COMMISSION DE L'OCÉAN INDIEN

Coral Reef Monitoring Manual

South-West Indian Ocean islands

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Coral reef monitoring in the Western Indian Ocean islands

A manual

Developed for the SW Indian Ocean islands GCRMN node through the ISLANDS project Coral Reef Facility

Indian Ocean Commission

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1. Purpose

This manual's target audience is the coral reef monitoring network of the Southwest Indian Ocean (SWIO) islands and its members, which form a node under the International Coral Reef Initiative's (ICRI) Global Coral Reef Monitoring Network (GCRMN). The manual is intended to serve as a reference for current methodology in coral reef monitoring, and to be used in training and skills improvement. Further, it provides guidance for use of the Coral Reef Information System (CRIS) developed for the same region, as an archiving solution for coral reef monitoring data.

The manual is not to be used as a stand-alone document, as it updates prior manuals (with a particular focus on the SW Indian Ocean region), and reference is made to further references and resources. Further, monitoring is most useful when data is fully analysed and communicated, and further developments of the CRIS following publication of this manual will mean that additional reference materials and guidance should be used by monitoring teams to make the most use of their datasets.

Finally, though developed with the specific needs of the SW Indian Ocean islands, the manual and database are designed to be generic for any GCRMN region, in particular to include the East African mainland states as members of the Nairobi Convention region, together with the SWIO islands, under the umbrella of the Coral Reef Task Force established by the Convention. More broadly, the manual and database will be applicable to any region of the GCRMN globally.

2.Preface

The Barbados Program of Action (BPoA) for the Sustainable Development of Small Island Developing States (SIDS) was adopted by 129 countries and territories in a global conference held in Mauritius, January 2005. It addresses the unique development problems of SIDS and sets out the basic principles and specific actions required at the national, regional and international levels to support sustainable development. It covers various economic, social and environment sectors in 20 thematic chapters, and recognizes the need for building capacity to implement sustainable development policies. The Mauritius Strategy (MS) was identified in 2005, setting out clear strategic objectives, accompanied by well-defined vehicles for accomplishing change and well-articulated adaptive mechanisms to respond to each of the thematic issues contained in its 20 thematic chapters.

The Small Island Developing States program of the Indian Ocean Commission (IOC), dubbed the "ISLANDS project" was started in August 2011, funded with 10 million Euros by the European Union (10th EDF). Among its objectives was to develop and operationalise a system for monitoring and evaluating the implementation of the Mauritius Strategy in the Indian Ocean, at national, regional and international levels. Included within this was a Key Result for the successful establishment of a Regional WIO Islands "Coral Reef Observatory" or facility, comprising tools and mechanisms for coral reef monitoring and mapping, interoperable with national and international existing systems, to help the countries better protect their coral reefs.

This manual is an output of the ISLANDS project, tied closely to a database, the Coral Reef Information System (CRIS), that helps monitoring teams archive and secure their data, maintain their privacy of access and ownership, but built into a system for hierarchical reporting of the health of coral reefs to national, regional and global levels. As such these outputs seek to assist countries in reporting under multiple international conventions.

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4. Introduction

4.1. Background and justification

The importance of coral reefs to the countries of the SWIO is described in the vision report establishing the coral reef key result of the ISLANDS project (Quod 2012). It summarises that across the 110 countries in which reefs are found, 30 % of them are now highly degraded and an additional 30% are threatened by the year 2020. This is in spite of the great value of coral reefs for both nature and people:

- They are among the most diverse of all marine and terrestrial ecosystems, in spite of their small proportion of total marine ecosystem area.
- They are critical in supporting the coastal economies of countries that have coral reefs, whether for coastal protection, tourism, transport and trade and cultural values.
- They are critical in the food and livelihood security of the low and medium-income populations of those countries, as they provide fish and other species for food, materials for construction, and a means of transport. These 'ecosystem services' are often not included in national monetary accounts (e.g. as measured by GDP).
- They are among the most impacted of terrestrial and marine ecosystems, as they receive inputs from both land and sea, and are at the meeting point for many human activities such as fishing, shoreline construction and transport activities.

This importance of coral reefs, and the need to measure their health and the scale of impacts to them are recognized by countries and many sectors of society through many overlapping initiatives including:

- The Convention on Biological Diversity, mentioning coral reefs and their importance in multiple areas of its workplan, in particular the Specific Work Programme on Coral Bleaching, and as a key ecosystem under Aichi Biodiversity Target 10.
- The United Nations through its General Assembly and Environment Programme.
- The International Coral Reef Initiative, which was established in 1994 as a cooperative group of leading countries and initiatives, and is continually active until today.
- Regional initiatives as the as the Coral Triangle Initiative, the Micronesia and Caribbean Challenges, and of relevance to this region, the Western Indian Ocean Coastal Challenge.

Coral reefs are among the only marine ecosystems that are being monitored, at some level, on a nearly global scale. While the level and accuracy of information being obtained globally varies, this is being undertaken through both organized and ad hoc initiatives, including:

- The Global Coral Reef Monitoring Network (GCRMN – www.gcrmn.org);
- Reefs at Risk and other global reports;
- Research scientists, with coral reefs fast becoming among the main focal ecosystems for marine science globally;
- Citizen science programmes, such as Reef Check and other local to regional participatory programmes involving fishing communities, scuba divers, and others.

This global distribution of coral reef monitoring has been recognized in new processes for organizing the reporting of biodiversity information at global levels, such as in the Working Group 5 of GEOBON (Group on Earth Observations – Biodiversity Observation Network), and the search for a minimal but necessary set of indicators suitable for reporting on the state of global biodiversity under the umbrella of the CBD and the Aichi Targets. The percent cover of corals was identified as one of ten indicators collected on a global basis[1] – and this has been reported consistently since 1999 in the context of the GCRMN and the Reefs at Risk programme (see Wilkinson 1999, 2002, 2004; Burke et al. 2011).

4.2. This manual

Given the growing interest in and need for more reliable reporting of coral reef data, and that additional indicators than percent coral cover will be needed for accurate assessments of health and trends, there is a need for more streamlined and reliable collection of data, and for its archiving and management in more accessible ways that enable value-addition to the primary datasets. This manual is developed in parallel with an online database system – the Coral Reef Information System[2] – that will facilitate this value-addition and accessibility of data. In order to maximize the value of the data, this manual focuses on prescribing methodologies to standardize the data inputs.

However, given that coral reef monitoring has been underway for 2 decades in many locations, it is critical to build on past methods in ways that maximize their value in relation to new techniques and opportunities for data collection. Thus, this manual for coral reef monitoring builds on the history of the Global Coral Reef Monitoring Network and its implementation in the Western Indian Ocean, by referring to the following documents:

1 Essential Biodiversity Variables workshop of WG5 of GEOBON, Townsville Australia, November 2013.

2 Currently hosted at http://www.globalecosystemmonitoring.com/CRIS/

- English et al. 1997 – this compendium of shallow water monitoring methods from the Australian Institute of Marine Science (AIMS) provided the base methods used by GCRMN when it was started in 1998/1999.
- Conand et al. 1999, 2000 – through the PRE-COI project funded by the European Union at the Indian Ocean Commission, twin English and French manuals were published presenting only the core of intermediate monitoring methods used by the GCRMN programme, based on those in English et al. 1997. This manual was targeted at monitoring teams in the SW Indian Ocean islands countries – Comoros, Madagascar, Mauritius, Reunion and Seychelles.
- Wilkinson and Hill 2004 – as a primary output of the GCRMN programme and building on English et al. 1997, focused on management of tropical shallow marine ecosystems, this manual was developed for guidance to managers and scientists tasked with ecosystem monitoring.

Justification for this manual is demonstrated by the findings of the regional and national studies on reef monitoring for this project[3]: a) that monitoring methods evolve over time for many reasons (changes in education, funding, technology, priorities for monitoring, etc.) and b) the ongoing focus of the Indian Ocean Commission on marine ecosystem management and coral reefs in its member countries required a restatement of core methods. Further, technological advancement (digital cameras, satellite remote sensing) has revolutionized what can be measured on coral reefs, and there was a need to provide guidance on incorporating these into methods being applied underwater. And finally, with a rapid increase in the number of scientific researchers working on coral reefs in the region, the links between research investigations and regular monitoring can make it challenging for managers to maintain consistent monitoring programmes while the science evolves and advances. This manual and the CRIS attempt to provide opportunities for evolution in monitoring systems, while assuring the base variables and indicators for management-oriented reporting remain stable.

The geographic scope of this manual and associated database encompasses the whole of the Western Indian Ocean. The reasons for this are numerous, but encapsulated in the region being a coherent coral reef province with common reef communities and species assemblages, as well as a common overarching governance framework in the form of the Nairobi Convention and its Coral Reef Task Force, the Large Marine Ecosystem (LME) framework that splits it into the Somali and Agulhas Current LMEs, and the multiple UNEP and UNESCO processes that link the countries of the region. The countries share common cultural, livelihood and economic dependencies on coral reefs, and share many of the same threats and opportunities of their growing, youthful populations and the changing global climate.

Thus, while the Indian Ocean Commission (IOC) project that supports this

3 See 1st section in the references

manual is focused on implementation in the island countries of the IOC (including Zanzibar), the methods and their implementation are common to the mainland countries of the WIO region, under the framework of the Nairobi Convention and its Coral Reef Task Force.

4.3. Why monitor?

This manual assumes that an organization/entity has already gone through the rationale for establishing monitoring of coral reefs, and has identified that the intermediate level of monitoring promoted by the GCRMN is appropriate for the management needs or stated goals. The methods described here, having been described and applied at many thousands of sites around the world have been demonstrated to be useful:

- from the local scale of an MPA or reef region where it is used to inform management decisions by a local or responsible agency,
- to the large scale of national and regional 'networks' of coral reef sites where consistent methods and reporting of data enable aggregation to higher levels for a more global statement of the status of coral reefs (see GCRMN status reports).

If the responsible organization has not undergone a process of identifying the specific goals and needs for management, this should be done with expert assistance prior to selecting or implementing any of the methods described here.

4.4. An 'intermediate' level for monitoring

The methods described in this manual are targeted at an intermediate level of monitoring capacity or expertise. That is, it sites at a middle point between two extremes of monitoring commonly recognized:

- 'volunteer' or public-interest monitoring, where the purpose is to engage and gain advantage from resource users and the interested public to contribute to monitoring by providing appropriate/simple systems for reporting. Because of the variable levels of involvement and training that individuals may receive, the data obtained is relatively coarse and simplified, but can be available from many tens of thousands of people and sites. Examples of this include Reef Check and Eye on the Reef. Reef Check is identified by the GCRMN as the preferred volunteer-level monitoring method as a complement to the intermediate level covered in this manual. Extensive manuals/ training materials have been developed by Reef Check (http://reefcheck.org/), so is not covered further in this manual.
- 'expert' monitoring, essentially driven by scientists and scientific

or research-based interests. More advanced, precise and accurate methods are needed for more detailed questions, and training of many years is often necessary to conduct, manage and interpret such monitoring. Where possible, it is advantageous to integrated more detailed expert monitoring and studies with intermediate monitoring programmes covered here, as the additional information can improve interpretation of both sets of data, to the benefit of both managers and scientists.

'Intermediate levels' cover a broad continuum, but in general ongoing training and dedicated staff are necessary to collect reliable data, but it is not necessary to invest in scientific training. However, scientific supervision or involvement to design the programme and train staff, then analyse and interpret the data, is helpful or even necessary. The intermediate level is often targeted at technical staff in institutions, such as protected areas, non-government organizations and others, where there are resources to maintain this level of expertise, and periodic (usually annual) field visits for monitoring.

Importantly, this intermediate level is often sufficient for general management needs, where targeted data is required to track performance of a management system, and adjust its actions based on the findings.

The main 'GCRMN' methods have been targeted at this level, for implementation by national agencies/NGOs, etc.

4.5. Overview of recent practise in the SWIO region

Coral reef monitoring in the SWIO region started in 1992 and has been active into recent years, summarized in a series of national reports and a regional report of the ISLANDS project, which compiled a dataset of some 1426 records documenting monitoring in over 500 sites spread throughout the islands (see ISLANDS projects outputs in References). The results from these reports indicate that:

- Benthic monitoring is the most common focus for programmes, followed by fish and then mobile invertebrates.
- The diversity of methods was least for fish monitoring (93% of all monitoring done using belt transects), given its greater technical difficulty and thus greater methodological training and consistency among programmes. Nevertheless, because of identification challenges, the mix of target taxa for fish varies greatly, and hence comparability among programmes is compromised.

- The diversity of benthic methods is highest, representing different origins of each monitoring programme and preferred methods, though the majority (60%) of all programmes use closely related methods (LIT, PIT), with a further 30% using photo-quadrat methods) that give broadly comparable results.
- The diversity of focus in invertebrate monitoring is high, with different programmes focusing on a variety of target taxa for multiple reasons, and with a mix of taxonomic levels from species (e.g. crown of thorns seastars, Acanthaster planci), to order levels (e.g. 'sea cucumbers').

The methods included in this manual were selected based on the above findings, and the purpose of the manual is to reduce the variation in details of sampling within any method to foster more consistent monitoring methods across the SWIO monitoring network. This will improve the reliability of comparisons among programmes, as well as the accuracy and rigour of data within each programme.

5. The methods

This section will cover the core methods that are now applied in the region and elsewhere in what can be called "GCRMN plus" – ie. beyond the scope of initial GCRMN guidance in the late 1990s/early 2000s, but within the principal interests of coral reef management.

While the manual gives significant guidance on implementation of a method, site selection, etc, a scientist/experienced monitor should always be involved in discussing/revising/upgrading methods for a new or existing monitoring programme.

5.1. Monitoring sites and stations

Choosing a monitoring site is an essential part of the process of monitoring, and once a site has been selected it should be fixed for the duration of the monitoring programme. In general, monitoring under the processes covered in this manual has already been underway, so several sites and stations are already selected. However in upgrading a monitoring programme, there may be opportunities to select additional sites. This should be undertaken with an expert team to ensure it is done well, and some criteria to be used in selecting sites include:

- representation of different major states of a system – ie. some sites may be selected because they are exposed to certain threats, others because they are free from threats. The purpose of the monitoring programme is important in this regard, and ensuring that extraneous sources of variation are excluded.

- Replication of sites within a common set of threats or exposures – having just one site that experiences a particular set of conditions does not allow for statistical analysis and verification that what is being observed is due to a particular threat, or may be due to some other characteristic of the site. A stratified randomized block approach for designing the monitoring programme can help with this.

In general, the following terms have been used in describing the different scales of locations in a monitoring programme (from Conand et al. 2000, and further interpretation).

- "a sector is an area of reef which is homogeneous from a geomorphological and environmental standpoint (climatic and oceanographic factors) and with respect to anthropogenic activities".
- "a site is a smaller area, which is used to define the characteristics of a sector".
- "a station is a reference point for monitoring purposes, where the transects, quadrats and other sampling units are situated".

Thus the station is the fine scale location where the monitoring teams apply their sampling methods, and depending on the logistics of place and time, transects or samples from multiple stations may be averaged together as a site. Typically, a monitoring programme must have multiple sites for statistically describing the condition of a particular sector of reef (e.g. 4 or 5 fore-reef sites to describe the status of fore reefs in a particular MPA). A monitoring programme will typically include sites in multiple sectors that may be a combination of multiple ways of classifying the reefs (e.g. exposed fore reefs, sheltered fore reefs, lagoon patch reefs, fringing reefs, degraded reefs, fully protected reefs, etc).

5.1.1. Reef habitats and types, and sampling depths

The diversity and complexity of coral reef habitats is high, and identifying the key habitats for monitoring is an important part of the planning process for monitoring. In general, most monitoring in the WIO region is done on more sheltered locations in lagoons (patch reefs and back reef locations), reef flats and fore reef slopes. Isolated banks and platform reefs are generally more distant from the shore, and with rougher conditions, so are sampled less (Obura 2013). Selecting key habitats and representative locations for monitoring should be done by an expert, to maximize the comparability of sites in the monitoring programme and coverage of key habitats of interest to monitoring. A key aspect to consider is that the more habitats that are monitored, the more sites are needed, increasing the costs of monitoring.

The depth of sampling at a station is a key choice for a monitoring programme. In the past, sampling at 7 and 15 m was prescribed (Conand et al. 1999, 2000). However, this can vary significantly among locations – e.g. where there is no reef deeper than 5 m, or the main reef assemblage is located at 10 or 12 m rather than 7 or 15 m. Decisions on primary depth for sampling must be made with sufficient expertise available, and justification based on the main purpose of monitoring.

The objective is to sample coral community habitats, so areas of principal reef growth should be sampled. The justification for the specific location of the stations should be justified in the site descriptions, and consistent with objectives for monitoring at the site/region.

5.1.2. Selecting sites and stations

The number of stations and sites for monitoring is also difficult to specify as it depends on the scale of the reef system being monitored, degree of variability from local to broader scales, as well as resources available for monitoring. In general terms at least 2 sites should be present in any defined sector (e.g. protected fore reef) as that allows for an average to be calculated, but 4 or more sites provides more reliable information and quantification of variation. The monitoring programme should cover the full gradient of reef state/threats (ie. un-impacted to highly impacted). With the reality of multiple reef zones in a system, it often means that only the best and also the most highly impacted sites are monitored – though intermediate reefs are desirable as they may demonstrate trajectories in either direction (recovery or degradation)[4]. There is value in selecting moderately impacted sites that are placed under a management regime, as this is where the effect of management in supporting reef recovery may be demonstrated. As a preliminary exercise, carry out a general survey of the reef sectors and sites to have an overall picture of the monitoring area, to ensure the representativeness of sampling stations,

5.1.3 Documenting sites - metadata

Once the sites/stations in a monitoring programme are selected, they should be described and quantified from multiple information sources, including general information and in-water observations. From general or secondary information, obtain all available information from a variety of sources (maps, documents, resource users, scientists) to describe the general characteristics at sector, site and station levels. Particular note should be made of the isolation of reefs from degrading influences so that some key reference sites are included in monitoring (though these may be far from pristine due to past impacts and a shifting baseline[5]). All sites and stations should be marked with GPS points collected in situ.

While some information on each site/station will be permanent, variable data should be collected on each sampling interval. A datasheet for this is provided, which serves two purposes:

- recording metadata on when/where sampling was conducted to maintain organization of datasheets and data for coding and input into the database;
- to document variable information such as water visibility, site conditions and any changing features such as human pressure, that may impact on data reliability or interpretation of results.

4 The PRECOI manual recommended 2 un-impacted and 2 impacted sites, Conand 1999,2000

5 The 'shifting baseline syndrome' is a severe problem for any new monitoring programmes, as sites may have already changed significantly from their prior state, and the monitoring programme may be starting from a middle or end point of a change process, rather than from the beginning.

Of particular importance is the need to record the site name, date and observer names as this essential information connects the datasheets to the overall sampling protocol. In some cases, time may also be critical, if more than one site, station or set of transects is collected in a day.

Table 1. Table of site metadata to be recorded in situ, based on Reef Check site forms. Note that it is important to minimize the number of items that must be recorded every single field survey, so at sites where the basic metadata has already been recorded, subsequent samples may not need to address all of these variables.

Station name	**Survey methods applied this time**
Country	LIT // PIT // image
Region/area/sector	Fish belt
Site/Station	Invertebrate belt
Data collectors/observers	Bleaching/threats
Date	Other (describe)
Time (started)	
Longitude	**Physical measurements**
Latitude	Air temperature
From GPS, chart or online?	Water temperature at bottom
Reef zone (Backreef/lagoon, Reef flat, Crest, Slope)	Horizontal visibility in water
Depth of surveys	Other (describe)
Orientation of transect (N-S, NE-SW, E-W, SE-NW)	
Exposure	
Weather	

5.1.4. Frequency of sampling

For most purposes in coral reef monitoring, annual monitoring has been found to be adequate to track long term changes in benthic structure and invertebrate/fish populations. It is essential that samples are collected in the same season each year (within 1-2 months) to avoid seasonal differences (which may be significant for algae and fish). The timing of samples should be set by accessibility and safety constraints in the monitoring area, when the water and winds are calmest and least unpredictable, with good visibility conditions. In the WIO, this is generally just before and during the northeast monsoon (November to April, with a period of difficult winds in the middle, around January), though there are significant sub-regional and local variations from this. As much as possible all sites/stations should be sampled within a minimum period possible (i.e. within one or two months), to minimize within-season differences that may be significant.

5.2. Line methods

Line transects sample a single dimension – the intersection of objects under a line (of zero width) and fixed length. They are well suited to benthic cover objects that are fixed in place and cover a proportion of the bottom, but not for discrete or mobile animals (see belt transects, section 5.3). Line Intercept Transects (LIT) are the most common method applied currently in the SWIO (43%, Obura 2014), followed by image methods (29%) then Point Intercept Transects (PIT, 14%). All three are described here, with LIT and image methods being recommended equally for application.

5.2.1. Laying a transect line – general principles

Transect lines should be run parallel to the main feature of a site – i.e. along a depth contour, parallel to the shore, reef crest or reef base, or along the long axis of the reef. Within each depth stratum (station), replicate transects need to be laid, so you must ensure there is sufficient space for them without resampling the same objects (corals/invertebrates/etc).

Selecting the specific location for a transect line (or any sample, including quadrats) is an important process. Two key aspects need to be considered:

representativeness of the location for the habitat. While the siting of a transect should not be biased (e.g. the best set of corals in a given area), transects should be placed in the correct habitat. That is, there is little to be gained by including excessive seagrass or sandy areas in a transect focused on coral community structure. Thus the length of transects and how to select the correct area for sampling, without biasing the procedure, must be worked out. For example, 20 m LITs may work along a continuous reef front, but 10 m or even shorter lines may be necessary for bommies in sandy lagoon.

a) random, haphazard or fixed locations. This affects the statistical rigour and bias in the monitoring sites. Most programmes use haphazard methods, ie. the observer selects an appropriate location for each sample as he or she goes along, being careful to avoid bias. However truly random and structured procedures are best statistically, but may be difficult to implement underwater. For the most accurate assessment of change, fixed sampels (transects or quadrats) give the best result as exactly the same location is sampled each successive time, however it becomes even more important to assure the initial locating of samples is randomized and unbiased.

b) Depending on the monitoring programe, the same line may be used for multiple purposes – e.g. all benthic, fish and invertebrate data. This is ideal where an objective may be to mmaximize the relationship between the benthic data and invertebrate/fish datasets. There may be cases, however, where this is not possible operationally, e.g. to separate observers in the water to ease their work, or to minimize impacts of diver behavior on fish.

General procedures:

Use transect lines of the correct length for the transects being done. i.e. using a 50 m tape measure for 10 m benthic transects can result in having to secure an unwieldy tape measure in surge.

The beginning of the transect tapes should have a hook or hoop to facilitate attaching it to the bottom, or a weight. Similarly, it helps if the spool of the tape is negatively buoyant, or there is extra tape/line to wrap around a rock/projection to keep it tight.

Typically, transects are laid end to end, with a spacing distance of 5-10 m, though in large flat expansive habitat, they may be laid parallel to each other or even in random directions.

5.2.2. Line Intercept Transects (LIT)

This is the principle recommended benthic method under GCRMN.

Method description: Line intercept transects (LIT) are used to determine the percentage cover of benthic communities. The LIT is the standard method recommended by the GCRMN to determine percentage cover for management level monitoring.

Identification: benthic categories can be assessed at different levels of identification, generally about 10 general benthic types (Level 1) through growth/function forms (Level 2) to genera (Level 3) for key groups such as hard and soft corals, and fleshy algae. At present, identification of at least functional forms (Level 2) should be standard for GCRMN, with progression to Level 3 (genera) being desirable. However some coral genera can have multiple growth forms (e.g. Acropora is represented by 5 growth forms), so converting between the two can be challenging.

Similar methods: LIT is a continuous version of PIT (Point Intercept Transect, section 5.2.2), and in this manual and the CRIS database, data entry is essentially the same. This is done by assuming that LIT as a best resolution of 1 cm, whereas PIT points may be 10 – 50 cm apart, depending on the programme.

Equipment required: 10 or 20 m long transect tapes; slate/pencils and datasheets.

Field personnel: 2 observers (snorkeling or scuba) with expertise in identification of coral reef benthic categories (see section 5.6.1).

General procedures:

Laying the tape

- LIT lines are generally 10 or 20 m long. See section 5.2.1 for selection of the specific location.
- Stretch the transect line tightly and close to the bottom (0-15 cm), using the edges of rocks/bommies/coral heads to stretch it tight. All care should be taken to maintain a straight, unbiased line, but to keep the line tight, sometimes it will have to zigzag a bit.
- Once the transect is completed (and depending on if the tape is also used for other purposes), roll it up, swim to a point at least 5-10 m beyond the end of the previous transect, and start again.

- Replication and sufficient sampling of the benthos are essential for statistical reliability. If 10 m lines are used, a minimum of six replicates should be collected. If 20 m lines are used, a minimum of 3-5 lines should be collected, all depending on the arrangement with fish/invertebrate lines. This means at least 60 m of sampling per site, and preferably significantly more than this (ie. > 80 m).

Recording data

- Ensure that accurate site metadata is entered on the datasheet, in particular station/site name, the name of the data recorder/observer and date. Other metadata on the site should be recorded in a primary site/station datasheet.
- Record the cover type under the 1 cm mark of the tape to start, then record the distance of each transition point on the tape (in cm, or m and cm) where the organism, substrate, growth form changes. The maximum distance of the transect (10 or 20m) should be the last point recorded.
- Identification of cover types can be done at three main levels (see 5.6.1) – gross cover types (level 1, basic), growth/functional forms (level 2) and genera (level 3). There is increasing push to improve the level of resolution, requiring greater training and experience for field teams.
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CRIS Underwater datasheets

- transect data is entered into three columns: distance along the transect (from 1 to the maximum length (in cm); cover type, according to the level being used by the observers; and any additional notes/ observations, such as on coral condition, physical damage, etc.
- four sets of columns are provided to optimize use of space underwater. A long transect should be entered across multiple columns, and the transect number recorded in the space above.
- Multiple transects can be recorded on the same sheet, so long as a clear break between transects is shown, e.g by crossing out intermediate rows or by starting in a new set of columns.

Advantages:

- The LIT method is simple to implement, and growth form categories allow the collection of useful information for those with limited experience in the identification of benthic communities, especially on high-diversity reefs;
- Minimal equipment required;
- LIT, point intercept transects, video transects and benthic photos give the best estimates of percent coral cover and diversity;

- Similar techniques, like belt and video transects provide comparable information;
- Information on coral colony size is obtained, providing a useful indicator of coral community stability (large average size indicates no recent disturbance; small average size indicates recent disturbance and recolonisation (Meesters et al. 2001), and see Obura and Grimsditch (2009)).

Limitations:

- It is difficult to standardise some of the growth form categories among observers;
- High variance in monitoring ability among programmes can lead to difficulties in comparing results across different levels of identification;
- The monitoring objectives are limited to questions concerning percent cover or relative abundance;
- Inappropriate for the assessment of demographic questions concerning growth, recruitment or mortality;
- Not good for quantitative assessments of cover or abundance of rare and small species;
- Does not provide direct data on colony size frequency distribution (although this can be estimated);
- Cannot track specific colony fate and sublethal impacts;
- Does not measure rugosity or uneven surface of coral reefs, though this can be added (see 5.2.4);
- Time consuming underwater.

LIT is more rigorous than PIT for determining percent cover of benthic communities, but is more time consuming. LIT is recommended if underwater time is not a problem; however, if time is a problem, PIT may be more appropriate. However, if resources and expertise allow, photographic methods are preferable.

Training required:

- Medium to advanced benthic community identification;
- Regular comparisons between observers is required to reduce inter-observer error. This is important if meaningful temporal data are required.

5.2.3. Point Intercept Transects (PIT)

PIT are essentially similar to LIT, except that LIT are continuous (ie. resolution is minimum effective for coral reefs, at about 1 cm), whereas in PIT cover under individual points, generally between 10 and 50 cm apart, is recorded. Effectively, this sets a resolution limit for PIT so is less accurate, but data can be recorded much more quickly.

Many monitoring programmes start with PIT because it is simpler and quicker, and the smaller number of points mean that lower levels of identification are more appropriate. However for long term monitoring, LIT is preferred, and skills should be built up to undertake LIT.

See the instructions for LIT (section 5.2.1), with the differences below applying to recording data under "General procedures".

General procedures

- Transects are laid out exactly as for LIT.
- The resolution of the PIT must be determined. In general, distances apart of each point such as 10, 20, 25 and 50 cm have been used, and a decision must be made which to use. The shorter spacing requires more effort and gives more precise results, while the longer spacing requires less effort, and gives less precise results.
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Recording data

- When recording data, swim over each point and identify the cover type below each point. Care must be taken to be vertically above the point (or perpendicular to the substrate, if on a slope), as parallax error can be very high due to the limited number of points used.
- With some approaches each individual point is recorded, though as with LIT, it is only necessary to record the point at which the benthic cover type changes.
- Transfer of data to the computer is the same as for PIT, though ensuring that the resolution of the PIT method is appropriately recorded to enable calculation of percent cover.
- With the lower resolution of data points in PITs, generally coarser identification categories should be used.

5.2.4. Rugosity

Rugosity, or the three-dimensional structure of the reef surface, is a key factor influencing the complexity and robustness of a reef community, as complex three-dimensional surfaces offer many more niches and more livable volume for species. A simple line-based method that can be combined with LIT and PIT sampling has been used by many programmes for estimating rugosity.

Equipment required: a light chain 10 m long, or the transect line in use for LIT/PIT.

General procedures:

- Implement this after recording the LIT/PIT data
- Use a light chain, or the transect line itself, though one end must be loosened for this.
- Starting at one end of the transect, drape the chain loosely over the substrate so that it is touching all horizontal, sloping and vertical surfaces. Ignore overhands and crevices by letting the chain hang vertically over these until it touches the bottom again.
- If using the transect line, press it gently over the bottom so it conforms to the topography. This will pull the far end of the line closer to you. As you pass over the line the earlier sections of line may float freely, so it is important to ensure the line does not slide under your hands.
- Continue until the 10 m mark of the chain/line. Measure the distance from this point to the start of the transect line, which will be a distance < 10 m.
- Rugosity is calculated as ten divided by the distance measured. A value of 1 represents a perfectly flat substrate, with the index increasing as rugosity increases.

5.3. Belt methods

Belt transects sample two-dimensional area, generally using a fixed width on either side of a transect line, recording over an area of the length * total width of the transect. They are used for sampling discrete animals/observations that are not well sampled by linear transects.

5.3.1. Fish belt transects

This is the principle recommended fish method under GCRMN, and used by 93% of monitoring programmes in the SWIO.

Method description: These methods aim to count (quantify) the abundance and community composition of fish on a transect. Since fish move, it is difficult to achieve a uniform sampling method along the transect. Observers should swim at a constant speed and be careful to not count the same fish or group of fish twice as they can move away from the diver along the transect. Care must also be taken to spend the same amount of time observing each part of the transect.

Identification: the taxa commonly used for fish surveys in the WIO have been determined through experience, and are shown in section 5.6.2. Identification at the family level is the most basic and may be sufficient for general management. Identification to species level is likely only to be done for key resource or indicator species that are easily recognizable, and the selection of species here combines current Reef Check species and additional key species for the WIO.

Similar methods: point counts are sometimes used for fish, where movement along a transect is impractical or inappropriate; roving diver or 'long swims' may be used where the area-restriction of a transect limits inappropriately the species or individuals that may be counted.

Equipment required: 25 or 50 m long transect tapes; slate/pencils and datasheets; fish models to practice fish length estimations.

Field personnel: 1 observer and 1 tape layer.

General procedures:

Laying the tape

- When benthic and other methods are also undertaken, often the same line is used for all (though benthic transects may only use the first e.g. 10 m of a 50 m tape for fish).
- Because of temporal differences in fish behavior, transects should be done during a consistent window over the middle of the day, avoiding sunrise and sunset – between 9 AM and 4 PM is ideal. Tidal state may also be important, particularly in shallow areas less than 4-5 m, and more so when tidal ranges are large (> 2 m).
- See section 5.2.1 for selection of the location and laying the transect.
- To minimize inhibition of shy fish, either
    - the main fish counter should swim first, followed closely by the buddy who will be laying out the transect line. The tape-layer alerts the fish counter when the end of the transect line is reached;

  - or, lay the line then wait 5-10 minutes for fish behavior to return to normal before starting to collect data.
- Replicates. Fish communities are hyper-variable due to their movement, so ideally a minimum of 5 lines and ideally 10 or more lines should be sampled per location. With shorter transects (25 m), more should be taken compared to long transects (50 m).

Recording data

- Record the horizontal water visibility on entry, as this can affect data collection particularly for shy/distant fish;.
- The observer swims ahead of the tape layer. Alternatively, wait for 5 to 15 minutes after laying the line before counting to allow fishes to resume normal behavior.
- Observers must look ahead and move at a consistent speed to spend the same amount of time on each part of the transect for each group of target fish.
- Swim slowly along the transect recording fish encountered in a tunnel 5 m wide and 5 m tall around the transect;
- Count the actual numbers of target species seen within the transect strip;
- If recording size classes, then estimate individual fish sizes in 5 or 10 cm classes;
- Do not compromise getting a good overview of the community by trying to count all individuals of some taxa, at the expense of missing estimates of abundance for others.
- In areas of high fish diversity and abundance, we recommend that the tasks be separated. This can either be done in 2 or more passes where different groups of species are counted on each pass, e.g. larger mobile fish on the first pass, and smaller territorial fish on the second pass; or the task can be split up between divers.

Underwater datasheets

- Ensure that accurate site metadata is entered into the header spaces, in particular station/site name, the name of the data recorder/ observer and date. The other data should be recorded in a primary site/station datasheet.
- The layout for underwater data collection can be very varied, based on the preferences of individual researchers and data collectors. Because of the high diversity of fish names being recorded, and multiple size classes for each name, it is often not possible to have a fully layed-out grid for recording numbers, as common fish may need more space to enter all the observations.

- A hybrid layout is often used, listing the principle families, with more space for the diverse/most common ones, with the most common genera/taxa already written, but leaving open space for noting the size class and numbers seen.

Advantages

- Visual census of fishes is one of the most common quantitative and qualitative sampling methods used;
- Rapid, non-destructive and inexpensive;
- Minimum personnel and specialised equipment required;
- The information obtained is useful for management and stock assessment.

Limitations

- Observers must be very well-trained;
- Fish may be attracted towards the divers, or actively swim away from the divers;
- Observer error and biases occur in estimating numbers and sizes;
- There is low statistical power to detect change in rare species;
- Transects are impossible to use on some reefs due to complex habitat features, strong currents, regulations or other.
- Accidental interference from other divers;
- Some fish are attracted to moving divers; some are repulsed. This biases the results;
- Transects are not suitable for sampling small, restricted areas, e.g. some reef microhabitats and areas

Training required

- Fish identification
- Estimating fish lengths underwater requires experience, especially if narrower (5 cm) size classes are used. Twenty or more randomly cut fish models, or pieces of PVC tube should be cut and can be strung randomly along a transect/float line for observers to practice estimating their size from different distances. Run periodic trials, recording the accuracy of each observer.

5.3.2. Invertebrate belt transects

This is the principle recommended invertebrate method under GCRMN, alongside meter-square quadrats if needed, for higher density invertebrates. Together, belt transects (78%) and quadrats (15%) are responsible for almost all invertebrate monitoring in the SWIO.

Method description: These methods aim to count (quantify) the abundance of key macro-invertebrates on a transect. However, since the invertebrates can be quite cryptic and may inhabit crevices in the reef framework, variation in numbers can be very high. Observers should swim at a constant speed and carefully examine crevices. If you determine that densities are too high to count in the belt, then application of quadrats may be more appropriate.

Identification: the taxa commonly used for invertebrates surveys in the WIO have been polled from different groups, see section 5.6.3. Identification level varies greatly by taxonomic group and monitoring programme. Identification at species level might be done for key resource or indicator species that are easily recognizable, and/or for management-oriented monitoring.

Similar methods: Used in conjunction with quadrats, which are used for high-density groups.

Equipment required: 25 or 50 m long transect tapes; slate/pencils and datasheets.

Field personnel: 1 observer/tape layer, may be done in conjunction with fish or benthic transects.

General procedures:

Laying the tape

- When benthic and other methods are also undertaken, selecting the location and tape laying may be done together.
- See section 5.2.1 for selection of the location and laying the transect.
- Replicates. Invertebrate communities are extremely variable due to their movement and often cryptic sheltering in the reef framework, so ideally a minimum of 5 lines should be sampled per location. With shorter transects (25 m), more should be taken compared to long transects (50 m).

Recording data

- Different programmes have used different belt widths for invertebrates, generally 1 or 2 m wide.
- Swim the transect twice; the first time count more mobile, larger and more clearly visible invertebrates. The second time, swimming back over the transect, count the less mobile and cryptic ones.

- Many mobile invertebrates can be cryptic, so careful inspection of crevices is needed.
- Many mobile invertebrates have strong diel behavior patterns (ie. determined by day or night, and even time of day and tide), so monitoring should be done within a consistent time band, most likely from mid-morning to mid-afternoon.
- Count the actual numbers of target species seen within the transect strip, and for those for which size data is required, record sizes as necessary.

Advantages:

- Visual census of invertebrates is one of the most common quantitative and qualitative sampling methods used;
- Rapid, non-destructive and inexpensive;
- Minimum personnel and specialised equipment required;
- The information obtained is useful for management and stock assessment.

Limitations:

- High variability in the presence of macro-invertebrates can result in very variable data that is difficult to analyze;
- There is low statistical power to detect change in rare species;
- Transects are impossible to use on some reefs due to complex habitat features, strong currents, regulations or other.
- Transects are not suitable for sampling small, restricted areas, e.g. some reef microhabitats and areas. In these cases, use quadrats.

Training required:

- Invertebrate identification

5.3.3. Coral condition/threats

Coral condition and threats are increasingly being monitored on coral reefs, though the diversity of threat types (e.g. bleaching, disease, predators, etc) can make it challenging to do this consistently across programmes. This section just describes the general method, but see section 7 for further advice on specific types of threats, such as coral diseases.

Identification: the selection of which threats to measure must be done with considerable local knowledge, to assure the most significant threats are monitored. It also requires expert guidance to identify at what level of resolution to monitor them and how. The general threat categories that can be monitored using this approach are summarized below.

Similar methods: Used in conjunction with LIT/PIT and mobile invertebrate belt transects.

Equipment required: 25 or 50 m long transect tapes; slate/pencils and datasheets.

Field personnel: 1 observer/tape layer, may be done in conjunction with benthic or invertebrate transects.

General procedures:

- Use the same tape and methods as described in invertebrate belt transects, using a belt width of 1 or 2 m.
- Count the actual numbers of target conditions/threats seen within the transect strip, and for those for which size data or descriptive notes are required, record these as necessary.
- Common target conditions included in monitoring programmes are indicated below (from Obura and Grimsditch 2009):
    - Crown of thorns seastars (COTs), Acanthaster planci.
    - Cushion star, Culcita.
    - Drupella – predatory snail, often found on branching corals.
    - Eroding sea urchins – large-bodied sea urchins, in particular the genera Diadema, Echinothrix and Echinometra.
    - Diseases of various types
    - Tubeworm and other types of infestations
    - Etc.

Training required:

- Identification of the target conditions/threats (e.g. see coral disease section).

5.3.4. Coral bleaching

Coral bleaching is among the most widespread indicators of stress to a reef today, and is increasing in frequency throughout the WIO with background warming and larger fluctuations in extreme summer temperatures (Hoegh-Guldberg 1999, McClanahan et al. 2014). Methods for monitoring coral bleaching are quite varied, including methods that are more rapid in nature (e.g. McClanahan et al. 2007) and those more tied to transects and based on monitoring methods (e.g. Obura and Grimsditch 2009). For consistency with the monitoring methods covered in this manual, transect-based techniques are emphasized here.

Identification: coral bleaching is difficult to measure by eye, being based on a subjective assessment of paleness or whiteness of coral tissue. Because of wide variation in natural colouration of corals, this is fraught with difficulties. Colour cards have been developed (Coral Watch) to assist with making colour analysis more objective, but recent findings show that only the whitest shade and the next whitest shade correspond reliably to bleached and pale conditions, respectively (Montano et al. 2010). On top of this, the observer must identify the type of coral, with the most useful level being to genus level.

Similar methods: Used in conjunction with belt transects for coral condition.

Equipment required: 25 or 50 m long transect tapes; slate/pencils and datasheets.

Field personnel: 1 observer/tape layer, may be done in conjunction with condition transects.

General procedures:

- See above sections for laying the transect line.
- In some cases, bleaching observations may be done on their own, to monitoring progression of a bleaching event, in which case no other methods will be applied.
- Use of a belt transect is advised (e.g. 1 m wide and 10 or 25 m long), as methods relying on just estimating an area in front of the observer can result in strong bias towards counting bleached colonies rather than normal ones (due to their visual appearance, and as that is the target of monitoring), and large rather than small ones.
- Where time allows, including colony size information is useful, as the combination of size and bleaching state may give useful information about the site. Using size classes rather than measuring individual size precisely enables more rapid data collection.

- Some programmes specify certain classes (e.g. pale, partially bleached, fully bleached, dead) into which to classify corals, but this can result in bias as many colonies may show differing proportions of each of these.
- Other programmes use a simpler classification of condition (normal, pale, bleached, dead), but then estimate the proportion of a colony showing each condition. This allows classification of major classes during data analysis, and better reflects the complexity of bleaching.
- Given that a bleaching event follows a progression over several months, monitoring of the event should be frequent, and as far as possible done at the peak level of bleaching, and several months later to document the final degree of mortality. Intermediate samples allow for more detailed construction of a timeline, and two-week intervals may be ideal when possible.
- Because of the complexity of a bleaching response, the method of bleaching monitoring should be carefully designed for the programme, so expert advice should be sought.

Training required:

- Identification of coral colour is critical, and assigning colonies reliably to set categories (see above). Otherwise, experience in belt transects and benthic monitoring is required.

5.4. Quadrat and circular count methods

Quadrats and circular plots sample two-dimensional area, and are used as alternatives or complements to belt transects for a variety of reasons, including:

- high densities of subject organisms require smaller units than belt transects;
- methods where the observer is stationary may have advantages over those where the observer is mobile (e.g. in the behavior of fish);
- aspects of logistics or diver safety, or water conditions, may make laying of transect lines impractical or hazardous.

There is also no a priori reason why a square quadrat should be used over a circle, and in some cases, circular plots may be easier (e.g. fish Stationary Point Counts) where the area is too large for use of a quadrat, or in cases where the equipment used (a radius line of 56 cm for 1 m^2 circle) may be simpler to carry and deploy than a 1m^2 rigid quadrat made of PVC piping. Table 2 shows radii for circular plots of varying sizes that might be used.

The main approach for laying quadrats is outlined first, then specifics for each of four special cases are given.

Method description: Involves set quadrats or plots, placed either haphazardly, at regular intervals along a transect, or randomly, in the sampling area. Which of these approaches is used must be defined by the programme and adhered to in subsequent years.

Table 2. Radii for circles of given area.

Circular plot dimensions	
Radius (m)	*Area (m^2)*
0.56	1
0.80	2
1.26	5
1.78	10
3.99	50
5.64	100
6.91	150
7.98	200
8.92	250

Similar methods: Used in conjunction with the transect methods described above.

Equipment required:

Quadrats - PVC piping is used to make quadrats though be careful to select high-density (pressure pipe) PVC as low-density (conduit pipe) PVC floats. Drill holes in the PVC piping to facilitate escape of air when entering the water, so the quadrat sinks.

- The standard size is 1*1 m, to make an area of 1 m^2. Smaller or larger units may be made, depending on the need. Very large quadrats could be laid out with weighted rope.
- For quadrats that are large relative to the size of the objective (e.g. coral recruits), they may be divided using string into squares to help estimation and counting, e.g. at the 50 cm, 25 cm or 10 cm intervals.

Circular plots – any string may be used, weighted at one or both ends (e.g. with a fishing weight) and cut to the correct radius, or with knots at specified radii for different circle areas (see Table 2).

Field personnel: 1 observer, may be done in conjunction with other teams.

General procedures:

- Quadrats/circles may be placed using a number of different approaches, which must be selected and fixed by the monitoring programme.
- Placement may be along transects used for other purposes (benthic, invertebrate), or haphazardly/randomly in the sampling area.
- The exact placement of the quadrats may be done in different ways.
    - At intervals along a transect tape, which may be selected in various ways, e.g. a) at fixed intervals along the tape (e.g. at 0, 5, 10, 15, 20 and 25 m on a 25 m tape), or b) using random numbers to select the location along the tape;
    - Haphazardly in the area of the transects; or
    - Truly randomly, using randomly generated numbers (from a table or computer) to identify distance of quadrats along a transect line, or in relation to some other fixed point in the sampling station.
- The method of selection of quadrat locations should be fully described and justified, as it has implications on statistical analysis.

Advantages:

- Cost effective;
- Less likely to overlook small, rare or cryptic species in small quadrats;
- Detailed information on algae type and abundance.

Limitations:

- Time consuming;
- Estimation of area/numbers can vary between observers. We recommend standard training for all observers.

5.4.1. Benthic cover

Today, most programmes use LIT, PIT or photographic methods for benthic cover, while in the past 1m^2 quadrats were popularly used. While not advised any more, if they are used, then the same benthic cover categories/identification should be used (see section 5.6.1).

General procedures:

There are two basic options for recording cover using quadrats:

- Estimation of % cover by eye – the observer must learn by experience the full range of % cover of life forms/benthic categories being observed.
- The quadrat is divided by strings, e.g. at 10 cm intervals across all sides, and the intersections of the strings are used as point intercepts to identify the cover type immediately below them. This is analogous to a grid of points for analyzing photo quadrats, see section 5.5).

5.4.2. Mobile invertebrates

Quadrats are used for high-density mobile invertebrates, most commonly boring sea urchins that can be present at > 10 per m^2, too numerous to count in long belt transects. In general, if you are counting more than 40-50 individuals in a sample unit (e.g in a belt transect of 2*50 m) then consider sub-sampling with smaller belts or quadrats.

General procedures:

- General procedures are very similar to the belt transect method.
- The smaller area of a quadrat can improve observations of cryptic species.

5.4.3. Coral recruits and juveniles

Quadrats of 50*50 cm or 1*1 m are commonly used for counting small corals under 5-10 cm in size. Because many coral recruits are hard to see and/or cryptic, it is necessary to search closely all 'bare' rock or coralline algal surfaces. The smallest corals reliably visible to the naked eye are in the range of 3-5 mm, and are easily mistaken with other encrusting invertebrates (e.g. soft corals, bryozoans, etc.), so experience is necessary to count small corals accurately.

General procedures:

- Identification of small corals is challenging, with genus and family generally being the best resolution possible, and in many cases 'unknown' will have to be recorded.
- Size of individuals - a ruler or caliper may be required if precise size is being measured. Alternatively, standard size classes may be used for coral recruits, e.g. 0-2.5 and 2.6-5 cm, or 0-5 cm).

- Some programmes record 5-10 cm colonies as well, though these are understood to be juveniles or 'immature colonies' now, rather than recruits.
- The use of ultraviolet (or 'black') lights is often recommended for recruit surveys, as fluorescent colours in the corals in reaction to the lights may make them more visible. However the reliability of the technique is less in broad daylight and very shallow waters, and validation of the percent increase in counts using lights vs. without them has not been well documented – so it is not clear how to compare data between programmes that do and don't use lights. Without greater attention to comparability of data using these lights, it is not recommended that general monitoring programmes use them.

5.4.4. Algal community

More detailed measures of algal community characteristics are measured by some programmes, and quadrats enable estimation of % area (by eye, or using grid intercept points, see 5.4.1) and measurement or estimation of algal frond height, giving an index of biomass in addition to percent cover.

General procedures:

- 1 m^2 quadrats are generally used for algal community data,
- the level of identification used is similar to that used in LIT (see section 5.6.1), from functional form to genus level.
- The percentage of the quadrat covered by each algal type is estimated similarly to the approach for benthic cover (5.4.1).
- The height of erect algal taxa can be measured with a ruler or stick, to the cm. Depending on the objectives of the programme the maximum or average height of each taxon could be measured, and/or several samples of height could be made enabling calculation of the average height.

5.4.5. Stationary Point Counts - fish

Stationary Point Counts are the equivalent of quadrats for fish. Because of the larger size of the sampling unit, circles are always used rather than squares. They solve some of the problems with belt transect methods, in particular where:

- It may be very challenging or inappropriate to lay a transect (e.g. strong currents, or to sample isolated bommies in large sandy areas, etc)
- The focus is on stationary and small/cryptic species that are very site-attached
- Where diver movement may bias data collection.

General procedures:

- No transect lines are used. The observer selects locations for placement of each sampling circle according to criteria established for the programme, e.g. representative patches of coral habitat, spacing over 20-30 m between circles, etc. These must be determined prior to sampling and standardized as far as possible to minimize subjectivity and bias in selection of each point.
- To minimize influence of the observer on shy species, the observer should identify the center of the circle before entering the perimeter, as well as estimating the perimeter of the circle.
- Record data on fish leaving the sampling unit as a result of the diver's behavior.
- A marker can then be placed at the center of the sampling circle, and the perimeter of the circle confirmed visually.
- The observer stays in the center, rotating slowly to record the target taxa until all large taxa are recorded, then swims around the circle to inspect crevices and document cryptic species and smaller individuals.
- Similar practices of how long to record each circle and intensity of inspection of crevices should be followed as would be set for belt transects.

Compared to belt transects for fish, point counts have the following advantages and disadvantages:

Advantages

- Not using a transect line, circular counts are easier to implement in difficult conditions (swell, currents, etc), and where dive safety and practices make it hard to return back and forth along the same line.
- Some research has shown the stationary observer has less influence on fish behavior than the swimming observer on a transect.
- By having the entire sample visible at any one time, there is less influence of fish swimming in and out of the transect, and other sources of variability.
- In patchy habitats (e.g. back reef bommies), circles may more effectively sample the habitat.

Disadvantages

- By covering less distance along a habitat, point counts may be more vulnerable to location bias.
- Point counts may be less effective in sampling wide ranging species than extended transects.

Since most programmes in the SWIO use transects rather than point counts, transects are more generally recommended. If point counts may be used, adequate consultation with experts should be done to ensure the benefits outweigh the disadvantages.

5.5. Photo and video methods

Image analysis is becoming increasingly common for benthic data, so is described here as a second set of recommended benthic methods under GCRMN. However, to reliably undertake image analysis, a programme must have the ability to PERMANENTLY have access to:

1. an underwater digital camera, including the ability to have a backup camera or the funds to replace a flooded camera at short notice; and
2. working computers with necessary software (e.g. Coral Point Count and Microsoft Excel (CPCe), http://www.nova.edu/ocean/cpce/).

Method description: photographic images, captured by still or video cameras are used to determine the percentage cover of benthic communities. In addition, they provide a permanent record of the appearance of a site, enabling re-analysis, viewing of ‘typical features’ and illustration of data reported from the monitoring programme, and new analyses not planned at the time of collection.

Similar methods: the decision to use still versus video images is covered below in advantages/disadvantages of the method. Though different from LIT/PIT data, analysis of the methods has shown that percent cover from these techniques is comparable, if collected without bias.

Equipment required: Underwater digital camera (still or video); 20 to 25 m long transect tapes optional; slate/pencils and datasheets. For still images, camera resolutions above 8 MP are standard now, and of sufficient quality for general analysis.

Field personnel: 2 observers (snorkeling or scuba divers) with expertise in identification of coral reef benthic communities (see below).

Lab personnel: Data entry, archiving.

General procedures:

Selecting the location

- Selection of the location is similar to LIT/PIT methods.
- Of key importance for image methods is that images must be taken perpendicular to the surface, so if the bottom topography varies greatly, there must be space for the camera to be placed appropriately, the correct distance from the image plane.
- Visibility is a key constraint for reliable images, and anything less than 8-10 m visibility can compromise the visibility of small features on the benthos.
- Replication and sufficient sampling of the benthos are essential for statistical reliability. Practise varies greatly between different programmes, see section 5.5.3.

Recording images

- Transect lines may be used to guide image-taking, particularly where these have been used previously for data collection. They may also help to reduce bias when sampling the substrate. If transect lines are used, note that if the tape is included in the image frame, then it obscures whatever might be underneath it so that some point observations will be 'null'. Further, light-coloured tapes may result in a bright flare in the image, obscuring some points on either side of the tape as well. Using a tape as a guide, but keeping it just outside the image frame, or at one edge of the frame, may provide the best compromise between the advantages/disadvantages of using a tape.
- Primary data is collected on the UW camera, but a slate/datasheet for recording metadata underwater can be helpful in keeping images organized, and assist with image analysis. Ensure relevant metadata about the site is recorded on each UW datasheet – site name, date observer name, and transect number or code are essential. Additional data, such as depth, total number of images, tape/transect details and others can be recorded. Before each transect or set of images,

take a photograph of your slate annotated with the site/transect information or of any non-benthic view to mark clearly the beginning/end of data images.

- Identification of unusual or small features on the images can be challenging, so notes on principal benthic types, unusual features/species and notes on any obscuring factors (e.g. surge, large fleshy algae, visibility, sun conditions, etc.) can help in image analysis.
- The camera to subject (benthos) spacing is a factor that should be fixed for a monitoring programme. In general, spacing of about 60-75 cm provides a good compromise between area of benthos covered, visibility of small objects, minimizing the effect of turbidity/obstructions in the water, light levels (e.g. flash power), etc.
- The monitoring programme must decide if the camera will be held perpendiciular to each image frame (ie. tracking the detailed topography of the site) or held at the same angle to the overall bottom/slope (ie. vertical/angle surfaces may not be visible enough to record data, and the camera to benthos distance may be different within a frame). They each have their strengths/weaknesses.
- Using a tetrapod/monopod is one of the main methods for ensuring the correct camera to subject distance. However, these may be difficult to operate in areas of strong currents or where divers must multi-task and collect other data. The tetrapod is the most stable, but difficult to manage, a monopod provides compromises for ease of use. If neither are used, then the observer must check frequently the camera to subject distance by estimation on a line, or a spacer stick/monopod that is not used in the frame itself.
- Use of a flash/strobes can greatly assist in visibility of items on the substrate, but adds the dimension of additional cost and risk of equipment failure. The table below summarizes some of the do's and don'ts of using flash versus natural light.
    - Flash – gives consistent and strong lighting with overall better results for the image, but strongly affected by back-scatter (higher turbidity, or suspended sediments in surge). Two flashes provide more balanced lighting than one. Problems: ensuring batteries are sufficiently charged, that photos are not overexposed, equipment becomes bulky and hard to manage. May be necessary for depths > 10-15 m.
    - Natural lighting – can be fine in depths < 10 m, and a filter or image correction to restore red in the images can provide ideal image contrast for identifying CCA and some invertebrates. Ensure the body of the observer/camera is not shading part of the image. Equipment is less bulky and there are fewer variables for equipment failure.

- At the beginning or end of the field session, take some general views of the site to help in contextualizing the data frames and also take close-ups of some of the characteristic or difficult-to-identify features that may appear in data frames. Note these on the datasheet.

Advantages:

- Images provide a permanent record of the primary source for data, which allows for reanalysis if there are any doubts, and a visual record that helps to understand the data obtained;
- Equipment needed is relatively standard now and affordable (a basic UW camera costs about $250, though for reliability and robustness, systems of $6-800 are better);
- Compatibility with other common methods such as LIT/PIT;
- Information (limited) on coral colony size can be obtained from the images;
- Rapid implementation underwater means that observers can collect other data, expanding the range of data that can be collected
- Does not require high identification skills for the underwater team, so can be collected by unskilled personnel, or those focused on other aspects of the monitoring programme.

Limitations:

- Some aspects of the three dimensional structure of the reef benthos cannot be recorded in images, so details may be lost;
- Some small or partially obscured features (e.g. small corals among fleshy/turf algae) can be very difficult to distinguish on an image;
- Very strongly affected by ambient conditions – light levels, turbidity, waves and roughness, etc.
- Does not measure rugosity or uneven surface of coral reefs;
- The time required for analysis of images on the computer can be extremely high, and may require more highly-skilled observers than for underwater identification (as underwater, an observer can spend more time and look more closely/from multiple angles at an object to assist with identification). Note – in the future, automated image analysis may be able to identify a percentage of bottom features (e.g. up to 70%), but this still will require an operator to identify the remaining items that are uncertain, and verify the automated analysis.

Training required:

- Low level of training for image acquisition – requiring physical skills underwater.;
- High level of training for image analysis.

5.5.1. Still image/photos

Some additional pointers for using a still camera:

- it is essential to hold the camera still when taking the photo, to minimize any blurring. Some programmes use a tetrapod (a four-legged frame with the corners marking the corners of the image) or monopod (a single-leg stick, mainly used to assure camera-subject distance) to stabilize the camera.
- If collecting images along a tape, swim forward to the prescribed distance marker, stop over it and take the photo.
- If not using a tape, or just using it as a guide, space the images by a fixed number of fin kicks (e.g. 3 cycles), and ensure there is no overlap of images from one to the next. Make sure you are stopped when taking the photo.
- At the beginning or end of the image series, take some general views of the site to help in contextualizing the data frames and also take close-up photos of some of the characteristic or difficult to identify features that may appear in data frames.

5.5.2. Video images

Some additional pointers for using a video camera:

- it is essential to move slowly and at a regular speed while holding the camera perpendicular to the substrate. Try and compensate for surge (side to side, or back and forth) to minimize its effect. Using a monopod may help with keeping a regular camera-to-benthos distance, but it can bump into uneven features causing jerking of the video image.
- If collecting images along a tape, ensure it stays in the same position in the image – i.e. in the middle or to one side.
- At the beginning or end of the image series, take some general views of the site to help in contextualizing the data frames. If the camera has high resolution still photo options, take close-up photos of some of the characteristic or difficult to identify features that may appear in data frames.

5.5.3. Recording data from images

Photographs, or freeze-frames from a video, are analysed for benthic composition and coral cover using dedicated software such as Coral Point Count (Kohler and Gill 2006). Alternatively, generic image software such as Adobe Photoshop can be used, where it is possible have several layers in one image. As with other methods, there are many decisions to take in designing the sampling approach from images, and expert advice should be obtained.

The number of images to use, and number of points for sampling on each image are interdependent. A rule of thumb (Obura and Grimsditch 2009) is to use a grid (or randomly selected scatter) of 25 points on one image, and combine the results of 4 images together to form one sample, or 'transect', of 100 points. The images for one transect can be sequential, but preferably, to reduce sampling bias, can be randomly selected from the available images using a random number generator. At least six of these transects should be scored to calculate the mean and standard deviation of cover types, and more is preferable. To ensure sufficient images are available, > 40 photographs should be captured for each site, to allow for out-of-focus/problem photos.

To maximize efficiency however, the number of points per image and number of images to collect can be identified though optimizing cumulative curves for the area – ie. if 10 points per image gives sufficient accuracy and 30 rather than 40 images, then the monitoring programme will be more cost-efficient. However this should only be done with high level advice.

5.6. Taxonomic identification

Identification is one of the key challenges in coral reef monitoring due to the high diversity at multiple taxonomic levels of coral reef species. To cope with this, basic programmes use general classes and functional morphology to group species together, but this also has its challenges due to variable morphologies among species and higher level taxa – the problem of identification is not reduced to zero.

For the level of monitoring proposed in this manual, and set as standard for the GCRMN, species-level identification is generally not required, apart from of key recognizable indicator (or flagship) species. A significant exception is for fish, where estimation of biomass from abundance and size class data is greatly improved by species-level data collection (see below). In all cases, the levels are grouped hierarchically with Level 1 being the most general, thus data collected at higher taxonomic resolution (i.e. Level 3) can be aggregated to compare quantitatively with data collected at a lower level (i.e. Levels 1 or 2). This helps to support a basic function of this manual and the CRIS, which is to facilitate national and regional level reporting of coral reef monitoring under the GCRMN.

5.6.1. Benthos

Three levels of identification for benthic data capture the range of practice currently being implemented globally, as well as in the WIO (Table 3):

Level 1 is intended to differentiate the main 10-12 major life forms and abiotic substrates that dominate space on coral reefs, differentiating hard from soft corals, other sessile invertebrates, 4 principal functional forms of algae (fleshy, erect calcareous, encrusting coralline and turf), and other major types such as sand, rubble, etc. Categories for bare rock and unidentified cover types are also included. In general usage in GCRMN there is some crossing of live cover type (e.g. turf algae) and substrate type (e.g. rubble – which could be covered by turf algae) that is avoided in other classifications (e.g. the MSA, see section 6.4).

Level 2 is intended to differentiate major functional forms within the main biotic classes, though historically with a focus just on hard corals (i.e. branching, encrusting, massive, submassive, Acropora (and this may be differentiated in several growth forms too). Some differentiation of soft corals is also given.

Level 3 is intended to allow genus level identification of hard and soft corals, algae and major invertebrates such as bivalves. In the WIO, sponges have generally not been identified. Note also that for some genera it is not possible to fully define a hierarchy from level 3 to level 2 classifications, as the genera may have multiple functional (growth) forms.

Table 3. Hierarchical classification of benthic cover types at levels 1 and 2 for standard reef monitoring, building on historical practice. Level 3 classification is at genus level, including for corals, soft corals, invertebrates and algae.

Level 1	Code	Level 2
Coral	HC	branching, encrusting, submassive, foliaceous, Acropora branching, Acropora digitate, Acropora encrusting, Acropora submassive, Acropora tabulate, massive, Millepora, mushroom, Tubipora
Soft coral	SC	leathery/carpeting, fans, branching/erect, encrusting/fine
Inverts-other	INV	anemone, gorgonian, corallimorph, zooanthid, hydroids, sponge, ascidian
Algae-macro/fleshy	AMAC	
Algae-Halimeda	AHAL	
Algae-coralline	ACOR	
Algae-turf	ATRF	
Bare substrate	BS	
Rubble	RUB	
Sand	SND	Sand, silt
Seagrass	SGR	
Dead Standing coral	DC	
Recent Dead Coral	RDC	
Unidentified/Other	UNID/OT	
Obscured	OBS/TWS	Note – code is derived from CPCe (Kohler and Gill 2006)

5.6.2. Fish

Three levels of identification for fish data are described here, though mainstream practice currently is for family level identification (Level 1) and species level identification (Level 3). Level 2, at functional group level, is emerging as a key level of interest, though see text below. Fish surveys demand a higher level of expertise than benthic surveys, because of the high diversity of fish found on a reef.

Level 1 - typically, basic monitoring for fish is done at family level, though usually programmes focus on just a subset of families that are important in reef community dynamics and/or for local fisheries. Because of the prominence of key fish species, many programmes may also record just key taxa, such as in Reef Check. This reduces the need for extensive training to learn identification of 100s of species, as well as uncertainty over identification for some families. By focusing on very recognizable indicator fish, several sources of error are avoided, but the resulting datasets don't have general predictability for the overall fish community, and comparison among studies may be impossible.

Level 2 - A focus on functional groups is commonly done at the analysis stage, aggregating species by their classification into functional group. This is particularly relevant where con-generic species may have very different trophic/functional roles such that family and even genus-level identifications are too coarse for assessing functional group. Some attempts have been made to identify specific clusters of species within genera or families that are distinguished by function (e.g. different herbivore groups, see Green and Bellwood 2009, Obura and Grimsditch 2009) – i.e. most fish can be sampled at the family level, but some key genera and even species may need to be identified as well.

Level 3 - A major justification for species-level monitoring of fish is for biomass estimation, as biomass gives a better overview of fish community structure than abundance does. The dependence of length-biomass conversions on the shape of a fish means that species-level identifications reduce variance associated with differences in body shape among species within genera and families, thus biomass estimation for genus and family level identifications introduces large inaccuracies.

Prior to implementation, a monitoring programme will need to set its list of fish taxa being monitored. Especially at Level 1, if all fish are targeted, then the experience level of the observer will have a strong influence on whether minor/uncommon families are recorded and/or recognized, so consistency demands having a fixed list of fish families. The most rigorous programmes identify key families and species to survey, and may use an 'other' category to group any other species/families to avoid the need to identify them precisely (see Table 4). The most common families recorded in the WIO include the Acanthurids, Balistids, Carangids, Chaetodontids, Haemulids, Labrids, Lethrinids, Lutjanids, Pomacanthids, Scarids, Serranids And Siganids (Table 4)

Table 4. Fish families included in some of the main coral reef monitoring programmes in the WIO. References to this table: sample data collected by Kenya Wildlife Service and SNCRN, Samoilys 2010, McClanahan et al. 2007.

	Most	Kenya (Kenya Wildlife Service)	Seychelles (sample data, SNCRN)	CORDIO (biomass/ resilience data)	WCS (biomass)
Acanthuridae	***	x	x	x	x
Balistidae	***	x	x	x	x
Caesionidae			x	x	
Carangidae	*	x	x	x	
Chaetodontidae	***	x	x	x	x
Diodontidae			x		
Elasmobranchs/ sharks		x		x	
Ephippidae				x	
Haemulidae/ Mullidae	***	x	x	x	x
Holocentridae			x		
Kyphosidae				x	
Labridae	***	x	x	x	x
Lethrinidae	*	x	x	x	
Lutjanidae	***	x	x	x	x
Muraenidae			x		
Pomacanthidae	***	x	x	x	x
Pomacentridae					x
Scaridae	***	x	x	x	x
Scombridae				x	
Serranidae	*	x	x	x	
Siganidae	***	x	x	x	x
Sphyraenidae		x			
Tetraodontidae			x		
Zanclidae			x		
"Others"					x

5.6.3. Invertebrates

Monitoring of mobile invertebrate taxa is very variable across different programmes, in both the target species/groups being monitoring, and the methods being applied. For mobile invertebrates then, only 2 levels of identification are offered in this programme, one at family level, and the other including key species differentiated for key invertebrate groups.

Table 5. Hierarchical classification of mobile invertebrates at levels 1 and 2 for standard reef monitoring. Practice varies greatly among programmes, and individual programmes will have to ensure that the CRIS can support the classifications they use.

Level 1	Code	Level 2
Sea urchins	urc	Diadema, Echinometra, Echinostrephus, Tripneustes, Echnothrix
Seastars	sta	Cushion Star, other species
Acanthaster planci	cot	
Sea cucumbers	cuc	by species
Bivalves	BIV	Tridacna, other key species
Lobsters	lob	by species
Octopus	oct	
Gastropods	gas	Triton conch, other key species
Drupella	dru	

As with fish, a monitoring programme should determine its list of target taxa to limit random inclusions/exclusions over time based on different observers or incidents.

6. Additional methods

This section lists a number of alternative methods for monitoring coral reefs that managers may be interested in to meet specific needs they may have. The purpose is to point towards more detailed resources and experts to help the managers determine if they should use them, how, and to plan training and implementation. Depending on their purpose, they might be used in conjunction with the monitoring methods described in this manual, or instead of them. Expert guidance should be sought in identifying which approach is most appropriate to given objectives.

6.1. Rapid Assessment programmes (RAP)/ Rapid Ecological Assessment (REA)

RAPs/REAs are a group of survey techniques that focus on biodiversity assessments, and include some element of ecological surveys as well. They thus blend some objectives and tools from this manual, but are generally constrained by the need to move rapidly over larger spatial scales. They are often conducted as initial scoping of an area, enabling identification of key sites that then become the focus for investment in management and monitoring – e.g. the Conservation International RAPs conducted in northern Madagascar from 2005-2011 (McKenna and Allen 2005, Maharavo 2012, Obura et al. 2012).

Given the current state of knowledge on coral reefs, RAPs have generally focused on assessing the diversity of key taxonomic groups such as hard corals, fish, echinoderms and gastropods. In some cases groups such as commensal infauna in corals have been included, as these provide a consistent sample unit from broad/diverse areas. Habitat/ecological sampling may be done using rapid in-water techniques, thus Reef Check, image-based methods, and visual assessments such as the MSA approach or others.

RAPs need to be planned with careful assessment of the geographic extent to be surveyed, diversity of habitats, and the time available for sufficient number of sites to represent this diversity. In some cases (e.g. N Madagascar), several RAP surveys may be required over time. Strategically, they should also be done when there is some confidence that follow-up investments in priority locations may be made, otherwise the information collected may not result in management impact on the ground.

6.2. Reef Check

'Volunteer' or public-interest monitoring (see 4.4) is broadly popular in coral reefs, attracting two main types of people. One is the small scale resource user, in particular fishermen, who are dependent on reefs for fishing and general livelihoods, have strong cultural and local ties to coral reefs and may live in remote locations with few scientific or technical resources. With the support of NGOs and other intermediaries, they have become strongly engaged with participatory monitoring of reefs, including in the WIO (Wells et al. 2006), which has grown in the last 5-10 years to a strong engagement with rights-based management and locally managed marine areas (BV report, McC, Sam???). The other main class of people involved in volunteer or participatory monitoring is the general public interested in SCUBA diving and snorkelling, typically students, coastal residents and tourists with a commitment to contributing to coral reef management. They may travel large distances domestically or internationally, and contribute their time to monitoring of coral reefs, usually with a local intermediary such as an NGO, dive center or diving club.

A number of monitoring programmes have been designed that match the skill levels, interest and time commitment for volunteer monitoring, the most globally widespread of which being the Reef Check method. Started in 1996, it has grown to have a near-global reach, with its outputs being included in scientific resources and publications (Hodgson 1999, Burke et al. 2011, Wilkinson 1999-2004). With a strong focus on user-support, extensive resources for recruitment, training and reporting are provided (www.reefcheck.org) with chapters catering to varied scales of interest and support, from sub-regional, to national to regional.

The Reef Check method simplifies the intermediate level of monitoring based on PIT and belt transects, by specifying four 20 meter transects, set consecutively along a 100 m line with 5 m gaps in between. Benthos, invertebrates and fish are recorded as follows: PIT with 50 cm spacing, belt transects 2 m wide and belt transects 5 m wide, respectively. Identification is at Level 1 or 2 for benthos, and 15-20 regionally-specific indicator species for invertebrates and fish (see. www.reefcheck.org). Formal reporting is conducted through dedicated online resources, simplifying aggregation and reporting of data at national, regional and global levels. Reef Check is included as the recommended basic level method for the GCRMN.

6.3. Eye on the Reef

In the last 5-10 years, the power of public reporting of information has attracted the interest of reef managers, particularly of large and extensive management areas such as the Great Barrier Reef. Particularly where there is extensive tourism, and operators with a vested interest in the health of the attractions that they depend on, citizen reporting of key indicators – such as of megafauna on the surface of the sea or while diving, infractions of site-based regulations, dead/stranding species, etc – can generate data that is not possible with management or scientist-oriented systems.

The Eye on the Reef programme of the Great Barrier Reef Marine Park Authority (GBRMPA) (www.eyeonthereef.org) is a recent large scale implementation of this type of observer reporting, and is being replicated on a smaller scale for the Reunion Marine Reserve (Protocole "Sentinelles du récif"). Differing from in-water monitoring efforts, these programmes may cover a wide diversity of types of data, but are specifically targeted towards a limited set of key indicators/variables accessible to the public but also useful for management.

Similar programmes can be developed with simpler resources for local monitoring, but need careful design and piloting to ensure that resources are being spent effectively – particularly the time and effort of resource users that participate in the programme by reporting.

6.4. Medium Scale Approach (MSA)

The Medium Scale Approach (MSA) was developed to bridge a gap from the detailed focus of LIT and mainstream reef monitoring methods, to estimate broader scale benthic features that better match the coverage of fish transects over the 50 m scale of these larger sampling units (Kulbicki and Sarramegna 1999, Labrosse et al. 2003, Clua et al. 2006). In standard reef monitoring techniques, as presented in this manual, the mismatch in resolution between benthic samples on a scale of about 10 m and resolution down to 1 cm, and fish samples on a scale of 50 m, with a resolution more comparable to about 1 m, sampled by mobile fish, can result in high variance in relations between benthic and mobile fish data.

The MSA method samples benthic characteristics on the same scale as a fish transect, using the same transect length of 50 m, and a width of 10 m. Sampling is done by visual estimation, of twenty 5*5 m quadrats (i.e. ten 5*5 m quadrats on either side of the transect line). Categories used for benthic estimates include 9 substrate types (e.g. sand, rock, etc.) and 7 live cover types (coral morphologies), all estimated on a semi-quantitative scale proposed in English et al. (1997). Separate semi-quantitative estimates for low-area cover types such as micro-algae may also be used. Analysis of the method indicates that variance between benthic and fish data was less for the MSA benthic methods than standard LIT methods, a result of the broader scale of the MSA methods.

More recently, the MSA approach has been used where estimation of broader habitat characteristics are seen as more relevant and resource-efficient than fine-scale quantitative surveys, such as in environmental assessments and regular monitoring around commercial operations, and where larger areas have to be sampled. More generally visual estimation of benthic characteristics has been demonstrated in research surveys to be as reliable as more quantitative methods, and more efficient for covering large areas with limited time (Wilson et al. 2007, Obura and Mangubhai 2009).

6.5. Resilience assessments

Interest in coral reef resilience has been growing in the recent decade (Grimsditch and Salm, 2006), with a corresponding interest in methods to quantify resilience. The general applicability of resilience principles to reef ecology is high, but adequately measuring it has proved challenging (Obura 2005). Key aspects important to understanding resilience are the dynamics of coral and algal communities, as well as of potential alternative stable states of reefs, e.g. under dominance by filter-feeding invertebrates such as sponges/ascidians, or soft corals. Herbivory by fish and invertebrates (e.g. sea urchins) is a key dynamic mediating benthic state. Over and above this, external influences both natural (sedimentation, productivity, storms/cyclones, thermal fluctuations) and anthropogenic (fishing, sedimentation, coastal construction, pollution, eutrophication, thermal warming, etc.) must be known, posing challenges for measurement (West and Salm 2003).

Practice is generally split between practitioners more focused on scientific methods and rigour (e.g. Mumby et al. 2013, McClanahan et al. 2012) and those focused on management decision-making requiring less accurate indicators but across a broader range of variables (e.g. Obura and Grimsditch 2009, Maynard et al. 2010, http://www.healthyreefs.org/cms/healthy-reef-indicators/). A method piloted under IUCN has been applied broadly across the Western Indian Ocean, including in the SWIO islands, though is under continual development to improve its accuracy and reliability and relevance of data (Obura and Grimsditch 2009, see www.iucn.org/cccr). An essential contributor to the quality of all approaches to measuring resilience is the availability of historical and background information, both from past monitoring of reef health, and secondary information/datasets on the various components of resilience. Scientific advice is necessary to design and implement a useful resilience-based assessment, so extensive research and consultation should be done prior to implementing any particular method.

Using resilience information in a management context also requires significant planning and capacity building, and a key resource for the WIO is the reef resilience network supported by The Nature Conservancy (www.reefresilience.org). Networking among managers is supported, as well as training materials for planning for reef resilience.

6.6. Disease

Coral diseases are an increasing focus of research and concern for management of coral reefs. They are frequently associated with reefs or corals under stress, and often are a response of the microbial community to an imbalance in the coral-zooxanthellae symbiosis resulting in production of a rich mucus layer on the coral that is attractive to bacteria. This can result from injury to the coral, such as from bites or scrapes, from coral bleaching, and from sedimentation and other metabolic stress. Recognizing diseases is complex, as many different pathogens/causes may result in similar appearance of a disease 'syndrome'.

Training in the identification of coral diseases has been promoted in the WIO by the ISLANDS project in a course in March-April 2014, the materials for which are available from ARVAM (Reunion). Earlier, the Coral Reef Targeted Research programme of the GEF/World Bank supported training on coral diseases in Zanzibar in 2008. Key references and resources from this are available at http://coraldisease.org/diseases. The most common coral diseases in the WIO appear to include black band disease, white syndrome, pink line syndrome, Porites white patch syndrome, and a red/orange condition on Porites that is in fact a sponge. Diseases are commonly associated with higher nutrients and lower water quality, and often found at higher abundance near hotspots or locations of human influence.

Monitoring for coral diseases is done through two approaches. Where disease incidence is low, broad searches for diseases are most rewarding. Where the prevalence of disease is high enough to be recorded in transects, belt transects of 1 m width are commonly used. In this case, disease monitoring can be incorporated into monitoring of mobile invertebrates and coral conditions.

6.7. Invasive species

Invasive alien species are a growing concern in all marine environments, particularly those frequented by increasing numbers of vessels that travel large distances, changing local climates that may reduce the vigour of local species in defending their niches, and those stressed by multiple other threats that may push them towards states more vulnerable to invasions. Projects by the IUCN on invasive species on coral reefs of the WIO in 2006-10 found little evidence for and impact of invasive species in coral reef communities, distinct from the high vulnerability and potential impacts in enclosed bays and harbours. Further work in Reunion Island has focused on invasive species, at early stages of developing methods and results for general application throughout the WIO.

With continuing climate change, resource extraction and pollution/development impacts to coral reefs throughout the WIO, greater attention to invasive species may need to be paid in the future.

7. Setting up a monitoring programme

Establishing a monitoring programme requires extensive planning, requiring a number of key elements from the beginning:

- a clear set of objectives for the monitoring programme – who is it servicing? What types of decisions need to be supported? What is the long term vision for the sites/area being monitored?
- knowledge of the resources available for monitoring in the beginning, and into the long term;
- expert consultation is essential to achieve the best results, involving both scientists (with knowledge on the strengths and weaknesses of the methods to be applied) and managers/responsible authorities (with knowledge on and mandates with respect to the main decisions that monitoring information should contribute towards);
- broad public consultation, so that stakeholders are aware of the advent of monitoring and can contribute their opinions and priorities to inform planning;
- the capacity of personnel available (and therefore also training needs) to implement the programme over time.

Two key elements are relevant for mention here – training and what type of sampling could be supported given the resources available.

7.1. Training

Capacity building is a fundamental problem for all monitoring programmes, as they must maintain a consistent standard over time, while personnel will always undergo changes. In many cases, experienced members of a monitoring team are promoted to higher levels, requiring their substitution with new personnel, invariably needing training. Passing on the knowledge of the experienced members to the new ones is critical, as well as systems for ensuring that consistent standards and procedures are maintained.

The ISLANDS project conducted a series of monitoring training courses in the countries of the ISLANDS project/ SWIO region in March-April 2014, on methods for a) Point Intercept Transects (PIT, Reef Check), b) Line Intercept Transects (LIT, GCRMN, and as presented here), c) coral diseases and d) mobile invertebrates (Reef Check). Other programmes with active monitoring programmes also conduct training as needed, or through internship programmes, such as in the national MPA programmes (e.g. Madagascar National Parks), national NGOs (such as Island Conservation Society, Seychelles), and several of the international NGOs (e.g. Wildlife Conservation Society). The Western Indian Ocean Marine Science Association hosts a certification programme for MPA managers (WIO-COMPAS) and bi-ennial training courses for university students, and some blending of these approaches may be possible to integrate students and others into long term monitoring teams within and among countries.

A strategy for maintaining a 'training ramp' for those conducting coral reef monitoring, and that can strongly support the inclusion of resource users in intermediate levels of monitoring can be to establish a regional training programme that first focuses on volunteer-level methods, such as Reef Check, then after a certain level of experience has been gained in that, key members of the monitoring networks are 'promoted' into intermediate level training programmes, gaining certification that reflects the higher skill levels. Integrating this programme with the university-oriented trainings for scientific monitoring may provide a further opportunity for the most capable basic/intermediate level observers to increase their skills to this highest level, and be valuable resources for advanced research on coral reefs. If such personnel can be incentivized to undergo this training ramp, e.g. through skill-based fees to be part of monitoring teams on an annual basis, a sufficient cadre of observers may be ensured over the long term, with links to university and research programmes that help to maintain standards and interest over time.

In addition to in-water methods, training is needed in data management, maintaining a database and analysis of data. The Coral Reef Information System (see section 8), being an online resource, will provide guidance on these aspects, as well as up to date training materials for the specific needs of using the CRIS.

7.2. Low vs. high-resource monitoring programmes

What can be implemented in the field depends greatly on the amount of funds available to pay all the costs – for people, fuel, and equipment. It is essential to design a monitoring system that makes the most of the resources available, balancing such things as the amount of time spent at a single site (the number of replicates and detail of data collection) to the number of sites that can be visited overall. The details of what should be implemented can only be worked out on a case by case basis, but the list and table below give an illustration of the issues to be considered, and how they might be resolved in a case of low vs. high levels of funding and resources available.

Objectives – the objectives for a monitoring programme will identify not only what individual data and variables need to be collected, but also set the reason why the data is being collected and therefore how much should be invested in different aspects of the programme. The objectives should also be closely tied to practical decision-making that can be made on the basis of the information obtained, and with respect to the interests of the key authorities and stakeholders involved.

Geographic scale/coverage – the size of the overall area to be monitored affects fundamentally the time and costs associated with monitoring, but is also influenced by the key issues and stakeholders involved. E.g. if local fisheries are a key focus then a small area may be justified, but if broader biodiversity maintenance is the focus, then larger scales may be necessary.

Number of sites – the cost of monitoring is multiplied by the number of sites visited, and this needs to be traded off against how many sites are needed to adequately represent the focal system and address the objectives for monitoring.

Multiple habitats – variation in coral reef habitats and how they respond to external drivers may require monitoring of multiple habitats, with consequent impacts on the number of sites that need to be monitored for each habitat and overall, and consequent logistics and costs.

Expertise/team – the composition of the monitoring team affects decisions on what level to undertake monitoring, as well as levels of training and refresher courses that may be needed periodically.

Methods – from the perspective of this manual, monitoring might be planned at intermediate or basic levels. This will influence the personnel costs as well as time required at each site. The method selected affects the amount of time required at each site, competence of the monitoring team and post-processing of data (e.g. of images). With greater competence, additional methods can also be added, such as for algae, coral recruits, etc.

Replication – the number of replicates profoundly affects the time required at each site, and hence the total costs and number of sites that can be visited. At the same time, it affects the reliability of results obtained from the monitoring programme. A fundamental tradeoff must be made between total sites visited and number of replicates at each site.

Frequency of sampling – in most cases for general reef monitoring, annual surveys are sufficient to track long term trends, and samples should be at the same time of year to avoid the influence of seasonal variability. However, some objectives will required seasonal or more frequent sampling, and this strongly affects costs.

Total cost, per year – costs vary greatly from country to country, and by location. It is not possible to give reliable figures on how much monitoring may cost, though on a broad scale it can be estimated that low-resource efforts likely need to be kept lower than about $3,000 per year for even medium-sized MPAs and coastal areas (up to 10-20 km in size). By contrast, to invest in sufficient resources to undertake good intermediate level monitoring as presented in this manual, at least $15,000 are likely to be needed for sites/areas of 20 km in extent and greater. In both cases, it is likely that on-site partners and supporters will contribute significant in-kind resources, personnel and infrastructure.

Table 6. Illustration of low vs. high levels of resources to implement a monitoring programme.

	Low	High
Objectives	Basic state of reef and primary resources, LMMA/ community monitoring, raising awareness, demonstrating on-site presence	Accurate state of reef and biodiversity, indicators for management decision-making, national/ international site of importance, communications and raising awareness
Geographic scale/ coverage	Small (1-10 km extent)	Variable (A few to 100 km extent)
# sites	Few (3-5)	Many (15-30)
Multiple habitats	None/few	Several
Expertise/team	Low, mostly fishers/ volunteers, basic staff	Moderate, technical staff, scientists/ university students
Methods, general	Basic and intermediate	Intermediate with additional components
Benthic	PIT/LIT	LIT or photo/video, recruit and algae quadrats
Invertebrate	Belts, for indicators species	Belts & quadrats, for key species/taxa
Fish	Belts, for indicators species	Belts, for comprehensive species/ families, and diversity estimates
Replication	Low (3-4)	Moderate to high (5-10)
Sampling frequency	Depends on the specific objectives, sites and methods, as low-cost community sampling may be done frequently	Depends on the objectives, as high-resolution expert-based sampling may not need high frequency recording
Cost ($), per year	0-$3,000 (high co-funding/in-kind contributions)	15,000-20,000+ (also including high in-kind contributions)

7.3. Sustainability of a monitoring programme

The issue of long term sustainability of a monitoring programme should be a key consideration when designing one. The true benefits of monitoring only become apparent after 10 or more years of data have been collected, and even 20 years. Thus it serves no real purpose to design a programme that is not sustainable beyond only 3-5 years. Accordingly, long term support and commitment, both financial and otherwise, must be considered, with careful attention to the contributions of different partners/participants, the existence of institutional/national budgeting to support at least the core elements of the monitoring plan, and the likelihood of external funding being maintained over time (e.g. from donors, lottery funds, local contributors/benefactors, etc.).

An important consideration in the sustainability is the usefulness of the monitoring programme to its principal end users. The more general the utility of monitoring programme to different users, the more likely it may be to generate funding from those users. Conversely, the more essential the programme is to a user, the more likely it will be to be funded reliably. Generating interest and commitment in these users can be a key component of assuring long term sustainability.

Another key element affecting sustainability is partnership with a university or other such research/academic institution that has a continual flux of students or staff requiring training and field sites for their work, and hence a renewable supply of trained and motivated personnel. Partnership with a key scientist/faculty is usually required for this, particularly if they are involved in initial design and establishment of the programme to also meet their research interests.

8. The Coral Reef Information System (CRIS)

All templates for underwater datasheets and data entry forms (in Microsoft Excel format) for online submission are obtainable from the CRIS

The Coral Reef Information System (CRIS) - http://www.globalecosystemmonitoring.com/CRIS/, developed by the ISLANDS project is custom-designed to support data entry, archiving and analysis, and can be used by any valid monitoring teams from the SWIO and WIO regions. Full instructions and materials for using the CRIS can be downloaded from its pages, this section provides a quick overview of the steps from use of UW datasheets to transcribing data onto forms designed for uploading into the CRIS.

A key functionality of the CRIS from the perspective of field monitoring teams is that in the field, data is entered into dedicated Microsoft Excel spreadsheets. When internet connectivity is available, these can generate text files that import the data into the CRIS. Thus, teams are not dependent on internet connectivity for the first steps of transferring their data onto a computer – a key consideration in the region.

8.1. Underwater datasheets

Model underwater datasheets for each of the methods presented in this manual are provided on the CRIS. However it should be noted that different practitioners and programmes may have very different preferences for how to organize an UW datasheet. Time underwater and ease of use of the datasheet are the prime considerations for its design, and these can vary tremendously with personal bias and experience of the data collector, and other expertise they have. Thus no single form is recommended.

The key principles for an underwater datasheet are to:

- Minimize the amount of writing that needs to be done, particularly of repetitive elements (e.g. full names of species/taxa, hence the use of codes).
- Maximize efficiency of utilization of the space on a datasheet, ie. give more space for common elements, as well as visual prominence for these; minimize wastage of space on unused or rarely-used items.
- Minimize the time required to scan the sheet to search for individual items (i.e. organize names alphabetically, or taxonomically, or functionally – whichever works best for the data collector).
- Provide some scope for flexibility, such as sufficient blank spaces for notes, additional species/taxa, spillover out of table cells, etc.

- Enter sufficient metadata/descriptive data on each UW datasheet to assure the date, site, observer and other details can be read from the sheet for future reference.
- As far as possible use good quality printable UW datasheets (among the best is 'Duracopy' paper (see http://www.riteintherain.com), which is produced in different versions for bubblejet printing and laser-printing/photocopying) for permanent storage/filing as backups for any losses of computerized data, or queries that need referral back to the original data.

Transposing data from UW datasheets to a preferred format for computer data entry requires experience and training, as the most efficient format for these is likely to be different. In most cases, data should be transferred reading along/down lines from the UW datasheet and entering each piece of information in turn, so that omissions or repetitions are not made by jumping around the datasheet following a format on the computer.

8.2. CRIS data forms

Data entry forms for the CRIS are organized to have one line per observation, in what is called 'tidy data' format (Wickham 2010). That is, if at a site you see 10 snappers in size class 26-30 cm and 2 in 31-35 cm, these are recorded on two separate lines. By ensuring that the number of transects at each site is specified clearly, then the database will fill in the missing values during calculation (e.g. none of size 21-25 cm). This also is the most efficient way to enter the data that you HAVE, rather than the data that you don't (large numbers of cells with zeros where specific size classes and species were not observed).

Each station (ie. with e.g. 6 replicate transects) is entered in a single worksheet containing all the transects, even if they were entered by different observers. Study the worksheets to ensure it is clear where the metadata (descriptive/factor data) for the site are entered (e.g. date, site name, observers, total number of transects, etc.), and where the primary data is entered (transect #, fish taxon, size class and number counted).

The level of identification must be indicated on the worksheet, as this will activate error-checking functions to ensure correct data entry. Only codes allowable for the specified identification level will be accepted, as well as codes for higher levels. E.g. if level 3 is indicated, as corals were identified to genus, algal codes can be entered at level 1. But if level 2 is ticked, then genus codes (Level 3) will not be accepted.

8.3. Data upload – csv file import

Once data entry into the CRIS data form is complete, the forms are designed to generate a csv file containing all the relevant data and metadata. Clicking on the 'generate upload file' button will produce and save this text file (.csv format) in the correct format for uploading to the CRIS. This functionality allows you to enter data into excel while in the field without any internet access, to be uploaded to the online database once connectivity is established. The .csv file will be saved with an automated name (that you can over-ride in the 'save' dialog) that specifies the sitename, date and method. For experienced teams, the .csv file could be generated directly.

Once online, and ready to upload data, the csv file for each station can be entered through a clear menu system in the 'Data entry' pages.

8.4. Using the CRIS online mapping system

The spatial relationships of coral reefs with the coastline and oceans around them, and of interactions of species and processes on a coral reef are fundamental in determining how a reef functions. At the broadest level, different reef habitats are found in predictable locations in relation to bathymetry, currents and other processes. Access to mapped resources, such as satellite/aerial imagery, and to datasets such as sea surface temperatures and current models, has increased rapidly in recent years, and the ability to show mapped information is increasingly fundamental in presenting monitoring information.

The CRIS gives some basic mapping tools to assist coral reef monitoring teams in checking the locations of their sites and visualizing coverage of the reef or MPA location by sites. Currently it is only available when the user is connected to the internet, being based on online mapping tools and Google Earth map layers. It simplifies visualization of coordinates by making it possible for the user to undertake minimal formatting of their dataset, which is often a large barrier to general use of GIS/mapping tools.

The input files can be generated from any spreadsheet or database software and has the following minimal requirements:

Ensure the top row of the spreadsheet is the headers for the dataset, and that the following headers are included: "Long" or "Longitude" and "Lat" or "Latitude"

Latitude and longitude columns must be in decimal degree formats, with south and west coordinates represented as negative numbers.

Other columns from the dataset can be included, and can be visualized in the map outputs by clicking over the individual points. To avoid problems, ensure these additional columns don't contain complex features.

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