered when following the perimeter from the back reef zone towards the front reef in a clockwise direction. The sites are usually situated on the northeast flank of the reef (Figure 23). Sites are separated by at least 250 m where possible.

There are five 50 m transects within each site. These transects were initially laid haphazardly, roughly following depth contours with 10 - 40 m between them. Transects are permanently marked with a star picket at each end and with lengths of reinforcing rod at 10 m intervals. Transects run parallel to the reef crest at about 6-9 m depth. SCUBA searches are carried out in a two metre wide belt (i.e. one metre each side of the tape) along the full 50m of each transect.

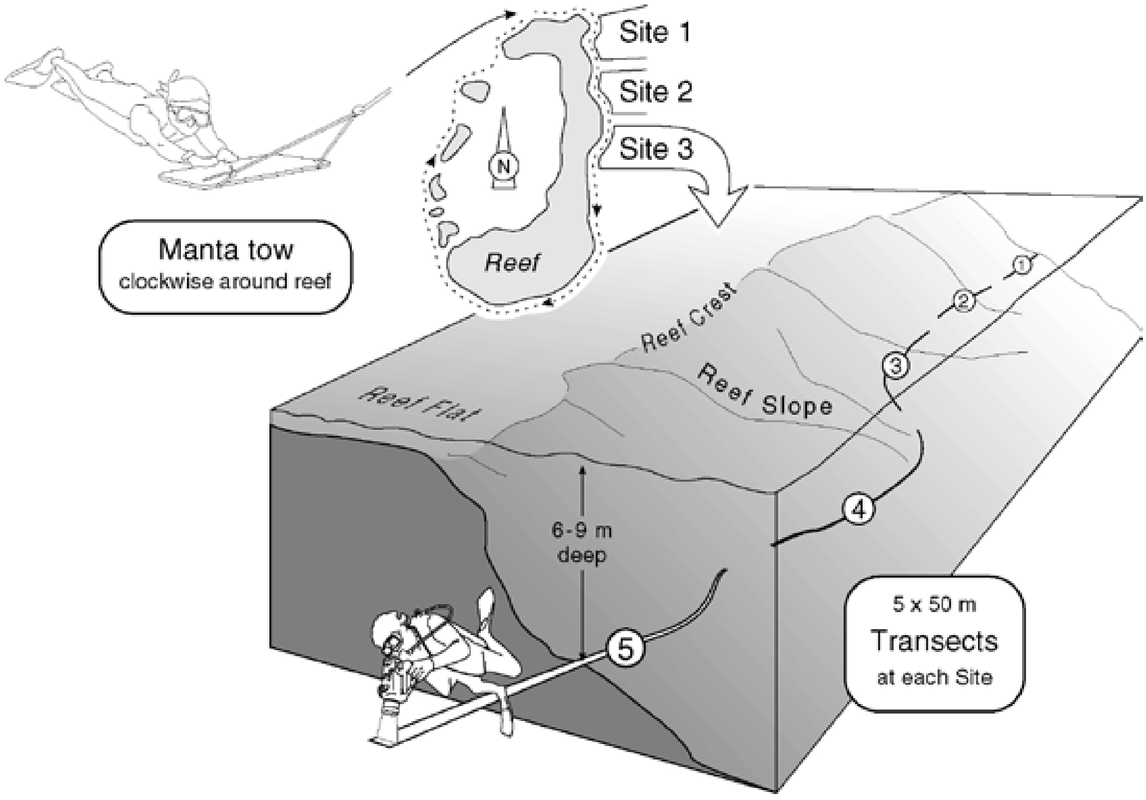

Figure 23. Schematic arrangement of sampling effort on a core survey reef.

Field sampling procedure

Often logistic considerations such as the number and experience of the divers and their allotted tasks will determine details on the most efficient way of carrying out the survey. In all surveys due consideration should be given to diver safety. For a detailed description of the other surveys conducted on these transects see Halford and Thompson (1994), Jonker et. al. (2008).

1. SCUBA search surveys are conducted along each 50m tape that has been laid down previously for other aspects of the LTMP fixed transect surveys.

2. The buddy pair consisting of a SCUBA search observer and, usually, the benthic observer doing photograph transects, follow along the pre-laid tape. At this time the fixed transect search is conducted by searching a 50 by 2m belt (i.e. one metre either side of the tape). The observer looks for areas of recent coral mortality and investigates these areas by closer inspection. Observations are recorded on the data sheet (Appendix III).

Timed transect searches

Sampling design
Timed SCUBA searches are a plotless method designed to determine fine-scale patterns of COTS distribution on reefs where this information is needed. These surveys can provide counts of recruits or densities of standing COTS populations. In conjunction with benthic surveys they can be used to determine benthic cover and factors affecting coral mortality.

Field sampling procedure

1. Each reef is initially manta towed to select sites by the presence of feeding scars, COTS or signs of disease. These sites are noted during the manta tow survey and where possible, a buoy is placed to mark the site. Upon relocating the site, the position is recorded using a GPS. Divers should search three to six sites on a reef.

2. At each site three divers each swim parallel to the reef slope along three separate depth contours (4 m, 8 m and 12 m). Where the slope is less than 12 m, divers swim parallel to each other, (at least 4 metres apart but depending

upon visibility) and cover the maximum practical depth range between the crest and the base of the reef slope.

3. Each diver swims for twenty minutes and scans approximately 1 metre either side of the swim path looking for evidence of coral mortality. Areas of recently dead coral are examined to determine the cause of mortality, and observations are recorded on the data sheet (Appendix III).

Data recording for transect searches

Data sheet

The data sheet (Appendix III) is a table consisting of five pairs of columns. The first column is used to record the type of scar (according to the key given at the bottom of the page) while the second column is used to record the life form (and genus where possible). Each column pair is used to record information from one transect or one timed swim. The information that is recorded is as follows:

Variables recorded

Transect

The number of transect surveyed, for a fixed transect, or the depth contour surveyed for a timed swim search (note GPS position for site is recorded under “site” on top of data sheet for timed swim searches).

COTS

COTS numbers recorded as J, A, B or C, according to size criteria listed in Table 4 (see Figure 5). Each individual COTS observed is noted according to its size in the appropriate cell at the bottom of the column.

COTS scars

Each individual colony with scar(s) attributable to COTS feeding activity is marked COTS and recorded in the scar column and the affected life form (and genus where possible) is recorded in the corresponding cell.

Drupella (Drup(#))

A review of previously recorded data suggests that it is almost impossible to identify a *Drupella* sp. scar without associated *Drupella* sp (see figure 10). Thus in this category the number of individuals associated with each scarred coral colony is recorded in the scar column and the affected life form (and genus where possible) is recorded in the corresponding cell.

Scars unknown (UN)

Any colony with scars that have no obvious cause is recorded as UN in the scar column and the affected life form (and genus where possible) is recorded in the corresponding cell.

White-syndrome disease (WS)

This category is recorded as each individual scar that can be attributed to a “white” disease (Figure 24). White syndrome is 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. Often the necrotic tissue can be seen sloughing off the edge of the scar. Each individual scar attributable to White Syndrome is recorded as WS in the scar column as well as the associated life form (and genus where possible) in the corresponding cell. Care must be taken when identifying the disease as the “sign” can easily be confused with those caused by predators such as COTS or *Drupella*.

Skeletal eroding band disease (SEB)

This category is recorded as each individual scar that can be attributed to Skeletal Eroding Band disease (Figure 25). This disease is a “white” disease of Acroporidae and non-Acroporidae corals. It can be distinguished from other “white” diseases by a black zone or black speckling on coral followed by a white speckled dead coral skeleton. A line of white skeleton may precede the dark area on the colony. The disease is caused by the sessile protozoan ciliate *Halofolliculina corallasia* that resides in a secreted black sac-like test called a lorica that is attached to the coral skeleton. Clusters of ciliates in lorica can sometimes form a line between live coral and dead coral giving a strong superficial resemblance to Black Band Disease. However the empty lorica on the white coral skeleton behind the dark band give a dotted appearance to the dead zone and can be used to visually distinguish SEB from BBD (Antonius 1999). The disease progresses when the protozoan produces motile larvae asexually. The larvae move ahead of the band onto the living coral tissue, locate a site suitable to take up residence and proceed to secrete a lorica of their own. Damage to the coral’s skeleton and tissue death come about as a result of a combination of chemicals associated with the production of the new lorica and the physical drilling of the lorica into the coral skeleton (Antonius and Lipscomb 2001). Each individual scar attributable to Skeletal Eroding Band is recorded as SEB in the scar column and the affected life form (and genus where possible) is recorded in the corresponding cell.

Brown Band disease (BrB)

This category is recorded as the number of scars that can be attributed to Brown Band Disease (Figure 26). The disease appears as a brown band of soft jelly like substance ahead of recently dead white coral skeleton. The disease is thought to be caused by the brown ciliate *Helicostoma nonatum*. Each individual colony with scar(s) attributable to Brown Band is recorded as BrB in the scar column and the affected life form (and genus where possible) is recorded in the corresponding cell.

Black Band disease (BBD)

Black band disease appears as a discrete band of soft black material ahead of recently dead white coral and behind the still living tissue (Figure 27). The disease is caused by the cyanobacterium *Phormidium corallyticum,* and a consortium of microscopic organisms including cyanobacteria, *Spirulina,* sulfate oxidising and reducing bacteria, heterotrophic bacteria and others. It is thought the consortium kills the coral through anoxia and the production of Hydrogen sulfide. Number of scars attributable to Black Band Disease are recorded as BBD in the scar column and the affected life form (and genus where possible) is recorded in the corresponding cell.

Atramentous necrosis disease (AN)

Atramentous necrosis is a putative term to describe a recently discovered disease found on the GBR (Jones et al. 2004). The disease presents itself as blackened lesions that spread within days across an infected colonies surface (Figure 28). The disease superficially appears similar to black band disease however instead of forming a band atramentous necrosis forms a distinctive mat. Each individual scar attributable to atramentous necrosis is recorded as AN in the scar column and the affected life form (and genus where possible) is recorded in the corresponding cell.

Porites pinking (PP)

The typical sign of Porites pinking is a bright pink line of scar tissue surrounding an area of the colony that is dead (Figure 29). It is difficult to tell if the pink colouration observed around dead and scarred tissue on *Porites* spp. hard coral colonies is the symptom of a disease or simply a response of the coral to a variety of competitive, invasive or parasitic interactions. On the GBR, from our observations, the observed discolouration ranges from pink through to white and appears on scar tissue that forms in a common response to stress, usually mechanical, imparted by a wide variety of factors (e.g. parasites, predators, commensals, competition for space, fish bite marks, the margins of damsel fish gardens, persistent rubbing by other benthic organisms, or margins around turf alga patches on the colony from unspecific causes). Each individual colony with scar(s) attributable to Porites Pinking is recorded as PP in the scar column as well as the affected life form recorded in the corresponding cell.

Hyperplasia (HYP)

These are identified as abnormal growths or tumors on corals (Figure 30). Tumors on hard corals form as a result of abnormal proliferations of cells that are also associated with an abnormal skeletal growth. These fall into two main categories termed hyperplasia and neoplasia. Hyperplasia is caused by an increase in the number of cells in a tissue or organ, thereby increasing the bulk of the tissue or the organ. These cells typically remain differentiated (i.e. have a clear polyp structure though this may be abnormal in shape and size) and maintain the colouration of the healthy coral. Each individual colony with abnormal growth attributable to Hyperplasia is recorded as HYP in the scar column and the affected life form (and genus where possible) is recorded in the corresponding cell.

Neoplasia (NEO)

These usually appear as white, globular masses of coral skeleton raised above the surface of the colony (Figure 31) and have few discernable polyp structures (in contrast to hyperplasms where macroscopic polyp structure remains visible and the tissues remain pigmented). Each individual colony with abnormal growth attributable to Neoplasia is recorded as NEO in the scar column and the affected life form (and genus where possible) is recorded in the corresponding cell.

Coralline algae orange disease (CLOD)

It is characterized by a "band" of bright orange in colour that spreads across the algal surface, leaving behind the bare skeletal carbonate remains of the coralline algae (Figure 32). Little is known about the pathology of the disease. Each individual scar on coralline algae attributable to Coralline Algae Orange Disease for each transect is recorded as CLOD in the scar column.

Coralline algae pink disease (CLAP)

This putative disease is similar to CLOD except in this case a narrow pink band marks the line of mortality (Figure 33). The disease often appears less virulent than CLOD and difficult to observe as commonly found on coralline algae under ledges and in nooks and crannies. This is a new disease that is yet to be described. Each individual scar on coralline algae attributable to Coralline Algae Pink Disease for each transect is recorded as CLAP in the scar column.

Sediment (SED)
Hard corals have evolved mechanisms to clear sediment that is deposited from the water column. However periodically the rain of suspended sediment can overcome these defenses and choke the coral polyps resulting in mortality to part or the entire colony. This can be recognized by recent mortality (dead white coral skeleton) underneath the patch of sediment (Figure 34). Each individual scar attributable to sedimentation is recorded as SED in the scar column and the affected life form (and genus where possible) is recorded in the corresponding cell.

Algal overgrowth (ALG)
In certain situations algae coral will out compete hard corals for space and overgrow live hard coral tissue and cause subsequent coral mortality. In other cases algae can interact with corals and induce mortality (Figure 35). Each individual colony with abnormal growth attributable to algal overgrowth is recorded as ALG and where possible the alga is identified and recorded in the scar column and the affected life form (and genus where possible) is recorded in the corresponding cell.

Ascidian overgrowth (ASC)
Colonial ascidians can also successfully compete with corals for space and in some situations will overgrow hard corals. If the ascidian can be removed, recently dead coral tissue will be seen (Figure 36). Each individual colony with spreading ascidian growth over live coral tissue is recorded as ASC in the scar column and the affected life form (and genus where possible) is recorded in the corresponding cell.

Sponge overgrowth (SPO)
Sponges play an important role in the benthic community and often aggressively compete for space with hard corals not only overgrowing hard corals but also penetrating and often eroding their skeletons (Figure 37). Each individual colony with abnormal growth attributable to algal overgrowth is recorded as SPO and where possible the alga is identified (for instance the bio eroding sponge *Cliona* sp. is distinctive Figure 37) and recorded in the scar column and the affected life form (and genus where possible) is recorded in the corresponding cell.

Comments
Pertinent notes of particular interest that may help with the interpretation of the data are recorded in the space between each table.

Figure 24. Tabulate ***Acropora*** sp. coral infected with a "white" syndrome disease.

Figure 25 Close up view of a branching ***Acropora*** .sp. coral infected with Skeletal Eroding Band Disease.

Figure 26. Branching ***Acropora*** sp. coral infected with Brown Band Disease.

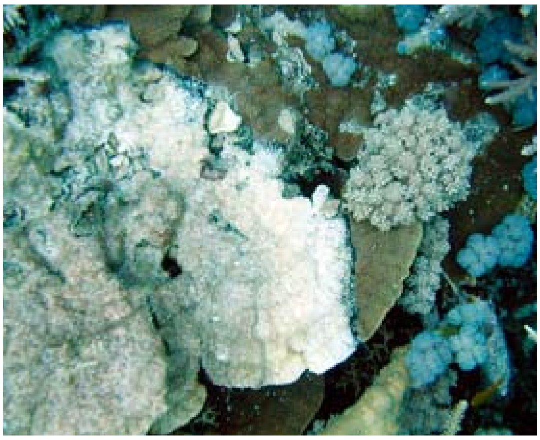

Figure 27. Foliaceous ***Montipora*** sp. coral infected with Black Band Disease.

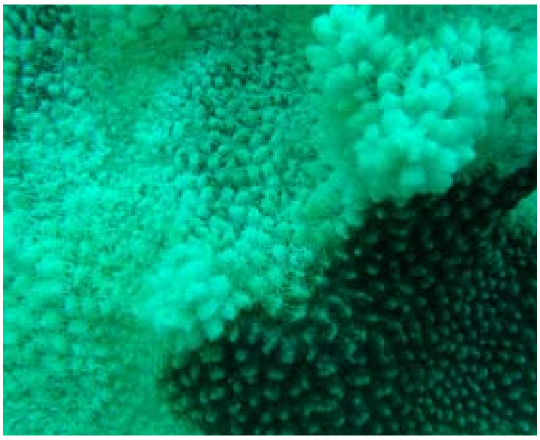

Figure 28. Submassive ***Hydnophora*** sp. coral infect with Atramentous Necrosis.

Figure 29. Photograph of Porites pinking. The cause of the pinking in this photograph is unknown.

Figure 30. Hyperplasia on a branching ***Acropora*** sp. hard coral gives the colony an odd lumpy appearance.

Figure 31. Photograph of neoplasia on a branching ***Acropora*** sp. hard coral. Unlike hyperplasia, neoplasia are characterised by undifferentiated cell growth giving the affected part of the colony a white globular appearance.

Figure 32. Photograph of coralline algal orange disease growing on a crustose coralline alga.

Figure 33. Photograph of coralline algal pink disease growing on a crustose coralline alga.

Figure 34. Photograph showing partial mortality to a ***Favites*** sp. hard coral as a result of sediment deposition**.**

Figure 35. A ***Seriatopora hystrix*** coral colony showing clear signs of mortality as a result of the action of an unidentified filamentous red alga.

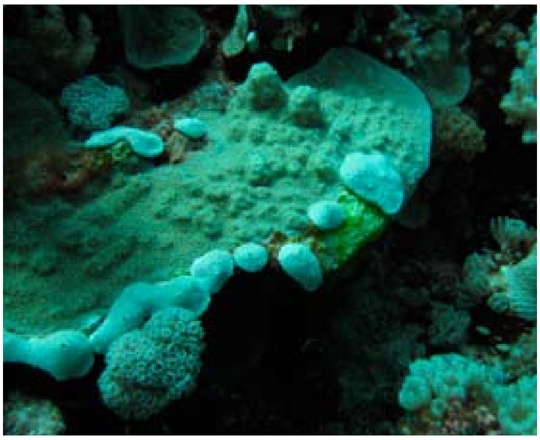

Figure 36. Photograph of a colonial ascidian (white mass) overgrowing a foliaceous ***Montipora venosa*** hard coral colony. Induced mortality can be seen as a white scar at the edge of the colony**.**

Figure 37. Photograph of a massive ***Favia*** sp. hard coral colony being overgrown by the bioeroding sponge ***Cliona*** sp.

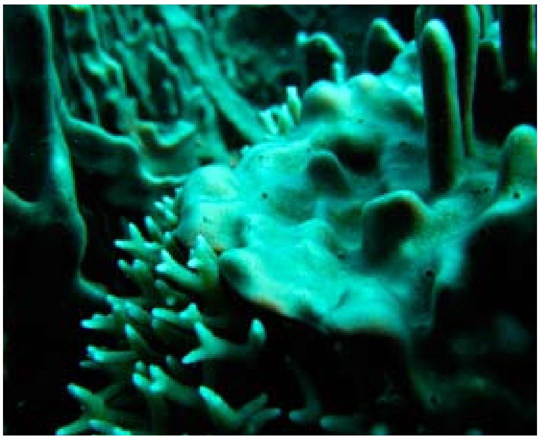

Figure 38. A ***Seriatopora hystrix*** coral colony slowly being overgrown by a sponge.

PART 3: DATA MANAGEMENT

Manta tow/SCUBA search data

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.

Data sheets

1. Rinse underwater data sheets in fresh water and dry.

2. Re-number the tow numbers on the manta data sheet and the reef aerial accordingly. This is so the numbers are continuous in a clockwise direction around the reef perimeter. The starting point is labeled as zero and should be the same point as 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 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.

Data entry

Data is entered into a laptop computer in the field using a Microsoft Access program designed for the AIMS Long-term Monitoring Program, called Reefmon. For a detailed explanation of the AIMS database structure, refer to Baker and Coleman 2000.

1. Enter the Reefmon program. Check the database location reads “LOCAL” and enter the cruise code, p-code, year, visit number. Click “RM Dives” to enter SCUBA search data or “Manta tow” to enter manta tow data including aesthetics information and photos for the pro-forma.

2. The sample-id is entered for that reef and the ‘sample data’ (i.e. Reefname, 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.*

3. The manta tow, reef pro-forma and SCUBA search 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. While manta tow data and reef pro-forma data share a common sample-id, SCUBA search data have their own individual sample-id at the transect level.

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 data base manager unload the data from Reefmon using mSync (purpose built software, see data base manager for details). Change the data base location on the Reefmon program to “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 print out, to reduce the possibility of errors. Make the appropriate corrections in Reefmon.

7. Keep the checked printout on file as a record of data entry errors.

8. File the data sheets with the checked printouts.

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 reef 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 reef folder.

4. Using the photo-editor of your choice (eg: Thumbs) 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 the image database entry scheme in Reefmon by clicking the Photos button in the Manta Tow Data entry screen.

6. Click on 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 the data entry page and the "image editor" screen can be viewed at the same time.

8. Drag and drop selected photos from the"image editor" into the appropriate box (i.e. back photos, flank1 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.

PART 4: TRAINING AND QUALITY CONTROL

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 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.

Procedure

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 does (Moran *et al*. 1989, Moran & De'ath 1992, 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 technique.

The second part involves showing photographs of corals and other benthic organisms to familiarize the new personnel with the different types of 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).

Field training

Field based training involves towing the inexperienced observer in tandem 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 39). 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 are 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 39. Photograph of observers being towed on the tandem manta board.

Through this method 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 reef (8 to 10 manta tows) is consistently within one median category of those obtained by direct comparison with at least three experienced observers.

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). To obtain the most precise estimates, an ongoing system of quality control can be employed. This is done by 'double towing' selected reefs to determine the variability between observers over a period of tows. From this, a measure of the precision of estimates for each survey trip is determined. This also enables observers to compare their estimates during each survey trip (Miller and Müller 1996). In practice applying the quality control methods described by Miller and Müller (1996) is generally time consuming and can hamper field sampling by reducing time available for other aspects of surveys during field trips. To maintain quality of the data the LTMP concentrates on standardizing observers before the beginning of each field season via a dedicated “training trip” where observers are trained as described in the previous section.

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APPENDIX I

MANTA TOW SURVEY

AUSTRALIAN INSTITUTE OF MARINE SCIENCE
Long-term Monitoring Program

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

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

Tow	Coral Cover			Vis.	C O T				Remarks
No.	Live	Dead	Soft		No.	Size	Scars		
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
21									
22									
23									
24									
25									
26									
27									

APPENDIX II-A

Key to Reef Description Pro-forma

1. POSITION AND REEF TOPOGRAPHY

a. Start tow

b. Exposure

1. Sheltered
2. Partly exposed
3. Exposed

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 (21-45°)
3. Steep (46-75°)
4. Vertical (76-90°)
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. > 20 m

f. Slope at reef base*

1. Shallow (0-20°)
2. Moderate (21-45°)
3. Steep (46-75°)
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 (ie. caves with an entrance at both ends)
6. Bommies
7. Pavement
8. Continuous wall

2. COMMUNITY DESCRIPTION

a. Dom benthic group	**b. Dom hard coral genus**	**c. Dom coral lifeform**	
1. Hard coral	A. *Acropora* genus	B. Branching	
2. Soft coral Acropora	P. *Porites* genus	T. Tabular	X. Bottle-brush
3. Macro-algae	C. A non-*Acropora* genus	D. Digitate	U. Mushroom
4. Coralline/turf algae	N. No one coral dominant	E. Encrusting	F. Foliose
5. Sponge		S. Sub-massive	
6. Gorgonian		M. Massive	
7. Millepora			
8. Sand			
9. Rubble			

3. OTHER DETAILS

a. Level of coral bleaching	**b. Areas of reef affected**	**c. Coral disease I**
0. 0%	1. Reef flat	1. BBD present
0+. Individual colonies	2. Reef crest	2. BBD common
1-. 1-5%	3. Reef slope (<10m)	
1+. 5-10%	4. Deep slope (>10m)	**d. Coral disease II**
2. 10-30%		1. WS present
3. 30-50%		2. WS common
4. 50-75%		
5. 75-100%		**e. Coral trout count**

f. Fish abundance	**g. Conspicuous target fish species**	
1. Low	1. Coral trout	6. Fusiliers
2. Moderate	2. Sweetlip	7. Baitfish (sprat)
3. High	3. Parrot fish	8. Pelagic predators
4. Very high	4. Surgeon fish	9. Snapper
	5. Pomacentrids	a. Sharks
		b. Butterfly fish

APPENDIX II-B

Reef: **Sample ID:**

Zone 1: Back Reef
Observer 1:
Observer 2:

1. Position and reef topography

a. **b.** **c.**

d. **e.** **f.**

g.

h.

2. Community description

a.

b.

c.

3. Other details

a. **b.**

c. **d.** **e.** **f.**

g.

Comments

Zone 2: First Flank
Observer 1:
Observer 2:

1. Position and reef topography

a. **b.** **c.**

d. **e.** **f.**

g.

h.

2. Community description

a.

b.

c.

3. Other details

a. **b.**

c. **d.** **e.** **f.**

g.

Comments

Zone 1: Front Reef
Observer 1:
Observer 2:

1. Position and reef topography

a. b. c.

d. e. f.

g.

h.

2. Community description

a.

b.

c.

3. Other details

a. b.

c. d. e. f.

g.

Comments

Zone 1: Second flank

Observer 1:

Observer 2:

1. Position and reef topography

a. b. c.

d. e. f.

g.

h.

2. Community description

a.

b.

c.

3. Other details

a. b.

c. d. e. f.

g.

Comments

APPENDIX III

FIXED SCUBA SEARCH SURVEY

Long-term Monitoring Program
Australian Institute of Marine Science

Reef: **Site:** **Date:** **Time:** **Observer:**

Transect 1		Transect 2		Transect 3		Transect 4		Transect 5	
Scar	**Genus/form**	**Scar**	**Genus/form**	**Scar**	**Genus/form**	**Scar**	**Genus/form**	**Scar**	**Genus/form**
								COTS J	
COTS J		COTS J		COTS J		COTS J		COTS A	
COTS A		COTS A		COTS A		COTS A		COTS B	
COTS B		COTS B		COTS B		COTS B		COTS C	
COTS C		COTS C		COTS C		COTS C		**Bleaching**	
Bleaching		**Bleaching**		**Bleaching**		**Bleaching**			

Bleaching recorded as a percentage of the total hard coral cover: 0=absent, 0+ = individual colonies, -1= 1-5%, +1= 6-10%, 2=11-30%, 3=31-50%, 4 =51-75%, 5=76-100%

COTS: **J** < 5cm, **A** = 6-15cm, **B** = 15-25cm, **C** > 25cm
COTS Scar: **COTS**
Drupella: **Drup(#)**
Bleaching: see above
Unknown: **UN**
White Syndrome: **WS**
Skeletal Eroding Band: **SEB**
Brown Band: **BrB**
Black Band: **BBD**
Atrementous necrosis: **AN**
Porites Pinking: **PP**
Hyperplasia: **HYP**
Neoplasia: **NEO**
Coralline Orange: **CLOD**
Coralline Pink: **CLAP**