

Standard Operating Procedures for repeated measures of process and state variables of coral reef environments

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The Coral Reef Targeted Research & Capacity Building for Management (CRTR) Program is a leading international coral reef research initiative that provides a coordinated approach to credible, factual and scientifically-proven knowledge for improved coral reef management.

The CRTR Program is a partnership between the Global Environment Facility, the World Bank, The University of Queensland (Australia), the United States National Oceanic and Atmospheric Administration (NOAA) and approximately 50 research institutes and other third-parties around the world.

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Product code: CRTR 002/2009

Editorial design and production: Currie Communications, Melbourne, Australia, September 2009.

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Acknowledgements

We thank the following individuals who either participated, provided support, facilitation or helpful comments in the development of these Standard Operating Procedures:

*Mehbrahtu Ateweberhan, Alasdair Edwards, Roger Green, Ed Gomez, Eric Jordán, Melanie King
Nancy Knowlton, Margareth Kyewalyanga, Yossi Loya, Miguel Angel Maldonado, Brian McArdle
Tim McClanahan, Christopher Muhandu, Pete Mumby, Juan Carlos Ortiz, Roberto Iglesias-Prieto,
Peter Sale, Paul Sanchez-Navarro, Gabrielle Sheehan, Robin Smith, Robert Steneck, Ali Ussi
Saleh Yahya, Assaf Zvuloni.*

We also thank the Herbert W. Hoover Foundation for providing funding to support the creation and management of a central database to be used by all CRTR Program locations.

I. Introduction

The Coral Reef Targeted Research and Capacity Building for Management (CRTR) Program is an international initiative designed to improve the knowledge base to help sustain the world's coral reefs for the future. The CRTR Program was conceived in 1998 to identify gaps in coral reef ecosystem knowledge and to establish more proactive (rather than reactive) approaches to environmental impacts. The main goal of the CRTR Program is to enhance current knowledge so coral-reef management is provided with improved options in managing risk.

The CRTR Program involves a network of over 70 international scientists representing more than 50 institutions worldwide, and is operating in four major world regions: Mesoamerica (Mexico); Southeast Asia (the Philippines), East Africa (Zanzibar) and Oceania (Australia) (Figure 1).



Figure 1. Four CRTR regions and locations of the Centers of Excellence

Within each region a Center of Excellence (CoE) has been engaged to enhance regional capacity for science-based management of coral reefs. The CoEs function as regional hubs, which create knowledge through research and training and disseminate information to an array of stakeholders, including local leaders and government, to facilitate informed decisions related to the use and protection of coral reefs. These regional hubs are in turn connected to the global network of scientists and institutions that serve as peer reviewers. These reviewers help synthesize the information at relevant scales, and strive to provide a source of credible and timely information about coral reefs to the public, and to local and national policy-makers.

Six thematic areas for targeted investigations were defined in consultation with managers and scientists around the world during the design of the CRTR Program. The themes serve as the technical foundation for the program and are defined as follows:

1. Coral bleaching and local ecological factors
2. Coral disease
3. Coral reef connectivity and large scale ecological processes
4. Coral reef restoration and remediation
5. Remote sensing
6. Modeling and decision support

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A key task of the CRTR Program is to improve the integration of information across scientific experts, regions, time and space (Figure 2). One of the most practical ways to do so is to demonstrate where CRTR Working Groups can collect and share data to strengthen potential relationships across scales of investigation, and to minimize the redundant and unnecessary collection of some data. Equally important, is to identify a core set of variables to monitor in each region, which will provide opportunities for interaction between Working Group members, Centers of Excellence and regional researchers. Thus, the establishment of monitoring locations in and around each of the Centers of Excellence, where a set of key process and state variables can be measured, is an important dimension and legacy of the CRTR Program.

Working group collaboration and integration of findings at each study location

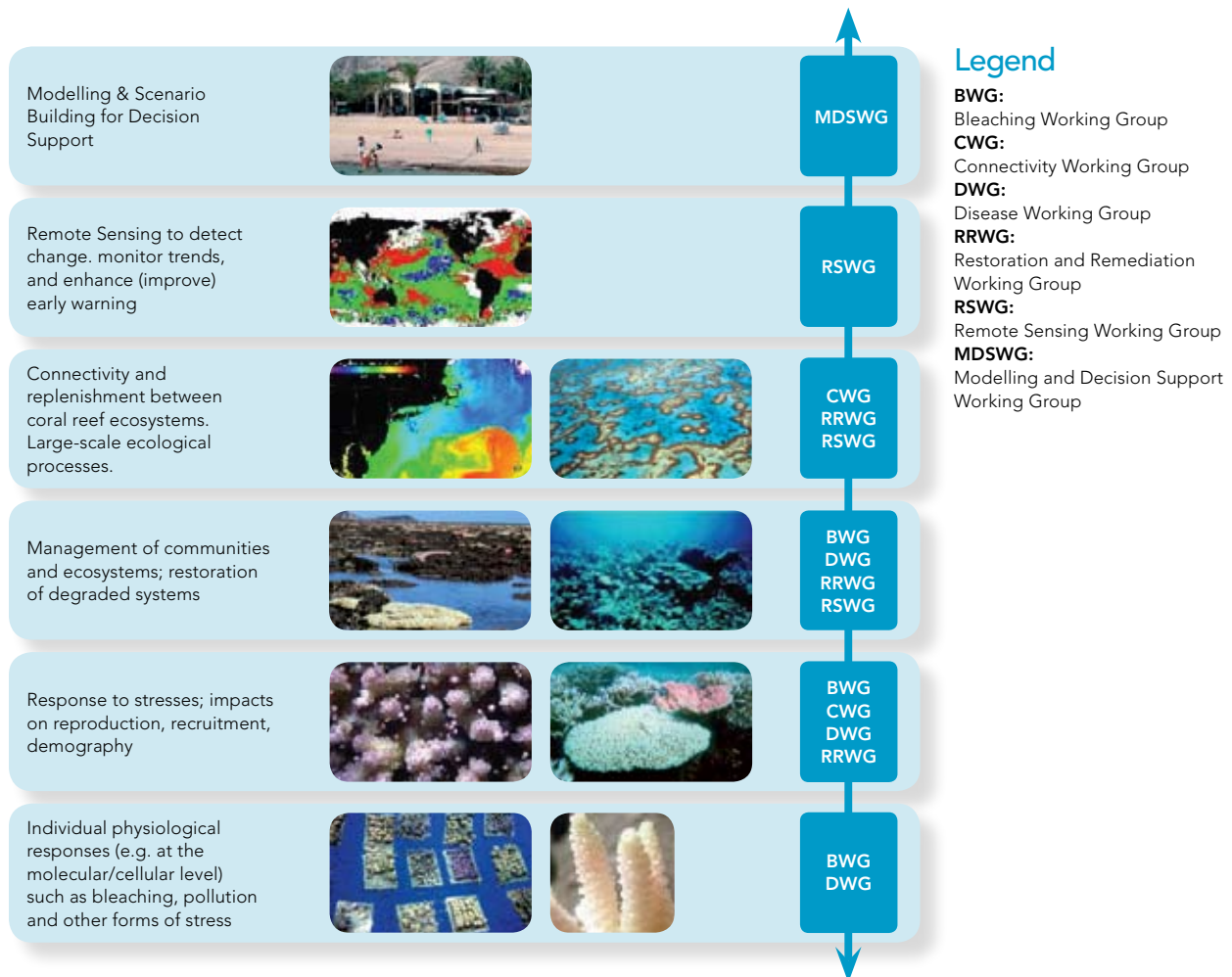


Figure 2. Potential for information integration between CRTR thematic areas and Working Groups. From molecular and physiological research, to organism, community and population dynamics, to seascape, regional and global levels, information can be shared across these scales to strengthen and apply new knowledge.

II. The ecological context

Most reef studies and monitoring programs examine the state variables (i.e. coral cover, macroalgal cover, size-frequency distributions) of coral reefs, by assessing the coverage of major benthic organisms; few studies examine the key ecological processes that drive these state variables. Processes of major interest include recruitment rates, individual growth rates, partial mortality rates of clonal organisms, and survival. We are also interested in macro-processes such as predation, herbivory, and oceanography and their influence. Understanding these key processes, assessing their spatial variation and their relationship with state variables will lead to predictive models of population trajectories, relative population size distributions, and community change under different climate change scenarios. Yet, key processes that drive community composition differ in accordance with regional settings, and possibly among localities within regions. Furthermore, the key processes that drive community structure and population dynamics may also vary in their influence depending on the spatial scale of observation.

There is limited information on process variables, especially collected in a similar, systematic manner. Thus, there is a pressing need to establish and evaluate, through repeated measures, processes at localities that may lead to comparisons across spatial scales over time. Indeed, the significance of processes may change over time. These Standard Operating Procedures present a standard approach with which to collect state and process variables at the various habitats in the vicinity of each CoE and other satellite locations. These methods are intended to be rigorous enough to make useful comparisons among localities, yet flexible enough to allow for different analytical approaches, within the CRTR Program. Development of Standard Operating Procedures will provide a means for other regions and research groups to adopt these methods, minimizing the variation in data collection and facilitate our interpretation and understanding of coral-reef dynamics. Therefore, the overall objective of this document is to outline a field protocol, within the auspices of the CRTR Program's network of scientists, which will allow comparisons of key *state* and *process* variables across three oceans.

III. Ecological field methods

The sampling strategy outlined below captures both state and process variables at a spatial scale of tens of kilometers. Our sampling units are randomly selected 75 x 25 m stations, spaced approximately 250-500 m apart, representing a 10^3 m spatial scale. Stations are nested within

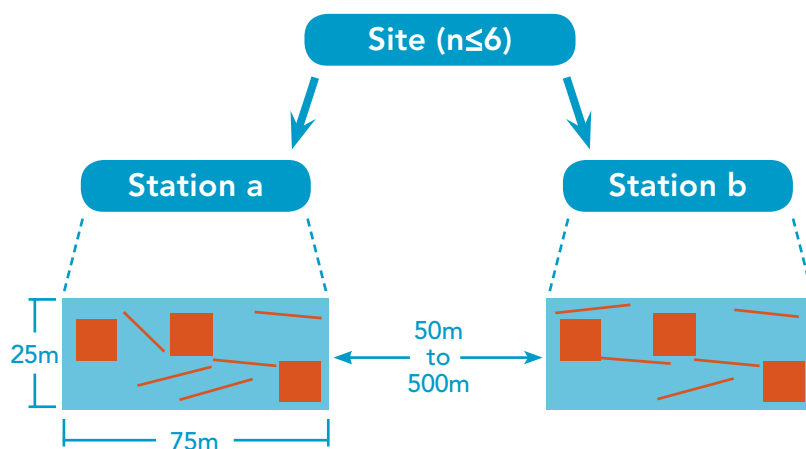


Figure 3. Hierarchical sampling design with three quadrats and five transects in each station and two stations nested within each site. (Robert van Woesik & Jessica Gilner)

growth, partial mortality, mortality etc.) across time (repeated measures design, see Figure 3). Both quadrats and belt-transects are effectively sub-samples from which we will derive estimates of means for each station at each sampling event (because the station is the effective sampling unit).

sites, which are spaced approximately 2 km apart, representing a 10^4 m spatial scale. In most cases we sample six to seven sites per location. Within each station we run at least five 50 m transects that are re-randomized at each sampling period, and used to estimate state variables (i.e. size frequency distributions, benthic composition, see Figure 3). Three randomly selected 16 m² quadrats are placed in each station, and marked for relocation purposes, and used to assess processes (i.e. recruitment,

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We focus sampling efforts to one depth zone (2-5 m) rather than stratifying the design by depth and reducing the spatial area to be sampled. We thoroughly appreciate that zonation is obvious on coral reefs (Darwin 1842), and hundreds of papers since Darwin's famous prose have quantified the differences among coral reef habitats (i.e. reef flat, crest and slope).

We are also cognizant of the fact that state and process variables may differ with depth. However, the variation in zones can be considerable – not only locally, but certainly regionally – and across oceans. Therefore, at the initiation of the CRTR Program in 2005, we focused our sampling efforts to one depth (2-5 m) across four locations; but this sampling protocol can be easily adopted on reef flats and deeper zones.

The methods described below can be executed from the same platform (e.g. if access to the site is remote and requires a collaborative and integrated approach to data collection) or sampling, as described in each of the following sections, can be executed separately (e.g. on different dates). Investigators should keep in mind the potential disturbance to benthic and pelagic species and should coordinate sampling to minimize impacts.

A. Coral demography methods

The coral demography field methods are designed to allow us to examine the driving forces behind changes in population structure and to investigate the composition of particular coral populations. Annual monitoring is conducted at approximately the same time of year.

Site selection and sampling structure

The sampling strategy captures state and process variables at each location, at a spatial scale of tens of kilometers. Sampling should aim to establish six to seven sites per location. Sites should be spaced approximately 2 km apart, with random stations nested within sites. Sites however should be systematically selected based on the targeted depth regime (2-5 m). Also, any sites that have ongoing studies for which there are historical data should be incorporated within the sampling. Sites must be selected as a representation of the habitat throughout the location. Once an adequate site is located, GPS coordinates are taken to aid relocation.

Two randomly selected stations should be established within each Site, whereby the station is the primary sampling unit. Each station will be approximately 1875 m², where actual dimensions should be considered 'plastic' and dependent on the survey environment. Stations are considered small enough to be located using GPS, yet large enough to examine fluctuations in population dynamics and key processes. Where the reef slope is steep, a station would be elongated, whereas for a flat-reef terrain the station should be approximately 75 x 25 m. Therefore, dimensions are plastic while the total area (1875 m²) must remain rigid. Once the stations are established, the boundaries should be permanently marked (e.g. GPS, or permanent markers where permitted) and then sampled and re-sampled strictly within the defined dimensions. Since each station is randomly defined within a site, the distance between stations within sites will vary from 50 to 500 m. Again, the effective sampling units are stations, each of which are sampled annually. Notably, a mixture of random transects and permanent quadrats will be used to quantify the targeted *process* and *state* variables (Figure 3).

Once stations have been established and marked if fishes are to be censused at the time of sampling, the very first sampling should be for large or cryptic fishes (or other larger, mobile species). Refer to Section E for details.

Data collection

Transects

Random-linear transects should be run using standard metric tapes to estimate state variables. At least five 1 m x 50 m belt-transects will be randomly placed in each Station. First, a line transect will be placed along the length of the Station (example: 75 m, if the station is 75 m long). Transects will be re-randomized during each sampling event. Excel® or another random generator should be used to randomly select transect location. Two sets of random numbers should be generated for each belt transect. Random numbers 1-25 and 50-75 m are generated which eliminates the middle area where a transect may not fit within the station dimensions. If the end result is too close to one edge, then the transect should be run in the opposite direction. The first being the starting point along the transect tape. The second number provides the distance one must travel at a 90° angle to begin the first transect (Figure 4). The belt-transect method quantifies the benthos as contiguous, and slightly overlapping (to create mosaics of 1 m² images).

- 1 Distance along 75m
- 2 Distance one swims at 90° angle from 75m transect
- ★ Starting point to run 50m transect

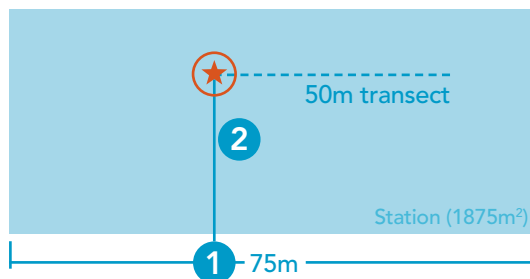


Figure 4. Randomization procedure used to place both transects and quadrats. (Jessica Gilner)

Equipment

1. Digital camera with an underwater housing, which will support an underwater wide-angle lens.
2. A 'frame' constructed to fit the chosen camera (Figure 5)
 - A frame is used to standardize the distance between the camera lens and substrate for all photos to provide scale. The frame is best made of PVC and Lucite, but can be constructed with any available material (e.g. aluminum, acrylic):
 - Camera must remain in the center of the quadrat, the images must capture the entire 1 m² quadrat area, but should be at the minimal distance from the substrate to ensure high-resolution photos.
 - Underwater housing must be equipped with a wide-angle lens otherwise the distance from the camera to the substrate is too great and resolution is lost.
 - **Frame construction:** The most durable PVC has been found to be schedule 40 grey conduit. White PVC causes considerable haloing and blurs the pictures, thus reducing image quality.
 - A minimum of 1" diameter PVC should be used.
 - The 1 m² quadrat should be constructed using eight sections
 - Note:** the exact length of each piece of PVC will depend on the couplers used, as couplers can add about 5 cm to total length.
 - The corners of the quadrat will be joined using elbow joints and the vertical pieces that join to the camera plate should be joined with T-joints.
 - The top of the frame should be also constructed with eight sections cut to a length that gives 40 cm total per side.
 - The exact lengths will depend on the type of camera and wide-angle lens chosen. For ease of transport, the legs can be cut in half and joined with a coupler, but keep in mind durability will be lost.
 - Centimeter markings (increments of 5 cm) should be made along the bottom of the frame for scale and calibration purposes.
 - **Camera bracing:**
 - A piece of 12.7 millimeter Lucite should be used to brace the camera to the PVC frame.
 - The Lucite should be approximately 40 cm x 20 cm using some type of a glass-cutter or a circular saw equipped with a glass cutting blade to avoid any cracking of the material
 - A semi circle should be cut in the center of one of the 40 cm sides to fit the camera.
 - Measurements should be taken to ensure that the lens fits directly in the center.



Figure 5. Example of camera-frame setup at Puerto Morelos, Mexico.

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Digital images provide permanent records of the reef state, and allow retrospective and comparative sampling. Furthermore, photo-acquisition increases the spatial coverage of the reef for any given field session, although deriving data from the photos may be slower than actually recording the data in the field.

Permanent quadrats

Permanent quadrats quantify the *process variables* (i.e., coral recruitment, growth and mortality rates, and herbivory). Within each station, three, 4 m x 4 m quadrats, should be established. The same randomization procedure used to demarcate belt-transect placement should be used for quadrat placement. Quadrat perimeters should be temporarily demarcated using PVC pipe or rope (Figure 6a and 6b). In locations where permitted, stakes should be placed at each corner of each quadrat, and one in the center. Quadrats should be photographed twice. First, using the camera and frame, and second, without the frame. Each image in the second round of photos should overlap by 70% with adjacent images. This technique is useful for mosaicing. Camera calibration (see Appendix A) will facilitate mosaicing.

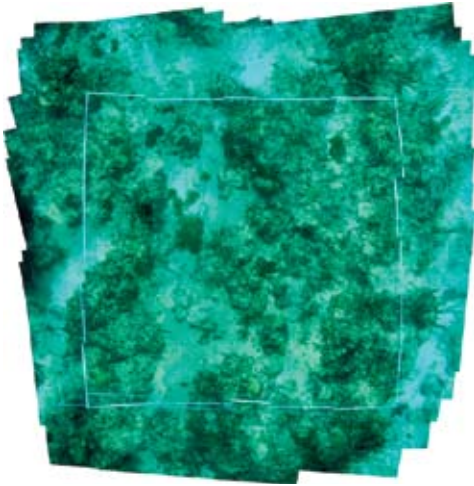


Figure 6a. PVC pipe was assembled underwater and used to temporarily demarcate the boundaries of the 4 m x 4 m quadrat. Make sure that all PVC is removed after field surveys. Photo: Jessica Gilner



Figure 6b. Here rope was used to temporarily demarcate the boundaries. Make sure that all rope is removed after the boundaries have been successfully marked. Photo: Rob van Woesik

B. Coral demography photo analyses

Digital photos should be analyzed using Sigma Scan Pro or ImageJ (both free software packages). Also, VidAna (developed under the auspices of the CRTR Program) can be used for determining percentage cover and area/perimeter ratios of quadrats and is freely available from <http://www.ex.ac.uk/msel>. A number of colonies will fall outside of the quadrat, yet within the photo, or a colony will take up more than just the 1 x 1 m quadrat, or colonies will fall along the edges with part of the colony within and part of the colony outside the quadrat. The best method to address these issues is to only identify and record coral colonies if their centers lie within the quadrat. There are considerable biases in popular and traditional sampling methods (e.g., quadrat, belt and line-transect) where size-frequency distributions suffer from boundary effects, yet the 'center-rules' method minimizes these biases and provides the most accurate size-frequency distributions. However, in regions where the 'center rules' cannot be used because of very large colony sizes, all colonies should be measured and the proper correction according to Zvuloni et al. (2008) should be applied to the dataset. Zvuloni et al (2008) provide an online supplementary Excel® spreadsheet that allows researchers to correct for biases. If these corrections are not applied then size-frequency distributions will not be accurate representations and the results will be unreliable. For our purposes, a coral colony is defined as a mass of continuous living tissue, rather than a structural mass. Corals should be identified to the highest taxonomic resolution (species where possible).

Size measurements

The maximum diameter of each section of continuous-live tissue, and the maximum width 90 degrees to the maximum diameter, will be a useful estimate of coral-colony size. The area of the colony should be estimated with the assumption that coral colonies generally take on an elliptical geometry (Loya et al. 2001). In the event of partial mortality within a coral colony, all tissue isolates, (i.e. areas that are not connected by live tissue) are to be measured using the same procedure and recorded as separate colonies. This definition is useful because it agrees with physiological examinations which have shown that tissue disconnection changes life-history functions. However, the tissue isolates will be noted using a colony ID to track ramets (fragments of a genotype) and genets (of the same apparent genotype). Within the database, all tissue isolates will be given the same genet ID code. (refer to section IV for details).

Partial mortality

Areas of enclosed partial mortality are straightforward to record, whereas areas of partial mortality that appear at the edge of a coral colony are more difficult to record. In the former case, the area enclosed by continuous live tissue should be measured by tracing around the perimeter of the dead area. In the latter case, and to ensure repeatability, measurements will be limited to a working definition of peripheral mortality: if 50% or more of the perimeter of partial mortality is in contact with continuous live tissue, then the area can be measured. If less than 50% is in contact with live tissue, then the area cannot be accurately measured.

Colony ID is used to link the partial mortality data sheet with the colony size datasheet. If a colony is intact, with no partial mortality, then the colony ID is labeled as a single number corresponding to that single measurement. If however, there is partial mortality that separates the colony into different live tissue isolates, then each isolate will be given the same colony ID, to distinguish small coral colonies from ones that are remnants of once larger colonies. Size-frequency distributions will then be constructed for each population, but ramet and genet contributions can be calculated, at least for the sampling period. Such estimates are useful because they identify rates at which ramets are being produced.

Benthic composition

To measure benthic composition, ten crosses can be randomly placed on a computer screen; or use the freely available CPCe, Coral Point Count with Excel Extension® program (available at <http://www.nova.edu/ocean/cpce/>). These random points will overlay each 1 m² quadrat. The organism or substrate type found directly under the cross, where the lines intersect (or point) will be recorded. Options include but are not limited to: CaCO₃ (with turf algae), rubble (<70 cm), sponge, zooanthid, gorgonian, coral, macroalgae, urchin, sand etc.

Step by step directions for Sigma Scan Pro

1. Open Sigma Scan Pro program. (Should have a tool bar at the top and an untitled data sheet at the bottom).
2. Open the desired image by clicking on the folder button on the toolbar or File, Open, Image.
3. Then go to Measure → Trace measurement options. (This will open the Trace Measurement Options dialogue box)
 - Now depending on what you are interested in measuring you need to select that parameter from the available measurements column and then click "add" at the bottom to move that selection into the active measurement column.
 - In the active measurements box there is a column (Col) area that indicates where the desired measurement will be recorded in the Sigma Scan Pro data sheet. This can be changed along with colors etc.
4. Once everything is set as desired click "OK".
 - For accurate measurements the image must be calibrated to a known scale in the photo.
5. Go to Measure → Calibrate Distance and Area. (This opens the Calibrate Distance and Area dialogue box)
 - Then select the 2 Point – Rescaling option.
 - Leave old distance as is and then change new distance to the known distance that is in the photos (ex: 100 cm for the edge of a 1 x 1 m quadrat).
 - In the X,Y and Distance Units box at the bottom type in the units of the known distance.
 - Click on the Image button in the Calibrate dialogue box.
 - This allows you to select two points on your image. (The ends of your known distance).
Note: The point is at the arrowhead.
6. Once the image is calibrated click "OK" on the dialogue box.

Measurement of maximum diameter and width

7. Scan the image for a coral colony by zooming in two to three times.
8. Then once a colony is located, identify the species and record on the data sheet.
9. To measure the maximum diameter, determine by eye the longest area of live tissue.
10. Then use your mouse and click on one side of the colony, then release and click on the opposite end of the colony, then right click. The measurement will be automatically placed in the Sigma Scan Pro spread sheet. Transfer this information to the data sheet.
11. The maximum width must be measured 90 degrees from the maximum diameter measurement. Use the same procedure to measure and record on the data sheet.

Measurement of partial mortality

12. The colony ID column is used to link the partial-mortality data sheet with the colony-size datasheet. If a colony is intact with no partial mortality then the colony ID is labeled as a single number corresponding to the single measurement. If there is partial mortality that separates colonies, each live-tissue isolate is given the same colony ID, but a unique code on the partial-mortality datasheet.
13. To measure the area using Sigma Scan Pro you will use the same trace tool used to measure maximum diameter and width.
14. Connect lines by left clicking at each perimeter's 'corner' until the entire perimeter is traced and then close the area, then right click to fill the area. The area measurement will be placed in the area column on the Sigma Scan Pro spreadsheet.

Measurement of benthic composition

15. Ten crosses (or points) will be randomly placed on a transparency or computer screen. These points (if on a transparency) will be placed over the computer screen showing a 1 x 1 m quadrat.
16. The organism or substrate type that is found directly where the cross lines intersect will be recorded.

Step by step directions for ImageJ

1. Open the ImageJ program, which can be downloaded as freeware from <http://rsb.info.nih.gov/ij/>
2. Select "File" then "Open" and navigate through the files to the folder containing the desired photos and select the individual photo.
3. Once the photo is loaded, it must be calibrated for further measurements. Here you must ensure that the photos are undistorted, which results from the wide-angle lens. PTlens® is a useful program to remove lens-related distortion for any given camera and lens: <http://epaperpress.com/ptlens/>
4. To calibrate the image, select the line tool from the toolbar menu. Then measure an area on the image of known length. Select "Analyze", then "Set Scale". The distance in pixels of the area you just measured will be given, then type in the known distance of that measurement. Calibration for future images loaded in the same Image J session.

Measurement of maximum diameter

5. To measure maximum diameter and width use the straight-line tool. Click on one end of the coral colony, and drag to the other end, and then let up. To get the measurement go to "Analyze" then "Measure" and it should pop up in a separate window. Once the measurement is visible ensure that it makes sense. For example, does a colony that takes up half of the quadrat measure at 50 cm?

Measurement of partial mortality

6. To measure partial mortality, use the freehand selection tool. Click and trace around the desired area. To obtain the measurement again select "Analyze", then "Measure" and record on the data sheet.

Measurement of benthic composition

7. Ten points (crosses) will be randomly placed on a transparency. These points will be placed over the computer screen showing a 1 m² quadrat. The organism or substrate type that is found directly where the cross lines intersect will be recorded. Options include but are not limited to: CaCO₃ (with turf algae), rubble (<70 cm), sponge, zooanthid, gorgonian, coral, macroalgae, urchin, sand and other invertebrates.

C. Coral recruitment methods

Ultimately, the data collected will provide the means to predict population dynamic parameters for coral-reef species. Understanding those populations that are successfully recruiting, and those that are not is the first step in determining which coral populations will be the winners or losers. Therefore, the number of recruits is a key parameter in determining the persistence of coral populations.

It is critical to identifying the working definition of a recruit to standardize all methods and analyses. For our purposes, a recruit is any coral colony under 2 cm in length. This definition is used to eliminate the subjectivity in determining recruits from coral remnants.

Data collection

Quadrats

Within each permanent quadrat, direct field observations are necessary. Not all recruits are obvious, but most have an upturned growing edge, and do not have identical adjacent species (they are generally fragments of once larger colonies). *Acropora* recruits are generally straight forward to identify as such in the field, *Porites* and faviids are more difficult. Great care should be taken to identify new sexual recruits, and not over estimate fragments. Each recruit should be identified in the field, because most settle on vertical surfaces and are not easily identified in photographs. Recruits should be identified to the lowest taxonomic level, measured to the nearest millimeters. Often this type of recruitment measurement only really captures post-settlement survival, because the considerable post-settlement mortality that can occur in stressed environments is lost in these surveys.

Terracotta settlement plates

Another, more accurate way to measure recruitment in the field is to use settlement plates. These plates provide a clean surface, free of recruits and remnants to be used as Time 0 and eliminate the researcher bias that exists when deciphering possible recruits on the natural substrate. It is important to compare recruitment between settlement plates and natural substrate to rule out any possible artificial influences.

The methods for placing terracotta settlement plates are detailed in the Mesoamerican Barrier Reef System (MBRS) manual called the 'Manual of Methods for the MBRS Synoptic Monitoring Program' found at <http://www.gefcoral.org>, see "Other Projects" section under "Targeted Research" – which are both revised versions of Mundy's (2000).

The following protocol comes from Bob Steneck's lab see

http://www.umaine.edu/marine/people/directory.php/profile/robert_steneck

and is now successfully deployed worldwide. Terracotta settlement plates should be 10 cm X 10 cm and approximately 1 cm thick (Figure 7). A 6.35 millimeter (or 1/4 inch) hole should be drilled in the center of each plate (use a masonry bit and a drill press). When dry, each plate should be numbered consecutively on the smooth underside of the plate with a permanent, water-proof pen (place the irregular surface facing up). Write the number above and below the hole, and cover the numbers with clear durable West System 105 epoxy (if this brand of epoxy is not available, then some similar, non-toxic substitute can be used). The number should also be largely written on the upper side (this will get covered and disappear as the plate gets colonized but it serves well for initial orientation). Using an embossing label maker with raised lettering, label the plate number on the underside. The raised lettering scratches free of algae, yet remains in place for an extended period.

In regions where permitted, settlement plates should be fixed in the field by drilling a hole into the dead coral substrate and inserting a plastic wall anchor into which a stainless steel bolt can be screwed (Figure 7). However, in regions where drilling into the reef is not permitted plates must be fixed to a removable stand and placed in both vertical and horizontal positions as it has been documented that many corals recruit onto vertical surfaces. Recruitment and post-settlement mortality will be measured both within the permanent quadrats and on the terra cotta settlement plates. The settlement plates should be placed near each corner of each permanent quadrat for ease of relocation and to ensure precise comparisons with the natural substrate within the quadrats. Plate placement should also be mapped before leaving the station.



Figure 7. Recruitment plate six months after deployment in the field.

D. Coral disease field methods

Since the early 1970's when white band disease took a toll on Caribbean acroporids there has been an exponential increase in the number of reported diseases and the number of locations with disease observations. Therefore, the CRTR Program designated a Coral Disease Working Group to fill in critical information gaps regarding coral reef diseases. Research priorities include assessing the global prevalence of coral disease, investigating the environmental drivers of disease and understanding the coral's ability to resist disease. For a more complete discussion and detailed information regarding coral diseases, refer to the *Coral Disease Handbook: Guidelines for Assessment Monitoring and Management* (Raymundo et al. 2007).

Equipment

Each researcher should be equipped with the following equipment for disease data collection:

1. Data sheets (Appendix B) printed on underwater paper
2. Transect tape measures or 10 m rope with meter demarcations
3. Pencil
4. Flexible one meter tape with centimeter markings to measure individual colonies
5. Two, 1 m sections of PVC used to create one meter quadrats along the 10 m transect tape
6. Coral disease ID cards
7. Coral species ID cards
8. Differential GPS
9. Magnifying lens
10. Plastic caliper and ruler
11. Digital camera

Data collection

To collect coral population and disease prevalence data, at least three haphazardly placed 10 m x 2 m (20 m²) belt transects should be run in each of the already CRTR Program's established stations. Because this project focuses on a wide variety of reef habitats it is important to identify the research questions of interest and conduct power analyses to ensure that the recommended three, 10 m x 2 m transects provide adequate replication for the region being sampled. Transects to capture coral disease are generally run in areas of 'high' coral cover to ensure adequate sample size for analyses along with controlling for some reef variations, which is why transects are haphazardly run and not truly random.

Transects

Collecting data from transects is best using two researchers, one on either side of the 10 m transect tape. The PVC sections (see Equipment box) are used to create 1 m² quadrats along each 10 m belt-transect. Within each section (i.e. quadrat) population information is collected including colony identification to the lowest taxonomic level possible, colony size measured by the maximum diameter and maximum width 90° from the maximum diameter, disease presence/absence, disease type, and area of recent mortality from the disease (which is a relatively biased estimate).

The area of recent mortality, identified by recently exposed skeleton, should not be mistaken for predation scars from fish or snails, or bleaching. For other diseases such as yellow band and dark spot that do not generally exhibit recent mortality, the area of discoloration is recorded for the area affected by disease. One effective way to distinguish between mortality caused by bleaching versus disease is to determine the presence/absence of tissue. If the tissue is still present, then it is most likely caused by bleaching. If the tissue is absent, then disease or predation is more likely. Deciphering between predation and disease is much trickier and generally takes a more experienced eye. Examining the pattern along the recent mortality line is a useful starting point in determining whether visible lesions are from disease or predation. Scars from snails are generally scalloped and are mostly located near the base, while fish have either little symmetrical circles

and/or scrapes. For a more complete description of diseases and possible factors that could be mistaken as disease lesions, refer to the *Coral Disease Handbook: Guidelines for Assessment, Monitoring and Management* (Raymundo et al. 2007).

Colony tagging

The belt-transect method provides more of a rapid assessment of state variables while monitoring individual colonies provides detailed information for a limited number of colonies. Coupling rapid assessments and colony monitoring is useful when asking questions regarding the reef status along with disease progression among individual colonies. Individual colonies can be monitored in the permanent quadrats. Other colonies outside of the quadrat can also be tagged and monitored to increase sample size or target a specific species that is not adequately represented in the quadrats. To monitor the rate of progression, the method for tagging varies based on the growth morphology. If the colony is of the branching morphology, then a cable tie is placed right below the progressing band (Figure 8). If the colony is of massive or encrusting formation, a nail driven into the dead skeleton (Figure 9) just below the progressing band could demarcate disease location and would be useful to estimate disease progression rate. A GPS point should be taken along with a map drawn complete with photographs should also be taken to aid relocation of the colonies. Benthic composition information (i.e. coral id, coral rubble, dead standing coral, pavement with turf algae, rock, macroalgae, soft corals, sand, silt and sponges) is also usually taken using replicated line-intercept transects.



Figure 8. A branch of *Acropora* with white syndrome. The green cable tie marked the original position of the band when it was first observed and was used to measure disease progression. Photo: L. Raymundo



Figure 9. A masonry nail (arrow) hammered into dead skeleton can provide a useful reference point and scale for monitoring disease progression in an active lesion. Here a massive *Porites* colony exhibits signs of white syndrome. Photo: L. Raymundo.

E. Fish sampling methods

Measuring both adult and recruitment of coral reef fish within each station provides useful information about the population dynamics and demography for the area investigated, if assessed repeatedly over successive years. The methods described below are not as advanced or detailed as those for coral recruitment. Sampling fishes is obviously complicated by the fact that they frequently move; however, these methods have provided useful data to compare population dynamics over time.

Prior to sampling fish adults or recruits, samplers should consider counting the larger and more cryptic fish that may occur within a station. Upon arriving at a station for sampling, fish observers should first confirm the station dimensions and should enter the water with intent to scan the entire boundaries and interior of the 25 m x 75 m station and record the presence of any large individuals, such as exploited groupers, *Bolbometapon* or *Scarus guacamaia* (as examples). The individuals of interest will obviously vary by region, but these should be investigated first given their tendency to flee after divers are in the water for extended periods. Then the sampling of adults and recruits should follow as per the following procedures.

Recruitment of coral reef fish should be estimated at each station only once per year; however, this should occur at the same time every year and should take place during the “end of summer” for each region (for example, in Australia, this would be in March; in the Caribbean, this would be during September). Sampling should also be within the first seven days following the new moon phase. Although many fish species vary in their most abundant recruitment periods, this consistent timing of sampling provides the best overall indication of the majority of new fish that will have successfully established within a coral reef system. Also, sampling should occur at low tide to further reduce the variability in observations. The best times for sampling is between 10 am and 3 pm whenever possible. If gaps in data occur, they should be noted and briefly described.

Equipment

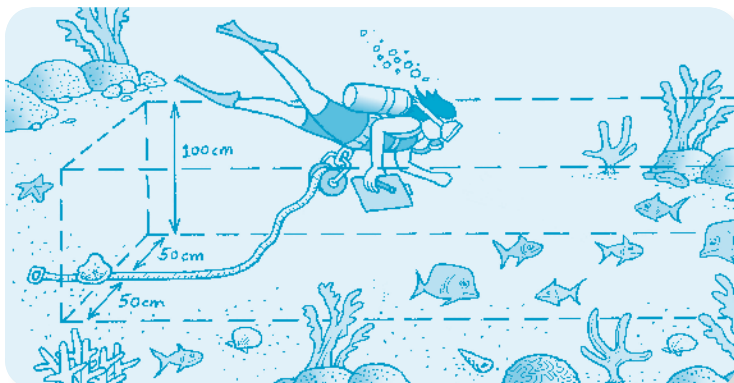
Each diver will need to carry:

1. Two underwater data templates for fish (Appendix C) per station
2. Plastic underwater slates
3. Two 30 m fiberglass surveying tapes or 30 m rope attached to a reel with a clip
4. Two 3 lb (or 1 kg each) weights to weight the end of the tape
5. Underwater cards to aid species identification

Data collection

For counting adults, five transects 30 m long by 4 m (i.e. 2 m on each side of the transect) should be conducted within each station. To measure recruitment, at least eight 30 m x 1 m x 1m transects are run to sample juvenile fishes within each station. The point of beginning is haphazardly selected within the confines of the already established stations. Each consecutive transect is

placed haphazardly at least 5 m from the previous transect. Power analyses should be run to determine whether the recommended number of transects provides sufficient replication required for the region being sampled.



20 Figure 10. Diver running a fish-census transect. (Stuart Roth)

For each transect within the station:

1. The recorder's name, date, time transect is started, site and station name, GPS location, and transect number is recorded on the datasheet provided.
2. To run these transects, the weighted end of the line must first be placed on the bottom (Figure 10). A special weighted transect is used and laid as the researcher is swimming so that it is behind the research, which minimizes any disturbance to the fishes.
3. Then with the transect clipped to your weight belt, or get a diver to follow you with the transect line, swim in a straight line by periodically focusing on a fixed object while releasing the tape from the reel as you count all the coral reef fish recruits found within a 1 m wide visually estimated belt transect.

It is best to swim along depth contours and along spurs to minimize depth changes. Each researcher must carry a data sheet on underwater paper, pencil and weighted transect tape, (Figure 10). The transect belt should be sampled by giving equal attention to each successive 2 m segment. This requires swimming at a more or less constant rate, while looking consistently 2 m ahead of your current position. However, high densities of counted fish species will slow this rate. Only individuals that are actually within the 1 m wide strip should be included in the census, even when counting a school.

Fish observers should be trained to estimate fish lengths by using consistency-training methods found below. Because fish recruits are cryptic they are harder to spot, therefore researchers should try to swim each transect 1 to 1.5 m over the substrate. Care should be taken to ensure that your fins do not accidentally come into contact with the reef or substrate.

For the Caribbean, only the species listed in Appendix C, should be counted to satisfy the requirements for the CRTR Program. Checklists for Indo-Pacific species can be downloaded at www.gefcoral.org, see "Other Projects" section under "Targeted Research". Some researchers may wish to census other species of fish not listed in the table for specific research questions. This is of course encouraged provided that these other species are counted on a separate pass over the transect. Otherwise, the census method will be substantially changed, and the data will not be directly comparable with other assessments. (These should be performed prior to and separate from sampling at the stations.)

Estimating length exercises

Since we do not attempt to catalogue every fish by their actual size all we need to do is be comfortable with estimating the maximum length and then recording every fish smaller that is found within the transect. For this we suggest two field exercises that will train your underwater size estimation skills. (These should be performed prior to and separate from sampling at the stations.)

Exercise 1: In this exercise, observers practice fish counting along a belt transect and estimating fish size. Each observer should have a T-bar (with 5 cm increments), a 30-m transect tape, and a datasheet. A practice transect line is laid on the substratum and fish models (made from drinking straws of various lengths that are attached to a weighed line) are haphazardly placed along the transect. One observer starts at the beginning of the transect line and uses a T-bar to estimate the width of the 1 m belt transect and the length of fish. Observers should mark on their data sheet the estimated size for each model observed in the sample area. Each observer should run the survey. After completing the exercise, compare the answers of all the observers with the correct fish lengths. Repeat exercises until observers are consistent between each other and their answers are close to the correct answers. We suggest cutting the straws at 0.5 cm increments starting at 1 cm and going to 5 or 6 cm. this way you will be able to estimate sizes longer than the maximum total length for each species. Data analysis should be by means of a linear regression between the estimated length and the real length of the model. The r^2 value will give an estimate of precision, whereas the slope will give an estimate of accuracy.

Exercise 2: Each observer will carry an underwater slate and a plastic measuring rule. The objective of this exercise is to estimate the size of an inanimate object and then compare this estimate to the actual length of the object. While drifting through the area identify small pieces of rubble or other small structures and try to estimate their length, then pick up the object and measure its length. Try to collect fusiform objects since these will mimic a fish's shape. This exercise differs from Exercise 1 in that while the straws come in 5 mm increments, fish rarely do, therefore you will be able to better estimate actual lengths rather than size classes. Analyze the data in the same way as for Exercise 1 to obtain your accuracy and precision values.

F. Rate of herbivory methods

The top priority for measuring rates of herbivory is to get good fish and urchin censuses by species, body size (actual standard length rather than size categories), and life phase. For fishes, it is appropriate to use 30 x 4 m transects (n=10) to predict total grazing and to quantify the grazing rate of species at size X. An optional census technique involves independent measures of grazing, whereby one deploys 1 m imaginary quadrats and to then quantify the number of bites x fish species x size x phase (i.e. terminal, intermediate phase, and juvenile phase) within 5 minute observations (Steneck, 1985). Do as many quadrats as possible within a dive. The objective is to gauge the effect of herbivorous fishes on algal composition by quantifying their level of herbivory. These data are highly variable, particularly when fish abundance is low: fish census using the 30 m transects is probably more useful. For urchins, use random 1 m² quadrats within each station. Undertake a power analysis on pilot data to make sure there is sufficient replication; 25 replicate quadrats per station is sufficient in most regions. In addition to, or alternatively, you may census the entire 16 m² area of permanently marked station quadrats established and discussed under section III.

Data collection for fishes (optional)

1. Use a 1 meter stick in conjunction with natural features on the reef (e.g. a small coral or gorgonian) to haphazardly delineate an area that is approximately 1 m square (do not mark or place a meter quadrat or other feature over the designated area, as some fish are particularly prone to biting novel objects placed within their feeding territories).
2. Back off as far as you can while still being able to see the meter square area. Watch for five minutes. Time of day, and number of bites from all species of fish from the three guilds listed above (identify the fish to species, if possible). Repeat for a total of five squares (and 25 minutes of observation). Note: you must be able to distinguish:
 - a. Juvenile scarids from other fishes with similar stripes, such as acanthurids and labrids (i.e. wrasses – which appear as if they are biting algae as they search for amphipods and other small crustaceans), and
 - b. Yellowtail damselfish (which are browsers) from other species of damselfish (that cultivate algal gardens). Be sure to remember to record the time of day, since fish activity varies temporally.
 - c. Different functional forms of parrotfishes including excavators (the genus *Sparisoma* in Caribbean, and genera *Bolbometapon*, *Chlorurus*, *Microrhinus*, and *Cetoscarus* in the Indo-Pacific) and scrapers (genera *Scarus* and *Hipposcarus*).
 - d. All juvenile *Nasos* and herbivorous adult *Naso* species such as *lituratus* and *unicornis* (Indo-Pacific), and
 - e. Rabbitfishes (Indo-Pacific) and surgeonfishes from non-herbivorous fishes of similar size like angelfishes.

IV. Data management

The amount of data the CRTR Program has collected and will continue to collect is immense. Successful completion of objectives and global comparisons relies on quality control and data management starting early and continuing throughout the Program. This will ensure that all regions are collecting data required for the targeted comparisons. Microsoft Access® has been used to create a relational database where data from all regions will be entered and kept at the Florida Institute of Technology as a central repository (however, database copies will reside with each CoE). Using the same database throughout all CoEs will provide a means of quality control to ensure all required data is collected and entered, and will ease global comparisons without wasting time deciphering individual's Excel worksheets.

Communication between CoEs and data sharing

Data will be requested from all CoEs by the Data Coordinator every year and should be provided in a timely fashion already entered into their copy of the Access database. Progress updates should also be provided to the data coordinator and program lead on a regular basis (preferably, monthly and more frequently if determined by either party). The Access database will be shared within the group to answer targeted questions posed either by the group or for individual dissertations or projects. Once results are published, then sharing with other groups and/or programs will be assessed on a case-by-case basis.

Database set-up

Microsoft Access allows you to create multiple tables that can then be linked together by shared data columns containing specific attributes related to sites and stations. This allows the researcher to query specific information based on these shared attributes, thus creating new spreadsheets ready for analysis within minutes. This database makes it possible to summarize large amounts of data into simplified reports within seconds. The key to successful queries lies in the proper linkage of data-tables through clear definition and shared attributes (e.g. similar columns in each separate table to be linked). The database description below indicates the key fields of data needed for sites and stations. They are accompanied by examples of how datatables are presented within Microsoft Access.

Site

ID	Station Name	Code	Latitude	Longitude	Average Depth	Geographical Region Code	Map Datum
1	Bocana	PM1	0	0	2	M	
2	La Ceiba	PM2	0	0	1	M	
3	Jardines	PM3	0	0	2	M	
4	Akumal Site 1	AK1	0	0	2	M	
5	Akumal Site 2	AK2	0	0	2	M	

Example of Microsoft Access table view for sites (data from the Caribbean region shown).

Station

ID	Station Name	Station Code	Site Code	Latitude	Longitude	Geographical Region Code
1	Bocana Outer	PM1a	PM1	0	0	M
2	Bocana Lagoon	PM1b	PM1	0	0	M
3	La Ceiba	PM2a	PM2	0	0	M
4	Ojo	PM2b	PM2	0	0	M
5	Jardines North	PM3a	PM3	0	0	M
6	Jardines South	PM3b	PM3	0	0	M
7	Akumal Site 1 Station 1	AK1a	AK1	0	0	M
8	Akumal Site 1 Station 2	AK1b	AK1	0	0	M
9	Akumal Site 2 Station 1	AK2a	AK2	0	0	M
10	Akumal Site 2 Station 2	AK2b	AK2	0	0	M

Example of Microsoft Access table view of stations that are part of sites (Bocana station data shown).

Database definition

The following are a listing of the data fields required for the CRTR relational database:

Site

- ID
- Site name
- Code
- Latitude
- Longitude
- Average depth
- Geographical region
- Map datum

Permanent quadrat description

- ID
- Permanent quadrat ID
- Time
- Geographical region
- Site code
- Station code
- Latitude
- Longitude
- Permanent quadrat code
- Map datum
- Quadrat name
- Photo code
- Management status
- ID
- Management status
- Site code

Family

- ID
- Family

Station

- ID
- Station name
- Station code
- Site code
- Latitude
- Longitude
- Geographical region

Photo code

- ID
- Photo number
- Photo name
- Photo code

Depth

- ID
- Depth range
- Depth zone code

Species

- ID
- Abbreviation
- Species
- Genus code
- Family code

Time period

- ID
- Time period
- Time code

Geographical region

- ID
- Geographical region
- Code

Genus codes

- Code (ID)
- Genus
- Family

TAU

- ID
- TAU name
- TAU family members
- TAU genus members
- TAU code
- Species
- TAU order
- Morphology
- TAU example (links to photos)

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Appendix A

Guidelines for capturing images for camera calibration and mosaics

Camera calibration

Camera calibration allows for correcting geometric distortions induced by the camera lens and housing. This calibration is based on processing a set of images of a calibration grid taken underwater. The grid is a flat-checked pattern that can be found at the following web-address (http://www.vision.caltech.edu/bouguetj/calib_doc/htmls/pattern.pdf). The calibration procedure is done using Matlab® using the camera calibration toolbox, which is freely available on the web (http://www.vision.caltech.edu/bouguetj/calib_doc/).

Camera calibration checklist

Print checkered patterns on water-proof paper. Furthermore, the calibration algorithm requires:

- Images to be acquired underwater (since the image distortion is different above water)
- 5 to 10 different images of the calibration grid *containing all the grid squares* (Figure 11)
- Distinct positions of the grid in the image (i.e. centered and near the image edges)
- Distinct grid orientations (0 to 45 degrees)
- The zoom setting of the camera must be the same as used for the mosaic acquisition

Some major pointers when taking the series of calibration photos are:

- The camera should be relatively close to the grid (Figure 11). For the best results, the grid should cover around 50% of the image area.
- Attach the grid to a rigid flat surface (e.g. clipboard) so that it stays flat.
- Take images of the grid under a slightly slanted angle (so that you can see the perspective effect in the pattern)

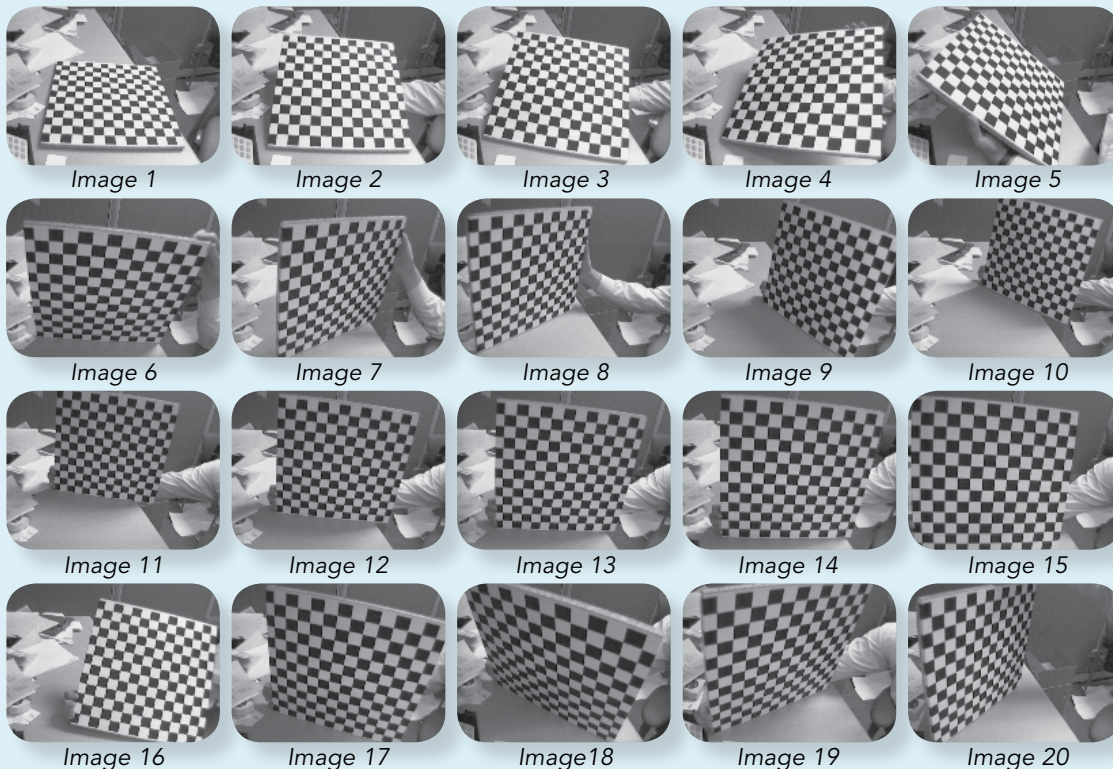


Figure 11. An example of a series of calibration photos (that must be taken underwater).

Image acquisition for mosaics

- Camera should be approximately parallel to the sea floor and kept at the same distance.
- Images in sequence should have a minimum of 70% overlap.
This means each new image should cover at least 2/3 of the previous image.
- There is no need to maintain the same “camera heading”, i.e. the camera can rotate around the vertical axis freely. However, it is usually easier for the diver to maintain the heading to keep track of the overlap between strips.
- The focal length of the camera should not change (i.e. do not alter the zoom settings)
- The most usual survey pattern is the ‘lawn mower’ pattern, starting with up and down parallel strips and ending with two horizontal and two diagonal strips. These final strips facilitate mosaicking (Figure 12).

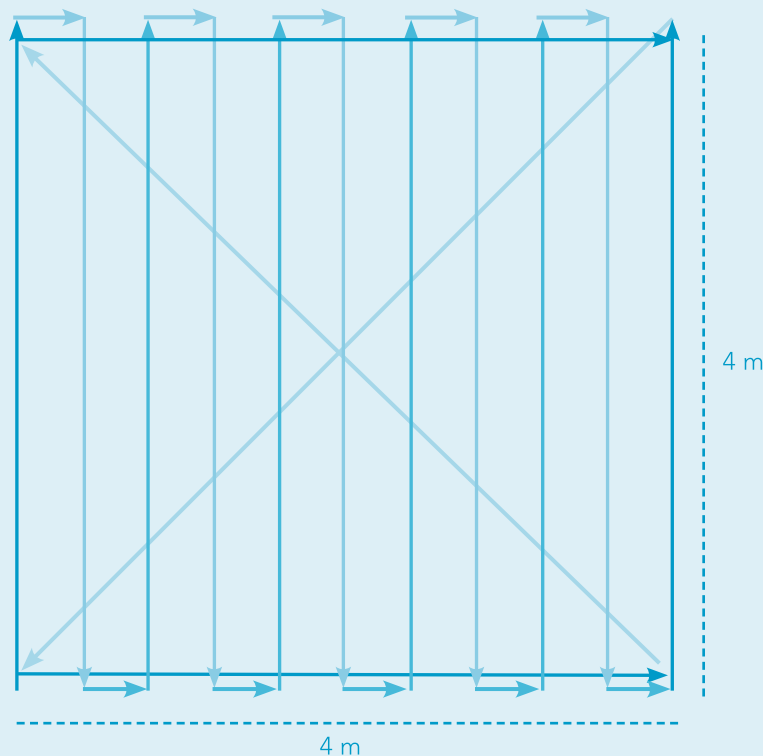


Figure 12. Ideal swim path for acquiring images for 4 m x 4 m permanent quadrats.

- If during the acquisition, the diver deviates from the intended trajectory, then there is no problem in going back to the area that was not properly imaged and taking more images (the order of the images is not important for the mosaicing algorithm).
- For the areas of high topographic variation, the overlap between images should be increased (whenever possible). A way to increase the overlap without increasing the number of strips is to acquire the images at a higher altitude, but keep in mind that some resolution will be lost. Another way to increase overlap without reducing resolution is to use a wide-angle lens (mandatory for benthic surveys) attached to the camera housing. There will be a bit of distortion around the edges, but can be easily fixed with lens correction software and calibration techniques.
- For the difficult cases of high topography or strong refracted sunlight, it helps to run a video camera, following the same guidelines. The video camera should be set to progressive scanning (i.e. not interlaced), and to 'sports' mode (to reduce motion blur under low light conditions). You can avoid doing multiple surveys by strapping the video camera and the still camera together.

Appendix B

Disease prevalence sheet. (Print this form on waterproof paper for use in the field).

Recorder:	Site:	Transect:	Depth:	Transect Position:			Date:		
	Total Colony Count	Growth anomaly	BBD	B+R	WS	PUWS	SEB	Patchy bleach	PR
Acropora	tabular								
	staghorn/bushy								
	bottlebrush/digitate								
	corymbose								
	isopora								
Anacropora/Astreopora									
Montipora									
Pocillopora									
Stylophora/Seriatopora									
Stylocoeniella/Madracis									
Porites	massive								
	branching								
	submassive								
Goniopora/Alveopora									
Favia/Montastrea									
Favites/Echinopora									
Platygyra/Goniastrea									
Cyphastrea/Leptastrea									
Other faviids (genera)									
Fungiids (genera)									
Galaxea/Simplastrea									
Pectinia/Oxypora									
Echinophyllia/Mycedium									
Lobophyllia/Symphyllia									
other Mussids (genera)									
Hydnophora									
Merulina									
Paraclav/Scapophyllia									
Pavona									
Leptoseris/Coeloseris									
Pachyseris/Gardinero									
Psammocora/Coscinarea									
Siderastrea/Pseudosider									
Euphyllia/Catal/Trachy									
Plerogyra/Physogyra									
Turbinaria/Tubastrea									
Heliopora/Tubipora									
Millepora									
Predation: 1Dr (Drupella) 1Co (Coralliophila) 1CT (COT) 1F (Fish) Algal overgrowth/abrasion: 2Cy (cyanobacteria) 2Ma (macroalgae) 2RF (red filamentous) Silt smothering/abrasion: SI									

Appendix C

Coral reef fish censusing

Proposed list of fish species to be censused to monitor recruitment in the Caribbean. This should form the basis of a data sheet to accompany each diver during data collection. Maximum sizes are shown as TL = total length. Fish that are larger than these sizes will have settled too far in the past to be included, and should NOT be counted.

Family	Species	Common name	Max. TL (cm)
Acanthuridae	<i>Acanthurus bahianus</i>	Ocean surgeon	5.0
	<i>Acanthurus coeruleus</i>	Blue Tang	5.0
Chaetodontidae	<i>Cheatodon striatus</i>	Banded butterflyfish	2.0
	<i>Chaetodon capistratus</i>	Four-eye butterflyfish	2.0
Grammatidae	<i>Gramma loreto</i>	Fairy basslet	3.0
Labridae	<i>Bodianus rufus</i>	Spanish hogfish	3.5
	<i>Halichoeres bivittatus</i>	Slippery dick	3.0
	<i>Halichoeres garnoti</i>	Yellowhead wrasse	3.0
	<i>Halichoeres maculipina</i>	Clown wrasse	3.0
	<i>Halichoeres pictus</i>	Rainbow wrasse	3.0
	<i>Thalassoma bifasciatum</i>	Bluehead wrasse	3.0
Pomacentridae	<i>Chromis cyanea</i>	Thalassoma bifasciatum	3.5
	<i>Stegastes diencaeus</i>	Longfin damselfish	2.5
	<i>Stegastes dorsopunicans</i>	Dusky damselfish	2.5
	<i>Stegastes leucostictus</i>	Beaugregory	2.5
	<i>Stegastes partitus</i>	Bicolor damselfish	2.5
	<i>Stegastes planifrons</i>	Threespot damselfish	2.5
	<i>Stegastes variabilis</i>	Cocoa damselfish	2.5
Scaridae	<i>Scarus iserti</i>	Striped parrotfish	3.5
	<i>Scarus taeniopterus</i>	Princess parrotfish	3.5
	<i>Sparisoma atomarium</i>	Greenblotch parrotfish	3.5
	<i>Sparisoma aurofrenatum</i>	Redband parrotfish	3.5
	<i>Sparisoma viride</i>	Stoplight parrotfish	3.5

Appendix C cont...

Date Site Observer Time

Species	Common name	TL	Trans	Trans	Trans	Trans
Acanthurus bahianus	Ocean surgeon	5				
A. coeruleus	Blue Tang	5				
Chaetodon striatus	Banded butterfly	2				
C. capistratus	Four-eye butterfly	2				
Gramma loreto	Fairy basslet	3				
Bodianus rufus	Spanish hogfish	3.5				
Halichoeres bivittatus	Slippery dick	3				
Halic. garnoti	Yellowhead wras	3				
Halic. maculipinna	Clown wrasse	3				
Halic. pictus	Rainbow wrasse	3				
Thalassoma bifasciatum	Bluehead wrasse	3				
Chromis cyanea	Blue chromis	3.5				
Stegastes diencaeus	Longfin damsel	2.5				
Steg. dorsopun	Dusky damselfish	2.5				
Steg. leucost	Beaugregory	2.5				
Steg. partitus	Bicolor damselfish	2.5				
Steg. planifrons	Threespot damsel	2.5				
Steg. variabilis	Cocoa damselfish	2.5				
Scarus iserti	Striped parrotfish	3.5				
Sc. taeniopterus	Princess parrot	3.5				
Scarus vetula	Queen parrotfish	3.5				
Spar. aurofren	Redband parrotfish	3.5				
Spar. viride	Stoplight parrotfish	3.5				

appendices

Appendix D

Taxonomic Amalgamation Units (TAUs)

It is often very difficult and at times impossible to identify certain scleractinian corals to species level, even for a trained and experienced eye. Because of these challenges and the additional challenges associated with identifying from photos, Taxonomic Amalgamation Units were developed. All four geographic regions use these TAUs. These regions, and their TAUs should be used by all future programs to ensure that comparisons can be made with the current program. Note: The species list given here is not exhaustive (because there are hundreds more coral species, globally); therefore the species list will expand within each TAU as monitoring is initiated in other regions.

*The TAU ID (Name) is provided with the associated species listed below each TAU.

1. **Pocillopora damicornis**
 - a. Pocillopora damicornis
2. **Pocillopora verrucosa**
 - a. Pocillopora verrucosa
3. **Stylophora spp.**
 - a. Stylophora spp.
4. **Seriatopora spp.**
 - a. Seriatopora spp.
5. **Isopora (Acropora)**
 - a. Acropora palifera
 - b. Acropora cuneata
 - c. Acropora brueggemanni
6. **Acropora corymbose**
 - a. Acropora gemmifera
 - b. Acropora humilis
 - c. Acropora nasuta
 - d. Acropora cerealis
 - e. Acropora divaricata
 - f. Acropora glauca
 - g. Acropora valida
 - h. Acropora digitifera
 - i. Acropora secale
 - j. Acropora verweyi
 - k. Acropora monticulosa
 - l. Acropora samoensis
 - m. Acropora subulata
 - n. Acropora tenuis
 - o. Acropora donei
 - p. Acropora selago
 - q. Acropora polystoma
 - r. Acropora selago
 - s. Acropora donei
 - t. Acropora anthocercis
 - u. Acropora millepora
 - v. Acropora samentosa
 - w. Acropora microclados
 - x. Acropora latistella
7. **Acropora branching**
 - a. Acropora muricata (formosa)
 - b. Acropora forskali
 - c. Acropora intermedia (nobilis)
 - d. Acropora microphthalma
 - e. Acropora striata
 - f. Acropora yongei
 - g. Acropora aspera
 - h. Acropora pulchra
 - i. Acropora grandis
 - j. Acropora austera
 - k. Acropora palmata
 - l. Acropora cervicornis
8. **Acropora table**
 - a. Acropora cytherea
 - b. Acropora clathrata
 - c. Acropora hyacinthus
 - d. Acropora paniculata
9. **Acropora 'hispidose'**
 - a. Acropora echinata
 - b. Acropora batunai
 - c. Acropora subglabra
 - d. Acropora carduus
 - e. Acropora awi
 - f. Acropora elseyi
 - g. Acropora longicyathus
 - h. Acropora turaki
10. **Acropora robusta group**
 - a. Acropora danai
 - b. Acropora robusta
 - c. Acropora abrotanoides
11. **Montipora foliose**
 - a. Montipora aequituberculata
 - b. Montipora foliosa
 - c. Montipora cebuensis
 - d. Montipora capricornis
 - e. Montipora crassituberculata

Appendix D cont...

12. *Montipora* encrusting

- a. *Montipora efflorescens*
- b. *Montipora grisea*
- c. *Montipora hoffmeisteri*
- d. *Montipora informis*
- e. *Montipora millepora*
- f. *Montipora tuberculosa*
- g. *Montipora undata*
- h. *Montipora venosa*
- i. *Montipora verrucosa*

13. *Montipora* branching

- a. *Montipora digitata*
- b. *Montipora gaimardi*
- c. *Montipora hispida*
- d. *Montipora cactus*

14. *Porites* massive

- a. *Porites lobata*
- b. *Porites lutea*
- c. *Porites astreoides*

15. *Porites* branching

- a. *Porites annae*
- b. *Porites cylindrica*
- c. *Porites nigrescens*
- d. *Porites profundus*
- e. *Porites negrosensis*
- f. *Porites samarensis*
- g. *Porites porites*
- h. *Porites furcata*
- i. *Porites divaricata*

16. *Porites* encrusting

- a. *Porites aranetai*
- b. *Porites rus*
- c. *Porites branneri*

17. *Favites* spp.

- a. *Favites abdita*
- b. *Favites chinensis*
- c. *Favites complanata*
- d. *Favites flexuosa*
- e. *Favites halicora*
- f. *Favites pentagona*
- g. *Favites russelli*
- h. *Favites vasta*

18. *Goniastrea* spp.

- a. *Goniastrea aspera*
- b. *Goniastrea australensis*
- c. *Goniastrea edwardsi*
- d. *Goniastrea pectinata*
- e. *Goniastrea peresi*
- f. *Goniastrea retiformis*

19. *Montastrea* spp.

- a. *Montastrea* spp.
- b. *Montastrea annularis*
- c. *Montastrea cavernosa*
- d. *Montastrea faveolata*
- e. *Montastrea franksi*

20. *Favia* spp.

- a. *Favia fava*
- b. *Favia helianthoides*
- c. *Favia laxa*
- d. *Favia lizardensis*
- e. *Favia maritima*
- f. *Favia pallida*
- g. *Favia rotumana*
- h. *Favia speciosa*
- i. *Favia stelligera*
- j. *Favia veroni*
- k. *Favia fragum*
- l. *Favia gravida*
- m. *Favia leptophylla*

21. *Leptoria* spp.

- a. *Leptoria phrygia*
- b. *Leptoria irregularis*

22. *Platygyra* spp.

- a. *Platygyra crosslandi*
- b. *Platygyra daedalea*
- c. *Platygyra lamellina*
- d. *Platygyra sinensis*
- e. *Platygyra pini*

23. *Lobophyllia* spp.

- a. *Lobophyllia corymbosa*
- b. *Lobophyllia hataii*
- c. *Lobophyllia hemprichii*
- d. *Lobophyllia robusta*

24. *Galaxea* spp.

- a. *Galaxea astreata*
- b. *Galaxea fascicularis*

25. *Symphyllia* spp.

- a. *Symphyllia agaricia*
- b. *Symphyllia recta*
- c. *Symphyllia radians*

26. *Fungia* spp.

- a. *Fungia* spp.

27. *Goniopora* spp.

- a. *Goniopora* spp.

28. Encrusting other

- a. *Pavona explanulata*
- b. *Pavona minuta*
- c. *Pavona bipartita*
- d. *Cyphastrea microphthalma*
- e. *Acanthastrea hemprichii*
- f. *Coscinaraea monile*
- g. *Cyphastrea chalcidum*
- h. *Agaricia humilis*
- i. *Dendrogyra cylindrus*
- j. *Madracis pharensis*

29. Massive other

- a. *Caulastrea furcata*
- b. *Caulastrea tumida*
- c. *Acanthastrea lordhowensis*
- d. *Alveopora fenestrata*
- e. *Alveopora tizardi*
- f. *Astreopora myriophthalma*
- g. *Coelosera mayeri*
- h. *Cyphastrea serailia*
- i. *Diploastrea heliopora*
- j. *Echinophyllia orpheensis*
- k. *Gardineroseris planulata*
- l. *Oulophyllia crispa*
- m. *Colpophyllia natans*
- n. *Dichocoenia stokesi*
- o. *Diploria clivosa*
- p. *Diploria labyrinthiformis*
- q. *Diploria strigosa*
- r. *Eusmilia fastigiata*
- s. *Isophyllastrea rigida*
- t. *Isophyllia sinuosa*
- u. *Manicina areolata*
- v. *Meandrina meandrites*
- w. *Mussa angulosa*
- x. *Mussismilia braziliensis*
- y. *Mussismilia harttii*
- z. *Mussismilia hispida*
- aa. *Siderastrea radians*
- bb. *Siderastrea siderea*
- cc. *Siderastrea stellata*
- dd. *Solenastrea bournoni*
- ee. *Solenastrea hyades*
- ff. *Stephanocoenia intersepta*
- gg. *Scolymia cubensis*

30. Turbinaria spp.

- a. *Turbinaria* spp.

31. Foliose-plates

- a. *Pavona cactus*
- b. *Astreopora expansa*
- c. *Echinophyllia echinata*
- d. *Mycedium mancaoi*
- e. *Echinopora lamellosa*
- f. *Pavona varians*
- g. *Pavona decussata*
- h. *Psammocora superficialis*
- i. *Coscinaraea crassa*
- j. *Echinophyllia aspera*
- k. *Podabacia motuporensis*
- l. *Psammocora contigua*
- m. *Agaricia agaricites*
- n. *Agaricia tenuifolia*
- o. *Agaricia fragilis*
- p. *Agaricia grahamae*
- q. *Agaricia lamarcki*
- r. *Agaricia undata*
- s. *Mycetophyllia aliciae*
- t. *Mycetophyllia danaana*
- u. *Mycetophyllia ferox*
- v. *Mycetophyllia lamarckiana*
- w. *Porites colonensis*
- x. *Scolymia lacera*
- y. *Leptoseris cucullata*

32. Branching other

- a. *Oculina diffusa*
- b. *Oculina varicose*
- c. *Cladacora arbuscula*
- d. *Madracis decactis*
- e. *Madracis formosa*
- f. *Madracis mirabilis*

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references

notes



The CRTR Program is a partnership between the Global Environment Facility, the World Bank, The University of Queensland (Australia), the United States National Oceanic and Atmospheric Administration (NOAA) and approximately 50 research institutes and other third-parties around the world.