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Surveys of benthic reef communities
using underwater digital photography and counts of juvenile corals

Long Term Monitoring of the Great Barrier Reef
Standard Operational Procedure Number 10

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Cover photo:
Diver capturing images to create 3D reconstructions for monitoring substrate complexity.
Photo Maren Toor

CONTENTS

TABLE OF FIGURES

1 PREFACE

The Australian Institute of Marine Science's Long-term Monitoring Program annually monitors benthic and reef fish assemblages and crown-of-thorns starfish populations and other agents of coral mortality (bleaching, coral diseases and Drupella). This is Standard Operational Procedure Volume 10, produced by the Long-term Monitoring Program (LTMP) at the Australian Institute of Marine Science (AIMS). It details the standard procedures for the use of digital photography to sample reef benthos along permanent transects, for image analysis and juvenile coral counts. Training protocols and data management procedures are also detailed.

2 INTRODUCTION

The main objective of the sessile benthic survey component of the LTMP is to monitor the status of coral reef benthic communities, and to detect and quantify major spatial and temporal changes in their condition.

Metadata records online describe the program and include references to changes in methods including the changes in cameras used to record transect data since the project started. https://apps.aims.gov.au/metadata/view/644db352-048b-4ac7-9a6a-d0cda30d1cde

The purpose of this Standard Operational Procedure document is to give an explicit account of the methods presently used by the LTMP at AIMS. This Standard Operational Procedure is also intended to act as a more general guide for other users who wish to use photography to monitor the benthic communities of coral reefs.

2.1 Photo transect technique

Temporal changes in benthic composition and abundance is key to understand long-term ecosystem trajectories as well as the effect of cumulative stressors. The photo transect technique is designed to record these changes and involves taking photos at regular intervals along the 50m transect then randomly selecting images from this sample for image analysis (Figure 1). Image analysis software developed at AIMS is used to identify what benthic organisms lying underneath a selection of points and this is converted to percent cover. Five fixed points per image, arranged in a quincunx, are identified to give a total of 200 samples per transect per year.

Figure 1. A diver taking photos along the transect on benthic surveys

2.2 Juvenile coral counting technique

The abundance of juvenile corals across space and time are the net result of reproduction, larval supply, settlement as well as pre- and post-settlement survivorship. Counts of juvenile corals are one method of monitoring and obtaining an early indicator of a reef's capacity to recover following disturbances.

3 PART 1 – USING UNDERWATER PHOTOGRAPHY TO SURVEY CORAL REEF BENTHOS

The following procedures are used by the LTMP as a standard survey method for sessile benthic communities using underwater still photography. They are specific to the objectives of the program but may be easily modified to satisfy other research objectives.

3.1 Personnel

A minimum of three people is required for the collection of sessile benthic data using this survey technique. One scuba diver is required to lay a tape measure along the centre line of each transect and a second diver to follow capturing images adjacent to the transect tape. The third person is required to remain in the boat as a divers' attendant and surface support. The preferred method of allocating tasks, particularly if there are new data collectors, is to split tasks within each site. One diver collects 3 photo transects and 2 juvenile/SCUBA search transects per site.

Benthic surveys are normally conducted by the LTMP concurrently with visual census surveys of reef fish, and scuba search surveys of the abundance of juvenile corals (see part 2), and agents of coral mortality, such as coral disease, the presence of Crown-of-thorns starfish (COTS) and Drupella spp., along the same transects. The procedures for these concurrent surveys can be found at https://www.aims.gov.au/docs/research/monitoring/reef/sops.html

3.2 Equipment

The following list of equipment is required for the collection of benthic data using underwater photography.

3.2.1 Field Equipment

- Handheld Geographical Positioning System (GPS) (WGS-84 datum)
- Surface marker buoy attached to a 20 m rope and drop weight
- Surface float and dive flag attached to 15 m rope with clip attached to leading diver.
- Five 50 m fibreglass measuring tapes (preferably in centimetre markings on both sides of the tape)
- Two complete sets of scuba diving equipment
- Waterproof carry case (for transporting camera in the housing to field sites) lined with neoprene layer to protect camera from bumps.
- 2 large waterproof carry cases:
    - one for camera containing:
        - Digital still cameras
        - Lens cleaning tissue
        - Lens cleaning fluid
        - Lens cleaning cloth
        - Memory cards (at least 3 SD cards each a min of 32 GB for camera)
        - 2 sets of camera batteries per camera
        - Battery charger and power cord for each camera
        - Appropriate download cable for camera
        - SD card reader
        - Camera manuals
    - and one for the underwater housing containing:
        - Underwater camera housing
        - Silicone grease
        - Housing manual
        - Spare batteries for leak detector inside housing
- QR code transect labels. These codes can serve as an identifier for automated sorting of images into transects but are also a more efficient labelling system for the diver
- Laptop
- Reefmon data entry software system
- External hard drive to back up images and data (2 x 4TB for each sampling year). Image sizes vary; however, one reef requires 5-8 GIG for transect photos with videos and approximately 10 GIGS for the 3D complexity photos.

3.2.2 Preparation of Camera Equipment

Instructions to prepare the housing and digital camera are given below. The AIMS LTMP is currently using Canon Powershot G7X mk II cameras and some of the camera settings described below are specific to this model.

Camera Preparation for Photo Transects

Ensure batteries are charged and images are deleted off SD cards before camera preparation. There are three SD cards that are used in rotation. This ensures that there is an extra back up of the photos for at least two days. Slide the battery cover open and carefully insert the fully charged battery into the camera. Check that the lens is free of dust or smudges and clean with lens cleaning tissue, lens cleaning fluid and a soft cloth if required. Turn the camera on by pressing the power button on the top of the camera and check the camera settings are correct for photographs and video.

Camera Settings for Photographs

1. Check all the icons in Figure 2 are displayed on the LCD screen on the back of the camera.
    a. In the top left of the screen "CTV" should be displayed. Use the 'mode' dial on the top of the camera to adjust.
        i. Use the shortcut dial (front of camera) to set the shutter speed to 1/125 as a minimum
    b. If the icons for the settings below are not displayed on the LCD monitor shown in Figure 2, press the SET button when the camera is in shooting mode and use the multi control wheel to scroll up, down, left and right to select the following settings. Figure 2 displays the back of the Canon G7X mk II.
        i. A quarter circle in front of the letter "M" (for medium image size and superfine resolution) should be displayed after the battery icon. This setting creates images of "3648 x 2432" pixels.
        ii. The flash icon has a circle with a line through it. This indicates the flash has been turned off. If this icon Is not present, turn the flash off by pressing the flash icon on the multi control wheel.
        iii. The metering mode should be set to "evaluative".
        iv. A fish icon (underwater shooting mode) should be displayed on the left of the LCD screen. On the G7X mk II the fish setting is found in the white balance menu.
        v. Set the ISO appropriate for the light conditions, preferably between ISO 100-800. For complex substrates, the aperture value should be f8 or greater, whereas for flat and less complex substrates the aperture should be at least f4. The aperture value appears when the shutter button is depressed. Note: If a red camera icon appears while the shutter button is depressed the lighting level is insufficient for the shutter speed that has been selected and the ISO should be increased.
2. Check that the Auto-rotate function is OFF. Press Menu in either the shooting mode or playback mode. Select the Set-up menu, then scroll down to "Auto Rotate" and select "OFF".

3. The review setting or drive mode on the camera can be altered depending on the preference of the benthic observer. Press Menu > my camera menu > review > scroll up or down. It is recommended that the playback of the image is either turned off (especially if the battery level is low) or set to playback for 2 seconds.
4. Turn exposure bracketing off.

Figure 2. Camera Settings for Transect Photos

Camera Settings for Videos

Turn the camera to movie mode and check the settings on this screen. Standard mode should be displayed, indicating video with a resolution of 1920 x 1080 pixels. The frame rate is set to 25 frames per second in PAL. If using a camera with the option of a higher resolution it would be better to use it.

Underwater Housing Preparation – Canon G7X Mk II Housing (Nauticam)

1. Ensure both sides of the housing window for the lens are clean. Use a lens cleaning tissue or the lens cleaning fluid with the soft lens cleaning cloth.
2. Remove the silicone O-ring from the underwater housing and closely examine it for nicks, scratches or other damage. If any damage is detected the O-ring should be replaced, otherwise clean the silicone O-ring and the O-ring groove with a lens cleaning tissue.
3. Apply a little silicone grease between thumb and forefinger and then run the entire loop of the O-ring between fingers several times to coat the entire surface with a film of lubricant. Carefully place the O-ring back into the groove without twisting or stretching and taking care not to place grease on the lens.
4. Switch on vacuum sensor within the camera housing. A blue light will appear on the indicator at the top of the housing.

5. Place the camera into the underwater housing. Mate the housing halves, ensuring that nothing is caught in between. Close the latch on the side of the housing by rotating clockwise.
6. To remove the air from the camera housing, unscrew the valve cover, place the pump over the red one-way valve. It usually takes three pulls of the pump to remove the air from the camera. The light will turn light green then dark green (Figure 3). Stop pumping once the light is dark green and screw cap back on. Ensure cap is firmly screwed on. The solid green light indicates the housing is sealed. To release after diving, unscrew the cap and push down the red valve button to release the pressure and turn off the switch inside the housing.
7. Take a test photo to ensure the camera has been correctly installed in the housing.
8. Place the housing in a non-air-conditioned environment to acclimatise for a short period of time. This ensures condensation on the lens is kept to a minimum. Transport in the tenders should be in a pelican camera case lined with neoprene. Before departure check that the light remains dark green. If this changes, there is an air leak and the housing will need to be depressurised, unmated and steps 1-8 will need to be done again.

Figure 3. Camera Housing Showing Vacuum Pump and Leak Detector

Pre-filming Checks

After entering the water, but before descending on each dive, ensure that the equipment is functioning properly.

1. Check the housing for leaks and check that the sensor light of the main housing is green. A habit should be made of occasionally looking inside the housing to check for leaks or condensation, particularly if the housing encounters any knocks or impacts.
2. Check the camera function buttons (i.e. On/Off, Mode dial and wheels for shutter speed and ISO adjustment).
3. Check that there is no condensation in the front lens port or the viewfinder. If condensation is present, delay filming until it disappears. If there is a leak, abort the dive.

3.2.3 Maintenance of Equipment Housing

After Every Use

1. Place the housing into the small waterproof camera carry case immediately after leaving the water.
2. Wash saltwater from the housing with freshwater, paying attention to controls and recesses around the O-ring seals. This is best done by submerging the sealed housing in a container filled with freshwater for as long as possible. Remove the housing from the water, then place under warm running freshwater. Depress the buttons on the housing and move the wheels before drying it with a clean towel. Leave the housing in a safe, clean, airy, salt-free environment to dry completely.
3. Open the housing by releasing the latch on the side of the housing. Carefully wipe any water on the mating surfaces of the two housing halves and leave to dry in a safe, clean, salt free environment. Turn off the leak detection switch.
4. Remove the camera battery and place it on the charger. Return the camera to a dry cracked waterproof carry case for storage. Always store the camera and housing to the carry case when not in use.

Regular Maintenance

1. Lubricate O-rings after a field trip.
2. All O-rings should all be replaced after 2 years regardless of the amount of use.
3. If scratches appear on the housing lens, discontinue use of the housing as it may affect the quality of the photographs

3.2.4 Equipment Storage

Camera

The cameras and housings should be stored in separate pelican cases to avoid saltwater contamination of the camera case. When not in the housing, store camera in a foam-lined waterproof carry case, in an air-conditioned environment. Carry cases should be closed to protect the camera but cracked to allow air circulation.

Housing

While the camera is in the underwater housing and it is being transported to the survey site, it should be stored in a closed waterproof camera carry case. Between dives the housing is best kept in a large freshwater-filled plastic container to reduce build-up of salt or corrosion. When the camera is not in the housing, the housing should be stored slightly open in a closed foam lined waterproof carry case, in air conditioning. If there is no air conditioning, use dry silica gel to remove any moisture and keep the housing closed.

3.3 Recording Photograph Data for each Transect

Any irregularities in data collection should be documented as these are likely to affect image analysis and data continuity. This includes changes in cameras due to malfunctions, known issues with transect locations, any change in the order or direction of photo collection. Details should be entered into the Reefmon comments field. These comments are transferred to the Oracle sample table (REEFMON_V_RM_SAMPLE) once the data is synched.

3.3.1 Panoramic Video

Panoramic videos should be filmed on the first and third transect at each site. Panoramic videos serve a visual record for the state of the reef in a given site and records broader scale features such as bommies, the reef slope and topographic complexity. To record the panoramic video, press the red button on the back of the camera to start and stop. Start the panoramic video by filming the QR code tag for three seconds so the site and transect can be identified, then bring the camera up to focus on the picket and tape until focus is achieved. Slowly film a 360-degree panoramic shot along the transect (showing the tape and star-picket) and then the reef surrounding the start of the transect, recording the video in a clockwise direction. The emphasis should be on recording the general structure of the reef, following the reef substrate at all times. Move slowly, holding the camera as steady as possible and the video should take at least 30-40 seconds for the best result.

Note: Avoid recording open water or a small area of the reef (<5 m radius) beneath you, as this may not represent the reef area. Also avoid sudden changes in the distances from camera to subject that will cause the image to be blurred, due to the time lag for the automatic focus to adjust.

3.3.2 The Transect

To photograph a 50 m transect it should take 41/2 to 6 minutes. The length of time required will vary depending on the topographic complexity of the reef and the water conditions, such as surge or current. It is important to pause while focusing, before taking each photograph as a sudden movement may cause the captured image to be blurred. When taking photographs ensure that a green square appears when the shutter button is half-depressed, before fully depressing the button to take the photo. A green square indicates that focus has been achieved. Failure to do this will result in blurred or unfocused images.

1. Turn the mode control dial to “Custom TV”. Take a photograph of the QR code tag for that transect.

2. Take a landscape reef shot at the beginning of each transect. This shot should be taken looking along the transect, so the star picket at the start of the transect is in the centre of the frame and the reef slope is visible (Figure 4).

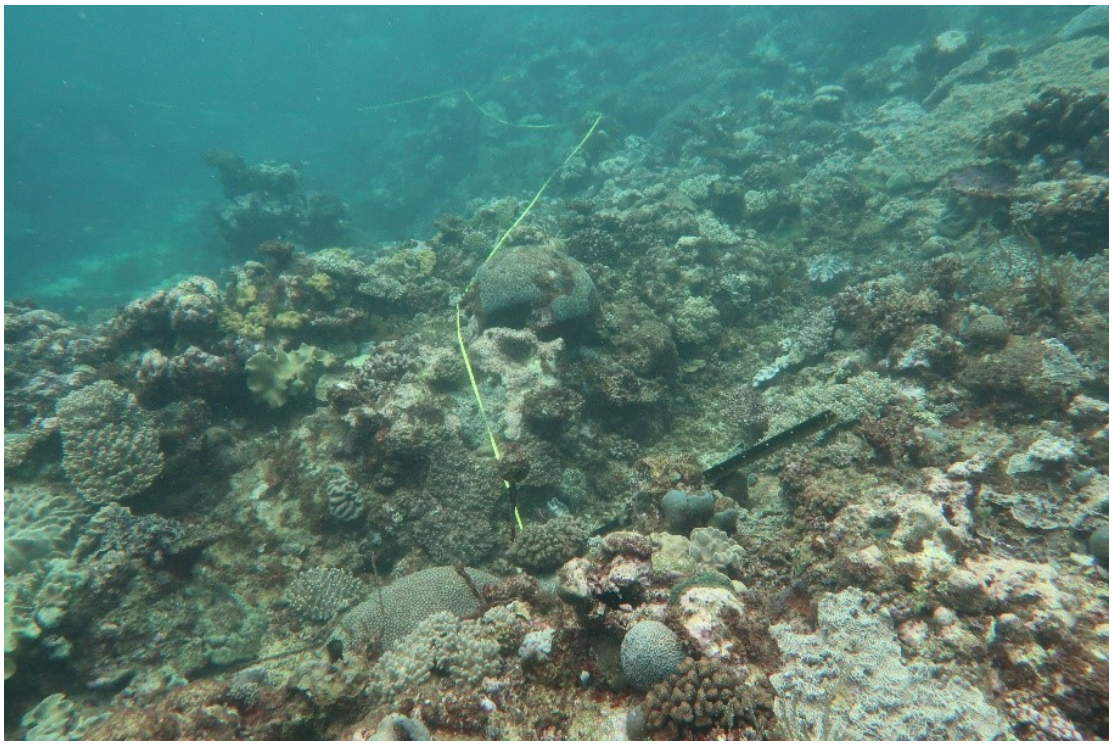


Figure 4. Landscape Reef Shot at the Beginning of a Transect

3. Ensure that the camera is held approximately 50 cm to the right of the star-picket and continue along the transect staying 50 cm to the right of the measuring tape. Make sure not to photograph the tape measure, as the reflective nature of the tape can adversely affect the exposure of the image. The camera lens should be kept parallel to the reef substrate at the same distance for each photograph. One way to determine the correct distance is to touch the substrate with your fingers and hold the camera so the lens alongside your elbow and take note of the distance between the camera and the substrate. Check your distance from the substrate at the beginning of several transects. The width of the image should be double that of a scale bar marker used for the 3D habitat complexity (Figure 5).
4. Follow the tape along the transect, taking photos at regular intervals. There should be approximately 75 photos taken per transect. That is, the gap between photos should be less than 1m, but photos should not overlap. Use the tape as a guide.

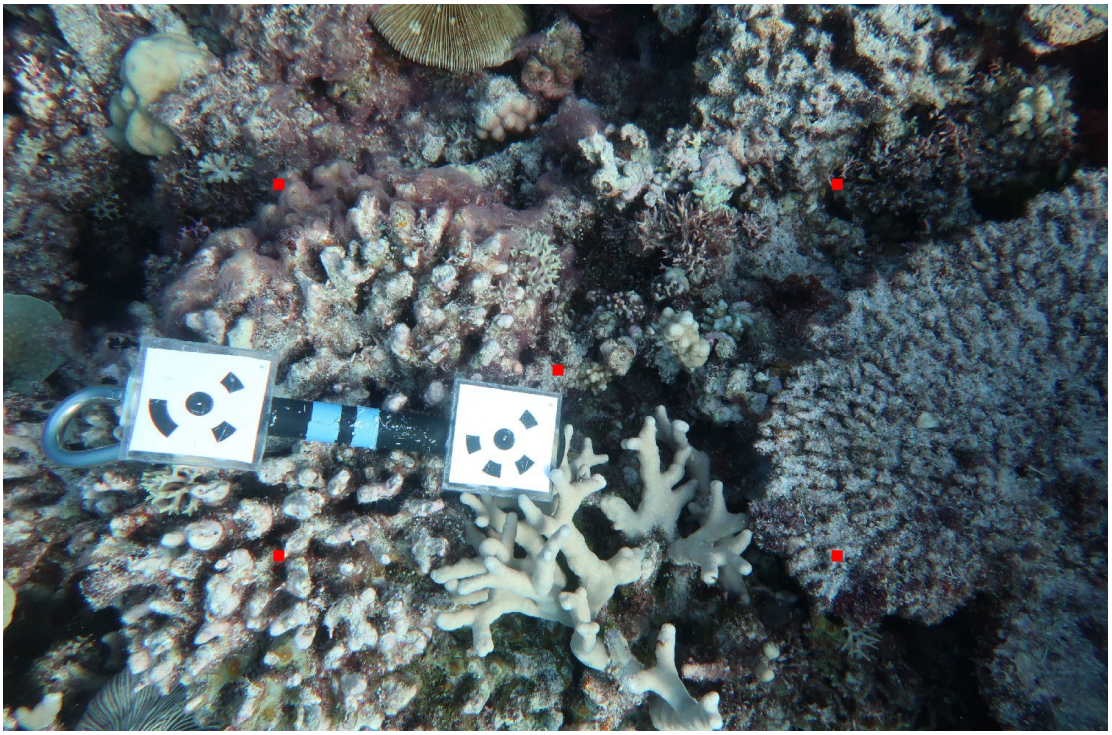


Figure 5. Photo showing correct image distance where the width of the photo (0.5m) is approximately twice that of the scale bar marker used for 3D habitat reconstruction.

3.3.3 Timing

On the Great Barrier Reef, it is recommended that photography takes place between the hours of 08:00 and 15:30 for best lighting conditions. These times can be extended during summer months.

3.3.4 Problems

The measuring tape that marks the centre of the transect does not always follow the contours of the reef, especially when there is a crevice or gap in the structure of the reef. If the tape does not follow the substrate, a decision must be made which determines the path to take with the camera. Deviation from the tape of up to 3 m is acceptable in order to maintain a constant distance from the substrate when taking photographs. With broad or deep crevices, it is not always possible to stay within 3 m of the tape and still have the camera at the standard distance from the substrate. In this situation remain at the same depth contour and cross the crevice at the narrowest point and resume photo collection on the other side. Do not photograph substrates that are more than 1m from the lens.

3.4 Data Management

Before going on a field trip check that the most recent version of the Reefmon data entry program has been loaded onto the field computer and it functions offline. The latest version can be found in: \\pearl\monshare\Database\programs\reefmon4

3.5 Downloading Photos and Videos from the Transect Camera to the Field Computer

1. At the start of each cruise go to the backup drive and copy the folder “copy this folder - rename with cruise code” and label the copy with the CRUISE_CODE.
2. Create a folder on the C: drive called “unsorted”
3. Create a folder for the current cruise code inside ‘unsorted’ and a folder for each reef.
4. Insert the SD card into the laptop and access it via File Explorer
5. Copy the photos and videos from the transect camera (G7XII) into the folder for the reef.
6. Select all the photos and right-click on ‘rename’. Rename the files by Reef name and visit number. eg Taylor_V28.
7. Open Reefmon and ensure that the database location is set to “LOCAL” and that the p_code, Visit_No, Cruise Code and Year_Code are correct as seen in Figure 6. Note: All four fields should have a value. If any are left blank, this will implications for the location of the photos when they are copied to the server.

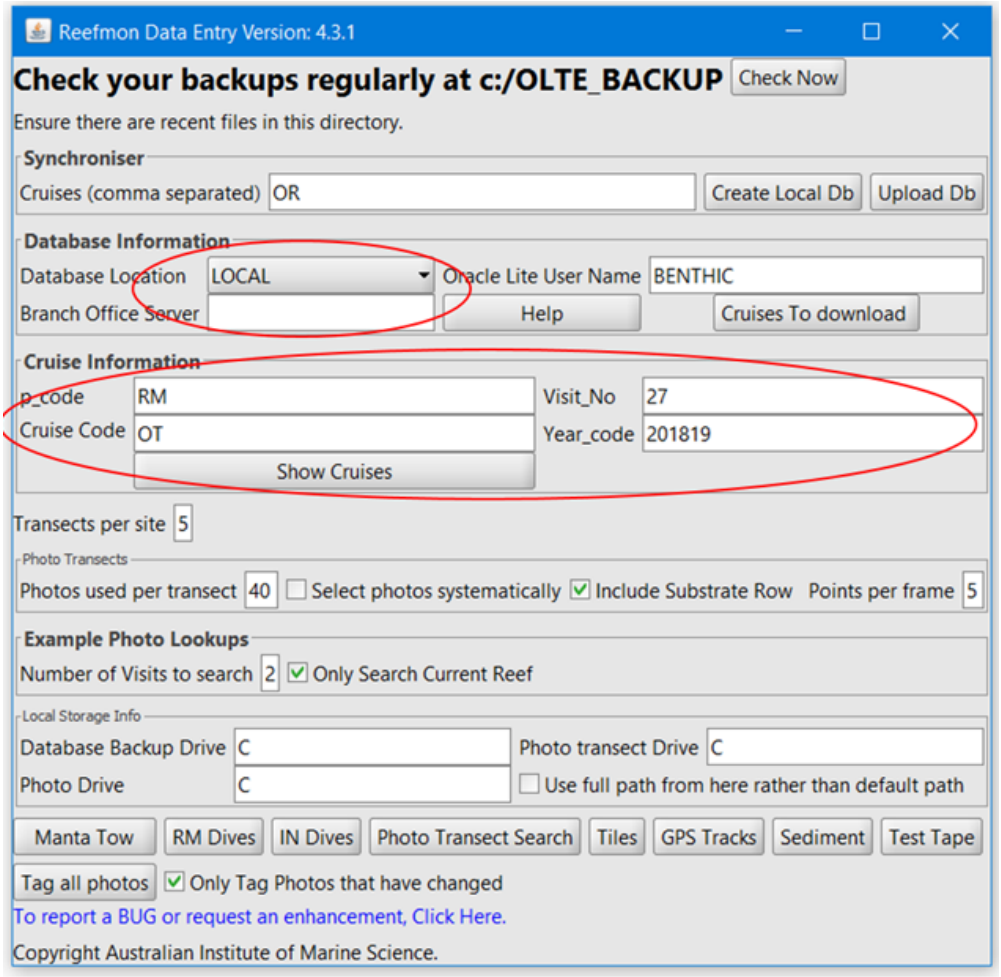
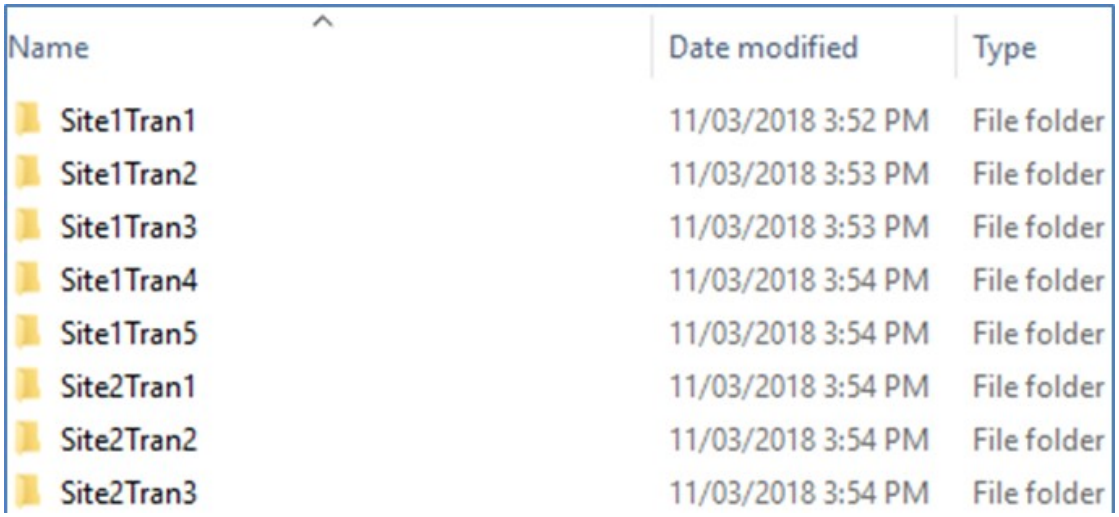


Figure 6. Reefmon data entry screen

8. Click on “RM Dives” (bottom left). Click on the “+” button in the bottom left of the screen to add a site record. Select the correct reef from the drop-down list and select site 1. Repeat for site 2 and site 3. Note: The sites must be entered in numerical order i.e. 1, 2 and 3, even if they were not surveyed in numerical order. This ensures consistent data entry among data types and smooth synchronisation to the server. Ensure the dates are correct as sites at one reef are not necessarily surveyed on the same day.
9. Click on the first site record for the reef then select “Data for one sample” then “Photo transects” from the menu at the top left of the screen.
10. Click on the “+” button in the bottom left of the screen to add a record for transect 1 adding the initials of the Photographer in the field OBSERVER. Repeat to add records for transects 2-5. Click on the “Make Directories” button down the left-hand corner, this creates the directories that the photos will be copied into.
11. Exit Reefmon.
12. Open the directories created using File Explorer. The directory paths will resemble C:\PhotoTransects\RM\201819\OO\BROOMFIELD REEF
13. Copy the photos from the ‘unsorted’ folder (do not CUT and PASTE) into the respective folders created by Reefmon. Copy the videos into the REEF level folder and name the videos to include the site and transect where the panoramic video was collected i.e. Broomfield_v28_S1T3.
14. Backup the REEF level folder to the Phototran folder inside the CRUISE_CODE folder on the hard drive. Check that each folder has the correct number of photos and that there are no empty folders. Also check that the contents of the folder have the correct Site/Transect labels on the QR code.
15. The contents of the folder ‘unsorted’ can be deleted if hard drive space is needed once both C:/Phototran and Backup:/Phototran have been checked.



Name	Date modified	Type
Site1Tran1	11/03/2018 3:52 PM	File folder
Site1Tran2	11/03/2018 3:53 PM	File folder
Site1Tran3	11/03/2018 3:53 PM	File folder
Site1Tran4	11/03/2018 3:54 PM	File folder
Site1Tran5	11/03/2018 3:54 PM	File folder
Site2Tran1	11/03/2018 3:54 PM	File folder
Site2Tran2	11/03/2018 3:54 PM	File folder
Site2Tran3	11/03/2018 3:54 PM	File folder

Figure 7. Folder structure created by Reefmon

3.6 Image Analysis

3.6.1 Transferring photographs and data on Reefmon to the server

1. After the field trip, connect the laptop to the AIMS network with a network cable and open Reefmon. Change the Database Location to “SERVER”. Use the “Synchroniser” panel to sync the data. Enter the Cruise code and then click “Upload Db”.
2. If there are differences between existing records, these will show up in a table (Figure 8). Press “update all local”.

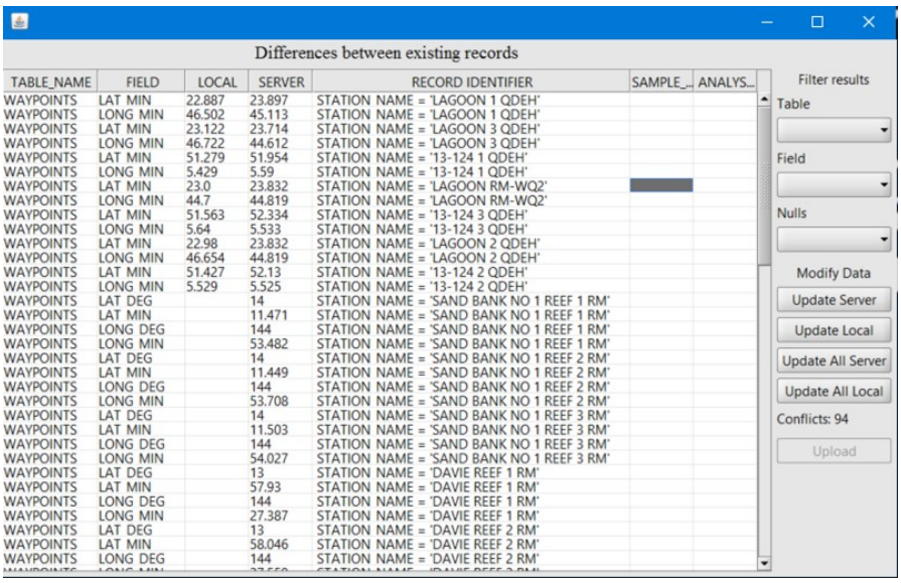


Figure 8. Differences between existing records

3. Once step 2 is done, or if there are no differences between existing records (Figure 9), the next screen will be displayed. Click on “Upload”.
4. This will generate a table showing the records uploaded (Figure 10). Click Ok.
5. In the next pop up window upload images. Press “Yes”. This will copy the images from the field computer to the server, using the same folder structure as Figure 10 for each reef.

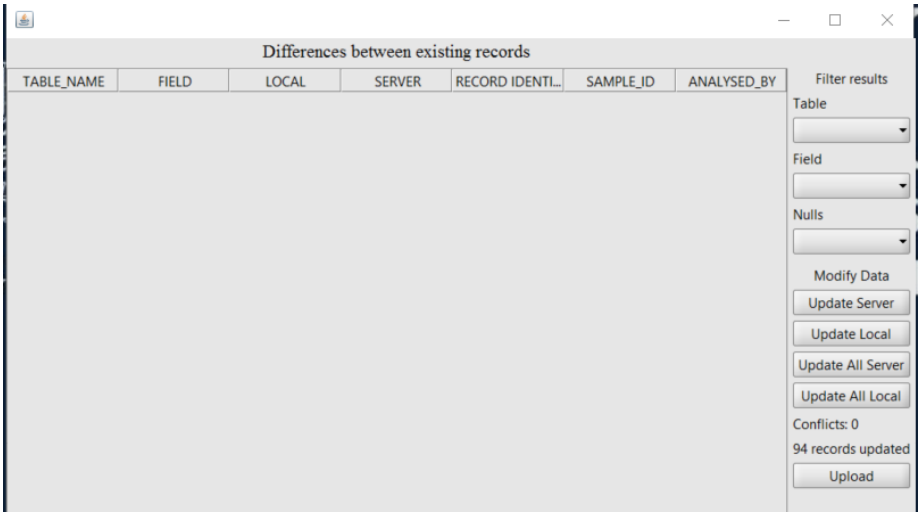


Figure 9. Screen with synchronisation resolved.

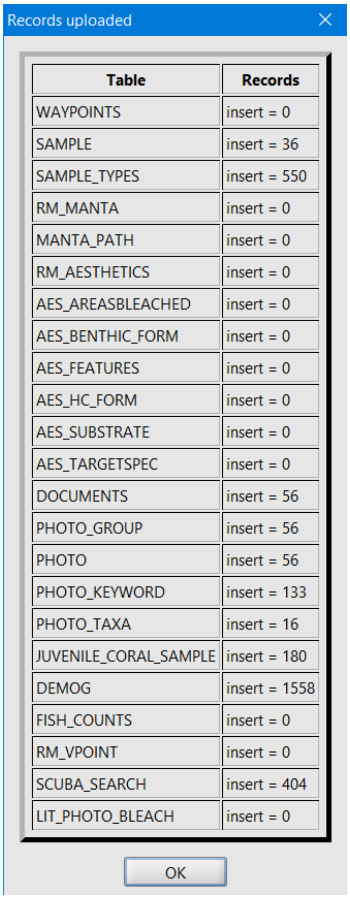


Figure 10. Records uploaded from data synchronisation

3.6.2 Automated Image Analysis

AIMS is constantly developing new approaches to amplify the capabilities of reef monitoring. Machine learning is currently being implemented as part of the regular protocol of benthic monitoring towards facilitating tools for fast tracking the status and trends of coral reef benthos derived from photo-transects.

A custom-made image classifier software (hereafter "the image classifier") has been developed at AIMS to automatically process all images based on a pre-trained convolutional neural network algorithm (sensu Williams et al 2019, Gonzalez-Rivero et al 2020). This classifier allows to rapidly identify benthic categories under each point in an image and breakdown images into patches to further advance the taxonomic identification of benthos under each point. A patch is cropped image using an around each point. Patches are individual sub-images from the original images collected in field that can be easily sorted based on the classification given by the automate image annotation.

Images can be processed through the automated image classification/analysis software once the images have been transferred to the server. This requires directing the software to the source of the images.

1. Open the Image Classifier app on your web browser http://tsv-apps.aims.gov.au/ic/.
2. Click on "View" on the right-hand side of the screen, then click on "Process Trip" (Figure 11).

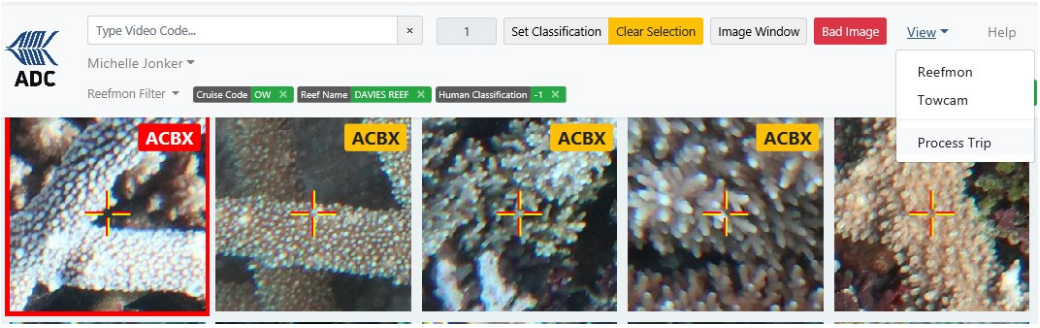


Figure 11. Screen with synchronisation resolved

3. Enter the number of photos a user would like to analyse (i.e. 40 images per transect). Enter the Cruise ID. Then press Process Cruise (Fig. 12).

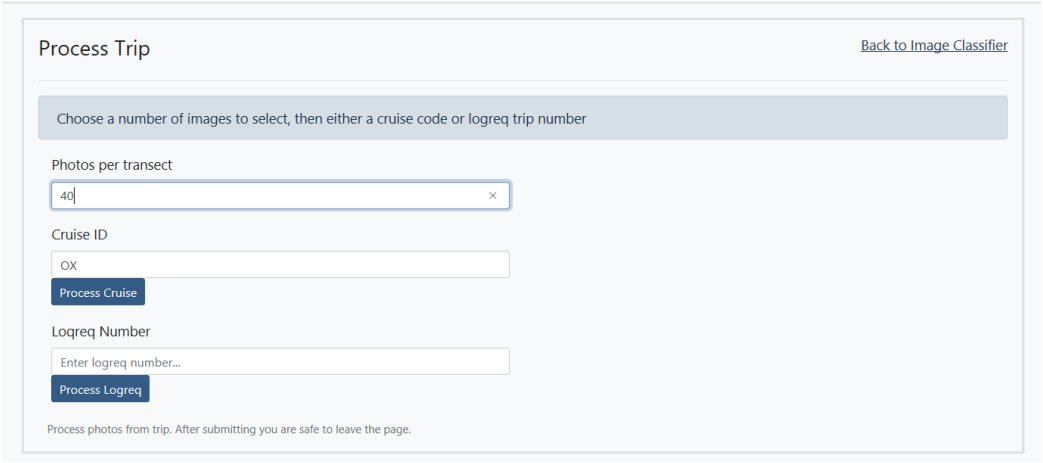


Figure 12. Initiate automated image analysis for the relevant Cruise Code using Image Classifier

4. You can close the web browser when the 'request has been submitted' (Fig 13).
5. Once the automated image analysis is complete, the images will appear when Image Classifier is opened in a web browser and will be ready for annotation, if required. The most recently processed Cruise ID will appear as the default filter for "Cruise Code". Liaise with the AIMS Data Centre if this takes more than a day

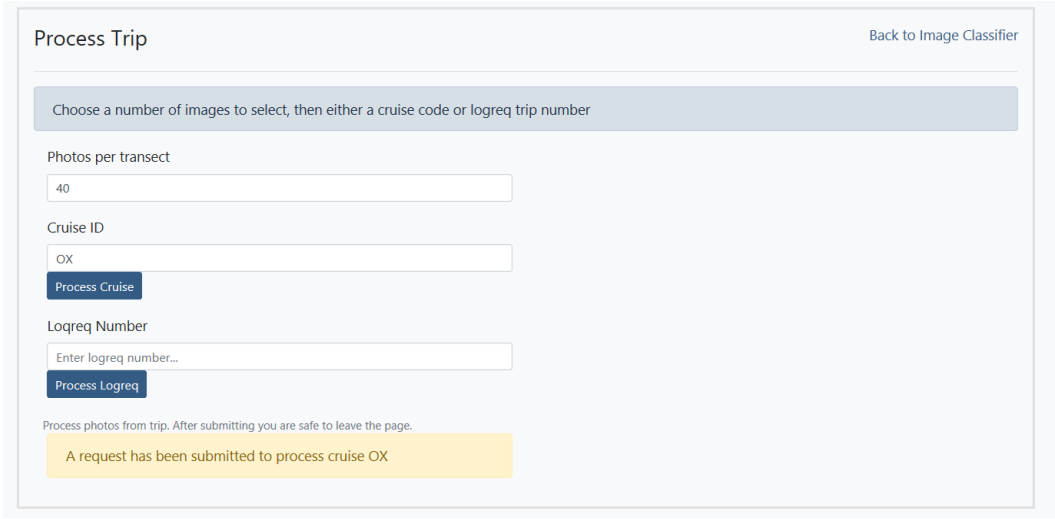


Figure 13. You can close the web browser once your request to process the cruise has been submitted

3.6.3 Set up of Computer Equipment

Image analysis is performed using a computer with internet access to the AIMS network and a large high-resolution screen. This was previously done in Reefmon software, which can still be used if transects need to be done without a connection to the internet. This requires images are stored on the PC. Information on how photo transect analysis is done in Reefmon was described in the previous edition of this SOP (Jonker et al 2008).

3.6.4 Photo Transect Analysis

Percent cover data is generated from the photo transects as the proportion of points assigned to a given label relative to the total number of points. The image classifier identifies patches from all the images. Each patch is labelled with the benthic code that the automated classification has assigned. The image classifier uses a subset of all possible codes, consisting of those that have historically been the most consistent since 1993, when images were still frames from video tapes and as such were of much lower quality (Appendix 11). A subset of patches is selected by the image classifier software that are also identified by a human observer. Forty images are randomly selected by the image classifier from all the images captured per transect. The image classifier displays five 'patches', per image each containing a fixed point for benthic classification. Each patch is displayed with a crosshair indicating the point to be identified.

This information can be used to train and improve the algorithms used in the automated image analysis.

3.6.5 Using the Image Classifier

This requires a computer and access to the AIMS network.

1. Login to the Image Classifier app from Internet Explorer http://tsv-apps.aims.gov.au/ic
2. The Image Classifier should be set to "Reefmon". This can be changed under the "View" tab on the top right side of the screen.
3. To filter the images, click on "Reefmon Filter" at the top left of the app. You can select filters such as the cruise code, reef name, site, transect, sector, shelf, project and the visit number, as well as the automated classification categories and the hierarchical structure of the human classification (Group, Family, Genus, Benthos, Video Code) (Figure 14). The patches can be sorted either by the classification category assigned by the automated classifier (and the statistical confidence of those annotations) or by the order of the images, and the 5 fixed points per image, taken along a transect.
4. There is a help menu on the right side of the screen that lists shortcuts. Bleaching categories can be assigned, patches can be tagged for easy searching, images can be viewed in full screen and the video code list can be searched.
5. Human classification of fixed points is assigned by typing the relevant video code for a selected patch (highlighted with a red border) and pressing the 'enter' key. A video code can be assigned to multiple patches by selecting all the patches, typing the relevant video code, then clicking on 'set classification' at the top of the screen.
6. Once analysis is complete for a set of reefs the data should be checked in "Checking" mode which is found in the "View" menu.

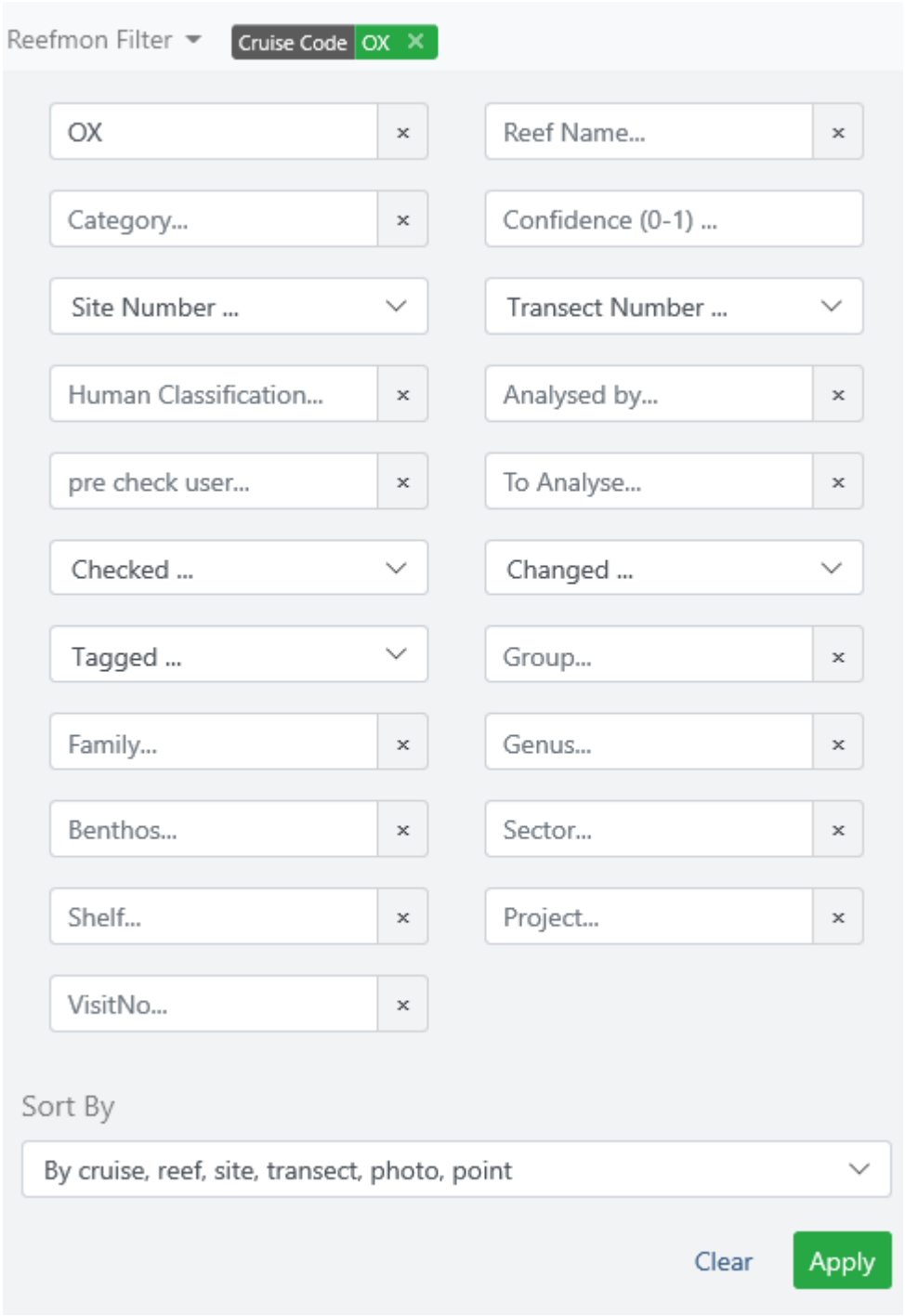


Figure 14. Image classifier filters

3.6.6 Codes Used in Photo Analysis

There are several thousand species of hard corals, soft corals, sponges and algae on reefs of the Great Barrier Reef. However, many cannot be identified accurately to species using only a photograph. Benthic organisms are assigned a unique code that describes the organism's family, genus or species combined with the life form. Hard corals should be identified at least to genus level, while for soft corals family is the minimum level. To simplify data entry each family, genera or species code and life form combination are assigned a numeric video code. Codes are structured in a hierarchy so that once data are entered, retrieval from the database can occur at different classification levels, benthic group,

benthic life form, family, genus and species. This also allows for changes in coral taxonomy to be incorporated. Updates are currently in progress but as of 2020 the codes reflect the taxonomy of Veron (1993).

There are nine groups, each of which can be subdivided into benthic life forms. The benthic group and life forms for hard corals were originally based on the ASEAN codes for the Line Intercept Transect technique (English et al. 1994) and are intended to reflect life history traits, in particular overall morphology. Lifeforms for soft corals and sponges are also morphology based. Sponge lifeforms generally follow guidelines described in CATAMI (https://doi.org/10.1371/journal.pone.0141039). Some categories are listed below to clarify how decisions are made where only photographic material is available. Benthic 'Group' level descriptions are depicted by '**G**:'.

G: Abiotic (AB) - This benthos group is used when there is no visible biotic life form present on the substratum. Sand (S) is the only code in Abiotic that is regularly used for LTMP analysis. Benthic codes within this group include:

Sand (S)- Ranging from fine silt to calcareous sediment to uncolonized, abiotic fragments <1 cm in diameter.

Dead coral (DC) - Recently dead coral that has a white or off-white colour and not yet colonised by turfing algae.

Rubble (R) - Fragments of dead hard coral >0.5 cm but <15 cm in diameter which are not consolidated into a hard or stable substrate and are not colonised by turf algae. This category is rarely used as it is unusual to see rubble without a living cover except where the reef has recently undergone exfoliation.

G: Hard Coral (HC) - All hard corals are assigned a benthic life form category. Life form categories are assigned to two sub-groups of hard corals: Acropora corals and non-Acropora corals. These are described below (adapted from Wallace 1999; Veron 1993).

Acropora corals - Growing parts of the colony characterised by an obvious axial apical corallite surrounded by radial corallites

Bottlebrush (ACX) - Colonies have small branchlets with both primary and secondary branching arising from main arborescent branches e.g. A. *echinata*.

Branching (ACB) - Colonies have both primary and secondary open branching, where branches are generally narrower than they are long e.g. A. *grandis*.

Digitate (ACD) - Short, protruding, vertically orientated digit like branches arising from an encrusting base e.g. A. *humilis*.

Tabulate (ACT) - Horizontal plates with a small area of basal attachment, where the colony is at least twice as wide as they are high e.g. A. *hyacinthus*. Tabulate colonies have limited secondary branching. Colonies with secondary branching but having a tabulate "shape" are labelled corymbose (ACO).

Encrusting (ACE) - Colonies adhere and encrust the substrate and have very little vertical growth e.g. *Isopora palifera* (This category is being kept for historical reasons or *Acropora palmerae*. *

Submassive (ACS) - Colony surface forms columns and/or ridges and may have encrusting edges e.g. *Isopora cuneata* (This category is being kept for historical reasons).

Non-Acropora corals - Growing parts of the colony not characterised by an obvious axial apical corallite surrounded by radial corallites

Branching (CB) - Arborescent corals with open primary and secondary branching where branches are generally narrower than they are wide e.g. *Seriatopora hystrix*.

Encrusting (CE) - Colonies with a thin layer of skeleton that covers the substrate e.g. *Pavona varians, Porites lichen*.

Foliaceous (CF) - Colony leaf-like in appearance or composed of flattened sheets which may be fused or convoluted to form whorls e.g. *Echinopora lamellosa*.

Massive (CM) - Colony is of generally solid construction and the same shape in all directions (hemispherical in shape) e.g. *Platygyra daedalea, Porites* spp.

Submassive (CS) - Colony has knobs, protrusions or columnar structures and more than 50% of the colony is raised indiscreetly from the underlying substratum e.g. *Scapophyllia cylindrica, Stylophora pistillata, Pocillopora damicornis*.

Mushroom (CMR) - Unattached easily moved solitary Fungiid coral.

Solitary (CL) - Attached or unattached solitary non-Fungiid coral e.g. *Cynarina lacrymalis* or *Scolymia vitiensis* or *Scolymia australis*.

Species codes

Hard corals should be identified at least to genus level. The species code consists of three letters derived from the genus name, followed by four letters derived from the species name, following a system developed for the ASEAN-Australia Living Coastal Resources project (English et al. 1994). Corals identified to genus are assigned a generic species code, eg. ACRSPP (Acropora species. Species that are readily identified in the photograph, such as *Diploastrea heliopora* and *Coeloseris mayeri*, can be assigned a seven letter species code, e.g. DIPHELI and COEMAYE respectively). Image quality influences species level identification and therefore, species level data is likely to be inconsistent.

G: Soft Coral (SC) - All soft corals including gorgonians (contrary to the ASEAN life forms (English et al. 1994)). Soft corals are identified to family level. Some soft corals can be identified to genus level consistently. Most soft corals have only one characteristic lifeform described in the LTMP code system.

G: Algae (A) - Algae are sub-divided into broad functional groups at the lifeform level; coralline algae, turf algae, macroalgae (an aggregate of further hierarchical groups) and an 'other' group.

Coralline Algae (CA) - This category includes all substrate and rubble covered with crustose coralline algae. Both colour and texture are used to visually discriminate CA from TA with coralline have a smooth, encrusting surface and often a pink or purple colour.

Macroalgae (MA) - Macroalgae are identified as having distinguishable structures such as fronds, stalks and holdfasts. Macroalgae from the brown, green and red algae families with

structural features, such as Sargassum, Caulerpa and *Chlorodesmis, Lobophora*, are included. Some macroalgae have encrusting life-stages that are recognisable and are classified as MA e.g. *Lobophora*. Algal assemblages where there are no clear basal algae are also included in this group. Macroalgae are identified to genus if possible.

Algal Other (AO) - This group includes cyanobacteria and golden noodle algae.

Turf Algae (TA) - Turf algae encrust the substrate and have no distinguishable structural features. Turf algae are usually short (less than 1cm in height).

G: Sponge (SP)- Includes all sponges (SP). Sponges are further classified by their lifeform.

Encrusting - Stretched over the substrate surface. Width is greater than height. This includes bio eroding sponges.

Hollow massive - Inhalants located on outside and exhalants located in central dip or hollow of the sponge.

Simple massive - Dome shape with similar height and width. Inhalants and exhalants on the same surface.

Erect branching - Height is greater than width. But colony has many branch-like structures.

Erect simple - Height is greater than width. May include massive, but not branching forms

Erect laminar - Erect and flattened body, but not encrusting.

G: Other (OT) - All identifiable organisms not placed in any of the above categories are given the group code Other (OT). Most (OT) organisms are given a more detailed species code, e.g. Anemones are given the species code OTHANEM and zoanthids, OTHZOA. If the organism identified does not have its own species code it is given the generic species code (OTHSPP).

G: Indeterminate (IN) - This benthic group is used for non-data points that are subsequently removed from percent cover estimates. Codes in this group are used for single points on an image, where all other points on the image are included data points. If the entire image is poor or unsuitable it should be discarded using the "Bad Photo" button. Examples of non-data points are water, very dark or bright areas where the substrate cannot be distinguished.

G: Seagrass (SG) – All seagrasses. Abundance of seagrass on LTMP survey reefs is very low and this category is rarely used.

3.6.7 Bleaching Codes

There are three bleaching categories used to record the bleaching status of the benthos identified under a point.

1. No Bleaching (NB) - This is the default code for this category and indicates there is no sign of bleaching under the point.
2. Partial Bleaching (PB) - Organisms are fluorescent in colour or not completely white. Soft tissue is still present in bleached colonies but may not be obvious on the image.

3. Bleaching (B) - Organisms are completely white or almost completely white. Soft tissue is still present in bleached colonies but may not be obvious on the images.

3.7 Training Others in the use of Underwater Photography

Training personnel in the use of underwater photography to survey reef benthos can be achieved by supervising trainees as they follow the instructions in this manual. Competency with underwater photography techniques requires familiarity with the still camera and housing, and proficiency in scuba diving (especially buoyancy control). Skill and consistency in taking photographs at a constant height and speed along the transect line is achieved through familiarity with using the equipment underwater, confidence and experience.

Training should cover the following components:

1. Preparation of the camera equipment
    a. Care and maintenance of camera equipment before, during and after field work.
    b. Operation of digital still camera and housing.
2. Sampling reef benthos using underwater photography technique
    a. Learning the correct sampling protocol.
    b. Practice to attain constant swim speed and camera position.
    c. Practice to choose best filming path along the transect line.
3. Data entry
    a. Use of the Reefmon database.
    b. Demonstrate proficiency in following protocols for photo sorting and storage.
    c. Sync data after field trip.
    d. Use the Image classifier.

Most of these objectives can be met by supervision of trainees in the field and the office.

3.8 Quality Control

To maintain data accuracy and confidence in both image interpretation and observer precision it is necessary to undertake quality control practices within the AIMS LTMP. Quality control is undertaken by a new observer before analysis of video transects and by all benthic observers through the data checking process completed for each set of photos.

3.8.1 Initial Training

To ensure data integrity is maintained when a new observer begins analysis, a new observer is required to complete three observer comparison transects from different habitats, and obtain 90% agreement at family level with existing observers before they begin analysing transects (Ninio et al, 2003).

3.8.2 Ongoing Assessments

To ensure data integrity each set of photos is cross-checked in the Image Classifier. Once all analyses for a trip are complete observers are assigned non-algal categories to check – this is completed in data checking mode so that all observers can revisit, learn and discuss any difficulties. Algae is checked on individual reefs to scan for data entry errors.

4 PART 2 – JUVENILE CORAL SURVEYS

AIMS commenced monitoring juvenile coral densities and distributions on inshore reefs in 2004, as part of the Marine Monitoring Program. The LTMP started juvenile surveys in 2007. Most recently AIMS WA commenced juvenile surveys in 2008.

Figure 15. A diver counting juvenile corals on benthic surveys

4.1 Field Procedure

This section outlines the procedure and alternative procedures for undertaking juvenile coral surveys. Logistical considerations such as the number and experience of the divers and their allotted tasks will often determine details on the most efficient way of carrying out the survey, while ensuring diver safety has been given due consideration.

1. Ensure the reef name, date, site and observer are recorded on the data sheet (Appendix V).
2. Searches for juvenile corals only occur within a small belt transect that is 5m (transect tape) by 34cm (length of the dive slate) on the right side of the tape.
3. Estimate the slope of the reef where the 50m transect tape lies. Repeat this for the slope where the 5m juvenile transect occurs so that you have a slope category at the photo transect scale and a slope category directly relevant to the 5m juvenile transect. The categories and angles are on the bottom of the juvenile coral datasheet (Appendix V). The broken category for slope refers to gullies and bommies interspersed with sand occurring in the transect. The slope categories are broad as their purpose is to recognise and record outliers, which may prove useful as an explanatory covariate in data analysis.
4. Categorise the complexity of the substrate (reef topography underlying the benthic cover) within the 5m juvenile transect area from 0-5. Categories generally follow descriptions in Polunin and Roberts 1993 and Wilson et al. 2007, though as they relate to the smaller spatial area surveyed. 0 = no vertical relief, 1 = low and sparse relief, 2 = low but widespread relief, 3 = moderately complex, 4 = very complex with numerous fissures and caves, 5 = exceptionally complex with numerous caves and overhangs (Wilson et al 2007).
5. Visually estimate the available substrate of the 5m x 34cm transect belt. Available substrate includes any type of benthos that coral larvae are likely to settle on and will typically be the combined cover of turf algae and coralline algae. Substrates excluded from the available substrate estimate are soft coral, hard coral, cyanobacteria, macroalgae, small loose rubble and sand.
6. Surveys are conducted for the first 5 metres of the belt transect, using the long edge of the dive slate (34cm) to guide the width of the transect belt. The observer should take a mental note of the tape position before they begin, so they know where to finish i.e. if the transect begins at the 0.5m mark of the tape, the observer should finish the survey at the 5.5m mark of the tape. If the first 5m contains more than 50% sand as substrate the juvenile observer moves to the first 5m section of tape where there is at least 50% hard substrate. Record the start position along the tape on the datasheet.
7. Even if transects are surveyed in reverse order, from transect 5 to transect 1, the area surveyed is still the same, so in this case it would be on the last 5m of the transect, on the left-hand side of the tape. When the tape does not follow the contour of the substrate the juvenile count should follow the contour of the substrate and adjustments made such that the area counted remains the same (5m x 34cm).

All juvenile corals up to 5cm in diameter are identified within the belt transect (Figure 16).

1. Using the transect tape, slate and pencil, create a 5cm-long reference mark on the slate and use it as a guide to judge the diameter of juvenile corals.

2. A waterproofed sheet of juvenile coral photo examples is available to assist with the identification of the coral genera. A photograph of the juvenile would also be useful to subsequently identify the coral.
3. Use the juvenile coral datasheet to record a tally for each hard-coral genus per transect (Appendix V). Search the belt transect including crevices and cryptic spaces.

Figure 16. Juvenile coral. The difference between the substrate and the juvenile hard coral is distinct in this image, as the smooth edge of the coral does not blend in with the substrate

Figure 17. Dead juvenile coral (*Turbinaria* spp.). Note the mucus covering the coral.

NOTE: Include bleached juveniles but DO NOT include dead juvenile corals (Figure 17) in the counts. Exclude remnants of corals from the counts, although If it is unclear if a small coral is a remnant or a juvenile, include it in the count. It can be quite difficult to tell the difference, so use the guidelines and images below.

4.1.1 Guidelines for Discerning Juvenile Corals from Remnant Corals

Fission and partial mortality generate small colonies that are not juveniles, but remnant adult colonies (Hughes 1980). Remnant colonies occur most commonly following crown-of-thorns outbreaks. Partial mortality of the coral can be a sign of a remnant colony (particularly damage around the colony periphery). Therefore, remnant coral colonies and injured juvenile coral colonies should be excluded from the juvenile counts. The following points outline guiding points to discern juveniles from remnant coral colonies:

1. Search the area surrounding the coral in question, looking for additional remnant colonies. For example, a collection of small Porites colonies, particularly with asymmetrical or poorly defined edges, can be a collection of remnants from one large colony that has suffered mortality (Figure 18). Alternatively, if the colonies are very small and round with smooth edges, while the surrounding substrate is heavily eroded, they are likely to be juveniles.
2. Check the area of attachment/colony perimeter and the surrounding substrate. If it has the same or very similar skeletal make up (Figure 19), which may be heavily eroded and/or covered in algae (Figure 20) it is most likely a remnant, so do not count it.

Figure 18. Remnant *Porites* spp. colony at the top centre of the image. This is easy to tell as the colony does not show the typical round appearance of an encrusting juvenile coral.

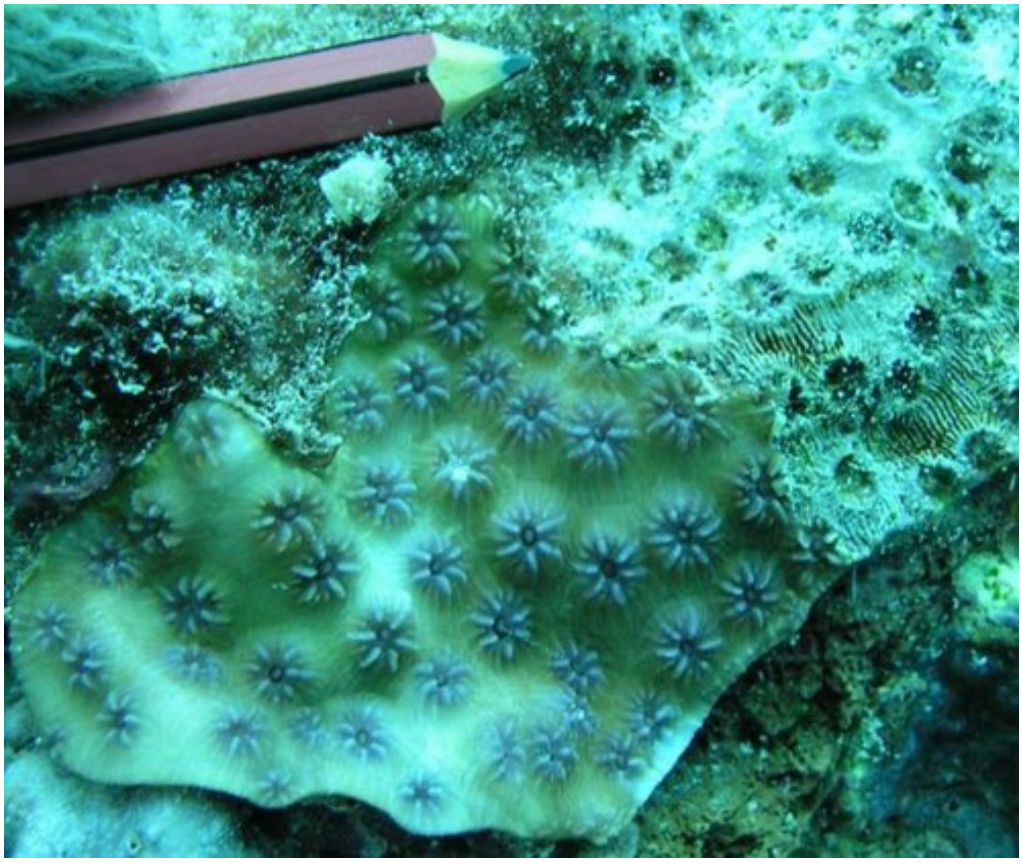


Figure 19. Remnant *Echinopora* spp. colony. On the upper right part of the image shows the detailed coral skeleton from partial mortality of the colony.

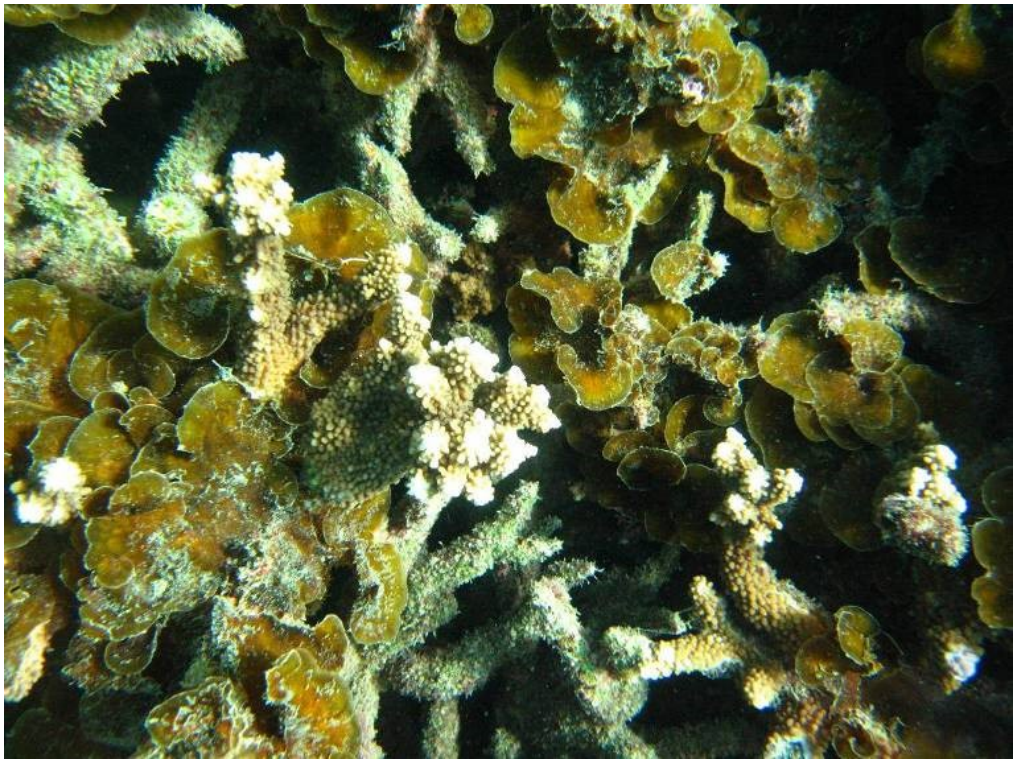


Figure 20. Remnant *Acropora* spp. colony, where partial mortality of the colony has occurred, leaving the framework intact.

Additional things you can look for to help identify juvenile corals:

1. Small corallites on the periphery
2. Encrusting forms of colonies or encrusting colony periphery for species that typically do not have encrusting growth forms as adults eg. Pocillopora damicornis, Seriatopora spp., Acropora spp.
3. Short branches compared to adult proportions (also useful for fragmenting species like Acropora nana and Acropora latistella)
4. Check if the juvenile is attached to the substrate by gently nudging it.

4.2 Reefmon Data Entry Program for Juvenile Corals

Ensure the latest version of Reefmon is on the computer and check the information for the trip is correct on the first page (refer to Part 4), then click on “RM dives”. The information for the reef and site number should be entered as per Part 4 of this document. Any irregularities in data collection should be documented in the site levels screen of Reefmon. Details should be entered into the Reefmon comments field. Relevant information includes missing samples, where sand has altered the start point, or if data has been entered under the incorrect SAMPLE_ID. These comments will be transferred to the Oracle sample table (REEFMON_V_RM_SAMPLE) once the data is synched.

Select the sample ID of the relevant reef and site in Reefmon. Click on the menu title “Data for one sample” and select “Juvenile Corals Sample. Enter the observer’s initials and estimates for the 5m transect slope, the 50m transect slope, complexity and ‘available substrate’. Close the frame.

Click on the menu title “Data for one sample” and select “Juvenile Corals”. Enter the transect number, coral genera and the number of juveniles for each transect. If no juveniles are recorded on the transect do not include this transect number. Close the frame and repeat the process for each site.

Photos of juvenile corals can be added to the database for each site on a reef. Go to the top bar and click on the “Photos” button. Then drag the photograph across to the “Other photos” bar at the bottom of the screen. Enter a caption and Keywords that will help identify the image when searching the database. Once synched all photos from a trip can be retrieved from AIMSCAPE using the search term CRUISE_(CRUISE_CODE) e.g. CRUISE_OX.

4.3 Checking Data

In the laboratory check the data with two personnel. The first person will read out the genera and tallies from the original data sheet and the second person will check these against a printout of the data from Reefmon. Any errors are recorded on the printout and changes are entered into Reefmon. The original data sheets and printouts are then filed. The same procedure also needs to be completed for the available substrate, slope and complexity estimates.

4.4 Training Others in the Identification of Juvenile Corals

Before training personnel to identify juvenile corals, it is essential that the trainee can identify all the relevant hard coral genera (and soft coral genera for the inshore MMP) for the area in which they will do field work, as the distributions of several genera do not occur on both the GBR and reefs in Western Australia.

The trainee should also be competent with underwater photography techniques, particularly with using the macro function, so that juvenile corals that cannot be identified in the field can be photographed and further examined in the laboratory.

Training should cover juvenile coral identification in the laboratory and in the field. Firstly, the trainee should read through and understand the correct sampling protocol outlined in Part 2 of this document. To assist the trainee to recognise and correctly identify juveniles, use images from photo collections e.g. Monshare/Benthic. These images should be scrutinised by the new observer and their identification should be recorded and then discussed with the trained observer. Once the experienced observer is confident with the trainees’ identifications, training in the field can begin.

In the field the new observer should first observe how an experienced observer conducts the searches for juvenile corals. The simplest method of training is to search for juveniles together and write the correct ID on a datasheet. Then swap so the new observer searches and records the ID. Photograph any juvenile corals that they have trouble identifying. The macro setting on the camera is best for photographing juvenile corals. All good quality photos should be identified and added to the image database in Reefmon.

4.5 Quality Control

To maintain data accuracy and confidence in observer identification and observer precision it is necessary to implement quality control practices within the AIMS LTMP. Quality control is undertaken by a new observer before participating in juvenile coral searches and by all juvenile coral observers on an annual basis.

4.6 Initial Training

To ensure data integrity is maintained when a new observer begins juvenile coral searches, the new observer will need to complete transects under supervision as outlined in the previous section.

4.7 Annual Training

To ensure data integrity, observer comparisons are conducted in the field on the annual training trip. The juvenile observers conduct a series of transects and quadrats along a 50 m tape. All observers mark the location of juvenile corals within a quadrat (35cm x 35cm) on waterproof paper. Observers also complete short transects (34cm x 5m) individually and compare their counts for each transect.

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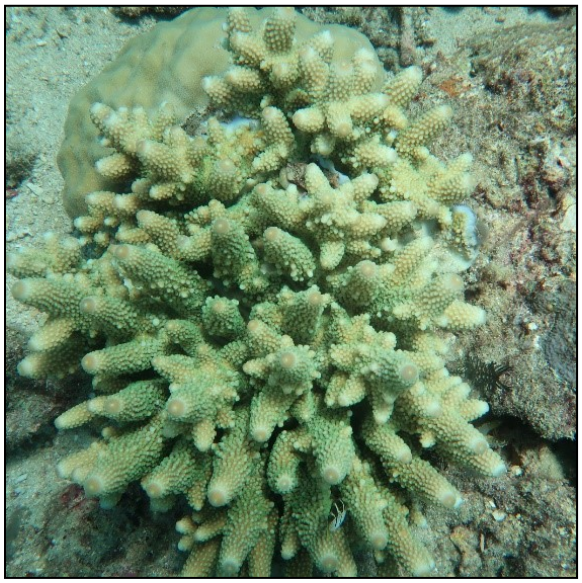
7 APPENDICES

7.1 Appendix I – Benthic Life Form Categories of Hard Corals

Bottlebrush *Acropora* (ACX)

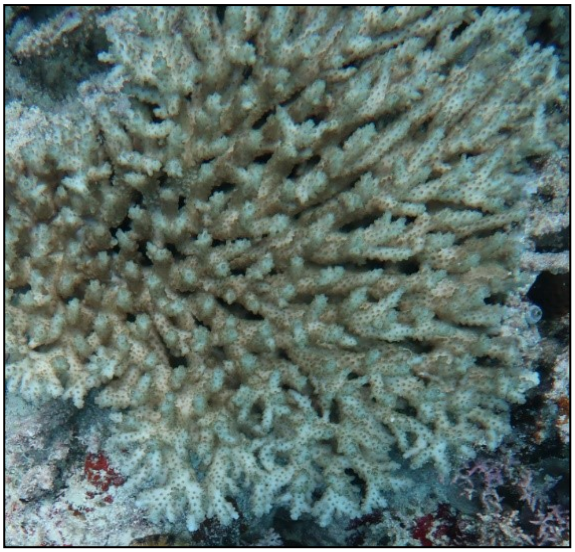
Branching *Acropora* (ACB)



Digitate *Acropora* (ACD)

Encrusting *Isopora* (ACE)

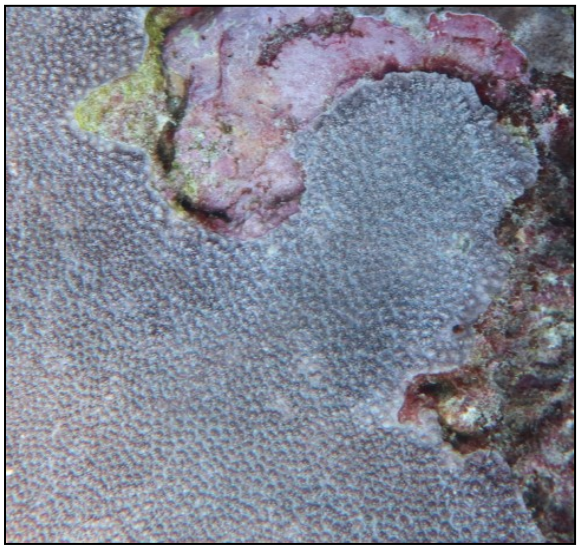
Submassive *Isopora* (ACS)



Corymbose *Acropora* (ACO)

Tabulate *Acropora* (ACT)

Branching non-Acropora (CB)



Encrusting non-Acropora (CE)

Foliaceous non-Acropora (CF)

Massive non-Acropora (CM)

Submassive non-Acropora (CS)

Mushroom Coral (CMR)

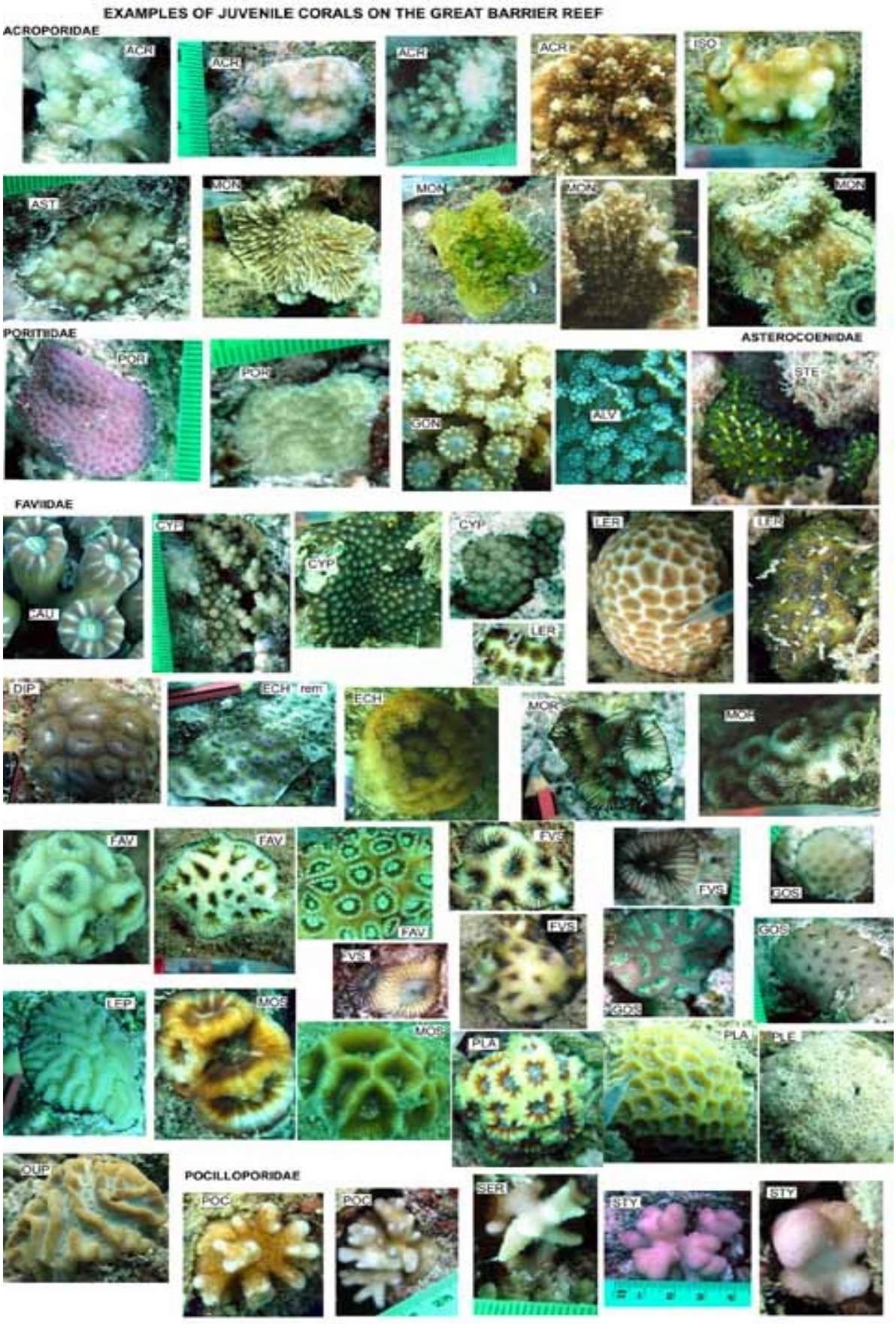
Solitary Coral (CL)

7.2 Appendix II – Image Classifier Codes Reference Table

GROUP CODE	BENTHOBOX CODE	DESCRIPTION
ABIOTIC	AB	Abiotic
ALGAE	CA	Coralline Algae
ALGAE	MA_BROWN	Brown Macroalgae
ALGAE	MA_GREEN	Green Macroalgae
ALGAE	MA_OTH	Other Macroalgae
ALGAE	MA_RED	Red Macroalgae
ALGAE	TA	Turf algae
HARD CORAL	ACBX	*Acropora* branching & bottlebrush
HARD CORAL	ACD	*Acropora* digitate
HARD CORAL	ACTO	*Acropora* tabulate & corymbose
HARD CORAL	COR_CBCF	non-*Acropora* coral branching & foliose
HARD CORAL	COR_CE	non-*Acropora* coral encrusting
HARD CORAL	COR_CMCS	non-*Acropora* coral massive & sub-massive
HARD CORAL	F_AGA_CEMS	Agariciidae encrusting & submassive
HARD CORAL	F_AGA_CF	Agariciidae foliose
HARD CORAL	F_DEN_CF	Dendrophyllidae foliose
HARD CORAL	F_DEN_CMCE	Dendrophyllidae massive & encrusting
HARD CORAL	F_EUPH	Euphyllidae
HARD CORAL	F_FAV_CEMS	Faviidae encrusting
HARD CORAL	F_FUN_CECF	Fungiidae encrusting & foliose
HARD CORAL	F_FUN_CMR	Fundiidae free-living
HARD CORAL	F_MUS	Mussidae
HARD CORAL	F_OCU	Oculinidae
HARD CORAL	F_PEC	Pectiniidae
HARD CORAL	F_SID	Siderastreidae
HARD CORAL	G_AST	*Astreopora*
HARD CORAL	G_ECH_CB	*Echinopora* branching
HARD CORAL	G_ECH_OTH	*Echinopora* other
HARD CORAL	G_GON_ALV	*Goniopora* & *Alveopora*
HARD CORAL	G_HYD_CB	*Hydnophora* branching & *Paraclavarina*
HARD CORAL	G_HYD_OTH	*Hydnophora* other
HARD CORAL	G_ISO_CE	*Isopora* encrusting
HARD CORAL	G_ISO_CS	*Isopora* sub-massive
HARD CORAL	G_MER	*Merulina* & *Scaphophyllia*
HARD CORAL	G_MON_CEMS	*Montipora* encrusting
HARD CORAL	G_MON_CF	*Montipora* foliose
HARD CORAL	G_POC_OT	*Pocillopora* other
HARD CORAL	G_POR_B	*Porites* branching
HARD CORAL	G_POR_CECS	*Porites* encrusting & sub-massive
HARD CORAL	G_POR_M	*Porites* massive
HARD CORAL	G_SER	*Seriatopora*
HARD CORAL	G_STY	*Stylophora*
HARD CORAL	S_POC_DAM	*Pocillopora damicornis*

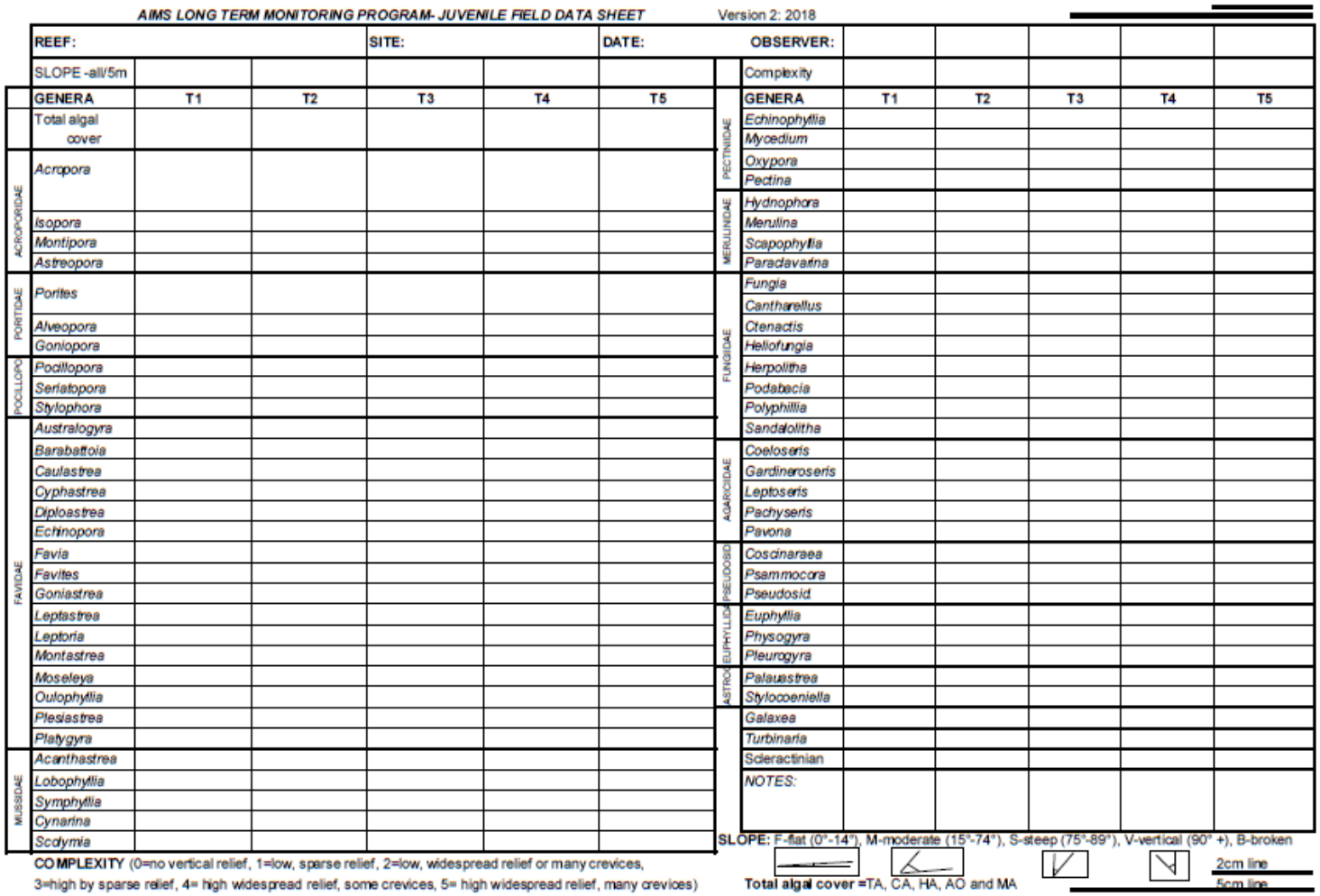
GROUP CODE	BENTHOBOX CODE	DESCRIPTION
HARD CORAL	S_POR_RUS	*Porites rus*
OTHER	F_MIL	*Millepora*
OTHER	OT	Other organisms
OTHER	ZOA	Zoanthids
SEAGRASS	SG	Seagrass
SOFT CORAL	F_SC_ALC	Soft coral Alcyoniidae
SOFT CORAL	F_SC_BRI	Soft coral Briareidae & Rhytisma
SOFT CORAL	F_SC_NEP	Soft coral Neptheidae
SOFT CORAL	F_SC_XEN	Soft coral Xeniidae
SOFT CORAL	SC_OTH	Soft coral Other
SPONGE	SP	Sponges & Ascidians

7.3 Appendix III – Examples of Juvenile Corals on the GBR




EXAMPLES OF JUVENILE CORALS ON THE GREAT BARRIER REEF- PAGE 2
AUSTRALIAN INSTITUTE OF MARINE SCIENCE
MUSSIDAE
LOB
LOB
LOB
SCO
SCO
ACA
ACA
MUS
CYN
SYM
PECTINIIDAE
ECL
ECL
PEC
PEC
PEC
MYC
OXY
OXY
OXY
OXY
HER
FUNGIIDAE
FUN
POD
POD
HEL
SIDERASTERIIDAE
COS
COS
GAR
PSA
PSA
OCULINIIDAE
GAL
AGARICIIDAE
PAV
PAV
PAC
COE
TES
DENDROPHYLLIIDAE
TUR
MERULINIIDAE
MER
SCA
HYD
EUPHYLLIIDAE
EUP
EUP
CAT

7.4 Appendix IV – Datasheet for Juvenile Coral Counts



AIMS LONG TERM MONITORING PROGRAM- JUVENILE FIELD DATA SHEET Version 2: 2018

REEF:			SITE:		DATE:	OBSERVER:					
SLOPE -all/5m						Complexity					
	GENERA	T1	T2	T3	T4	T5	GENERA	T1	T2	T3	T4	T5
	Total algal cover						PECTINIIDAE *Echinophyllia*					
ACROPORIDAE	*Acropora*						PECTINIIDAE *Mycedium*					
							PECTINIIDAE *Oxypora*					
							PECTINIIDAE *Pectina*					
	Isopora						MERULINIDAE *Hydnophora*					
	Montipora						MERULINIDAE *Merulina*					
	Astreopora						MERULINIDAE *Scapophyllia*					
PORITIDAE	*Porites*						MERULINIDAE *Paradavaina*					
							FUNGIIDAE *Fungia*					
	Alveopora						FUNGIIDAE *Cantharellus*					
	Goniopora						FUNGIIDAE *Ctenactis*					
POCILLOPO	*Pocillopora*						FUNGIIDAE *Heliofungia*					
	Seriatopora						FUNGIIDAE *Herpolitha*					
	Stylophora						FUNGIIDAE *Podabacia*					
FAVIIDAE	*Australogyra*						FUNGIIDAE *Polyphillia*					
	Barabattoia						FUNGIIDAE *Sandalolitha*					
	Caulastrea						AGARICIIDAE *Coeloseris*					
	Cyphastrea						AGARICIIDAE *Gardineroseris*					
	Diploastrea						AGARICIIDAE *Leptoseris*					
	Echinopora						AGARICIIDAE *Pachyseris*					
	Favia						AGARICIIDAE *Pavona*					
	Favites						PSEUDOSID *Coscinaraea*					
	Goniastrea						PSEUDOSID *Psammocora*					
	Leptastrea						PSEUDOSID *Pseudosid*					
	Leptoria						EUPHYLLID *Euphyllia*					
	Montastrea						EUPHYLLID *Physogyra*					
	Moseleya						EUPHYLLID *Pleurogyra*					
	Oulophyllia						ASTROCOE *Palauastrea*					
	Plesiastrea						ASTROCOE *Stylocoeniella*					
	Platygyra						*Galaxea*					
MUSSIDAE	*Acanthastrea*						*Turbinaria*					
	Lobophyllia						Scleractinian					
	Symphyllia						*NOTES:*					
	Cynarina											
	Scolymia											

SLOPE: F-flat (0°-14°), M-moderate (15°-74°), S-steep (75°-89°), V-vertical (90° +), B-broken

COMPLEXITY (0=no vertical relief, 1=low, sparse relief, 2=low, widespread relief or many crevices, 3=high by sparse relief, 4= high widespread relief, some crevices, 5= high widespread relief, many crevices)

Total algal cover =TA, CA, HA, AO and MA

2cm line

5cm line