

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

D.K. Bass and I.R. Miller

**Long-term Monitoring of
the Great Barrier Reef**

**Standard
Operational Procedure
Number 1**



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PREFACE

This Standard Operational Procedure was first produced as an internal report in January 1995. Since then, it has been used for training in reef monitoring throughout the Pacific. This second edition has been revised to suit the wider audience and also to include modifications to the design of the Great Barrier Reef Monitoring Program. The Australian Institute of Marine Science's Long-term Monitoring Program monitors benthic communities, reef fish abundance, crown-of-thorns starfish populations and water quality parameters on an annual basis. Both reef fish and benthic communities are monitored along permanently marked transects, on selected reefs.

This Standard Operational Procedure is Volume 1 in a series of five, produced by the Long-term Monitoring Program at the Australian Institute of Marine Science. Part one describes the standard procedure used to manta tow entire reefs, and Part two describes how to conduct fixed transect and timed searches. Further details of the Long-term Monitoring Program are described in Oliver *et al.* (1995).

INTRODUCTION

This document describes the procedures for broadscale 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. Two basic techniques are used in these surveys: manta tow and SCUBA searches. Part one details the manta tow technique previously described by Moran *et al.* (1989) and more recently in the *Survey Manual for Tropical Marine Resources* (eds. English *et al.* 1997, 2nd ed.). Since the technique was first described, a number of changes have been made to address problems associated with observer bias and also to standardise data collection procedures. Part two describes the SCUBA search technique that has been used in broadscale surveys at AIMS to provide additional information on low level populations of COTS, and to investigate the causes of coral mortality. This document describes the equipment, survey methodology, data recording, data entry and training procedures for both techniques. A detailed description of the database is provided by Baker *et al.*(1991).

SAMPLING DESIGN

Reefs are surveyed for crown-of-thorns starfish using the manta tow technique 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). Benthic communities are surveyed annually within six of these sectors (Cooktown/Lizard Island, Cairns, Townsville, Whitsunday, Swain and Capricorn Bunker sectors) on permanent sites. In each of these sectors (except for the Capricorn Bunker sector) three shelf positions (inner, mid and outer) have been identified. In the Capricorn Bunker sector, only outer shelf reefs are represented, with four reefs being surveyed. Shelf position is determined by the position of the reef relative to the coast and continental slope, with inner shelf reefs being closest to the coast. In addition to the manta tow survey and water sampling, a single habitat is surveyed on each reef, typically situated on the north-east flank of the reef. It is defined as the first stretch of continuous reef, going in a clockwise direction from the back reef zone towards the reef front, with a slope less than vertical. The selection of a common habitat allows comparisons to be made between reefs, both within and between sectors. Within this habitat three sites are selected, each containing five, permanently marked, 50 metre long transects, lying roughly parallel to the reef crest. Further details of the design can be found in Oliver et al. (1995). Transects are set-up along the reef slope between 6 and 9 metres depth. The transect is marked at the beginning and at the end with a starpicket and at 10 metre intervals with steel reinforcing rods (10 mm dia.). A tape measure stretched between the starpickets and rods mark the centre line of each transect. Each starpicket is labelled with an aluminium tag (identifying the transects as belonging to AIMS project 221). The GPS position of the starpicket at the beginning of the first transect of each site is recorded in a database. This starpicket is also marked with a subsurface buoy to aid in locating the site. Fish abundance surveys, benthic surveys and SCUBA search surveys for coral mortality are conducted along each transect.

PART 1: MANTA TOW TECHNIQUE

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 1). The observer holds on to a 'manta board' 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 when the boat stops, on a data sheet attached to the manta board. The manta tow technique was 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 part of, reef). A 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 standardisation of the technique at AIMS.

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 can be calibrated to predict estimates obtained from more intensive searches using SCUBA.

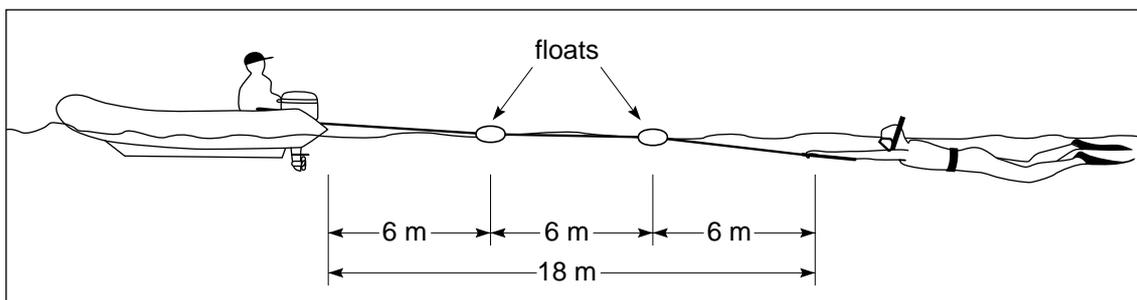


Figure 1. The manta tow technique.

Personnel

A minimum of four people are required to conduct the surveys efficiently. One person, nominated as the cruise leader is responsible for planning the trip and ensuring that the surveys follow a standardised 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 and its fauna, be an experienced snorkeller and possess a speed boat driver's licence.

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 m) boat with 15-20 HP outboard motor and necessary safety gear
2. Waterproof VHF hand-held radio
3. Rope harness which attaches to the boat's transom (Figure 2)
4. Manta board with fitted harness and attached pencil (Figure 2)
5. 17 metre, 10 mm 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 1).*)
6. A4 size data sheet printed on underwater paper (Appendix I). (*This is held in the recess on the manta board by a fixed clamp (Figure 2).*)
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. Snorkelling gear (mask, fins, snorkel and wetsuit or stinger suit) for each person
10. Two large buoys, 2 ropes (10 m) and 2 dump weights
11. Waterproof, digital watch with countdown function

Extra gear on ship

1. Field logbook
2. One reef aesthetics and 2 manta tow data sheets for each reef
3. Extra data sheets (manta tow and SCUBA search)
4. 486 laptop computer with data entry software (Reefmon) and HD 3.5 inch disks
5. Marine Park zoning maps of the Great Barrier Reef
6. Maps of manta tow paths of previously surveyed reefs
7. Spare stationery items
8. Tide tables
9. Basic toolbox and spare snorkelling gear

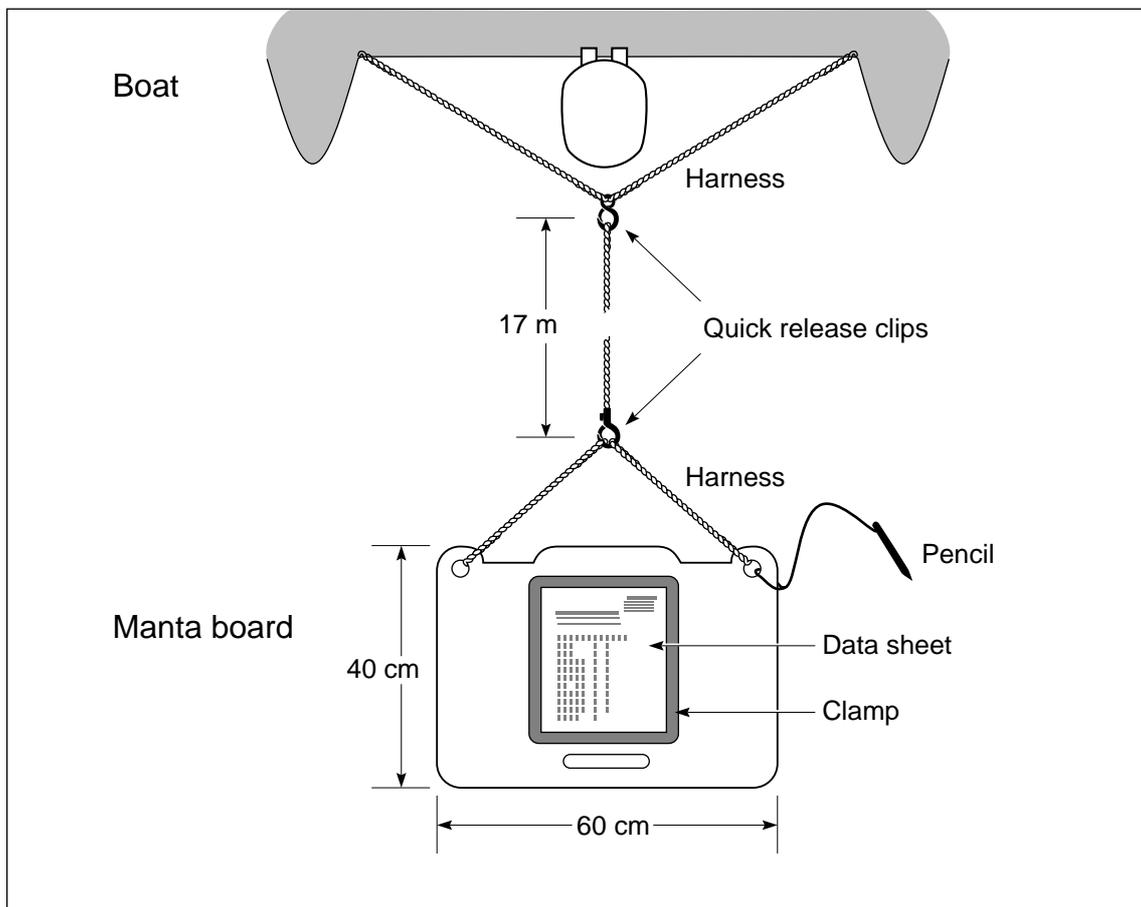


Figure 2. The manta board and attachments.

Procedure

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

1. The two teams discuss the location of the starting point, manta tow path and weather conditions before commencing the survey. The cruise leader must ensure that everyone is aware of tides, currents, daylight hours remaining, and present weather conditions. *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 the two boats may be out of visual contact.*
2. Begin the survey at the set 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.)
3. Clip the tow rope to the transom harness 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 tow path and the towing speed (see English *et al.* 1994). The driver tows the observer holding the manta board, behind the boat at a constant speed of about 4 km/hr (the actual speed may vary, depending on wind and current). *Note. Observations are generally made from the surface, however when closer inspection is required, the observer can manoeuvre the manta board below the surface. To dive down, tilt the leading edge of the board down, and tilt upwards to ascend.*

The tow path should be parallel to the reef crest, and close enough for the observer to see as much of the reef slope as possible. The search area will vary, depending

on tow path, speed of the boat, visibility, reef gradient, distance from substrate, distribution and density of organisms being counted (Moran & De'ath 1992). This variability of the reef slope and weather conditions make it difficult to define a search area however, observers should consciously try to restrict their search width to about 10 metres (see English *et al.* 1994).

5. The driver times the manta tow and stops after two minutes by idling the motor. The tow rope will become slack allowing the observer to record the data for that tow (ie. 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 3). When the observer signals that the data recording is complete, the driver recommences towing, stopping again after two minutes.
6. The observer and driver change roles after an agreed time, (usually after fifteen tows) to avoid fatigue. During the changeover time, it is important to discuss observations about the reef and sea conditions.
7. 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.

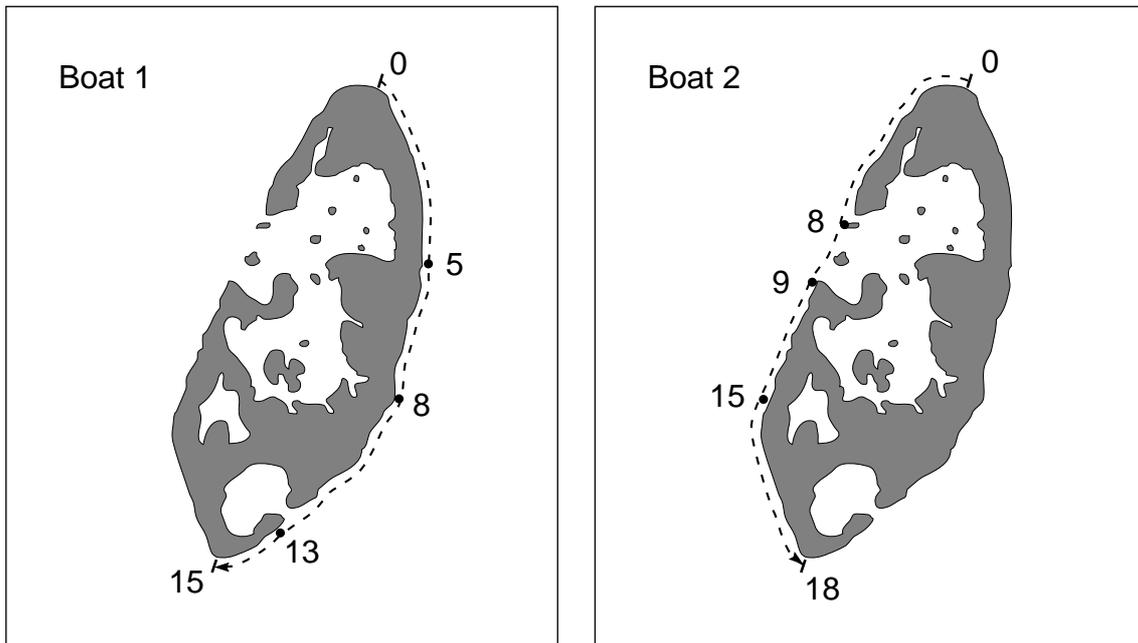


Figure 3. Reef aerial maps showing numbered tow paths for each boat.

Potential problems

At any time, if the observer or driver feels conditions are unsuitable for towing they should assess the situation giving consideration to their safety. Listed below are some of the common problems that make towing conditions difficult.

1. Rough seas: Generally on the Great Barrier Reef, the reef front receives the roughest seas on the southeast edge. Rough sea conditions can make it difficult and dangerous to manta tow, so drivers should know their limits. As a guideline, if the waves are greater than 2 metres, or breaking erratically then it is unsafe to manta tow. *Note. This is only a guide and each person should use their discretion.* If at any point one team decides to stop towing, then they must notify the other team by radio, and decide upon a point to continue towing where conditions are more suitable. If a break in the tow path is made, it should be clearly marked on the aerial.
2. Currents: When there is a strong current flowing along the reef edge, towing speed and/or direction should be modified. 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.
3. Low tide: At low tide, the water may recede from the reef periodically exposing the crest. In this situation, the driver should keep a safe distance from the reef crest, to prevent the boat or the observer being caught in the surge. On a reef front where the wind is blowing the boat onto the reef, the driver should head the boat into the wind, especially when towing on a low tide to avoid being pushed onto the reef crest.
4. Low visibility: Generally if the visibility is less than 6 metres, (ie. 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). The observer should beware of diving down in poor visibility.

5. Channels: Occasionally the reef perimeter is broken by a channel that may be quite deep and/or have a strong current running through it. If the channel is deep (>9 m) 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 tow path should be marked on the aerial photograph.
6. Sandy back areas: Some back reefs are typically shallow and lack a solid edge, making it difficult to determine the correct tow path. In these areas the driver must decide upon a straight tow path across the back reef to include as much hard substrate as possible. It is important to keep the orientation of the reef in mind when selecting the tow path and to mark any recognisable points on the aerial photograph.

Data recording

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 from 1 to 5, described in Table 1.

Table 1. Wind strength categories.

<i>Category</i>	<i>Wind strength</i>
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. From a position where the entire sky can be seen, estimate the amount of cloud as a fraction of eight. Thus, a cloudless sky is recorded as 0 eighths or oktas and an overcast sky is recorded as 8 oktas.

Sea state

Sea state is described by a modified Beaufort scale (Table 2).

Table 2. Sea state description.

<i>Sea state</i>	<i>Description</i>
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

The tide state is defined as either low, high, falling or rising and is determined from a Tide table. These states are described in Table 3.

Table 3. Tide states.

<i>State</i>	<i>Description</i>
Low	One hour either side of Low water
High	One hour 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 feeding scars, visibility and any observations of note are recorded (Appendix I).

COTS numbers

The number of COTS observed during a manta tow is recorded.

COTS size

The size of COTS is recorded as: juvenile (J), 5 cm or less; sub-adult (A); or adult (B), greater than 15 cm (Table 4). If no COTS are seen, then this column is left blank. When several size categories are seen, only the most numerous category is recorded in this column, and a note is made of the other size categories in the 'other' column.

Note. Juvenile COTS are not usually seen while manta tows.

Table 4. Size of COTS categories.

<i>Category</i>	<i>Size</i>
J	<= 5 cm
A	6 - 15 cm
B	> 15 cm

Live coral cover

Percentage cover estimates of live coral are made from the total tow path area observed during each 2 minute manta tow. Live coral refers to the living reef-building Scleractinian corals. This does not include the non-Scleractinian corals such as *Millepora*, *Heliopora* and *Tubipora*. Live coral is coloured by the presence of living tissue and can be easily recognised by its colour and the detailed structure of the corallites. The percentage cover estimates of live coral are recorded as one of 6 categories (Table 5).

Dead coral cover

Dead coral is defined as coral that is not covered by living tissue but still has distinguishable corallum structure. A 'newly' dead coral is easily recognised by its brilliant white colour. The white skeleton is then colonised by a succession of algal types, initially with turf algae giving the dead coral a dull, greenish/brown colour.

Eventually, coralline algae take over giving the coral skeleton a smooth pink appearance. By this time, the detailed structure of the coral skeleton is lost, due to the algal colonisers and weathering, and the colony is considered part of the substrate, or if fragmented, becomes rubble. The percentage cover estimate of dead coral is recorded as one of 6 categories (Table 5). *Note. Once a coral skeleton has become encrusted by coralline algae it is considered to be substrate and not dead coral.*

Table 5. Percentage cover estimates. For each category (except 0) a plus (+) or minus (-) is added to denote whether the cover estimate falls into the upper or lower half of each category.

<i>Category</i>	<i>Cover estimate</i>
0	0
1	>0 - 10%
2	11 - 30%
3	31 - 50%
4	51 - 75%
5	76 - 100%

Scars

Feeding scars are patches of recently dead coral easily recognised by their white colour (Figure 4). 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*, can produce feeding scars similar to those of COTS, however, COTS scars are distinguished by their large size and stark white colour. Feeding scars of COTS are recorded as absent (A), present (P) or common (C) (Table 6).

Table 6. Feeding scars.

<i>Category</i>	<i>No. of scars/2 mins</i>
Absent	0
Present	1-10
Common	>10

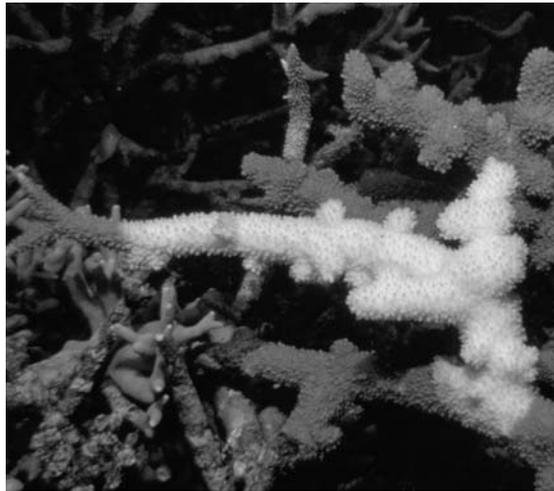


Figure 4. Acropora coral with distinctive feeding scar.

Soft coral cover

Soft corals, as their name implies, lack the hard limestone skeleton typical of scleractinian corals. There are many forms of soft coral, but in a manta tow survey we only look for the ‘fleshy’ soft corals, such as those from the families Alcyoniidae, Neptheidae, Xeniidae and Briareidae. Soft coral cover is also recorded as a percent cover category (Table 5).

Visibility

Water visibility estimates are recorded during the first manta tow and subsequently whenever the visibility changes. An estimate of visibility is made by diving below the surface and looking at the two floats attached along the tow rope at six metre intervals. Depending on how far the observer can see along the tow rope, 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 visibility is scored as category 4 and if the nearest float cannot be seen, then the visibility is scored as category 1 (Figure 5).

Table 7. Categories for estimating visibility.

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

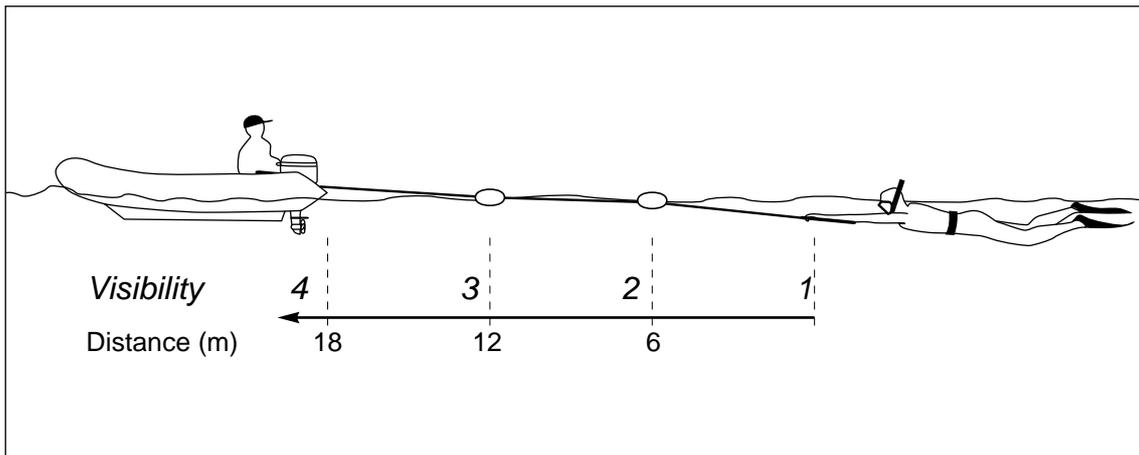


Figure 5. Visibility category estimates for manta tow surveys.

Other

The other column is for any observations such as the reef structure, slope, diversity, fish abundance, number of giant clams, coral mortality or any information required for the reef aesthetics sheet (Appendix IIa). Giant clams are counted for each tow. However if the observer feels clam counts may interfere with counting COTS, then a note should be made in the other column to say ‘no data’ for clams.

Reef aesthetics surveys

The reef aesthetics data sheet is designed to provide descriptive information about the reef slope. The data are obtained from the collective manta towers’ observations. The result is a qualitative impression of the reef’s topography and value (Appendix II).

Procedure

When recording the manta tow data the observer writes descriptive notes in the ‘other’ column on the manta tow data sheet that describe the reef slope and depict areas of change. At the end of the day’s work, these notes are used in conjunction with a discussion by the observers to form an overall impression of the reef. To help form this impression, a series of attributes have been devised to describe the reef. A category is assigned for each attribute from the description sheet (Appendix IIb) and recorded on the reef aesthetics data sheet.

Data recording

A reef outline is drawn on the data sheet (Appendix IIa) and is divided into four zones. For each zone, ten descriptive attributes are assigned to describe the area. Below this are four rows of boxes, each row corresponding to a reef zone. In each box a number or letter representing a category is recorded. See Appendix IIb for categories.

Zone

The zones, marked on the reef outline are labelled in a clockwise direction starting from the back reef (leeward side).

1. Back reef
2. Flank number 1
3. Front reef
4. Flank number 2

Reef slope

The reef slope is defined as the average angle of the slope in the zone and has been categorised as follows:

1. Shallow (0 - 20°)
2. Moderate (21 - 45°)
3. Steep (46 - 75°)
4. Vertical (76 - 90°)
5. Broken - If the reef edge is not well defined, or is made up of scattered bommies.
6. Back reef slope - Is described as having a steep upper slope and a shallow, sandy, lower slope.

Reef aesthetics

This is a subjective attribute based on the observer's judgement and experience of the relative merits of a reef. This value judgement should incorporate coral cover, diversity of life forms, fish life, reef structure and general appeal. Observers should take care not to allow the present weather conditions to bias their judgement when assigning this category.

1. Very poor
2. Poor

3. Average
4. Good
5. Very good
6. Excellent

Dominant benthic form

When determining percentage cover of hard coral during a manta tow survey the observer should note if a particular benthic form dominates an area. The dominant benthic form categories used to describe a reef are:

1. Hard coral - Scleractinia coral species
2. Soft coral - Alcyonaria species
3. Macro algae - Large, non-filamentous algae with a well-developed stems
4. Coralline/turf algae - All forms of encrusting algae and filamentous turf algae
5. Sand/Rubble - All unconsolidated substrate such as sand and broken fragments of coral and rock
6. Sponge - Porifera species

Dominant hard coral genus

If hard coral is the dominant benthic form in a zone, then it is broadly categorised as *Acropora* or non-*Acropora*. If hard coral is not dominant, or there appears to be equal dominance of *Acropora* and non-*Acropora*, then it is classified as 'no one coral genus dominant'.

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

Dominant hard coral form

There are eight coral life forms, which commonly dominate a reef slope. If there is no one dominant coral form, or if hard coral is not dominant, then it is recorded as 'no dominant form'. The coral forms are pictured in Figure 6 and are described below:

- B. *Branching* - consist of arborescent branches of variable thickness that have a common base. They are typified by the staghorn corals such as *Acropora grandis* and *formosa*. Other branching species include *Porites cylindrica* and *Seriatopora hystrix*.

- C. *Corymbose* - a growth form characteristic of *Acropora* where colonies are composed of horizontal branches and short to moderate vertical branchlets that terminate in a flat top, such as, *A. tenuis*, *A. valenciennesi* and *A. cerialis*.
- D. *Digitate* - a growth form of *Acropora* where colonies are composed of short, non-anastomosing branches like the fingers of a hand eg., *A. humilis* and *A. gemmifera*.
- E. *Encrusting* - have a prostrate, spreading growth form, that adheres to the substratum eg., *Mycedium elephantotus*, *Lithophyllon edwardsi* and many *Montipora* species.
- F. *Foliose* - are erect, with a flattened, leaf-like growth form that may be folded and convoluted, often forming whorls. This form can sometimes be difficult to differentiate from encrusting corals, eg., *Turbinaria mesentaria* and *Echinopora lamellosa*.
- M. *Massive* - have a similar shape in all directions (ie. spherical) and may form very large colonies, eg., *Favia lizardensis*, *Diploastrea heliopora* and many *Porites* species.
- S. *Submassive* - are typically robust but have a wide morphological range and do not easily correspond to any other life form category. Many branching or massive corals may become submassive especially in high energy zones of the reef, eg., *Acropora cuneata*, *Stylophora pistillata* and *Pocillopora meandrina* which have a knobbed or bushlike appearance.
- T. *Tabulate* - as their name suggests, tabulate corals have a tiered growth form consisting of horizontal, flattened plates, eg., *A. hyacinthus* and *A. clathrata*.

Live hard coral cover

Coral cover is determined from the median cover category estimate recorded by manta tow over the given reef zone. The categories are listed in Table 5.

Structural complexity

This is a subjective category designed to indicate the topography of the reef slope.

1. **Uniform** - a consistent, featureless area of reef, such as reef pavement, vertical drop-offs, flat, sandy, back reef areas or an area of staghorn coral.
2. **Mixed** - a variable reef slope that may be a solid edge interspersed with occasional grooves.
3. **Complex** - a very diverse slope that may consist of “spur and grooves,” caves, holes, overhangs or bommies.

***T. gigas* abundance**

The giant clam (*Tridacna gigas*), is easily observed and identified while manta towing. The number of *T. gigas* is recorded for each manta tow in the 'other' column on the data sheet. These counts are totalled for the zone and given an abundance category. If clams are not counted then a note should be made in the 'other' column.

0. None
1. 1 - 10
2. 11 - 25
3. 25 - 50
4. > 50

***Fish* abundance**

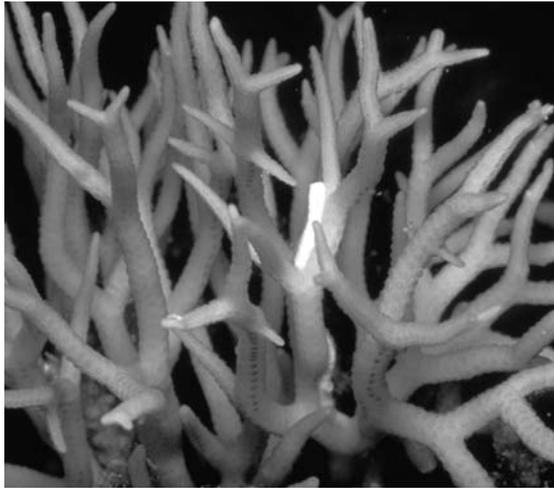
This attribute is an estimate of the total fish abundance over the zone. The categories are subjective and rely on the observer's perception and experience.

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

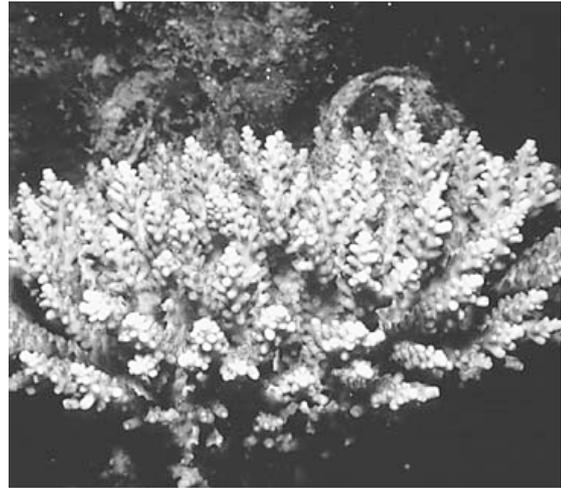
Coral bleaching

Coral bleaching looks similar to scars caused by COTS, as the corals appear brilliant white. 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. It is recorded as a percent cover category (Table 5).

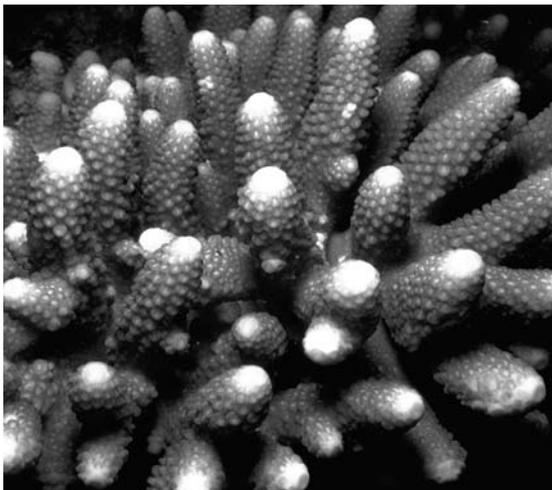
Figure 6. Dominant hard coral forms.



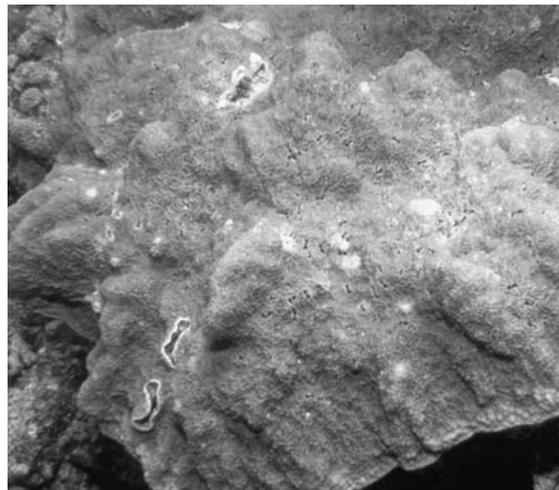
Branching



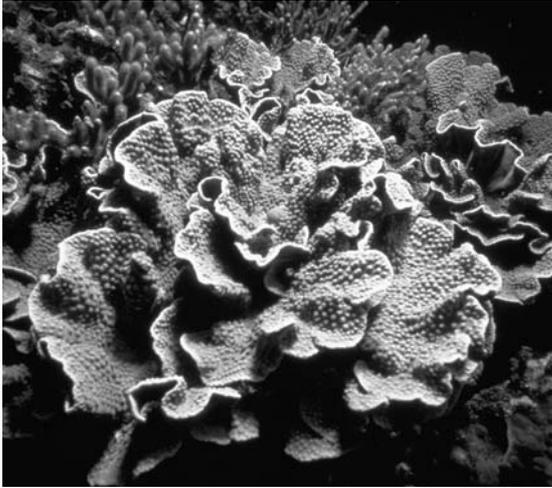
Corymbose



Digitate



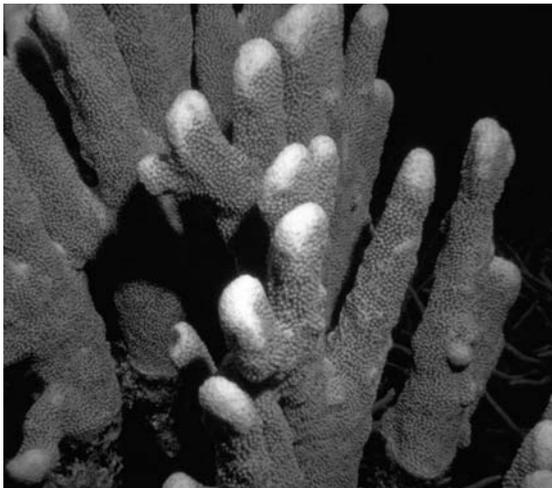
Encrusting



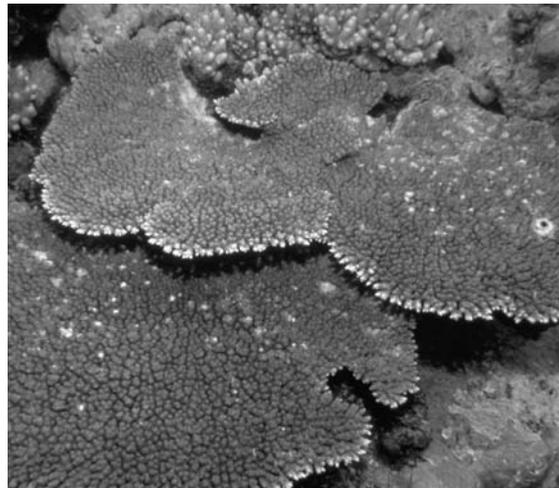
Foliose



Massive



Submassive



Tabulate

PART 2: SCUBA SEARCH TECHNIQUE

Technique

Introduction

SCUBA searches were used in conjunction with manta tow surveys to provide quantitative measures of abundance of COTS (Endean 1974, Kenchington & Morton 1976, Roads & Ormond 1971). More recently, SCUBA searches have been employed to investigate possible biases in manta tow surveys (Fernandes, 1990, Fernandes *et al.* 1990). SCUBA searches are used to examine the reef in greater detail than is possible with the manta tow technique. They provide important additional information for COTS surveys, enabling:

1. The detection of low densities of COTS, because they are usually cryptic and more difficult to detect using manta tow.
2. 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.
3. The diver to detect other factors that may be causing coral mortality such as *Drupella*, bleaching or disease (eg., white band 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). The detection of juvenile starfish provides a basis for understanding recruitment events and forecasting population increases. The aim of SCUBA searches in the Long-term Monitoring Program is to detect COTS and/or coral mortality that may not be visible by manta tow. Two methods of SCUBA searching are used, fixed and timed transects.

Fixed transect searches

Sampling procedure

The following section outlines the procedure for undertaking SCUBA search surveys for coral mortality on the long-term monitoring sites on the GBR. For a detailed description of the other surveys conducted on these transects see Halford and Thompson (1994) and Christie *et al.* (1996).

1. On completion of surveys of the five, 50 metre by 5 metre transects, the fish observer returns along the transects (which are marked with a tape along the centre line) counting Pomacentridae fish in a 1 metre wide strip up the reef slope from the tape.
2. The diver who lays the tape follows the fish observer winding up the tapes. At the same time, this person conducts a fixed transect search to look for coral mortality, the presence of COTS and *Drupella*.

Timed searches

Sampling procedure

1. Each reef is initially manta towed to select sites by the presence of feeding scars and/or COTS. These sites are noted during the manta tow survey and marked with a buoy. Upon relocating the site, the position is recorded using a GPS. Divers should search three to six sites on a reef if possible.
2. Ideally three divers each swim parallel to the reef slope along three separate depth contours (4 m, 8 m and 12 m). However, this will depend greatly on the topography of the reef slope. Where the slope is less than 12 m, divers should swim parallel to each other, (4 metres apart) covering the maximum practicable 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 should be examined to determine the cause of mortality, and observations are recorded on the data sheet (Appendix III).

Data recording

The data sheet is a table consisting of the following columns:

GPS/Transect

The number of the transect surveyed for a fixed transect, or the position recorded with the GPS for a timed swim search.

COTS

COTS numbers recorded as J, A or B, according to size criteria listed in Table 4.

COTS scars

The number of individual feeding scars attributable to COTS

Drupella

Individual *Drupella* species are counted.

Drupella scars

All feeding scars directly attributable to *Drupella* are recorded in this column. Searching near these scars may reveal an aggregation of *Drupella*. One feeding scar is defined as a contiguous area of recently dead coral on a colony.

Scars unknown

Any scarring where there is no obvious cause apparent.

Bleaching

The percentage of coral bleached along the transect is recorded as a category from 0 to 5 (same categories as used for the manta tow technique, Table 5).

Comments

Notes about coral mortality or health (such as black band and white band disease) recorded on the corresponding numbered line below the data table.

DATA MANAGEMENT

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

Data sheets

- Rinse underwater data sheets in fresh water and dry.
- Staple manta data sheets and reef aerial maps together.
- Re-number the tow numbers on the manta data sheet and the reef aerial accordingly to number continuously in a clockwise direction around the reef perimeter. The starting point is labelled as 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.
- Label each data set for the manta tow and reef aesthetics data with the same sample identification number* for a reef, starting at 001. A different sample identification number is assigned in sequential order to each repeat survey for the fixed (transect) or timed (depth contour) searches.
- Complete the reef aesthetics 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 *et al.* 1991.

* A sample identification number consists of a two letter code unique to each survey trip, followed by a three digit number starting at 001, eg. AC001. The numbering increments up to 099 and then continues again at 600. The scuba search data follow on in sequence from the manta tow and reef aesthetics data.

- The sample-id is entered for that reef and the 'sample data' (ie. 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.*
- The manta tow, reef aesthetics 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.
- Enter the last line of the data table and then run the data check before saving and exiting the table.
- Back-up the data to a disk.
- Unload the data from Reefmon to a disk and copy A:\REEFMON.MDB into the C:\REEFMON directory on the office PC to overwrite any existing data files.
- Print the data and check it against the data sheets. Make corrections in Reefmon, before exporting it as a comma delimited text file to the ORACLE database.
- Keep the checked printout on file as a record of data entry errors.
- File the data sheets together with the checked printouts.

TRAINING AND QUALITY CONTROL

Training new personnel

The AIMS manta tow technique while being relatively precise 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, standardisation 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 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. This is done by familiarising them with the historical development of the technique and how it is currently applied (Moran *et al.* 1989, Moran & De'ath 1992, English *et al.* 1994). A discussion with experienced observers to debate the advantages and disadvantages of manta tow as an ecological sampling method also helps to understand the technique. The second part involves showing slides and video footage of coral and other benthic cover to familiarise the new personnel with the different types of cover present on a coral reef. This includes discussion of common problems such as the definition of dead coral and how to estimate the appropriate cover categories (ie. live coral, dead coral and sand and rubble).

Field training

Initially inexperienced observers need to familiarise themselves with the practical aspects of being towed before recording data. Once they are happy with this, they are towed in tandem with an experienced observer on a 'double board' (Miller 1994) to learn how to record data. This enables the inexperienced observers to become familiar with estimating coral cover by comparing their estimates with the experienced observer over the same

area. This technique enables paired observers to recognise and compensate for any variations between their COTS counts and benthic cover estimates. Inexperienced observers should tow with different experienced observers to avoid personal biases.

Quality control

The precision of estimates is expected to vary between observers because estimates are influenced by a variety of factors (Moran & De'ath 1992). To obtain the most precise estimates and to detect 'drift' (defined as a consistent movement or difference in the direction and magnitude of bias between observers over time) between experienced observers an ongoing system of quality control is employed. This is done by 'double towing' selected reefs to give a measure of the variability between observers over a period of tows. Where problems in estimation occur (Miller & Muller, 1997) then observers are retrained using the two person manta board. This system is perceived to have a number of advantages:

1. It can detect problems with individual observers and groups of observers as they arise.
2. It provides a means where observers can compare their estimates in the field and form a consensus on cover estimation.
3. It provides an ongoing estimate of the precision of surveys as they occur in the field.
4. Because training is ongoing, problems in estimation can be identified and dealt with as they arise thus lessening the need for annual training of all personnel in the field at one time.

Procedure

To 'double tow' a reef, two boats are used, but instead of towing in opposite directions around the reef, the two boats go in the same direction. One boat follows about 100 m behind the other in a clockwise direction around the reef. Thus, each boat will drive around the entire perimeter of the reef resulting in two complete data sets. This procedure takes twice as long to survey a reef, so only reefs which are less than 30 tows are selected for double towing. A minimum of three reefs should be double towed each survey trip to allow each of the 4 observers to be compared.

1. Two pairs of personnel (A, B and C, D) begin to manta tow the reef. The second pair follow at about 100 metres behind the first boat.
2. After 15 tows, or after half of the total number of tows expected for the reef, the first pair (A and B) stop, and wait for the other pair (C and D).
3. The observers compare their cover estimates.
4. Observers and drivers from the same boat then swap roles. This procedure is continued until the whole reef is towed.
5. At the next reef, comparisons are made between different observers (boat pairs; A, D and B, C). The observers and drivers change combinations at each reef. In this way, each of the 4 people are compared to each other during a survey trip.

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APPENDIX I

Manta tow data sheet.

Reef Time DateCollectors

Wind Cloud Sea Tide

Re- No.	Tow No.	C O T		Coral Cover		Scars	Cover SC	Vis.		Other
		No.	Size	Live	Dead					
	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									

APPENDIX IIA

Reef aesthetics data sheet.

Reef Number of tows

Date Sample ID

Zone	Slope	Aesth	Benth	Genus	Form	Cover	Struct	T.gigas	#T.gigas	Fish	Bleach	Observers	
1	<input type="checkbox"/>												
2	<input type="checkbox"/>												
3	<input type="checkbox"/>												
4	<input type="checkbox"/>												

Comments

1 _____

2 _____

3 _____

4 _____

APPENDIX IIB

Reef aesthetics description.

Zone

1. Back reef
2. Flank #1
3. Front reef
4. Flank #2

- F. Foliose
- M. Massive
- S. Sub-massive
- T. Tabulate
- N. No dominant form

Reef slope

1. Shallow (0 - 20°)
2. Moderate (20 - 45°)
3. Steep (45 - 75°)
4. Vertical (75 - 90°)
5. Broken
6. Back reef slope

Live hard coral form

0. 0%
1. 1-10%
2. 11-30%
3. 31-50%
4. 51-75%
5. 76-100%

Reef aesthetics

1. Very poor
2. Poor
3. Average
4. Good
5. Very Good
6. Excellent

Structural complexity

1. Uniform (pavement, wall, sand, thickets)
2. Mixed (spur & groove, back reef)
3. Complex (many diverse structures)

Dominant benthic form

1. Hard coral
2. Soft coral
3. Macro algae
4. Coralline/turf algae
5. Sand/rubble
6. Sponge

T. gigas abundance

0. None
1. 1-10
2. 11-25
3. 25-50
4. > 50

Dominant hard coral genus

- A. Acropora genus
- C. A Non-Acropora genus
- N. No one coral genus dominant

Fish abundance

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

Dominant hard coral form

- B. Branching
- C. Corymbose
- D. Digitate
- E. Encrusting

Coral bleaching

0. 0%
1. 1-10%
2. 11-30%
3. 31-50%
4. 51-75%
5. 76-100%

APPENDIX III

SCUBA search data sheet.

SCUBA SEARCH SURVEY

Long Term Monitoring Project
Australian Institute of Marine Science

Reef Site Date Time Observer

G.P.S./ Transect	COTS	COTS (< 4 CM)	COTS (4-15 CM)	COTS (> 15 CM)	Drupella scars	Drupella scars	Scars unknown	Bleaching % category
5								
4								
3								
2								
1								

Comments

5 _____

4 _____

3 _____

2 _____

1 _____